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A Single-Antenna Repeater for HF Radio Propagation Studies

by

A. C. Phillips

October 1969

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TECHNICAL REPORT NO. 154

Prepared under
Office of Naval Research Contract
Nonr 225(64), NR 088 019, and
Advanced Research Projects Agency ARPA Order No. 196

RADIOSCIENCE LABORATORY
STANFORD ELECTRONICS LABORATORIES
STANFORD UNIVERSITY • STANFORD, CALIFORNIA



A SINGLE-ANTENNA REPEATER FOR HF RADIO PROPAGATION STUDIES

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Radioscience Laboratory
Stanford Electronics Laboratories
Stanford University Stanford, California

ABSTRACT

The purpose of the work described in this report was to develop and test a compact, portable, calibrated single-antenna repeater which has application to HF radio propagation studies. For example, high-frequency backscatter ionograms--depending on the terrain--generally show one or more discrete range intervals where the returned energy is appreciably greater than the general noise-like return from other ranges. The ground features which cause these areas of enhanced HF energy reflection are not as yet fully understood. A portable repeater is capable of being operated in those areas where such reflections exist so that a direct comparison can be made between the repeated signal and the natural echoes. The repeater described in this report is especially useful with FMCW sounding waveforms.

A fundamental problem in building any repeater is the avoidance of oscillations when it is attempted to retransmit an amplified signal with receiving and transmitting antennas in the same locality. The solution adopted in this case consists of switching one antenna rapidly between transmitting and receiving modes. The received signal is amplified, then stored for the duration of the receiving period. At the end of that period it is transmitted. The act of switching in this way does not seriously degrade the operation of the repeater; in fact, it confers certain unique advantages.

The portable repeater described herein has been tested in the field, and has been found to perform satisfactorily.

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I. INTRODUCTION

A. PURPOSE

The purpose of this report is to describe a single-antenna high-frequency (HF) repeater which is particularly useful in HF radio propagation studies where a compact, easily transported piece of equipment is required.

B. STATEMENT OF THE PROBLEM

The systems for which this work is relevant involve HF radio signals which have been propagated via the ionosphere. Studies of the properties of ionospheric propagation are aided by repeaters which retransmit amplified signals with some well-defined relationship to the incident radio waves.

High-frequency backscatter ionograms made with high-resolution sounders [Refs. 1,2] generally show discrete range and azimuth intervals wherein the backscatter energy is appreciably greater than the general level of noise-like return from most other range and azimuth intervals [Ref. 3]. This circumstance has been studied by Basler and Scott [Ref. 4].

If one had a repeater which could easily be transported to any part of the world, these areas of enhanced backscatter energy could be identified by making the repeater "echo" coincide with the position of the enhanced ground "echo". By observing the terrain at the repeater location, one could perhaps deduce what feature was distinctive about the area that might cause high coherent reflection of HF energy. Also, given the gain of the repeater, one could estimate the effective cross section of the ground reflector.

C. PROPOSED SOLUTION

The basic problem in building a repeater is the occurrence of oscillations when it is attempted to retransmit an amplified received signal with receiving and transmitting antennas in the same locality. The solution to this problem chosen here consists of switching rapidly between transmitting and receiving modes. The received signal is amplified,

then stored for the duration of the receiving period. At the end of that period it is transmitted. The repeated signal is therefore identical to the received signal except for delay and for the on-off keying which originates frequency components not in the received signal. When used with an FMCW sounding system, the device performs as an ideal repeater with delay, because the sidebands generated by the pulsing can be made to fall outside the FMCW receiver bandwidth.

II. DESCRIPTION OF THE DELAY-LINE REPEATER

A. PRINCIPLE OF OPERATION

The principle of operation of the delay-line repeater is illustrated by the block diagram shown in Fig. 1. A "transmit-receive" (TR) switch assigns the function of the antenna to alternating periods of transmitting and receiving. During the "receive" period the received signal is stored in analog form in a delay line. After a receiving time equal to or greater than the delay τ , the system transmits the amplified output of the delay line.

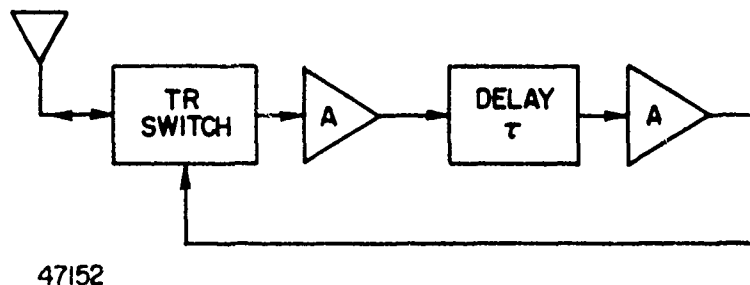


Fig. 1. DELAY-LINE REPEATER.

To prevent oscillations a dead period must be provided between the "transmit" and "receive" periods. This dead period can be accomplished by leaving the TR switch in the "receive" mode for a little longer than the delay time τ .

The signal transmitted by the repeater is equal to the delayed received signal, pulse-modulated and amplified. The spectrum of the transmitted signal is the same as that of the received signal, except that frequency components are repeated on each side of the received spectral components in proportion to, and positioned according to, the frequency components of the pulse modulation.

The delay-line repeater is expected to be particularly useful in sounding systems using transmissions having large time-bandwidth products, such as FMCW and coded pulse. For FMCW systems the receiver bandwidth is typically so narrow that the sidebands produced by the pulse modulation that originates in the repeater fall outside the receiving bandwidth, thus

making the delay-line repeater appear to be an ideal device for use in such systems.

B. DESIGN REQUIREMENTS

1. Pulse Width

A delay-line repeater could be designed to operate successfully with any sounding system having a transmitted waveform which has significant amplitude over a time at least twice the time delay of the delay line. Because of the dead time required between transmitting and receiving phases, a minimum pulse width to meet this condition would be about 50 μ sec. The gain of the repeater for systems having pulses much longer than the time delay of the delay line is a linear function of the transmitting duty cycle. For waveforms which are only slightly longer than twice the delay-line delay, the effective gain of the repeater will vary depending on the relation between the time of the pulse and the repeater switching. For a repeating pulse whose repetition frequency is not a subharmonic of the repeater-switching frequency, the repeater gain will vary in beat-note fashion. If the pulse-repetition frequency is a subharmonic, the gain will be unknown between the limits of the beat variation above unless the phase of the repeater switching can be locked to a harmonic of the pulse-repetition frequency.

If synchronizing control is available to adjust the phase of the repeater switching in order to ensure that the repeater will be in the receiving mode when a pulse arrives, the above restriction on pulse width is removed, and the repeater will work for any pulse system. The equipment described in this report, however, would not be able to handle the peak power which would be required for a wide-bandwidth simple-pulse system (a "simple pulse" being one without phase or frequency modulation) having the same average power as an FMCW system.

Given a simple repetitive pulse system having a pulse shorter than the delay-line delay, and given that it is desired to make use of the simplicity of the delay-line repeater without any synchronizing control, the repeater echo could be made visible by randomizing the width

of the receiving period of the repeater. If alternating periods of repeater visibility and invisibility are acceptable it would be sufficient to have a non-random receiving period which results in a repeater switching rate which is not harmonically related to the sounder PRF.

For FMCW and simple-pulse systems which meet the requirements for application of the delay-line repeater, the repeater will perform as an ideal non-switching repeater, since the sidebands generated by its switching process are filtered out before the final data display. For a coded-pulse system, however, some spurious range sidelobes can be expected, since the pulse modulation in the repeater would degrade the quality of the autocorrelation function of the code.

2. Delay Line

The requirements for the delay line used in the delay-line repeater are easily met by employing an ultrasonic delay device having quartz or glass as the delay medium. These ultrasonic delay lines can be manufactured with a bandwidth in excess of 50 percent of their bandpass center frequency. The bandpass center frequency is selectable up to about 50 MHz. For extremely phase-stable repeating, the glass delay line is preferred because its temperature coefficient of delay is better than one part per minute per degree centigrade (1 ppm/°C), while the quartz has a temperature coefficient about equal to 70 ppm/°C.

Assuming a particular duty cycle, the amount of delay determines the rate of switching between the transmitting and the receiving modes. If this switching rate were too low, say less than 5 kHz, an audio tone would be produced in any fixed-station communicator that received the repeater signals. To avoid the occurrence of this very noticeable type of interference, it is desirable to use a delay having a value low enough to give a switching rate in excess of 5 kHz. However, if a switching rate much greater than that dictated by the interference consideration is used, the resulting duty cycle is decreased because of the necessity of leaving the TR switch in the "receive" position slightly longer than the delay τ . In view of these considerations, an appropriate value for the delay is between 50 μ sec and 100 μ sec.

3. Gain

To prevent loop oscillations, the attenuation in the "off" position of the TR switch must be greater than the loop gain.

The amplifier preceding the delay should have a gain in excess of the delay-line attenuation for two purposes:

1. To maintain the best possible ratio of received signal to circuit noise.
2. To minimize the gain between any two points in the system and thereby minimize the problems of leakage feedback.

The net loop gain must be adjustable to accommodate the varying path losses between the desired-signal transmitter and the repeater. Tests using a two-antenna repeater have shown that the maximum gain that would be required is less than 90 dB. In normal operation the gain would be adjusted to cause the output to be slightly below the output amplifier power capability.

In some cases it may be desirable to translate the received frequencies before retransmission in order to simplify detection of the repeater signal by causing its frequencies to fall outside the range of the ground backscatter. This frequency translation is easily accomplished by inserting a balanced diode mixer at a point within the repeater loop where the signal level is low.

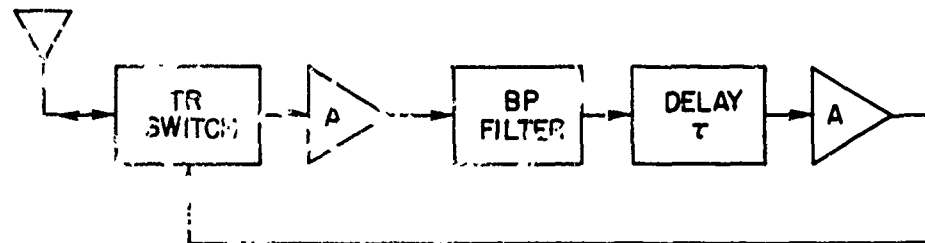
C. INTERFERENCE CONSIDERATIONS

1. Interference by Repeater to Other Users of the HF Spectrum

The mere repeating of HF received signals would not be likely to cause annoyance to other users of the HF spectrum, since the probability would be small that the repeated signal strength would be nearly the same as the non-repeated signal strength at a particular receiving location. However, the delay-line repeater retransmits a signal not only at the received frequency, but also at other frequencies. This is because a received transmission is retransmitted at time intervals corresponding to the repeater switching frequency. Thus the repeater, in effect, originates frequency components not in the original received signal. For a given received signal, the largest repeater-originated

component of transmission has an energy equal to about one-fourth that of the output signal component which has the same frequency as the received signal.

A first simple step for minimizing the interference problem is to reduce the frequency range of the repeater to the minimum useful value by adding a bandpass filter within the delay-line loop, as shown in Fig. 2.



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Fig. 2. FREQUENCY-LIMITED DELAY-LINE REPEATER.

The repeater-generated transmissions can be made less objectionable if they are made similar to random noise rather than to frequency-translated replicas of the received waveforms. It is planned to introduce such a noise-like property into the spurious generated frequencies by randomizing the lengths of the "receive" periods.

2. Repeater Performance Degradation Caused by Interference

When the repeater is used to retransmit incident waves originated by ionosphere sounders, the only significant effect produced in the repeater by HF signals other than the desired signal from the sounder is the gain suppression and intermodulation which occur if the peak power required for linear operation exceeds the capability of the repeater power amplifier. For the case where the received sounder-signal energy is considerably greater than the energy of all other signals within the repeater bandwidth there is no degradation from interfering signals, and the repeater gain can be set to such a value that the sounder signal is near the peak capability of the repeater power amplifier. If it is desired to increase the gain of the repeater further, this can be done if the sounder-transmitted signal can be reduced until the point is reached where the interfering signals are about equal to the sounder signal. Thus, in summary, to obtain a maximum in repeater visibility the following steps are taken:

1. The sounder signal is adjusted to obtain about unity in the ratio between the sounder signal and all other energy received by the repeater.
2. The gain of the repeater is increased to the point of saturation of the repeater power amplifier.

D. PERFORMANCE MONITORING

It is expected that an oscilloscope will be used to monitor in detail the operation of the prototype repeater. However, a number of similar repeaters will be constructed in the future, and it will probably be necessary to monitor their operation by means of a meter circuit. Such an arrangement would permit checking for proper repeater operation to be carried out by unskilled operators or by a telemetering system.

Adequate check of the repeater system would be obtained by measuring the following parameters:

1. Noise at the antenna terminal, with a 50 ohm terminator replacing the antenna and with the loop gain set at maximum. This check would verify proper operation of all the amplifiers, assuming proper operation of the switching circuits.
2. The percentage of time the TR switch is in the "transmit" position. This would verify proper switch operation.
3. The percentage of time the output amplifier is driven to near-saturation during operation. By setting the loop gain to keep this percentage low, one can be confident of accurately knowing the effective gain of the system.

III. HARDWARE DEVELOPMENT AND TESTS

A. PROTOTYPE TEST

A preliminary laboratory prototype of the delay-line repeater was assembled at the Stanford University radio field site in Bearden, Arkansas during the week of 11 November 1968. Figure 3 is a block diagram showing the equipment used.

The switch control, switches, and filters were laboratory-developed items. All other equipment was of standard commercial type. All switches were essentially the SPST type shown by the schematic diagram in Fig. 4. The "transmit" and "receive" switches shown in Fig. 4 were required since the isolation provided by the combined TR switch was not adequate.

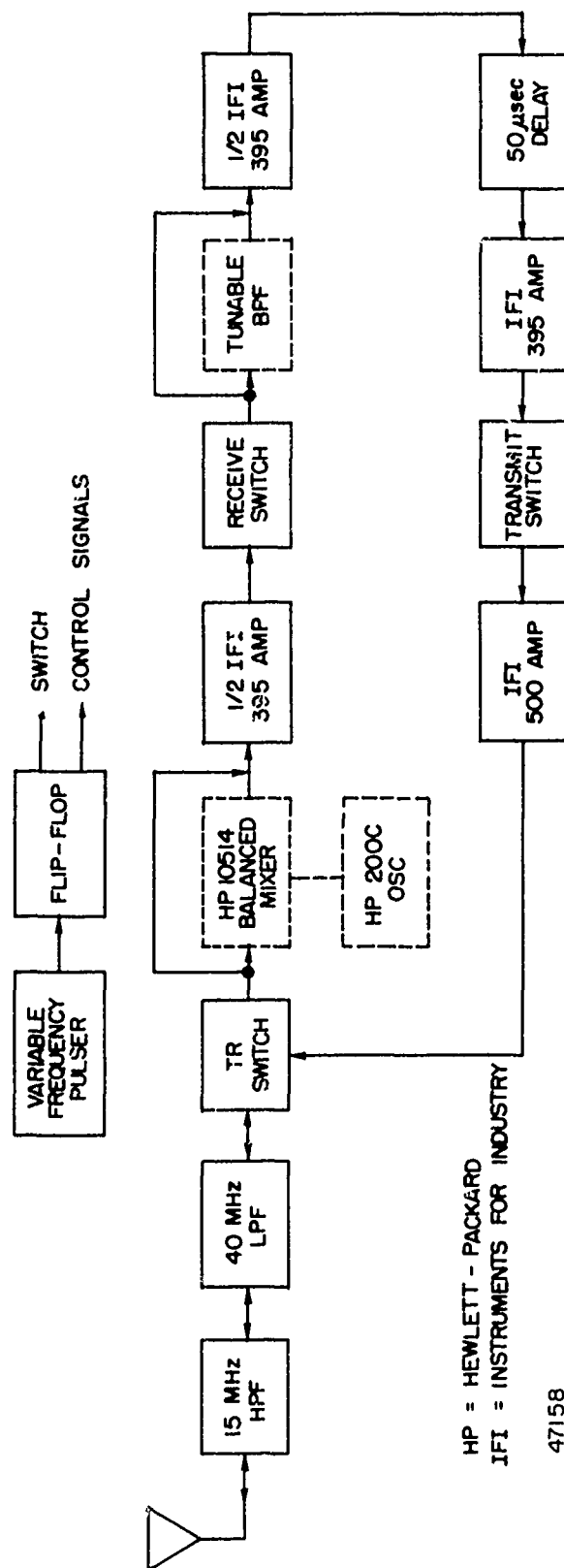
The high-pass (HPF) and low-pass (LPF) filters which preceded the TR switch were added to restrict the repeater operation to frequencies useful for the backscatter tests and thus prevent interference to users of frequencies outside the range of interest. One would not want to put a narrow-band filter (BPF) ahead of the TR switch because the resultant energy storage would be likely to cause oscillation.

Backscatter ionograms were produced by transmitting from the Stanford Los Hills site, and receiving at Los Baños [Ref. 3]. Figure 5 shows a typical backscatter ionogram with the repeater "echoes" clearly visible. The tunable bandpass filter and the balanced mixer were not used in this test. Because of the high sensitivity of the FMCW system to the phase-stable repeater signal, only 160 mW of energy at the desired frequency were required from the repeater for the ionogram in Fig. 5.

B. IMPROVED PORTABLE DESIGN

A compact and more efficient version of the delay-line repeater has been completed and installed in a vehicle.

The block diagram is shown in Fig. 6, and a photograph of the equipment in Fig. 7. The commercial amplifiers were replaced by integrated circuits where signal levels are low and by transistor amplifiers where signal levels are high. Filters may be added as in Fig. 3 if interference problems appear likely during use.



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Fig. 3. BLOCK DIAGRAM OF TRANSPONDER PROTOTYPE.

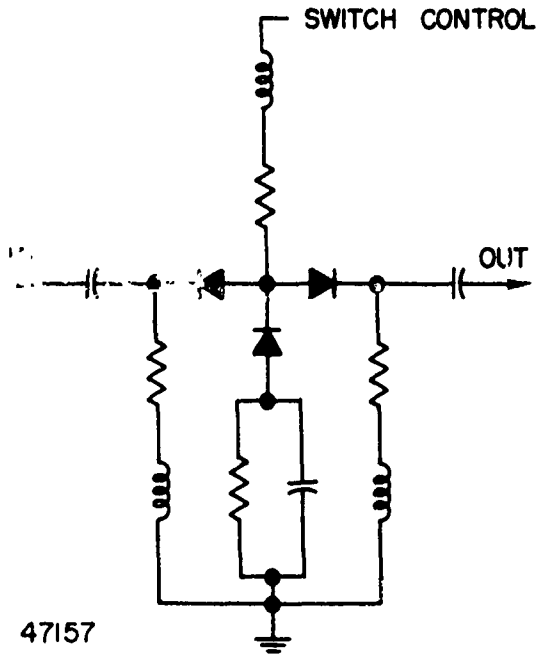


Fig. 4. TYPICAL SPST SWITCH CONFIGURATION.

All circuitry has been designed to operate from a +20 V supply. A small DC-to-DC converter develops -50 V for back bias of the diodes in the TR switch. The input power requirement is about 50 W.

The symmetrical flip-flop has been replaced by an astable multivibrator which gives the capability of independent adjustment for "transmit" and "receive" times. This independent adjustment feature will make it convenient to provide a random voltage determining "receive" time, and thereby impart a noise-like property to the sidebands generated by the switching process.

C. INTERFERENCE MEASUREMENTS

As pointed out in an earlier section of this report, the visibility for a given repeater power amplifier capability is determined by the amount of interference received by the repeater. Measurements were made at the Bearden field site to obtain data showing the magnitude of the interference received there in a wide bandwidth repeater. Table 1 gives

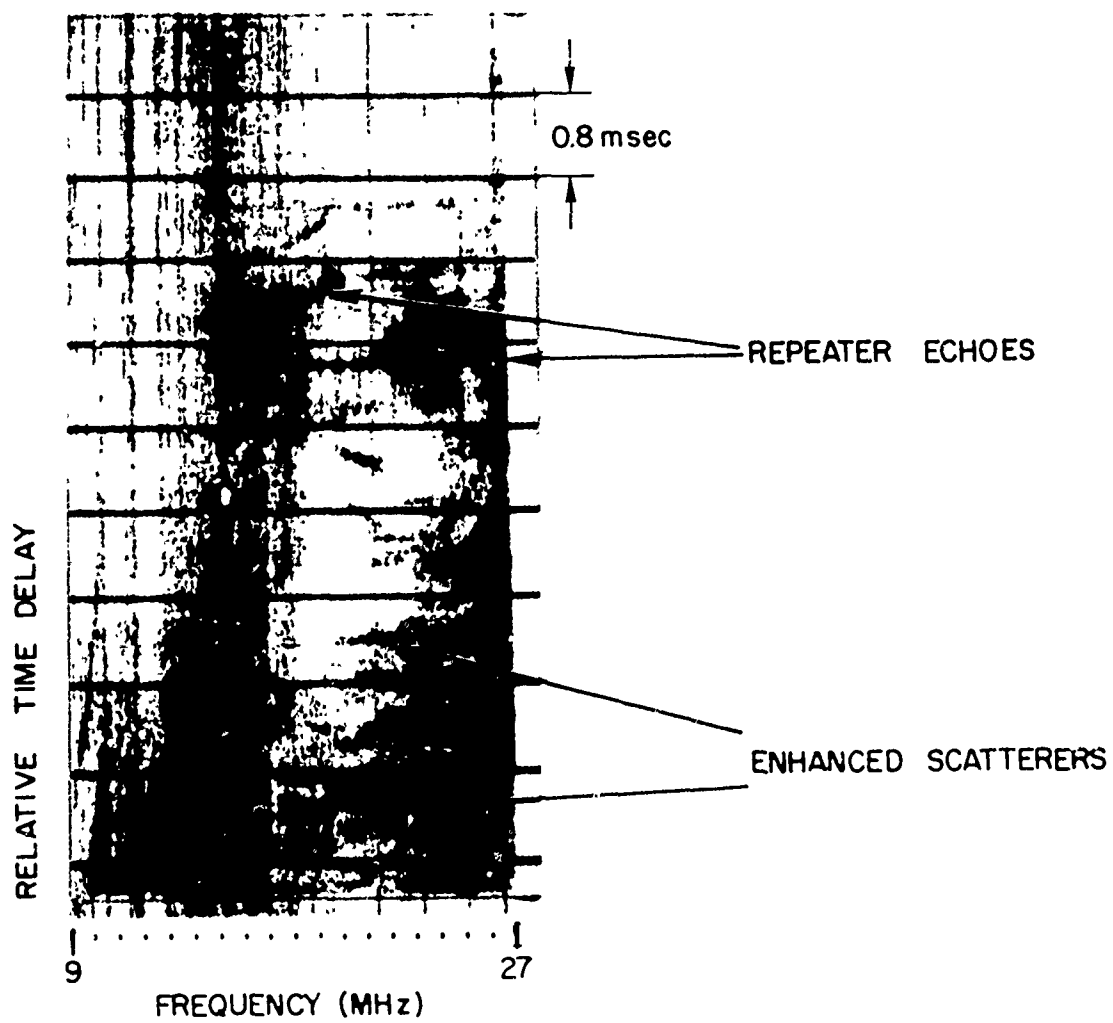


Fig. 5. BACKSCATTER IONOGRAM, LOST HILLS/LOS BAÑOS.

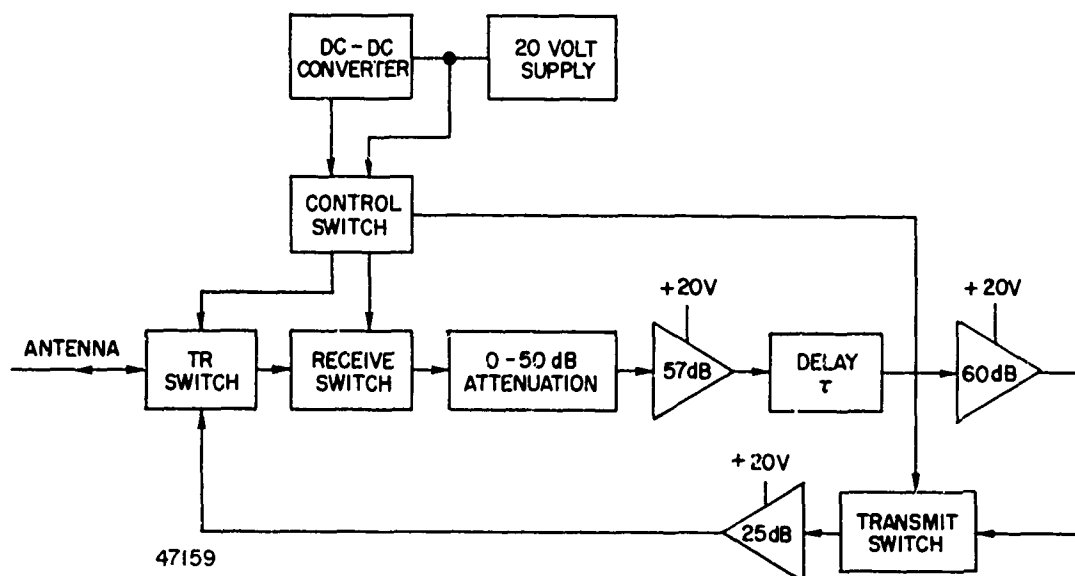


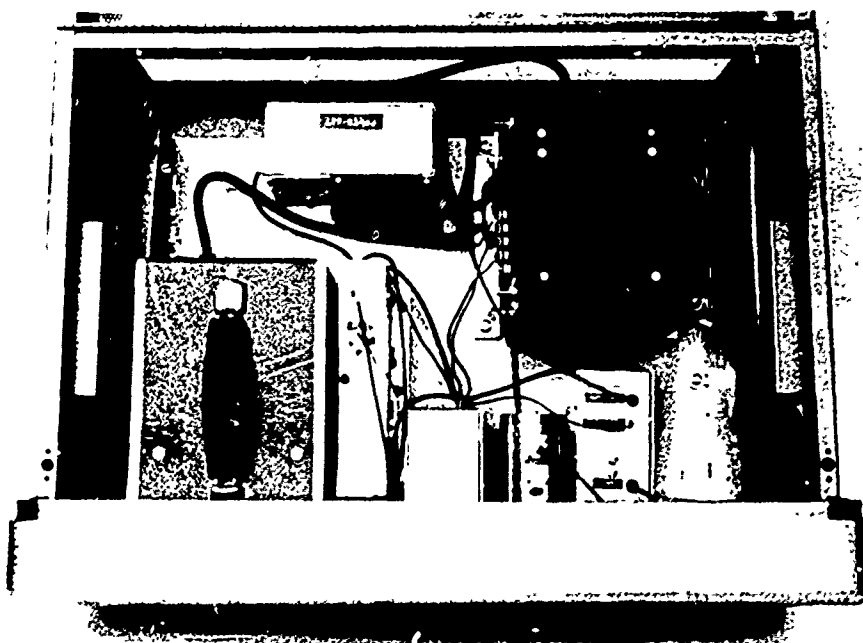
Fig. 6. COMPACT REPEATER BLOCK DIAGRAM.

the beamwidth and the frequency coverage for the antennas which were used to make the interference measurements. The "T-whip" is an 18 ft uncompensated whip mounted on top of the field-site trailer. The "G5-whip" is a 10 ft ground-mounted whip with four 50 ft ground radials. The "G5-whip" was compensated by a network in series to give a voltage standing wave ratio (VSWR) of less than 1.5 to 1 over the frequencies between 20 and 28 MHz. The repeater delay line has a lower cutoff frequency of 7 MHz, so that the Collins LPA coverage between 3 and 7 MHz did not contribute significantly to the noise measured.

The interference data are presented in Table 2 by recording the loop gain of the repeater which causes a 10 W power amplifier to clip about ten percent of the time. The significance of the 287 deg bearing is that this is the bearing toward Stanford's Los Baños, California field site.



a. Front view



b. Top view

Fig. 7. PORTABLE DELAY-LINE REPEATER.

TABLE 1
ANTENNA CHARACTERISTICS

Antenna	Beamwidth	Frequency Coverage
ITT-FTM	90°	7-27 MHz
Collins-LPA	60°	3-40 MHz
T-whip	-	-
G5-whip	-	21-28 MHz

TABLE 2

MAXIMUM PERMISSIBLE PORTABLE-REPEATER LOOP GAIN

Antenna	Direction	Loop Gain (dB)									
		1 April 1969			2 April 1969			4 April 1969			7 April 1969
		1000 CST	1200 CST	1400 CST	0900 CST	1130 CST	1600 CST	0900 CST	1130 CST	1600 CST	0900 CST
LPA	0°	88	86	85	84	83	81	85	85	82	82
"	90°	87	77	76	76	74	74	74	75	74	73
"	180°	90	85	83	83	82	82	80	79	79	81
"	270°	91	89	88	87	86	84	85	85	83	82
"	287°	87	85	87	87	85	81	84	83	78	83
ITT	287°	84	86	85	85	83	78	82	83	78	81
G5-whip	--	91	91	90	88	88	86	90	92	87	90
T-whip	--	81	83	81	31	77	76	79	82	75	80

IV. CONCLUSION

A. SUMMARY OF RESULTS

A single-antenna repeater for HF use has been constructed and tested. Figure 5 is a backscatter ionogram showing echoes resulting from the repeater. The repeater is compact enough to be easily transported by a car or an airplane. A photo showing the prototype repeater is reproduced in Fig. 7.

The portable feature of the single-antenna repeater is expected to be very useful in ionosphere research. A particular use will be to attempt to identify backscatter echoes which are caused by areas on the ground that reflect larger-than-average amounts of incident HF radiation. Some of these echoes are pointed out in Fig. 5.

B. CONCLUSIONS

The construction and operation of a single-antenna repeater can be accomplished in a relatively simple manner for ionosphere sounding systems using an FMCW waveform. Some interference to other users of the HF spectrum does occur; but this is not, in general, expected to be a serious problem for the following reasons:

1. The FMCW system is very sensitive to the phase-stable signal of the repeater, so that a relatively low repeater gain is sufficient for operation.
2. The repeater can be designed to randomize the interference which is generated by the pulse modulation. The resulting noise-like interference is not expected to be noticeable, particularly if the repeater is operated for only short periods of time in any particular location. (This is the expected mode of operation.)

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The purpose of the work described in this report was to develop and test a compact, portable, calibrated single-antenna repeater which has application to HF radio propagation studies. For example, high-frequency backscatter ionograms--depending on the terrain--generally show one or more discrete range intervals where the returned energy is appreciably greater than the general noise-like return from other ranges. The ground features which cause these areas of enhanced HF energy reflection are not as yet fully understood. A portable repeater is capable of being operated in those areas where such reflections exist so that a direct comparison can be made between the repeated signal and the natural echoes. The repeater described in this report is especially useful with FMCW sounding waveforms. A fundamental problem in building any repeater is the avoidance of oscillations when it is attempted to retransmit an amplified signal with receiving and transmitting antennas in the same locality. The solution adopted in this case consists of switching one antenna rapidly between transmitting and receiving modes. The received signal is amplified, then stored for the duration of the receiving period. At the end of that period it is transmitted. The act of switching in this way does not seriously degrade the operation of the repeater; in fact, it confers certain unique advantages. The portable repeater described herein has been tested in the field, and has been found to perform satisfactorily.			

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REPEATER
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IONOSPHERE BACKSCATTER SOUNDING