A MICROWAVE SYSTEM FOR TRUNK SERVICE

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Introduction

The system described in this paper was designed to provide trunk facilities for telegraph purposes. The accumulated experience of the Telegraph Company's New York-Washington-Pittsburgh radio relay triangle was of value in the early stages of planning. This commercial service, which was installed in the latter part of 1946 and placed in operation early in 1948, highlighted many of the problems that are encountered with this transmission medium.

Simultaneously with the operation and monitoring of the triangle circuit, Western Union embarked on long-term propagation tests. The results of these tests, which have been described in technical papers,[1,2] were conclusive enough to establish that the effective radiated power of the transmitters would have to be increased to meet the continuity of operation demanded by telegraph services. The additional margin of 20 db that was desired was achieved by placing a SAC-41 Klystron amplifier after the original 2K56 transmitter reflex tube. The SAC-41, which was developed by the Sperry Gyroscope Company under Western Union contract, covers the 3700 mc to 4200 mc common carrier band, and as an amplifier delivers about 10 watts. The reduction of fading outages[3] with this added power made this a reliable service.

In addition to engineering this improved propagation reliability in the new system, the effects of "aging" between regular maintenance intervals was explored. This "aging" normally manifests itself in a marked reduction in signal-to-noise, and if serious enough actually reduces the load carrying capacity of the system. Aside from the obvious complaints of the Operating Department and those responsible for radio maintenance, this entails a rather sizeable capital investment in test equipment. To reduce the effects of "aging," the new system employs subcarrier and heterodyne repeaters.

The heterodyne feature eliminates the distortion inherent in modulating and demodulating with the basic intelligence at each repeater, and the sub-carrier features permit long-term variations in repeater amplitude and phase characteristics with minimum effect on the modulation.

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[1] J. Z. Millar and L. A. Byam, Jr., "A microwave propagation test," Western Union Tech. Rev., vol. 4, no. 2, April, 1950; Proc. I.R.E., vol. 38, no. 6, June, 1950.

[2] J. Z. Millar and L. A. Byam, Jr., "Notes on microwave propagation," Western Union Tech. Rev., vol. 7, no. 3, July, 1953; Conv. Rec. I.R.E., Part 2, Antennas and Communications, 1953.

[3] J. J. Lenehan, "A radio relay system employing a 4000 mc, 3 cavity klystron," Western Union Tech. Rev., vol. 6, no. 3, July, 1952.

Modification

A simplified block diagram of the MLD-4A microwave system is shown in Fig. 1. The 1.5-mc modulator was designed to handle the bandwidth required for a 40 voice-band frequency division type of multiplex equipment. The composite output signal of the multiplex terminal frequency modulates the 1.5 mc produced in this unit and on peaks achieves a deviation of ± 500 kc. With this deviation and suitable band-pass characteristics, the sub-carrier is maintained within the octave of 1 mc to 2 mc and some improvement in cross-talk suppression is realized over the method which employs more than an octave.

The modulation of the SAC-41 by the 1.5-mc output of the modulator is somewhat different from the more conventional means employed with reflex tubes. In a klystron of this type the anode potential is varied at the modulating frequency rate, which produces phase modulation of the tube's electron stream. With a beam potential of 750 volts, the modulating potential is approximately 25 volts rms for the equivalent FM deviation of ± 3.25 mc. To produce this voltage with the relatively heavy loading of the klystron electron stream, it was necessary to design a high power 1.5-mc driver, which is illustrated schematically in Fig. 2. The driver output is developed across chokes L_1 and L_2, and the modulating potential is in effect placed in series with the klystron's beam voltage. The rf source is coupled to the first of the three synchronously tuned cavities and because of variations in tubes, the microwave input must be adjusted for optimum drive. The phase modulation characteristic in the SAC-41 is changed to equivalent FM to achieve the optimum improvement factor by maintaining a 6-db slope over the modulating frequency range of 1 mc to 2 mc.

Crystal Control

The microwave frequency employed for the receiver local oscillator and transmitter source is developed in the Crystal-Controlled Multiplier. The advantages of this method are high stability and minimum maintenance adjustment. The basic frequency in the multiplier range is produced by a temperature-controlled crystal with a stability of ± .005 per cent. Multiplication to the 200-mc range is accomplished by typical lump constant circuitry, and two cavity-tuned lighthouse stages are employed as doublers to reach 800 mc. The multiplication from 800 mc to 4000 mc is obtained by an SMC-11-H klystron. This type contains within one envelope an input cavity tunable over the range of 740 mc to 840 mc and an output cavity that will cover the 3700-mc to 4200-mc common carrier band.

The front view of the crystal multiplier showing the relative position of the stages is shown in Fig. 3.

At terminals, the service channel, which is independent of multiplex channels and is employed for maintenance and the fault-locating functions to be described later, modulates the Crystal Multiplier. The normal service channel deviation is ± 100 kc and is accomplished by phase modulation in the second stage of the multiplier chain.

In the design of the multiplier, it is necessary to be aware of the relatively strong fields at the frequencies of the multiplier chain that can appear as interfering signals in the rf and if amplifier units of the system. The first obvious precaution is the choice of frequencies for the individual stages, which do not fall into the bandpass of any of the units. Aside from these, however, are the other harmonics always present as well as sums and differences that can mix in the receiver crystal input and fall in the amplifier bandpass. This effect becomes more prominent as the noise figure of receiver is improved. To minimize radiation effects, a shield is placed over the rear of the multiplier which is equipped with a press-fit cover that can be removed for maintenance. A rear view of this unit is shown in Fig. 4 with the shielding cover removed.

Frequency Allocation

When designing a relay system employing heterodyne repeaters, one of the basic problems is the relationship of transmitter frequency to received frequency at each relay station. In the design it was realized that since Western Union is co-user with other common carriers of the 3700 to 4200-mc band, it would be best to maintain a circuit frequency allocation that was compatible with systems already in the field. The upper section of Fig. 5 shows the channel assignment employed by the Telephone Company's TD-2 system, and it can be seen that 20-mc wide channels are placed at 40-mc intervals. To reduce the mutual interfering effects on parallel and crossing paths, it was decided to interleave the MLD-4A channels so that they fall between those occupied by the Bell System. The Western Union frequency allocation for the MLD-4A is shown in the lower section of Fig. 5. With this method of a channel interleaving, optimum utilization of the band is achieved by employing a $\pm$ 40 mc relationship between the received and transmitted frequency at each repeater.

Repeater

The units which provide the necessary repeater gain and produce the desired relay frequency translation are depicted in the block diagram of Fig. 6. At each repeater the incoming signal is converted to the 70-mc intermediate frequency by mixing with the energy supplied by the crystal-controlled microwave source. The receiver amplifier is flat within less than 1 db over a 10-mc range and includes agc and limiting. The next step in the relay frequency translation is accomplished in the 70-mc to 110-mc converter. This unit produces the frequency shift by heterodyning the receiver amplifier output with a crystal controlled 180-mc oscillator. There are additional stages to provide the necessary selectivity and bandpass characteristics for the 110-mc difference frequency.

The circuitry used for high level mixing of repeaters is similar to that employed at terminals for modulation. Fig. 7 is a schematic illustration of this circuit. The 110-mc phase modulates the microwave input and as in any modulation system there is a signal distribution of 1st, 2nd, etc. order of sidebands. The second and third cavities will not pass the entire modulated band, but are tuned to either the upper or lower first order sidebands. The level of 110-mc is set for maximum first order sideband while the microwave input is adjusted for optimum drive. With this method of synchrodyning, the transmitter power is of the order of 6 to 8 watts.

Photographs of the front and rear view, respectively, of a two-way MLD-4A repeater appear in Figs. 8 and 9. In general, all metering and tuning can be done from the front, while tube replacement is accomplished from the rear.

Demodulation

The functions of the terminal can best be described by referring to Fig. 1. As at a repeater, the incoming signal is converted to 70 mc, and within the same unit the signal is demodulated by a 70-mc discriminator. This discriminator is also available in the receiver panels at repeaters. At terminals, where both the 1.5-mc and service channel are desired, a filter provides the necessary selectivity. The 1.5 mc is amplified to the proper level for extended cable runs, before it is fed to 1.5-mc demodulator which removes the composite multiplex intelligence for operation of the carrier terminal.

Fault Locating

In any system which employs unattended repeaters, the fault-locating system has, as a minimum requirement, the location of the tower at which a system failure occurs. Fig. 10 is a block diagram representing a failure between towers A and B. This failure is of the simpler type since the circuit is assumed to be operating normally in one direction. The fault-locating equipment at each station monitors receiver agc current as well as relative transmitter power. When either of these fall below a predetermined level, that station sends back a tone whose frequency is peculiar to the repeater, and coding of the tone denotes whether it is low agc or low transmitter power. In the failure shown in Fig. 10, the west terminal would receive a coded tone from B if the failure is in the receiver at Station B. If the failure is due to low transmitter at Station A, the west terminal will receive this information from tower B.

The more complex fault is one where the circuit fails in both directions. This type of failure is especially difficult in heterodyne type repeaters where transmission at each station depends upon a received signal. With any break the rf path is lost beyond the break, and in order to restore the transmission path, a 70-mc reinstatement oscillator is activated and replaces the receiver output as drive to the 70-mc to 110-mc converter. Fig. 11 is a more detailed block diagram of the repeater fault-locating functions.

The point at which the 70-mc reinstatement oscillator of each station comes on is a function of the agc potential, but this cannot be the only determining factor. The point where the received signal has dropped low enough to cause circuit interruption is not a fine line, as it is determined among other things by operating conditions on the other links of the system as well. To insure that the 70-mc oscillator does not come on while the circuit is still capable of carrying traffic, one additional requirement has been placed on the operation. When an actual break has occurred, the terminal sends out a 20-kc tone. The reception of the tone activates a relay and the combination of this tone and low agc place the reinstatement oscillator in operation.

Antenna System

It is not within the scope of this paper to detail the design efforts involved in the antenna equipment, but the pertinent points of interest from an overall standpoint will be described briefly.

The economic advantages of the passive reflector method made this type of radiating system attractive. In order to determine quantitatively the cross-coupling effects with such devices, Western Union made a test installation at Monsey, N. Y. Fig. 12 is a view of this tower, showing the mounting of the passive reflectors. An analysis of the results of these tests has been completed and will be published, but it might be briefly stated here that passive reflectors are desirable for routes which have a small number of rf channels and where it is possible to use a separate frequency for each transmitter and receiver at a given station. On heavily loaded routes where a large number of circuits are required, and the resulting necessity for frequency conservation reduces the two-way transmission to two frequencies, that is, to receive on one frequency from both directions, and to send on a second frequency in both directions, a more elaborate antenna system is required. A type that appears promising for this application is the "hog-horn" or horn reflector shown in Fig. 13. This photo is a picture of the test set up at the Water Mill Laboratory.

In addition to the radiating elements, the antenna system of the MLD-4A consists of suitable waveguide components for either duplex or multiplex operation. When duplexing, the received and transmitted rf signals to be separated in the filter system are spaced by 120 mcs, so that a single antenna may be used for both transmitting and receiving on one side of a repeater.

When two or more channels are required on one route, a system of multiplexing is employed so that all the transmitters for one direction are on a common antenna and all receivers are on a second antenna. With this method the location of the receiver and transmitter frequencies alternate their position in the band at each station.

Emergency Power

Fig. 14 is a view of the emergency power equipment to be used with the MLD-4A installations. It consists of a common shaft coupled ac motor, ac generator, and dc motor-generator. Under normal conditions the ac motor is operated on the commercial power and the ac generator provides the primary source for operating the radio equipment. At this time the dc machine is functioning as a generator and is providing trickle charge for a bank of batteries. If the commercial power fails, the dc machine instantly becomes a motor, driven by the batteries and the ac generator continues to supply power for the MLD-4A equipment.

The battery life cycle here would be about three hours which is hardly sufficient to cover some serious power failures. The lengthy failures are covered by a gasoline-driven alternator that comes on when the commercial power fails. It does not, however, take over the load until it has reached proper voltage and frequency. The entire system is an improvement on the one employed on the New York-Washington-Pittsburgh triangle in that it eliminates vibrators, but maintains its predecessor's ability to switch without losing even one telegraph signal pulse.

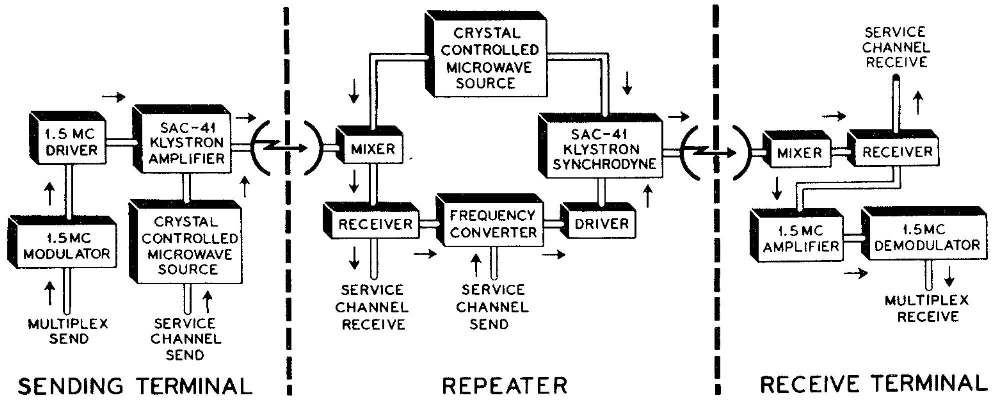

Fig. 1 - Block diagram of MLD-4A system.

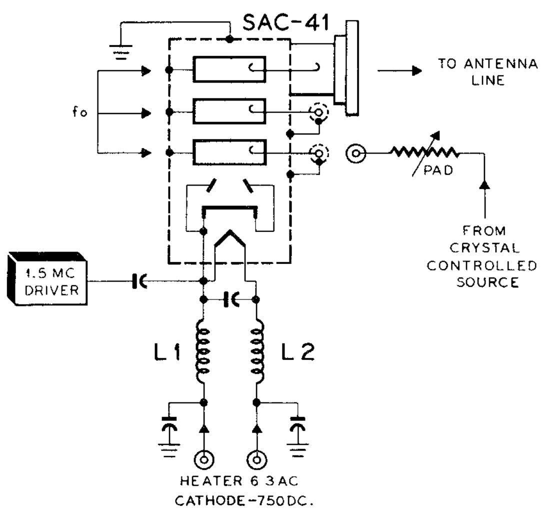

Fig. 2 - MLD-4A repeater, SAC-41 transmitter circuit.

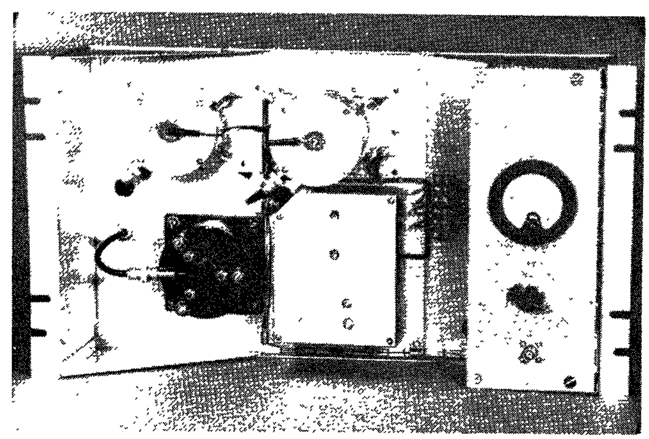

Fig. 3 - Front view of crystal-controlled multiplier.

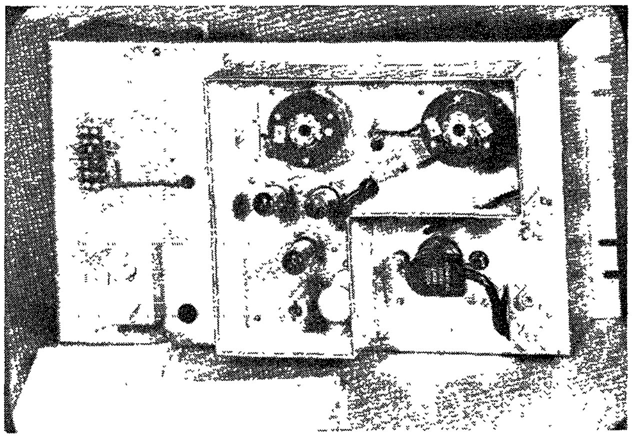

Fig. 4 - Rear view of crystal-controlled multiplier.

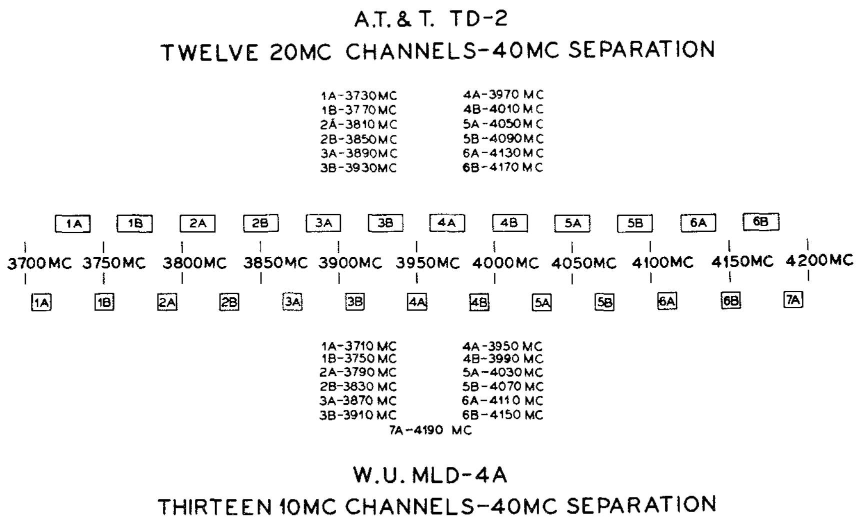

Fig. 5 - 3700-mc to 4200-mc frequency allocation.

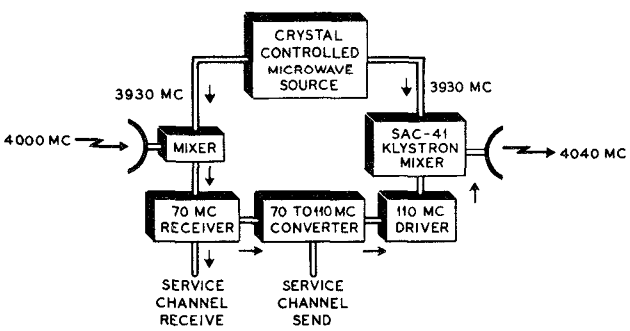

Fig. 6 - Block diagram of MLD-4A repeater.

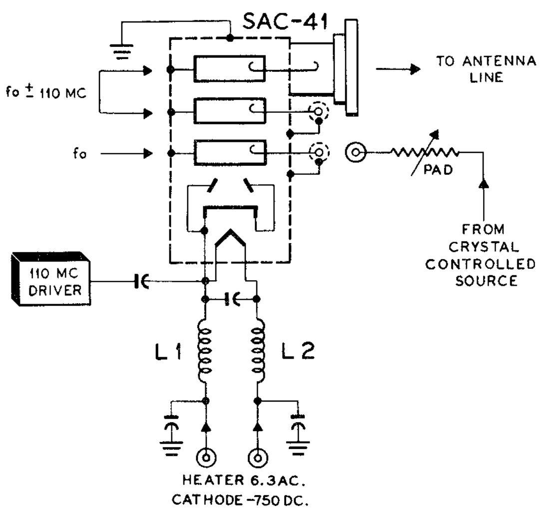

Fig. 7 - MLD-4A repeater, SAC-41 transmitter circuit.

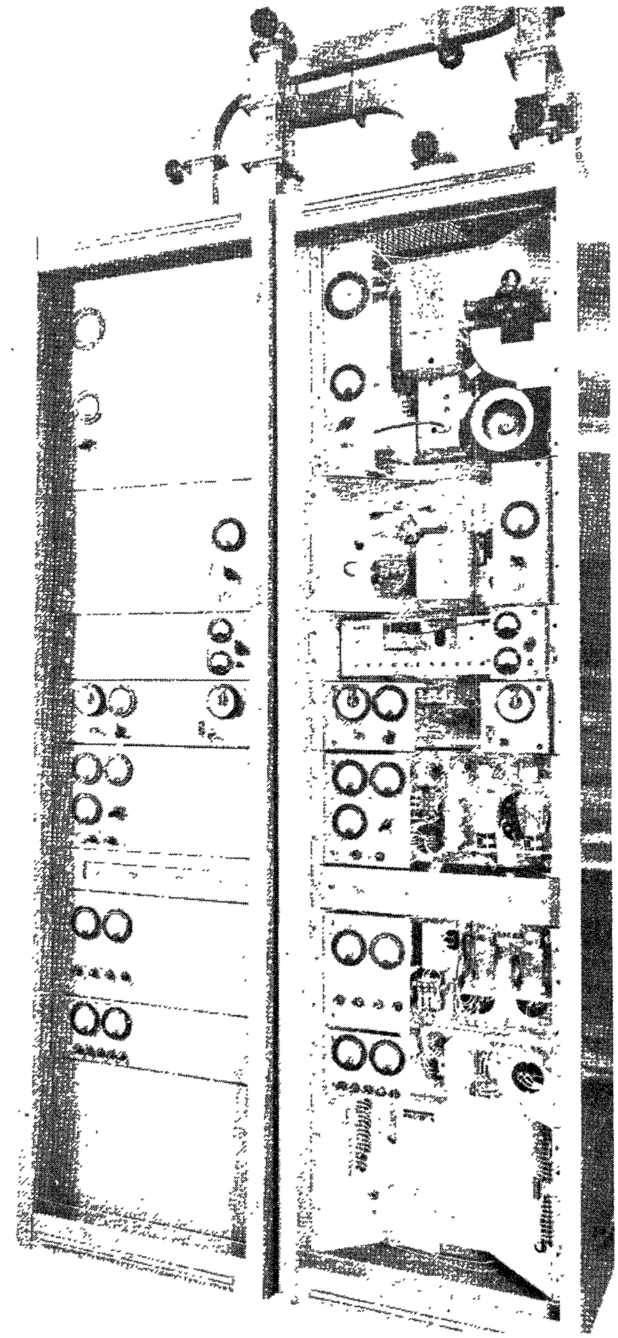

Fig. 8 - Front view of MLD-4A two-way repeater.

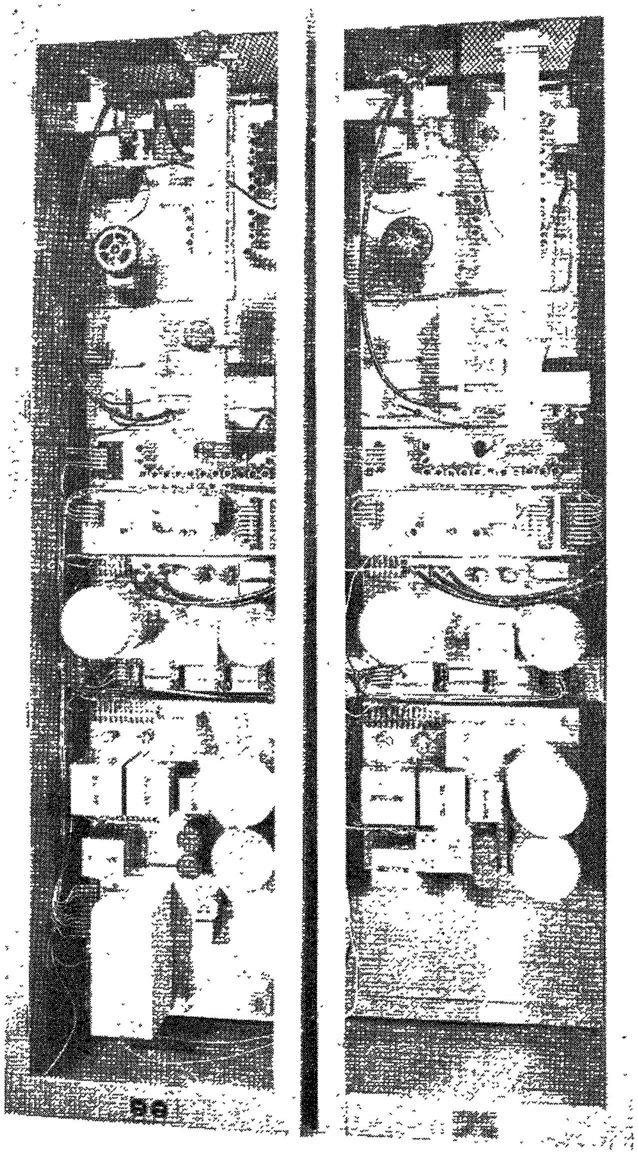

Fig. 9 - Rear view of MLD-4A two-way repeater.

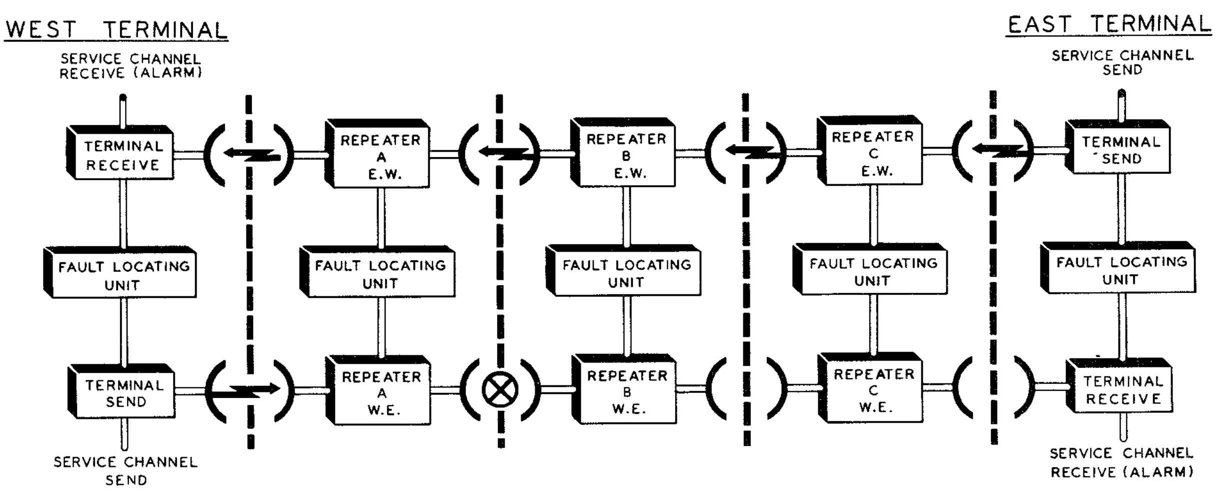

Fig. 10 - Block diagram of MLD-4A fault-locating system.

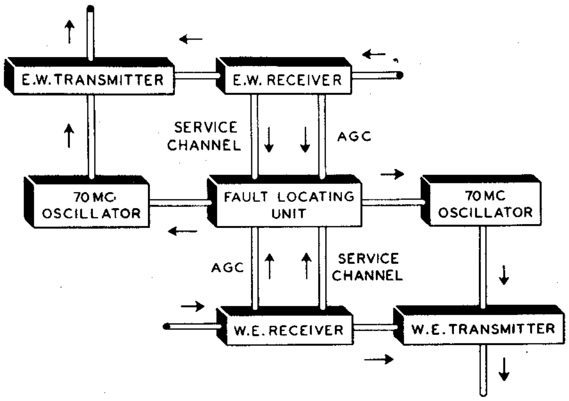

Fig. 11 - Block diagram of MLD-4A fault-locating repeater.

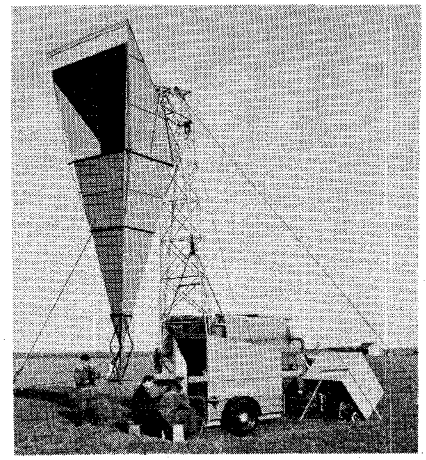

Fig. 13 - Horn-reflector antenna.

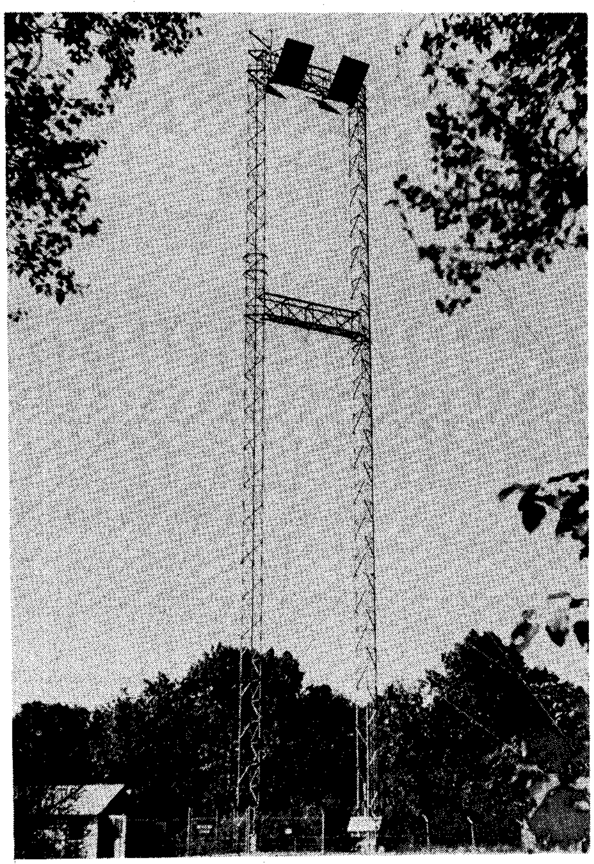

Fig. 12 - Experimental passive reflector tower.

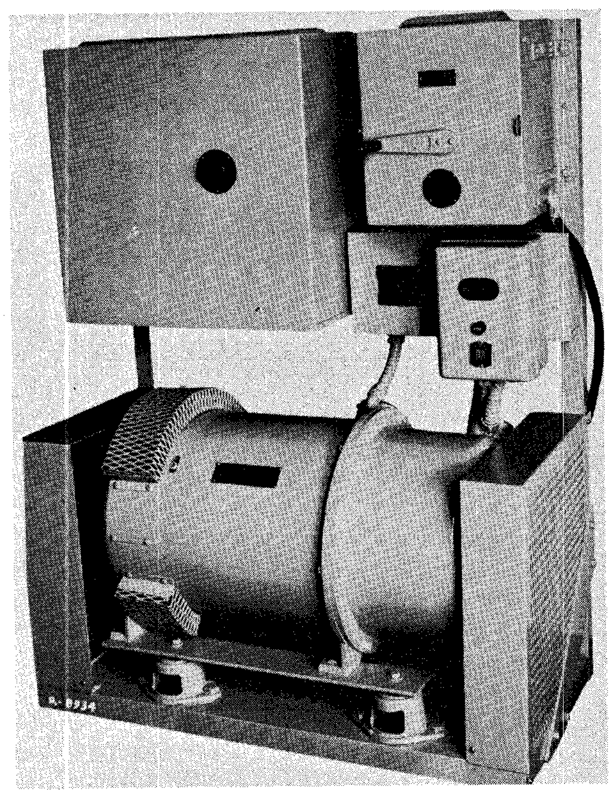

Fig. 14 - Three-unit rotating machine.