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A SPLIT-BEAM MICROWAVE RANGE

- L. G. COX -

OTTAWA

APRIL, 1969

A SPLIT-BEAM MICROWAVE RANGE

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SUMMARY

This report describes a system designed to provide accurate guidance of vessels in narrow channels when normal visual aids are obscured by weather conditions.

The shore station comprises a microwave X-band magnetron transmitter, with a rotating mechanical chopper to switch the transmitter output between a pair of horn antennas. A battery-operated receiver onboard the vessel compares the amplitude of the signals received from the two horns, and the result is displayed on a zero-center meter as deviation from true course.

March, 1969

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INTRODUCTION

None of the various aids to navigation which are available to pilots such as compass, radar, buoys, range lights, etc., are infallible and the experienced pilot considers them as mere aids to assist him assessing the information from all sources in deciding his course of action. However in inclement weather the optical aids disappear and radar is required to distinguish the buoys along the channel.

The navigation season has been gradually extended on waterways such as the St. Lawrence Seaway, until it extends well into the winter season. At the beginning of the winter season the metal channel buoys are lifted to prevent their being carried away or damaged by ice and are replaced by wooden spar-buoys. These wooden buoys do not give a useful radar echo and may even be submerged under the ice or shifted by it. However, floating ice floes can give a radar echo which may conceal the true shorelines.

Under these conditions when the range lights which are the primary aids to navigation are obscured by fog, rain or snow, all shipping in narrow channels must come to a halt, frequently for hours at a time. This happens daily at a time when shipping is trying to clear the St. Lawrence Seaway before freeze-up.

The Split-Beam Microwave Range was designed to provide accurate guidance of vessels in narrow channels, especially during bad weather conditions. It indicates whether the vessel is following the center line of a channel, or the degree by which the vessel has deviated from the center line.

GENERAL DESCRIPTION

About 15 years ago the National Research Council investigated the possibility of providing navigational assistance to small vessels and devised a microwave lighthouse with a battery-operated directional receiver. The transmitter used a general coverage antenna of about 135^{o} beamwidth and the receiver consisted of a parabolic cylinder using a slotted waveguide antenna with 6^{o} bandwidth, crystal detector and a 4-transistor amplifier with the output driving headphones. The bearing of the microwave lighthouse could be determined within 1^{o} with this equipment. For narrow channels and harbour entrances, a split-beam transmitter was used. The magnetron was pulsed continuously and a mechanical switch produced complementary coding, such as AN or DU on the two beams. Within a narrow area less than 1 degree wide, the beams were approximately equal strength and a continuous tone was heard in the 'phones.

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The general reaction was favourable, but the outstanding objection was to the oral presentation, because pilots depend on hearing for information in dirty weather and would not condone the introduction of an extraneous source of sound.

The present system consists of a shore-based microwave transmitter and a battery-operated shipborne receiver with a center-zero course indicator. The transmitter produces trains of 25 pulses with two different repetition rates, the energy being fed alternately to horn antennas 6° either side of the center line of the course so along the center line of the course the two signal strengths are equal. The transmitter location is shown on Fig. 1. The receiver uses a single horn antenna with a crystal detector. The train of pulses are amplified, separated according to their repetition rates, and their amplitudes compared, with the results displayed on the zero-center meter. Two degrees off course will produce a full scale meter deflection.

<u>Block Diagrams</u>

A block diagram of the transmitter is shown in Fig. 2. An etched printed circuit chopper disc driven by a motor alternately couples the energy from the magnetron to horns A and B. Auxiliary slots near the edge of the disc allow photocells to be illuminated, such that when horn A is in use, the output of a 2280 Hz oscillator drives the trigger generator, and when horn B is in use an 1980 Hz oscillator output is used. The trigger generator provides a firing pulse for the hydrogen thyratron allowing a pulse forming network to discharge into the pulse transformer energizing the magnetron. Fig. 3 shows the details of the chopper disc. Figure 4 is a block diagram of the basic receiver. The video pulses from the crystal detector on the receiving horn are amplified by the video amplifier and are used to trigger a monostable multivibrator (MMV) with a delay of 250 microseconds. At the end of this time two other MMV's with periods of 245 and 178 microseconds are triggered, giving total delays of 495 or 428 microseconds. The output of these MMV's are differentiated and open their respective gates for about 20 microseconds. If the pulse train being received has a repetition rate of 1980 per second the second pulse of the train will arrive at gate #2 while it is open and pass through it to the pulse stretcher. Similarly, the first pulse of the 2280 per second train opens gate #3 in time for the second pulse of the train. The second pulse in turn has triggered the first MMV so that all but the first pulse of the train of pulses pass through the appropriate gate, thus the signals from the two beams are separated into two channels; after the separation the only active devices are emitter followers having essentially unity gain. The pulse stretchers convert the pulses into d.c. levels which are then compared by the previously mentioned zero-center

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meter. The stronger of the two signals drives an automatic gain control amplifier which controls the current through forward-biased diodes used as variable attenuators in the video amplifier. A loss of signal circuit flashes a lamp to indicate when the signal strength is below a useful level.

Multiple Stations

Referring to Fig. 1 again, a second transmitter in the direction B would be required to guide the vessel after it had approached the crossing point C, so when crossing from one range to another, some means must be employed to differentiate between the two transmitters. The simplest way to do this is to use a different pair of repetition rates, e.g., 1830 and 2130 for a second transmitter. However at point C when the vessel is very close to transmitter A which is using higher repetition rates the system will be susceptible to interference from A. Once the first MMV has been triggered either by the desired pulse or by an interfering pulse it cannot be re-triggered for over 250 microseconds, and if a desired pulse arrives during that period it will be lost.

A slightly more complicated method of providing identification and also of greatly reducing interference is by the use of a double pulsed transmitter. If a pair of pulses with relatively close spacings are transmitted, the pulse spacing may be used to differentiate between different transmitters as well as to reject radar pulses. Figure 5 shows the modification necessary to the basic receiver of Fig. 4 to accomplish this. Another gate and a fast MMV with a selectable delay to either 10, 12 or 14 microseconds is inserted between the video amplifier and the 250 microsecond MMV. The #1 gate is open for only 1 microsecond. With this modification only the second pulse of pairs of pulses with the desired spacing will be passed to the main multivibrator and the vulnerable period is reduced to about 10 to 15 microseconds out of about 500. The only effect of interfering pulses is to block occasionally the desired pulses from passing the gate, but one missing pulse is insignificant in the train of 25. The transmitter will now require a second thyratron and pulse forming network which utilizes a common pulse transformer and magnetron.

Transmitter Circuit Diagram

The circuit diagram of the transmitter is shown in Fig. 6. The system requires reasonably accurate repetition rates for operation and these are generated by tuning fork oscillators, using transistors Q_4 and Q_8. The tuning forks themselves are subminiature, about 1/4 inch square by 2 inches long, with ceramic transducers on each tine suitable for transistor drive. Over a temperature range of -30° to +65°C and a power supply variation of ±50% the frequency change was not over 2 Hz in 2000. The signals at the collectors of Q_4 and Q_8 are differentiated and the negative spikes cut off transistors Q_3 and Q_7. If the gate transistor Q_2 or Q_6 has been turned off by light falling on phototransistor Q_1 or Q_5, positive pulses are generated at the appropriate collector and fed through isolating diodes to the base of the emitter follower Q_9 which supplies a large pulse to drive Q_{10} into saturation. The output from Q_{11} is differentiated and an emitter follower Q_{12} drives Q_{13} into saturation for about 5 microseconds. The output of Q_{13} is coupled to the grid of the 3C45 hydrogen thyratron by a pulse transformer with a step-up voltage ratio of 1 to 15 producing an open circuit voltage pulse of +250 volts at the grid. The diode across the primary of the pulse transformer prevents ringing. Connected to the anode of the thyratron is an artificial 50 ohm transmission line which is charged to 2700 volts. When the thyratron fires it becomes effectively a short circuit and the line is discharged through the primary of the magnetron pulse transformer. The bifilar secondary winding on the transformer produces a -5 KV pulse at the magnetron cathode, generating a peak power of about 7 KW in the magnetron. The average magnetron current may be measured by means of the test point shown. The differentiated output from transistor Q_{11} is also used to trigger a monostable multivibrator.

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Transistors Q_{14} and Q_{16} are the active elements of the multivibrator. Q_{15} provides voltage and temperature compensation for the multivibrator. Adjustment of the constant current through Q_{15} sets the multivibrator time delay to the desired period of 10, 12 or 14 microseconds. The remainder of the circuitry Q_{17} through Q_{21}, thyratron and pulse forming network are identical to those immediately above and provide a second magnetron pulse with the delay set by the multivibrator.

Receivers

Figure 7 is the circuit diagram for the video amplifier for the receiver. Multiple inputs from receiving antenna horns are shown on the left. Bias is supplied to the crystal detectors to extend their logarithmic range. Four common emitter amplifier stages Q_1 to Q_4 are used, followed by an emitter follower Q_5. The signal level at this point is about 0.25 volts peak. The main video amplifier transistor Q_6 increases the level to about 10 volts peak, and an emitter follower Q_7 feeds the signal to the multivibrator stages. Q_8 and Q_9 are complementary emitter followers used in the automatic gain control circuit. The output from Q_8 feeds bias current to three forward-biased pairs of diodes at the inputs to Q_1, Q_2 an Q_4. These diodes act as variable resistors and each pair has an attenuation range of about

30 db. At the extreme right of the diagram is the loss of signal circuit. The input to the automatic gain control amplifier is also fed to the emitter follower Q_{10}. A silicon controlled switch Q_{11} compares the voltage with the zener diode voltage applied to the anode gate, and when the level drops below that of the zener the lamp will begin flashing.

Figure 8 is the circuit diagram of the first and second multivibrators. Q_{14} is an emitter follower biased so that only large amplitude signals will trigger transistor Q_{16}. Q_{16}, Q_{17} and Q_{18} are the transistors for the fast monostable multivibrator which is almost identical to that shown in the transmitter diagram of Figure 6. The delay in the multivibrator is controllable by a switch. The waveform from Q_{18} is differentiated, and amplified by transistors Q_{19} and Q_{20}. The transistor Q_{21} is normally biased hard on, however, the gating pulse will turn off the transistor for about a microsecond, and during that time a pulse on the emitter of Q_{13} will be passed to the base of Q_{22}. Q_{23} is an emitter follower which drives the 250 microsecond multivibrator using transistors Q_{24}, Q_{25} and Q_{26}. Q_{27} is an emitter follower which feeds the signals to the final pair of multivibrators, shown in Fig. 9.

Figure 9 shows the circuit diagram of the final multivibrator gates, pulse stretchers and meter. Except for the different timing in the input multivibrators, the upper and lower circuits are identical on Figure 9. The input stages are multivibrators with periods of 245 or 178 microseconds respectively. The output from the multivibrators are differentiated, amplified and used to turn off transistors Q_{32} or Q_{41}, which are used as gates, similar to Q_{21} on Fig. 8. Following the gates we have emitter followers and pulse stretchers so that the output from emitter followers Q_{36} and Q_{45} are slowly varying d.c. levels. These levels are compared in the zero-center meter shown at the right-hand side of the diagram. The multi-position switch and appropriate circuitry also allows the meter to be used as a battery voltage monitor.

Signal Nulls

When a microwave signal is reflected from the surface of water at shallow grazing angles the water behaves like a lossy dielectric, giving a 180^{o} phase shift and almost unity reflection coefficient. Consequently when the path difference between direct and reflected rays is an even number of half-wavelengths there can be very deep signal nulls at close ranges with calm water. This situation may be alleviated by mounting two receiving antennas, each with its own crystal detector, at different heights on the vessel. The path difference for direct and reflected rays will not normally be an even number of half-wavelengths simultaneously for both antennas, and the stronger signal will fill the nulls of the weaker.

Transmitter Monitor

Although for simplicity it has not been shown on the transmitter diagram, there is also a unijunction time delay which provides a three-minute delay in the turn on of the high voltage to the thyratron. This time delay unit is also used in conjunction with the transmitter monitor system. There is a plexiglass plate in front of the horns, but snow or ice on the plate can attenuate the two lobes unevenly, effectively shifting the apparent center line of the course. A small receiving antenna is mounted 50 to 100 feet ahead of the transmitter and is used with a modified receiver. The meter is replaced by a sensitive meter relay, arranged to switch off the transmitter and recycle the time delay if the two beams are of unequal strength.

Prototype Equipment

Plate 1. shows a rear view of the chopper and horn assembly of the laboratory model, with the cover removed. The waveguide T and the printed circuit wheel of the chopper may be easily seen. At the lower left of the wheel may be seen the bulb which illuminates the photocell slot.

Plate 2. shows the antenna assembly. The rights to produce this device were obtained by an Ottawa firm and Plate 3 shows their preproduction model of the transmitter.

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All the circuitry including magnetron, thyratrons, etc., is included in this case which is designed to be securely bolted to a concrete pier. The antenna is rotatable over a limited arc for alignment after the case itself has been bolted down.

Plate 4. shows the receiver and a receiving antenna. The rear section of the receiver contains the battery pack which may be either a carbon-zinc battery or rechargeable nickel-cadmium batteries providing about 20 hours operating time between charges. Approximate weights are; transmitter = 75 lbs; and the receiver (with battery and charger) = 7 lbs.

Environmental Tests

A test range was set up on the roof of the National Research Council laboratories in Ottawa, Canada, and the equipment operated continuously for four months under various winter conditions - ice, snow, sleet, rain, hail and temperatures to -30°C.

Deviations were caused by uneven deposit of precipitation on the two halves of the transmitter faceplate and usually did not exceed ± 1/10 degree.

In a second series of winter tests a transmitter was set up on the North shore of the St. Lawrence River near Montreal, (Ile Perrot) and the receiver was placed on the wharf at the Beauharnois Locks, about 2 miles distant. As a ship crossed the beams there would be a fairly rapid fluctuation of the meter needle with an apparent course deviation of 1/10 to 1/2 degree for a few seconds, with a loss of signal if the ship's superstructure blocked the line-of-sight between the receiver and transmitter. There was no interference between the microwave range and the ship's radar, or UHF communications. During this set of tests we also had ice, snow, sleet, rain, which did not affect the performance of the microwave range.

Tests were conducted on the Ottawa River, using the motor vessel "Radel II" (owned and operated by the National Research Council). The wheelhouse was blacked out and runs were made using only the microwave range and the ship's compass. Without experience in the operation of the compass it was found to be quite easy to keep the vessel within 1/5 of a degree of the center line of the course. On some runs the vessel stayed within ± 1/10 of a degree, that is within ± 30 feet at 3 miles.

CONCLUSION

The split-beam microwave range can be an extremely useful device under conditions where other normal aids to navigation are not usable due to weather conditions. It can also be valuable where it is desired to follow a straight course with no convenient aids to navigation, for example during hydrographic survey runs. The

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transmitter may be set up on the shore for the run in and shifted along the shore for each succeeding run, allowing the ship to follow parallel sounding courses.

ACKNOWLEDGEMENT

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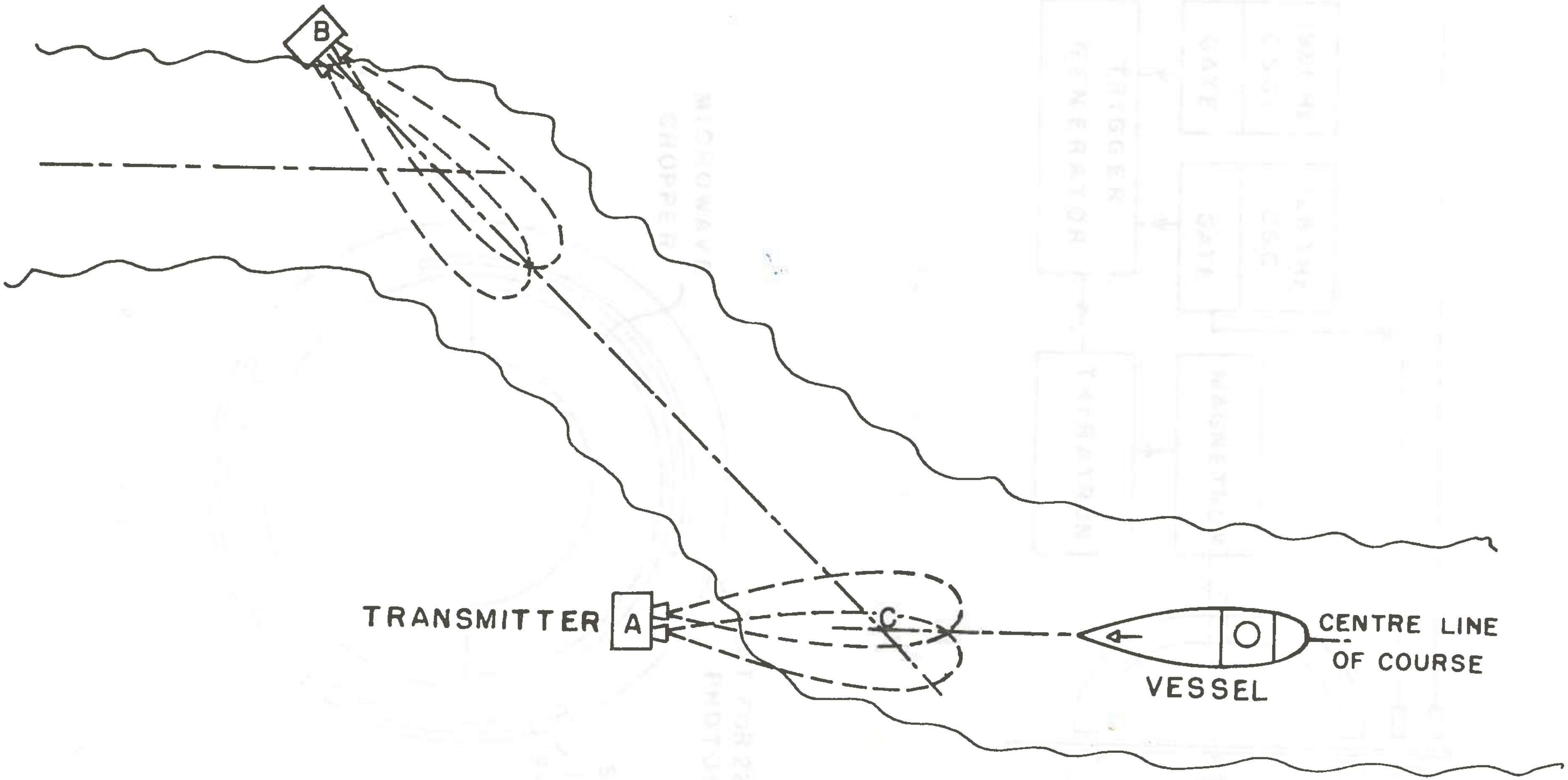

Fig. 1 - Transmitter Location

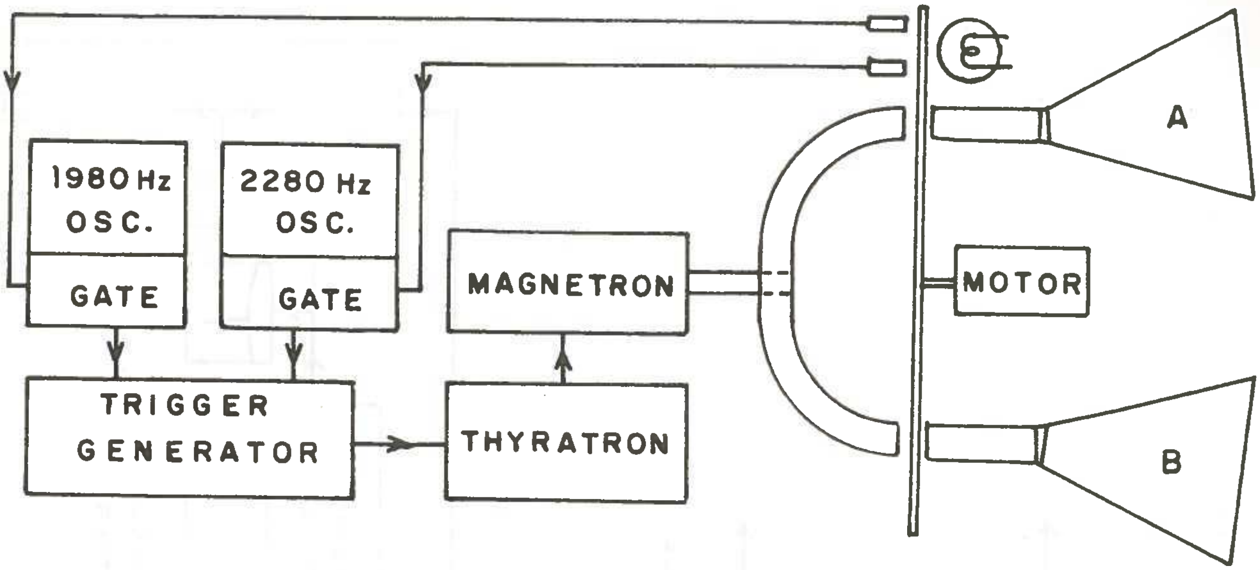

Fig. 2 - Basic Transmitter

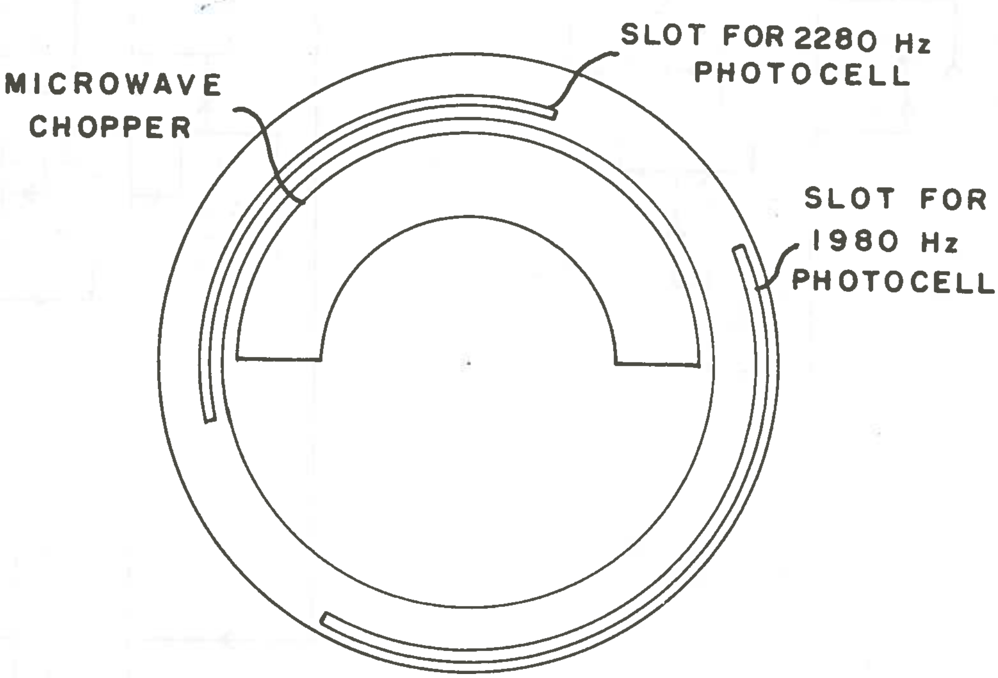

Fig. 3 - Chopper Disc

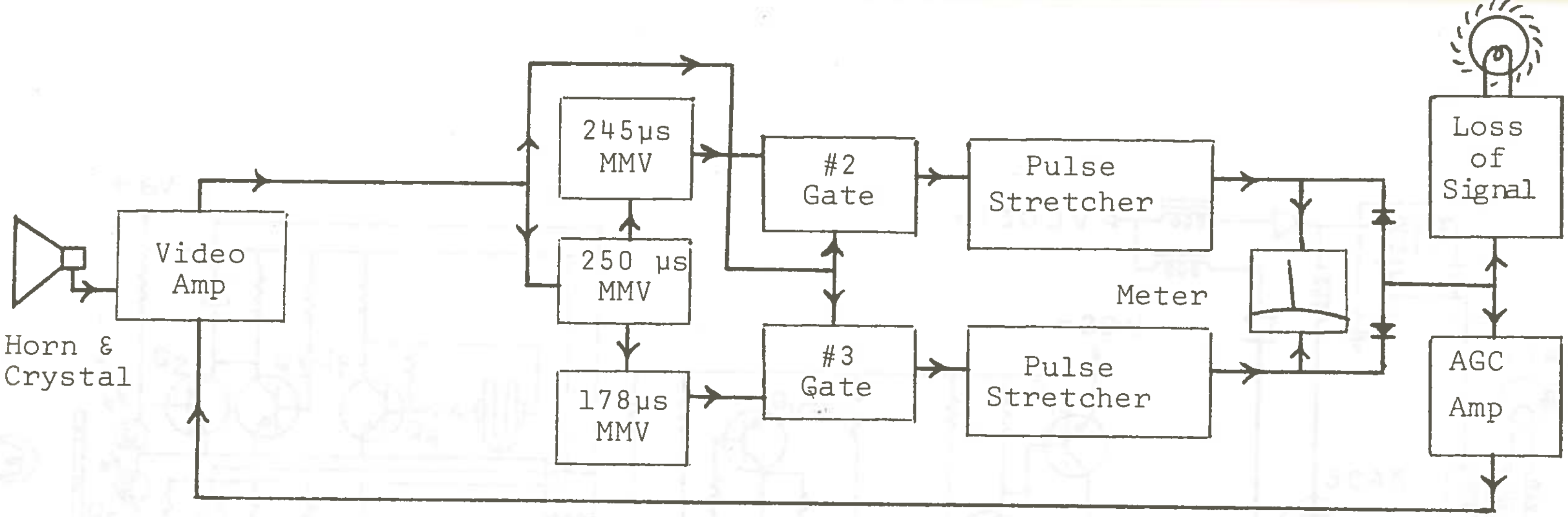

Fig. 4. Basic Receiver

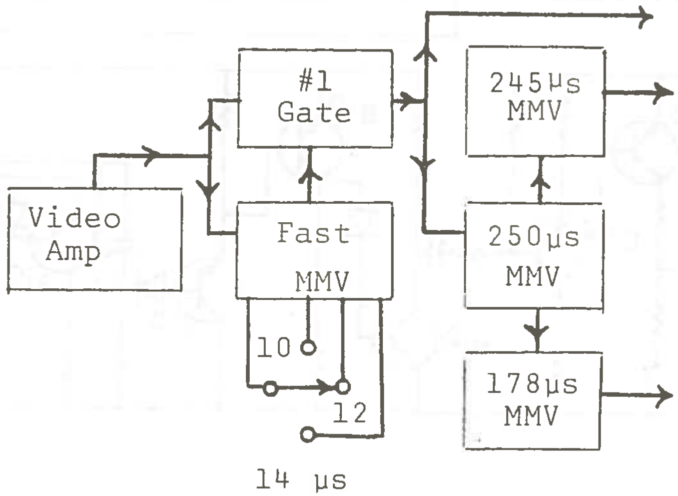

Fig. 5. Receiver Modification for
Double Pulse Reception

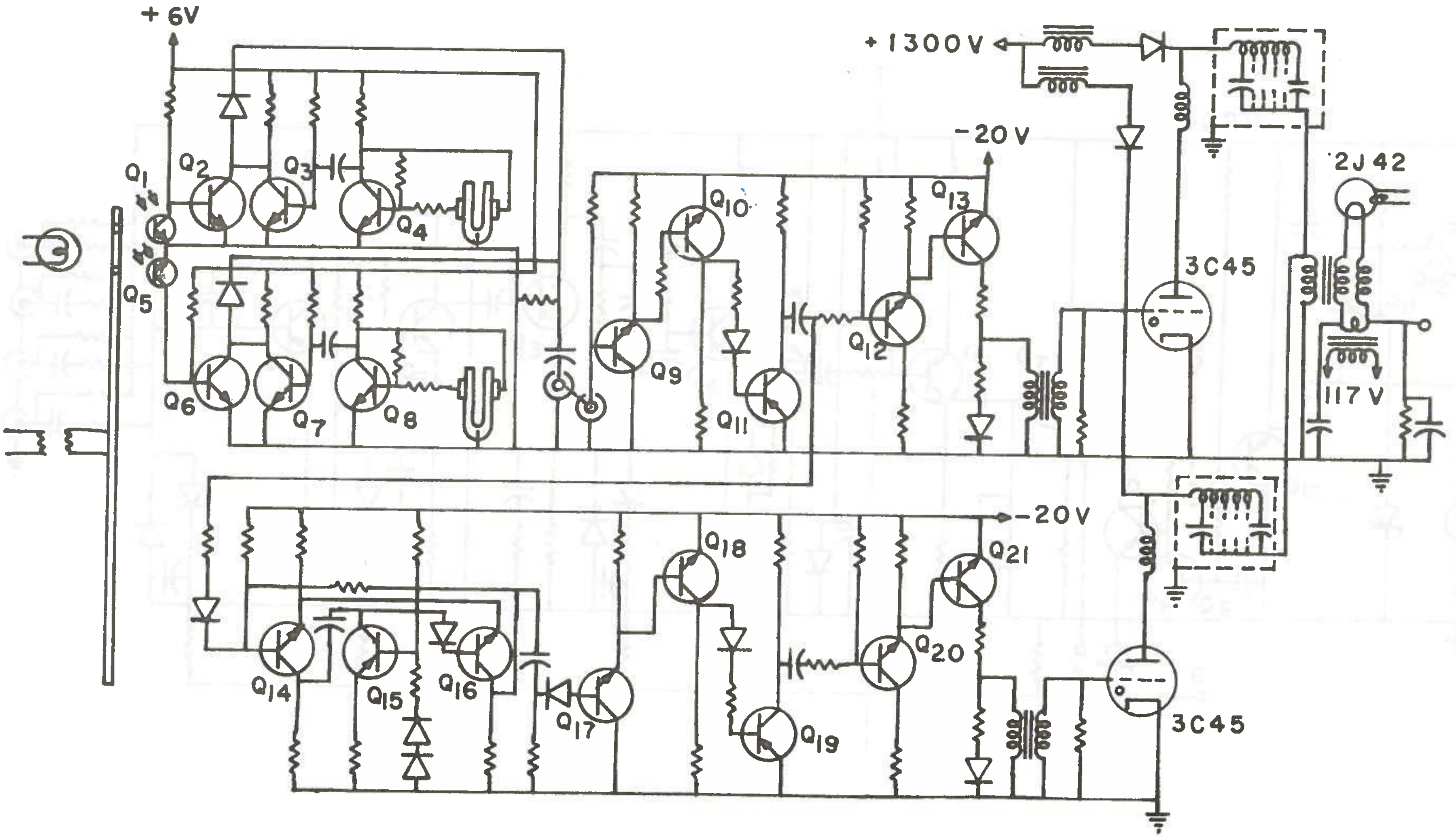

Fig. 6 - Double-Pulse Transmitter

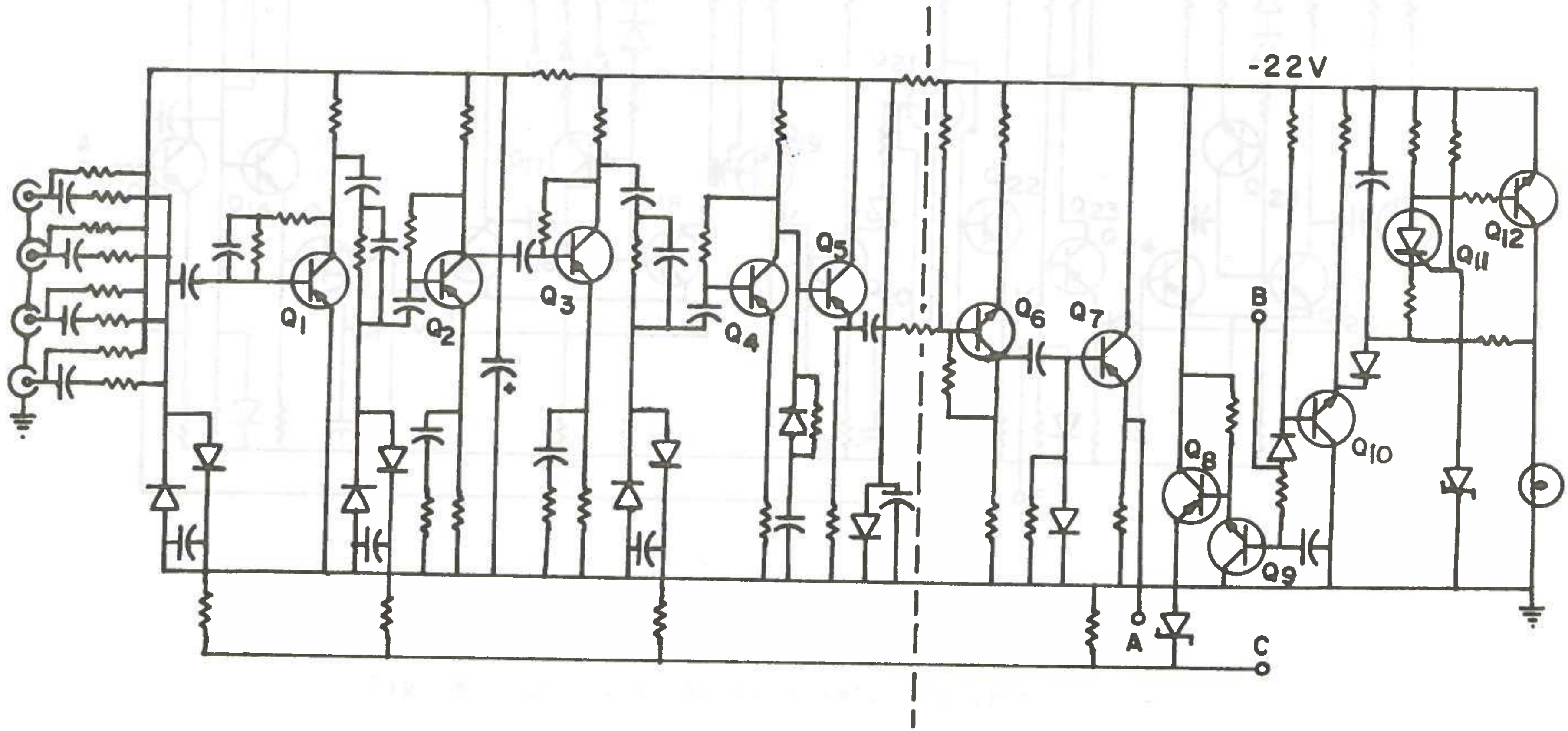

Fig. 7 - Receiver (Video Amplifier)

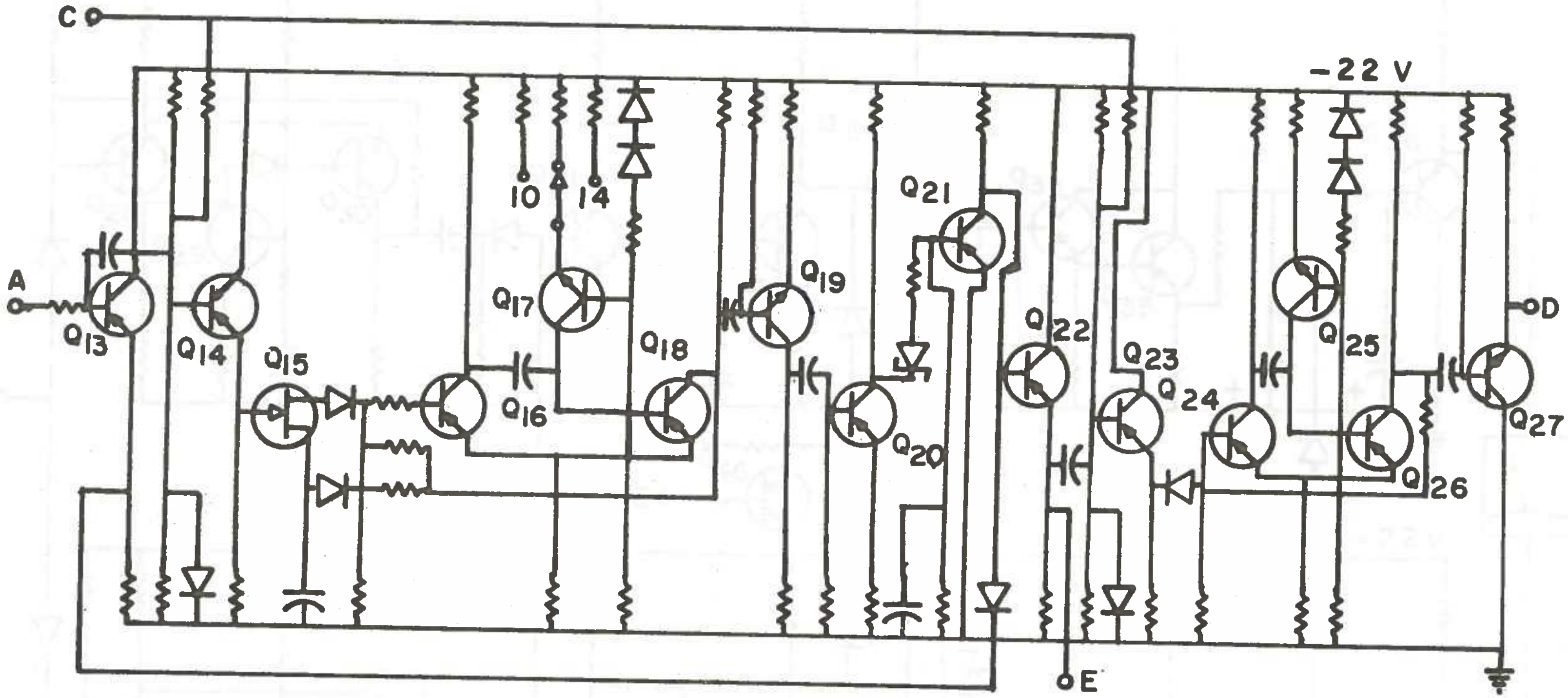

Fig. 8 - Receiver (Multivibrator Section)

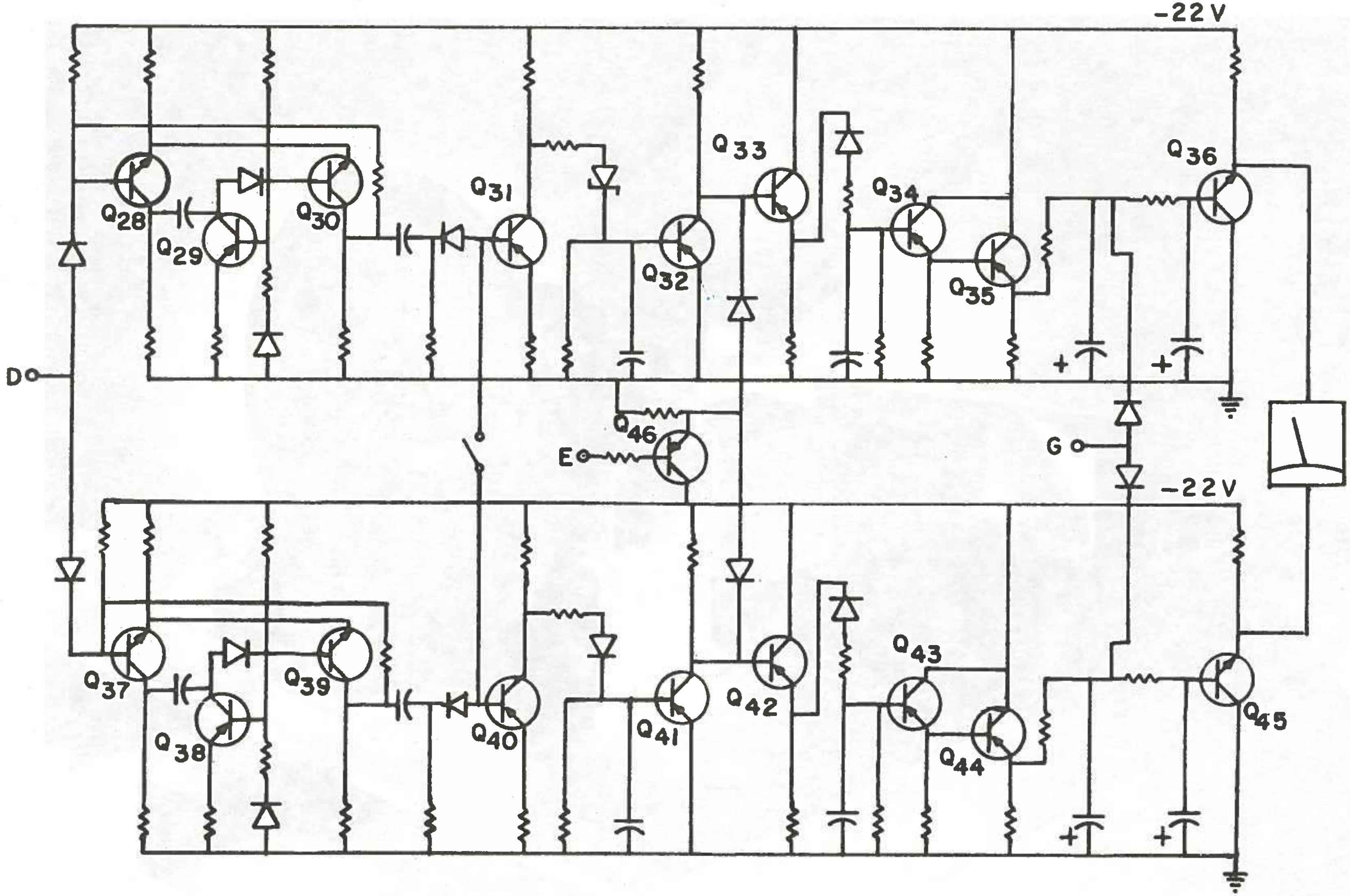

Fig. 9 - Receiver (Gates, Pulse Stretchers and Indicator)

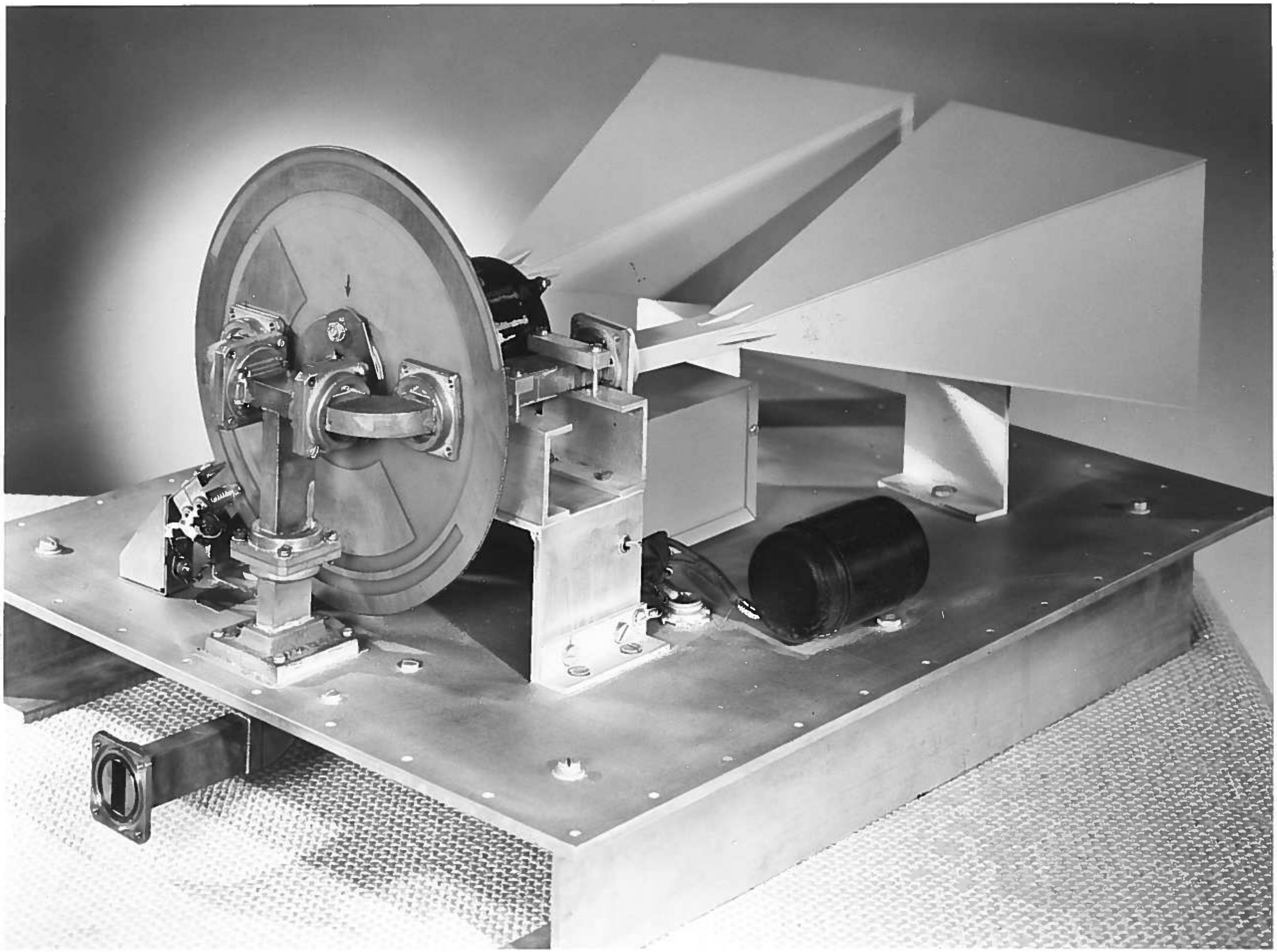

Plate 1 Chopper and horn assembly

Plate 2 Front view of antenna assembly

Plate 3 Preproduction prototype transmitter

Plate 4 Preproduction receiver and receiving antenna