AN AUTOMATIC MONITOR SYSTEM FOR RADIO RANGES

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AN AUTOMATIC MONITOR SYSTEM FOR RADIO RANGES

SUMMARY

Radio range systems are the prime navigational aid to flying in the United States and the need for a monitoring system for the courses produced by these ranges has been evident for some time The various monitoring methods employed up to the time of this report are reviewed and the details of a new completely automatic monitoring system are described This monitor equipment was installed to monitor both the Indianapolis and Salt Lake City radio ranges and extensive tests were made to determine the operating characteristics of the equipment at each location It is concluded that a satisfactory automatic monitor system has resulted from this development and that future monitor equipment should contain most of the automatic features provided in this equipment

INTRODUCTION

The necessity for the provision of monitor equipment for radio ranges[1] has been realized for several years. Various monitoring methods have been investigated in an effort to determine what features should be adopted for the ultimate monitor system The most common method and the only one that has been adopted throughout the country consists of two general types of monitor stations. One is called the distant radio range monitoring station and the second is designated as the local radio range monitor All radio range stations are assigned one or more monitors located at distant "off-course" and "on-course" locations Course shifts and timbre changes are more easily detected by "on-course" monitors while link circuit relay and keying irregularities are recognized more readily at "off-course" monitors On-course monitors may be located either exactly on the course or in the twilight area while "off-course" monitors are located where a predominant "A" or "N" is present Each distant monitor station is required to check the operation of the range at least once each hour and continuous monitoring may be accomplished when any unusual conditions exist Distant monitor stations are usually located at adjacent radio range stations, marker stations, or weather reporting stations At Salt Lake City, for instance, monitoring of the south, west, and north legs of the Salt Lake range is provided by the Tintic, Wendover and Plymouth, Utah, range stations The Albany, New York, range is monitored by the Glens Falls weather reporting station on the north course and the Utica radio range station on the west course

Continuous local monitoring of all radio range stations is provided by a receiver located in the Communications Station associated with the local range Communications Stations are ordinarily located at airports which may be 2 to 10 miles from the range stations In this type of monitoring the range course monitored is the one which passes over or near the airport

Several auxiliary monitor systems have been installed at a few range stations throughout the country At Washington, D C , a range course monitor has been installed consisting of a detector unit located on the range plot and a simplified monitor equipment in the range station The detector unit consists of a vertical antenna and a one-tube rectifier The detector is so located as to receive an on-course signal The location of the detector, however, is not on the true on-course as determined by the radiation field This displacement is due to the proximity of the detector unit to the tower radiators The monitor does not, therefore, indicate the position of the

[1] D M Stuart, "Circuit Design for Low-Frequency Radio Ranges," Technical Development Report No 23, November, 1939

true radiated course which is used by aircraft in flight The audio signal provided by the detector unit is transmitted by cable to the range station and the monitor equipment This equipment consists principally of a copper oxide rectifier, a micro-ammeter and a phone jack The audio signal received by the detector is rectified and the direct-current signal is applied to the microammeter for visual monitoring of the range signal The audio signal is also applied to the phone jack for aural monitoring of the range This aural signal is also useful in adjusting the link circuit relay for minimum key clicks No effort is made to transmit the signals to the Communications Station where the operating personnel are located The equipment is useful, therefore, only to the maintenance personnel and cannot be considered as meeting all of the essential requirements of a monitor system

At other locations monitor systems have been used which provide indicator lights working from the rectified output of the airport communications station monitor receiver These systems are not positive and only indicate on the course at the airport

With an effective monitor system it is essential that the operating personnel be given continuous positive indication of the condition of the final approach course This is the course reciprocal to the course passing over or adjacent to the airport In the usual instrument approach, aircraft proceed along whatever course they are following to the cone-of-silence marker area The cone-of-silence marker or Z marker radiates a narrow vertical beam which, when received on board the aircraft, operates a light on the instrument panel of the airplane This light gives the pilot positive indication that he is directly over the range station After passing the cone-of-silence area the aircraft proceeds out, away from the station along the final approach course Upon reaching a predetermined point such as a fan marker, the pilot makes a 180° procedure turn and proceeds toward the station along the final approach course The fan marker radiates a fan-shaped vertical beam which operates a light on the instrument panel of the aircraft and provides a definite "fix" point for the pilot Until the 180° turn is made, the pilot maintains sufficient altitude to clear all obstacles such as high mountains and towers After the turn has been made the pilot begins his let-down at a given rate depending on his distance from the airport He again passes over the cone-of-silence at a specified altitude and gets a definite position "fix" and proceeds to the airport for a landing Range stations are usually so located that either the range course opposite to the final approach course or the projection of the final approach course passes over the airport When the course in the direction of the airport passes over the airport, the pilot follows this course in from the cone-of-silence marker When the course does not pass over the airport, the pilot maintains a gyro compass heading which has been established during his descent along the final approach course and proceeds to the airport with this heading In any case, it can be seen that it is more essential to monitor the final approach course than other courses provided by the range system It is absolutely necessary to know that the course upon which the let-down is made is correctly aligned and that the range is functioning properly in this area This is particularly true where there are high mountains or other obstructions on either side of the approach course and where any appreciable deviation of the course toward these obstructions would prove fatal in an instrument approach

Local monitor receiving equipment at the airport cannot meet these requirements These monitors can only indicate that the range is operating and that the alignment of the airport course is approximately correct

Distant monitor stations provide an accurate indication of the alignment of the course and the general operation of the range under static-free conditions, when a continuous watch is maintained at the monitor receiver When even moderate static conditions prevail, however, it becomes difficult to interpret the received signals and with heavy static it is practically impossible to determine anything about the range except that it is operating Because of the low signal level at distant monitor stations the static level often exceeds the signal level The average distance of distant monitor stations from range stations is approximately 70 miles At this distance the signal intensity from the range may be as low as 45 microvolts per meter on the high power 400 watt stations At most distant monitor stations it is required that the range be checked only once an hour and it is possible that an operator who was busy performing other tasks assigned to him would not notice any deviation of the range occurring outside of the required monitor period All of the monitors that have been described provide an aural signal only or, in some cases, a visual signal to be observed on a meter or by indicator lights In the case of the aural signal, it is possible for the operating personnel to become so accustomed to hearing the range signals that the signals are subconsciously but unintentionally ignored and any deviation of the range would not be noticed immediately The visual signals provided by some of the systems are such that a continuous watch would have to be maintained on the indicating instrument in order to detect changes in signal composition. In most cases this cannot be accomplished since operating personnel have other duties to perform and cannot watch the indicating instrument continuously

The most desirable monitor system would be one that provides an unmistakable automatic alarm to ground personnel whenever certain faults occur. It would further be desirable to warn the pilot automatically by means of certain signals superimposed on the range signals It was decided, therefore, that the following services should be furnished by the future monitor systems

(1) The monitor receiver should be located on the final approach course
(2) The received aural signals should be transmitted to the Communications Station and all airline offices
(3) Visual signals indicating course deviation should be provided at the Communications Station and the airline offices
(4) An alarm system should be actuated by the monitor receiver which would automatically operate sirens and red lights at the Communications Station and in all the airline offices whenever the following radio range faults occurred.
    (a) Whenever the range course moves more than plus or minus 3°
    (b) Whenever the link circuit relay becomes locked on one side.
    (c) Whenever the link circuit relay fails to produce interlocked A's and N's
    (d) Whenever the radiated field drops below 50 per cent
    (e) Whenever more than one-half of the station identification is missing.
(5) The characteristic warning letters XXX should be superimposed upon the range signal once during each A-N cycle (30 seconds) whenever any of the above faults occurred
(6) It should be possible to silence each siren manually but the red light should remain lighted until the fault is cleared at the range station A green light should indicate normal operation of the range
(7) A shielded loop-type antenna should be used for the monitor receiver to assist in the elimination of static
(8) A continuous recording of the aural signal should be made with time indication so that the recorder chart can easily be interpreted at any time.
(9) Voltage regulation should be provided to assure stable operation of all circuits.

Specification CAA-426 dated March 20, 1941, was prepared on the basis of these requirements. A contract was awarded to Airguide, Inc , Islip, N Y , on June 13, 1941, for the development of one automatic monitor system The equipment was delivered and installed at Indianapolis in June, 1942

INSTALLATION AT INDIANAPOLIS

On-Course Receiver Site Selection

The monitor equipment was first installed at the Civil Aeronautics Administration's Experimental Station at Indianapolis to observe the operation of the equipment over an extended period. The final approach course of the Indianapolis range is the west leg and it became necessary, therefore, to select a suitable site on this course for the monitor receiver. The original plan was to locate the monitor receiver not more than one or two miles from the range station. However, at Indianapolis it was impossible to obtain a site this close to the range that was free of interference from power and telephone lines and yet had power and telephone service sufficiently close for economical installation. As shown in figure 1, the west course extends for quite some distance along Federal highway 40 where there are a considerable number of overhead power lines and telephone lines. Field measurements made on the ground in this area indicated a very erratic course and at no time did the course so observed align itself with the true course observed in flight. This effect was due to re-radiation from the power and telephone lines. A suitable site could not be obtained between the intersection of the course with highway 40 and the range station because of the inaccessibility of the ground in that area. Likewise, it was impossible to obtain a suitable site in the vicinity of Plainfield due to the building congestion in that location.

The closest suitable site was found on property located on the Cartersburg-Danville highway approximately one-third of a mile north of highway 40 and approximately 5.7 airline miles from the range station. Telephone lines extended along the east side of the highway and power lines along the west side of the highway. Figure 4 is a photograph taken from the on-course receiver site showing the proximity of power and telephone lines along the highway, adjacent to the site. Displacement of the course was quite evident near these lines but at 200 feet no interference was noted. The receiver site was located 250 feet from the highway and lines, and at a distance of 20 feet from a fence three feet high to the south of the site. At no time was any displacement of the course noted due to re-radiation from the fence. The plot was 25 feet square and was considered of ample size since there were no obstructions within 250 feet. Underground cables were installed from the highway to the site to supply power and telephone services.

All ground checks made to locate the site were made using the equipment shown in figure 3. The equipment consisted of a portable aircraft receiver operating from 12 volts direct current, two six-volt batteries in series to provide the required 12-volt power supply, a Weston output meter, a vertical whip-type antenna and a pair of headphones. The complete assembled equipment was of a convenient size and weight as to provide an excellent portable field detector. Course deviations of approximately 1° could be distinguished by noting differences between A and N voltages on the output meter when this amount of deviation could not possibly be distinguished by ear with the headphones. The location of the center of the course was found by determining the location of the points 5° on either side of the course, and dividing the distance between these points by two to obtain the point mid-way between them. This method was more accurate than attempting to locate the actual mid-point with the field detector since 5° deviations can be much more easily observed on the output meter than the on-course point. Upon completion of the ground check with the portable detector unit, a flight check was made to determine if the course as observed on the ground was in the same position as that observed in normal flight. Complete agreement between the ground check and the flight check was obtained.

The equipment that would normally be installed in the Communications Station was installed in the Experimental Station at Indianapolis in order that extensive tests could be carried on without disturbing operating personnel. This installation required the use of an extra telephone line from the Experimental Station to the Communications Station that would not be required in a normal installation. Figure 2 is a block diagram showing a normal installation and the installation at Indianapolis. Figure 5 is a more complete block diagram of the Indianapolis installation.

The remote receiving equipment consists of a receiver, a loop antenna, and a voltage regulator. Figure 6 is a photograph of the remote receiving equipment and figure 7 is a schematic diagram of the remote receiver.

On-Course Receiver

The remote receiver is a conventional crystal controlled superheterodyne without automatic volume control. The receiver input circuit consists of a balanced tuned loop connected to the receiver through a short shielded plug-in cable. One radio-frequency amplifier stage is provided using a 6SK7 tube. The image frequency response is 90 db below that of the desired frequency response. The crystal stage employs a 6J5 tube and the output of this stage is used to feed the suppressor grid of the first detector which is a 6SA7. Sufficient excitation is provided so that when the excitation voltage is reduced to 25 per cent of normal there is only a change of 1.6 db in the output voltage. Figure 8 shows the excitation characteristic. One stage of intermediate-frequency amplification at 175 kilocycles is provided by one 6K7 tube. The degree of selectivity provided by the intermediate-frequency stage is such that the attenuation at a point 2 kilocycles off resonance is approximately 6 db. This attenuation increases to approximately 60 db at 8 kilocycles off resonance. One type 6SQ7 tube is used as a second detector and first audio amplifier. The diode detector section of the tube provides linear detection with modulation percentages varying from zero to 100 per cent. The detector characteristic is shown in figure 9. Peak noise is limited to 100 per cent modulation by V7, a 6H6 rectifier. A 1020-cycle band-pass filter is inserted between the first and second audio amplifier stages, so that only the 1020-cycle range signals appear at the output of the receiver. Voice signals and extraneous noises are greatly attenuated by this filter. The final audio amplifier is a 6J5 tube and is capable of providing a maximum output of 170 milliwatts. The output circuit is designed to feed a 600-ohm ungrounded telephone line. In accordance with common telephone practice, the input to the telephone line is maintained at one milliwatt. Figures 10 and 11 show the receiver noise rejection and volume control range, respectively. A voltage regulator is provided to further insure receiver output stability. Figure 12 is a photograph of the top of the chassis of the on-course remote receiver.

General Description of Monitor

As indicated in figures 2 and 5, the output of the remote receiver was connected to a telephone line extending from the remote receiver site to the laboratory of the Experimental Station. The output of the line at the Experimental Station was connected to the range monitor equipment shown in figure 13. A rear view of the assembled monitor equipment is shown in figure 14.

The signal received by the on-course receiver is normally a steady tone produced by an interlocked A and N signal. If the course shifts, a difference in signal strength between the A and N will appear. Course deviation is indicated, therefore, by measuring the difference in intensity between the two signals. To measure and compare the intensities of the A and N components, the combined signal is first amplified, then separated, and each component is fed into two different channels. There, each separate signal is rectified and the direct-current output of each channel combined in opposite polarity to feed a balanced bridge circuit. When the range course is properly aligned, the output of the A channel is equal and opposite in polarity to the output of the N channel and zero voltage appears at the bridge. When the course shifts, the signal from one channel predominates and the resulting positive or negative voltage unbalances the bridge causing a zero-center instrument to indicate right or left of center depending upon the polarity.

An auxiliary off-course keyer receiver is used to separate the on-course signal into its original A and N components. This receiver is placed in an off-course position and provides pulses which alternately bias to cut-off the two separate channels in synchronism with the transmitted signal. This allows one amplifier to operate during the A signal and a second amplifier to operate during the N signal.

Other discrepancies in the range such as locked link circuit relay, improper keying by the link circuit relay, reduction of power, and lack of station identification are detected by electronic and mechanical time delay relays

Off-Course Keyer Receiver

The auxiliary off-course keyer receiver is substantially the same as the on-course remote receiver except that an automatic volume control and a squelch control have been added A schematic diagram is shown in figure 15 This receiver should be located as far off-course as possible in order to provide a definite A or N impulse The ratio of A to N signal intensities of 2/1 or better is desirable The equipment is designed to operate, however, with signal ratios of 1/1 25 by careful adjustment of the circuits. Signal ratios of this order frequently occur at Communications Stations and a ratio of 1/1 27 was measured at the Experimental Station This ratio was measured at the output of the receiver with the automatic volume control in operation Without automatic volume control this ratio became 1/1 32 Since the ratio exceeded 1/1 25 the off-course keyer receiver was located in the same relay rack with the remaining monitor equipment as shown in figure 13 The loop antenna for the off-course receiver is mounted on the top of the rack while the receiver itself is the top unit mounted in the rack At locations where sufficient ratios of A to N are not available, the off-course receiver would be located at another point and the output fed through a cable to the monitor equipment It is usually possible to find a suitable location within airport property and where long telephone lines are unnecessary

A squelch circuit is included in the off-course receiver to eliminate the unwanted weaker signal At Indianapolis the N signal was used to operate the electronic keyer in the monitor and the squelch control effectively eliminated the unwanted A signal The squelch control is incorporated in tubes V5, V7, and V9 The second detector, V5 is a type 6B8 tube One diode of the tube is used to provide linear detection similar to that shown in figure 9 for the on-course receiver The audio signal is passed through a 1020-cycle band-pass filter, similar to the on-course receiver, and amplified by V7 Part of the audio output is rectified by the second diode of V5 and the direct-current voltage obtained is used to control a direct-current amplifier provided by the pentode section of V5 Resistor R26 is common to the plate circuit of the direct-current amplifier and the grid-cathode circuit of amplifier V9 The direct-current amplifier, V5, has a sharp cut-off action so that the rectified bias produced by an audio signal of a certain value from the second detector is sufficient to cut off this tube When no current flows through R26, V9 amplifies in a normal manner If the modulation drops appreciably, however, the bias is no longer sufficient and the plate of V5 draws current through R26 The voltage drop across R26 biases V9 to cut-off blocking any audio from being transmitted to the output stage The receiver at Indianapolis was located approximately 7° from the course in the N sector with a ratio of A/N of 1/1 27 The direct-current amplifier squelch control was adjusted so that the N signal just tripped the direct-current amplifier, V9 amplified normally and the N signal was heard at the output terminals The A signal did not have sufficient strength to operate V5 thereby cutting off V9. Therefore, with nearly an on-course signal, only the N signal was heard at the output terminals Figure 16 shows the operating characteristic of the squelch circuit with various degrees of control

When the squelch circuit was properly adjusted, received ratios of A/N signals of 1 27/1 provided output ratios of 5/1 The squelch control should not be advanced to a point where only an "N" signal is produced at the receiver output terminals when the receiver is operated within 10° of the course If this is done the "edges" of the N signal pulses become rounded instead of square and a time lag is introduced which will prevent sharp keying of the keyer circuits in the monitor A flat automatic volume control characteristic is required in the off-course receiver to enable the squelch circuit to function properly over a wide range of field strengths The automatic volume control characteristic of the receiver is shown in figure 17. Figure 18 is a photograph of the top of the chassis of the off-course receiver

Airport Monitor Equipment

Figure 19 is a schematic diagram of the airport monitor equipment The signal transmitted to the airport from the on-course receiver is connected to the terminals marked INPUT The off-course receiver output is connected to the terminals marked KEYER The on-course signal is amplified by V1, and introduced through an attenuator network to the grids of V7 and V8 At Indianapolis the off-course receiver was located in the N quadrant Under this condition V8 and V9 comprise the channel which will amplify and rectify the N signals only, and V7 and V10 comprise the channel which will amplify and rectify the A signal

The N signal from the keyer receiver is amplified by V3, and rectified by the diode section of V4, producing negative direct-current N pulses which are fed to the grid of the pentode section of V4 The triode section of V4 is a direct-current amplifier With no bias on the grid of V4, the plate draws current through resistor R25 which is also common to the grid-cathode circuit of amplifier tube V8. The voltage drop through R25, caused by no bias on V4, biases V8 to cut-off and prevents the tube from amplifying During the N signal the grid of V4 is supplied with negative voltage from the diode rectifier V4 is biased to cut-off, the voltage across R25 becomes zero, and V8 functions with normal bias from the cathode resistor R27 Therefore, during the N impulses V8 amplifies and allows the N portion of the on-course signal to be amplified During the remainder of the cycle V8 is cut off, effectively blocking the passage of the A signal The N portion of the received on-course signal is thus amplified in V8 and rectified by V9 A direct-current voltage appears across R48 which is proportional to the intensity of the N signal received at the on-course receiver

The A channel functions in a like manner The N signal from the keyer receiver is rectified by V5, into positive direct-current pulses. V6, a direct-current amplifier whose plate circuit resistor R36 is common to the grid-cathode circuit of V7, is normally biased to cut-off by cathode resistor, voltage divider R34-R35 The positive pulses from V5 during the N signal cause V6 to draw current through resistor R36 The voltage drop across R36 therefore biases V7 to cut-off during the N portion of the cycle, thus blocking passage of the N signal As V6 is biased to cut-off during the A interval, there is no voltage drop across R36

The A portion of the received on-course signal is thus amplified in V7 and rectified by V10 A direct-current voltage appears across R49 which is proportional to the intensity of the A signal received at the on-course receiver

Resistors R48 and R49 are connected in series such that the polarities of the voltages across them oppose each other. The voltages that appear alternately across each resistor are applied to a resistor-capacity filter R50 and C20-C21 This filter smooths out the pulses of opposite polarity and a resultant voltage of zero is obtained when the A and N signals are equal If the N is stronger, a resultant positive voltage with respect to ground appears across C20-C21 equal to the difference between the two voltages Similarly, when the A is greater a resultant negative voltage appears across C20-C21

V11, V12, and V13, are type 6J5 tubes comprising one arm of a bridge The zero-center indicating instruments are connected in series across the bridge from the tube plates to the junction of the opposite arms R53 and R54 The grids are connected to the output of the resistance-capacity filter At zero grid voltage the bridge is balanced by R55 and no current flows through the instruments A positive or negative voltage applied to the grids will unbalance the bridge and cause a current flow which will actuate the instruments

Sensitive relay RL1 is connected in series with the instruments When an off-course deviation of 3° occurs, 2 milliamperes direct current flows through the meters and relay RL1 is set to close at 2 milliamperes coil current This relay actuates time delay circuits which then operate the warning system.

The A-N keying cycle is interrupted every 30 seconds to key the station identification signal. Therefore, means are provided to prevent the indicators from showing an off-course deviation and operating the warning devices during this period. Part of the same circuits which remove the indicating circuit during station identification also monitor the keying, the station identification signals and the signal strength.

The input from the remote receiver is fairly constant during an A-N cycle. This signal is amplified by V14, and rectified by V15. The rectified current is used to actuate the recorder to provide a record of the received on-course signal. The voltage developed across the rectifier load resistance is applied as negative bias to the grid of the grid-controlled rectifier V16. The bias is adjusted so that if the receiver output were to drop to one-half normal, V16 will rectify and energize relay RL2. At the end of an A-N keying cycle, there is a short period of zero output before station identification keying begins. At the instant the output drops to zero, RL2 is energized by the rectification of V16. RL2 operates relay RL3, which is used to provide a slight time lag. RL3 energizes latching type relay RL4 which closes and locks. RL2 and RL3 will pulse during identification keying but RL4 will remain latched. RL4 opens the circuit to the meters and relay R1, causing the alarm system to be inoperative to course deviations during the station identification keying. RL4 also energizes time delay relay RL9 which is set to close at the beginning of the next A-N cycle. RL9 closes at the end of the station identification, opens the circuit to time delay relay RL8 and releases RL4, placing the indicating system back in operation. When RL4 is released, time delay relay RL9 is also de-energized. RL9 then energizes RL8 which is set for slightly less than the time for one A-N cycle or approximately 27 seconds. If the signal drops to 50 per cent of its normal intensity or the keying is not interlocked during the A-N cycle, RL2 and RL3 will close or pulse with poor interlockings. RL4 will not be energized and will stay open since time delay relay RL8 will not close until the end of the A-N cycle to complete the circuit to RL4. With RL2 and RL3 closed or pulsing and RL4 open, the circuit from the grid of V18 through open RL4 and closed RL3 to ground will be completed, and the alarm system will function.

V18 is a grid-controlled type 2051 rectifier acting as a hold-over relay operating the alarms. The cathode of V18 is above ground by plus 43 volts. In normal operation the grid is at cathode potential through resistor R62 and V18 rectifies. RL6 is energized and holds the alarm system on green. When the grid is returned to ground through RL3 and RL4, or by RL5 or RL1, the grid becomes negative by 43 volts. V18 is cut off, RL6 opens and the alarms are actuated. C30 is charged to minus 43 volts when the grid is grounded. When the grid of V18 is removed from ground condenser C30 discharges through R62. When the potential across C30 drops to 2 volts, V18 again rectifies. RL6 is energized and the alarms are made inoperative. If R62 has a resistance of 3 megohms, the circuit will hold relay RL6 open for 30 seconds after the grid circuit has opened. Thus, if the interlocked keying becomes poor, the monitor circuit will detect it as a series of pulses of RL2 and RL3, a pulse occurring whenever the interlocking is poor. As long as the pulses occur at a speed greater than 1 pulse in 30 seconds, the grid of V18 will remain more than 2 volts negative and the alarm will be held on continuously.

V17 is another grid-controlled type 2051 rectifier acting as a hold-over relay to check on station identification keying. During A-N keying RL3 is open, the grid of V17 is at ground (-43 volts) potential, V17 is cut-off and RL5 is open. The circuit from ground through RL5 and RL4 to the grid of V18 is open. At the end of the A-N cycle relay RL3 closes and RL4 is latched closed. Condenser C29 starts to discharge through R61. The circuit from ground through RL5 and RL4 to the grid of V18 is broken by RL5. Relay RL3 pulses with identification keying. The time constant of C29-R61 is set for 3 seconds lag. If RL3 remains closed for more than 3 seconds due to failure of station identification keying RL5 will close grounding V18 and starting the alarms. The time constant of C29-R61 can be decreased if desired, to slightly more than the longest space normally occurring in the identification interval. With faulty keying, this space will probably lengthen and energize the alarm system.

Relay RL6 controls the alarm system. During normal operation it is energized and operates the green light. When a fault occurs, RL6 opens and energizes the sirens and red lights. Each siren is equipped with a silencing push button. The push button energizes and locks latching type relay RL7 This opens the circuit to the siren When the fault clears, the release coil is energized which resets RL7 and the siren circuit

When a fault occurs, relay RL6 also energizes relays RL10 and RL12 RL12 is a slow acting relay which allows RL10 to latch-in and then de-energizes RL10 RL10 energizes the dial keyer motor and relay RL14, which connects the monitor system with the telephone line to the Communications Station equipment The dial keyer dials the numbers 22 over the line This number energizes the equipment at the transmitter which keys a warning signal on the carrier After the number has been transmitted, the motor stop cam energizes the release coil of RL10 and resets it for the next fault The motor will not be immediately re-energized as RL12 is closed and the circuit to RL10 is broken

When the fault clears, RL6 closes, lights the green lights and energizes RL13 and RL11 RL11 energizes the dial keyer for another half revolution, dials the number 23 and shuts off the transmitter warning signals

Tube V2 is used to amplify the received on-course signal sufficiently to be applied to the phone jack on the monitor and on all airline office indicators A voltage regulator is provided in the 60-cycle power line for all of the electronic circuits to maintain constant operating conditions

The monitor equipment is actually constructed using four different chasses exclusive of the off-course receiver chassis The first chassis contains all of the preliminary stages of amplification, the electronic keyer, the bridge circuit, and a panel containing the indicator lights as well as the zero center instrument A photograph of the top of this chassis is shown in figure 20 The second chassis which contains the keying relays, the electronic relays and the siren is shown photographically in figure 21 The third chassis contains the graphic recorder and the chronograph pen time clock The time delay relays, RL8 and RL9, and the alarm relays are mounted on the fourth chassis The dialing motor and voltage regulators are mounted on the floor of the relay rack

The recorder provided with the equipment is a standard Easterline-Angus 0-1 milliampere graphic instrument, Model AW A spring-driven mechanism is used so that the recorder will continue to operate during periods of power failure Where a single chart speed is used continuously, accurate timing is provided by the chart calibration If a synchronous type of chart drive was used the recorder would stop during power failure periods and a complete loss of time record would result

Remote Indicator - Alarm Units

Figure 29 is a photograph of one of the remote indicator-alarm units that would ordinarily be installed in airline offices These units each contain a zero-center course indicating instrument, a red light, a green light, a siren, a prone jack, and a silencing button for the siren A six-wire cable is required for the interconnection of these units Operation of these units is identical with that of the indicators on the main monitor unit A schematic diagram of a remote indicator-alarm unit is shown in figure 23 Whenever the green light is energized on the main monitor unit relay, RL2 in the remote unit is unenergized Therefore, the green light, I2 is energized on the remote units When the alarm sounds and the red light operates in the main monitor unit this relay is energized and the siren, S1, together with the red light I1, in the remote units operate Closing push button, P1, operates relay RL1 and opens the circuit to the siren The red light, however, remains lighted until relay RL2 opens The meter, M1, is connected in series with all the instruments in other remote units and with the instrument in the main monitor unit The phone jack, J1, is connected in parallel with all the other phone jacks on the remote and main monitor units

Figure 24 is a photograph of the equipment as installed in the laboratory of the Experimental Station at Indianapolis

Communications Station Equipment

Because of the fact that the Indianapolis installation was made at the Experimental Station rather than the Communications Station, it was necessary to provide equipment that would not otherwise be required It was necessary to lease another line from the Experimental Station to the Communications Station in order to connect to the Strowger control line In addition, it was necessary to install three relays at the Communications Station in order to maintain proper control of the Strowger control line If the Experimental Station equipment were placed in parallel with the Communications Station equipment on the control line, it would be possible to obtain a condition of simultaneous dialing by the two stations In this case, of course, the correct number for either station would not be dialed at the transmitting station In case of major course shifts or other faults it was believed desirable that the range warning dial pulses take precedence over whatever dial pulses were being transmitted by operating personnel In fact, it might happen that the range warning pulses would occur at the same time that Communications Station personnel were dialing In this case, it would be necessary to return the dial cam at the range station to its normal position before the range warning signal could be correctly dialed

Figure 25 is a schematic diagram of the equipment installed at the Communications Station When the dialing cam of the dialing system in the monitor equipment first starts to turn, a 115-volt, 60-cycle, potential is placed on the line This potential operates relay RL15 at the Communications Station which, in turn, energizes time delay relay RL17. At the instant RL17 is energized and its contacts closed, relay RL16 operates and removes the Strowger control line from the Communications Station equipment and connects it to the Experimental Station monitor equipment Relay RL17 is a synchronous time delay relay and has auxiliary contacts which apply power to the relay to keep it operating after the closing pulse by RL15 has been applied Therefore, RL15 can be opened after RL17 has obtained a short pulse and RL17 will continue to operate until the timing mechanism trips. The timing for RL17 was set for 6 seconds, thereby insuring that the maximum time that the control line was disconnected from the Communications Station equipment was also 6 seconds This was considered more than sufficient time to return the dial cam to normal at the range station, provided it was not already in that position, and to dial the range warning signal on or off as the case may be

By inspection of the dial cam shown in figure 19 it will be seen that when the cam operates, the 115-volt, 60-cycle, potential is applied only for a short time The cam is then cut so that no potential exists on the line for a brief period This feature allows the dial cam at the range to return to normal Then the potential is again applied to the line and one of the range warning numbers dialed These operations consume approximately 4 seconds At the end of 6 seconds the time mechanism trips RL17 and the control line is returned to normal The two second period between the end of the dialing operation and the return of the line allows ample time for the dial cam to reset for any further dialing by operating personnel

In a normal installation where the monitor equipment is located in the Communications Station, the three relays RL15, RL16, and RL17 would be unnecessary It would only be necessary to make RL14 in the monitor equipment a double-pole double-throw relay and the same result would be effected

When a range fault occurs, the number 22 is dialed on the control line and, when the fault clears, the number 23 is dialed The relay procedure is identical in either case

Range Station Equipment

Figure 26 shows the circuit arrangement at the range station The 1000-cycle tone from the audio oscillator is connected to the transmitter speech amplifier through relays RL19, RL20 and the contacts on the X cam. The X cam is mounted on the same shaft and directly above the interlock cam with the X arranged to key during the same interval that the dash portion of the N sector is transmitted This is done to prevent interference with the off-course receiver which uses the N sector signal to separate the AN signal in the monitor If the off-course receiver were placed in the A sector, the X should be arranged over the dash portion of the A on the interlock cam

When the number 22 is dialed, the Strowger bank supplies 48 volts direct current from terminal 22 to relay RL20 which closes and latches

Time delay relay RL19 is used to allow the X to key three times before each identification interval It is controlled by contacts on the interval cam which close at the beginning of the identification interval When these contacts close they start the time delay relay which is set to run for 26 seconds The contacts of the time delay relay are so arranged that they are closed when the relay is not energized and open when the relay is operating

Thus, RL19 is operating during the 26 seconds and the X keying circuit is held open When relay RL19 resets, it completes the keyer circuit and the letter X will be keyed with each revolution of the interlock cam At the beginning of the next identification, relay RL19 is again energized, and stops the X keying The difference between the 26-second setting of the time delay relay and the time of an A-N cycle provides time for three X's before the next cycle starts

If four X's are desired, the setting of the time delay relay should be delayed by the time of one revolution of the interlock cam

If two X's are desired, the setting of the time delay relay should be advanced by the time of one revolution of the interlock cam

Relay RL18 is also energized when relay RL20 is latched closed The contacts of RL18 complete the circuit to the modulator control relay, holding the modulator on for the X keying.

When the number 23 is dialed, the release coil of RL20 is energized which releases the contacts of RL20, de-energizing RL18, RL19, and the modulator

TESTS AT INDIANAPOLIS

Upon completion of the Indianapolis installation tests were made to determine if all the requirements of specification CAA-426 were provided in the equipment. The first tests were made without the "XXX" pilot warning signal operating because an additional relay was required which had not been delivered The recorder chart speed on the first tests was three quarters of an inch per minute The clear signal frequently mentioned in the text and noted on the records is defined as that instant immediately following the extinguishing of the red light, the energizing of the green light, and the termination of the XXX warning signal Figure 27 indicates that the alarm system exclusive of the XXX warning signal was working properly for conditions of course shift Figure 27A is a recording of the aural signal transmitted to the monitor equipment from the on-course receiver when the course was shifted 1°, 2°, 3°, and 5° by rotating the goniometer at the range station Course deviations on this part of the graph were in a northerly direction so that the N signal predominated All deviations were actually degrees change from the normal goniometer dial setting but these were considered to be practically identical to the actual course movement Gradual changes as well as sudden changes of the course position were made Figure 27B is a similar recording except that the course movement was toward the south so that the A signal predominated It will be noted that the alarm did not sound for 3° of course shift southward The alarm did sound, however, with 4° of course shift in this direction It will be noted that a true on-course signal was not received with the goniometer set at the normal position. Although it is not evident on the graph, the course was actually slightly south of the on-course receiver and a slight N signal was being received under normal conditions This condition would easily account for the alarm not operating with a southward course movement of 3° Continuous observations of the course under normal conditions indicated that course movements of plus or minus 1° could be expected from day to day and from day to night This accounts for the fact that a true on-course signal was not present at the start of tests shown in figure 27 A second recorder was used during almost all of the tests This recorder was placed in series with the zero-center meter circuit in the monitor equipment and recordings were made simultaneously with the recordings of the aural signal Figure 27C is a recording of the visual (meter circuit) signal taken simultaneously with the aural signal records of figures 27A and 27B A much slower chart speed was used for this recording This record shows the build-up and decay time of time constant circuit R-50 - C20-C21, with changes in course position

Figure 28 shows recordings of the aural signal with various degrees of transmitter power reduction, with transmitter power reduced to zero (transmitter turned off and on instantaneously), with parts of station identification missing and with the link circuit relay held on one side The specification required that the alarms sound with a 50 percent reduction of the radiated field The reduction in radiated field was obtained by decreasing the output current of the transmitter which was obtained by reducing the voltage to the input of the plate rectifier transformer which supplies both the carrier and sideband channels This was accomplished by inserting a variac in the power input circuit Figure 28A shows a recording of the aural signal with variations of normal carrier current from 100 percent to 90, 80, 70, 60, 55, 52, 50, 40, and 34 7 percent As indicated on the recording, the alarm operated when the transmitter output current was reduced to 52 percent of normal From the results of the tests shown in figure 28A, a curve was plotted showing the variation in amplitude of the recorded signal with variation in carrier current and carrier plate voltage This curve is shown in figure 22

Figure 28B is a recording showing the operation of the alarm when the range transmitter was turned off instantaneously This was accomplished either by changing from the main transmitter to the standby or actually disconnecting the plate voltage supply for short periods The alarm operated at the instant of zero signal in these cases and the clear signal was given approximately 1 minute later in each case Further tests to determine the action of the alarm with part of the station identification missing and with the link circuit relay held open on one side are shown in figure 28C When the link circuit relay was held open on one side, the alarm sounded instantaneously, with the clear signal appearing approximately one minute after the relay was allowed to operate normally The alarm sounded when more than one-half of the station identification was missing or with an absence of signal for approximately three seconds during the station identification period

Figures 31 and 32 are recordings of tests similar to those shown in figure 27 except that course shifts of 4°, 7°, and 10° were made in both directions and the chart speed was increased to 12 inches per minute In this and all subsequent recordings the XXX warning signal was in operation when the faults existed Figures 31A, 31B, 31C, and 32E are simultaneous recordings of the received aural signal and the visual signal appearing at the zero-center instrument The chart speed in figures 31 and 32 is sufficiently fast so that the predominating course signal and the station identification signal is clearly indicated The recording of the zero-center instrument current also clearly indicates the build-up and decay time of the time constant circuit as well as the time that this circuit is open for station identification The XXX warning signal is shown on the recordings of the aural signal as the signal which is superimposed on the range signal on the last three interlocks before station identification In this case as well as in figure 27, the course did not pass directly over the on-course receiver under normal conditions and there is a corresponding difference in amplitude between identical course deviations on either side of the course

The XXX warning signal shown in figures 31 and 32 is very erratic in composition of the characters due to a low frequency beat condition between the 1020-cycle keyed X-signal and the 1020-cycle sideband range signal A beat note of approximately 10 cycles per second was obtained This condition was later corrected by lowering the frequency of the oscillator for the XXX signal down to 960 cycles which eliminated the objectionable beat note Figure 30 shows recordings of the aural signal before and after the low frequency beat condition was corrected

A second test was made to observe the effect of lowering the carrier channel current to 45 percent of normal for a short period The alarm operated one minute after the power was reduced The clear signal came on one minute after normal conditions were resumed. The results of this test are shown in figures 33A and 33B The XXX warning signal was inoperative during this test since the transmitter used was not equipped with warning equipment The method used for reducing the carrier current was identical to that previously described Figure 33C indicates the operation of the alarm circuit with an instantaneous changeover of transmitters Figures 34A, 34B, and 34C indicate the operation of the equipment with conditions of improper link circuit relay keying, improper station identification, and a locked link circuit relay, respectively As indicated on the recordings, the alarm operation was practically instantaneous for the first test condition For other conditions the alarm operated in a very few seconds While figure 34C indicates that the alarm operated after locking the link circuit relay on one side for about 2 seconds, the average time in other similar tests was approximately 7 seconds

In most of the figures where the XXX warning signal is present, it will be noted that the first series of X signals after the alarm has sounded contain a varied number of X characters This effect is due to the fact that it takes one complete A-N cycle to synchronize the keying equipment for the XXX warning signals so that only three are transmitted If the alarm occurs immediately after a station identification, the next A-N cycle will have the X signal superimposed on the range signal for the full cycle Subsequent A-N cycles will contain only three X signals superimposed on the last three interlocks When the fault clears the X signals cease immediately Consequently, there may not be three X signals on the last A-N cycle before normal operation is resumed

During the tests it was decided that a recorder chart of 12 inches per hour would be sufficient to show the operation of the range under most conditions. Under these conditions it would be necessary to change paper in the recorder every 4 days since each roll contains 100 feet of recorder chart This is the slowest speed at which the recorder can be operated and still have sufficient spacing between station identification periods The recorder furnished with the equipment had two speeds available and it was possible to change from 12 inches per hour to 12 inches per minute merely by shifting a lever on the recorder. At a chart speed of 12 inches per minute the signal is so spread out on the graph that the slightest imperfection in keying may be noted Therefore, the operating or maintenance personnel may shift to the fast speed at least once a day for a short period to closely examine the content of the range signal If only one speed is to be used the chart time calibration itself will be sufficiently accurate for all practical purposes However, where it is intended that the speed be changed each day, it becomes necessary to provide marking at the edges of the record to accurately record time. This was done by providing two chronograph pens at the margin of the chart, one to mark minutes and the other to mark hours Thus the chart speed may be changed at will but the time record is accurately maintained by chronograph pens These pens were operated by a 6-volt direct-current circuit through contacts of a spring-driven clock Thus time marking was accurately maintained even though the chart speed was changed by the operating personnel Figure 35 shows recordings made with both 12 inches per hour and 12 inches per minute chart speed with the XXX warning signal present. Figure 36 is similar to figure 35 except that the XXX warning signal is not present indicating that the range was operating normally In both of these figures the hour and minute chronograph pen indications can be clearly seen on each margin of the chart

Figure 37A is a recording of the XXX warning signal superimposed on the range signal with the carrier modulation set at 80 percent and 60 percent

During all of the tests it was noted that the broadcast warning signal always caused the alarm system to operate This broadcast warning signal consists of very fast dots of 1020-cycle modulation keyed through the carrier channel with the sideband channel de-energized The signal is used to warn pilots that an important voice transmission is about to be made and that they should transfer to the voice output of their filter system if they are not already in this position The spaces between these dots appear as intervals of zero signal or improper link circuit relay keying to the monitor system and the alarm circuit is energized At first it was considered satisfactory to key this broadcast warning signal with the sideband channel energized and merely superimpose the signal on the range as in the case of the XXX signal This arrangement was tried but it was found that the warning was not nearly as prominent as when the sidebands were removed Figure 37B shows the tests made with various combinations of warning conditions A decision was made, therefore, to refrain from any changes in the method of keying tne broadcast warning signal and devise some other method for preventing the alarm from operating when this signal was transmitted The most satisfactory method appeared to be one which actually disabled the alarm system whenever operating personnel were dialing on the automatic telephone system. This could be accomplished by the use of two extra contacts on the dial key at the Communications Station This modification was not made at Indianapolis since the equipment was not installed at the Communications Station and wires did not exist between the Communications Station and the Experimental Station to conduct tests with this circuit However, it is apparent that this circuit would prevent the alarm from operating during transmitter changeover intervals as well as during the broadcast warning dots

Figure 38 shows the aural signal recorded during two occasions of severe static conditions. During these periods it was noted that although the alarm did not sound from failure of the monitor equipment during static, the zero-center instrument which normally was in the center position was actually indicating a course shift of almost 3° This condition was found to be caused by static which interrupted the proper operation of the off-course keyer receiver and the electronic keyer rather than an actual course shift In figure 38B there was a power failure at the on-course receiver site for about six minutes The high amplitude static level recorded during this period indicates that most of the static is picked up on the telephone line from the site to the Experimental Station rather than being picked up by the receiver The recording in figure 38B was taken during a tornado at Indianapolis occurring in the evening of June 19, 1942

The recordings indicate the following information relative to the elapsed time after a fault occurs until the alarm sounds and the elapsed time after the fault has cleared before the clear signal is given

		Average Alarm Time
1	Course Shift	1 8 Minutes (3°) 1 55 " (5°)
2	Link Circuit Relay Locked on One Side	7 Seconds
3	Loss of Power	Instantaneous
4.	Improper Link Circuit Relay Keying	Instantaneous
5	Missing Station Indentification	3 Seconds

		Average Clearance Time
1	After Course Shift	1 35 Minutes (3°) 1 45 " (5°) 2 55 " (10°)
2	After Link Circuit Relay Locked on One Side for 7 Seconds	2 Minutes
3	After Restoration of Normal Power	1 2 Minutes
4	After Restoration of Normal Keying	1 2 Minutes
5	After Restoration of Normal Station Identification	1 2 Minutes

MODIFICATION OF EQUIPMENT FOR SALT LAKE CITY

During the service operation of the monitor equipment at Indianapolis, it was found that the movement of the approach course of the Indianapolis range was relatively small and it was concluded that the monitor could be used to better advantage at some station where a greater course movement could be expected It was decided, therefore, that the equipment should be moved to Salt Lake City, Utah, for further service testing at that point Several additions and modifications were made which were tested and found to be satisfactory before the Indianapolis installation was discontinued

The original equipment obtained from the contractor transmitted the XXX warning to the pilots on one set of transmitting equipment only Before the equipment could be installed and operated under actual service conditions, it was necessary to add sufficient equipment at the range station so that the XXX warning signal would be transmitted over either of the two sets of transmitting equipment that are provided at all radio range stations.

Some difficulty was encountered at Indianapolis with relays RL10, RL11, RL12, and RL13 which control the operation of the dialing circuit This difficulty was corrected without the addition of any new parts by revising the contact sequence of these relays Difficulty was also encountered in the original installation with interference to nearby receiving equipment caused by the keying of relays RL2 and RL3 during station identification This was corrected by isolating this part of the 115-volt, 60-cycle, circuit and feeding this circuit through a voltage regulator made available by the deletion of other equipment in the monitor. Two relays were also added to the equipment to be installed at the Salt Lake City Communications Station to disable the alarm circuits during the dialing periods on the automatic telephone circuit This was done to prevent the alarm from being actuated during the transmission of the broadcast warning dots and during periods of transmitter changeover The relays added were made available by the deletion of the auxiliary relay equipment at the Indianapolis Communications Station Since the Salt Lake City installation was made in the Communications Station, these relays were not needed for the same purpose as at Indianapolis

The most important modification in the monitor system was brought about by the deletion of the off-course receiver and the vacuum tube keying circuit containing tubes V3, V4, V5, V6, V7 and V8 together with the components associated with these tubes

The off-course receiver was replaced by a 6X5 diode rectifier connected to the "N" goniometer primary at the range station as shown in figure 40 The rectified "N" impulses were then transmitted by underground cable to the Communications Station to key a relay at that point This method of obtaining keying impulses which were synchronized with the range station link circuit relay was chosen for Salt Lake City in view of the fact that a government-owned cable with extra conductors already existed for transmitting the impulses to the airport. It was felt that the use of the off-course receiver in this case would not offer any advantages and would add to the telephone line problem since the Communications Station at Salt Lake City was not located sufficiently off-course to allow the receiver to be mounted with the monitor equipment It was, therefore, considered much simpler and more economical to use the rectifier at the range station and transmit the rectified impulses back to the airport on existing cable conductors

The vacuum-tube keyer circuit used in the Indianapolis installation contained six vacuum tubes and a considerable quantity of component parts It was felt that a circuit containing this number of tubes would eventually cause trouble in continuous service operation especially if the tubes were not checked periodically In the modified equipment the six tubes were replaced by one tube and one relay The tube V3 was used to compensate for the gain formerly obtained in tubes V7 and V8 A schematic diagram of the modified monitor equipment is shown in figure 39

The choice of a relay to replace the tube keyer was very carefully made It was eventually decided that a Western Electric type 215FA or 215FB would be very suitable for this purpose This relay is of the type commonly used in high-speed telegraph or teletype circuits where precision equipment is necessary Either type of relay is capable of operation at 60 or more words per minute in teletype circuits and should perform for long periods of time without adjustment with the slow A-N keying encountered in the monitor circuit The two relays are rated to give satisfactory high speed performance at coil currents of 0 5 and 0 8 milliamperes respectively The type 215FA was finally used although there was little choice between the two units Actually a coil current of 4.5 milliamperes was used in the circuit to allow wider spacing of the contacts and to provide positive keying of the relay for almost an indefinite period without adjustment The manufacturer of the relay was consulted and it was found that coil currents in excess of 5 milliamperes could be used safely in continuous operation

In operation of the 215FA relay obtains a positive voltage to ground from the 300-volt high-voltage supply through series resistor R101 Approximately 9 volts are applied to the relay The rectified impulses obtained from the range station had considerable background current during spaces due to the goniometer being set at 44° The signal actually obtained at the Salt Lake City Airport was approximately 24 volts of "N" signal and 12 volts of background or "A" signal This voltage was decreased through variable resistor R-100 to an "N" signal of 12 volts and an "A" signal of 6 volts These voltages, which were negative to ground, were also applied to the 215FA relay and opposed the positive internally applied voltage The result was a positive 3 volts of "A" signal and a negative 3 volts of "N" signal thereby providing positive action of the relay in both directions. The resulting relay current was approximately plus and minus 4 5 milliamperes

Balancing "T" pads R-102 and R-103 were placed in the separated "A" and "N" circuits to balance out any non-uniformity in the circuits and to compensate for any small deviation in the location of the on-course receiver Phonejack J4 was provided as an easy means of setting up the proper relay current by adjustment of R-100

The equipment is operated in much the same manner as before Relay RL6 is blocked in the down-position during adjustments to prevent operation of the alarm A few minutes are required after turning on the monitor to allow relays RL8 and RL9 to become synchronized The bridge balance using R55 is identical to that described for the unmodified equipment Gain control R1 is advanced until the recorded signal is at about mid-scale Gain control R2 is advanced until 70 volts of audio signal appear at J2 and J3 This voltage should be carefully measured with a vacuum-tube voltmeter since it is the value of this voltage that determines the correct calibration of 3° on the course indicator, M1 The relay current and circuit balance is adjusted as previously described Upon completion of adjustments, relay RL6 should be unblocked

In the modified equipment, relays RL15 and RL17 are provided to prevent operation of the alarm circuits during transmitter changeover or transmission of broadcast warning dots from the range station Before an alarm can sound from any cause except a course shift or a locked link circuit relay, relay RL3 must become energized In order to prevent the sounding of an alarm due to the dialing of a transmitter changeover or emergency broadcast, the coil circuit for relay RL3 was placed in series with a pair of open-when-dialing contacts on the operator's dial key Thus, whenever the operator dialed any function, that part of the alarm circuit through RL3 was made inoperative but only during the dialing interval It was also necessary to prevent alarm operation due to dialing of these functions at the range station by maintenance personnel This was accomplished by placing sensitive relay, RL15, across the call bell circuit in the Communications Station Strowger equipment When RL15 operates, time delay relay RL17 is also energized The series circuit from the coil circuit of relay RL3 is also carried through open-when-energized contacts on RL17 Thus, when it is desired to dial a transmitter changeover or broadcast warning at the range station, the dial key is first operated upward for a very short period This provides a very short ringing pulse on the call bell at the Communications Station. Since RL15 is in parallel with the bell, the relay operates during the pulse which in turn operates relay RL17 Relay RL17 remains locked in the energized position for a predetermined time and then de-energizes itself. During the period that RL17 is energized, the alarm circuit through RL3 is inoperative and sufficient time for dialing and performance of the dialed function is obtained At Salt Lake City relay RL17 was set for 15 seconds

The operation of relays RL10, RL11, RL12 and RL13 was changed to provide more positive operation The modified circuit for RL10 and RL12 operates in the following manner. Whenever an alarm circuit to V18 is made, relay R16 opens and operates the siren and red light In addition 115 volts, 60 cycles, is placed on the locking coil of relay RL10 through the armature and upper contact of relay RL12 This closes and locks RL10 which in turn energizes the coil of relay RL12 This opens the circuit to RL10 so that the dialing function will not repeat itself indefinitely When RL10 locks, voltage is applied to the dialing motor and the alarm number 22 is dialed on the Strowger line energizing the XXX warning signal equipment at the range station After the number 22 has been dialed a circuit is made due to the cam action on the contacts of the control cam to the release coil of RL10 This de-energizes the dialing motor and the system is set up to dial 23 for the clearance signal Relay RL10 will not operate again during a given alarm period since the locking coil circuit is open at relay RL12 Relays RL11 and RL13 operate in a similar manner

Relay RL14 was made a double-pole double-throw relay instead of double-pole single-throw in order to simplify the installation at Salt Lake City from that at Indianapolis. RL14 now performs the same functions as RL14 and RL16 combined in the Indianapolis installation

A schematic diagram of the range warning equipment at Salt Lake City is shown in figure 41 There is very little difference between the Salt Lake City and Indianapolis equipment in this respect except that dual warning cams and contacts are provided with a suitable changeover relay All of this equipment with the exception of the changeover relay is mounted on one side D panel in the Strowger relay rack The changeover relay is mounted in the coupling unit immediately behind the mid-point between the two Boehme keyers

TESTS AT SALT LAKE CITY

The monitor system was installed at Salt Lake City during the first part of July, 1943 Figure 42 shows the location of the range station and monitor with respect to the airport Figure 43 shows on-course receiver installation while figure 44 shows the monitor installation at the Communications Station Remote indicator-alarm units were installed in the offices of United Air Lines and Western Air Lines The equipment was adjusted and tested during the period of July 12 to July 24, 1943 Further adjustments were made from August 1 to August 3, 1943 The operation of the equipment was substantially identical to that obtained at Indianapolis Copies of the recordings made during the tests at Salt Lake City are shown in figure 45 The recorder chart speed was increased from 12 inches per hour to three-quarters of an inch per minute at the request of maintenance personnel Later the chart speed was again changed to a rate of 12 inches per hour in order to avoid frequent winding of the recorder spring mechanism and excessive use of the recorder chart

The recordings shown in figure 45 indicate the following information relative to the elapsed time after a fault occurs until the alarm sounds and the elapsed time after the fault has cleared before the clear signal is given

		Average Alarm Time
1	Course Shift	4 5 Minutes (4°) 1 0 " (7°) 35 Seconds (10°)
2	Link Circuit Relay Locked on One Side	10 Seconds
3	Loss of Power Resulting in Less than 50% Carrier Current	Instantaneous
4	Improper Link Circuit Relay Keying	Instantaneous
5	Missing Station Identification	3 Seconds

		Average Clearance Time
1	After Course Shift	2 66 Minutes (4°)
		2 9 " (7°)
		*2 5 " (10°)
2	After Link Circuit Relay Locked on One Side for 10 Seconds	3.2 Minutes
3	After Restoration of Normal Power	3 0 Minutes
4	After Restoration of Normal Keying	2 2 Minutes
5	After Restoration of Normal Station Identification	1 1 Minutes

The average alarm time coincides very closely with that observed at Indianapolis except the 4° point. The goniometer mechanism at Salt Lake had considerable backlash and it was difficult to determine the exact number of degrees that the course was shifted The 4° shift noted on the dial of the goniometer could easily have resulted in less than a 4° course shift Since the voltage applied to the diode rectifiers was the same for both Indianapolis and Salt Lake City, it is reasonable to suppose that the 4 5 minutes required for alarm operation on a 4° goniometer shift was due to less than a 4° course shift The values of alarm times shown are for instantaneous course shifts from normal course alignment Gradual course shifts which are more commonly encountered would cause the alarm to sound much faster For instance, with an instantaneous shift from 3 5° to 5 0° the alarm sounded in 20 seconds while it takes about 1 5 minutes for the alarm to operate when changing from normal alignment to a shift of 5° The average clearance times at Salt Lake City were generally longer than those observed at Indianapolis This was probably due to a change in values in the time constant circuit C30-R62 These values were changed at various times during the tests and modifications at Indianapolis It is not known if the same constants were used at Salt Lake City as were present during the final tests at Indianapolis

During the adjustment and testing of the equipment at Salt Lake City, it was noted that there was a considerable variation in the level of the recorded range signal from mid-afternoon when low levels were observed to early morning when high levels were encountered Level ratios as high as 1 7/1 were observed It was first thought that this variation was due to line voltage variations However, on one occasion in mid-afternoon during a severe thunderstorm accompanied by a considerable temperature drop, it was noted that the signal rose to approximately that value previously observed in early morning This would indicate that the level variation was due to temperature rather than line voltage variations

The effect of the variations in range signal level was to cause the zero-center course indicator to show a course shift of about 1° when no course shift actually existed This was due to the difference in the input-output characteristics of the type 6H6 rectifiers V9 and V10 If the indicator was balanced to read on-course at a given level and the level changed appreciably, the output of the two rectifiers would no longer be balanced and a course shift would be indicated Further work is being conducted to correct the cause of the level changes and when this has been accomplished, normal operation of the monitor course indicator will have been restored Appreciable changes in level of range signals were not encountered at Indianapolis

On one occasion the operation of the monitor was observed during a severe thunderstorm when all other Communications Station receivers were completely blocked by precipitation static No static was observed on the monitor signal during this period The shielded loop-type antenna, the underground telephone cable and the proximity of the monitor receiver to the range station probably all contributed to this very desirable condition.

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* Not left at 10° position long enough for course indicator to reach 10° deflection

CONCLUSIONS

It is concluded that a satisfactory monitoring system for radio ranges has resulted from this development and that all of the following original nine requirements stipulated for an approved system have been provided

(1) The monitor receiver is located on the final approach course

(2) The received aural signals are transmitted to the Communications Station and all airline offices

(3) Visual signals indicating course deviation are provided at the Communications Station and all airline offices

(4) An alarm system is actuated by the monitor equipment which automatically operates sirens and red lights at the Communications Station and all airline offices when any of the following radio range faults occur

  (a) Whenever the range course moves more than plus or minus 3°

  (b) Whenever the link circuit relay becomes locked on one side

  (c) Whenever the link circuit relay fails to produce interlocked A's and N's

  (d) Whenever the radiated field drops below fifty percent

  (e) Whenever more than one-half of the station identification is missing

(5) The characteristic warning letters XXX are superimposed upon the range signal once every A-N cycle whenever any of the above faults occur.

(6) It is possible to silence each siren manually but the red light remains lighted until the fault is cleared at the range station A white light indicates normal operation of the range

(7) A shielded loop-type antenna is used at the monitor receiver to assist in the elimination of precipitation static

(8) A continuous recording is made of the aural signal with time indications so that the recorder chart can be easily interpreted at any time

(9) Voltage regulation is provided to assure stable operation of the electronic circuits

FIGURE INDEX

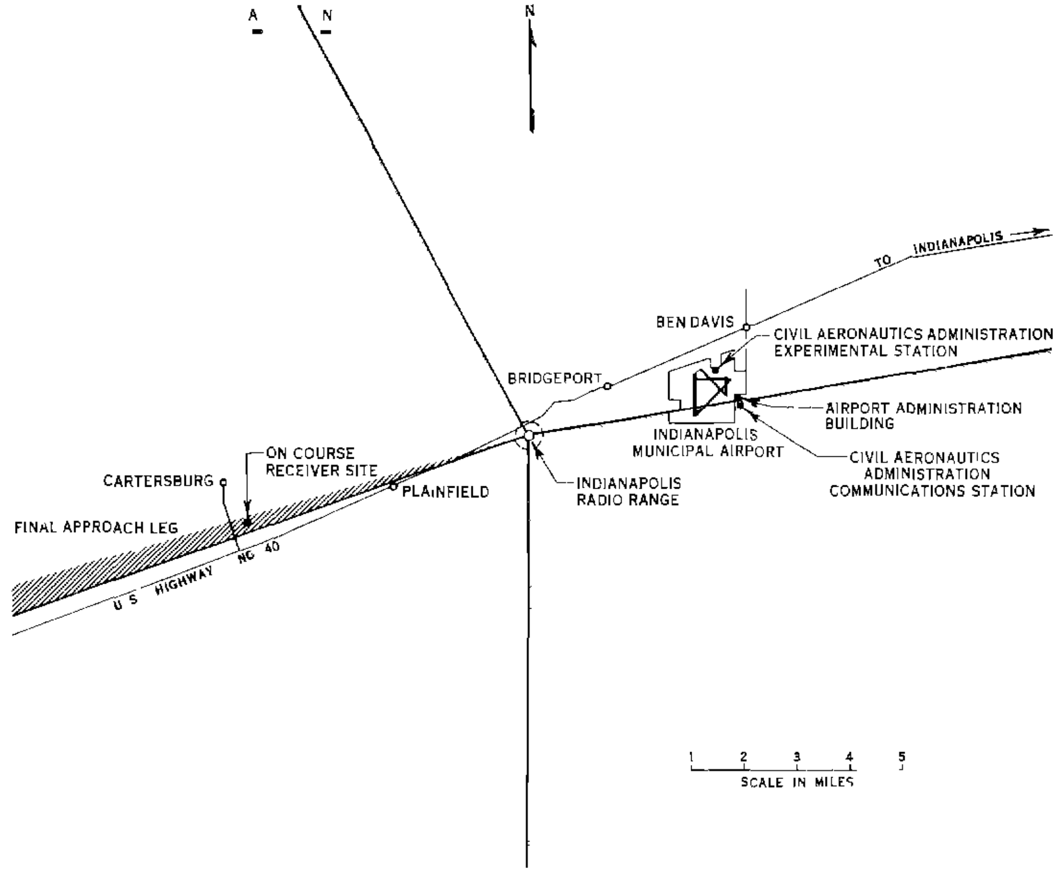


Figure 1 Map Showing Location of the On-Course Receiver Site, the Indianapolis Radio Range, and the Indianapolis Airport

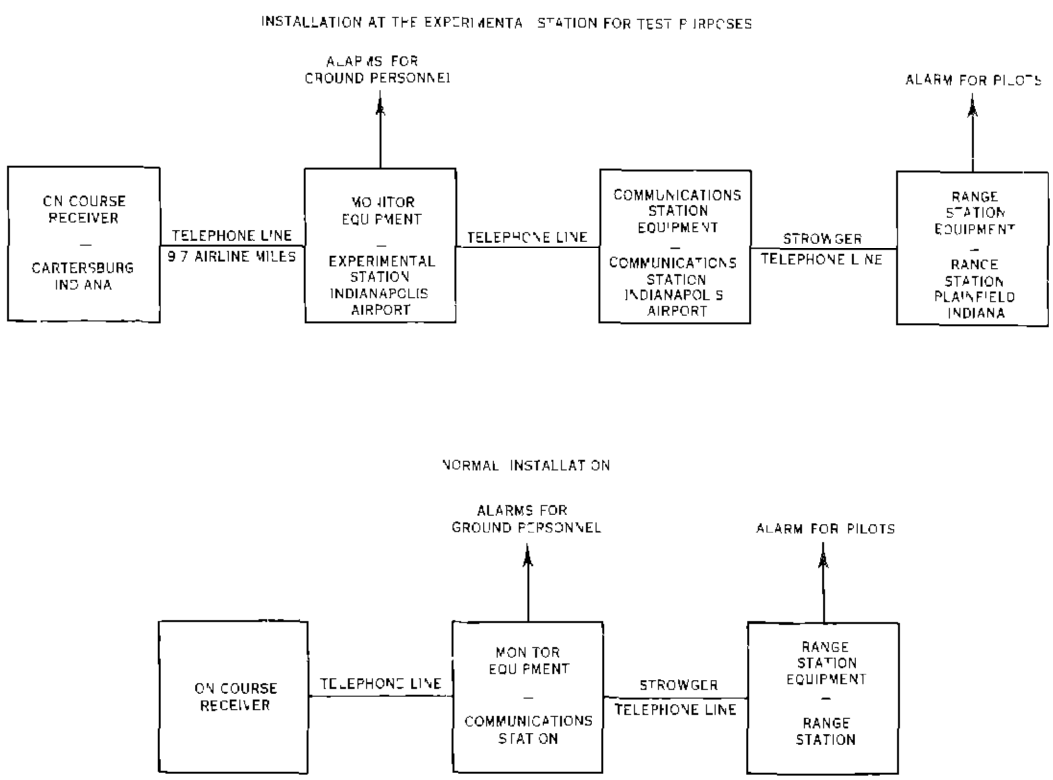


Figure 2 Block Diagrams of Indianapolis and Normal Installations

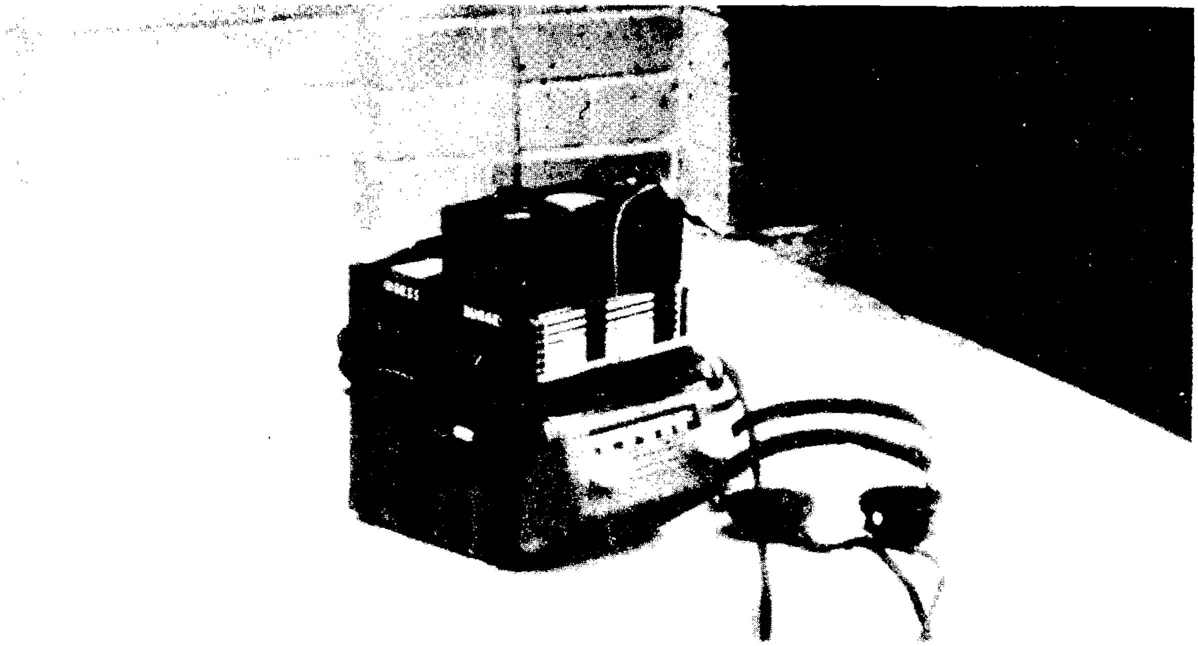


Figure 3. Portable Field Detector.

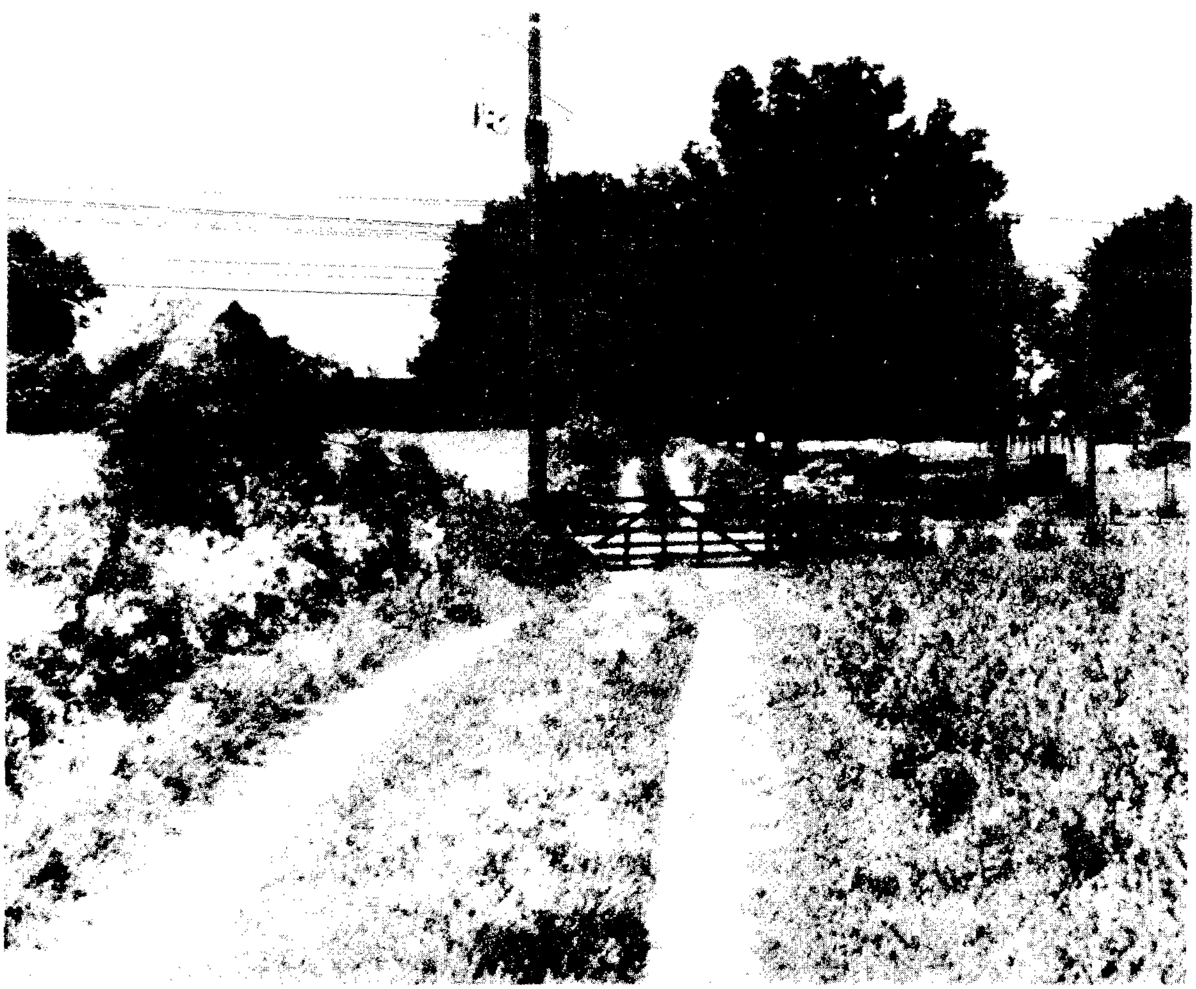


Figure 4. Power and Telephone Lines on the Cartersburg-Danville Highway as Viewed from the On-Course Receiver Site.

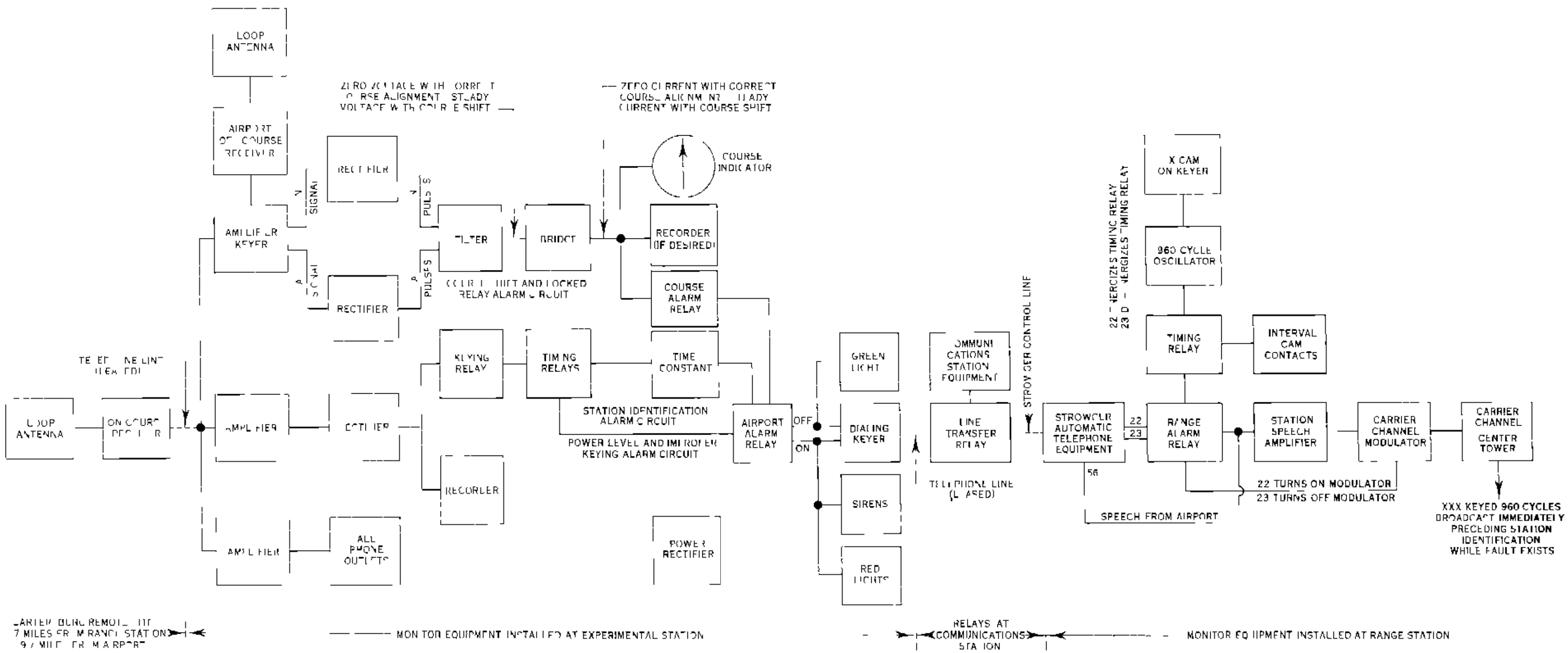


Figure 5 Complete Block Diagram of the Indianapolis Installation

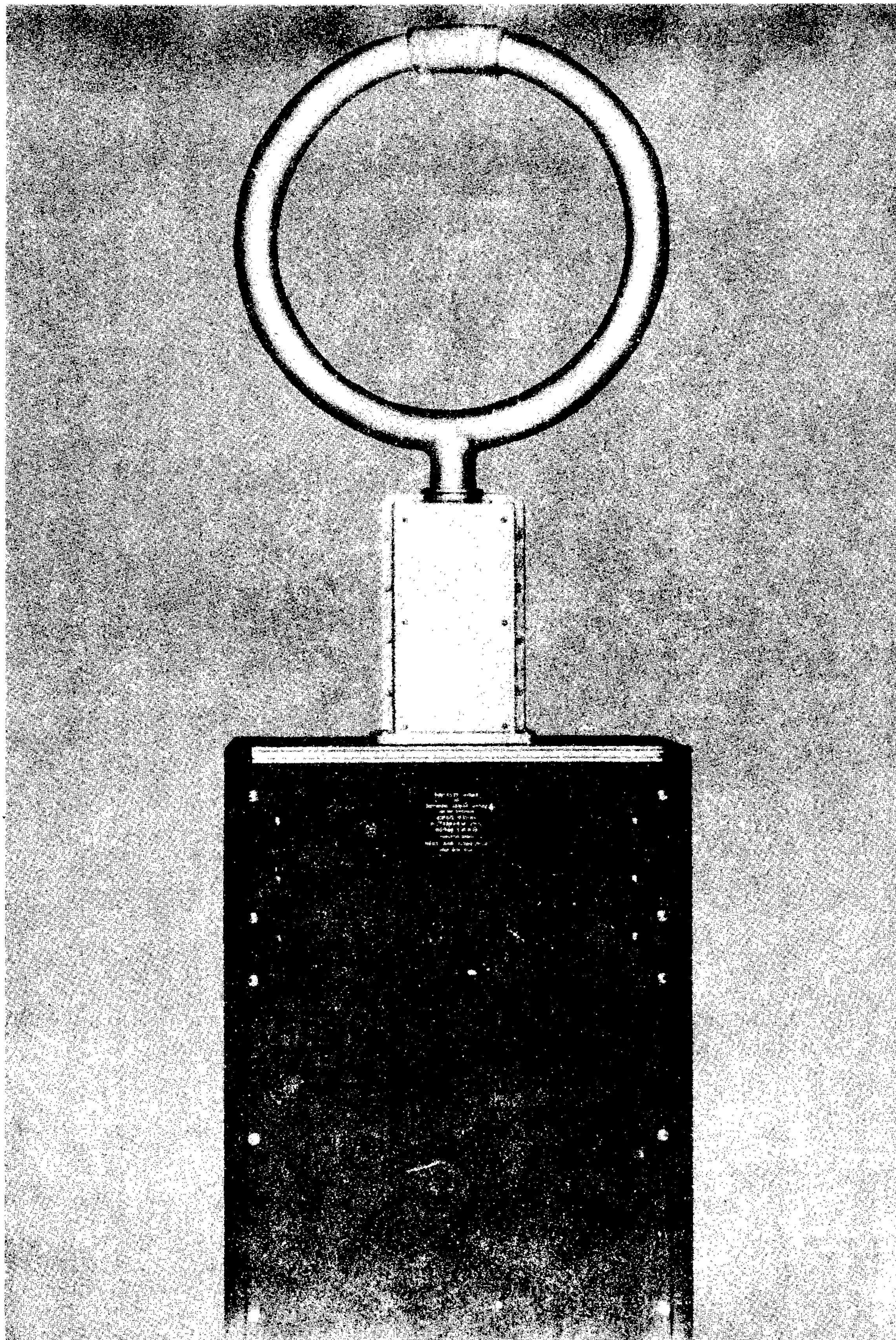


Figure 6. On-Course Receiving Equipment Installed at Site.

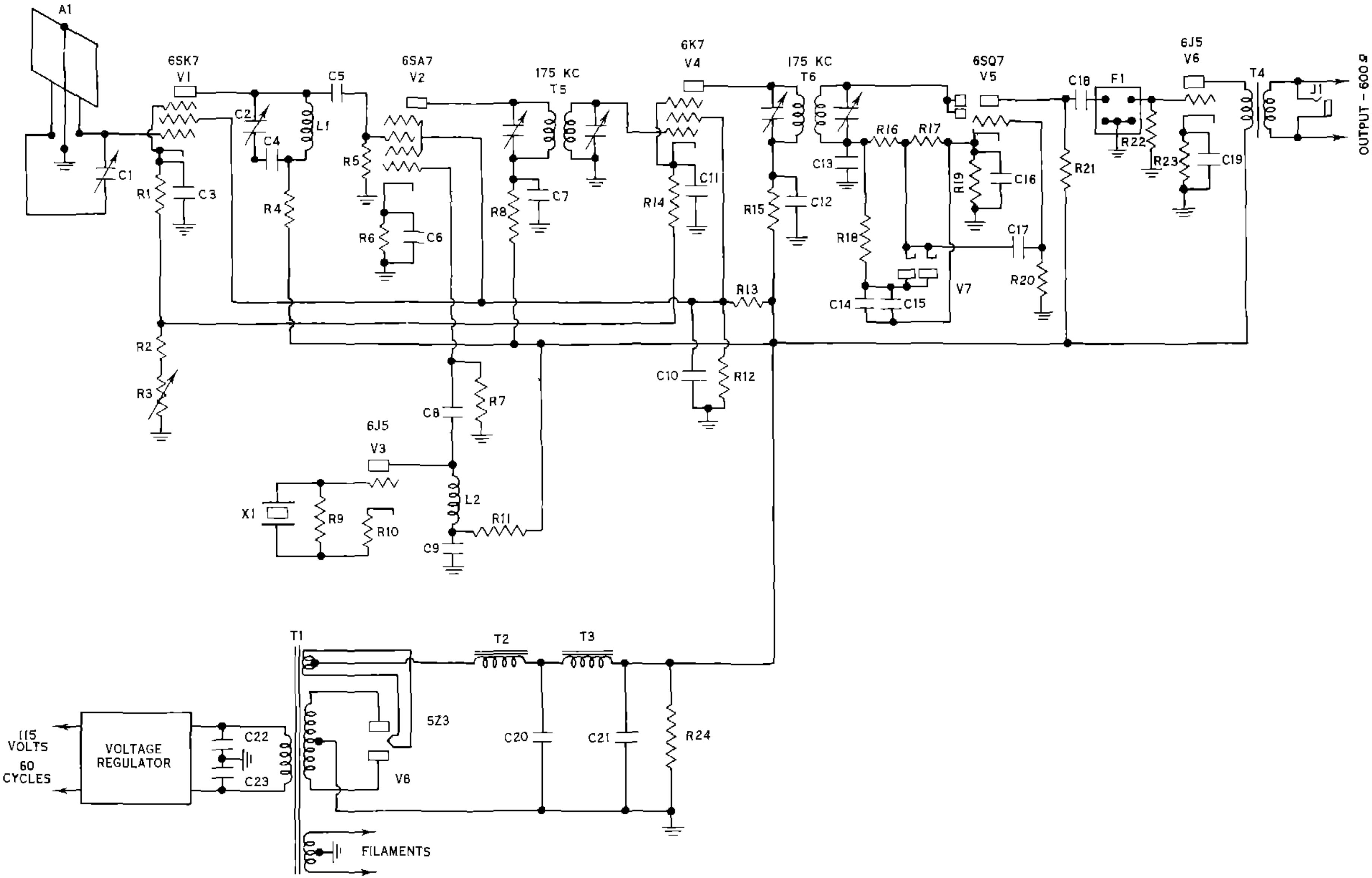


Figure 7 Schematic Diagram of On Course Receiver

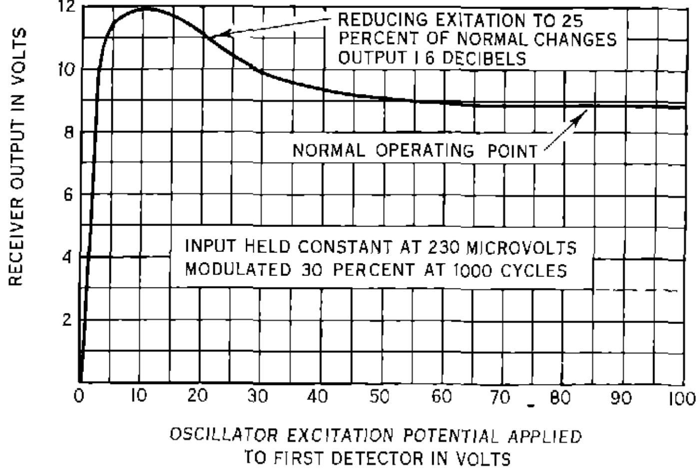


Figure 8 Excitation Provided by the Oscillator in the On Course Receiver

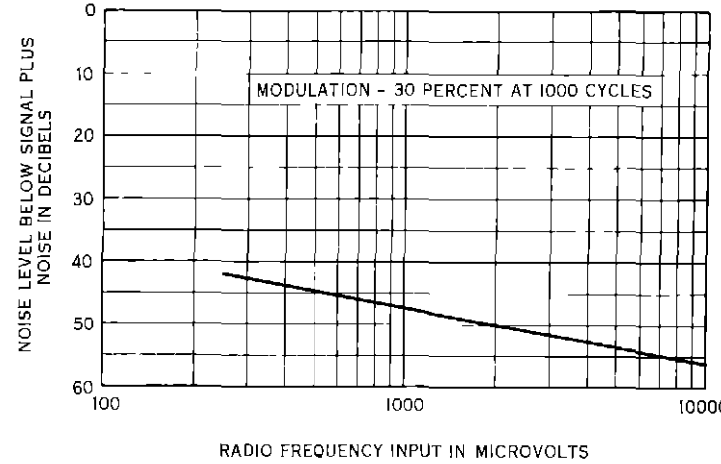


Figure 10 Noise Rejection Provided by the On Course Receiver

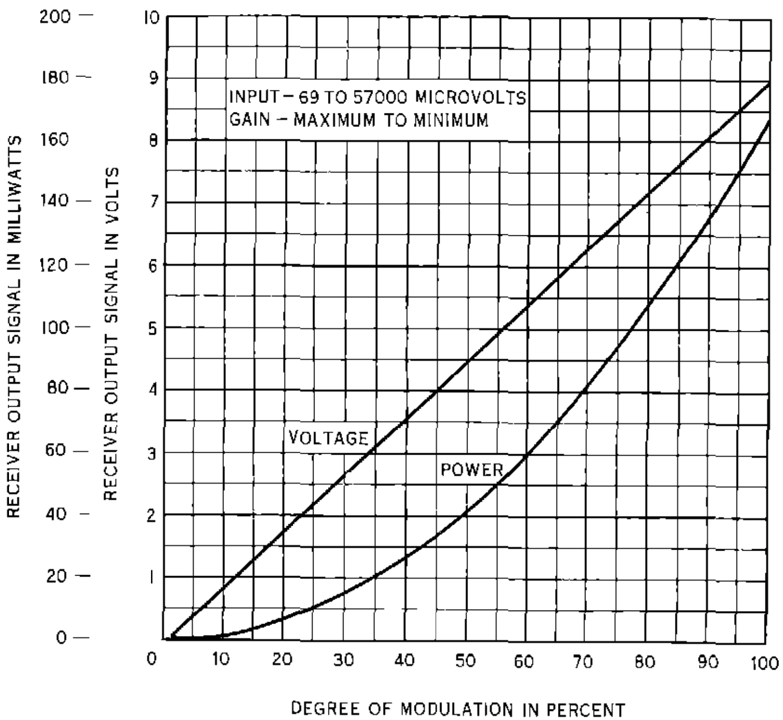


Figure 9 Detector Action of the On Course Receiver

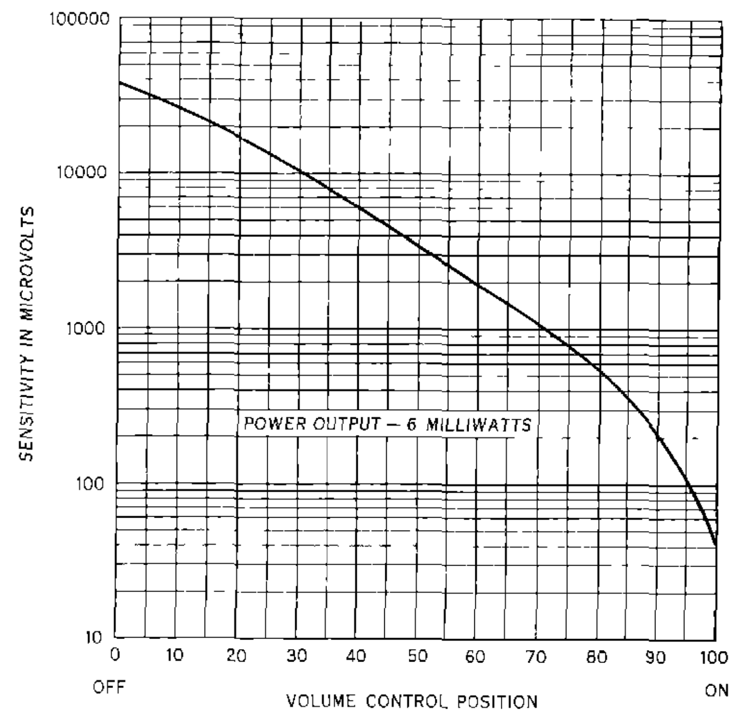


Figure 11 Volume Control Action of the On Course Receiver

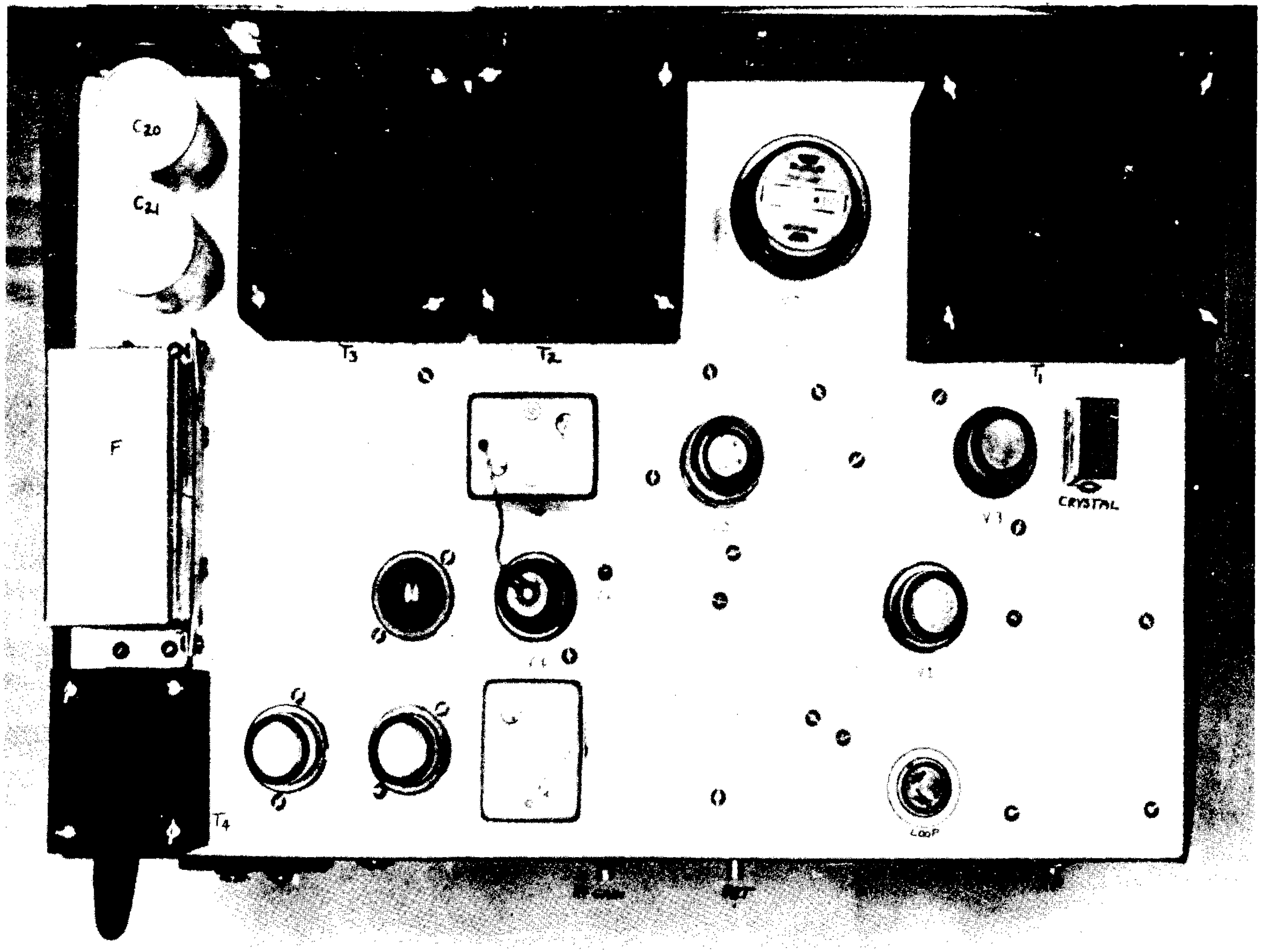


Figure 12. Top View of the On-Course Receiver Chassis.

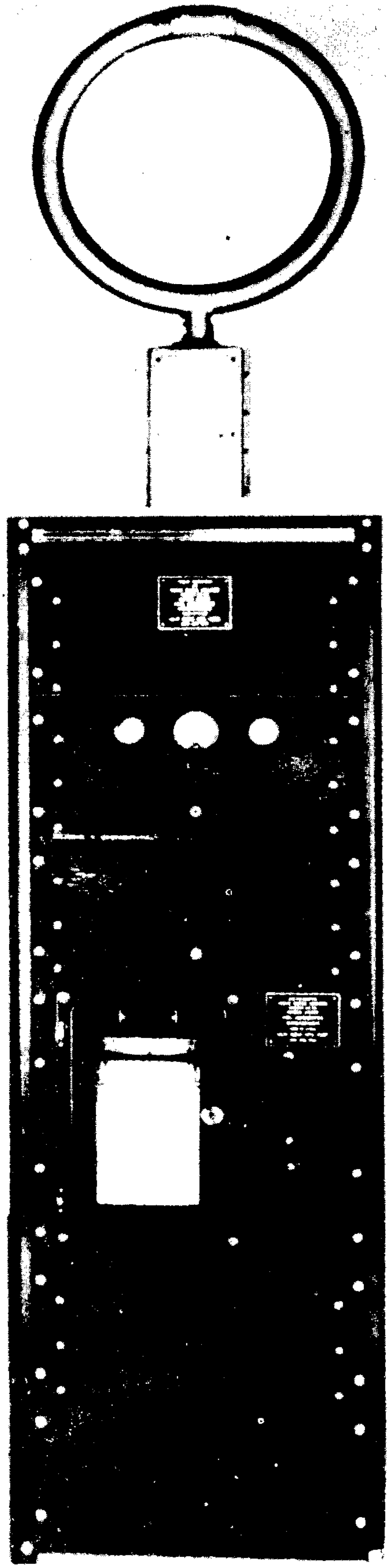


Figure 13. Front View of Assembled Airport Monitor Equipment.

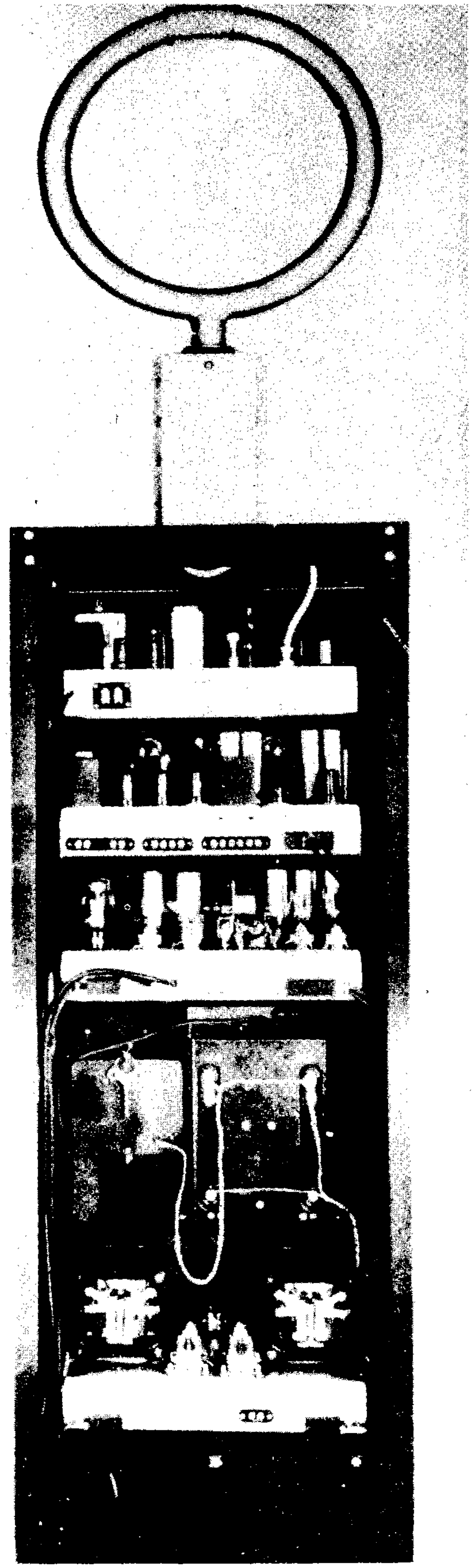


Figure 14. Rear View of Assembled Airport Monitor Equipment.

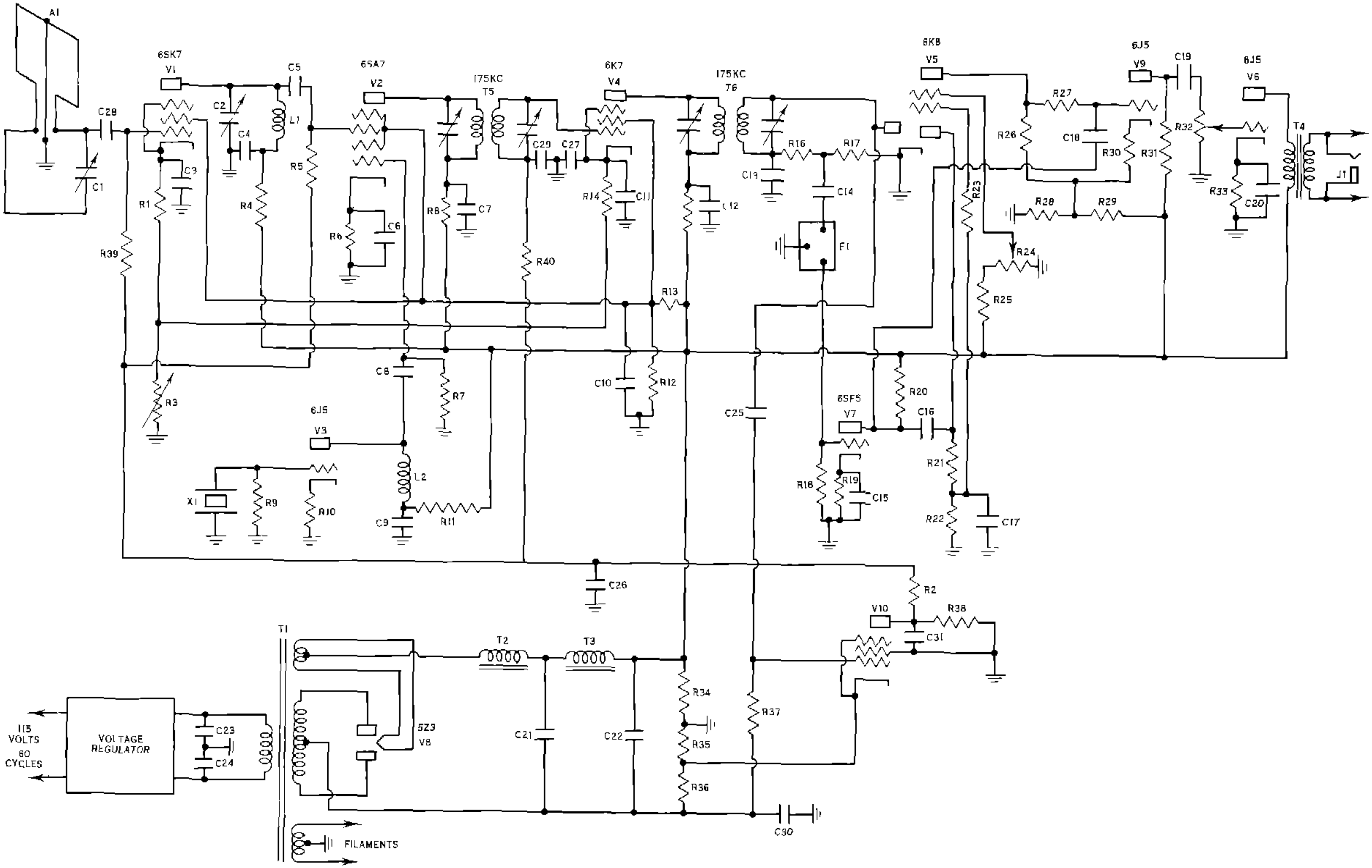


Figure 15 Schematic Diagram of the Off-Course Receiver

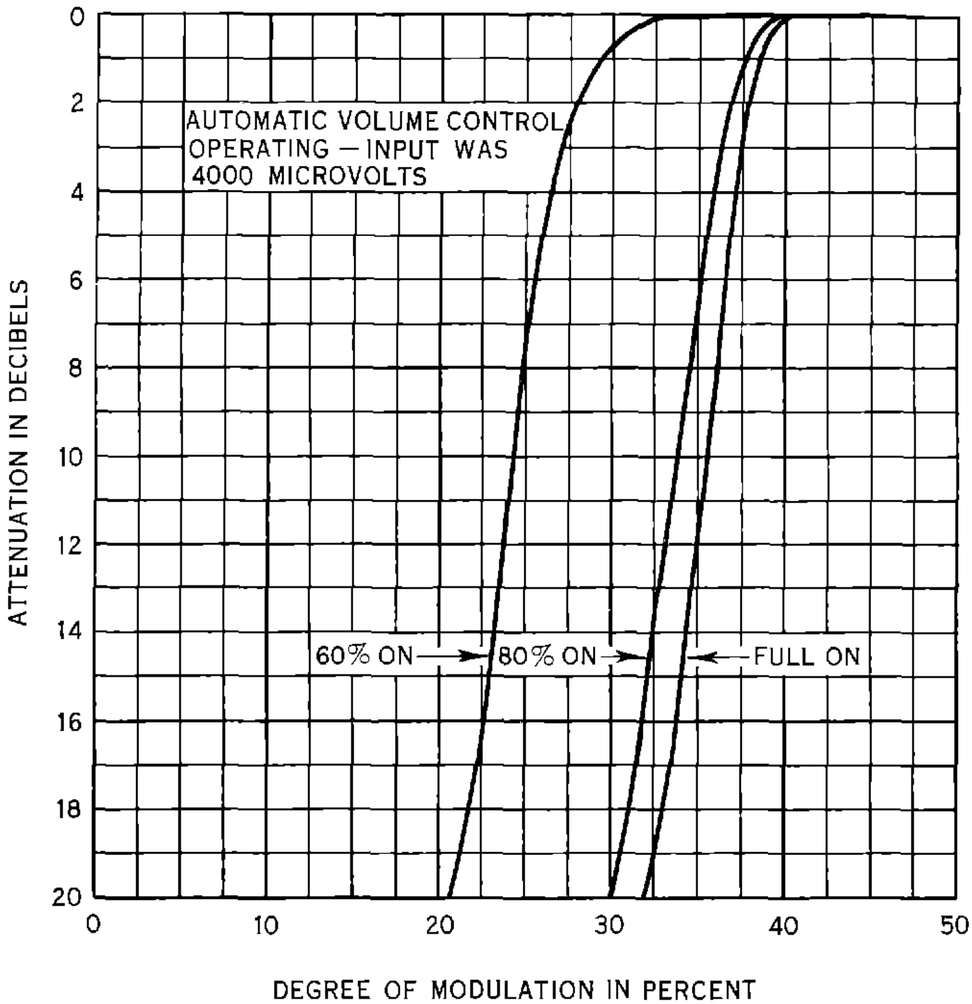


Figure 16 Squelch Control Action Provided by the Off-Course Receiver

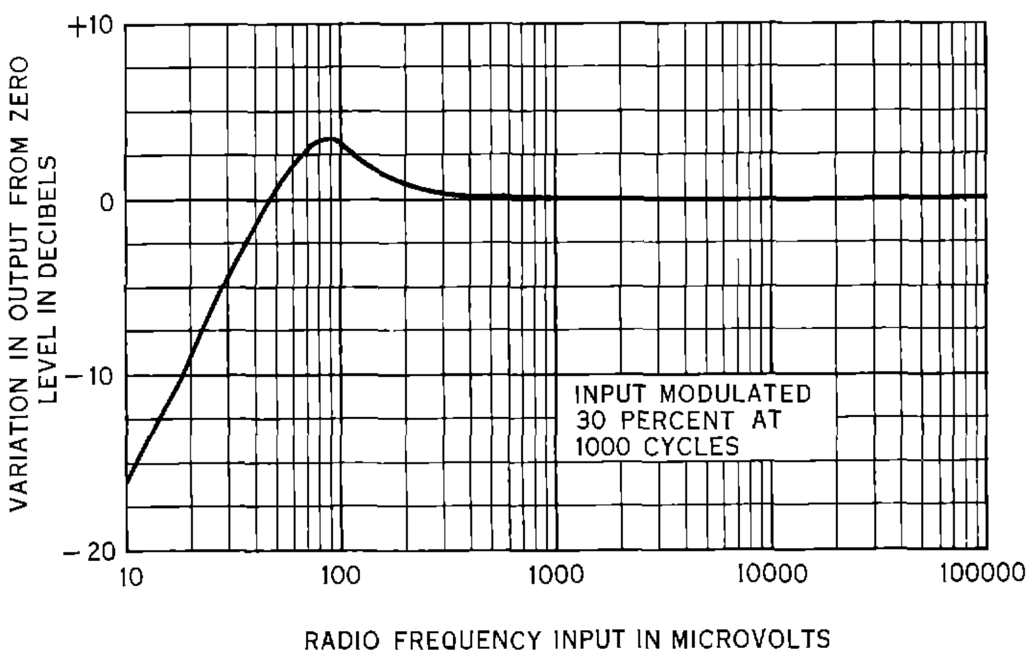


Figure 17 Automatic Volume Control Characteristics of the Off-Course Receiver

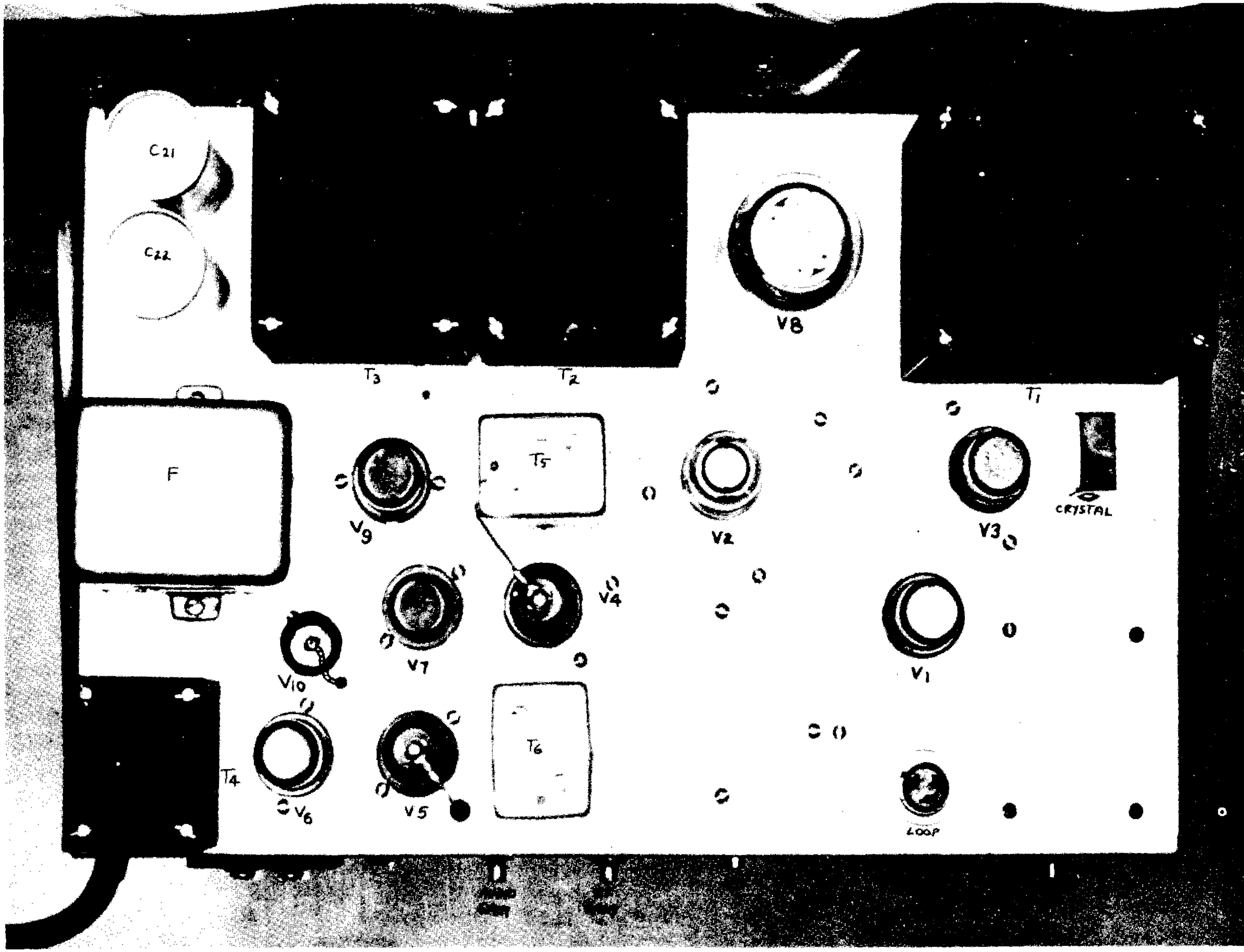


Figure 18. Top View of the Off-Course Receiver Chassis.

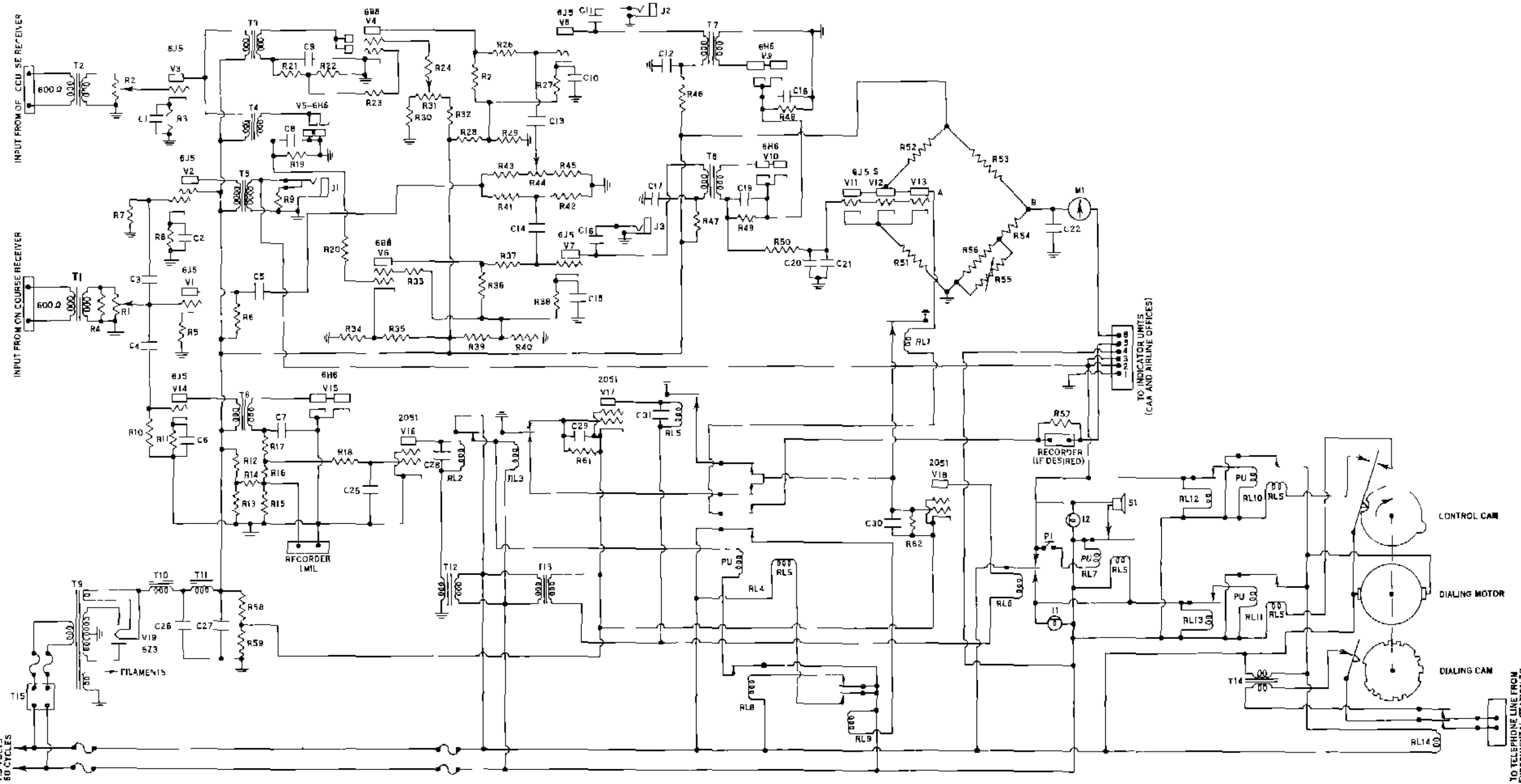


Figure 19 Schematic Diagram of Airport Monitor Equipment

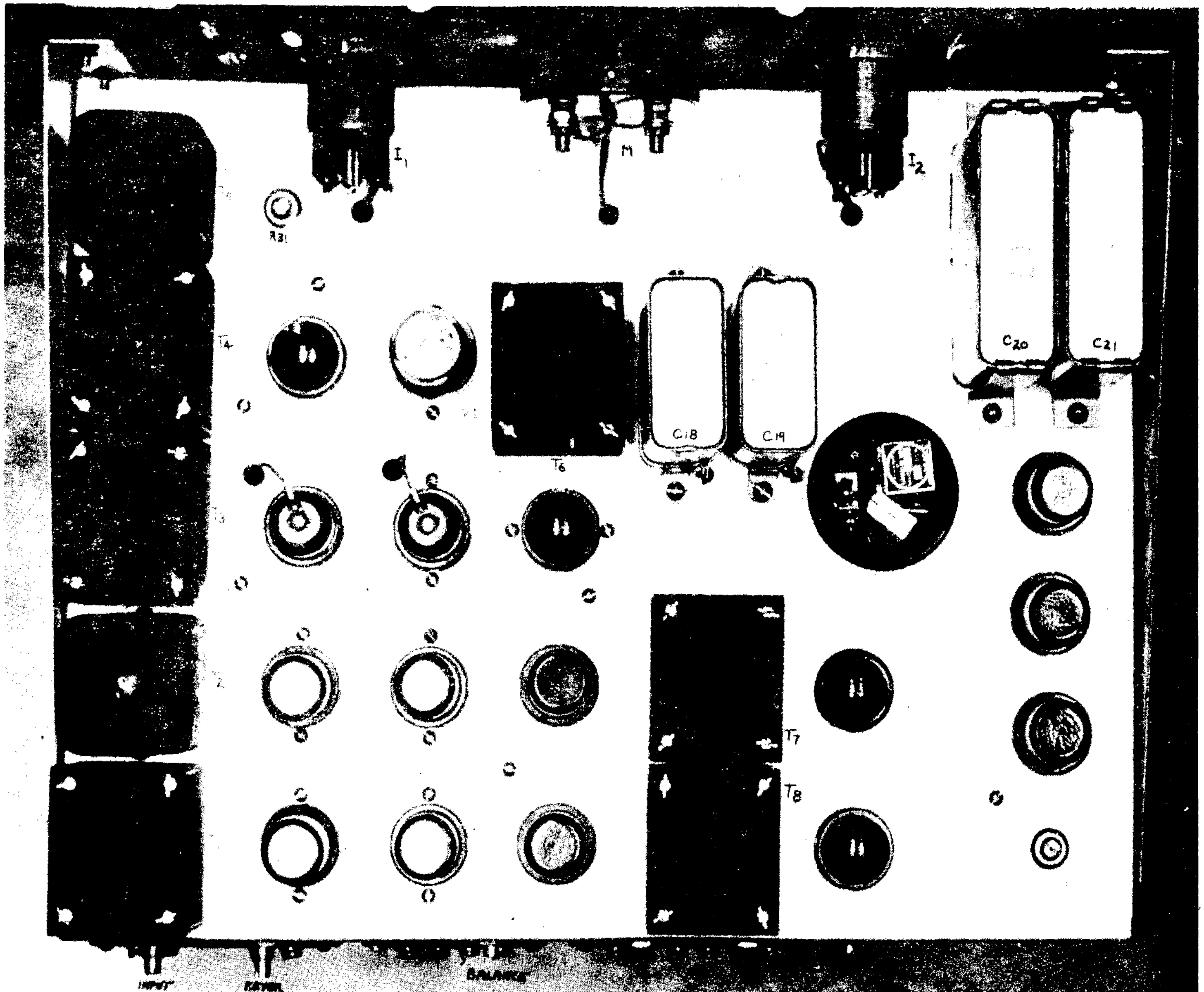


Figure 20. Top View of Electronic Keyer - Bridge Chassis.

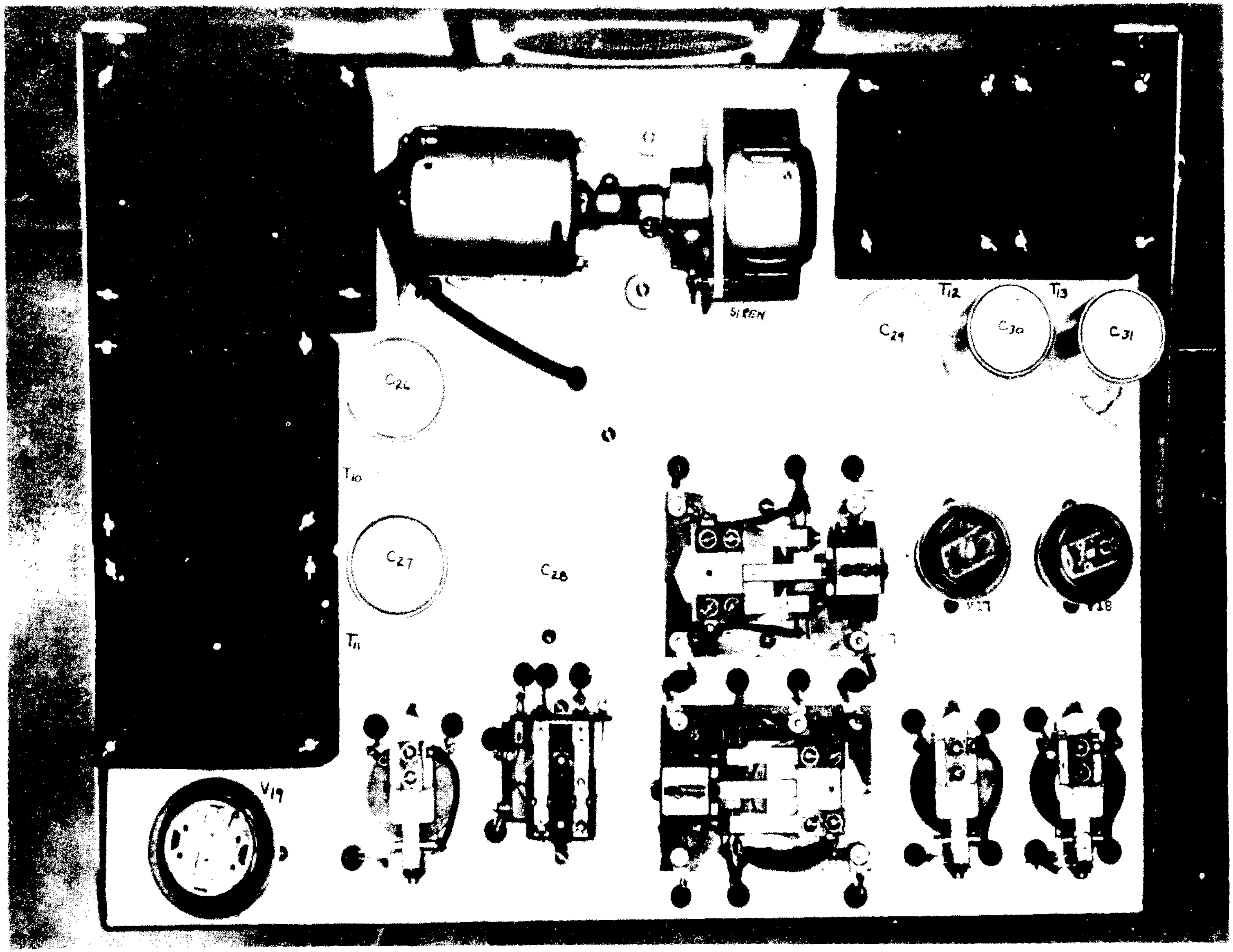


Figure 21. Top View of Relay - Alarm Chassis.

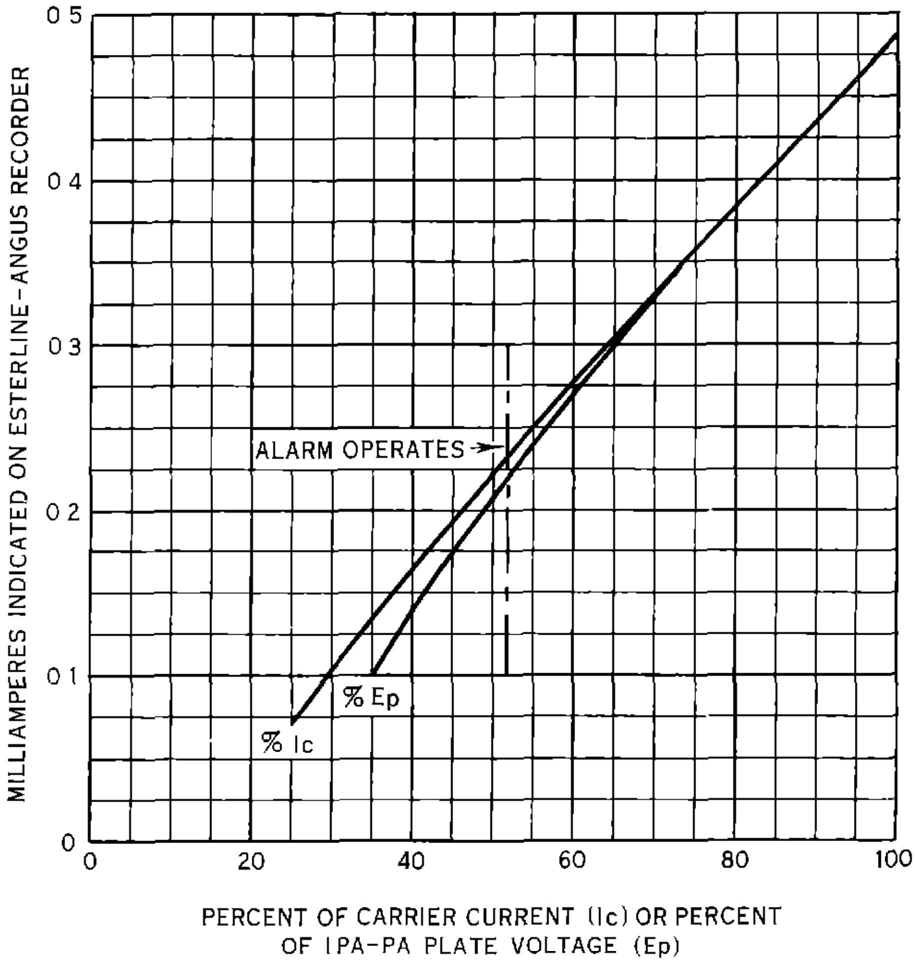


Figure 22 Variation of Recorder Chart Amplitude with Transmitter Plate Voltage and with Transmitter Carrier Current

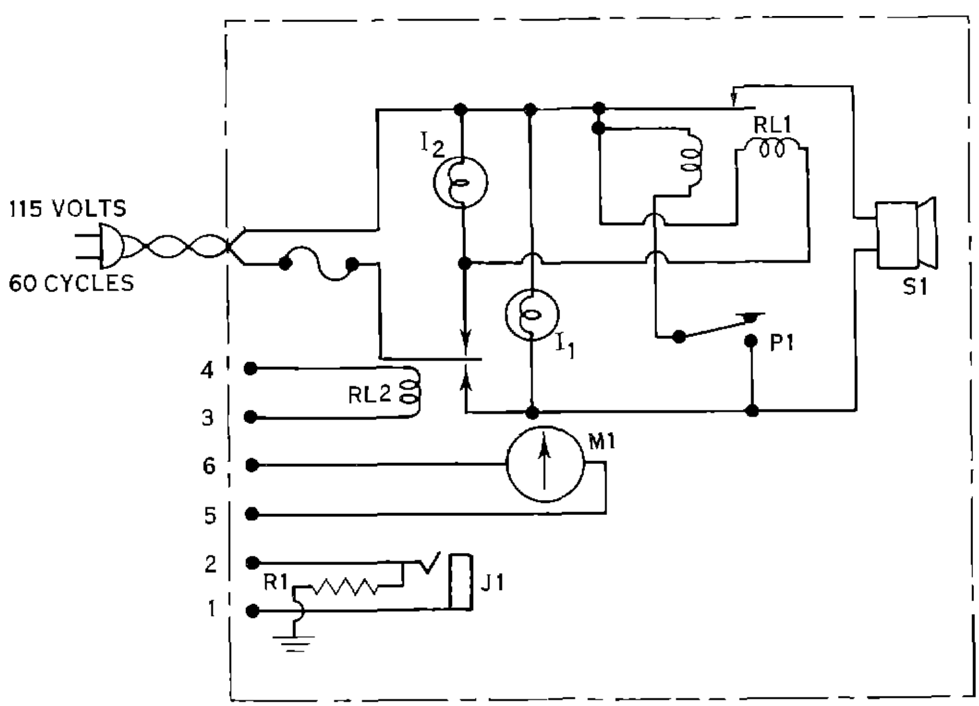


Figure 23 Schematic Diagram of Remote Indicator Alarm Unit

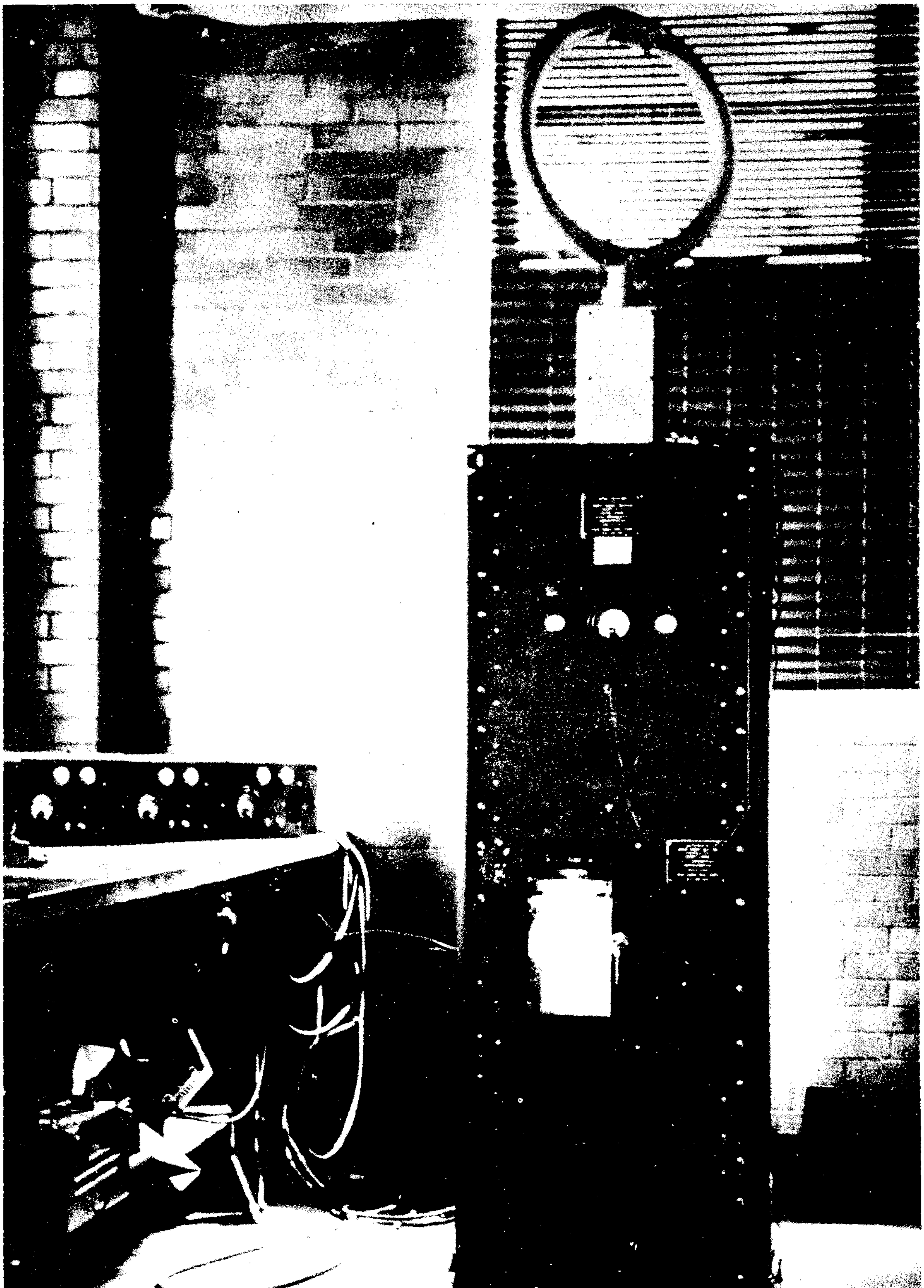


Figure 24. View of Entire Airport Monitor Equipment Including Remote Indicator - Alarm Units as Installed for Test at Indianapolis.

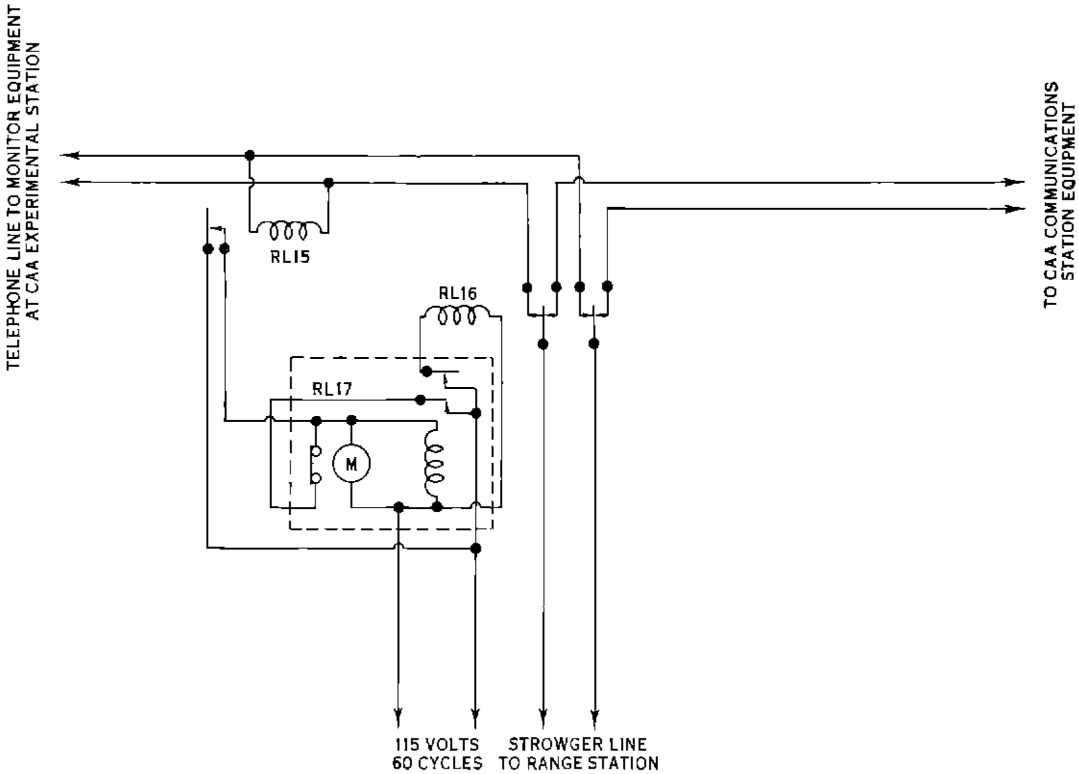


Figure 25 Schematic Diagram of Communications Station Equipment

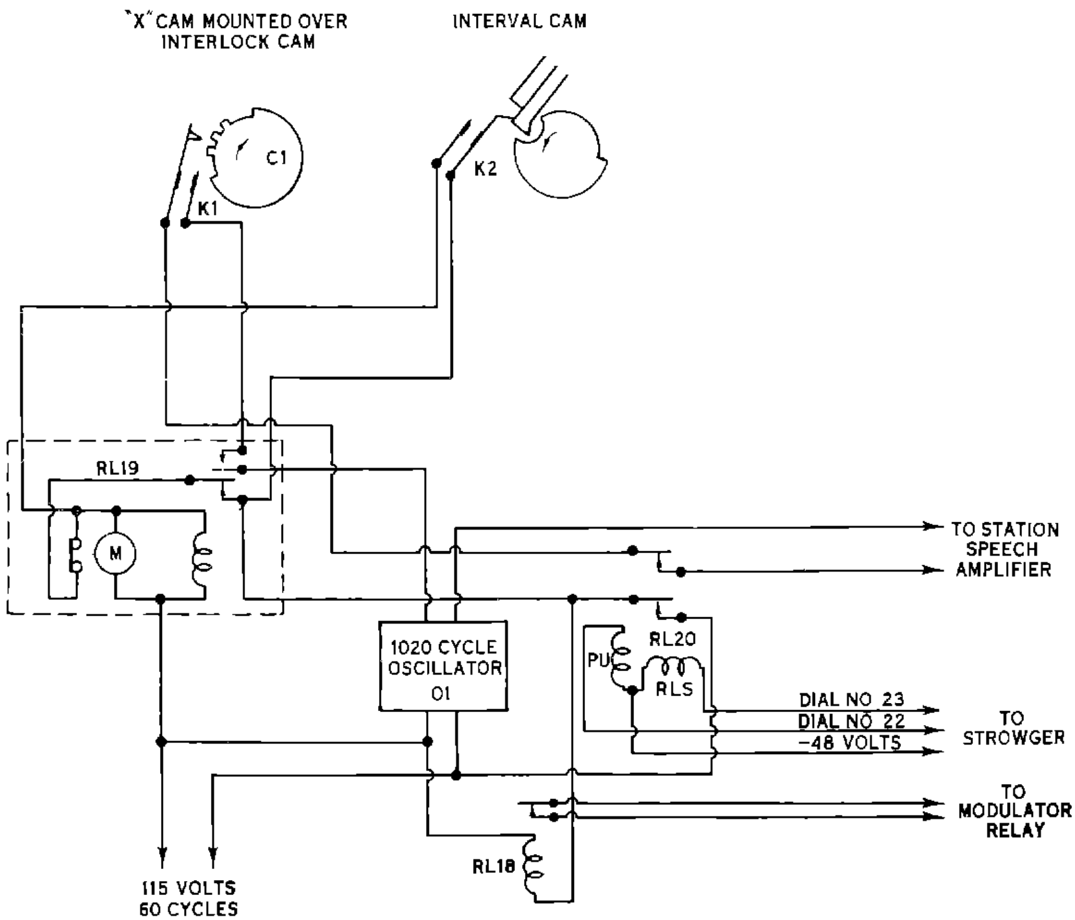


Figure 26 Schematic Diagram of Range Station Equipment

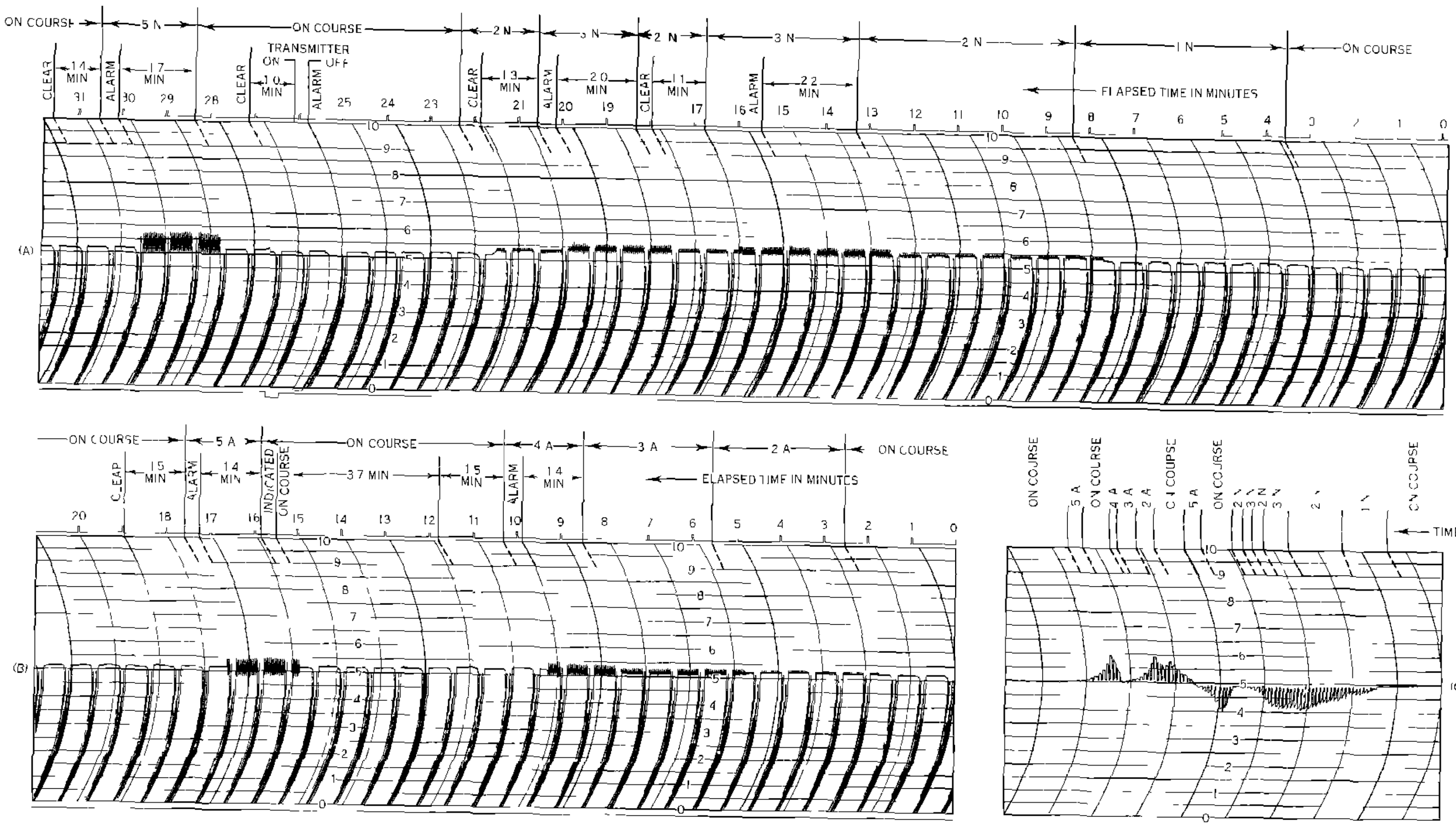


Figure 27 Graphic Records of Course Deviations During Tests

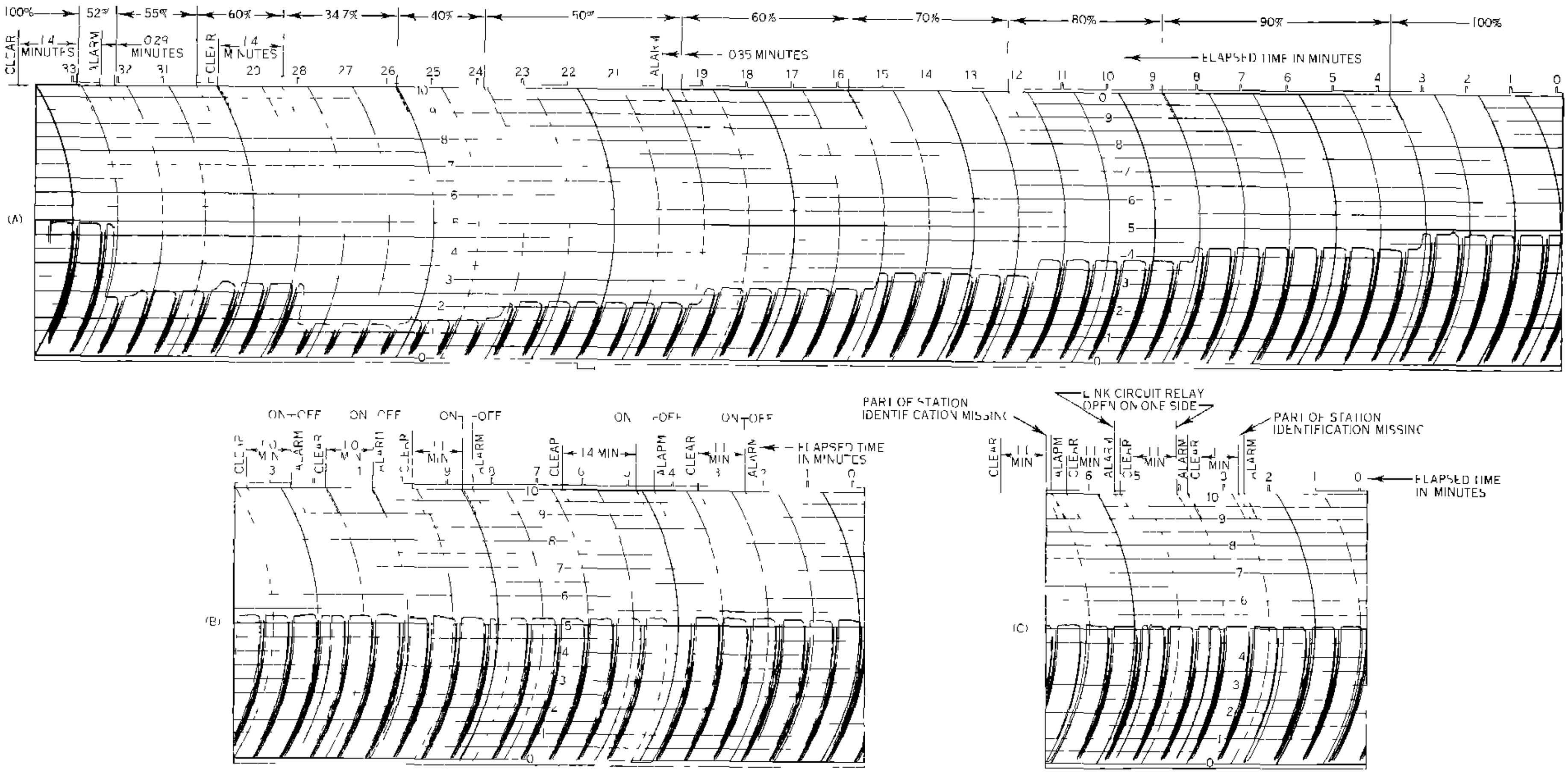


Figure 28 Graphic Records of Power Reduction, Instantaneous Signal Interruptions, Partial Station Identifications and the Effect of a Locked Link Circuit Relay

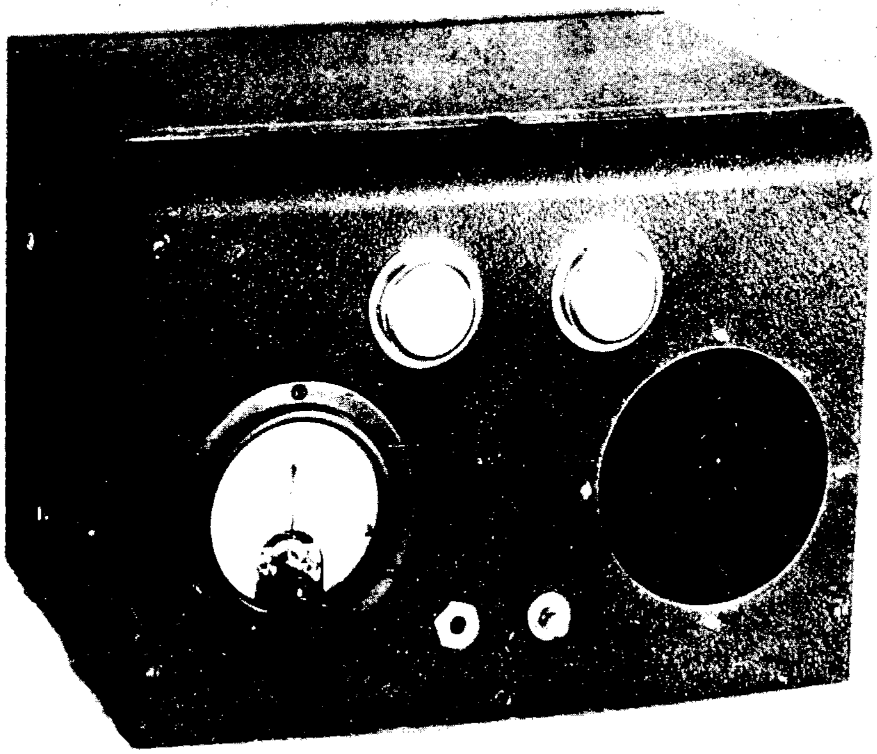


Figure 29. Remote Indicator - Alarm Unit.

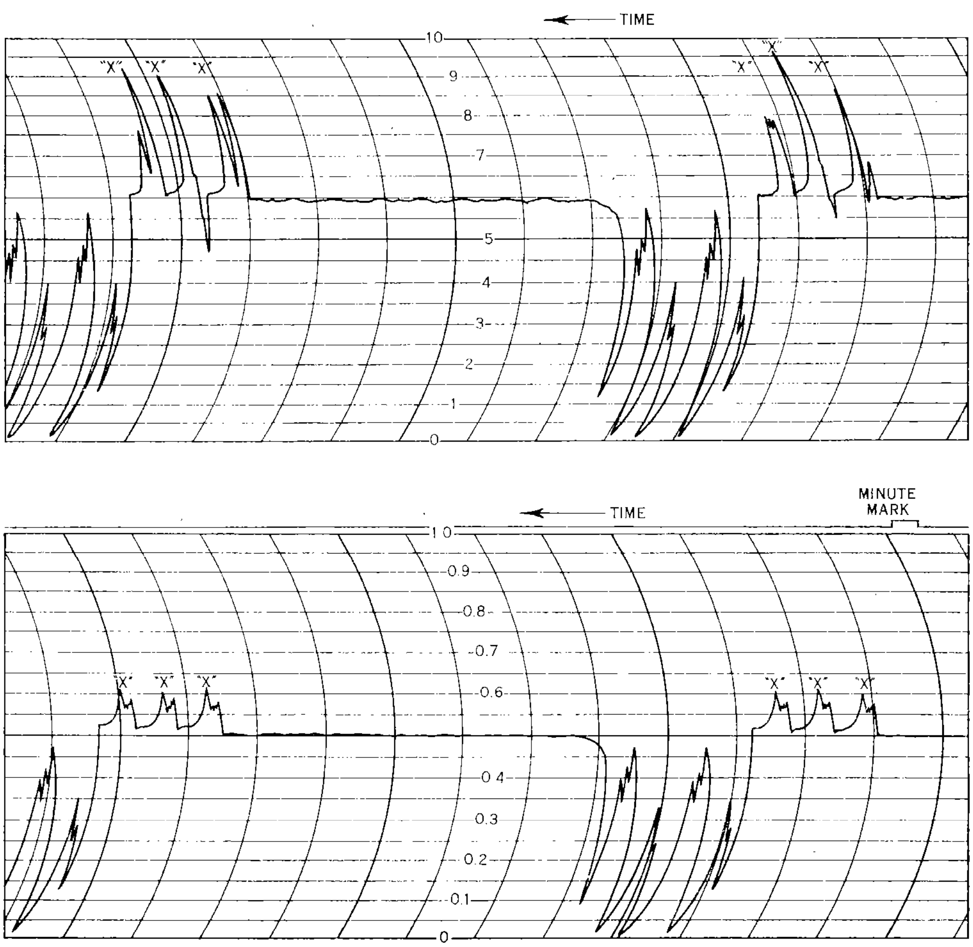


Figure 30. Graphic Records Showing the "XXX" Warning Signal with and without a Low Frequency Beat Note with the Range Sideband Signal.

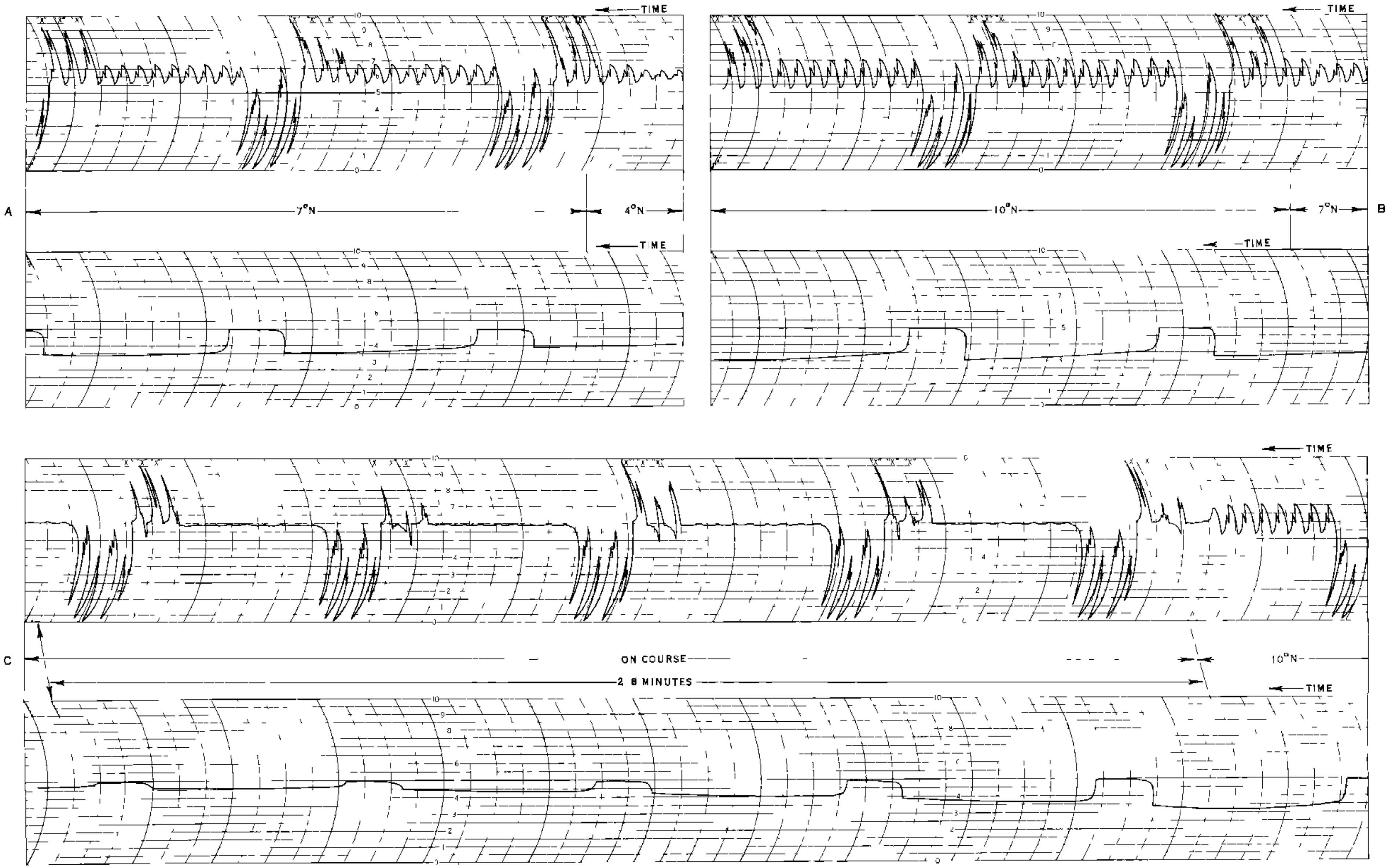


Figure 31 Graphic Records of Course Deviations

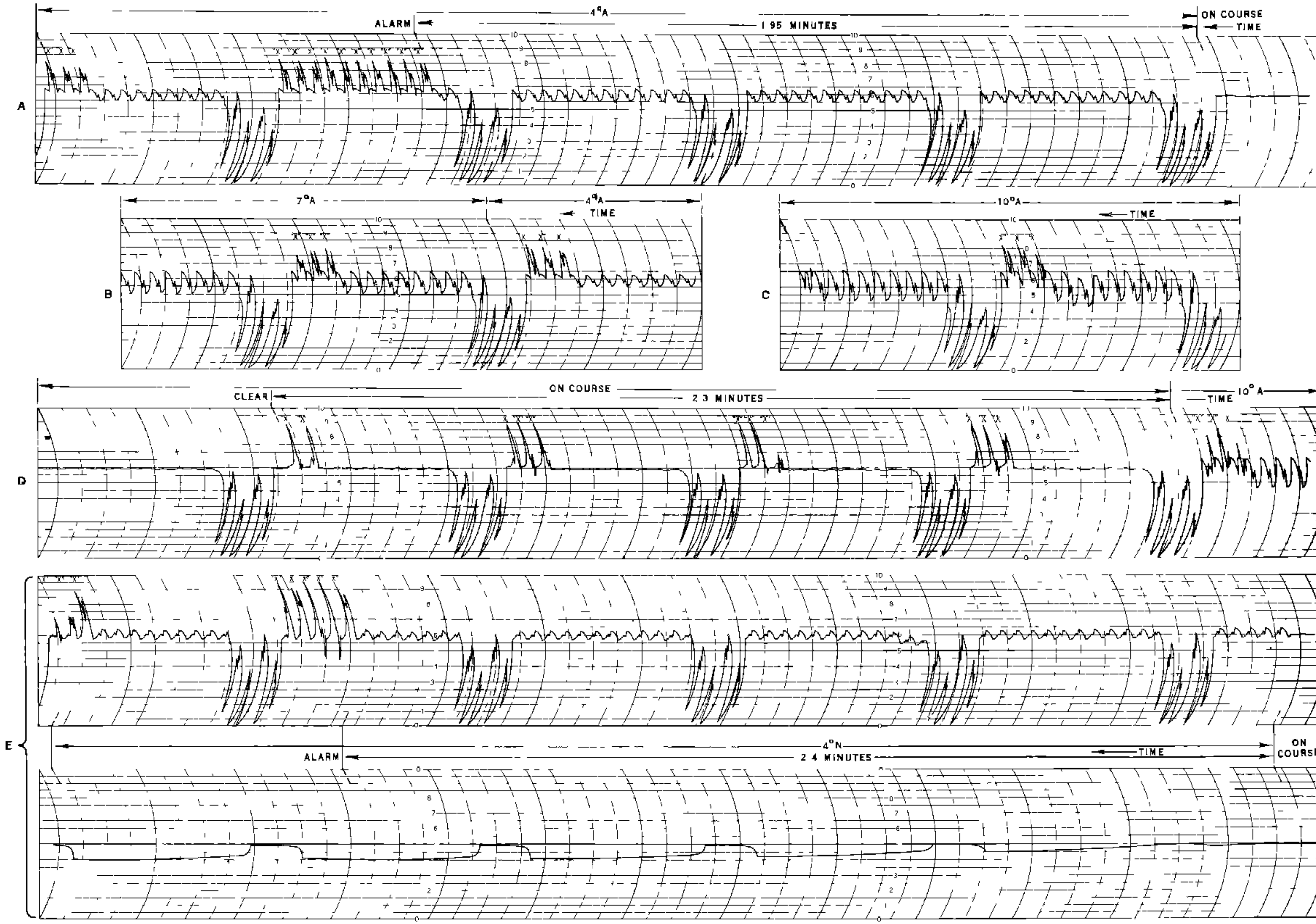


Figure 32 Graphic Records of Course Deviations

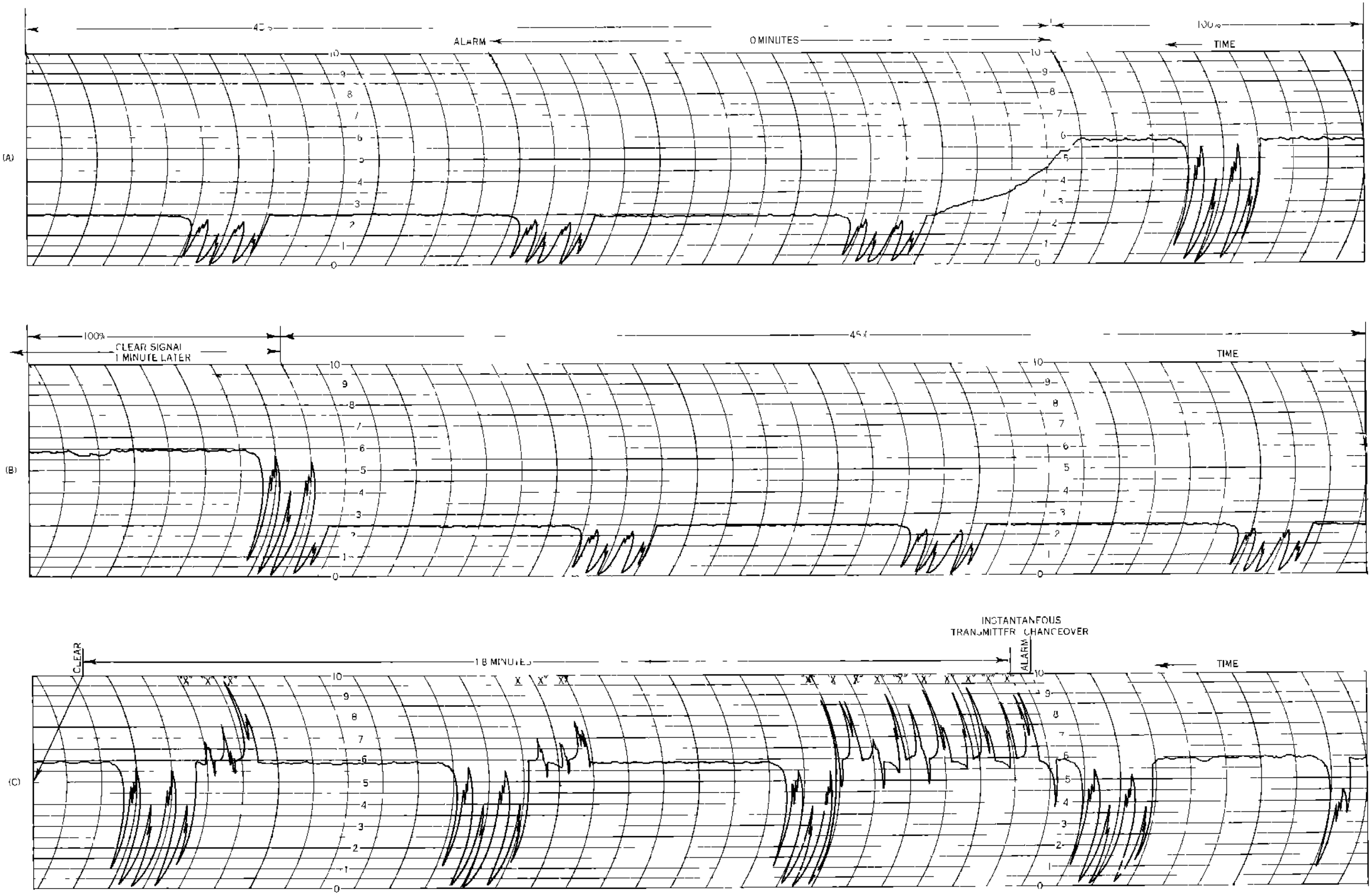


Figure 33 Graphic Records of Power Reduction and Intervals of Transmitter Changeover

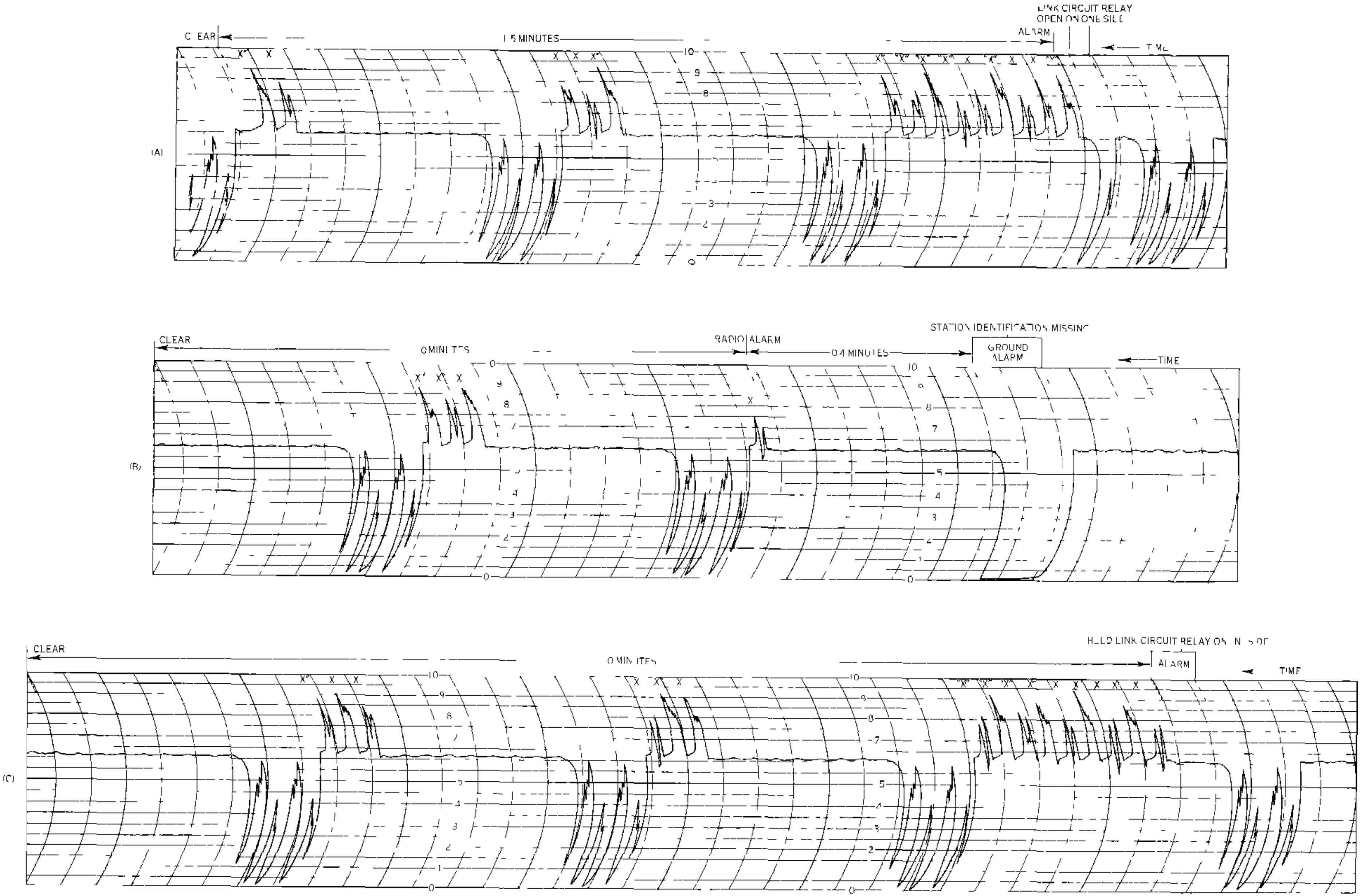


Figure 34 Graphic Records of the Effect of Improper Link Circuit Relay Keying, Partial Station Identification, and a Locked Link Circuit Relay

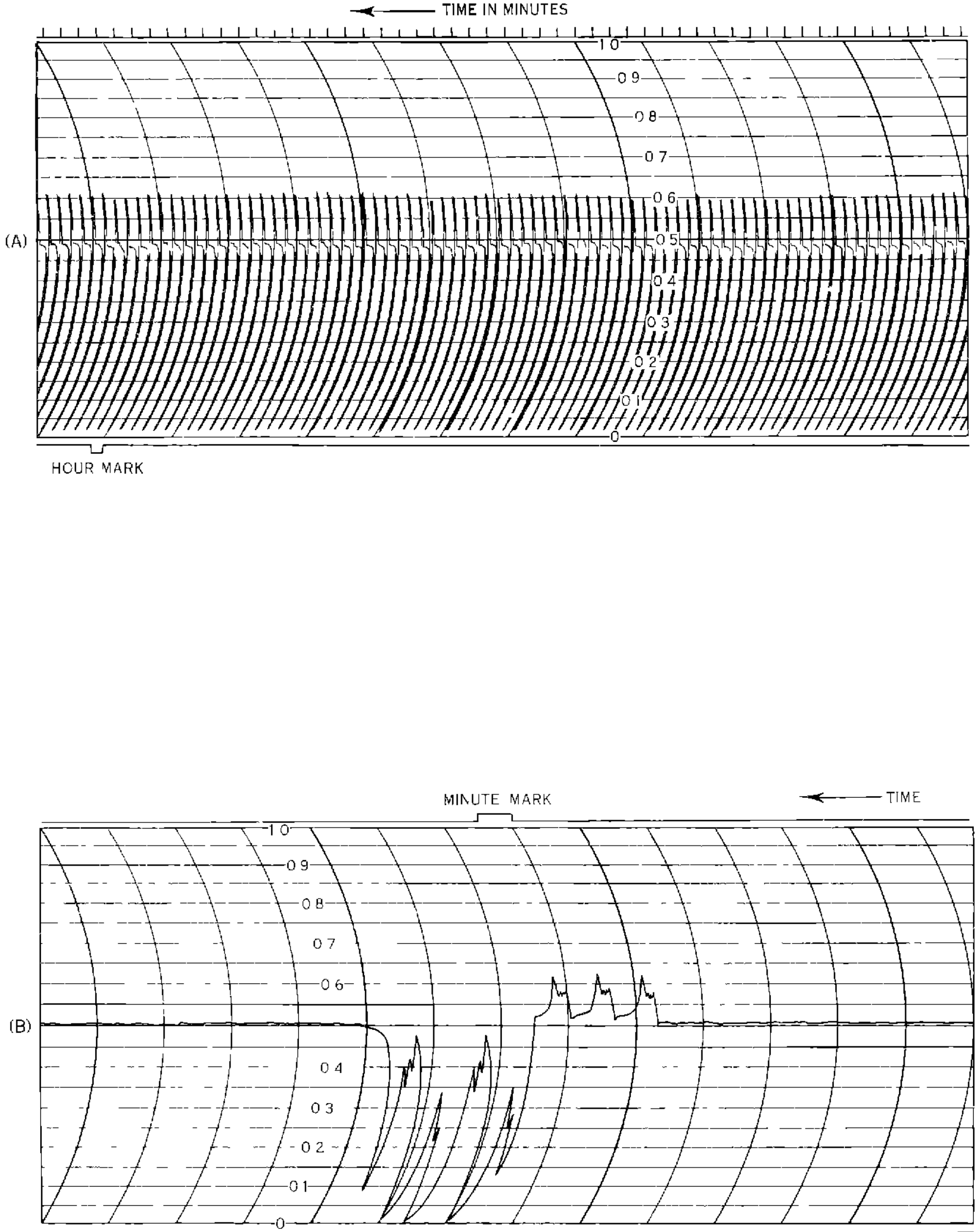


Figure 35 Graphic Records of the "XXX" Warning Signal Superimposed on the Range Signal with Chart Speeds of 12 Inches Per Hour and 12 Inches Per Minute

(A)

(B)

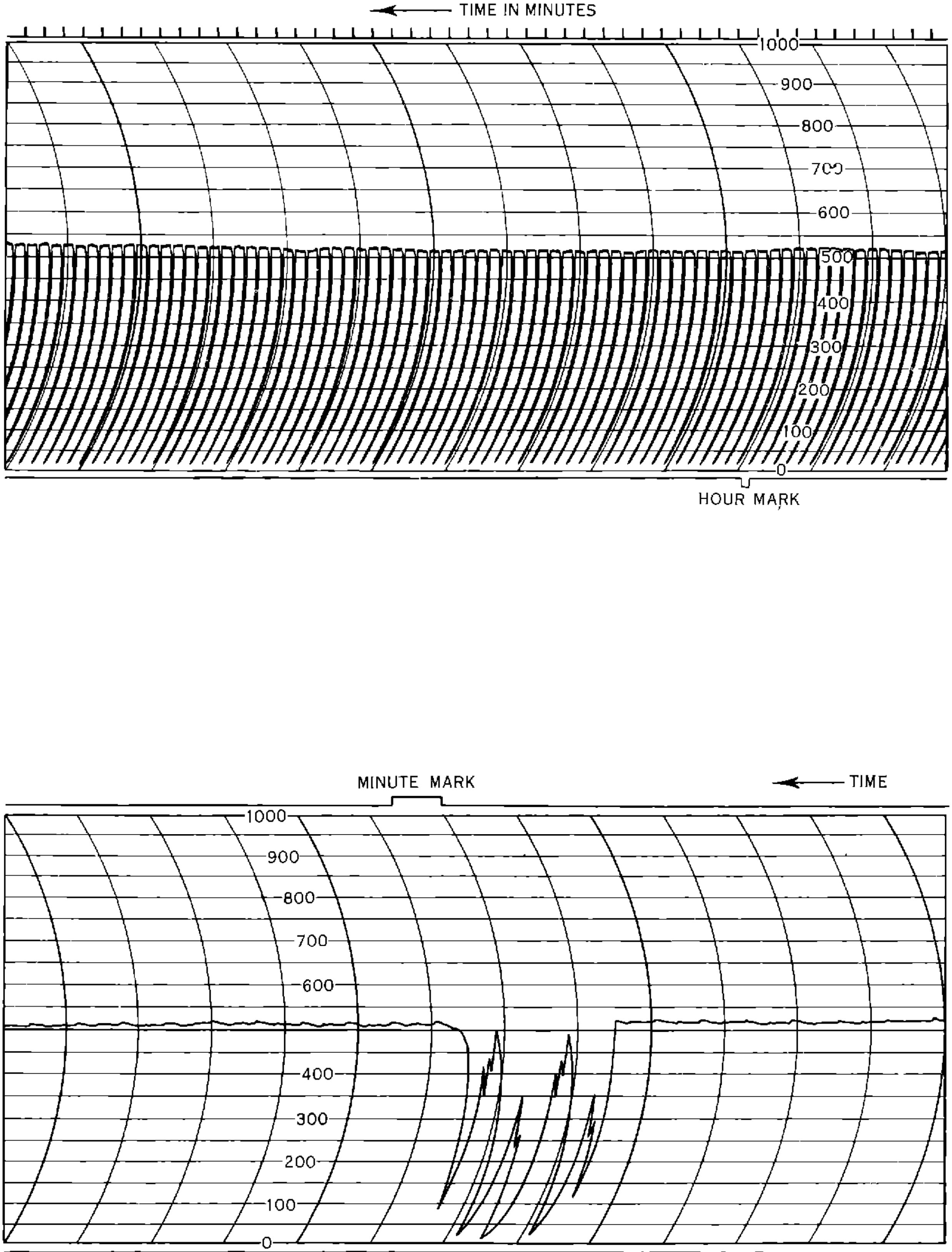


Figure 36 Graphic Records of a Normal Range Signal with Chart Speeds of 12 Inches Per Hour and 12 Inches Per Minute

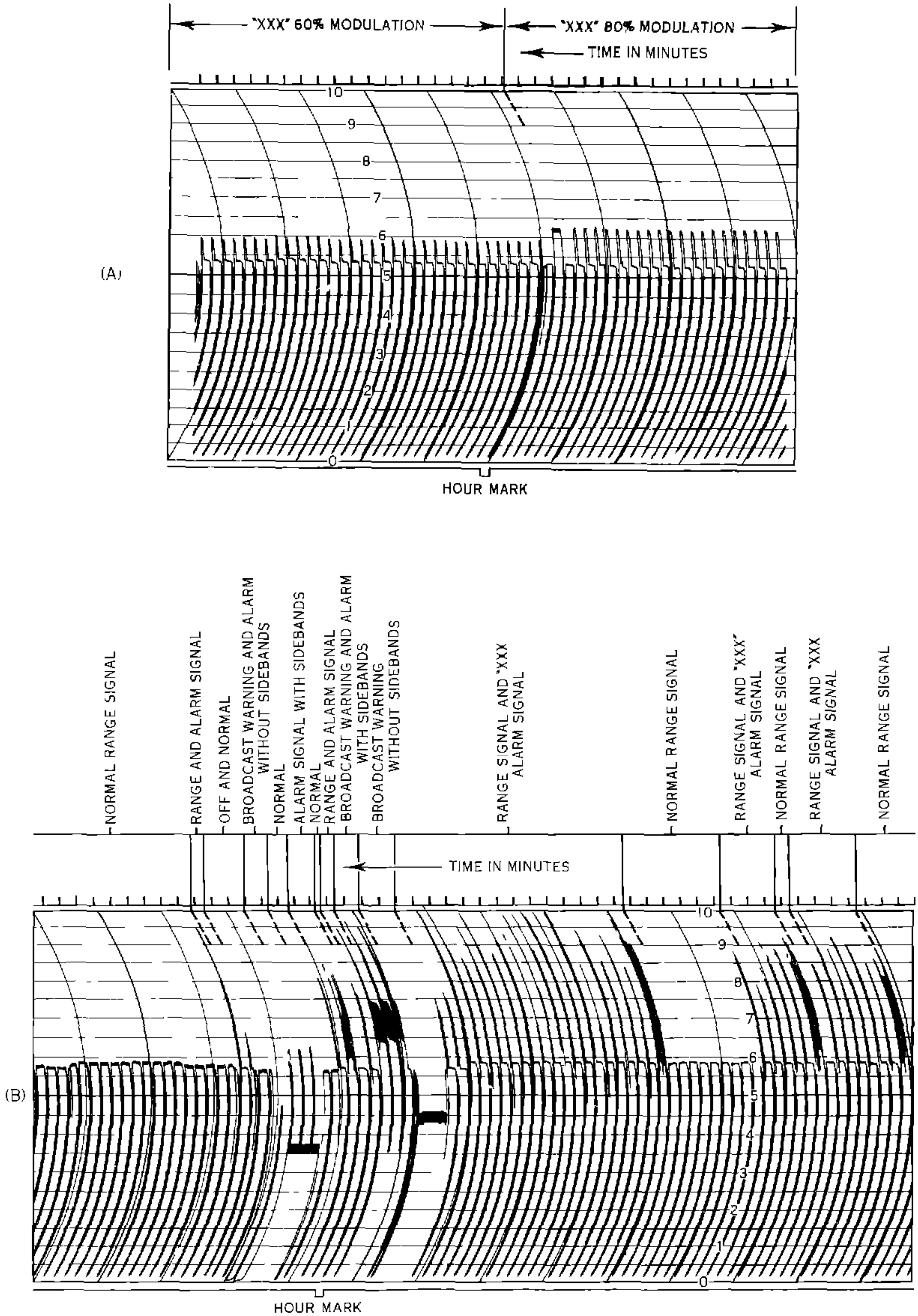
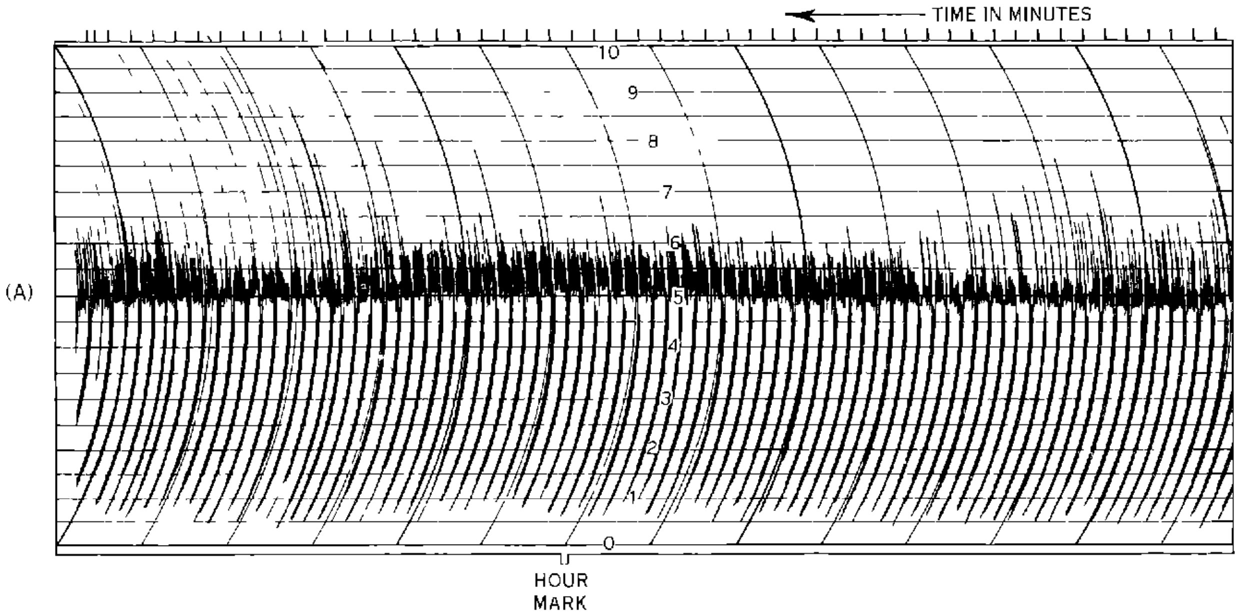


Figure 37 Graphic Records Showing the Effect of Varying the Modulation of the Carrier by the "XXX" Warning Signal, and Showing the Effect of Various Arrangements for Keying the "XXX" Warning Signal and the Broadcast Warning Dots with and without the Presence of the Range Sidebands



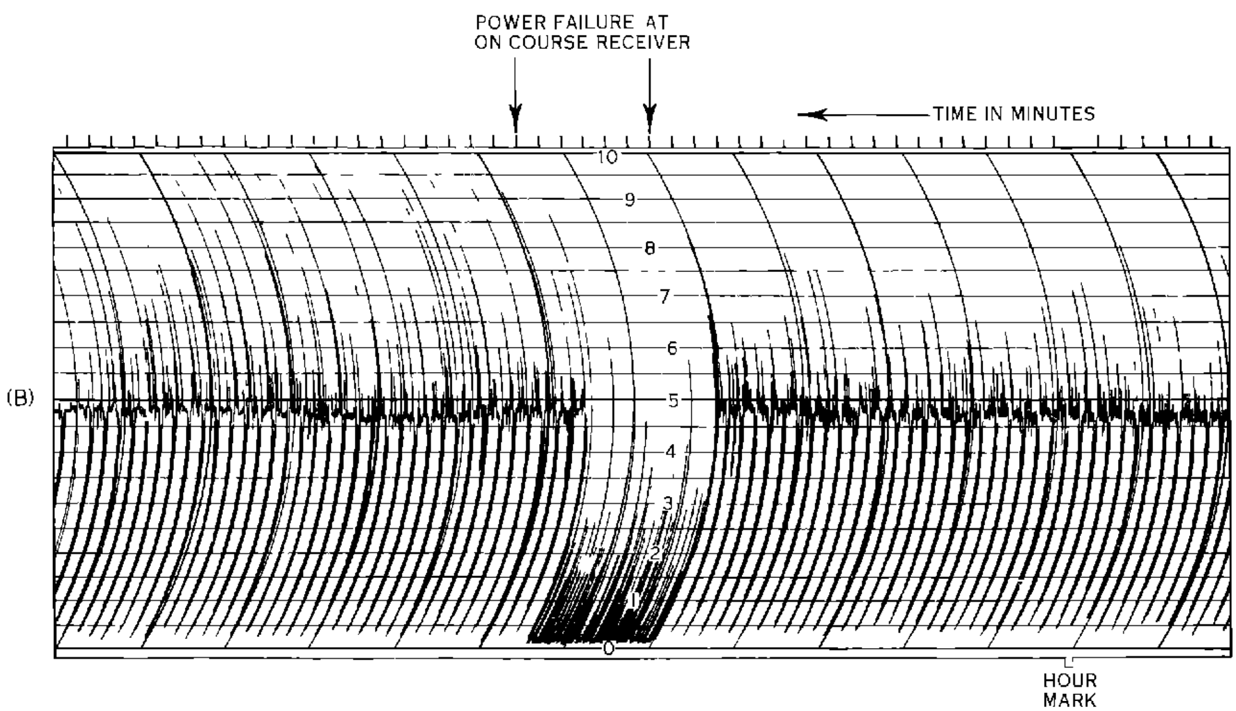


Figure 38 Graphic Records of the Range Signal During Periods of Severe Static

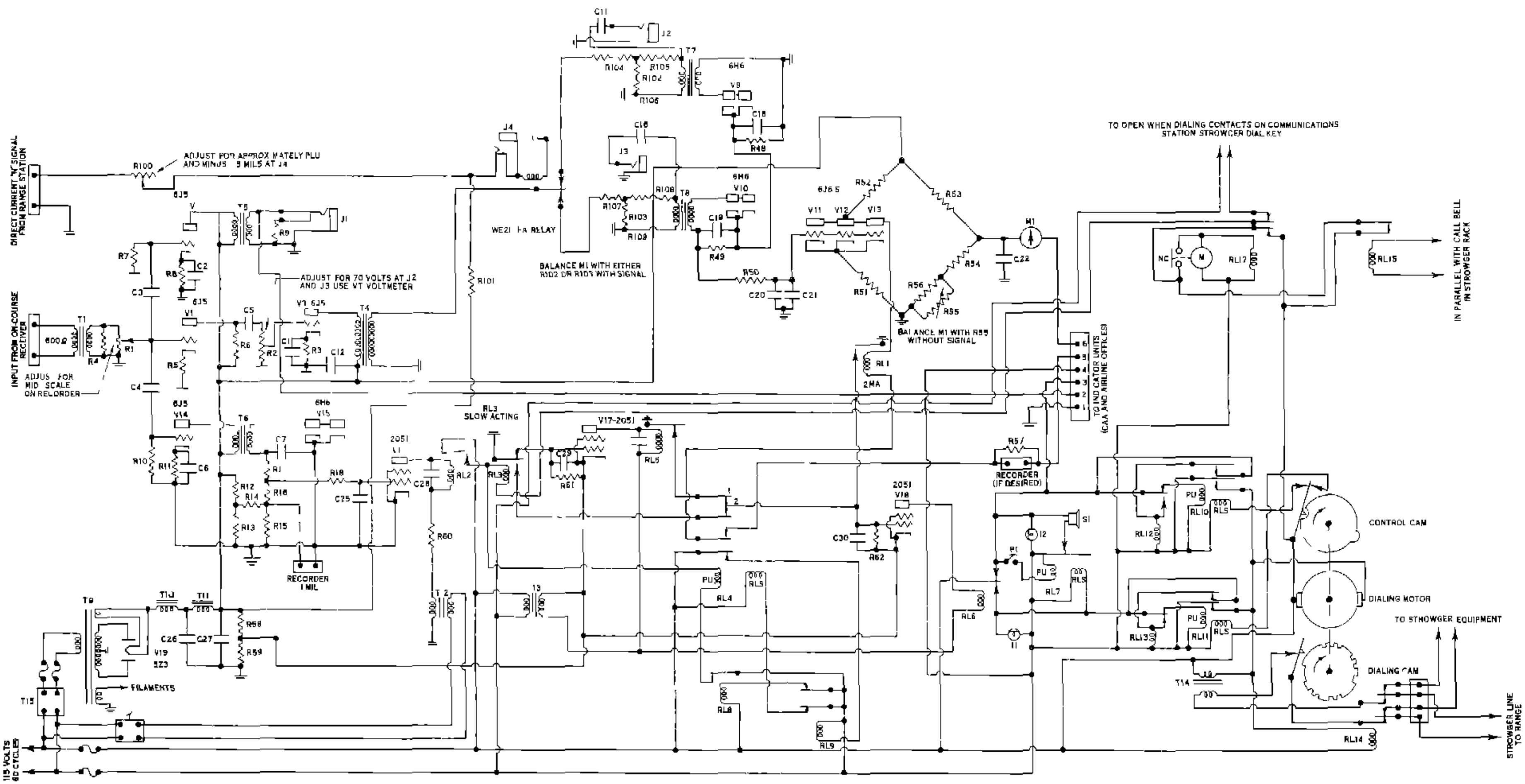


Figure 39 Schematic Diagram of the Modified Airport Monitor Equipment

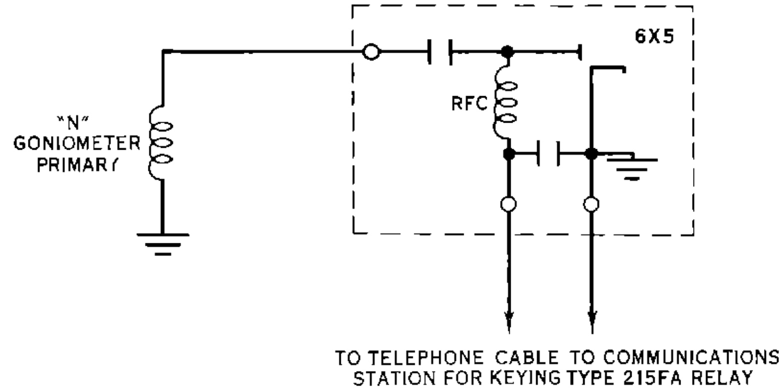


Figure 40 Schematic Diagram of the N Signal Rectifier at the Range Station

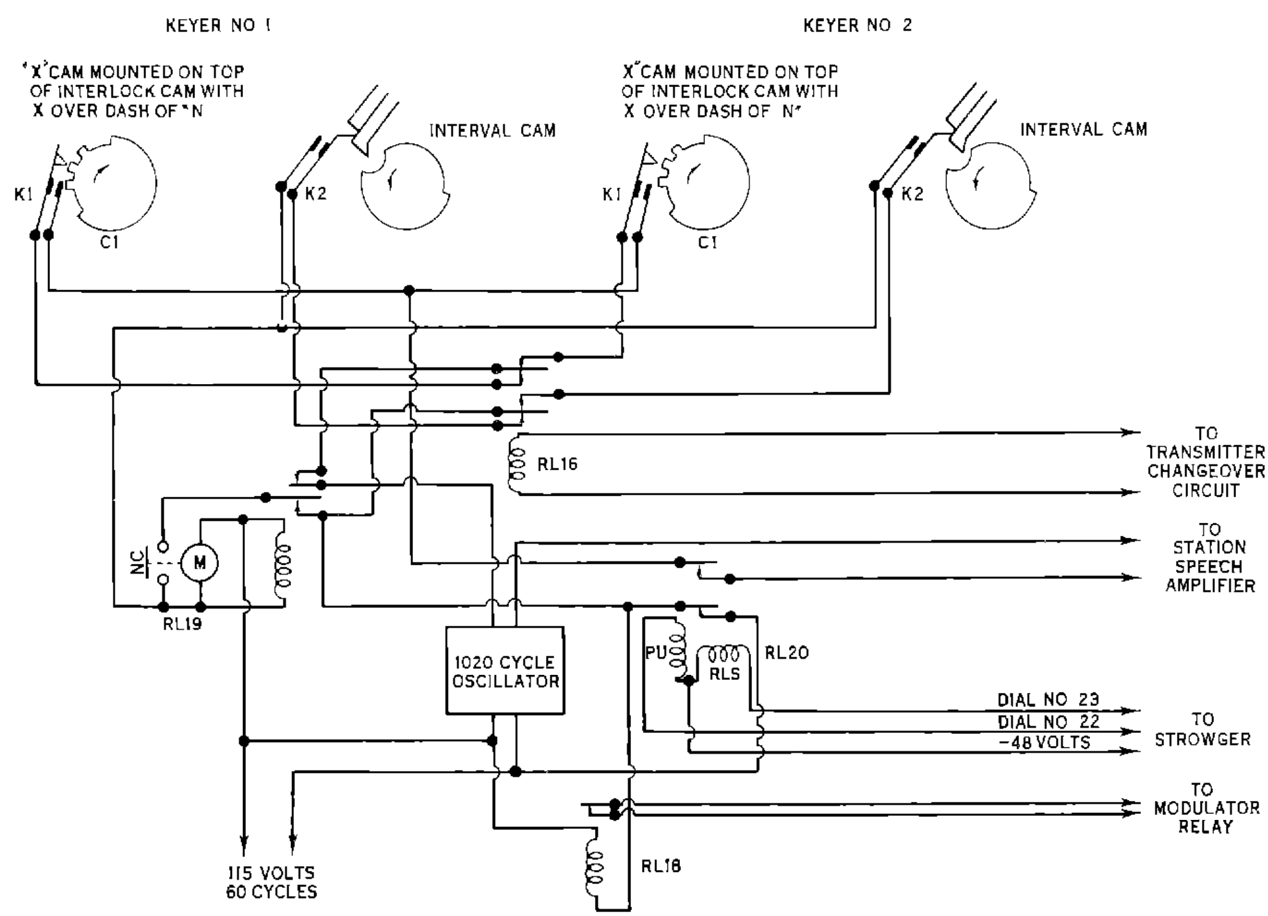


Figure 41 Schematic Diagram of the Modified Range Station Equipment

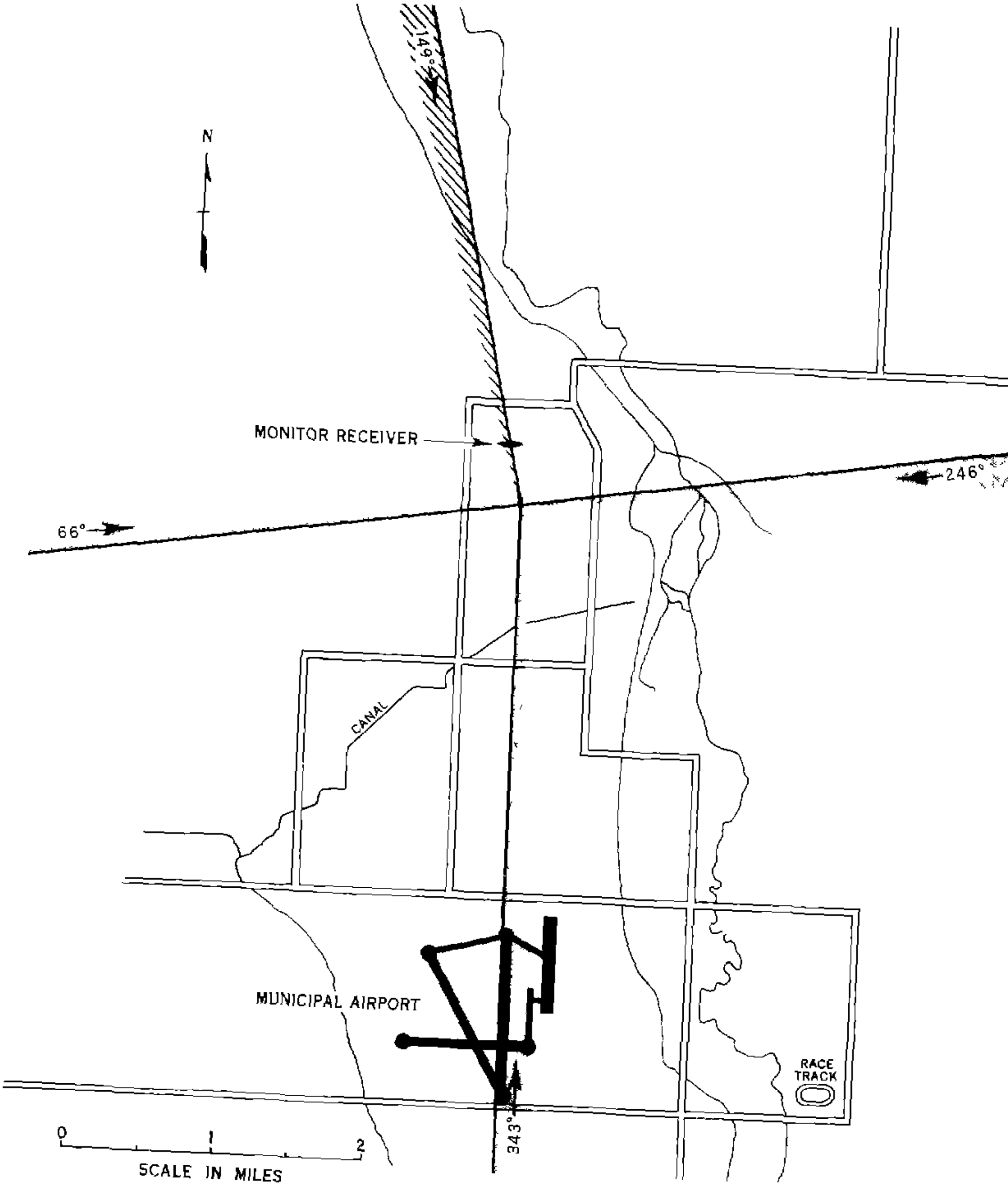


Figure 42 Map Showing Location of On-Course Receiver Site, the Salt Lake City Radio Range and the Salt Lake City Airport

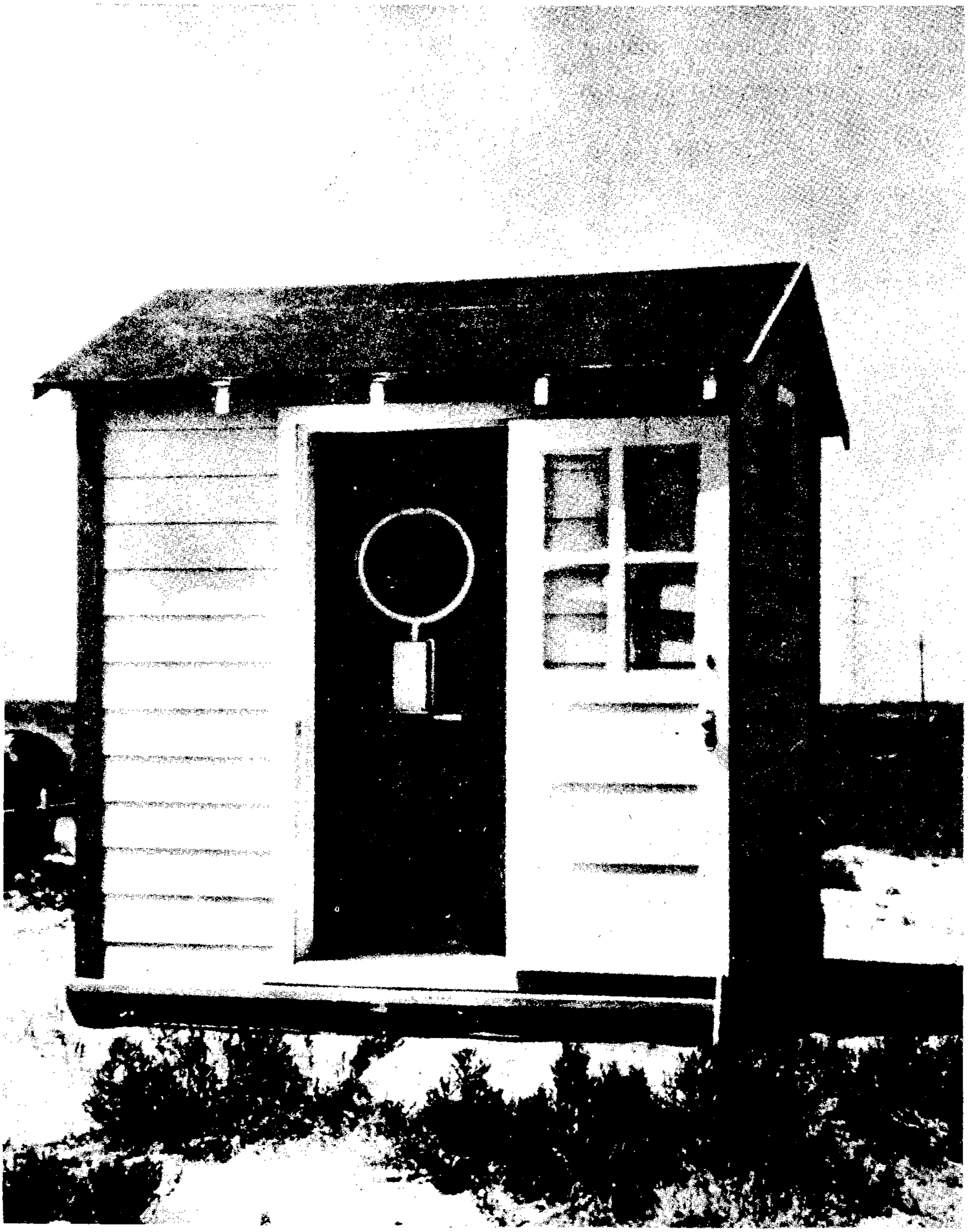


Figure 43. On-Course Receiver Installation at Salt Lake City.

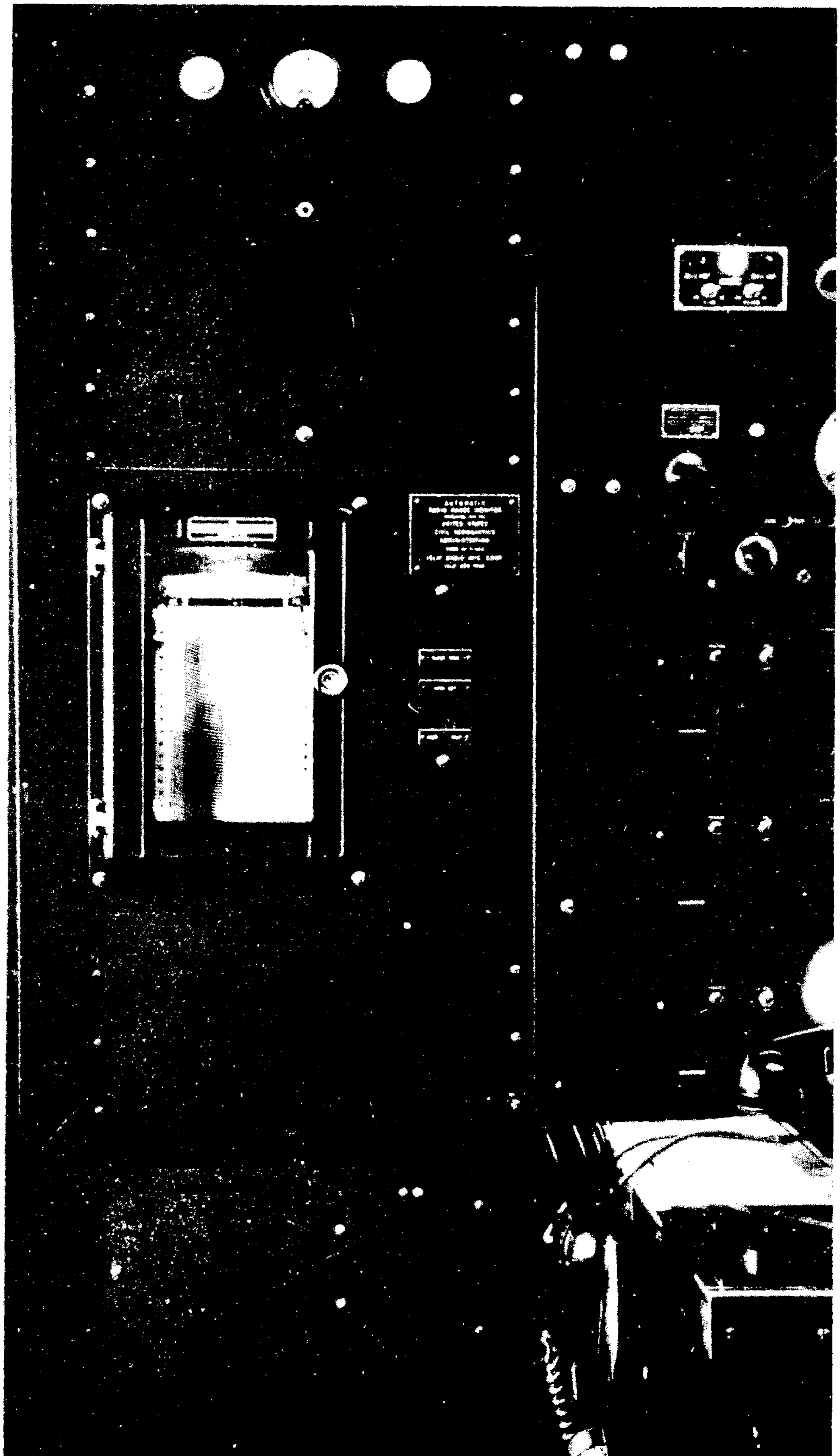


Figure 44. Communications Station Installation at Salt Lake City.

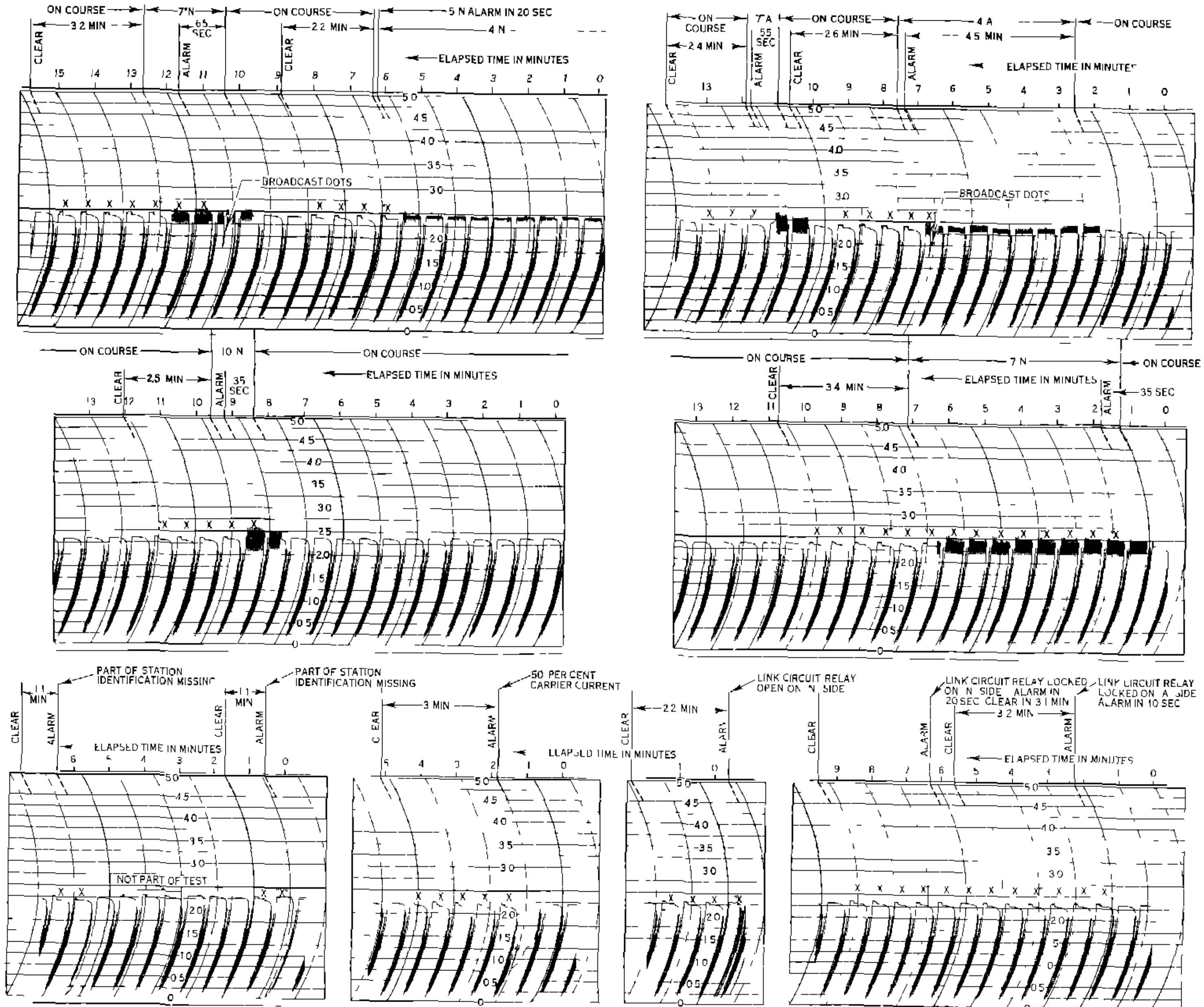


Figure 45 Graphic Records of Course Deviations, Locked Link Circuit Relay, Improper Keying of the Link Circuit Relay, Power Reduction and Partial Station Identifications Made During Final Tests at Salt Lake City