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EVALUATION OF A TRAFFIC CONTROL MONITOR FOR USE WITH THE PRECISION APPROACH RADAR

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SUMMARY

This report describes the operational and technical evaluation of an air traffic control aid called the PAR-1 Traffic Control Monitor, built by Gilfillan Bros., Inc., and modified by engineers at the Technical Development and Evaluation Center of the Civil Aeronautics Administration. The equipment was designed to monitor aircraft making precision radar approaches and to perform the co-ordination function between the PAR controller and the departure controller. The equipment is also designed to act as a monitor of the control instructions issued by the PAR controller and to sound an alarm if less than minimum separation develops between aircraft on approaches.

The PAR-1 Traffic Control Monitor includes direct-reading meter indications of the distance from touchdown, the point at which the airplane touches the ground, and of the ground speed of landing aircraft. It also includes means of actuating a no-take-off warning alarm when aircraft on approach reaches a preset minimum distance from touchdown. The overtake warning alarm is actuated when aircraft on approach have less than minimum separation from other aircraft. Malfunctioning of the equipment is indicated by a no-video alarm.

In the evaluation of the monitor, use was made of both actual and simulated aircraft targets. The results of the evaluation tests indicate that the PAR-1 Traffic Control Monitor in its present form considerably increases the work load of the PAR controller and is not sufficiently reliable to be used in the control of air traffic.

INTRODUCTION

Precision Approach Radar (PAR) has been in operation at the major civilian air terminals since 1947. It was found necessary to locate the PAR indicators in a darkened room beneath the tower or under a tent-like structure within the tower since present radar indicators must be used at low light levels. A problem of co ordination between positions of operation became apparent as soon as the operating positions were separated. Close co-ordination between the PAR controller and the departure controller must be maintained, because the departure controller must know the proximity to touchdown of arriving aircraft before clearing a departing aircraft for take-off. This co-ordination at present is accomplished by direct voice communication under conditions of high ambient noise or by use of either intercommunication equipment or information light panels when positions of operation are not immediately adjacent. Each method has undesirable features.

It appeared that one solution to this problem would be to have equipment which would perform automatically the required co-ordination between the PAR and departure controllers. In order to investigate possible equipment for this purpose, the Air Navigation Development Board purchased from Gilfillan Bros , Inc., experimental range-tracking equipment using circuits developed for the automatic ground control approach system, an instrument landing system (ILS) developed for the Department of the Air Force by this company. The resulting equipment, the PAR-1 Traffic Control Monitor, was delivered to the TDEC for evaluation during February 1951.

EVALUATION OBJECTIVES

The purpose of this project was to perform the required technical and operational tests to evaluate the PAR-1 Traffic Control Monitor equipment when used with the PAR-1 radar. The evaluation objectives were:

1. To determine the accuracy and reliability of the range-tracking circuits, of the range-metering circuits, and of the no-take-off alarm circuits
2. To determine the accuracy and reliability of aircraft velocity indications and the desirability and reliability of the velocity memory circuits.
3 To determine the accuracy and reliability of minimum aircraft separation alarm circuits when two and three aircraft are being tracked over the distance range provided.
4. To study and to make technical changes, where required, for the purpose of improving acquisition and tracking of targets and of improving operation of alarm and velocity memory circuits.
5. From the traffic controller's viewpoint, to determine necessary changes in position or arrangement of controls and indicators and to study the desirability of tracking-gate presentation on the PAR-1 displays.
6. To conduct appropriate flight tests for the purpose of evaluating the equipment as a traffic control aid and to determine how the equipment may be used to best advantage at busy terminals when operating under present-day standard PAR traffic control procedures. To determine minimum aircraft separation and the number of aircraft that can be handled simultaneously.

EQUIPMENT DESCRIPTION

The PAR-1 Traffic Control Monitor was built by Gilfillan Bros., Inc., and modified by engineers of the TDEC. This equipment, as shown in Fig. 1, was designed to perform automatically the required co-ordination between the PAR and departure controllers. A no-take-off alarm consisting of a chime tone and a red signal light is actuated when an aircraft on approach passes a predetermined range which can be adjusted from one to five miles from point of touchdown. Meter indications are available to show the distance from touchdown of aircraft on approach and the ground speed of these aircraft. In addition, the PAR-1 Traffic Control Monitor was designed to monitor control instructions issued by the PAR controller by actuating a warning alarm if aircraft on approaches have less than minimum separation from other aircraft. This overtake alarm consists of a warning buzzer and an amber light.

The monitor permits simultaneous visual tracking of three aircraft during their respective approaches to the instrument runway. The radar target returns of aircraft entering the ten-mile range are bracketed on the PAR radar indicator by two vertical video lines, or index marks, which are generated locally by tracking gates in the monitor equipment. These index marks are adjusted simultaneously by a manual slewing control. Once the radar target is bracketed, the tracking gate is switched from the control marked "Slew" to that marked "Track." The index marks should then automatically follow the radar target during the approach to touchdown Each of the three tracking units of the monitor may be operated independently of the other two, and any three aircraft within the ten-mile approach may be tracked at a given time. These three units are mounted vertically, as shown in Fig. 1. A no-video alarm, consisting of a warning bell and white light, is actuated if radar signals fade and the gates cease tracking.

The monitor, as received from the manufacturer, included the operating controls on the front panel of each unit. Groups of controls were separated, and their operation would have required considerable visual attention on the part of the PAR controller. To simplify operation, parallel remote controls were installed at the left side of the PAR-1 desk beneath the three-mile PAR radar indicator This permitted the controller to operate the controls of the monitor with his left hand, his right hand being free for operation of the PAR controls and the microphone, s indicated in Fig. 2. Controls for each tracking unit of the monitor include the following:

1. An adjustable knob or slewing control for positioning the index marks of the tracking gate on the PAR radar indicator.

2. A switch to change tracking gates from slewing to tracking operation and to actuate a signal lamp which lights when the switch is in the tracking position.

3. A switch to turn off the no-video warning bell. An associated signal lamp which lights to indicate the no-video condition when the tracking gates are in the tracking position.

4. A button to reset the overtake alarm An associated lamp signal which lights when the overtake alarm circuit is actuated.

5. A switch to turn off the index-mark presentation on the PAR indicator.

6 A signal lamp which lights to indicate that there should be no take-off.

The material which follows is a résumé of information presented in the Gilfillan Bros., Inc., Handbook [1]

Each one of the three range-tracking units is identical to the others in circuitry and components and is composed of the basic circuits shown in the block diagram, Fig. 3.

BLOCK FUNCTIONS

Delay Multivibrator.

Trigger-in signals are received from the PAR equipment and amplified by the 12AT7 triode buffer stage V-1A The triggers are then applied to the 6J6 multivibrator stage V-2 The multivibrator gate output is differentiated by capacitor C-4 and resistor R-13 in the grid circuit of the 12AT7 blocking oscillator V-3 The positive pulse corresponding to the trailing edge of the gate triggers V-3. The positive portion of the pulses produced by oscillator V-3 appear alternately at the suppressor grids of the 6AS6 early-late gate detectors V-4 and V-5, causing them to be placed in a condition that they may conduct when standardized video is applied to their control grids.

Standardized Video.

Video from the PAR equipment is applied through the video gain control to the grid of V-12, the first tube of a two-tube, 6AK5 amplifier circuit. Amplified video above a level determined by potentiometer R-80 fires blocking oscillator V-14, a 12AT7 tube, which produces pulses of

[1]Gilfillan Bros., Inc., "Handbook of Instructions for Traffic Control Monitor for Precision Approach Radar PAR-1," Jan 25, 1951, pp 1-8, Section IV.

uniform height and width for tracking purposes. The blocking oscillator is also gated by intensity gates from the sweep limiter of the PAR equipment (blanking gate in), which allows only those radar echoes appearing on the indicator display to reach the tracking circuit of the traffic control monitor. The blanking level is controlled by potentiometer R-82. This gating is necessary to permit blanking of the normal heavy ground clutter occurring along the ground line of the elevation display Video pulses from the blocking oscillator V-14 are applied to the control grids of the 6AS6 early-late detectors, which are so biased that they will pass current only when video pulses and pulses from the early-late generator coincide. The signal passed by the early-late detectors at the time of coincidence of video signals and either the early or late gate is applied to the grids of a differential integration circuit consisting of two triode sections of a 12AT7 tube V-7.

Range and Speed Information.

Range-gated video signals which are applied to the 12AT7 differential integrator V-7 are used to vary the charge on capacitor C-11. Video coinciding with an early gate will be passed by one triode section of V-7, charging this capacitor C-11 Video coinciding with the late gate, however, will be passed by the other triode section and will discharge capacitor C-11. A voltage proportional to the speed of the aircraft appears across capacitor C-11 and will, therefore, appear at the cathode of the 6J6 cathode follower V-8. When the range-tracking unit is set to the tracking function, this voltage is applied to the input of the 6AU6 range integrator V-9 by means of relays in the slew-track circuit The signal applied to V-1B, a 12AT7 cathode follower, results in a variable voltage drop across the resistance network R-38, R-39, and R-62. A voltage changing with range is therefore applied to the range voltmeter, the no-take-off circuit, the multivibrator delay control circuit, and the minimum coast speed circuit.

Range Voltmeter.

The potential existing between the more positive end of the R-38, R-39, R-62 resistance network and ground is measured by the range voltmeter on a linear scale, with the maximum range of ten miles represented by a 50-volt potential

Speed Indicator.

The output measured by the range voltmeter is applied to a differentiating network consisting of capacitor C-14 and resistor R-52. The voltage at the output of the differentiator, representing speed, is applied to a control grid of V-11, a 12AX7. This speed voltage, appearing as a potential across the plates of V-11, is measured by the speed indicator on a scale of 0 to 50 microamperes, expressed as 0 to 250 miles per hour (mph) Test points, for external measurement and for remote indicators, are provided at both the range meter and the speed indicator.

Multivibrator Pulse Width Control Circuit.

The potential measured by the range voltmeter is also applied to the control grid of one section of the 6J6 delay multivibrator V-2. The gate width of the multivibrator output is controlled by range voltage divided through the R-10 and R-11 potentiometer combination

The variable pulse width of the output of multivibrator V-2, controlled as a direct function of range voltage, causes the tracking movement of the index marks on the indicator display of the PAR equipment. Aircraft approaching the radar installation cause video pulses to coincide with the early gates, charging capacitor C-11, causing the speed voltage at the cathode of V-8 to rise and the range voltage from V-9 to fall Decreasing range voltage decreases the gate width of the output of multivibrator V-2 and causes the index marks to move along the PAR display toward the point of indicated touchdown.

Index-Marks Control and Output.

The positive pulse of the 12AT7 early-late gate generator V-3 is applied to the grids of mixer stage V-6, a 12AT7. The pulse on one control grid, however, is delayed with respect to that on the other grid by the two-microsecond delay line. Output of the mixer V-6 consisting of two pulses separated by a two-microsecond time interval is taken from the cathode of V-6 through the index-marks gain control potentiometer R-60 and applied by coaxial line to the PAR equipment. A switch in the grid return circuit of the dual-triode mixer circuit turns the index-marks pulses on and off when desired. The symmetry of the pulses applied to the mixer stage is controlled by the potentiometer R-16 in the cathode of V-3.

Minimum Coast Speed Circuit.

A tap on the R-38 potentiometer determines the direct current (dc) voltage applied to one grid of the 5687 dual-triode regenerative amplifier V-10. A voltage-dividing network in the plate circuit of the first triode section of V-10 is so arranged that decreasing range voltage will cause the first triode section to cut off and the second triode section of V-10 to conduct when the tracked aircraft reaches a given range from touchdown The value of the potential applied to the control grid of the first triode section, and therefore the circuit controlling voltage, is varied by potentiometer R-38. Minimum coast speed voltage from potentiometer R-43 is applied to a control grid of the 6J6 cathode follower V-8. This causes an approximately equal voltage to appear at the cathodes of V-8 and maintains a minimum input value to the range integrator V-9. For a minimum tracking velocity corresponding to 50 knots, the cathode of V-8 is held at approximately five volts positive with respect to ground.

Velocity Memory Stiffening.

Conduction by the second triode section of V-10 causes normally closed relay K-1 to open, inserting resistor R-26 in series with capacitor C-11. This increases the time constant of the circuit driving the 6J6 cathode follower V-8 and stiffens the velocity memory of the circuit.

No-Take-Off Warning

Range voltage at the cathode of V-1B appearing across potentiometer R-39 is applied to a control grid of the 5687 dual triode V-23. Decreasing range voltage causes the first triode section of V-23 to cut off and the second triode section to conduct when the tracked aircraft reaches a given range from touchdown In conducting, the second triode section closes relay K-5, sounding the no-take-off chime and illuminating the white no-take-off panel lamp. The control grid voltage, corresponding to the range from touchdown at which the no-take-off warnings are actuated, is varied by potentiometer R-39.

No-Video Alarm.

Video coinciding with either early or late gates is applied to one triode section of amplifier stage V-20, a 12AT7 tube. The amplified video is then applied to blocking oscillator V-15, a 12AT7 The output of V 15 is rectified by one section of V 16, a 6AL5, and charges capacitor C-41 to a negative potential The negative potential of capacitor C-31 biases V-22, a 2D21 tube, to cutoff. Decay of this bias by the discharge of capacitor C-31 through resistor R-93 and R-88 (no-signal time delay) causes V-22 to conduct, closing relay K-6 which illuminates the red no-video panel lamp and sounds the alarm bell. Due to circuit constants, the potential of capacitor C-31 will discharge through resistor R-93 in five seconds. Thus, the absence of video signals for a five-second (adjustable) time period will actuate the no-video warnings.

Overtake Warning.

The late gate pulse from the two-microsecond delay is amplified by one triode section of V-17, a dual triode 12AT7 A negative-going gate is generated by V-17B and V-18A, beginning at the end of the late gate and enduring for a time equivalent to the desired minimum separation of aircraft on the glide path approach. The width of the gate generated by V-17B and V-18A is controlled by potentiometer R-105 (overtake range).

The gate generated by the V-17B and V-18A multivibrator is mixed with corresponding gates by V-18B, whose cathode is connected in parallel with cathodes of corresponding tubes in the other two range-tracking units by the protection bus. The protection bus, therefore, carries positive-going gates representing the safety zones behind all aircraft being tracked. A pulse corresponding to the early gate is compared with all protection gates by mixer V-19, a 6AS6 tube, which is so biased that it will conduct only when the range pulse (early gate) coincides with any portion of any protection gate existing on the protection bus. Such coincidence, therefore, occurs only in the unit tracking the overtaking aircraft. It cannot occur within a single unit, since a two-microsecond delay occurs between the range pulse and the initiation of the gate. Conduction by V-19 ionizes the 2D21 thyratron V-21, closing relay K-7. This relay, in closing, actuates the overtake warning buzzer and illuminates the amber overtake warning panel lamp.

Slewing Control

The slewing control R-64 affords manual adjustment of the gate-width control voltage applied to the delayed multivibrator V-2 When the range-tracking unit is set to the slewing function, a fixed dc drop appears across resistor R-64, and a variable portion is applied to the grid of the 12AT7 cathode follower V-1B. This potential, in turn, appears at the cathode of V-1B and is applied to the delayed multivibrator V-2.

Track-Slew Control

A Track Position

When in track position, the track-slew switch provides the following functions·

1. Connects the circuit of the range differentiator, or speed indicator, by the closing of relay K-3.

2 Connects the circuit of the range integrator V-9 and the cathode follower V-1B by closing certain contacts of relay K-2.

3 Illuminates the green track light by closing contacts on relay K-3 and turns off the blue slew panel lamp

4 Removes dc voltage from potentiometer R-64 from the grid of cathode follower V-1B.

5. Disconnects the grid of V-8A from ground

B Slew Position.

When in slew position, the track-slew switch provides the following functions.

1. Disconnects the circuit of the range differentiator, or speed indicator, by the opening of certain contacts of relay K-3.

2. Grounds the control grid of the range integrator V-9 and disconnects the grid circuit of the cathode follower V-1B by opening certain contacts of relay K-2.

3 Applies dc voltage from potentiometer R-64 to the grid of cathode follower V-1B by closing certain contacts of relay K-2.

4 Resets the no-signal alarm by removal of a plate potential from thyratron V-21.

5. Resets the overtake warning by removal of a plate potential from thyratron V-21.

6 Resets the overtake warning relay by removal of the actuating voltage.

7. Shuts off the green track panel lamp and illuminates the blue slew panel lamp by opening and closing of certain contacts of relay K-3

8. Connects the grid of V-8A to the ground.

TECHNICAL EVALUATION AND RESULTS

Target Simulators and Video Mixers.

In order to evaluate the equipment, two target simulators for the PAR-1 were designed and constructed to provide either two separately controlled targets or to provide ground clutter. The simulated targets may be controlled in velocity, size, range, azimuth, and elevation angles. A schematic diagram and a discussion of the theory of operation of the PAR-1 target simulators is given in Appendix I. A video mixer was designed and constructed so that the simulated targets could be mixed with the radar returns from the PAR-1. Appendix II contains a schematic diagram and discussion concerning the theory of operation of the video mixer

Revisions of the Original Circuitry.

At the beginning of the evaluation of the PAR-1 Traffic Control Monitor, it became apparent that the method provided for mixing the PAR-1 video information with the video of the index marks that come from the monitor was not satisfactory. With the direct mixing system provided, the index-marks video output of the tracking units appeared at the input of these units. As a result, they tended to track the index marks that they generated To rectify this situation, a second video mixer was constructed to provide for insertion of the index-marks video for presentation on the PAR-1 indicator at a point isolated from the video input of the monitor. This video mixer is identical with the one mentioned previously

The method provided for coupling the sweep-limiting blanking output of the PAR-1 sweep limiter chassis to the monitor was unsatisfactory.

Since the low input impedance of the monitor is in shunt with the high impedance source of blanking in the PAR-1 sweep limiter, this affected the sweep limiter operation. The resistance-capacitance method of mixing the sweep-limiting blanking with the PAR-1 video in the tracking unit was undesirable because of its discriminatory frequency characteristics An analysis of the video amplifier circuitry of the monitor revealed that several factors contributed to the narrow video bandwidth and insufficient video output from this circuit. The effect of the limited band-pass of the video amplifier was to cause discrimination against sharply defined targets and to eliminate them completely in many cases. The video standardizer circuitry was revised to correct the deficiencies in the original circuit. Fig. 4 is a schematic diagram of the original circuit, and Fig. 5 is a schematic diagram of the revised circuit.

Limiting in the circuit of V-12 was caused by low screen voltage The value of R-67 was changed from 47,000 ohms to 4,700 ohms. The resistor R-134 in the grid circuit of V-13 formed a low-pass filter in conjunction with the input capacity of V-13, which limited the video band-pass. This resistor was eliminated in the revisions. The high resistance load for the plate circuit of V-13, associated with stray and tube capacities, further decreased the already limited band-pass. Tube V-13 was changed to a 6AH6 to give the required increase in video output to drive V-14, and resistor R-78 was changed to 3,300 ohms to improve the bandwidth of the video amplifier. A blanking mixing stage was added to give the required isolation from the PAR-1 sweep limiter circuit and to give a method of mixing the video and blanking signals that was not frequency selective within the desired band-pass.

The output sweep-limiting blanking signal of the PAR-1 sweep limiter is fed to a high-resistance voltage divider in the grid circuit of the blanking mixer The signal in the plate circuit of the first half of 12AU7 is the same amplitude as in the grid circuit, but of opposite phase. A crystal diode in the grid circuit of the second half of the 12AU7 blanking mixer restores the dc component of the waveform The plate of the second half of the blanking mixer has a common connection to the plate of V-13 and to the grid of V-14A to preserve the dc component of the blanking and video signals at the grid of V-14A. The signal level that will cause conduction in V-14A can be varied with the potentiometer in the cathode circuit of V-14A.

Comparative tests were made of the original and revised circuits. The revised circuit corrected the undesirable features of the original circuitry.[2] The limited bandwidth of the video amplifier was due mainly to the use of incorrect resistor sizes. In addition, some of the coaxial cables provided with the monitor were of the incorrect impedance.

When tests were started to evaluate the effect of ground clutter on the operation of the tracking circuits of the monitor, erratic operation of these circuits prevented the taking of data that could be repeated with any degree of accuracy. With the no-video alarm circuit disabled and the slew-track switch in track position, the tracking gate drifted at high speed in either direction. The tracking circuits would not acquire a target when this high velocity drift occurred. An investigation of the cause of instability in the tracking circuits revealed that the trouble was in the time-discriminator circuit, shown in Fig. 6. The circuit is arranged so that the two triode sections are in series across the +150 and -150 volt dc power supply voltages. The cathode of V-7A has a common connection to the plate of V-7B and to the grid of V-8A. The integrating capacitor C-11 is charged to the peak value of the error voltage by current flow through either half of V-7. The resistance to the ground at the junction of the cathode of V-7A, the plate of V-7B, and the grid of V-8A would be infinite if it were not for tube and circuit leakage. Tube leakage causes a charge to be built up across C-11. This may either add to or subtract from the error voltage across C-11 and cause a fixed drift component to appear across it The amount of leakage of V-7A and the polarity varies with individual tubes, aging, and tube temperature. This leakage made the operation of the tracking unit unreliable.

In 12AU7 tubes, two types of leakage exist. Current flow from the cathode to the filament caused C-11 to charge in a positive direction. A circuit modification, using a separate filament transformer for V-7 with the center tap returned to a variable negative voltage, neutralized the effect of this type of leakage. The other type of leakage may be due to small quantities of gas liberated in the tube, causing C-11 to be charged negatively. The quantity of gas increases with tube aging This type of leakage cannot be controlled with a minor circuit modification Various types of tubes were tried in place of the 12AU7. Of the types tried, the Type 6AU6 was the only one that would not upset the operation of the circuit because of individual tube characteristics and aging. The

[2]Gilfillan Bros , Inc., were advised of these revisions. They had developed the circuitry for the blanking and index-marks mixing for a model of the GCA radar other than the PAR-1.

revised schematic diagram of the time-discriminator circuits is shown in Fig. 7. The grid bias resistor networks were changed to compensate for the smaller grid cutoff voltage of the 6AU6 tubes.

It was found that the overtake alarm would not operate with the minimum separation control adjusted for three miles. In addition, the overtake alarm was frequently triggered by switching transient signals. In order to make the alarm action independent of range and less subject to triggering by switching transients, certain modifications of the circuit were required. The original circuit is shown in Fig. 8, and the revised schematic diagram is shown in Fig. 9. A crystal diode type of dc restorer was added to the suppressor grid circuit of V-19 to prevent changes of duty cycle of the gating waveform from changing the output signal at the plate of V-19. The sensitivity of V-19 was lowered by adding a 10,000-ohm resistor in parallel with R-119 and a 470-ohm resistor in series with the cathode of V-19. A capacitor was added to the control grid circuit of the range delay multivibrator V-2A to integrate switching transients that caused instability in the range gating signal.

TESTS AND CIRCUIT ANALYSIS

The action of the tracking circuits is such that a target positioned on the early gate will produce a larger error voltage than one positioned on the late gate. If the tracking gates are centered on a slow-moving target, an overtaking target will take over control of the tracking gate when it passes the slower target. When a target that is being tracked passes through heavy ground clutter, the gate will jump ahead slightly upon encountering this clutter and will stop for an instant until the target slides up far enough on the early gate to overcome the error signal from such clutter. The larger error voltage derived from the early gate is an aid in tracking through clutter. When tracking targets through noise such as signals returned from precipitation the larger error voltage from the early gate is detrimental, since there is a tendency for the tracking gate to pull ahead of the target. When a target that is being tracked passes through heavy ground clutter, the error signal varies widely. This causes the velocity meter to fluctuate between such wide limits that a close approximation of the target speed cannot be obtained It may be desirable if the velocity meter were more heavily damped to average out these fluctuations.

The value of the no-video alarm circuit is questionable. If video signals are lost in ground clutter, the alarm will not operate because the clutter will provide an equal video signal required to hold the alarm circuit beyond cutoff. The no-video alarm can be set for a five-second delay in warning if the target is lost in the absence of other signals. When switching from slew to track, the no-video alarm will operate in one second if the target is not acquired in that time. In the technical evaluation tests the no-video alarm circuit was made inoperative so that the tracking gate could be brought to rest at the desired range with the unit in the track position. Under these conditions, the signal from a target running into the gate will take control of it so that acquisition of a target is simpler. A circuit designed to give warning when the velocity of the tracking gate falls below a specified value might prove to be of more operational value than the present no-video alarm circuit

Tests were conducted to determine the minimum signal-to-noise ratio which would allow reliable operation of the monitor Simulated signals were used for this measurement and were mixed with the noise in an additive mixer. Since the signal from the radar would have different characteristics because the noise and signal are subjected to a modulation process in the radar receiver detector, a slight error may have been included in this measurement.

The signal-to-noise ratio was measured as the ratio of peak signal power to average noise power To measure the average noise power, the PAR-1 antenna scanning mechanism was stopped in the elevation position. The receiver gain was turned to maximum, and the transmitter and target simulator were turned off so that no video signals were present at the input of the tracking unit. A dc restorer circuit was capacity-coupled to the input of the tracking unit, and a dc vacuum tube voltmeter was used to measure the average value of the noise across the dc restorer. This restorer insured that the noise level would rise in a positive direction from the reference level of zero volts. PAR-1 antenna scanning and the simulator were then turned on, the output of the simulator was adjusted for the minimum signal for reliable tracking, and the peak-to-peak value of the signal was measured in the absence of noise. The minimum signal-to-noise ratio which would allow reliable operation of the monitor while tracking a target having a velocity of 120 mph was 3 decibels (db).

Tests were conducted to determine the ability of the monitor to track simulated targets through ground clutter. The simulated target velocity was kept at 120 mph The PAR-1 azimuth antenna was tilted as far down as possible to get maximum ground clutter, and the signal-to-noise ratio of the video information to the tracking unit was adjusted to 16.7 db The monitor tracked simulated targets under the above conditions at ranges of ten to one-half miles. At one and one-half miles the ground clutter on the PAR-1 ten-mile indicator completely covers the azimuth sector of the sweep and 33 per cent of the elevation sector Fig. 10 is a view of the

PAR-1 three-mile indicator showing ground clutter conditions that existed during the performance of the above tests. Fig. 11 shows the PAR-1 ten-mile indicator under the same conditions, and Fig. 12 shows the PAR-1 ten-mile indicator with a simulated signal-to-noise ratio of 3 db

After modification, the PAR-1 Traffic Control Monitor was operated for a period of 112 hours without readjustment. This was done to determine the stability of its circuits. Periodic checks were made on two of the tracking units. There was no measurable change in the accuracy of the overtake alarm circuits, and the accuracy of the range meter calibrations remained within ten per cent. The minimum coast speed remained within ten per cent of the original velocity of 50 mph, and the range accuracy of the no-take-off alarms remained within the limits of accuracy of the range meters The accuracy of the speed indications on both tracking chassis was within three per cent immediately after alignment. Checks were made with velocities of 50, 100, 150, 200, and 250 mph. The electrical zero adjustments of the velocity meter drifted considerably after several hours of operation. After 112 hours, the velocity meter indications with the tracking gates at rest were 20 and 16 mph The maximum velocity error of the two units during this period was 49 and 11 per cent for low velocity targets. The maximum error for high velocity targets was 15.4 and 20.2 per cent. The larger percentage error at low velocities on the first unit occurred because the error of zero setting added to the target velocity. From the tests conducted, it is apparent that the instability and insufficient damping of the speed meter circuitry limits its operational value.

OPERATIONAL EVALUATION AND RESULTS

Description of Eight PAR-1 Approaches

A series of flight tests was made to determine the operational value of the PAR-1 Traffic Control Monitor. During the flight tests, sequential photographs were made of the faces of the PAR-1 indicator tubes. The tests were conducted using two of the three tracking unit chassis. The video standardizer and overtake alarm circuits of one chassis were modified. The other had all of the modifications previously described. The one with the modifications made to the tracking circuitry gave more stable operation The range circuits of both units were realigned for nautical miles to conform with PAR-1 indicator calibration

The results from eight PAR-1 approaches are presented in Table I. Typical photographic views of the PAR-1 ten-mile and three-mile indicators representing unusual and average conditions are shown in Figs. 13 to 20. Only a few of the photographs taken are included in this report.

TABLE I

RESULTS FROM EIGHT APPROACHES

APPROACH NO. 1

Exposure No.	Fig. No.	Aircraft Type	Range (miles)	Remarks
1	13a	Navion	6 1/2	Weak signals, tracking properly
2	none	Navion	5 1/2	Tracking properly
3	13b	Navion	4 1/4	Tracking properly
4	none	Navion	3 3/4	Tracking properly
5	none	Navion	3	Weak elevation signals, tracking properly
6	13c	Navion	2 1/2	Weak elevation signals, tracking properly
7	none	Navion	1 3/4	Tracking properly through ground clutter on azimuth display
8	13d	Navion	3/4	Tracking properly through ground clutter on azimuth display

APPROACH NO. 2

Exposure No.	Fig. No.	Aircraft Type	Range (miles)	Remarks
1	14a	Beechcraft twin-engined	7	Tracking properly, no elevation signals
2	none	Beechcraft twin-engined	5 1/2	Tracking properly, weak elevation signals
3	14b	Beechcraft twin-engined	5	Tracking properly, weak elevation signals, ground clutter on azimuth display
4	none	Beechcraft twin-engined	4 1/4	Tracking properly, weak elevation and azimuth signals
5	14c	Beechcraft twin-engined	3	Tracking properly, weak elevation signals
6	none	Beechcraft twin-engined	1 1/2	Tracking properly, no elevation signals, ground clutter on azimuth display
7	14d	Beechcraft twin-engined	1 1/4	Not tracking, no elevation signals, ground clutter on azimuth display

TABLE I (CONTINUED)

RESULTS FROM EIGHT APPROACHES

APPROACH NO. 3

Exposure No.	Fig. No	Aircraft Type	Range (miles)	Remarks
1	15a	DC-3	6 1/2	Tracking properly
2	none	DC-3	5	Tracking properly
3	15b	DC-3	4	Tracking properly
4	none	DC-3	2 1/2	Tracking properly
5	15c	DC-3	2	Tracking properly
6	none	DC-3	1 1/2	Tracking properly
7	15d	DC-3	1	Tracking properly

APPROACH NO. 4

Exposure No.	Fig. No	Aircraft Type	Range (miles)	Remarks
1	16a	Beechcraft twin-engined	7 1/2	Tracking properly
2	none	Beechcraft twin-engined	5 1/2	Tracking properly
3	16b	DC-3	4 1/2	Tracking properly
		Beechcraft	2	Tracking properly, no elevation signals
4	none	DC-3	4	Tracking properly
		Beechcraft	1 1/2	Not tracking
5	16c	DC-3	3 3/4	Tracking properly
		Beechcraft	1	Not tracking, no elevation signals, weak azimuth signals
6	none	DC-3	2 3/4	Tracking properly
7	none	DC-3	1 3/4	Tracking properly
8	none	DC-3	1 1/3	Tracking properly
9	16d	DC-3	1	Tracking unstable

TABLE I (CONTINUED)

RESULTS FROM EIGHT APPROACHES

APPROACH NO. 5

Exposure No	Fig. No.	Aircraft Type	Range (miles)	Remarks
1	none	DC-3	8	Tracking properly with transponder
2	none	DC-3	5 1/2	Tracking properly with transponder
3	17a	Beechcraft	7	Tracking properly
		DC-3	3 1/2	Tracking properly with transponder
4	none	Beechcraft	6	Tracking properly
		DC-3	2 1/2	Tracking properly with transponder
5	17b	Beechcraft	5	Tracking properly
		DC-3	1 1/2	Tracking properly with transponder, no elevation signals, tracking transponder relay
6	17c	Beechcraft	4 1/2	Tracking properly
		DC-3	1 1/4	Not tracking because transponder reply stopped when aircraft turned off course
7	none	Beechcraft	3	Tracking properly
8	17d	Beechcraft	2	Tracking properly

APPROACH NO. 6

Exposure No	Fig. No.	Aircraft Type	Range (miles)	Remarks
1	none	DC-3	7 1/2	Tracking properly with transponder
2	18a	Beechcraft	7 1/2	Tracking properly
		DC-3	5 1/2	Tracking properly with transponder
3	18b	Beechcraft	6 1/2	Second transponder reply from DC-3 has merged with reply from Beechcraft, tracking properly
		DC-3	4	Tracking properly with transponder
4	18c	Beechcraft	4	Tracking properly, Beechcraft passed second transponder reply and pulled the tracking gate with it
		DC-3	3	Tracking properly with transponder
5	18d	Beechcraft	2 1/2	Not tracking, weak elevation signals
		DC-3	2	Tracking properly on transponder reply

TABLE I (CONTINUED)

RESULTS FROM EIGHT APPROACHES

APPROACH NO. 7

Exposure No.	Fig. No.	Aircraft Type	Range (miles)	Remarks
1	19a	DC-3	7	Tracking properly with transponder
2	19b	Beechcraft	6 1/2	Tracking properly
		DC-3	4 1/2	Tracking properly with two replies from transponder
3	19c	Beechcraft	4 1/2	Not tracking, ground clutter on azimuth display
		DC-3	3	Tracking properly with transponder replies
4	19D	Beechcraft	3 1/2	Tracking properly after resetting tracking gates
		DC-3	2	Tracking properly with transponder

APPROACH NO. 8

Exposure No.	Fig. No.	Aircraft Type	Range (miles)	Remarks
1	20a	Beechcraft	6	Tracking properly
2	20b	Beechcraft	4 1/2	Tracking properly
3	none	Beechcraft	3	Tracking properly
4	20c	Beechcraft	2	Tracking properly
5	20d	Beechcraft	1 1/2	Tracking properly, no elevation signals

Data and photographs obtained during the approaches show that the equipment tracks weak signals properly in the absence of ground clutter signals. Under severe ground clutter conditions, strong signals from both the elevation and azimuth antennas are required for satisfactory operation. Strength of video signals fed to the tracking unit depends upon a number of factors including the PAR-1 intermediate-frequency amplifier gain adjustment and upon the accuracy of antenna servoing.

In most cases, tracking of the different types of aircraft was satisfactory until the aircraft were from two to one miles from the PAR-1 or approximately one and one-half to one-half miles from touchdown. Generally, when the tracking unit lost the target at the small ranges, ground clutter signals were present and signals from the elevation antenna were weak because of improper PAR-1 sensitivity control adjustment or because of incorrect servoing of the elevation antenna. At these ranges, accurate servoing of the elevation antenna requires frequent use of the antenna servoing switch. The horizontal angle of the aircraft with respect to the antenna center line changes rapidly at small ranges because the PAR-1 is located on one side of the runway. When more than one aircraft is being tracked it is impossible to servo accurately on all aircraft, particularly if one is near the touchdown point. Ground clutter effects will be more serious at airports having more obstacles on the ground under the approach path.

During the first four approaches, the PAR-1 sensitivity time-control circuit adjustment was incorrect and signals from targets at small ranges were attenuated excessively. The sensitivity time-control circuits were adjusted to provide less attenuation after the fourth approach was made. The Rho/Theta Transponder replies appear slightly to the right of the aircraft on the displays, because correction for transponder delay had not been made at the time of these flights. If transponder delay is corrected, the aircraft target and transponder replies would coincide. The angular size of the transponder reply on the indicators is no larger than the normal target. Addition of the transponder reply almost doubles the length of the target in range, since the pulse length of the transponder pulse is approximately 1.0 microsecond. The PAR-1 pulse width is approximately 0.5 microsecond.

Results of 150 Simulated and Actual Approaches

A total of 150 simulated and actual approaches were conducted during the operational evaluation. Of this total, 96 actual aircraft approaches were made, the balance being radar targets from an electronic aircraft-simulator device.

The first approaches were conducted to check the reliability of the tracking units. A Navion airplane was used for these tests. It was necessary to operate the PAR antenna servo control frequently to obtain the strongest possible target with a minimum of ground clutter because of the tendency of the tracking gates to be captured by ground target returns. PAR controllers reported an increase in work load as a result of the constant critical adjustments required in antenna servo controls.

The no-video alarm was actuated five times during the first seven approaches. On each occasion that the alarm was actuated, the aircraft radar return was visible on the PAR indicator and was considered a usable target for conducting approaches, however, the radar return was apparently not strong enough to keep the tracking gates in operation. During 54 of the actual aircraft approaches, the no-video alarm was actuated 29 times not including no-video alarms actuated when the tracking gates failed to capture initially and to track a new target. The no-take-off alarm was actuated each time the tracking gates followed the aircraft target to the present no-take-off point two miles from touchdown.

Eleven approaches were made to check the accuracy of the range and velocity meters The actual ground speed of the aircraft was determined by stop-watch timing of the aircraft target on the PAR indicator from the eight-mile range line to the six-mile one and again from the four-mile range line to the two-mile. Range meter accuracy was determined by comparing the meter reading with a direct reading of the radar range of the target on the PAR indicator.

A Douglas DC-3 and a twin-engined Beechcraft were used in performing the range and velocity meter checks. The aircraft range indications were very reliable; however, the velocity meter varied almost continuously over a range of 10 knots less than the actual ground speed to 30 knots greater than the actual ground speed. The velocity meter indications were not considered accurate enough for traffic control purposes.

Several approaches were conducted to check the reliability of the overtake alarm. The alarm circuit was adjusted to operate when aircraft being tracked were separated by a distance of two miles or less. The pilots of both aircraft were instructed to make the turn into final approach at varying distances from touchdown. As soon as the gates of the monitor were tracking the aircraft radar returns, the pilots were requested to vary air speed to allow the following aircraft to catch up with the preceding one. The overtake alarm was actuated each time that the one following was two miles or less behind the one leading.

During the multiple approaches, the tracking gates lost the aircraft radar returns several times This actuated a no-video alarm and was believed to result from servoing the PAR antennas to one aircraft to obtain a better radar target Such servoing results in reduction in radar return from the other aircraft. This was particularly noticeable when the azimuth antenna was servoed to obtain the best return from the first aircraft on the glide path with the second one still below and approaching the glide path. Similar difficulties were experienced when the glide-path antenna was servoed to the first aircraft for best returns and when the second was not yet lined up on the localizer course. As pointed out previously, it was essential to obtain maximum aircraft returns and minimum ground returns by proper servoing in order to prevent the tracking units from being captured by ground returns. Ground returns were greatest between the touchdown point and the four-mile range, and it was therefore necessary to favor the first aircraft on approach when servoing antennas.

A number of ILS approaches were monitored during rain conditions, causing varying degrees of precipitation clutter on the precision radar scopes The tracking gates normally would not track targets if any degree of precipitation clutter was apparent, even though the target could be followed visually by the PAR controller.

The Douglas DC-3 airplane was equipped with a transponder for some of the tests. During these test runs, the PAR receiver intermediate-frequency gain was lowered until normal video and ground returns were not visible on the PAR indicator. The tracking gates then functioned very satisfactorily. All of the alarms and warnings were actuated at the proper times, and the velocity meter gave a very steady indication. The amount of controller work load was reduced considerably when the transponder target was used. Some test runs were made with one aircraft equipped with a transponder in combination with an aircraft not so equipped. The tracking gates followed the transponder targets very well, but considerable difficulty was again experienced in tracking the other.

During all of the flight tests it was necessary that the controller constantly watch the progress of the tracking gates on the PAR indicator to see if they were still following the radar returns. Frequently the tracking gates would be captured by ground returns for periods of 5 to 15 seconds before the no-video alarm was actuated. As a result, the PAR controller could not depend upon the alarm circuits for proper warnings but was forced to check the monitor constantly to insure that index marks were following targets properly.

Though only two of the three available tracking units had been modified for these tests, it was difficult for the controller to determine rapidly which index marks on the PAR indicator were associated with alarm signals and to determine where corrective action was necessary after an alarm was actuated. When using all three units, the controllers found it quite difficult to remember which tracking unit was following a specific target

When the equipment operated properly and continuously tracked aircraft on approach, the co-ordination information supplied to the departure controller was very adequate

The operating controls placed at the left side of the PAR desk appeared to be in a satisfactory operating location.

The index marks on the PAR indicator obscured other video information considerably. This was particularly true of the range marks The index marks also tended to obscure the aircraft radar return, increasing the visual work load of the PAR controller However, no other practical method of using the tracking gates was determined, since the quickest and most reliable way to check proper operation was to see if the index marks were bracketing the target

CONCLUSIONS

Based on tests using artificial and actual targets, the conclusions regarding the operation and circuitry of the PAR-1 Traffic Control Monitor are as follows.

1. The accuracy and stability of range meter indications, overtake alarm circuit calibration, minimum coast speed, and no-take-off alarm calibration were considered to be adequate.

2. The velocity meter indications were not considered sufficiently accurate for traffic control purposes, because the meters varied almost continuously over a range of 10 knots less than the actual ground speed to 30 knots greater than the actual ground speed. Inaccuracies in the velocity meter indications were due to drift in electrical zero adjustments and inadequate damping in the meter circuits

3. Improvement of the no-video alarm circuit is required to provide operators with a more reliable alarm when the operation of the monitor is unsatisfactory

4 The equipment performed satisfactorily when transponder-equipped aircraft were used, since the normal video returns could be turned down to a point where the tracking gates would not be captured by ground clutter or other returns.

5 Under heavy precipitation conditions, the equipment did not track targets when an observer was able to follow the target visually on the PAR-1 indicators.

6. The tracking-gate, index-mark presentation on the radar indicators obscured other video information.

7 The location of the operating controls at the left side of the PAR-1 desk was satisfactory.

8 The PAR controller work load, including visual observations and manual operations, was increased considerably. With three aircraft on the approach, use of the equipment caused confusion if any malfunction occurred or when an alarm sounded Minimum separations of two miles were used in these tests for the overtake alarm circuits. Further tests for reduction in minimum separation standards would be required if reliable equipment can be developed.

9. When using the monitor equipment, failure of a tracking gate to follow the aircraft on approach requires the PAR controller to resort to other methods to advise the departure controller of the progress of the inbound aircraft. The extra work load imposed upon the PAR controller in checking and observing the index marks to insure that the tracking gates are operating properly and the additional work load required for operating the monitor controls and PAR antenna servo controls are not commensurate with the usefulness of the monitor.

10. Monitor equipment for separation of aircraft on approach is not essential to the PAR controller, because he is constantly observing the progress of the aircraft by direct reading of the PAR indicators. The overtake alarm, which indicates a minimum separation between aircraft, is not considered essential with proper spacing of aircraft on approach from the holding point.

11. Simpler equipment such as an automatic video-gated alarm to advise the departure controller when an aircraft making an approach has passed the outer marker of the ILS and has passed a predetermined no-take-off point would appear to be sufficient for co-ordination between the PAR and departure control positions The information that an aircraft is on the approach and has passed the outer marker is an indication to the departure controller that he must have the landing runway cleared by the time the approaching aircraft has reached the no-take-off point This point usually is between two and three miles from touchdown. Thus, the departing aircraft must have started taking-off before the arriving aircraft has reached the no-take-off point.

RECOMMENDATIONS

The PAR-1 Traffic Control Monitor in its present form is not required for present or proposed future traffic control procedures. An automatic video-gated alarm appears to be a solution to the present problem of co-ordination between positions of operation. However, if future procedures should require an automatic range-tracking device, the following modifications of the present equipment are recommended·

1 Additional blanking should be provided to the tracking input circuits to remove all video signals except those from sectors of space sufficiently large to include aircraft making normal approaches. Such blanking would reduce the effect of ground clutter signals

2 Modifications are required that would be equal to or better than those made for the purpose of improving the method of index-mark insertion and the method of coupling PAR-1 sweep-limiting blanking signals to the tracking units Bandwidth of the video amplifiers, time-discriminator circuit stability, and overtake alarm circuit operation should be improved.

3 Stability should be improved and damping of the velocity meter circuit should be increased

4 A more reliable no-video alarm circuit should be provided.

APPENDIX I

DESCRIPTION OF THE PAR-1 TARGET SIMULATORS

Referring to Fig 21, the elevation and azimuth antenna angle voltage outputs of the PAR-1 are fed to the grids of the isolation tubes V-8A and V-14A of the target simulators The signals appearing at the cathodes of V-8A and V-14A are applied to the angle voltage clipper tubes V-9 and V-15. The outputs of V-9 and V-15 are applied to the grids of the differential amplifier V-10 and V-11. The circuits of the differential amplifiers are arranged so that angle gating signals will appear in their output plate circuits when both halves of the clipper diodes are in nonconducting states The amplitudes of the angle voltages that will produce output signals from V-10 and V-11 can be varied with the potentiometers labeled Azimuth Angle and Elevation Angle. Variation of these controls results in an angular displacement of the gating signals with respect to the PAR-1 sweep.

The increment of amplitudes of the angle voltages producing output signals can be varied with the controls labeled Azimuth Gate Width and Elevation Gate Width Variation of these controls results in Variation of angular width of the gating signals in respect to the PAR-1 sweep

The gating signals from the outputs of V-10 and V-11 are shaped into rectangular gating pulses by the gate-shaping amplifiers V-12, V-13A, V-16, and V-17A. The gating signal outputs of V-13A and V-16A are applied to the grids of the gate mixer V-4. The output gating signals from V-4 are applied to the video gating stage V-3

The PAR-1 trigger output signals are applied to the grid of the isolation stage V-5B, the output of which operates the delay phantastron with tubes V-7 and V-6A The delayed output of V-7 is controlled by the sawtooth voltage applied to V-6A. This voltage imparts a linear change of range or constant velocity to the delayed trigger output of V-7 The slowly changing sawtooth voltage is generated by the sawtooth generator with tubes V-5A and V-13B. V-5A is a cathode follower type of sawtooth generator V-13B is connected in a manner to provide bootstrap action to improve the linearity of the sawtooth wave form which is applied to the dc amplifier with tubes V-18A and V-17B The target can be placed at maximum range by turning the switch marked Discharge - Moving Target to the Discharge position. When the switch is in the moving target position, the target will advance toward minimum range at a velocity determined by the setting of the velocity potentiometer. The target may be manually positioned at a fixed range by placing the switch labeled Manual - Automatic in the manual position and positioning the target with the range potentiometer.

The delayed trigger output signals from V-7 are fed to an external pulse generator. The length in range of the target can be changed by varying the pulse width output of the external pulse generator.

The output of the external pulse generator is applied to the video gating amplifier V-3. The output of V-3 consists of delayed PAR-1 trigger pulses that are gated "on" during increments of the elevation and azimuth sweeps These signals are mixed with those from another simulator in the mixer stage V-2 The output signals from V-2 are applied to the grid of the cathode follower V-1 The cathode of V-1 supplies output signals to be mixed with other information which is to be supplied to the PAR-1 Traffic Control Monitor and the PAR-1 indicator

APPENDIX II

DESCRIPTION OF THE PAR-1 VIDEO MIXER

Referring to Fig. 22, the video outputs of the PAR-1 and target simulators are fed to the grids of the mixer tube V-1, the output of which is fed to the grid of the video amplifier V-2. The output signals from the plate of V-2 are applied to the grid of the cathode follower output of V-3 A dc restorer Y-1 is connected across the grid leak resistor of V-3 to insure that the video signals rise in a positive direction from the reference bias set by the bias rectifier Y-2, regardless of the duty cycle of the video information. The maximum over-all voltage gain of the video mixer is approximately two, and the video band-pass is approximately five megacycles

The tubes associated with the 300-volt regulated power supply are the rectifier tube V-4 regulator tube V-5, reference tube V-6, sampling tube V-7, and the series tube V-8

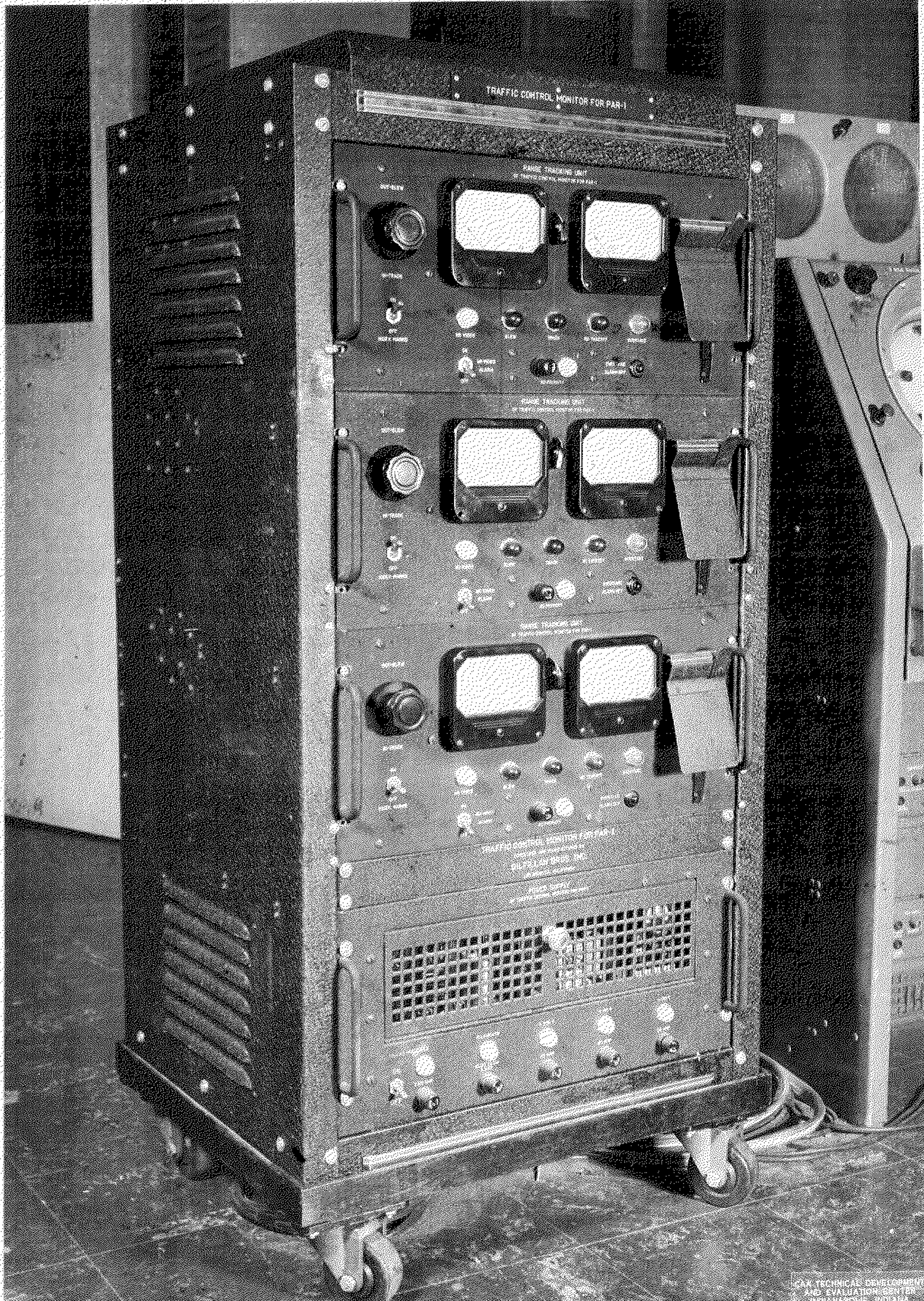

FIG 1 PAR-1 TRAFFIC CONTROL MONITOR

FIG. 2 ARRANGEMENT OF REMOTE CONTROLS FOR PAR-I TRAFFIC CONTROL MONITOR

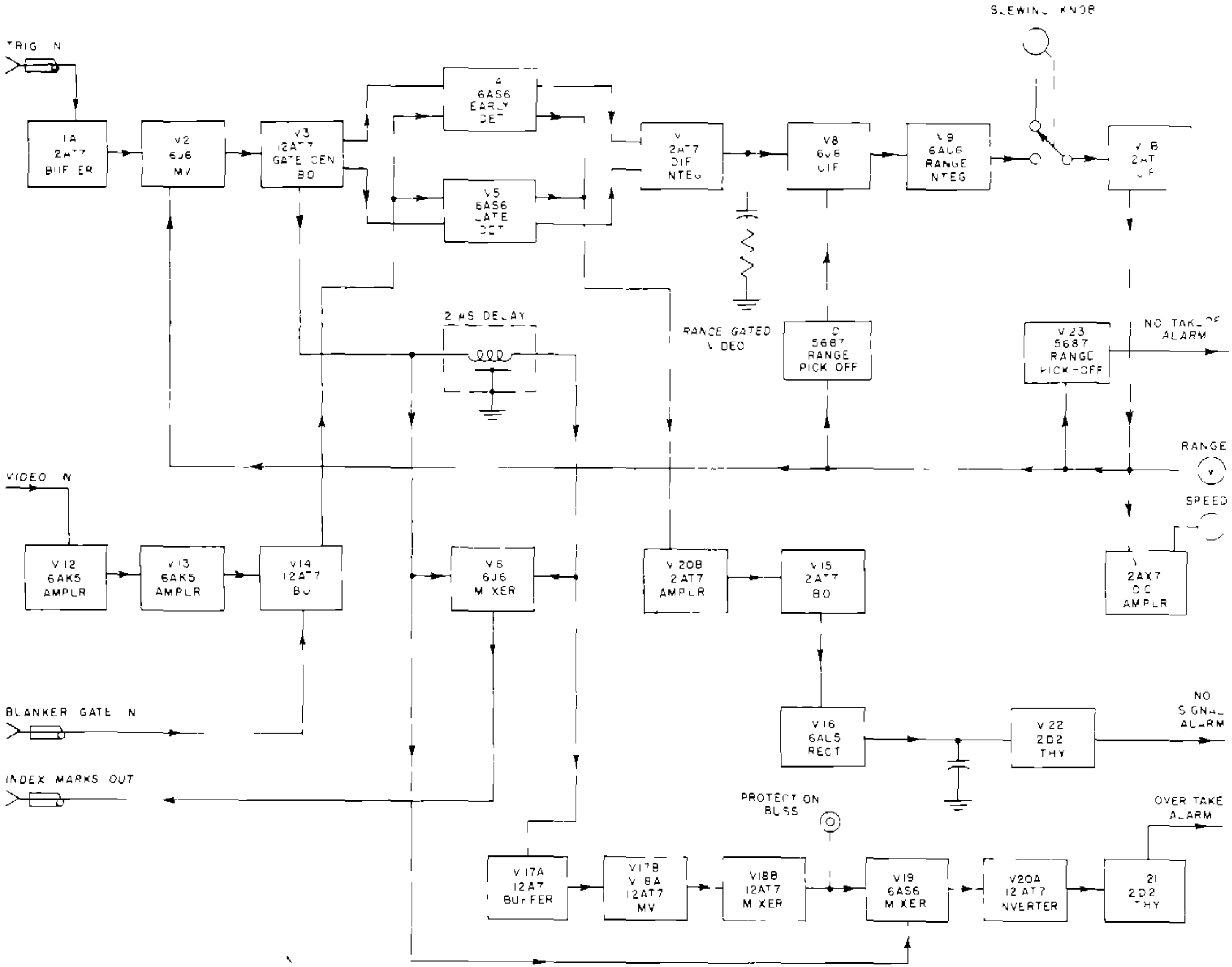

FIG 3 BLOCK DIAGRAM OF RANGE UNIT ONE CHANNEL OF TRAFFIC CONTROL MONITOR EQUIPMENT FOR PAR

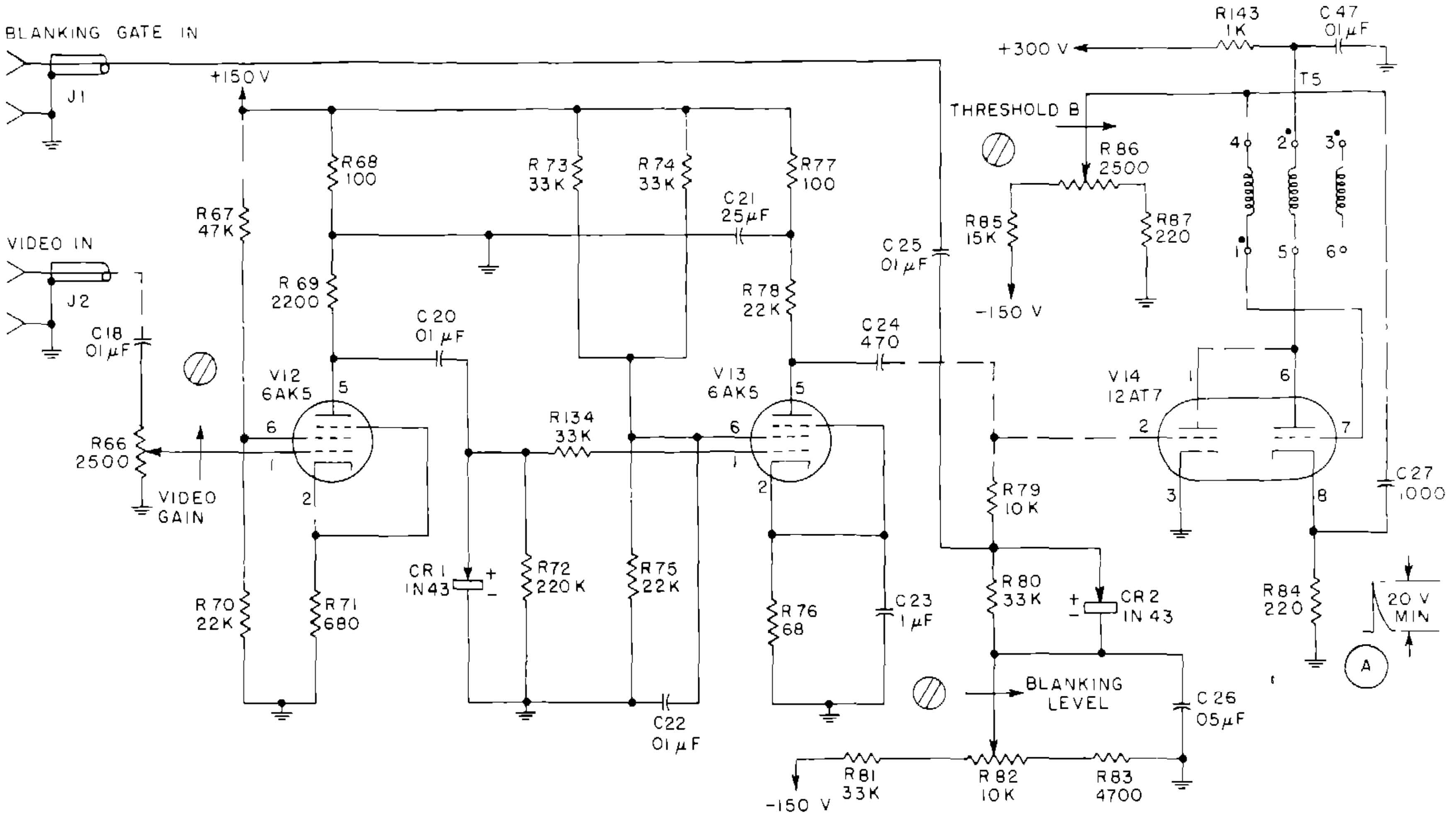

FIG 4 VIDEO STANDARDIZER OF MONITOR TRACKING UNIT FOR PAR-1

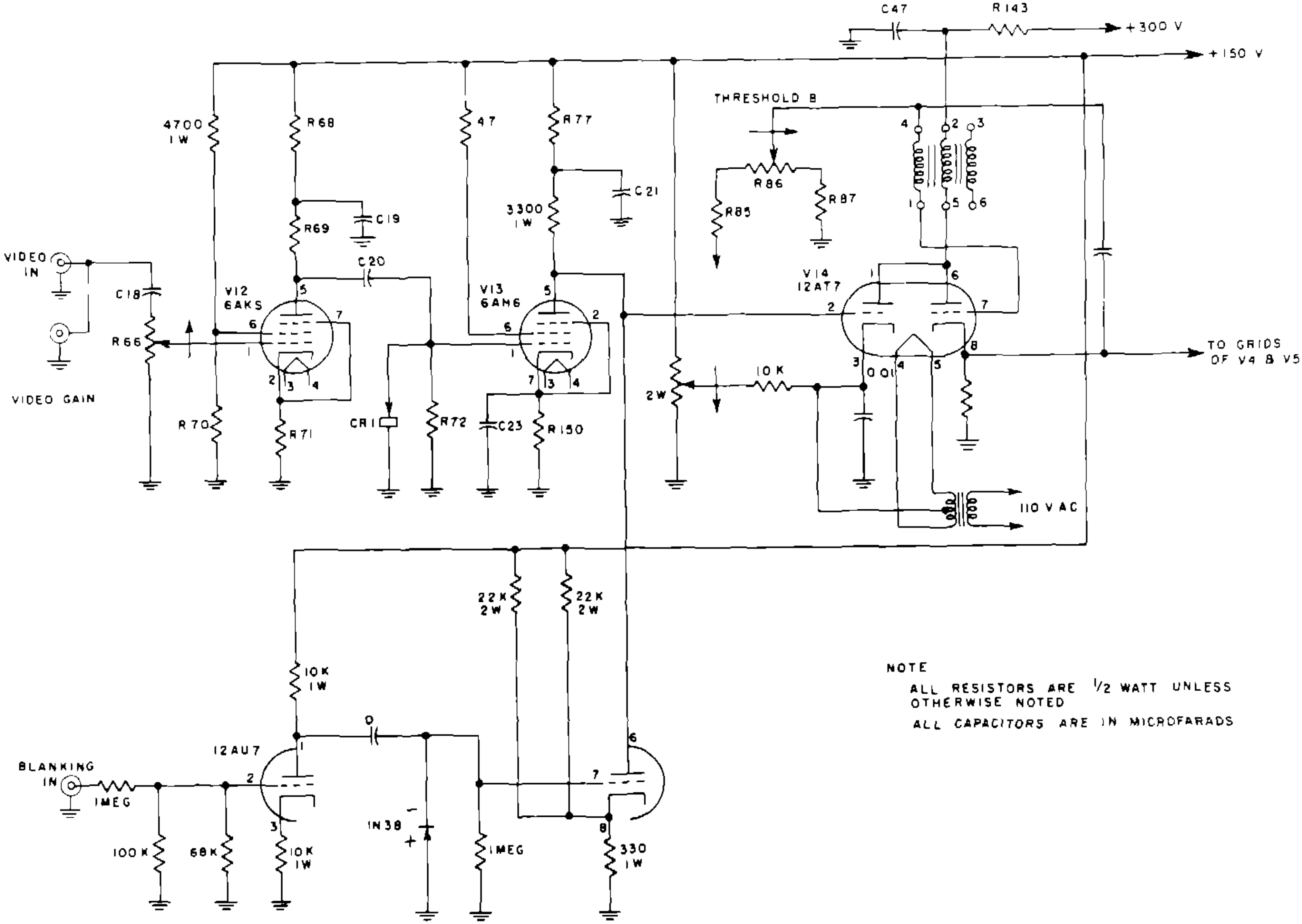

FIG 5 REVISED CIRCUIT DIAGRAM OF VIDEO STANDARDIZER

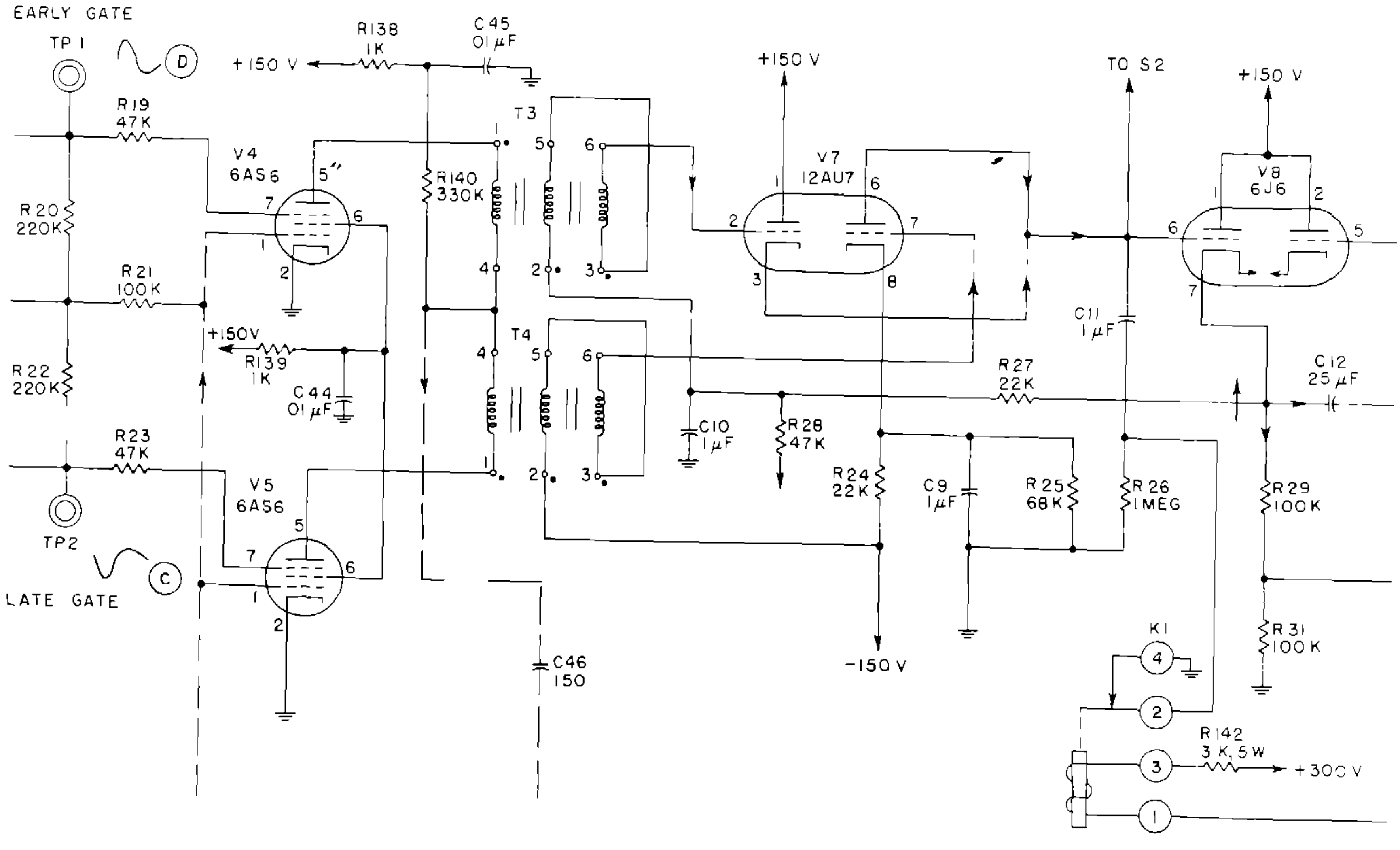

FIG 6 ORIGINAL TRAFFIC MONITOR TIME DISCRIMINATOR CIRCUIT

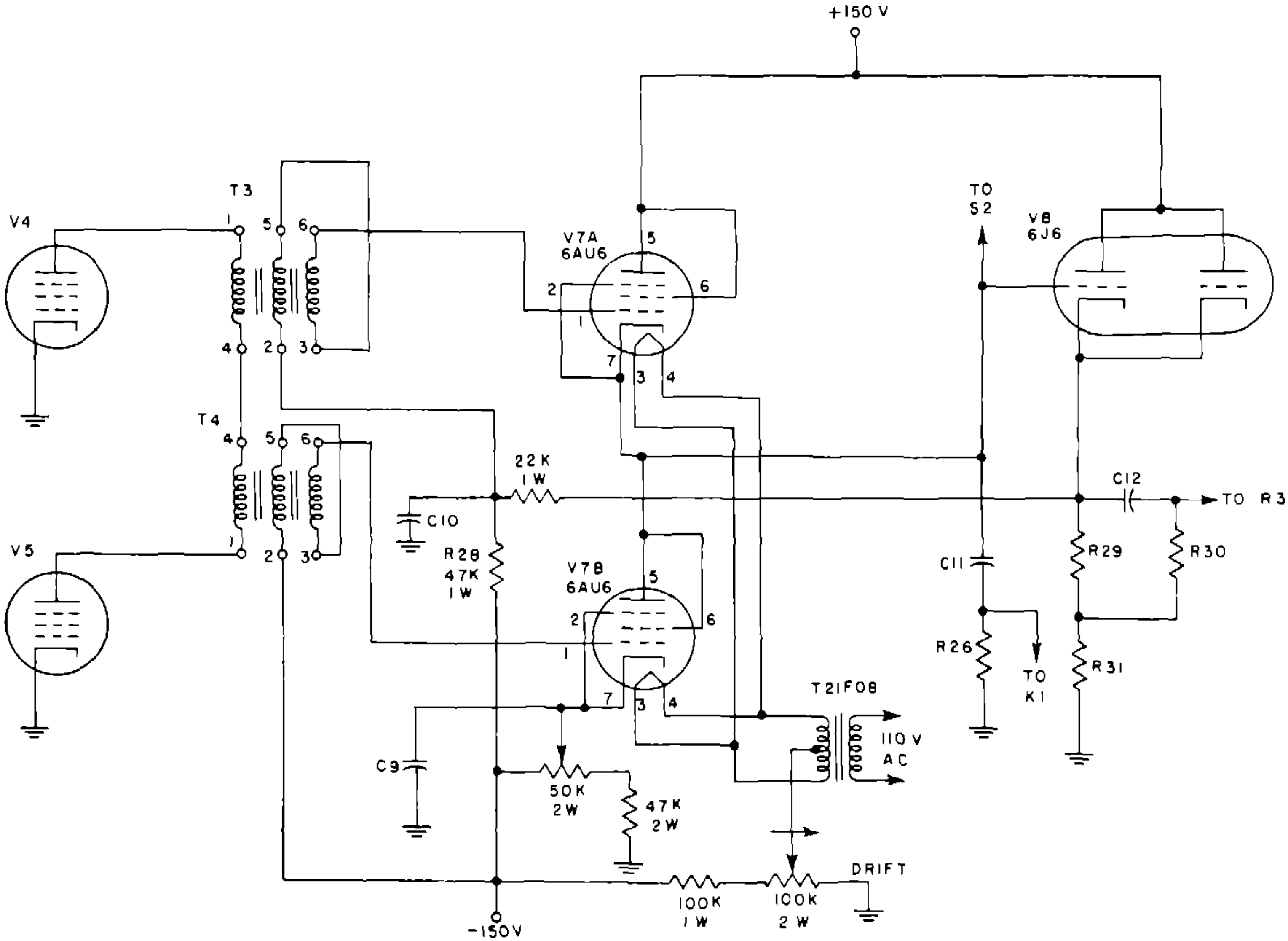

FIG. 7 TRAFFIC MONITOR TIME DISCRIMINATOR REVISIONS FOR PAR-1

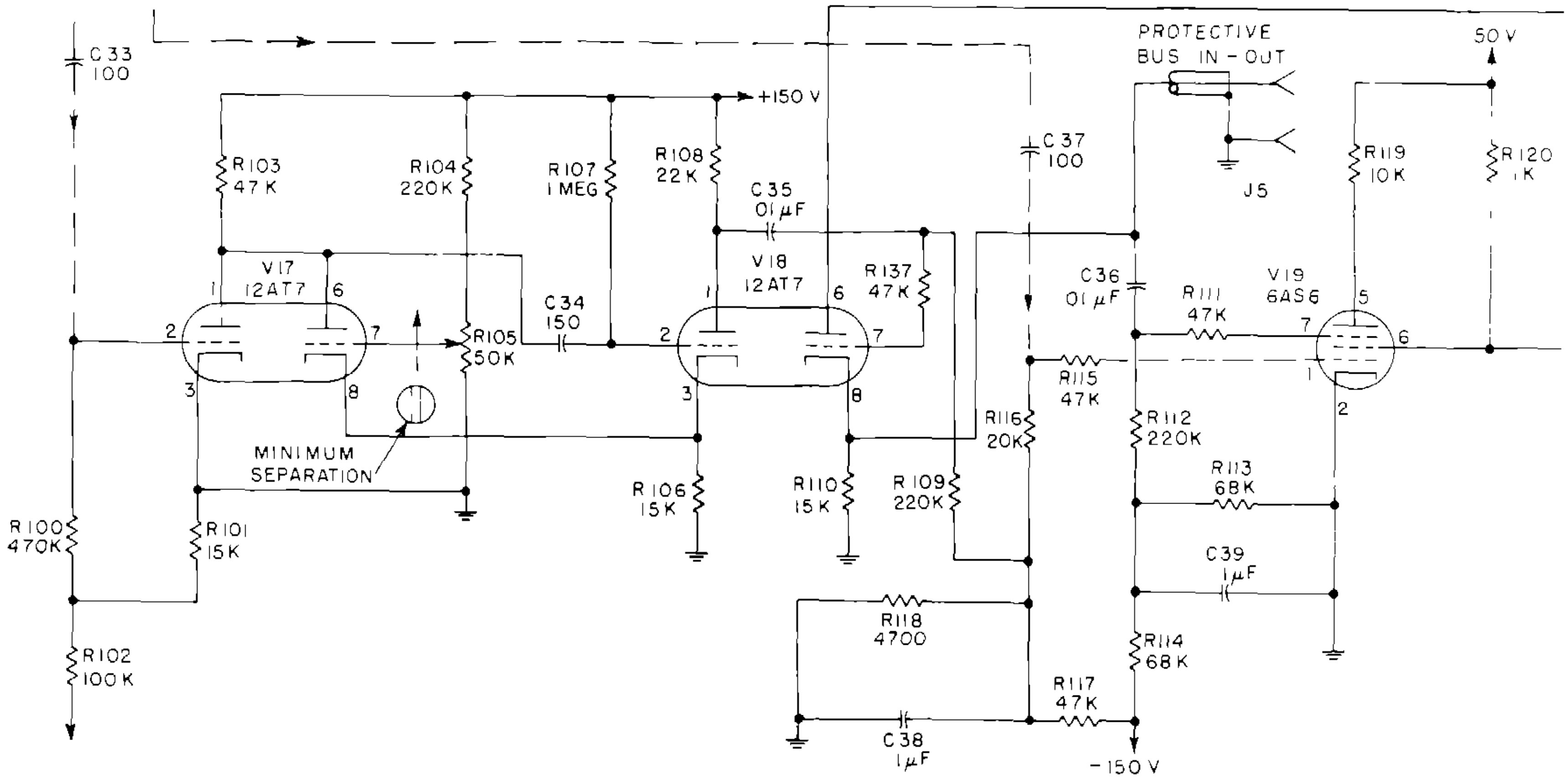

FIG 8 ORIGINAL TRAFFIC MONITOR OVERTAKE ALARM CIRCUIT

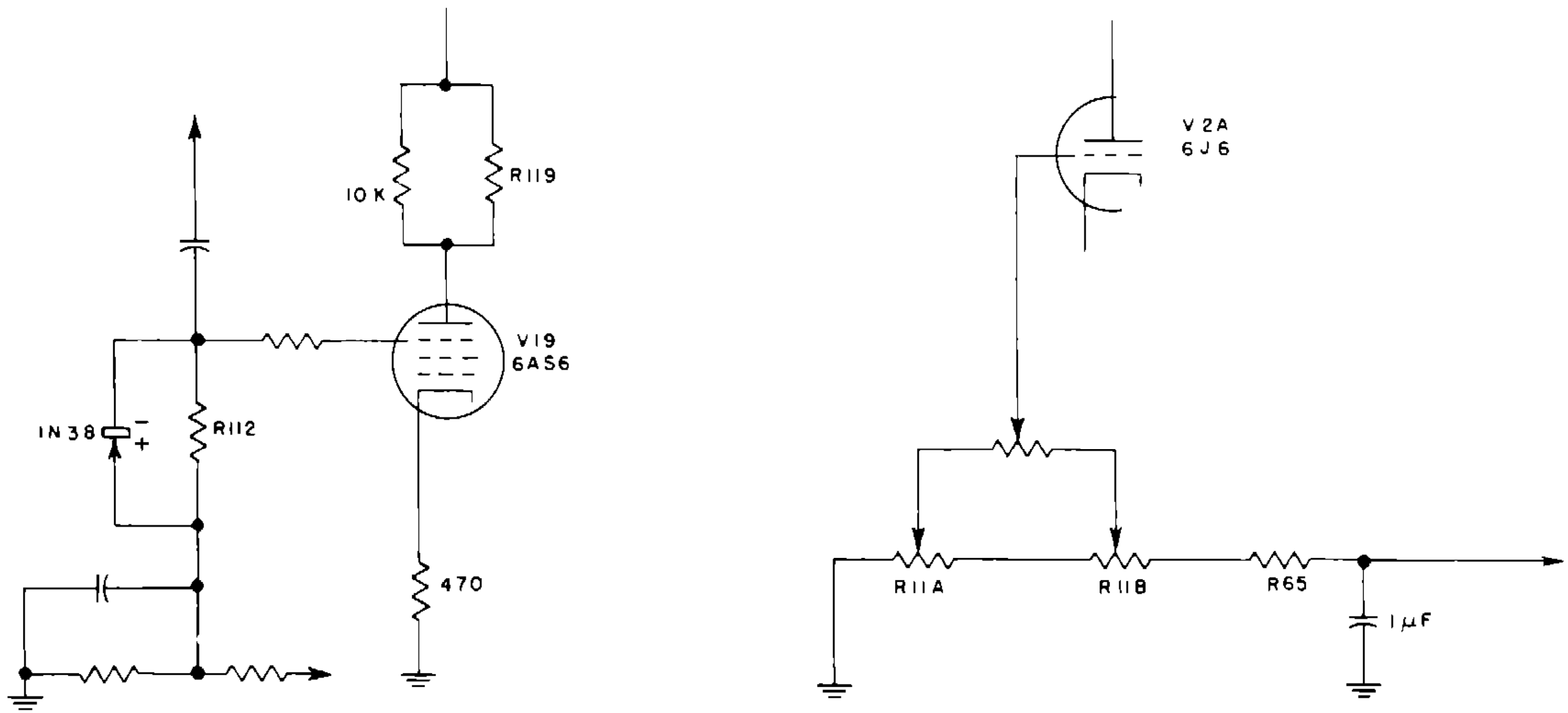

FIG 9 TRAFFIC MONITOR RANGE TRACKING REVISIONS FOR PAR-1

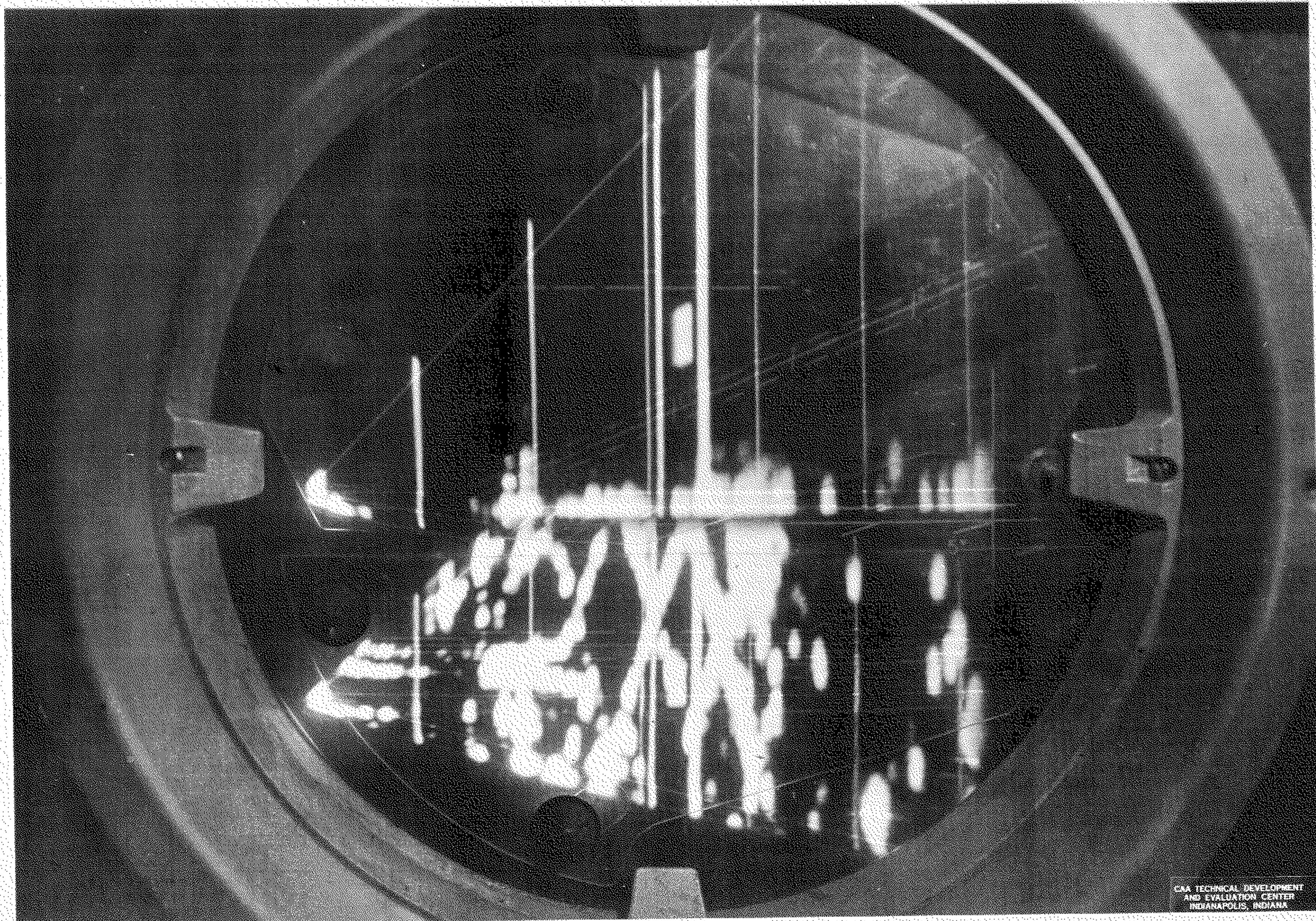

FIG. 10 PHOTOGRAPH OF PAR-1 THREE MILE INDICATOR
MADE DURING GROUND CLUTTER TESTS

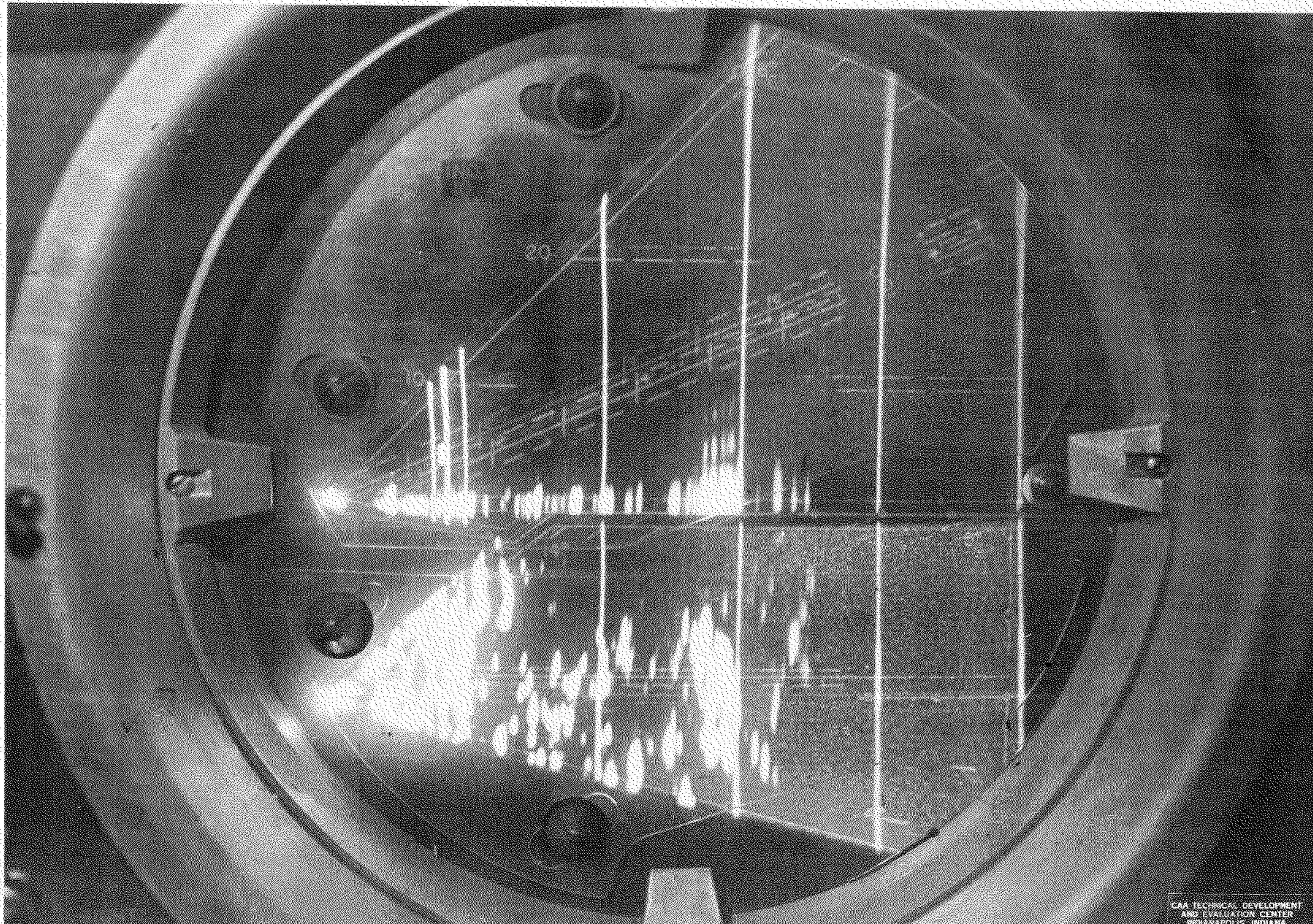

FIG. 11 PHOTOGRAPH OF PAR-1 TEN MILE INDICATOR
MADE DURING GROUND CLUTTER TESTS

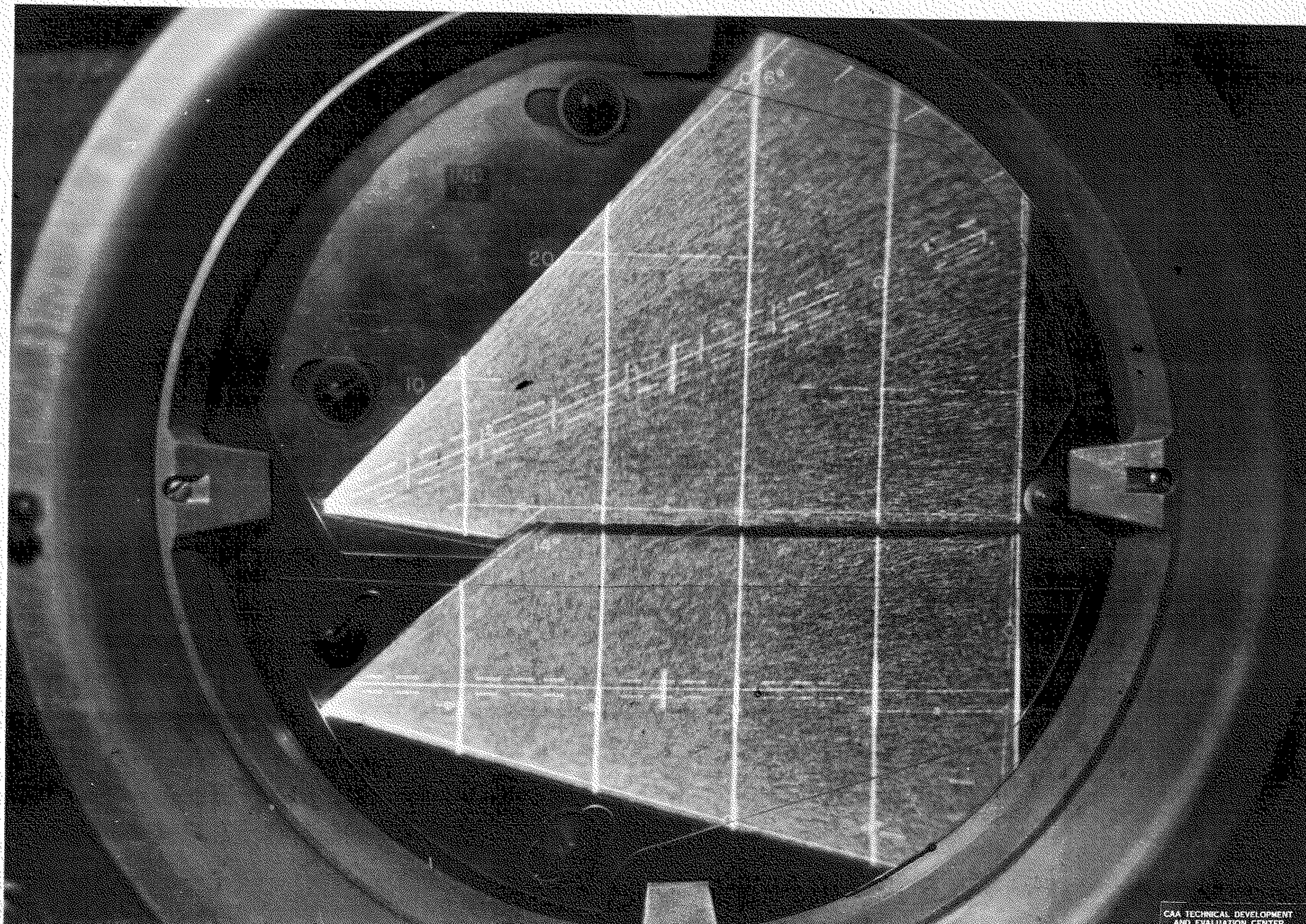

FIG. 12 PHOTOGRAPH OF PAR-1 TEN MILE INDICATOR WITH
A SIMULATED SIGNAL-TO-NOISE RATIO OF 3 DB

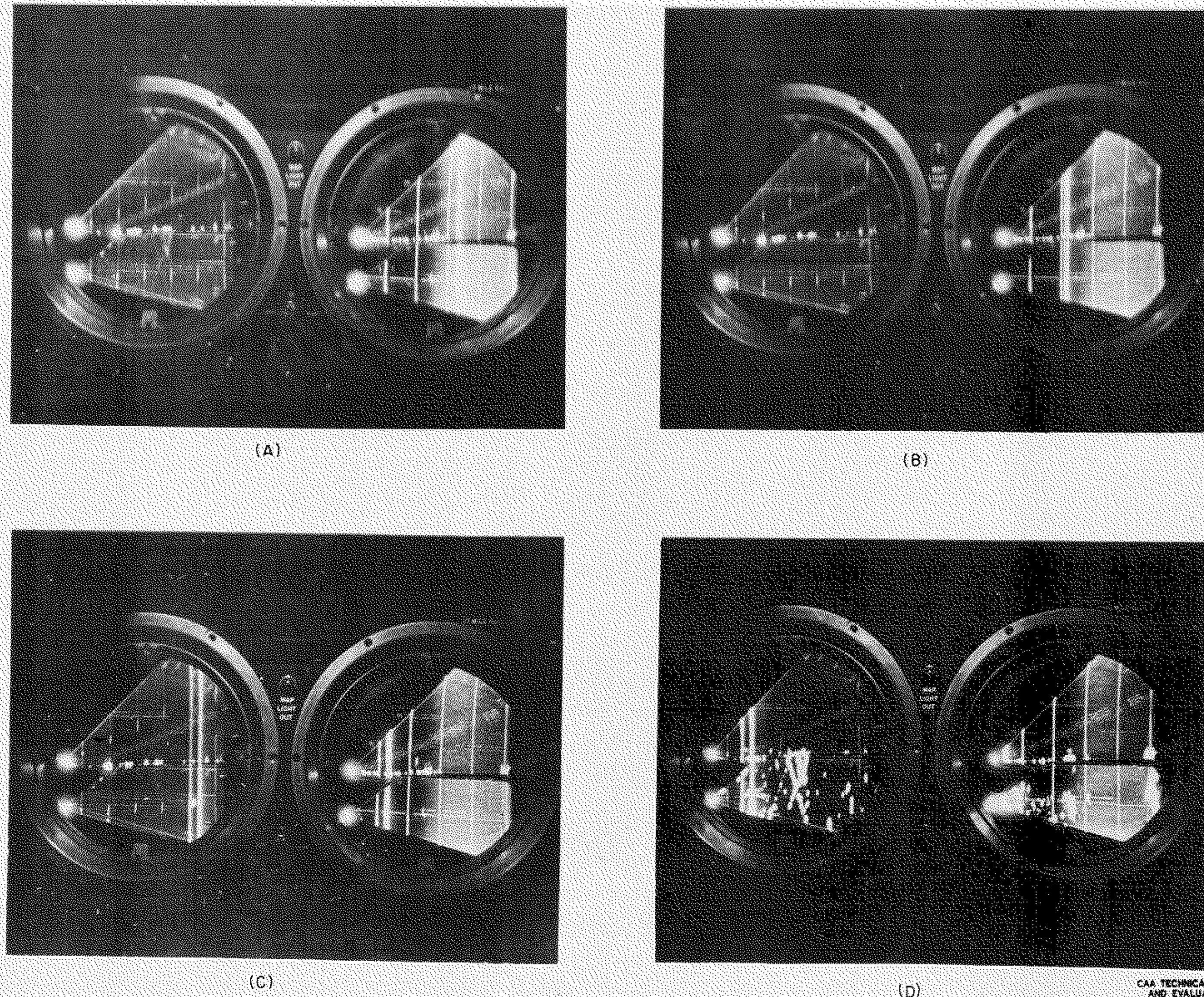

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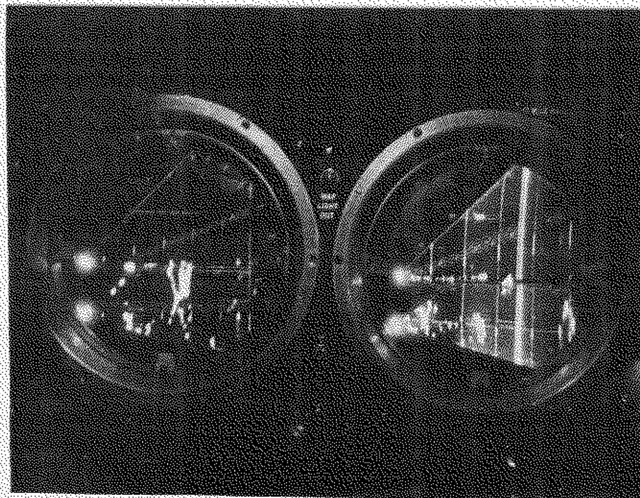
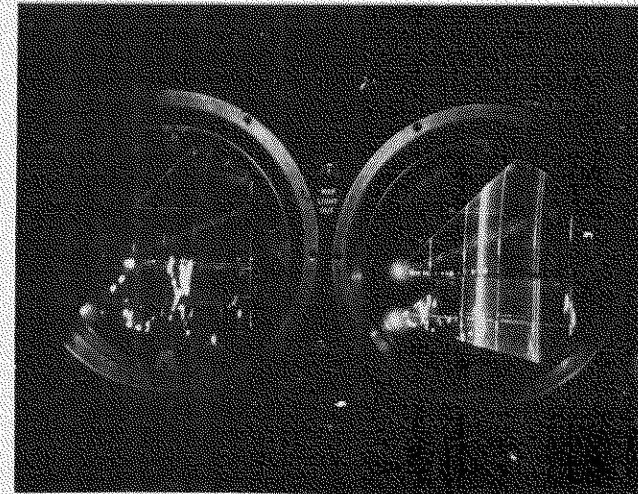
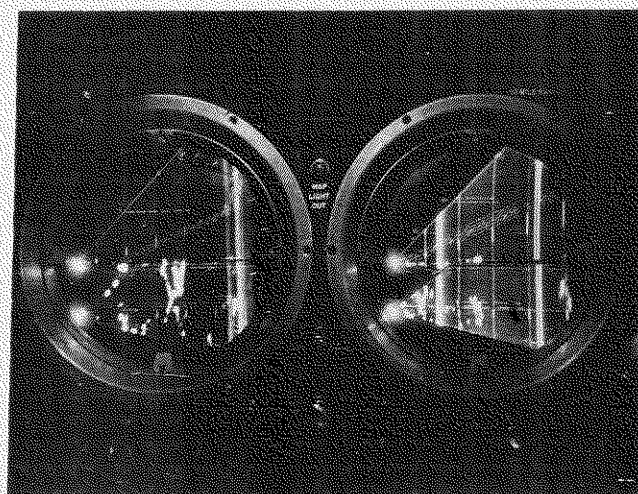
FIG. 13 PHOTOGRAPHS OF AN AIRCRAFT MAKING A FINAL APPROACH AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS



(A)



(B)



(C)

(D)

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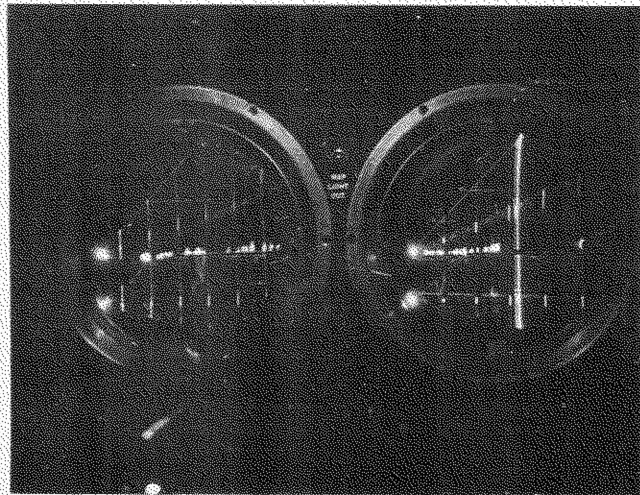
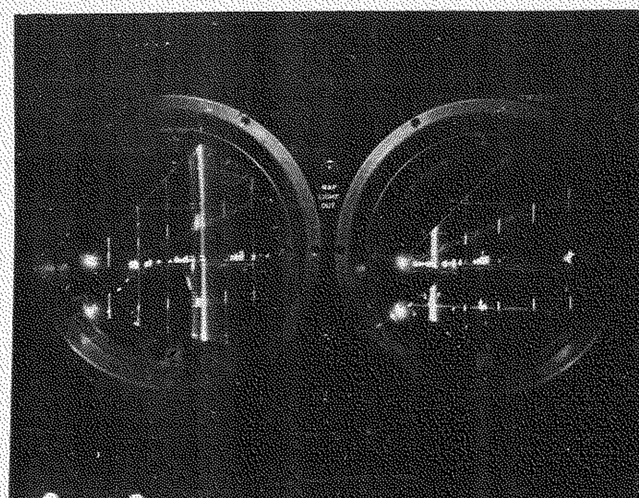
FIG. 14 PHOTOGRAPHS OF TWO AIRCRAFT MAKING FINAL APPROACHES AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS



(A)

(B)



(C)

(D)

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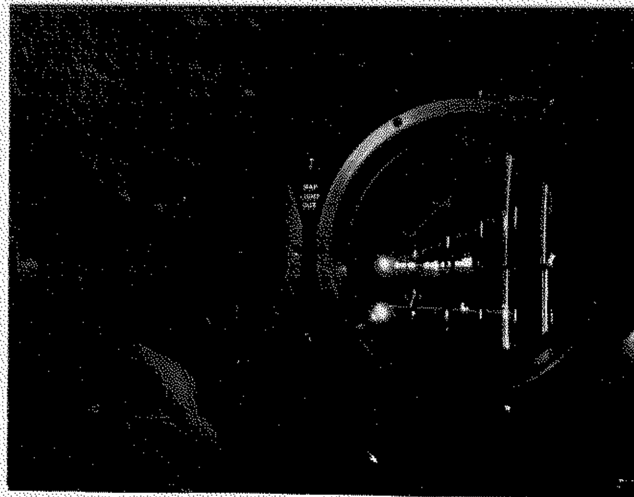
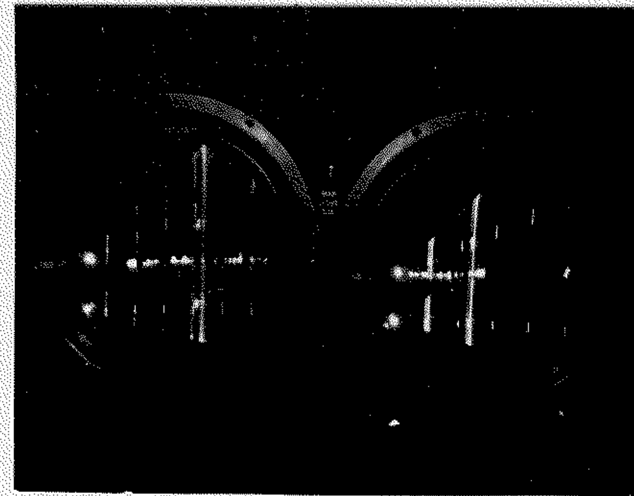
FIG. 15 PHOTOGRAPHS OF AN AIRCRAFT MAKING A FINAL APPROACH AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS

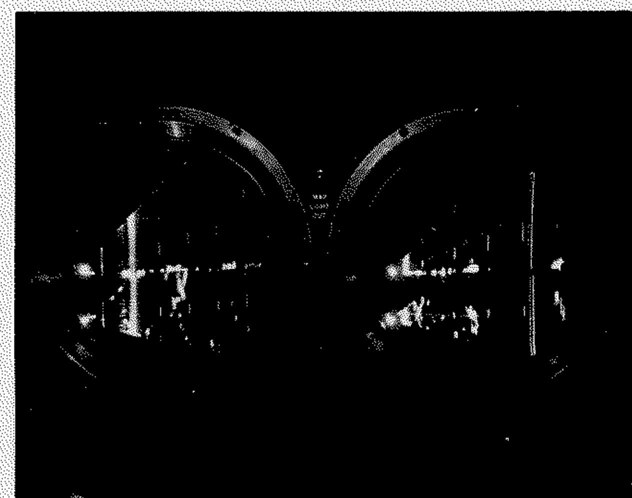


(A)



(B)

(C)



(D)

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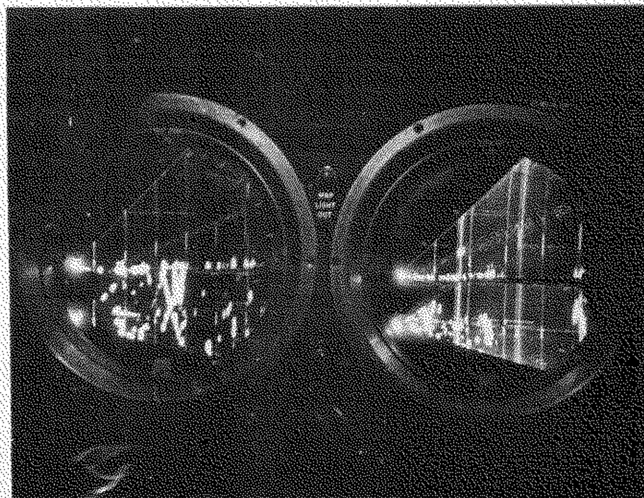
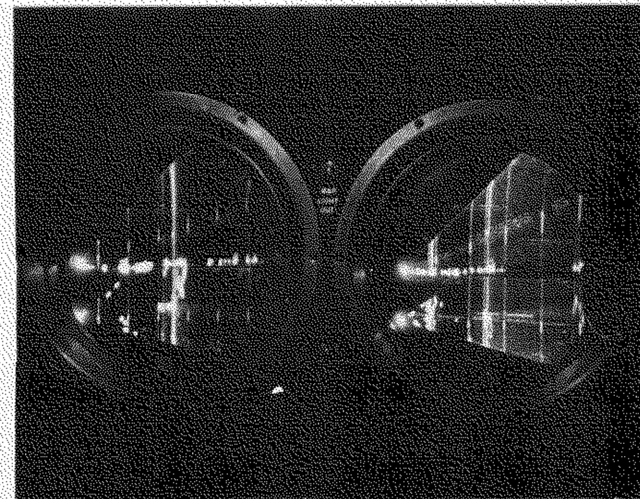
FIG. 16 PHOTOGRAPHS OF TWO AIRCRAFT MAKING FINAL APPROACHES AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS

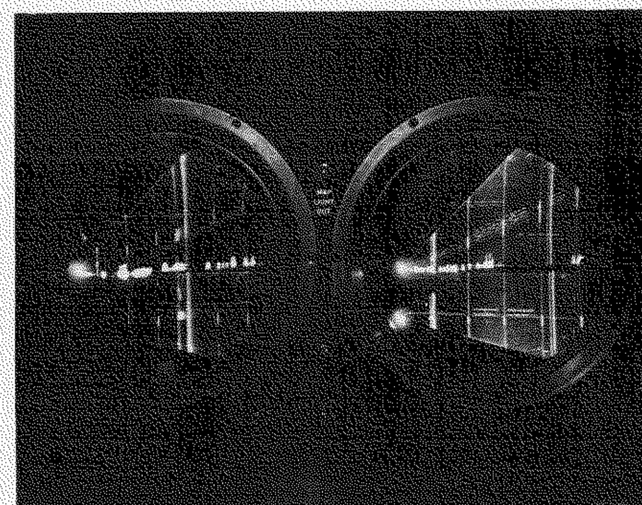


(A)



(B)

(C)



(D)

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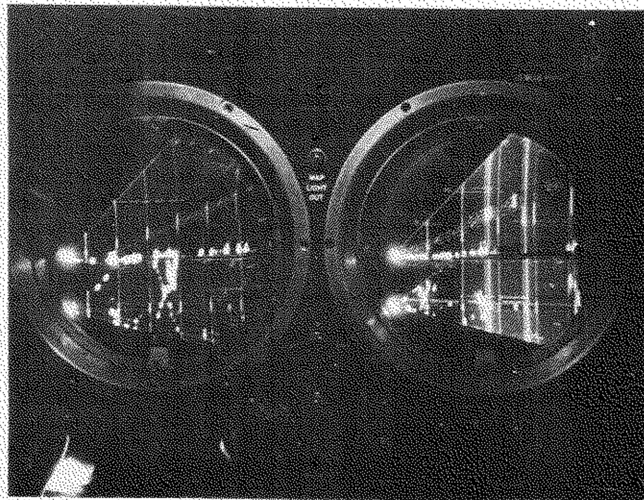
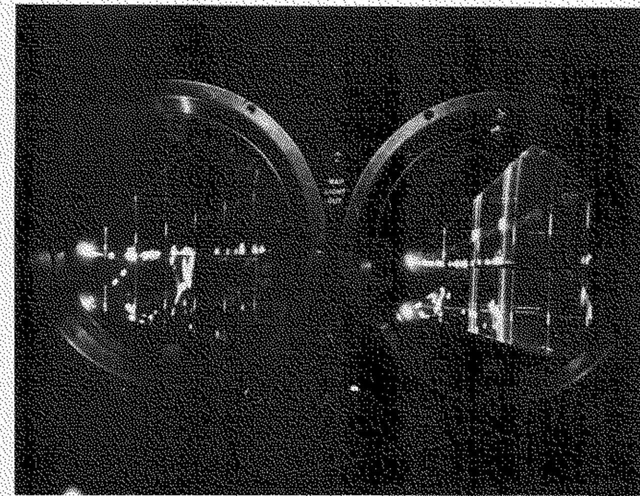
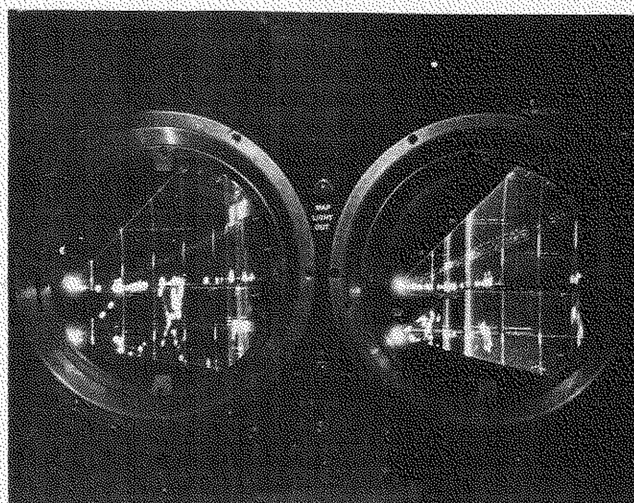
FIG. 17 PHOTOGRAPHS OF TWO AIRCRAFT MAKING FINAL APPROACHES AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS. A TRANSPONDER REPLY CAN BE SEEN FOLLOWING ONE TARGET



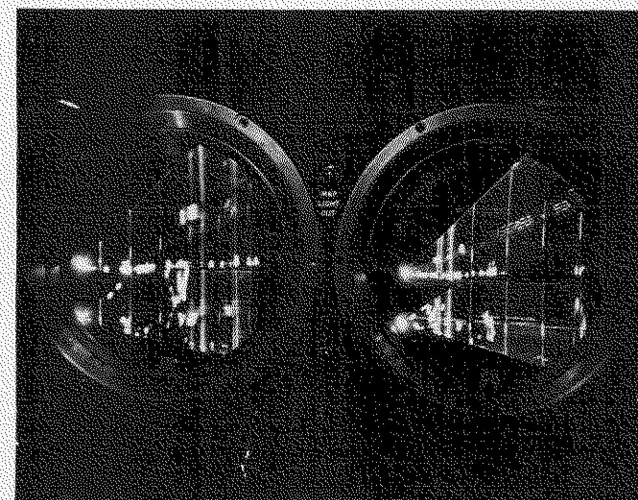
(A)



(B)

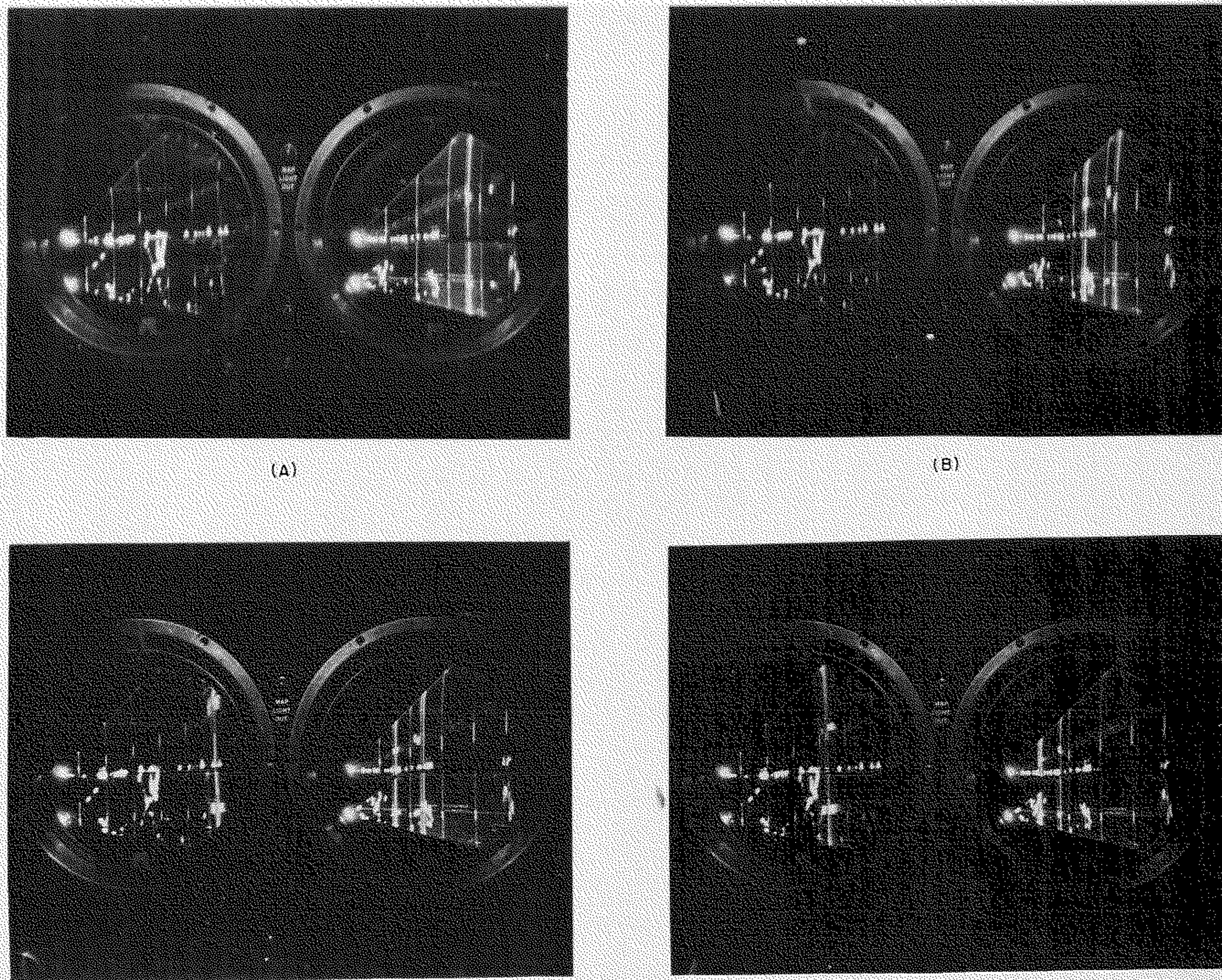


(C)



(D)

FIG. 18 PHOTOGRAPHS OF TWO AIRCRAFT MAKING FINAL APPROACHES AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS. A TRANSPONDER REPLY CAN BE SEEN FOLLOWING ONE TARGET



(A) (B) (C) (D)

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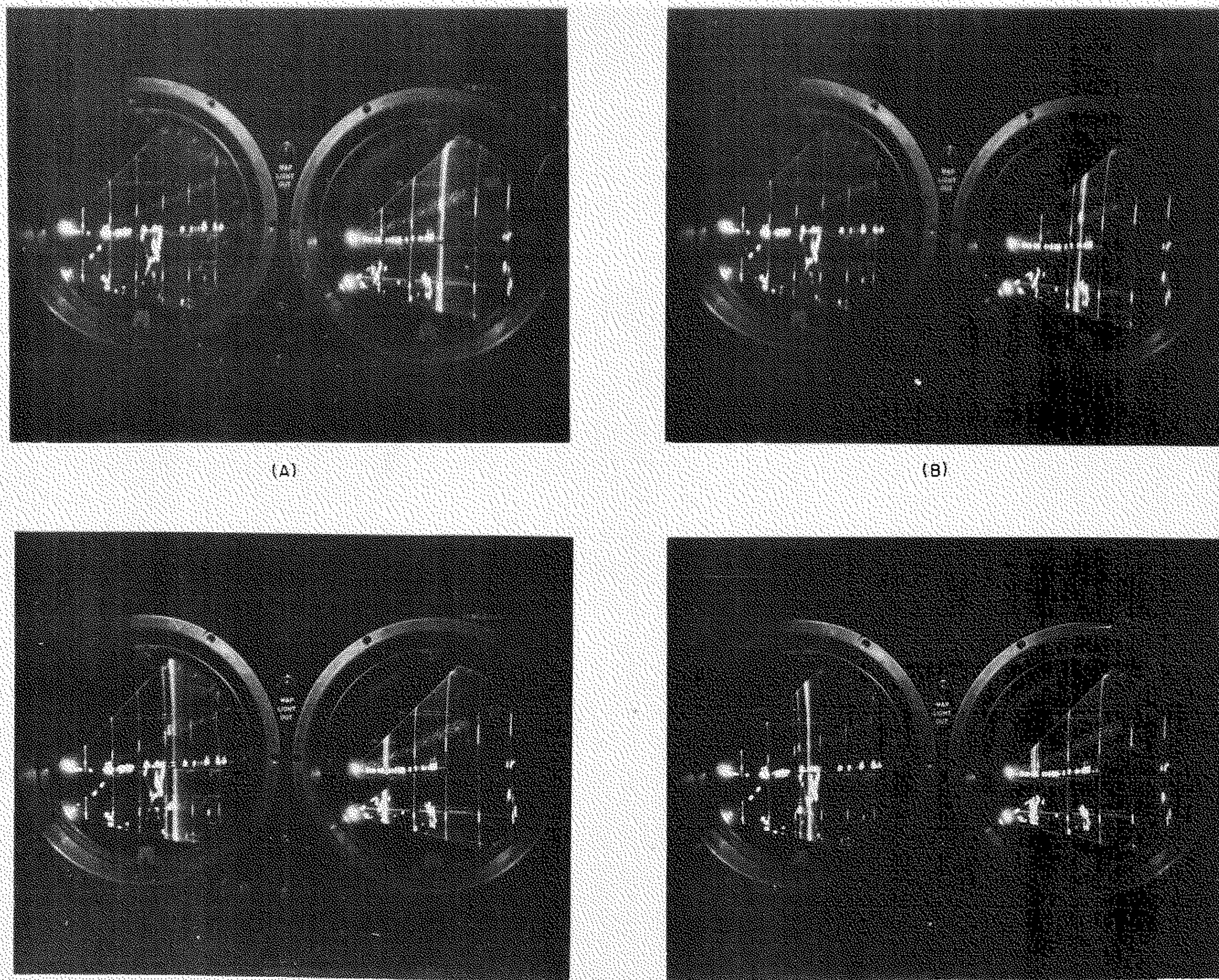
FIG. 19 PHOTOGRAPHS OF TWO AIRCRAFT MAKING FINAL APPROACHES AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS. TRANSPONDER REPLIES CAN BE SEEN FOLLOWING ONE TARGET



(A) (B) (C) (D)

FIG. 20 PHOTOGRAPHS OF AN AIRCRAFT MAKING A FINAL APPROACH AS VIEWED ON THE PAR-1, THREE AND TEN MILE INDICATORS

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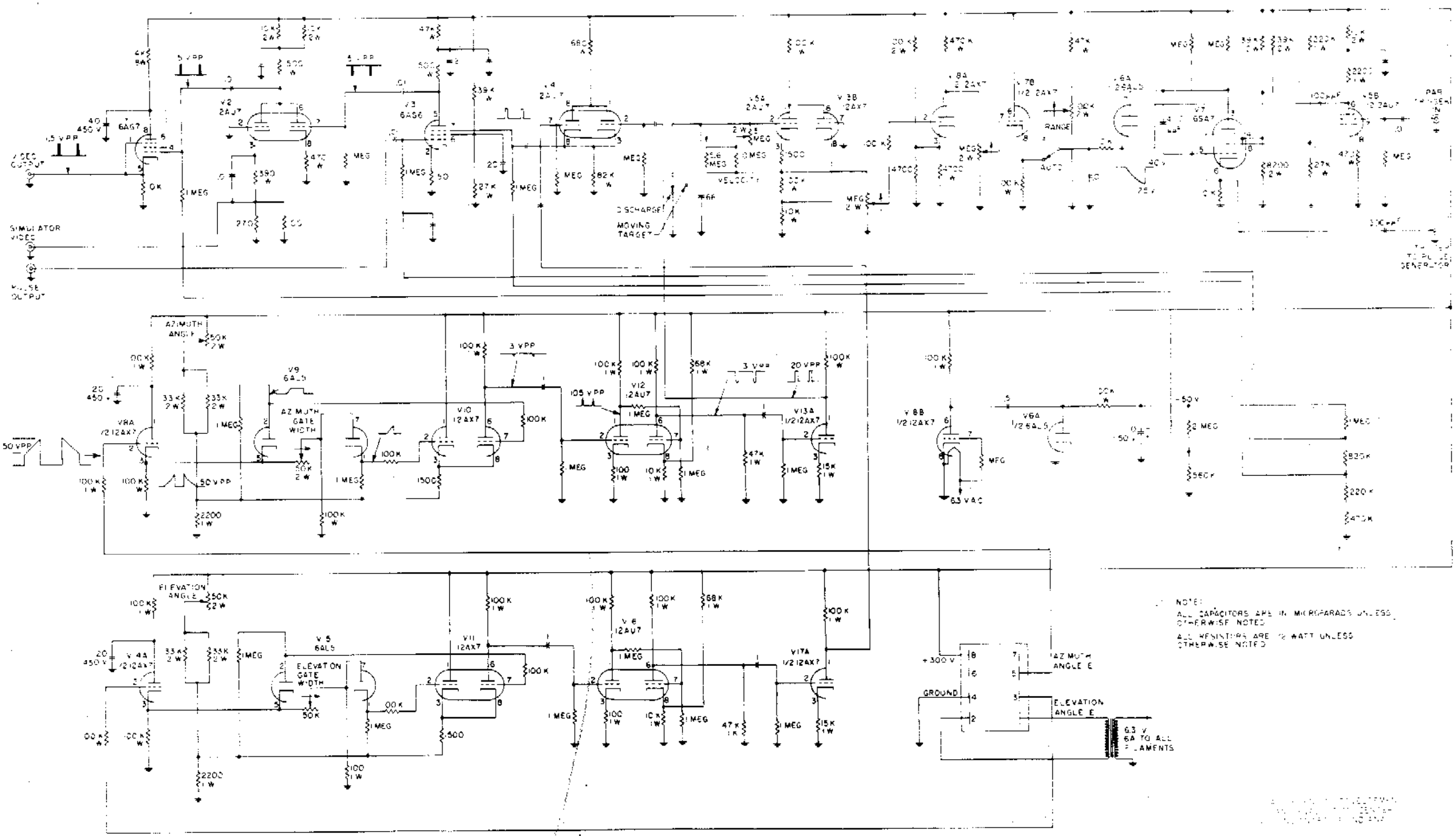

FIG. 21 SCHEMATIC DIAGRAM OF TARGET SIMULATOR FOR PAR-1

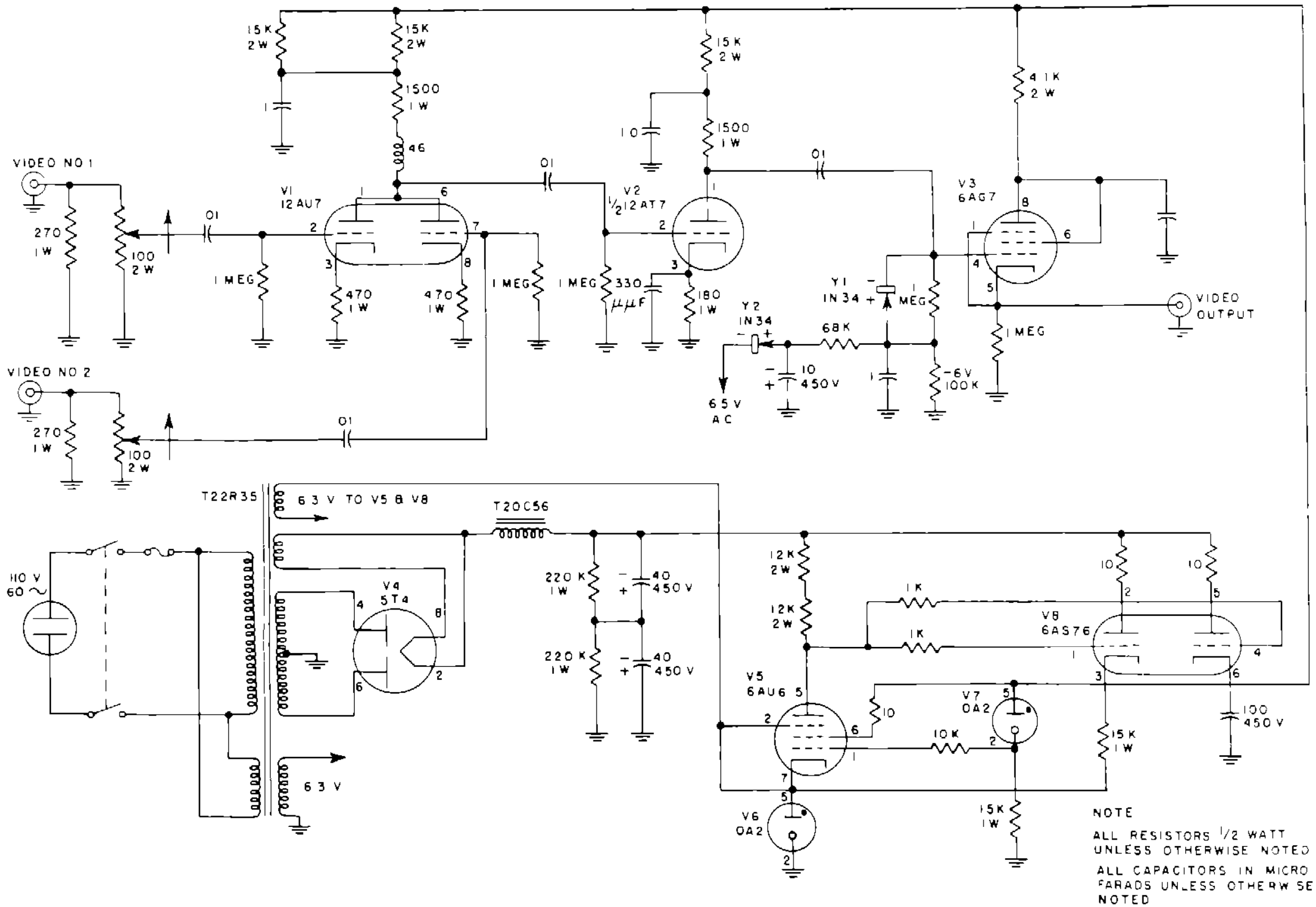

FIG 22 SCHEMATIC DIAGRAM OF VIDEO MIXER FOR PAR-I