Evaluation of the Dumont SRD-1 Bright Radar Display and Initial Study of Other Display Techniques

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EVALUATION OF THE DUMONT SRD-1 BRIGHT RADAR DISPLAY AND INITIAL STUDY OF OTHER DISPLAY TECHNIQUES*

SUMMARY

The DuMont SRD-1 bright radar display uses a Graphechon storage tube for scan conversion and storage purposes Radar information in polar-scan form is converted into a television-type rectilinear scan to provide video and synchronizing output signals to drive two 12-inch indicators and one 30-inch indicator which were furnished as part of the equipment Bright-phosphor cathode-ray tubes are used in the indicators to obtain bright displays Because bright-phosphor tubes have low persistence, the storage capabilities of the Graphechon tube are used to add storage or persistence to the final display The storage time can be adjusted to permit storage of targets for several antenna scans as desired The video and synchronizing output signals also may be used to drive other television-type indicators, including television projection systems for large displays, and they may be remoted to distant points by available broadband relay systems

Results of the evaluation indicated that the brightness of the display is satisfactory for use under high ambient light levels In spite of its complexity and bulk, the equipment stability was satisfactory in most respects during long periods of operation The resolution of the final display was less than that of a normal plan position indicator using a cathode-ray tube with a P7 phosphor Likewise, its ability to display readable signals in noise was not as good as might be expected from the normal radar plan position indicator

Results of the initial studies on other display techniques indicate that future efforts should be directed toward the development and evaluation of direct-view storage tubes, dark-trace tubes, and rapid photographic projection systems

INTRODUCTION

Radar now is an integral part of the air traffic control system Utilization of aircraft target range and azimuth information provided by surveillance radar has expedited air traffic movements within many terminal areas and has provided for safer flight operations The control of en route air traffic has been aided by long-range radar, and the installation of long-range radar systems for use at several en route traffic control centers has been completed

For en route air traffic control, information other than the aircraft range and azimuth data provided by the radar indicator is required to control traffic effectively and safely The en route air traffic controller must have at hand information concerning the identity, altitude, and flight plan of the aircraft, and it must be presented to him in some symbolic form, such as flight progress strips, in order that he may effect required aircraft separation and issue clearances Another requirement for a bright radar presentation exists in the terminal area tower cab which has a high ambient light level Such radar provides the terminal area controller with information required for more intelligent and judicious control of landings and departures, including the vectoring of aircraft during instrument flight conditions

The requirements of en route and terminal air traffic control point up a real need for a radar presentation which may be viewed under rather high ambient light levels Most of the present radar indicators utilize cathode-ray tubes having P7 or P19 phosphors These phosphors meet the storage or persistence requisite set by the scan methods of radar, but they are restricted in their use because they must be viewed under relatively low ambient light levels This limits their installation to darkened rooms, and it places a curb on the use of any tabular or symbolic information which may be necessary to the operation

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Tests performed at the Civil Aeronautics Administration (CAA) Technical Development Center (TDC) at Indianapolis indicated that scan conversion techniques using the Graphechon storage tube should provide a satisfactory approach to this problem [1] This technique provides for writing the radar information on a storage element within the Graphechon, then reading the stored picture out at such a rate that a continuous display may be presented on cathode-ray tubes having bright and short-persistence phosphors, thereby providing a display which may be viewed under relatively high ambient lighting. On the basis of these tests, specifications were prepared and a contract was awarded to the Allen B DuMont Laboratories An operational and technical evaluation of the bright radar display equipment is described in this report

PURPOSE OF THE EQUIPMENT

The SRD-I bright display equipment is an electronic display system providing television pictures of radar plan-position indicator (PPI) video,[2] VHF automatic direction finder (ADF),[3] secondary radar or beacon,[4] and video mapping information It provides simultaneous displays of any combination of this information at a high level of brightness, and it is designed for use in an airport traffic control tower or wherever operational requirements include reference to radar information under conditions of high ambient lighting This equipment was designed for use in conjunction with the ASR-2 airport surveillance radar A typical installation is shown in Fig. 1. The ASR-2 radar provides target range and azimuth information to the bright display equipment which converts that information from PPI-polar form to television rectilinear form and adds storage as required.

The bright display equipment is a dual channel system Each channel may be utilized independently of the other. Simultaneous display upon separate consoles of two different range scales of the ASR-2 airport surveillance radar may be accomplished, or two separate radar outputs may be utilized to provide a different radar presentation on each console

Video mapping circuitry which generates video signals corresponding to photoengraved map slides is included in the bright display equipment Separate maps are provided for each radar range scale and for certain desired off-centered displays Fifteen different maps may be used at each channel, and they may be selected from the operator's console The video mapping signals are mixed with radar video, resulting in a combined presentation of radar and mapping signals for each selected range

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[1] Albert W Randall and Jack S Marshall, "Bright Display Equipment for Surveillance Radar," CAA Technical Development Report No 173, June 1952

[2] The ASR-2 airport surveillance radar provides range and azimuth information of aircraft within a 60-mile range from the airport at which it is installed It is operated in the frequency range between 2,700 and 2,900 Mc. Five range scales (6, 10, 20, 30, and 60 miles) are provided on the PPI in addition to an off-centered operating position The antenna scan rate is 25 rpm and the antenna beamwidth is 2 1/4° The radar pulse width is one microsecond, with a pulse repetition frequency (prf) of 1,200 pulses per second (pps) Moving target indicator (MTI) provisions are included in the radar

[3] The operation of the ADF may be described as follows When an aircraft communicate with the control tower, an automatic VHF-ADF receiver takes a bearing on the airplane and transmits this bearing in the form of electrical signals back to the radar indicator When the ADF bearing signals are received at the indicator, the normal radar display is interrupted for a very short time while an ADF strobe line is traced on the tube The strobe line originates at the ADF site and passes through the target, thereby indicating to the control tower operator the azimuth of the aircraft which is in communication with him

[4] The basic components of the ATC radar-beacon system include an interrogator-responsor (I-R) unit for ground installation and a transponder for airborne use The I-R unit transmits interrogation pulses which are received by the transponder The corresponding transponder replies are received by the responsor portion of the I-R unit and are connected to a video interconnection unit which performs decoding functions and allows selection of beacon video only, radar video only, or beacon and radar video mixed The output of the video interconnection unit is connected to the video input circuit of the bright display equipment (BDE) where the radar and beacon signals are displayed as superimposed arcs.

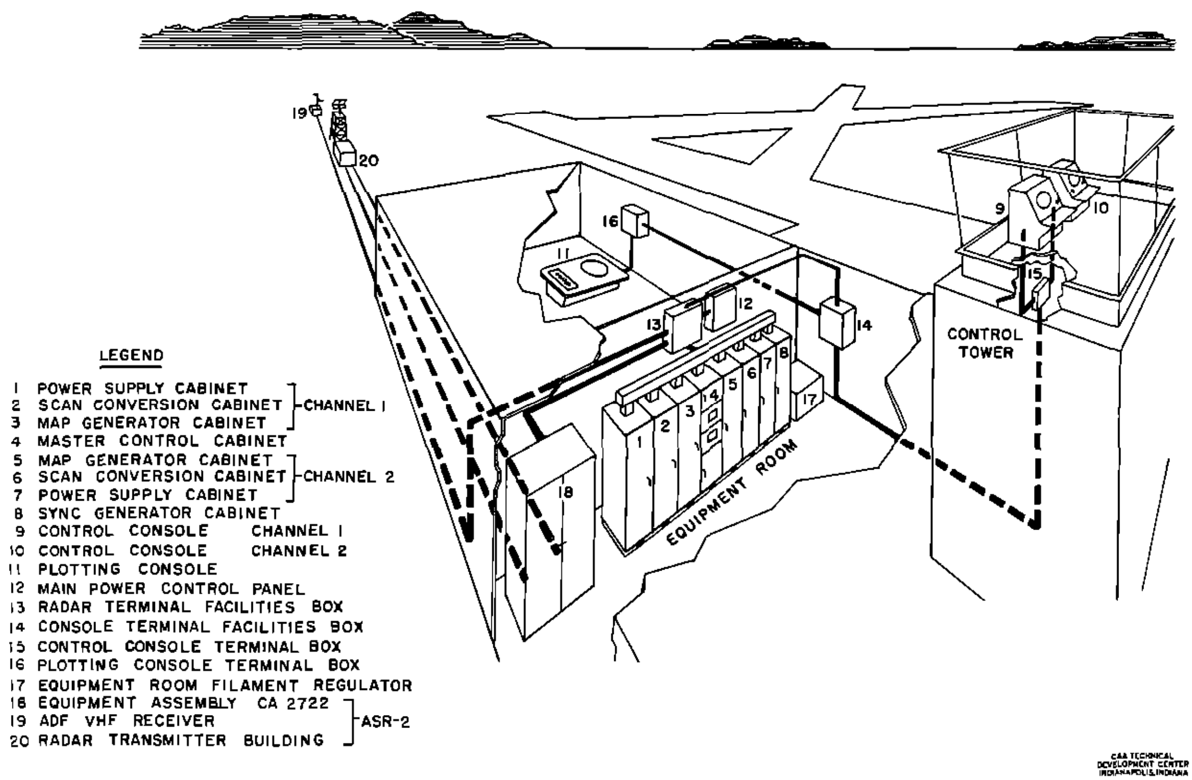

Fig 1 SRD-1 Bright Display Equipment Typical Installation

The bright display equipment also provides a composite television video output signal which is suitable for transmission by VHF or UHF links to remote towers or centers for presentation upon indicators having standard television scans This signal can contain radar, mapping, and ADF data

A functional block diagram is shown in Fig 2 The major components of the bright display equipment consist of 8 cabinets of equipment, two 12-inch display-control consoles, and a 30-inch direct-view plotting display console The display control consoles include all of the essential controls for the radar set normally found on the original radar PPI, with the exception of the synchroscope The plotting display console, however, has no control over the radar set, and its control of the bright display equipment is limited to selection of the output signals from either channel for presentation on the plotting console The plotting console acts as a slave to either the Channel 1 or the Channel 2 control console Either of the two channels can be selected, but no further control can be exercised over the operation of the bright display equipment or the ASR-2 radar Figures 3 and 4 show the operating consoles and associated cabinets of equipment

DESCRIPTION OF THE EQUIPMENT

Referring to the block diagram of the SRD-1 bright display equipment, Fig 2, 2 channels of operation are provided in 8 racks of equipment plus 2 control consoles and the plotting console which may be slaved to either channel The functional units common to the operation of either or both channels are sync generator, sync distribution amplifier, linearity grating generator, picture monitor, waveform monitor, plotting console mixer amplifier, and plotting display console The major units of the individual channels are scan conversion unit, map generator, control console mixer, and display control console

Sync Generator

The sync generator forms and shapes the pulses necessary to the standard television scan used in the SRD-1 bright display equipment It employs a very stable oscillator operating

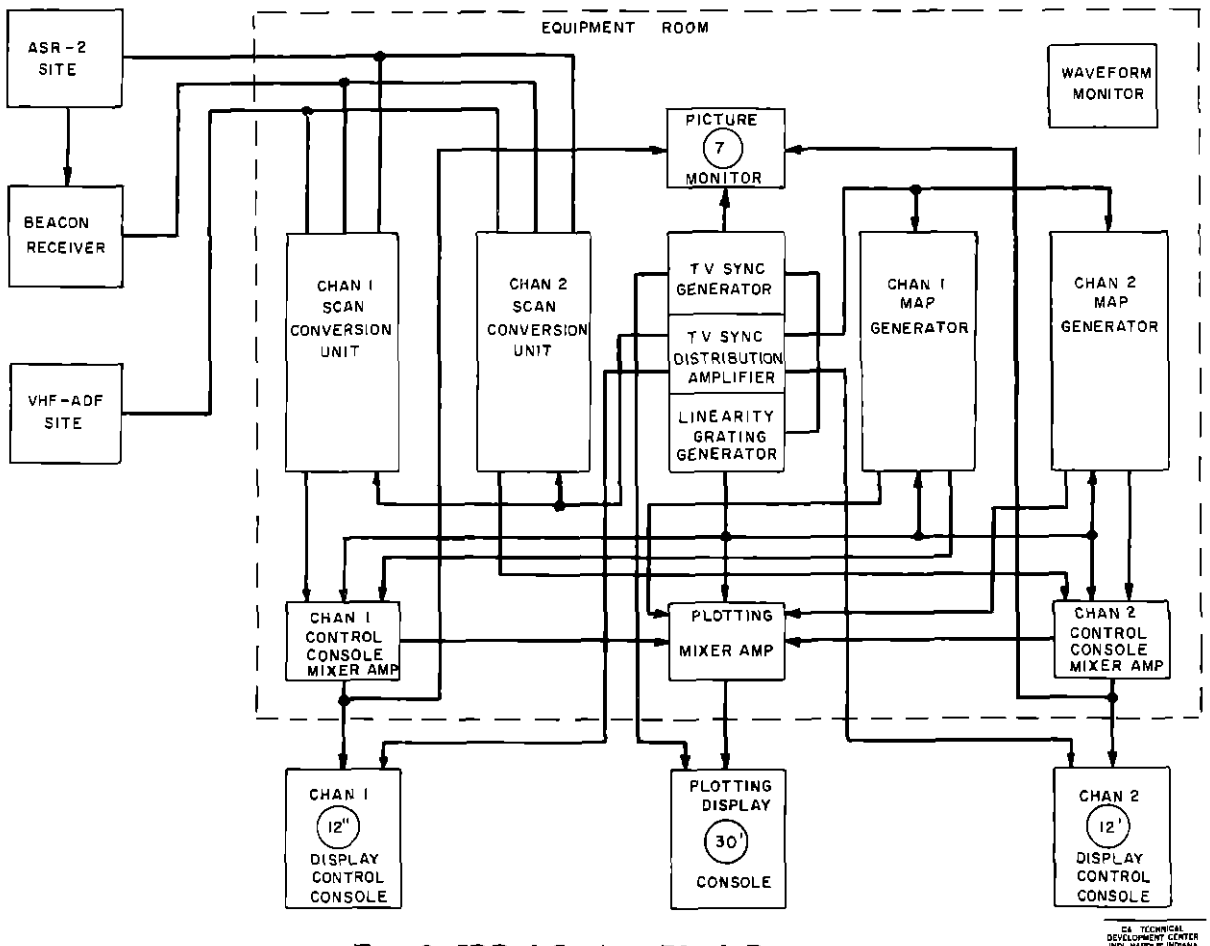

Fig 2 SRD-1 System Block Diagram

at a frequency of 31 5 kc Gas tube counting circuits are used to divide down to 15 75 kc for the horizontal synchronization pulses and to 60 cps for the vertical synchronization pulses Standard vertical and horizontal drive pulses and composite blanking pulses are produced In addition, composite synchronizing pulses for use with a microwave relay system are provided An AFC system, to lock the basic oscillator to the local line frequency, is not incorporated

Sync Distribution Amplifier

The sync distribution amplifier receives the drive pulses from the sync generator and provides low impedance outputs to the various equipments requiring these pulses

Linearity Grating Generator

The linearity grating generator, operating with pulses from the sync generator, provides vertical and horizontal bar video pulses for use in linearity adjustments of the various TV rasters throughout the SRD-1 equipment

Picture Monitor

The picture monitor located in the master control cabinet is centrally located with respect to the components of the two channels, and it provides a visual display for adjustment purposes A three-position selector switch permits viewing either channel presentation or the linearity-grating generator pattern

Waveform Monitor

The waveform monitor located in the master control cabinet is for viewing the various waveforms throughout the SRD-1 equipment. The probe provided with the monitor has a BNC

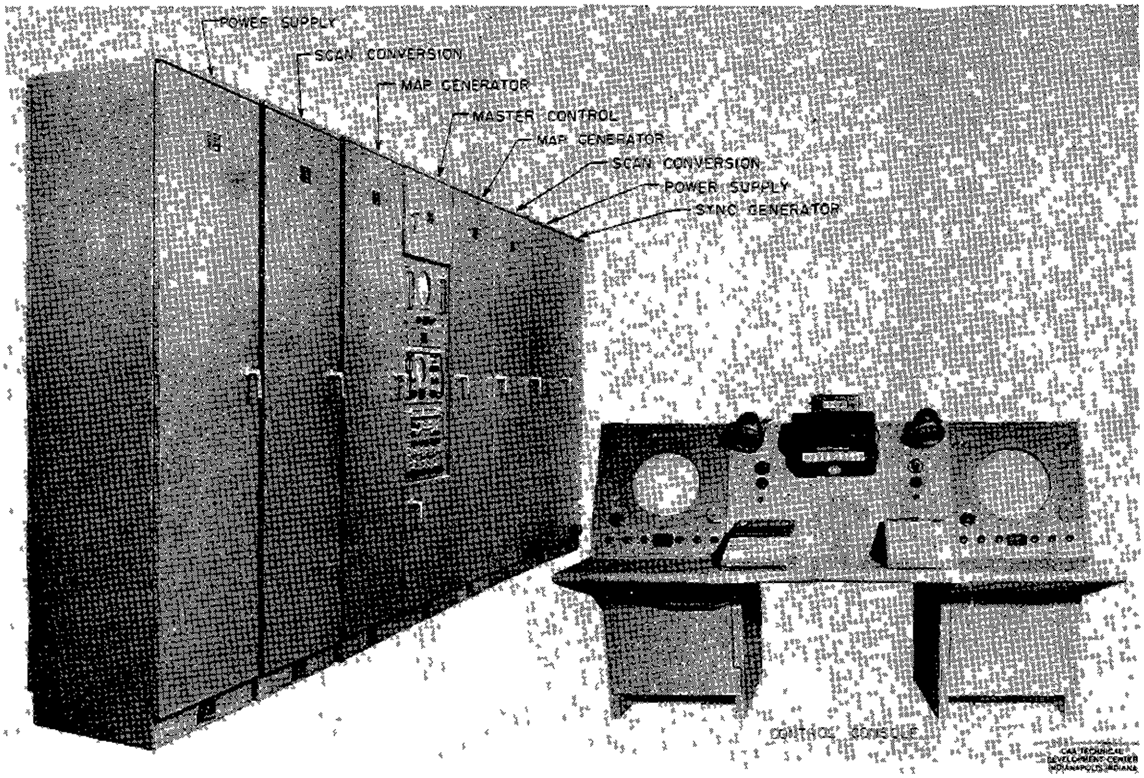

Fig 3 SRD-1 Bright Display Equipment

Fig 4 Plotting Console

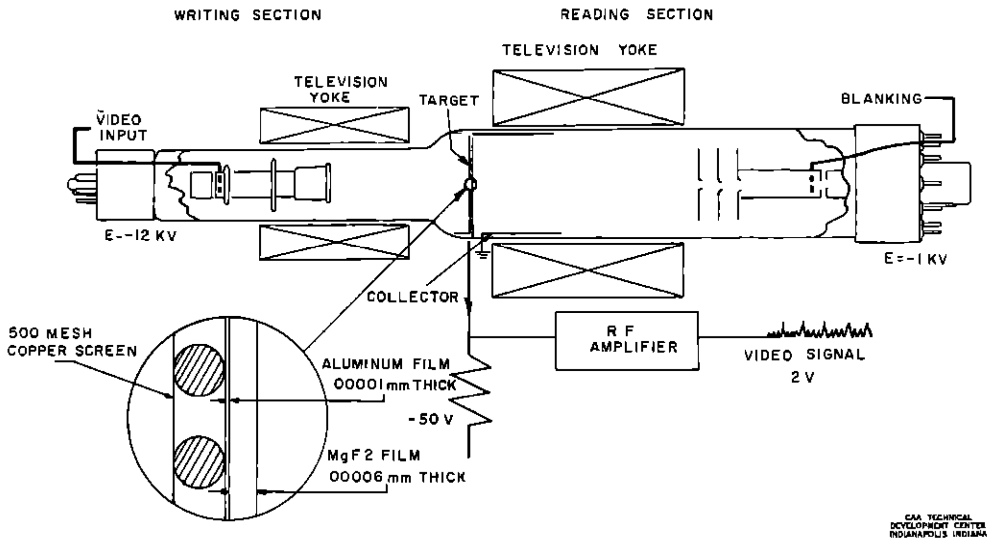

Fig 5 Early Type Graphechon

connector to facilitate connection to the test points which are available at the inputs and outputs of most of the signal-handling circuits of the equipment

Scan Conversion Unit

Each channel of the SRD-1 bright display equipment has a scan conversion unit Because it is the heart of the system and utilizes circuitry and components not found ordinarily in either TV units or in radar PPI units, its operation is described in the following paragraphs

1 The Graphechon storage tube The Graphechon storage tube is a development of RCA Laboratories, Inc The theory of its operation has been presented a number of times in engineering publications [5,6,7] Briefly, the Graphechon, shown in Figs 5 and 6, is made up of three principal elements a writing gun, a reading gun, and a target The two guns are similar to other cathode-ray tube gun assemblies utilizing magnetic deflection and electrostatic focusin They are placed at opposite ends of an evacuated bulb about 18 inches long Approximately midway between the guns is the target The side of the target facing the reading gun is composed of a thin (0 006 micron) insulating film deposited on a very thin (0 001 micron) sheet of aluminum Facing the writing gun is a fine wire mesh screen which supports the aluminum and insulator film This mesh and the aluminum backplate normally are at a negative potential of from 25 to 50 volts which is applied through a finger contact to a target connection brought through the bulb A graphite coating on the inside of the bulb acts as the final accelerating anode for the two guns and collects the secondary electrons emitted by the target An external silver coating acts as an electrostatic shield for the tube and grounds any radio-frequency (r-f) energy appearing on the internal conductive coating

The writing end of the tube is fitted with a rotating yoke carrying the sawtooth sweep currents, and the radar video is connected to the grid of the writing gun A standard TV deflection yoke is fitted to the reading end of the tube Blanking pulses are provided to cut off

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[5] L Pensak, "The Graphechon--A Picture Storage Tube," RCA Review, March 1949

[6] A H Benner and L M Seeberger, "Graphechon Writing Characteristics," RCA Review June 1951

[7] W T Dyall, G R Fadner, and M D Harsh, "Development of an Improved Graphechon Storage Tube," RCA Review, December 1952

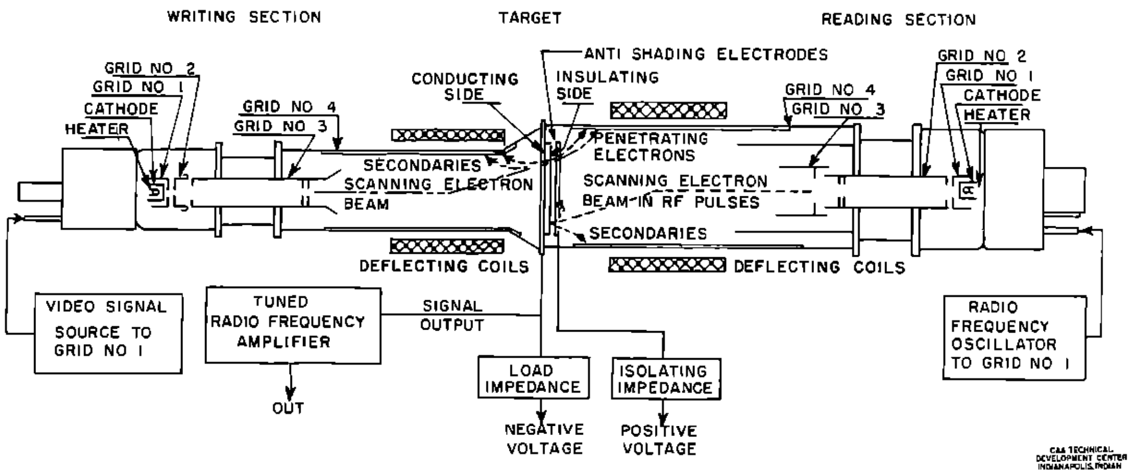

Fig 6 Improved Type of Graphechon

the reading beam during retrace time In the absence of writing input signals, the reading beam scans the insulator screen, and its accelerating potential of 1,000 volts causes the electrons to land with enough velocity to drive off more secondary electrons than arrive in the primary beam The secondary electrons move to the more positive graphite collector, and this process continues until the insulator reaches an equilibrium state of approximately ground potential When the writing-gun beam is turned on, its accelerating potential of 9,000 volts causes the electrons to land on the backplate of the target with enough velocity to produce bombardment-induced conductivity in the insulator film, whereby it takes on the backplate potential at the point where the beam strikes As the beam moves on, the insulator regains its insulating property but retains the backplate potential charge on its surface When the reading beam scans the insulator, an increase in secondary emission occurs when it lands on a negatively charged portion This increase in secondary emission results in a change in current flow in the capacitor formed by the charged insulator particle and the aluminum backplate An output signal is developed across a load resistor connected between the backplate and ground The amplitude of the signal is proportional to the secondary emission current Each scan of the reading beam reduces the charge on the insulator by a given amount, depending upon the reading-beam current, until the equilibrium state again is reached Thus, the written information is stored for a time, dependent on the writing-signal amplitude, target backplate potential, and the reading-beam intensity

In order to prevent crosstalk between the reading and writing beams of the tube appearing in the final output signal, the reading beam is modulated by the output of a 30-Mc oscillator The signal from the load resistor is amplified through a wide-band r-f amplifier and then is detected Simultaneous reading and writing functions thus are permitted

In order to keep the signal output portion of the tube at near ground potential, the reading- and writing-gun cathodes are operated at potentials of minus 1,000 volts and minus 9,000 volts, respectively

The target assembly of the Graphechon is mounted in a metal ring support which is in electrical contact with the backplate, hence, it assumes the negative potential of the backplate Shading of the picture scanned from the target has been attributed to the fact that this support ring repels some of the lower velocity, secondary electrons which leave the insulator near its field The result is that they fall back toward the center of the insulator and cause a higher output noise signal from that portion of the insulator Later developments of the Graphechon have resulted in ring-seal construction for the precision alignment of the two guns and the target The target assembly is mounted in one of the ring seals which provide the external connection to the target In addition to the target, an insulated metallic ring is mounted around the edge of the target on the insulator side A contact brought through the bulb permits this ring to be operated at some positive potential which offsets the repelling effect of the target backplate potential and eliminates or greatly minimizes the shading problem The results of recent tests with the new Graphechon indicate that it will provide a much better quality picture than did the earlier types

An undesirable feature of the Graphechon for PPI scan conversion service is its inability to write halftones Written signals of different amplitudes are read out with the same highlight brightness, however, the writing amplitude does affect the storage time Thus, higher amplitude signals remain visible longer Tests of the new type tube have shown that the signal decays through several discernible increments of brightness so that aircraft heading information is apparent in the final display, a desirable feature not noted in the earlier tubes

2 Writing deflection generator The writing deflection generator unit receives the radar video and trigger from a line compensation amplifier It generates range marks, sweep currents, and unblanking waveforms synchronized with the trigger circuits The radar video is amplified and mixed with the range marks, unblanking, and ADF video Variable scan-rate compensation is used to provide increasing video amplitude from the start of the sweep out to the edge The composite signal is applied to the grid of the writing gun

3 Reading deflection generator The reading deflection generator receives vertical and horizontal drive pulses from the sync generator rack and generates the standard TV raster scan for the reading side of the Graphechon Blanking derived from the drive pulses is coupled to the suppressor grid of the 30-Mc oscillator The oscillator modulates the control grid of the Graphechon reading gun. The signal from the target of the Graphechon then is the 30-Mc signal which has been modulated with the information written on the target The signal from the target is amplified, detected, and passed to the mixer amplifier The information at this point is in the form of TV video

Map Video Generator

Map video for mixing with the TV video is generated by use of flying spot-scanner techniques. A TV raster is written on a kinescope which has a Type P15, short-persistence phosphor A refractive optical system focuses the raster through a transparency containing the desired map information on a photomultiplier tube The light reaching the phototube is modulated by the information on the map transparency, and the resultant phototube output signal is fed through a video amplifier with the necessary response correction to the mixer amplifier where it may be mixed with the TV video A large, motor-driven disc holds a number of maps around its perimeter which are positioned in the flying spot-scanner optical system as different range scales are selected at the control console indicator

Control Console Mixer Amplifier

The control console mixer amplifier receives radar TV video, map video, TV blanking, bar generator video, and composite sync signals It provides radar TV video mixed with the proper blanking level for the 30-inch plotting console A composite video and sync waveform is provided for single-line or microwave transmission Map video, mixed with TV radar video with blanking, is fed to the control console indicator A switch on the mixer amplifier permits viewing either the grating pattern for linearity adjustment or the TV radar video at the console Adequate clamping of the video signals is provided

Control Console Indicator

The control console indicator employs a 12-inch kinescope with a P4 phosphor Included in the unit is the circuitry necessary for deflection to provide a TV raster. Video is received from the mixer amplifier at a level of approximately 1 5 volts, peak to peak, amplified and applied to the cathode of the kinescope

Controls on the front of the console permit a selection of radar ranges of 6, 10, 20, 30, and 60 miles Sixty miles is the maximum range of the ASR-2 radar With each range selection, a video map is presented to scale for the range being used Front panel controls also permit adjustment of radar TV video and map video signal levels at the input of the mixer amplifier This is accomplished by varying the bias on the input stages. A number of remote controls for the radar equipment also are present on the control console panel

TECHNICAL EVALUATION

The technical evaluation of the SRD-1 bright display equipment consisted of tests of resolution, a comparison of the discernibility of weak signals displayed by the SRD-1 and the ASR-2 indicators, brightness measurements, and an extended operational test

Resolution

The tests of resolution were made in such a manner that the limiting effects of the equipment as a whole, from the ASR-2 radar video amplifier output to the kinescope display

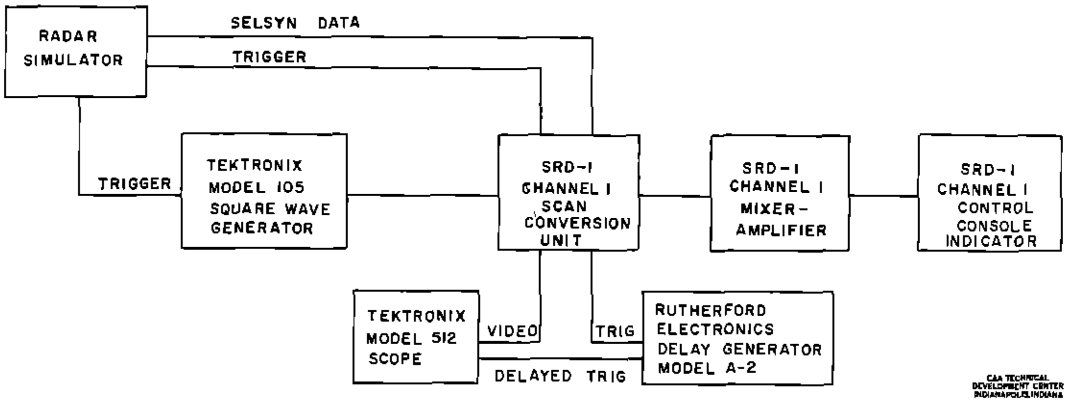

Fig. 7 Block Diagram Showing Equipment Connections for Resolution Measurements

in the control console, were considered One basic piece of equipment used for the resolution tests and all other tests was a radar simulator This simulator originally was constructed by RCA for use with the pictorial situation display equipment [8] Because work on this equipment had been discontinued, the various components were available for this evaluation To make it suitable for these particular tests, the simulator was modified to include a trigger generator to provide a more stable, jitter-free trigger and circuitry for inverting the trigger to provide a negative polarity Video from the simulator provided two targets 180° apart, but at the same range which could be varied Noise from a gas tube noise generator could be mixed with the video

A block diagram of the equipment connections employed in the resolution tests is shown in Fig 7 Trigger and selsyn information from the radar simulator was applied to the SRD-1 equipment The trigger also was used to synchronize a Tektronix Model 105 square-wave generator which provided a variable-frequency square-wave output for use as a writing signal This writing signal appeared as closely spaced, concentric circles in the final display The vertical input of a Tektronix Model 512 oscilloscope was connected to the Graphechon writing-gun grid to measure writing amplitude System trigger was connected to a Rutherford Electronics Company time-delay generator, Model A2, and the delayed output of the delay generator was used to trigger the horizontal sweep of the oscilloscope This permitted accurate measurement of the frequency of the square waves

In testing, the frequency of the square-wave generator was varied until the observer at the control console indicator determined visually that the separation of adjacent concentric circles was barely distinguishable Period, writing amplitude, and storage time were recorded

Because the tests were made with the writing sweep set for the 60-statute-mile range, the time required for writing 1 sweep was 642 microseconds The period of the written square wave divided into 642 microseconds and multiplied by 4 gave the total number of lines, black and white, for the full diameter of the viewed screen Because the concentric circles were viewed in the right-hand center portion of the indicator screen, the results obtained apply to horizontal resolution only Results of the resolution test for two types of tubes are shown in the curves on Fig 8 A plot of resolution versus writing-signal amplitude is shown for an old type Graphechon tube of unknown age and one of the new types from a production run of March 1955 The new type Graphechon, Type 1855, exhibited a considerable improvement in resolution It is apparent that resolution capabilities better than the 460 lines shown would be of little value as long as the readout scan is in accordance with RMA television standards

Relating the resolution of the SRD-1 equipment to the resolution of a radar indicator using a cathode-ray tube with a P7 phosphor, the 460 lines are equivalent to 115 resolvable

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[8] R. E. Baker, T H Bottoms, W E Miller, and C S Bartholomew, "The Status of the Experimental Pictorial Situation Display Project," CAA Technical Development Report No 218 (limited distribution), October 1953

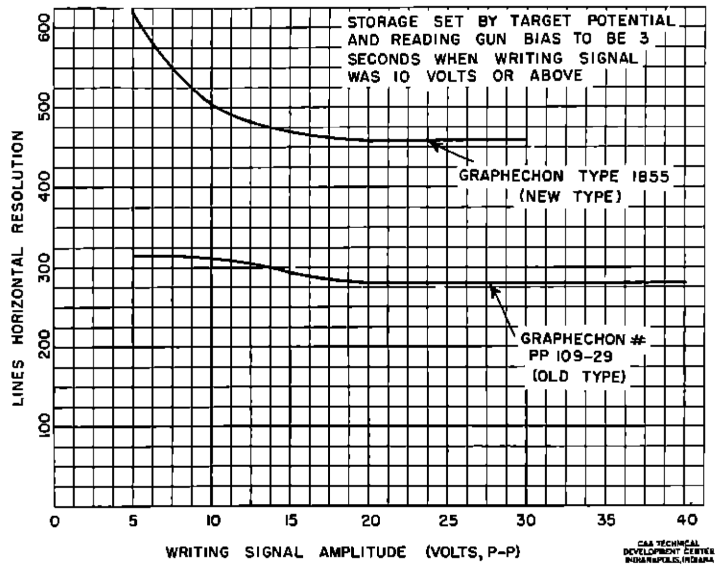

Fig 8 Resolution Versus Writing Signal Amplitude for New and Old Types of Graphechons

spots on the radius of a centered PPI This is somewhat less resolution than that of P7 tubes designed for radar use which have resolution capabilities of 150 to 200 spots along the display radius

Signal-to-Noise Characteristics

The method used to determine the signal-to-noise characteristics of the SRD-1 equipment was to compare its capabilities with those of the regular ASR-2 indicator The approach taken was somewhat statistical in nature, inasmuch as observations of a number of trained traffic controllers versed in the use of radar displays for traffic control were used

The equipment connections are shown in the block diagram, Fig 9 Video from the radar simulator was connected to the line compensation amplifiers of both the SRD-1 and the ASR-2 display units Trigger, generated at the simulator, was applied directly to the units, by-passing the line amplifiers Selsyn information was supplied to both units An RCA volt-ohmyst with a crystal detector probe was connected to the video output of the radar simulator in order to monitor noise levels for comparative purposes A Tektronix Model 524-D oscilloscope was used to measure the peak amplitude of the simulated target signals which were approximately one microsecond wide at the half-power point The simulated target was varied in amplitude and was repositioned manually in range and azimuth. The noise which was mixed into the video with the target was varied in amplitude

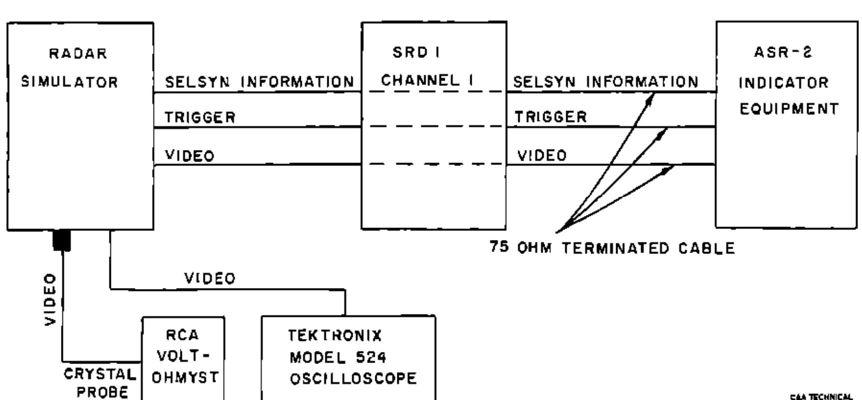

Fig. 9 Equipment Connection for Comparing Signal-to-Noise Characteristics

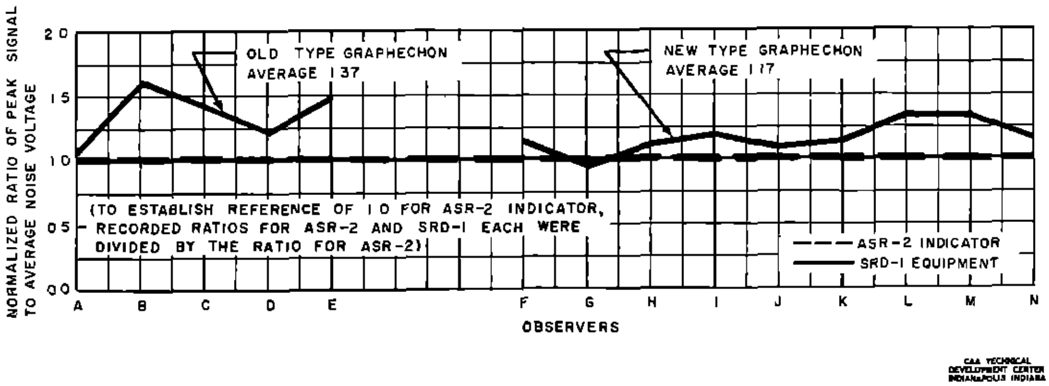

Fig 10 Comparison of Signal-to-Noise Characteristics of SRD-1 Equipment and ASR-2 Indicator

After giving the observer an opportunity to accustom himself to the process of looking for the target in the noise, the testing was started In the test, the observer did not know where the target was to appear He was given approximately 9 seconds to point out the target to a checker who was aware of its position The checker then recorded the observation as seen or unseen without informing the observer of his success or failure It was decided arbitrarily that the peak signal-to-noise ratio would be adjusted until the observer was able to identify the target 8 times in 10 tries The peak signal and noise values then were recorded The test usually was rerun at the recorded signal-to-noise levels to determine that the observer saw the target at least 8 and not more than 9 times in 10

The observations of five experienced controllers viewing the SRD-1 indicator and the ASR-2 indicator were recorded during tests with the old type Graphechon installed in the SRD-1 equipment Later, after installation of the new type tube, the tests were repeated The observations of 9 controllers, 4 of whom were experienced in the use of radar displays for the control of air traffic, were recorded The equipment setup was the same as before, with the exception that the output of the radar simulator was fed directly into the inputs of the indicators, by-passing the line compensation amplifiers

The results of the signal-to-noise tests indicated that the SRD-1 equipment was not capable of providing the same discernibility of weak signals in noise as that of an indicator using a P7 phosphor, cathode-ray tube As shown by the graph of the results in Fig 10, when using the new Graphechon, the SRD-1 equipment required a peak signal-to-noise voltage ratio of 1 17 when that for the ASR-2 indicator was 1 0

Figures 11, 12, and 13 are photographs made simultaneously of the SRD-1 12-inch indicator and the AN/SPA-8A indicator when both equipments were receiving radar video from the ASR-2 radar unit The AN/SPA-8A indicator is a Navy equipment which utilizes a 10-inch, P7 cathode-ray tube Precipitation clutter areas are shown in these pictures In the clutter areas, the write-in appears more solid on the bright display equipment than on the P7 tube of the conventional PPI It is believed that this condition is caused by the lack of halftone rendition inherent in the Graphechon Signals of all amplitudes within a given range write to the same degree of brightness, as shown by the curve in Fig 14 Storage time versus writing-signal amplitude also is shown in this curve

Brightness Measurements

The tests of the brightness capabilities of the SRD-1 equipment were made on the 7-inch monitor, the 12-inch control console indicator, and the 30-inch plotting console These units use standard commercial television kinescopes, hence, the brightness of each display is the same as may be expected from that of any television system using the same cathode-ray tubes and operating potentials.

To adjust the units for optimum picture quality, a General Electric Company Model 4PH-3A1 monoscope camera, with the familiar Indianhead test pattern, was utilized The indicators then were adjusted for best resolution, brightness, and gray-scale rendition with the recommended input video amplitude The rooms in which the measurements were made were darkened to prevent erroneous readings which might be caused by reflections The

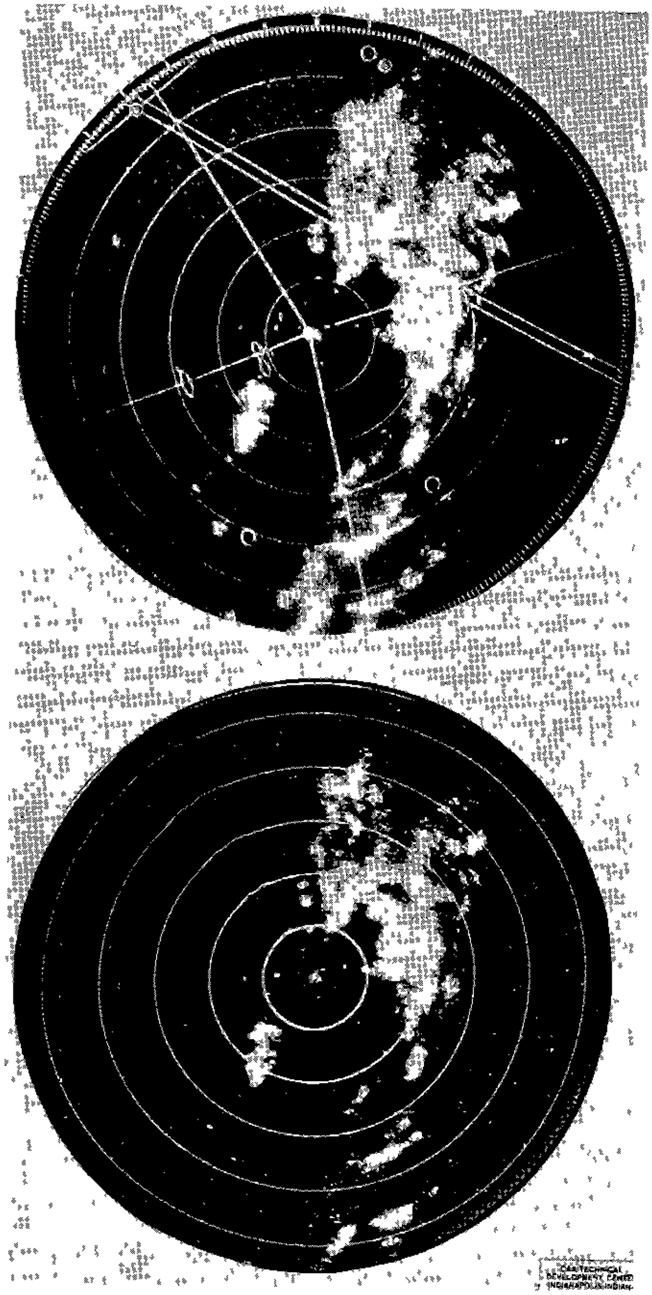

Fig 11 Bright Display Indicator (Upper) and SPA-8A Indicator Showing ASR-2 Radar Information with Precipitation Clutter (60-Mile Range)

ambient light levels were measured with normal room lighting A Luckiesh-Taylor brightness meter was used to take readings of highlight brightness in the white portion of the test pattern Table I lists the results of the brightness measurements

The highest ambient light level obtainable at the location of the 12-inch indicator was 70 foot-candles A radar presentation still was usable under this light level As pointed out

TABLE I

BRIGHTNESS MEASUREMENTS

Indicator	Brightness (foot-lamberts)	Ambient Light (foot-candles)
12-inch	35	18
7-inch	15	8
30-inch	7	17

in an earlier report,[9] brightness in a control tower on a sunny day may vary from 25 to 350 foot-candles, depending on the area within the tower Brightness from the 12-inch indicator should be adequate for tower use if care is used in selecting a location and/or if a hood is provided to shield the scope from direct sunlight.

Extended Operational Test.

The extended operational test was performed to determine the stability of the display for a prolonged period of operation Because the equipment would have been unattended during weekends, it was operated only five days a week It was energized on Monday morning, and it was operated until Friday evening. This procedure was followed for five weeks

The first two days of the test were spent in adjusting the equipment and linearizing the map generator, the scan conversion unit, and the control console of Channel 1. The radar simulator was used to provide the necessary radar trigger, video, and azimuth information It should be understood that a great number of circuits must maintain a very close degree of adjustment in order that the picture quality and linearity may be optimum at all times For example, to provide a linear radar presentation with video map on one 12-inch console, 1 radial radar sweep and 3 standard television scans must be linear This fact imposes a more stringent design problem in deflection circuitry than is found in the usual radar indicator. A satisfactory solution seems to have been incorporated in the SRD-1 equipment, however. Initial adjustment of the circuits for linearity is a time-consuming and painstaking operation, however, once they are properly adjusted, this adjustment is maintained. After the initial adjustments were completed, only minor readjustments were required from day to day Centering circuitry on both the writing side and reading side of the Graphechon conversion unit appeared to have somewhat less stability than the sweep circuits and required more frequent attention The centering of the writing-side sweep is accomplished by application of d-c potentials to the ADF yoke Off-center operation of the writing sweep also is accomplished by changing the d-c potentials One difficulty noted in every case was that in returning from off-center to centered-sweep operation, the sweep would remain off-centered for several minutes and then gradually would return to the correct center position It is believed that the metallic parts of the Graphechon retained some of the magnetism set up by the d-c potential in the centering coils during off-center operation, and that this condition may be corrected by use of a properly applied a-c potential to the centering coils during the switching period for degaussing Because switching from off-center to center operation is not required in the immediate use of the equipment, no attempt was made to determine the suitability of this solution to the problem

In order that the video mapping may be useful, it must be linear at all times With the grating generator and map-linearity slide available in the equipment, it is possible to obtain linearity within 0 75 to 1 5 per cent During the extended operational tests, no difficulty was experienced in maintaining the linearity, but, as in the other scan circuits, there was a tendency for the map to move slightly off-center. However, any displacement from the center position was easily detected and corrected

During the first two weeks of extended operation, the equipment required more frequent attention and adjustment than during the remainder of the period Most tube failures occurred during this time No components other than tubes were replaced during the entire operational test Circuits requiring the most frequent adjustment, other than the aforementioned

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[9] Randall and Marshall, op cit

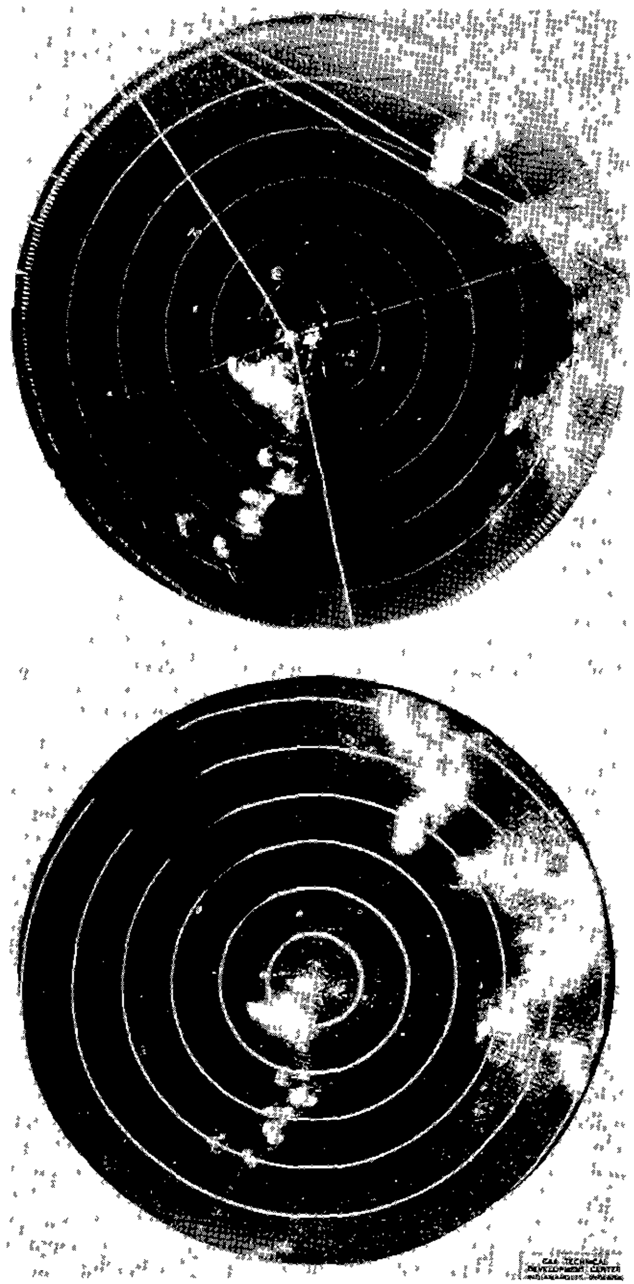

Fig 12 Bright Display Indicator (Upper) and SPA-8A Indicator Showing ASR-2 Radar Information with Precipitation Clutter (30-Mile Range)

centering circuits, were the sync generator count circuits Several of the gas tubes used in the count circuits were replaced, and the count adjustments were readjusted frequently during the early part of the test After approximately two weeks, however, the weak links were eliminated and the equipment was comparatively trouble-free in operation

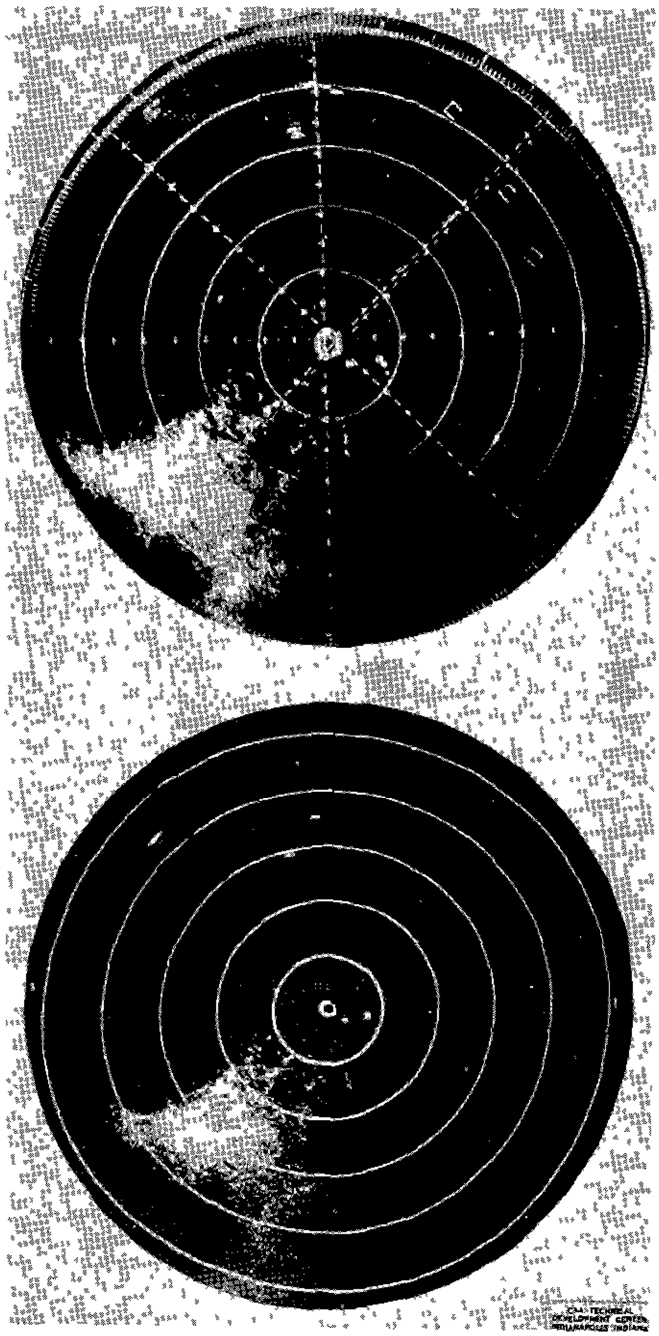

Fig 13 Bright Display Indicator (Upper) and SPA-8A Indicator Showing ASR-2 Radar Information with Precipitation Clutter (10-Mile Range)

OPERATIONAL EVALUATION

The operational evaluation of the bright display equipment consisted of observations of the indicator in varying conditions of ambient lighting, and a side-by-side comparison of the display with that of an indicator using a P7 phosphor, cathode-ray tube. Photographs made during the comparison are shown in Figs 11, 12, and 13 This evaluation is mainly a consideration of operational advantages and/or disadvantages of a display of this type in the light of present and future ATC procedures and requirements

Advantages

The main and most important advantage of the bright display equipment, considering current operational requirements, is its suitability for operation under conditions of higher ambient lighting than heretofore was possible The radar information itself is of little importance until certain other information is associated with the radar targets This supplementary information consists of altitude, identity, and flight-plan information, including estimates of positions along the various airways and geographical fixes The controller must associate the radar target information with flight data such as written information on a flight progress strip in order to formulate traffic control clearances which will move the air traffic safely and expeditiously Sufficient ambient light to permit easy reading of the flight progress strip causes deterioration of the usual radar presentation where a long-persistence phosphor is used and if the light level is decreased to the extent that the radar display is not affected, it is not possible to read the written information on the flight progress strips Some work has been accomplished on IFR room lighting in the form of blue lighting which was used in the Wright-Patterson Air Force Base RAPCON [10] The British Civil Aviation News Letter reports note the results of several tests made in room lighting for radar quarters [11] There appears to be some question, however, concerning the psychological effect on the controllers working under predominantly blue ambient light

The trichromatic lighting[12] which has been in use at TDC has been satisfactory for IFR room lighting This system utilizes the light from a mixture of three colored fluorescent bulbs (red, blue, and green) to produce an apparently white light This light, when used in conjunction with a deep orange filter over the radar indicator, has provided a level of ambient light which is satisfactory for the reading of tabular displays and yet does not cause serious degradation of the radar presentation Of course, this type of lighting is satisfactory only in those quarters where it is possible to mount the lights properly and where it is possible to exclude all other light except that from the trichromatic source. A lighting system which employs ambient lighting deficient in the green region of the spectrum and scope filters which pass only green light has been developed by the Franklin Institute Laboratories.[13] This lighting system is being evaluated

It has been possible at some radar locations to provide a light source which is adequate for reading tabular displays and yet does not seriously affect the readability of the radar presentation It should be pointed out, however, that each location is unique, having its own problems requiring special consideration and solution For this reason, a type of bright display is needed which is relatively unaffected by the ambient light level and which is usable under all conditions and levels of lighting. The use of the bright display equipment offers a solution to the problem of providing proper lighting for the area in which the radar indicators are to be used

A second advantage of the bright display equipment and the scan conversion technique, in general, is that once the presentation is in the form of a TV scan, additional indicators are relatively simple and inexpensive This means that it would be possible to make extensive use of the radar presentation without great cost For example, an indicator could be mounted in the operations panel in the control tower cab By necessity, it might be hooded to keep the direct rays of the sun from the tube face to prevent loss of some of the contrast, but it would be there in constant readiness to answer the controller's question of the separation between two aircraft approaching from opposite directions, whether time existed in which to clear a takeoff following a jet arrival, or many of the other questions that radar can answer for the

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[10] C. L Kraft and P M Fitts, "A Broadband Blue Lighting System for Radar Air Traffic Control Center," WADC Technical Report No 53-416

[11] J V Noyes and J. W Birchall, "Interim Report on Lighting System to be Employed in New LATCRS Operations Room," ACTEU Report No 21, Ministry of Civil Aviation, Air Traffic Control Experimental Unit, London Airport

[12] C M Anderson and T K. Vickers, "Application of Simulation Techniques in the Study of Terminal-Area Air Traffic Control Problems," CAA Technical Development Report No 192, November 1953.

[13] Walter W Felton, "Summary of Engineering Services for the Airways Operations Evaluation Center," Franklin Institute Laboratories Final Report No F-A1816-1, Contract C13ca-530

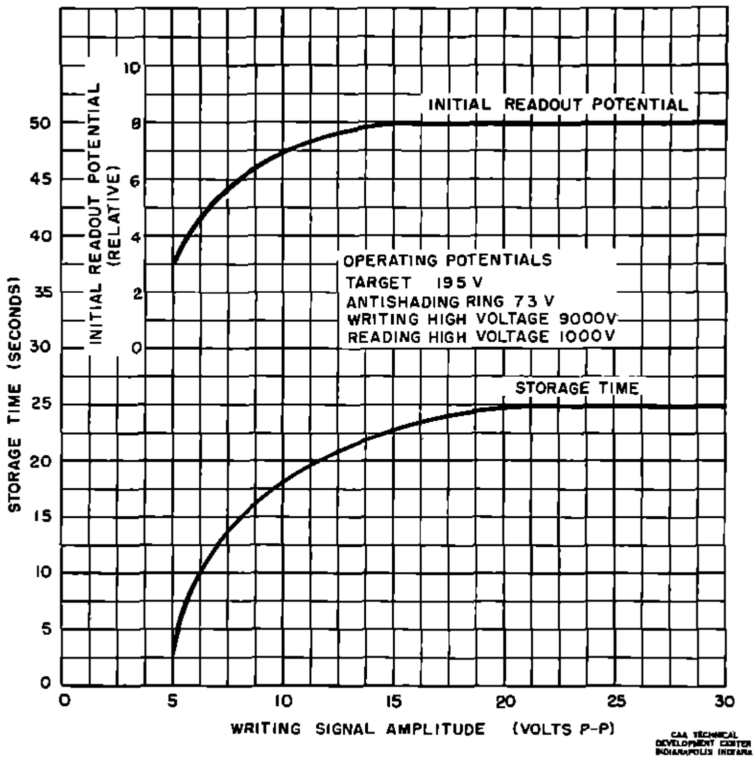

Fig 14 Storage Time Versus Writing Voltage and Initial Readout Amplitude (Within One Second After Writing) Versus Writing Voltage for New Type Graphechon

controller in the tower cab on a VFR day The installation of long-range radar at the en route traffic control centers has made necessary the installation of many indicators and has pointed up the need for large horizontal plotting indicators. The large indicators are necessary so that several controllers around a single display can observe air traffic targets and can pass information for coordination purposes directly to each other instead of through telephone lines or through a third person Through the use of large-screen television methods, a large and bright display can be provided, and with the TV transmission facilities and techniques now available, it would be possible to remote several geographically spaced radars to a common point for the use of en route traffic control

Disadvantages

A limitation of the SRD-1 equipment is that only one picture at a time is available from a scan conversion unit. This means that two different pictures are available from the dual-channel equipment All indicators connected to the same channel have the same picture When the control console for a given channel is changed to show another range, all indicators connected to that channel display the new range. A fault common to any scan conversion technique, however, is a lack of flexibility and control of the radar information at the indicator

In the display of beacon targets on the SRD-1 equipment, it would not be practicable to display double blips to denote transmission of the selected code when the decay time is set to store a signal for three or four antenna scans, because the second blip would be obliterated The single-blip beacon display is quite satisfactory, however Fruit, or nonsynchronized beacon returns, as well as MTI residue, would be more objectionable at the longer storage settings

The minimum time for complete erasure of written information on the Graphechon has varied from 1 second to as much as 30 seconds, depending on the tube In those cases where the minimum erasure time is long, it is not practical for a controller to switch from one range to another for a few seconds to view a situation and then return to the original range to continue his operation Written information for both range scales is displayed for a short time so that the display is unintelligible No doubt there are other disadvantages as well as advantages of the SRD-1 equipment which would become evident as additional experience with this equipment is gained.

The SRD-1 equipment was used to drive indicators for the Airways Operations Evaluation Center at Indianapolis A television projection system was mounted near the ceilin of the operations room and was projected downward to provide a 36-inch radar display on a panoramic display board, a new tool for en route traffic controllers which was developed and now is being evaluated at this Center The information from an ASR-2 radar was displayed The 30-inch plotting console of the SRD-1 equipment also was used in conjunction with the television system of the dynamic air traffic control simulator to provide a large plotting-type display for use in simulation of en route control problems.

RESULTS OF TESTS AND STUDIES OF OTHER DISPLAY TECHNIQUES

Because of the continuing need for a bright display for terminal area use and an increasingly urgent requirement for large horizontal displays for en route traffic control, tests and studies of various techniques have been made at TDC One approach, which has been given considerable attention, has been the utilization of the direct-view storage tube having a brightness suitable for projection

The immediate advantage of the direct-view, storage-type tube over a tube such as the Graphechon is that it is possible to write the radar information and view it directly Thus, the scan conversion process is unnecessary, and much complicated circuitry and equipment are eliminated The Farnsworth Electronics Company has developed one such tube, the Iatron. In the fall of 1954, tests of a three-inch Iatron were performed, using first a TV scan and then a radar plan-position scan The results of these tests were encouraging, and a specification was prepared for a projection radar indicator based on a storage tube of the direct-view or projection type The purpose of the specification was to obtain a radar display large enough and bright enough for horizontal plotting to facilitate en route traffic control Because it was apparent that both brightness and resolution would be marginal using currently available tubes, the concept of projecting from overhead directly onto a white matte surface was utilized This method of projection appeared to provide the optimum in brightness and resolution for viewing from all angles Before a contract was awarded for the equipment, the projection method was tested in connection with ATC simulation studies at TDC A TV projection unit was mounted overhead so that a 36-inch-diameter display was projected onto a plotting board used with the simulation of en route traffic control problems. The technique seemed satisfactory from an operational standpoint The simulated aircraft blips fell on top of markers carrying flight data. The markers were moved along as the blip moved in simulated flight

The Farnsworth Electronics Company ultimately was given a contract to build three radar projection display units. The first of these was delivered in March 1956, and it now is in process of evaluation It uses one of the Farnsworth four-inch tubes Preliminary studies indicate that the Iatron radar projection unit is capable of providing a display 48 inches in diameter with a highlight brightness of about 3 foot-lamberts Its resolution appears to be adequate for most radar display applications The Farnsworth company has indicated that within a short time, it hopes to have a four-inch tube available with a greater useful tube-face area The present useful area is approximately three inches in diameter Should this be increased to about 4 inches, the available display brightness would be increased by a ratio of 4 3

The results obtained so far with the projection-storage tube seem to warrant further investigation into this method of obtaining a large, bright display Consideration should be given to sponsoring development to improve direct-view storage tubes Equipments using the storage tubes of other manufacturers also should be considered for evaluation as they become available

Scan conversion techniques by use of a television camera and a PPI have been explored A TV camera with an Image Orthicon tube was used to televise a PPI display The PPI cathode-ray tube had a P7 phosphor The results were unsatisfactory The range of light output available from the indicator tube was too great for the Image Orthicon camera. It could not be adjusted to show both the initial writing on the kinescope and the trail information without excessive "blooming " In no case was it possible to adjust the camera to show the decayin light from the indicator tube for more than 2 or 3 seconds It was concluded that the Image Orthicon tube is as complicated as the Graphechon from the standpoint of associated circuitry, and because it could not provide as good as picture, this work was discontinued

The possibility of using a simple Vidicon camera for scan conversion appeared attractive, and was investigated Indicator tubes with P7 and P25 phosphors were televised In both cases, however, the Vidicon sensitivity was not sufficient to provide a picture of the trail information. The targets became invisible within about two seconds In further tests, a Skiatron dark-trace tube, Type 4AP10, was installed in an ASR-2 PPI and was televised with a Vidicon camera The results were somewhat promising, and procurement of 2 recently developed 10-inch dark-trace tubes was initiated It is hoped that the faults of the 4AP10, such as poor decay characteristics and contrast, will be less evident in the new tubes The new dark-trace tubes use light rather than heat for control of erasure of the written information, and they are reported to have higher contrast ratios

Another method for producing a large and bright radar display consists of a rapid film-processing camera unit and projection system Demonstration of such equipment has resulted in plans for procurement and operational evaluation of the system for possible application in air traffic control The rapid-processing camera and projection system combines in one unit a radar indicator, a means of photographing the cathode-ray tube, development of the recorded image in a very brief period of time, and projection of the recorded image One such equipment observed in operation incorporated such features as 35-mm film usage, a 1,000-watt, mercury arc-projection light source, and a minimum film-processing time of 4 seconds The developed image on the film is permanent, and it forms a record which may be referred to at any later time This feature may be desirable in air traffic control Recent developments in the rapid processing of color film indicate that such equipment will be satisfactory for continued usage upon the introduction of color displays in air traffic control

The major advantage of the rapid-processing camera and projection system is the increase in brightness of the radar display over that of the other systems described This type of display is to be evaluated to determine whether the display characteristics are suitable for air traffic control use, and whether such factors as cost and storage of film and chemicals and maintenance required to change the film and clean the chemical system are of serious consequence

CONCLUSIONS

The SRD-1 bright display equipment provides a bright radar display for use under high ambient light conditions Its limitations basically are those of the Graphechon storage tube, which are

1 Discernibility of weak signals in noise is less than may be expected of a conventional PPI using a P7 phosphor This weakness appears to result from the Graphechon's inability to display written halftones or gray scale Although this difference is slight in terms of the voltage ratios, as noted in this report, it does mean that very weak targets which are barely discernible on the normal PPI are not discernible on the SRD-1 display
2 Resolution, although not of as great importance as the signal-to-noise characteristics, is less than that of a normal PPI
3 The complexity and amount of equipment required to provide one display are greater than for a conventional PPI because of the linearity requirements of the several sweep circuits and the necessity for rigid control of the video circuits and stability of the synchronizing signals The use of the equipment would require carefully trained maintenance personnel
4 Because each scan conversion unit is capable of providing but one display, the cost of the equipment is prohibitive unless the unit can be used to drive several displays

Advantages of the SRD-1 equipment are

1. Brightness of the final display, of course, is the foremost advantage The SRD-1 equipment permits viewing of the radar display under conditions of much higher ambient light levels than are permissible with any of the long-persistence phosphor displays
2 Where the need exists, many presentations of one radar display could be provided by each channel by the use of simple repeaters
3 The variable-storage capability of the Graphechon permits a storage adjustment to compensate for the slower antenna scan rates Added storage means longer target trails which would lessen the objection to slower antenna-rotation rates Slower antenna rotation gives some improvement in target quality when scanning clutter is the limiting factor in MTI operation
4 The use of projection TV techniques in conjunction with the SRD-1 equipment provides a means of obtaining a large horizontal display for en route traffic control
5 The more readily available TV signal transmission techniques and facilities should make it simpler to remote the SRD-1 output signals than the radar video, trigger, and azimuth information which is required if a PPI is used