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MODIFYING SCR-584 RADAR UNITS FOR INSTRUMENTATION AT SALTON SEA TEST BASE

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January 25, 1949

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FOREWORD

It is an acknowledged fact that in scientific achievement the invention of radar is surpassed only by that of the atomic bomb.

Radar affords new facilities to man's sensory equipment. It enables objects to be "seen" -- that is, detected and located -- at distances far greater than those at which they could be distinguished by the eye alone. This "sight" is unimpaired by darkness, fog, clouds, smoke, or most other obstacles to ordinary vision. Radar also permits the range, azimuth angle, and elevation angle of the object it "sees" to be measured with a convenience and precision heretofore unknown.

The superiority of radar to ordinary vision lies, then, in the greater distance at which "sight" is possible, in the ability of radar to "see" regardless of the light conditions or the obscurity of the object, and in the unparalleled ease with which the range of the object and its rate of change can be measured. However, radar does not present a detailed definition of the target, but only the gross outlines of a large object. Radar is at its best when detecting isolated targets on relatively featureless backgrounds, such as aircraft in the air, ships on the open sea, islands, coast lines, and cities situated on a plain.

The coined word "radar" is derived from the phrase "radio detection and ranging". Radar operates by sending out radio waves from a transmitter antenna powerful enough that echoes of measurable amounts of radio energy reflect from a target and

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are indicated on a radio receiver usually located, for convenience, at the same site as the transmitter. Most basic radar units use the same antenna for transmitting and receiving. The properties of the echoes form a particular picture, or presentation, on the radio receiver from which the properties of the object causing the echoes can be determined. The transmitter of the most practical and widely used radar unit is modulated to send out intermittent intense, brief pulses of radio energy. Between the pulses of the transmitter the receiver is active. Soon after the transmission of a pulse, echoes from the nearest objects are received first, those from more distant objects later. When sufficient time has elapsed to receive the echoes from the most distant objects of interest, the transmitter is keyed to transmit another short pulse, and the cycle is repeated. Because the radio waves used in radar are propagated with the speed of light, the time between the transmission of a pulse and the reception of an echo from the object at range R will be $T = \frac{2R}{c}$; the factor 2 is involved because the distance to the object is traversed twice, once out and once back. Therefore, range measurement is reduced to a measurement of time, and time can be measured more accurately than any other basic physical quantity.

Because the radiation from the antenna is in the form of a narrow beam, angular measurements are obtained by determining the direction in which the radar antenna is pointing. In some radar units, the antenna is made to move both in elevation and azimuth.

These are the principles on which the basic radar unit operates.

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MODIFYING SCR-584 RADAR UNITS
FOR INSTRUMENTATION AT
SALTON SEA TEST BASE

Summary. -- It would have been advantageous to include photographs of all modifications described herein; however, this was not possible because the modifications to the SCR-584 radar units were incomplete when the report was published. When these modifications are completed, a supplemental pictorial report will be published.

So that extensive development and modification procedures could be performed, special electronic test equipment was required. Several necessary test instruments were not immediately available from vendors; therefore, the Radar Section engineers had to design and fabricate numerous components. Some of the instruments they designed were (1) electronic target simulator, (2) range scope sweep calibrator, (3) special type pulse generator, (4) pulse transformer testing unit, and (5) variable gate generator.

The basic SCR-584 radar unit is being developed and modified by Radar Section engineers to convert it from a gun-laying radar unit for tracking slow-moving targets into an accurate radar theodolite. Primarily the modified radar system will furnish accurate trajectory, velocity, flight path, and other ballistic and some aerodynamic data on field test operations conducted by the Field Test Department. Other data furnished by the radar units will be impact time, impact point, release point and time, as well as time-of-flight of the target or missile. The SCR-584 is a pulsed radar unit operating at a

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frequency around 2900 megacycles. Two of these highly modified SCR-584's will be permanently installed in concrete buildings at the Salton Sea test base. One modified SCR-584 is capable of measuring and recording accurately the azimuth and elevation angles and slant range, thereby supplying three-dimensional position data.

(A). Introduction

In operational use the modified SCR-584 has many advantages over other tracking instruments: (1) it can locate and track targets far beyond the range of any optical instrument; (2) it can track fast targets flying at extremely high altitudes, consequently it is adaptable to any type of field test operation; (3) it does not require clear visibility as do optical trackers. The SCR-584 can track and record data on targets flying through broken or solid overcasts. (4) Its angular tracking rates are superior to those of any other tracking system. (5) It can track small targets. (6) It is especially adaptable for use in directing or positioning other devices during operations.

Plans are under way for the construction of permanent buildings that will house the radar systems at the Salton Sea test base; at present, the radar units are installed in trailer mountings. Two modified SCR-584 radar units will be used to furnish data on field tests. In conjunction with the radar system, an optical tracker will be used, when required, for remote positioning of the radar antenna. The optical tracker will be used primarily to insure that, should the radar system fail momentarily during a test, by switching the radar to remote control the radar system, on resuming operation, may be immediately positioned on target and continue to record ballistic data.

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Many modifications are being developed and installed on the radar units to increase their efficiency and adapt them for instrumentation on particular types of specialized test operations.

(B). Setup for Modification

To convert the SCR-584 radar unit to an accurate recording instrument, it is necessary (1) to modify many electronic circuits, (2) design new circuits and components, (3) develop the existing electronic and mechanical components, and (4) fabricate and install camera systems and indicator scales.

(C). Purpose

These developments and modifications will convert the basic SCR-584 radar unit into a highly specialized radar theodolite:

(1). Azimuth and Elevation Scales. -- Azimuth and elevation scales have been designed and are being fabricated by the Precision Machine Shop, SLF, for installation on the antenna pedestal of the SCR-584 unit. These scales are so precisely graduated that angular measurements can be recorded to the nearest 10 seconds. This angular accuracy corresponds to 3 feet at 11 miles. Once installed, these precision scales will make the radar units at the Salton Sea test base the most accurate in existence for angular measurements. The instantaneous angular data furnished by the scales will be recorded by a precision data-recording camera. (The system for synchronizing the scale camera with the remaining data-recording cameras is discussed in paragraph C-4, Data-Recording Cameras.)

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(a). The azimuth scale is constructed of an aluminum ring 38 inches in diameter, 2 inches wide, and 1/2-inch thick. The outer top surface is graduated into 6400 equal divisions with special identifying graduations at every fifth and tenth division. Each tenth division represents a 10-mil angular measurement; the numeral corresponding to the angle is stamped near the graduation. The stamped numerals may be considered the multipliers of each 10-mil graduation.

The azimuth scale, permanently mounted on the antenna pedestal, must be perfectly level to avoid small errors in the data caused by a tipped axis.

(b). The elevation scale is similarly graduated and marked. This scale rotates with the antenna and furnishes data through only one quandrant of elevation, hence is graduated into 1600 equal divisions (90 degrees) plus 200 divisions in the negative direction from the horizontal plane for measuring the angles of depression.

The elevation scale, mounted on the antenna counterweight so as to move through the elevation quandrant, centers its rotation about the horizontal axis. (One camera is used to photograph both the azimuth and elevation scales.)

(c). A small azimuth vernier is installed on a mounting bracket so as to rotate with the antenna, its graduated surface being 0.003 inch from the outer graduated surface of the azimuth scale. This vernier permits a direct reading of azimuth angle that is accurate to within 0.05 mil.

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(d). An elevation vernier is installed on a mounting bracket so as to rotate in azimuth with the antenna, its graduated surface separated 0.003 inch from the graduated surface of the elevation scale.

(e). The recording camera for the scales is mounted on a bracket that rotates in azimuth with the antenna and at all times is perfectly aligned with the elevation and azimuth verniers. The camera is mounted at such an angle that the camera axis bisects the right angle formed by the azimuth and elevation scales. This particular mounting allows the camera to be properly focused on (1) the azimuth scale, (2) the azimuth vernier, (3) the elevation scale, and (4) the elevation vernier.

(f). A photoflood lamp, such as an RSP-2, will be used to illuminate the scales and verniers for photographic purposes.

(2). Auxiliary 2000-Yard Range Indicator. -- An auxiliary 2000-yd range indicator and its power supply have been developed and fabricated by Radar Section engineers to present a cathode ray indication of the target being tracked by the radar unit. A camera, synchronized with other data-recording cameras, photographs the instantaneous coarse and fine range data of the target provided by the auxiliary 2000-yd range indicator.

Fine range data are presented by the cathode ray tube, which has a 2000-yd circular sweep. The fine range reading is obtained through the use of a circular scale graduated into 1-yard divisions.

The major components of the auxiliary 2000-yd range scope are (1) one J type cathode ray tube, (2) one selsyn indicator, (3) two sweep-transformers to obtain the circular sweep on the

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cathode ray tube, (4) one 81-kc transformer, (5) one 81-kc sine wave amplifier, (6) one range gate amplifier, (7) two stages of video amplification, and (8) operating and control circuits.

The power supply, of conventional design, supplies regulated and unregulated positive voltages and regulated negative voltages.

(3). Automatic Range Tracking Unit. -- A component known as an automatic range tracking unit, which makes the SCR-584 a completely automatic tracking instrument, has been designed by W. A. Janvrin of SLA-2 and fabricated by the SLF Electronic Shop. The Radar Section engineers are developing and modifying this unit to improve its efficiency for the operations conducted at Salton Sea.

The electronic range tracking by this unit is dependable and accurate; its ability to track high-velocity targets far exceeds that of any manual tracking mechanism. It can electronically range-track targets up to 5000 mph in radial velocity; furthermore, the electronic range tracking gates follow the target within ± 5 yards at radial velocities up to 3000 feet per second. This tracking tolerance is not detrimental to the measurement of range data obtained by the radar system, however.

The automatic range tracking unit is a complicated electronic component comprising 32 tubes; its separate power supply has 14 tubes that provide the required voltages.

Its operation can be summarized as follows:

> An early and a late gate are generated, the widths of which are 0.5 microsecond and are separated in time by 0.7 microsecond. These gates are electronically moved to keep the 0.8 microsecond target echo centered between the early and late gates. When the center of the target echo lags the midposition established by the early and late gates, it causes half of

a coincidence tube to conduct more heavily and thereby repositions the gates to center around the target echo. When the target leads the gates, it causes the other half of the coincidence tube to conduct more heavily, and, conversely, repositions the gates to center around the target echo. When the gates are centered around the target echo, the same amount of current is conducted through both halves of the coincidence tube and, with this condition, the gates do not move. This correctional operation is so rapid that a maximum range tracking error of ±5 yards will occur when target velocities are 3000 feet per second. A servomechanism is also a part of the automatic range tracking unit. Its operation causes the mechanical range indicators to follow the position of the electronic tracking gates.

(4). Data-Recording Cameras. -- To obtain precision data from a radar system, a means of recording the data is necessary. Movie cameras are the best recorders for use with the SCR-584. A system has been developed whereby 35-mm cameras photograph (1) azimuth and elevation angles, (2) slant range, and (3) the actual target that the radar is tracking. The three cameras are so synchronized that data recorded in one picture frame by any one camera will correspond in time to the same numerical frame of either or both of the other recording cameras. A reference mark is generated and placed on a recorder, such as an Esterline-Angus or a Hathaway, each time the camera shutter opens. All pertinent timing signals used as a time base for all instrumentation at the Salton Sea test base are also placed on the recorder.

Bell and Howell "Eyemo" cameras, operated by a common synchronous drive system, record radar data at 20 frames per second. Specially designed interlocks are the driving mechanism that synchronizes the camera shutters.

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The range camera, installed on a special mount in such a position as to maintain proper focus, photographs the fine range data on the auxiliary 2000-yd range scope and at the same time photographs data indicated on the dial of the coarse range selsyn near the picture surface of the 2000-yd scope.

The scale camera is installed on a bracket mount on the antenna and rotates in azimuth with the antenna. This camera photographs both azimuth and elevation angles each time the shutter is opened.

The tracking camera, installed on the antenna in such a position that an 80-in. focal-length lens barrel looks through a hole in the parabolic antenna reflector, photographs the target. A highly magnified picture is obtained by use of the 80-in. focal-length lens barrel, which was designed by the Optical Measurements Division, SLT. The tracking camera provides a means of applying tracking corrections to the angular measurements as recorded from the azimuth and elevation scales. For example, in one picture frame the elevation of the radar antenna may be 1.5 mils under the elevation of the target. Consequently, the elevation-scale reading would be in error by 1.5 mils. The picture taken by the tracking camera would show the target 1.5 mils off the horizontal axis of the camera and in a direction opposite the vertical path of the target. Using information obtained from the film of the tracking camera, absolute corrections may be made to the elevation-scale reading. Azimuth corrections can be similarly made.

After all tracking corrections have been made, it is readily understandable how angular measurements obtained by radar are accurate to 0.05 mil.

(5). The 96,000-Yard Range Extension. -- Fundamentally the SCR-584 was designed to track targets automatically from 0 to 32,000 yards. So that the radars might track aircraft and test vehicles used in operations at the Salton Sea test base, their automatic tracking limit was extended to 96,000 yards by an extensive modification for which numerous electronic circuits and mechanical operations had to be developed.

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Electronic circuits were developed that reduced the pulse-recurrence frequency of the radar unit from the original 1707 cps to 854 cps. This was necessary to extend the interval between pulses so that echoes could be received from objects up to 96,000 yards. To reduce the pulse-recurrence frequency, however, it was necessary to alter the frequency-dividing multivibrators, gate-forming multivibrators, and delay multivibrators in the basic range unit so that they would perform properly throughout the extended range. The range unit, an extremely complicated component, is the heart of a radar system. Each of its electronic circuits was developed to meet and maintain the precise functional requirements.

A new sweep circuit was designed to present on one range scope three individual 32,000-yd sweeps -- 0-32,000 yards, 32,000-64,000 yards, and 64,000-96,000 yards. An electro-mechanical system was designed to switch automatically to the sweep which meets the range requirement. As a part of this development, a range indicator system was designed to operate automatically so that an operator can rapidly determine target range without calculations.

The mechanical gear train of the range indicator system was modified radically to conform to the extended range. Personnel of the Radar Section, SLT Engineers, and SLF designed and fabricated the modified gear train.

(6). Extension of Range for PPI Presentation. -- The plan-position indicator (PPI) of the basic SCR-584 presented target data 70,000 yards distant. A selector switch offered two range sweeps, 35,000 and 70,000 yards. Operations conducted by the Field Test Department require the radar to track aircraft at a greater distance than is possible by use of the basic SCR-584, so to adapt the radar system to the maximum requirements, the range of the PPI had to be extended. This was accomplished by modifying the PPI to present target data from 0 to 140,000 yards. New sweep circuits as well as a three-position switch were designed so that the operator can select PPI sweeps of (1) 35,000 yards, (2) 70,000 yards, or (3) 140,000 yards. This modification enables the radar system to detect large aircraft eighty miles away.

Because large aircraft eighty miles distant can be detected by radar, accurate alert warnings can be determined at the radar station and passed on to the control tower and range instrument installations. Accurate alerts, such as 5-, 4-, 3-, 2-, and 1-minute warnings, can be readily given to within ±3 seconds. With radar operators supplying this information, personnel in the aircraft may be relieved of the responsibility. Moreover, the approach warnings determined by radar information will be far more accurate than those given from the test aircraft.

(7). Wide-Band Video Amplifier. -- The video amplifier component of the basic SCR-584 was not designed to make such precise range measurements as required for computing accurate three-dimensional position data.

The only appreciable range error inherent in the SCR-584 is produced by amplitude variations of the target echo. As the amplitude of the echo increases, the leading edge of the echo may be erroneously positioned because of the insufficient frequency-band pass of the intermediate-frequency amplifiers and video amplifiers. Because the leading edge of the echo cannot be a positive indication of the target range, a single range measurement may be as much as 25 yards in error. By plotting several range measurements on a moving target, the smoothed range data is usually accurate within 5 to 10 yards.

As the modified radar system can accurately measure angles to 0.05 mil, it is desirable that it measure range with comparable accuracy. A new video amplifier component has been designed that reduces the range error approximately 75 per cent. The design of a wide-band intermediate-frequency amplifier strip will further improve the ability of the radar unit to measure range. As soon as time permits, a complete radar receiver will be designed to make range measurements approach absolute accuracy.

The newly designed video amplifier component has a frequency-band pass sufficiently wide that all frequencies of

the echo will be passed. All video circuits are designed to produce an extremely steep leading edge of the echo pulse, which further reduces the possibility of error in range measurements. Each video stage has a separate function in clipping, shaping, and amplifying the echo.

The new video component has a higher over-all voltage amplification factor than the original one, thereby helping to deflect the scope trace so the break in the base line at the leading edge of the echo will approach 90 degrees. This rapid deflection improves the accuracy of range measurement.

(8). The N^2 Gate Modification. -- The basic SCR-584 was designed to track a target automatically in azimuth and elevation throughout the 32,000-yd range. The automatic antenna positioning was accomplished by developing and utilizing an error voltage to operate a servomechanism, which points the radar antenna at the desired target. The error voltage is directly proportional to the instantaneous pointing error of the antenna. To prevent the entrance of error signals into the servo channels from the many objects lying within the 32,000-yd range, a gating system was incorporated to disable the antenna-positioning servo except when the coincidence range gate was applied. The original range gate normally was approximately 1800-yards wide and could be delayed for manual tracking purposes through the entire 32,000-yd limit, thus the only error signals entering the servo channels would be from objects within the limits of the 1800-yd range gate. However, tracking the target by this system was erratic because too many objects were within the limits of the 1800-yd range gate.

To overcome these disadvantages, a modification, known as an N^2 Gate Kit, was developed by the Signal Corps. "N^2 Gate" means "narrow narrow gate". The kit installed on an SCR-584 reduces the width of the original 1800-yd tracking gate applied to the antenna servo channels to approximately 50 yards. This eliminates interference from undesired objects so long as they are more than 50 yards slant range from the desired target.

Because the radar units at Salton Sea must furnish extremely accurate position data, engineers in the Radar Section installed an N^2 Gate Kit on each operational radar. This installation necessitated the modification of numerous electronic circuits in the receiver, range unit, and range indicator unit. Moreover, interconnecting cables had to be designed, fabricated, and installed because the N^2 Gate Kits were incomplete.

(9). Master Range Unit. -- The master range unit modification was designed to obtain the highest degree of efficiency in tracking. It provides a means of synchronizing the triggering of two or more SCR-584 radar units; it prevents the main pulse of one radar unit from drifting through the tracking gate of a unit nearby causing it to lose the target or cause faulty tracking when the interfering main pulse is within the limits of the tracking gate.

The master range unit utilizes the chassis of the present SCR-584 range unit and has no external components other than two impedance-matching transformers to match (1) the coaxial cable to the transmission line, and (2) the transmission line to the coaxial cable at the slave radar site.

To complete the master range unit modification, the range unit of all adjacent radar units had to be modified. These were then considered slave radar units.

In all types of equipment, operational failures can be expected; consequently the slave range unit was designed to switch automatically to its own crystal oscillator should the synchronizing 81-kc sine wave from the master range unit be interrupted.

The operational function of the master range unit and a slave range unit follows:

The 81-kc sine wave in the master station is fed through (1) a specially designed amplifier, (2) an impedance-matching transformer,

(3) a section of RG-58/U coaxial cable, (4) an impedance-matching transformer, (5) a long two-wire open transmission line, (6) an impedance-matching transformer, (7) a length of RG-58/U coaxial cable, (8) through an impedance-matching transformer, to. (9) the input of the slave radar range unit. The two radar systems are approximately three miles apart. At the slave unit the 81-kc sine wave from the master station is coupled to the control grid of the crystal oscillator and is used as a synch voltage. So long as the synch signal is of sufficient amplitude, the radar units are synchronized. Should the synch signal fail, the slave station will automatically switch to operate from its own crystal oscillator.

(10). Pre-Amplifier. -- A newly designed pre-amplifier for the input of the radar receiver is being fabricated by the L. H. Terpening Company and should be ready to be installed on the radar units at Salton Sea about February 21, 1949.

Improving its receiver is the most desirable and practical method of increasing the effective range of a radar unit. A 3.0-db gain in the receiver extends the effective range about 25 per cent. To extend the range 25 per cent by increasing the transmitter power it might be necessary to design new high-voltage rectifiers, a driver unit, modulator unit, and possibly a new type of transmitting tube. Therefore, when the effective range of a radar system is to be extended, the receiver is the logical starting point.

The pre-amplifier to be installed on the radar units at Salton Sea will actually produce a 2.9-db gain obtained mainly by the design of the new input circuits that decrease noise. The signal-to-noise ratio of this amplifier will increase the effective range of the radar units about 25 per cent.

(11). The 8-Foot Parabolic Antenna Reflector. -- The parabolic reflector on the original SCR-584 was six feet in diameter and, while in conical scan, produced a wide beam of approximately 8 degrees at the 50 per cent power points.

The new parabola, eight feet in diameter, decreases the conical-scan beam width to approximately 4.5 degrees, thereby concentrating greater power in the beam. Consequently, the effective range is increased approximately 25 per cent.

Two 8-ft parabolas have been ordered and should be ready for installation about February 21, 1949.

(12). Cabling for the Radar Buildings at Salton Sea. -- New interconnecting cables must be fabricated before the installation of SCR-584 radar sets in the permanent buildings can be completed. Radar Section engineers have completed the design layout of cables for all interconnecting electrical circuits of the radar units. This required designing, labelling, and drawing specifications for more than 100 cables.

Four complete sets, more than 400 cables, are being fabricated by SLF. The cables will be installed in the radar buildings at the Salton Sea test base by Radar Section personnel.

(13). Velocity Feedback for the Automatic Tracking Unit. -- The automatic tracking unit is being modified to enable the antenna to follow the target more closely. A velocity feedback is utilized in some electronic circuits to cause the antenna to point in reaction to a smaller error signal; thus the automatic hunting about the target is more rapid and is limited to a smaller field of search.

This modification requires numerous changes and critical adjustments in the electronic circuits, but it will enable the tracking units to follow the target accurately and furnish more positive three-dimensional position data. The modification is of further advantage when the radar system is used to position a remote instrument.

(14). Modulator Modifications. -- Numerous circuits in the driver and modulator units have been developed and installed to stabilize operation and increase the peak power output of the radar system from 250 to approximately 375 kilowatts.

A delay multivibrator was designed and installed in the driver unit to permit variable positioning of the main pulse on the range scopes for aligning the zero range indicator with the leading edge of the main pulse.

(15). Remote Plan-Position Indicator. -- A PPI unit is being modified for remote operation in the Operations Room of the new instrument laboratory at the Salton Sea test base. This instrument will be at the test conductor's console and will present a plan-position picture of the target being tracked by one of the radar units.

Extensive development is required before operational data from the radar site can be transmitted to the instrument laboratory. Numerous circuits within the PPI are being modified to make it a simple and practical data indicator. This remote unit will provide a constant flow of target-position information to the test conductor, enabling him, in turn, to perform his duties more precisely and efficiently. He will be able to transmit accurate 5-, 4-, 3-, 2-, and 1-minute alert warnings to all range stations. By viewing the remote PPI scope, he will be able to cancel a test during the last few seconds should he see that the aircraft was off course.

(16). Optical Tracker. -- The Mk 51 Mod 2 director is being modified to operate in conjunction with each permanently installed radar unit at the Salton Sea test base. It will provide a means of tracking targets optically and through the servosystem, which is a component part of the director, it will be capable of remotely positioning the radar antenna in azimuth and elevation.

Such an installation is of immeasurable value to the radar system because it can be used in many different operational functions. The Mk 51 optical tracker will be manned during all

phases of test operations that are within the visibility limits of the telescopes.

While the optical tracker is following a target, the radar operator only has to throw a selector switch for the radar antenna to assume immediately and maintain the same pointing position as the optical tracker.

Should the automatic tracking circuits fail during a test, by remotely controlling the antenna from the optical tracker, the radar system can continue to gather data. Occasionally the action of the overload relays momentarily disrupts the high-voltage operating the magnetron and causes the radar system to lose the target. This might mean that upon restoring the radar to operating condition, operators could not find the target in time to complete the test. Using the optical tracker as a means of remotely positioning the radar antenna, the target can be found within two or three seconds. The optical tracker helps separate targets when the separation is in azimuth or elevation while it maintains the same slant range.

Ordinarily the optical tracker will be used as a form of insurance; that is, when the need arises, the tracker will be used to position the SCR-584 antenna. Under normal conditions, the radar system is far more dependable when operating in automatic tracking; therefore the optical tracker is used only when circumstances require.

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