curriculum include a thorough grounding in the broad fundamentals of the sciences and engineering, an integrated sequence of courses in social, humanistic, and business studies, and a moderate amount of specialization along the lines of further developing fundamental principles in a particular field of specialization. It recommends that some of the more specialized engineering material now taught in the undergraduate curricula be transferred to the graduate program, in order to clear the way in the undergraduate curricula for higher priority material of a more fundamental nature. It is fully cognizant of the fact that this program will not turn out experienced and mature engineers, and industry must therefore assume the burden of training the student along specialized lines required for the particular industry.

Rather than extend the duration of the undergraduate engineering curricula,[4] the committee recommends concentrating attention upon (1) making a critical selection of course material; (2) providing a better correlation of material and improving the underlying continuity of courses in the engineering curriculum; and (3) improving the effectiveness and efficiency of instruction methods.

The committee has strongly emphasized the importance of providing for a carefully planned and co-ordinated sequence of social-humanistic courses. It is becoming increasingly apparent that many of the larger and more difficult problems facing the engineering profession today are of a social, economic, or political nature. The engineer must take his full share of responsibility in the solution of these problems, or democracy and the engineering profession will surely suffer. Education for democracy is fully as important as education for a profession. This portion of the educational program would include a fundamental treatment of (1) the individual and his environment, including an analysis of factors contributing to the rise and degeneracy of ancient and modern civilizations; (2) the functioning of social and industrial institutions, including labor and management problems; (3) economics of our modern industrial society; (4) an analysis of political systems; and (5) moral, ethical, and social philosophies.

The issues discussed here are but a few of the more controversial problems facing the engineering colleges. Space limitations preclude a discussion of many of the problems considered at the Sections meetings. Several of the less controversial issues included the necessity of improving the selection of students admitted to engineering schools; the need for better mathematical preparation in the high schools; the desirability of having students and faculty members alike supplement their engineering education with experience in industry; and the need for stimulating research in engineering colleges as a desirable adjunct to engineering education.

The problems discussed here are, in general, not amenable to clear-cut decisions based upon tangible evidence alone, but rather, must necessarily reflect the combined experiences of industry, educators, and the engineering profession. A free interchange of ideas is vitally necessary in order to assure an enlightened viewpoint as a basis for intelligent decisions. In the final analysis, however, the destinies of engineering education lie in the hands of the individual instructors in the colleges; theirs is the privilege and the obligation of assuring American supremacy in engineering education.

[4] For a discussion on extension of undergraduate program, see H. J. Gilkey, "Discussion of SPEE committee report on engineering education after the war," *Jour. Eng. Educ.*, vol. 35, pp. 332–334; January, 1945.

Radar in the United States Army*

History and Early Development at the Signal Corps Laboratories, Fort Monmouth, N. J.

ROGER B. COLTON†

Summary—**The evolution of radar technique is traced and the radar-development program of the United States Army Signal Corps at the Signal Corps Laboratories, Fort Monmouth, New Jersey, described from its inception to America's entry in the War. Two radars developed by the Signal Corps Laboratories during this period, SCR-268 and SCR-270, are described in detail.**

Introduction

RADAR, the chief electronic weapon of the war, has a much longer history than is realized. The scientific concepts on which radar is based go back to the last century, and the military concept of its use arose at least 15 years ago. So generally was the idea appreciated that most of the major belligerents had radar equipment ready before their entry into the war. The United States was no exception. Both Army and Navy had radar ready. On December 7, 1941, the Army had 580 sets on hand. An Army radar, the SCR-270, gave warning of the impending attack on Pearl Harbor.

The military and naval accomplishments of radar, before and since that time, are of the first magnitude. Time and time again, winning a victory has proved easier because we have had more and better radar than

* Decimal classification: R561×R090. Original manuscript received by the Institute, September 18, 1945. Presented, New York Section, September 5, 1945.
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our enemies. In critical stages of the war, notably the battle of Britain and the early naval engagements in the Pacific, radar has proved to be one of the decisive factors second only to guns, armor, ships, planes, and the men who fought the battles.

The value of radar has been no secret to our enemies. Throughout the war there has existed a technical race to achieve and maintain radar superiority. While this race continued, many of the interesting achievements could not be described. But sufficient time has passed to permit disclosure of early work. It is my purpose in this paper to describe that portion of this early work with which I am most familiar, namely the radar-development program of the United States Army Signal Corps.

The Evolution of Radar Technique

Radar's primary purpose in war is to give knowledge of enemy activity. It does so by exploring the region of battle with a directed beam of radio energy, and by detecting the echoes which arise when the beam en-

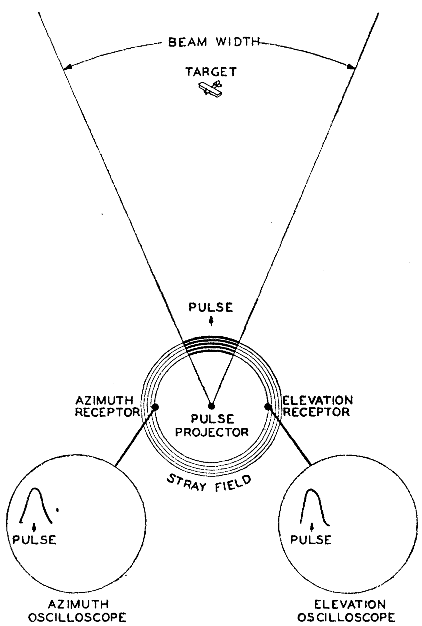

Fig. 1—Diagram of pulse in transit, showing record on oscilloscope. Taken from Signal Corps Laboratories 1937 annual report.

counters an enemy target. To detect targets at great distances, which is necessary to give adequate warning of their approach, it is necessary to transmit at the highest possible power and to receive the echoes with the most sensitive possible receiver.

Radar is, in this respect, one of the most inefficient devices known to electrical science. Radar transmitters customarily have peak power output in the tens or hundreds of kilowatts, and the effectiveness of this power is increased several hundred times by directive antennas. But the power received back from a target, at the maximum range at which the target is detectable, is measured in micromicrowatts, or roughly a millionth of a millionth of a millionth of the power transmitted.

It is no wonder, therefore, that radar development has demanded the most advanced techniques known to radio engineers and scientists. But the basic idea is simple. It depends on five requirements: (1) the production of a high-power beam of radio energy, capable of being moved about in search of targets; (2) the transmission of short bursts or pulses of energy, with comparatively long quiet periods between them during which the echoes may be detected; (3) the reflection of these pulses by the target; (4) perception of the echoes by a highly sensitive receiver and cathode-ray indicator; (5) meas-

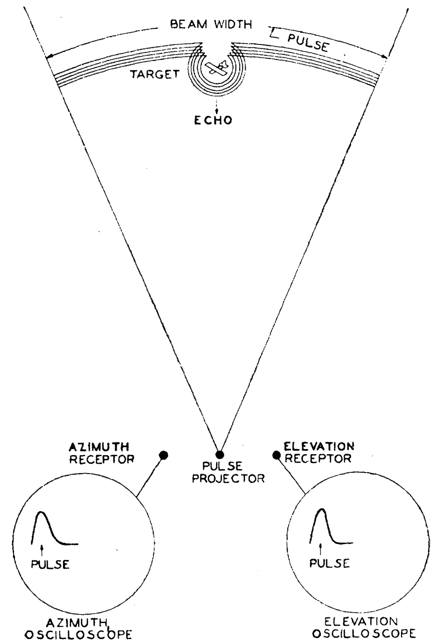

Fig. 2—Diagram of pulse in transit, showing reflection at target. Taken from Signal Corps Laboratories 1937 annual report.

urement of the time between transmission of a pulse and reception of the echo, to determine thereby the distance to the target.

Fig. 1 illustrates the first step in sending out a pulse of energy for the purpose of detecting the target airplane. In Fig. 2 the pulse of energy has reached the target airplane and is being reflected in all directions from the airplane. Fig. 3 shows the reflected energy arriving back at the position of the radar equipment.

All of these requirements could be met, in some degree, very early in the history of radio science. Hertz demonstrated in 1885, using 66-centimeter radio waves, that beams could be formed and that solid objects would reflect them. Moreover, when the identity between light and radio waves was established, it became clear that a radio wave, reflected back on itself, would create a wave-interference pattern, and that this pattern would in itself be evidence of the reflecting object.

This wave-interference detection method, the forerunner of the pulse method, was reported by various groups of workers in widely different applications, in the early 1920's, both in the United States and abroad.

In the latter 1920's the pulse method of detection of the ionosphere was introduced by scientists in this country.

The Signal Corps program leading directly to the development of radar began in 1931 with the transfer of "project 88" from the Office of the Chief of Ordnance to the Signal Corps Laboratories at Fort Monmouth. This project was entitled "Position Finding by Means of Light," the word " light" being interpreted in the broad sense to include infrared and heat rays. Later, the project was extended to include very short radio waves. At the start, the activity of this project was confined to the development of infrared devices, to detect the heat of aircraft engines and the funnels of surface ships. These devices were, in fact, included as a part of the first radar equipment built at the Laboratories.

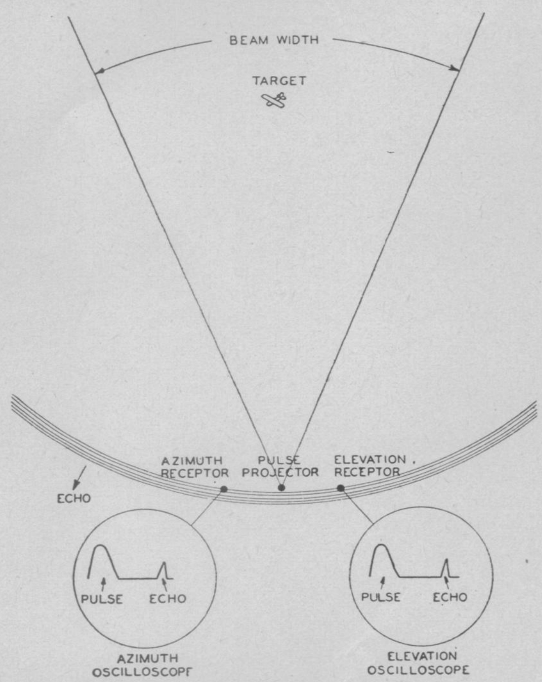

Fig. 3—Diagram of arrival of echo at receptor. Taken from Signal Corps Laboratories 1937 annual report.

In 1932 it had become clear that infrared radiation suffers from obstruction by clouds and that infrared receivers do not have sufficient sensitivity to provide detection at great distances. Consequently, in 1932 and 1933, the Signal Corps Laboratories undertook a systematic survey of the production of very short radio waves, and subprojects were set up to study "radio-optical detection and position finding." The information provided by other agencies was studied and had considerable influence on subsequent Signal Corps activity.

The first experiments were conducted in 1933 with continuous-wave equipment, employing a 9-centimeter magnetron of Westinghouse design. Ranges of a few hundred yards were obtained on moving vehicles.

In 1934, experiments were made with somewhat similar Radio Corporation of America equipment (Figs. 4 and 5). Both of the above equipments were of too low power for practical results.

The first proposal to use pulses within the Signal Corps organization was made in July, 1934, in the annual report of the Signal Corps Laboratories, as follows: "It appears that a new approach to the problem is essential. Consideration is now being given to the scheme for projecting an interrupted sequence of trains of oscillations against the target and attempting to detect the echoes during the interstices between the projections. No apparatus for this purpose has yet been built."

Up to this time the Signal Corps work was in the hands of Major Clayton and Messrs. Anderson, Zahl, Golay, Hirschberger, and Noyes. These gentlemen laid a good foundation and continued to assist in the program.

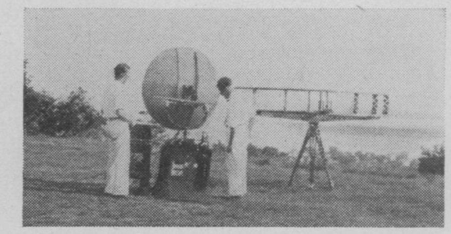

Fig. 4—Early experiments by Signal Corps Laboratories on 9-centimeter continuous-wave equipment. Twin Lights, New Jersey August, 1934.

Fig. 5—Early experiments by Signal Corps Laboratories on 9-centimeter continuous-wave equipment located on Signal Corps boat. August, 1934.

In 1936, funds in the amount of $80,000 were made available by the War Department for active prosecution of airplane-detection work during the fiscal year 1937. Before the apparatus was built, an important decision was made. It was decided to abandon the attempts to use microwaves, because transmitter power and receiver sensitivity were inadequate, and to use frequencies in the 100-megacycle region, for which negative-grid tubes of high power output were available.

At this time, responsibility was transferred by Lieutenant Colonel Blair, the Laboratory Director at that time, to Major Corput and Mr. Watson, who remained in charge thereafter and who deserve the major credit for the successful conclusion of the project.

A breadboard model was constructed early in 1936 on 133 megacycles, and later the frequency was changed to

110 megacycles. This construction marked the beginning of the Signal Corps development of the SCR-268 and SCR-270, the first United States Army radars.

The 1936, equipment had a power of 75 watts, and was pulsed at a rate of 20,000 pulses per second. It comprised, in addition to the transmitter: a phasing unit, keying unit, superregenerative receiver, cathode-ray indicator, and simple directive antennas.

The early pulse equipment was unsuccessful at first because the receiver used was incapable of recovering its sensitivity immediately after being blocked by the transmitted signal. Using the continuous-wave method, beat notes were detected between direct and reflected waves. The transmitter and receiver in this case were separated by several miles. This equipment was successful in November, 1936, in detecting aircraft if they were close to the line connecting transmitter and receiver, but its inability to indicate the direction of the aircraft was a serious stumbling block, so the method was dropped and work on the pulse method continued. The superregenerative-receiver recovery time was shortened by increasing the quench frequency. Superheterodyne receivers were also developed with low-Q circuits for the same purpose. In December, 1936, using these receivers, aircraft were successfully tracked over ranges up to seven miles using the pulse method. A yagi transmitting antenna was used to provide directivity and the separation between transmitter and receiver was about one mile.

Mr. Hessel designed the superregenerative receiver which as usual was the forerunner of the superheterodyne (designed by Mr. Moore). Perhaps here a little credit should be given to Major E. H. Armstrong, for the basic design of receivers of this kind.

This first success of the pulse equipment was marred by the inaccurate indication of direction, so attention was directed toward improved antennas. Arrays of half-wave dipoles were constructed early in 1937 to provide a high degree of directivity in azimuth (horizontal angle with respect to north). The array consisted of 12 dipoles, each $4\frac{1}{2}$ feet long, arranged in two horizontal rows of six dipoles each. When two such arrays were used, one on the transmitter and one on the receiver, a B10-B bomber was tracked up to 23 miles, the error in angle being of the order of 7 to 8 degrees. This was a great improvement over previous results, but still not of sufficient accuracy for the intended purpose. Bell Laboratories gave us help in this task, and throughout all our later development.

The next step was to build three different arrays, one for the transmitter (5 dipoles high by 2 dipoles wide), a receiving array for azimuth indication (4 dipoles high by 8 dipoles wide), and a second receiving array for elevation indication (5 dipoles high and 2 dipoles wide). The large size of these arrays made it impracticable to mount them all on a single structure, so three mounts were built, each capable of directing the associated array in any direction. The three mounts were connected by selsyn indicators so that all three could be pointed in the same direction at once. Meanwhile, a new transmitter of 5- to 10-kilowatts peak power was constructed and two superheterodyne receivers provided, one for each receiving array. The transmitter was pulsed at a rate of about 8000 pulses per second. During this period we received considerable help from the Radio Corporation of America.

Many successful tests were conducted with this equipment in the early months of 1937, culminating with a demonstration to Mr. Harry Woodring, the Secretary of War, on May 26. On this occasion the direction of the receiving arrays was transmitted directly to a searchlight. As the radar arrays were tracked on the target (a B10-B aircraft) by the operators, the searchlight followed the aircraft and could illuminate it at the will of the officer in charge—always provided the radar was doing its work. When Mr. Woodring attended, the equipment worked exceptionally well, to the surprise and relief of all concerned. Planes were detected and tracked at distances as far as 20,000 yards (11 miles). Actually using an RCA transmitter, which was not used in the demonstration, we once covered a distance of 32 miles during our preliminary tests.

FIG. 6—First 110-megacycle test of complete radar system together with heat detector. This is the first radar system in which azimuth, elevation, and range were obtained from one equipment. Signal Corps Laboratories, May, 1937.

Fig. 6 shows the complete layout of the equipment used in the May, 1937, demonstration. On the left is the elevation receiving antenna. The second antenna is the azimuth receiving antenna. The next object in the foreground, which looks like a searchlight, is the heat detection unit; and the next antenna, which, however, does not show very clearly in the picture, is the transmitting antenna.

Fig. 7 is a close-up view from the back side of the azimuth receiving equipment. The receiver is in the little box below the axle of the mount. The soldier sitting with his back to the camera is looking into the oscilloscope by means of which he sets the antenna in azimuth. The box on the right houses the Rangertone range unit.

The transmitter assembly shown in Fig. 8 was developed by Mr. Marks. Fig. 9 is a close-up view of the elevation receiving equipment. The receiving equipment here was designed by Mr. Moore.

In the foreground of Fig. 10 is the range unit developed by Rangertone, while Fig. 11 shows Zahl's heat

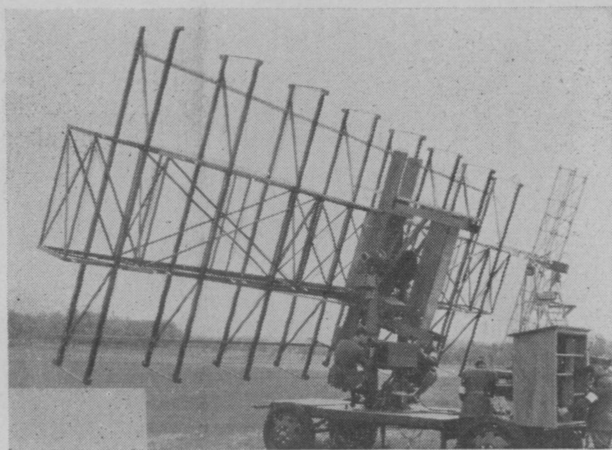

Fig. 7—Detailed view of azimuth antenna used in system shown in Fig. 6. May, 1937, tests.

detector, developed by Zahl and Golay. Fig. 12 shows the organization of the personnel and equipment.

The directivity of the arrays still remained unsatisfactory. In the demonstration just described, a thermal

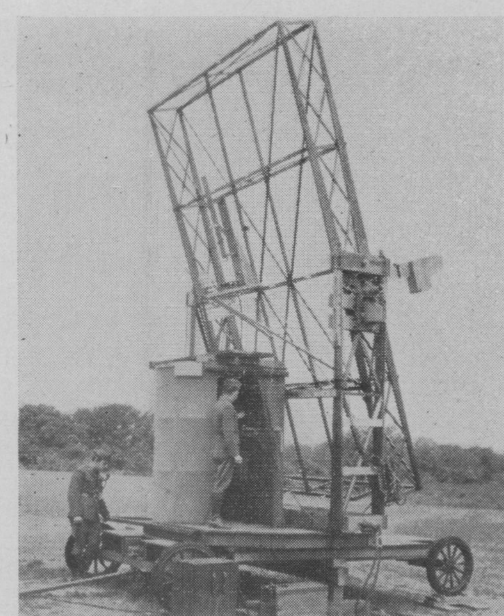

Fig. 8—Detailed view of transmitting antenna. May, 1937, tests.

detector was used to improve the sharpness of angular indication. The susceptibility of the thermal indicator to interruption by weather difficulties required that some means be found of improving the angular precision of the radar. The means was found in the technique known as lobe-switching.

The difficulty was that a sufficiently narrow beam could not be produced, at a frequency of 110 megacycles, by an array of practical size. The direction of the target was obtained by moving the beam past the target and attempting to determine the direction at which the received signal was strongest. Since the beam was broad (20 to 30 degrees at the half-power points) the direction of maximum signal was correspondingly imprecise, generally not better than 10 degrees. The military requirement was for angular precision of 1 degree or better.

The clue to the answer was found in the "A–N" radio-range beacon, used in navigating aircraft, developed by Lieutenant-Colonel Murphy at the Signal Corps Aircraft

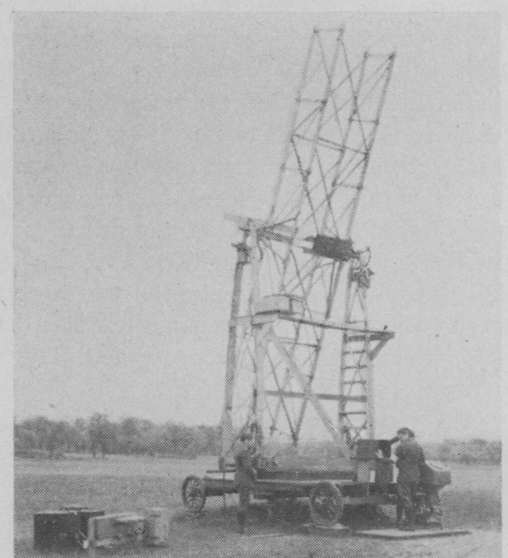

Fig. 9—Detailed view of elevation antenna. May, 1937, tests.

Radio Laboratory. In this system, a precise path is found by overlapping two broad beams and following a path in the overlap region where the two beams have equal strength. The general principle is illustrated in Fig. 13.

If the direction of the target is outside the overlap region (along the line *OGFE* for example) there is a wide disparity between the signal strengths of the two beams, whereas equal signal strength is found only along the line *ODC*, i.e., the center of the overlap region.

The first application of this principle to the Signal Corps radar equipment took the form of two arrays,

Fig. 10—Detailed view of range-finding equipment located in rear of azimuth antenna. May, 1937, tests.

mounted at an angle to each other. The input of the receiver was switched rapidly from one array to the other, and the two signals were displayed side by side on a cathode-ray tube whose sweep circuit was displaced synchronously with the switching between arrays. The two arrays were then moved, as a unit, until the two signals had the same amplitude. The overlap region of the two arrays then pointed directly at the target, within an error which was very small compared with the width of the beams employed. This elementary type of lobe-switching was introduced in August, 1937, in the form of a twin array consisting of two units, each four dipoles wide, the two units diverging in the direction by 20 degrees.

The provision of the double-lobe pattern in both the vertical and horizontal planes from a single antenna was contemplated by the Signal Corps group from the inception of the lobe-switching idea; however, there were many problems other than the consolidation of an-

Fig. 11—Detailed view of radar and thermal-control unit. May, 1937, tests.

tennas to be solved, and it was not until 1938 that a systematic attack was made on this problem. The method finally adopted was based on the simple theory that if an antenna is fed from the right-hand side the reaction will be different from, but symmetrical to, that which will occur when it is fed from the left-hand side. This reasoning eliminated consideration of all complicated formulas for matching, phasing, and the like. Upon trial of this method it was immediately found that good lobe-switching resulted, but there still remained many problems in connection with keeping lobes steady in relation to the axis of the antenna as the antenna was rotated either in elevation or azimuth. Several methods were found for doing this to a high degree. As finally resolved, the problem turned out to be constructing the array in such a way as to eliminate, as far as possible, all but one type of radiation. In the actual case of the SCR-268, this meant the elimination, as far as possible, of all radiation other than horizontal radiation. The lobe-switch and indicating design work was done by Messrs. Moore, Cole, Deisinger, and Slattery.

While this development was under way, other branches of the Army were kept advised of progress, and specific military uses for the new equipment were considered. Two such uses were evident: (1) detection and tracking of aircraft as an aid to searchlight control and antiaircraft fire; and (2) warning of the approach

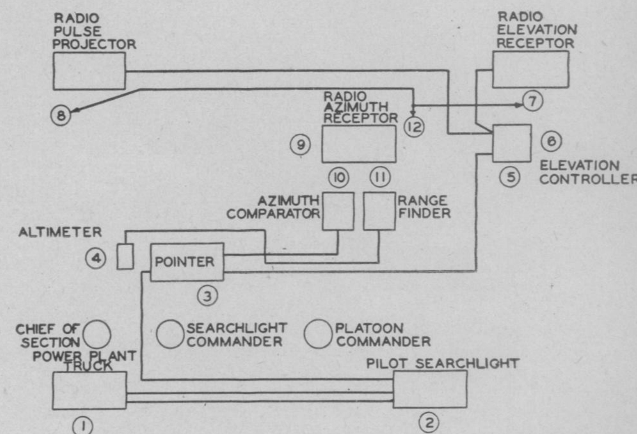

Fig. 12—Block diagram showing arrangement of equipment used in the Signal Corps tests of May, 1937. Word "pointer" refers to thermal-detector.

of enemy aircraft at great distance. The first application was fulfilled by the development of the SCR-268 series of radars, and the second by the SCR-270 series.

Officially, the development of the SCR-268 began in February, 1936, when the Chief of Coast Artillery prepared a set of "military characteristics" describing the desired aircraft detector. The requirements specified were: (1) ability to operate in daylight or darkness; (2) ranges up to 10,000 yards in mist, rain, fog, smoke, or 20,000 yards under average atmospheric conditions; (3) the position of the aircraft to be determined to an angular accuracy of 1 degree in azimuth and elevation; and (4) the distance to be accurate to one per cent of the range. Either thermal detectors or radio detectors or a

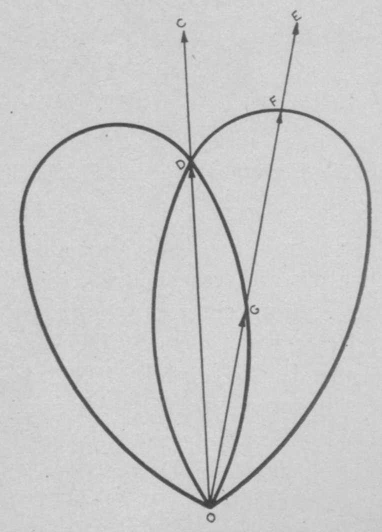

Fig. 13—Extract from an early Signal Corps report showing the principle of direction finding with two antennas displaced with respect to each other.

combination of the two was acceptable. In its attempts to solve the problem posed by the Coast Artillery, the Signal Corps Laboratories designed and built three models of the SCR-268 radar. The last of these met the specifications and was put into large-scale production.

The first service-test model was the SCR-268-T1. This radar employed the equipment described in the preceding paragraphs. The frequency was 110 megacycles; the transmitting, azimuth, and elevation arrays were separated, and each receiving array was of the twin type providing double-lobe tracking. The equipment included a heat-detection device to track the aircraft by the heat of its engines. This thermal element was mounted separately and resembled a searchlight in appearance. The equipment was ready for demonstrations early in 1938, and Coast Artillery personnel were trained in its use. In November, 1938, the equipment, being mobile, was moved to Fort Monroe, Virginia, to the Coast Artillery Board, to see whether it met the requirements of military use. During two weeks of continuous testing, tracking B-10 and O-25 aircraft, the following facts were apparent: The radar had a range of 40,000 yards, twice that set up in the military characteristics. The angular errors as reported by the Coast Artillery Board averaged about 4 degrees in azimuth and $2\frac{1}{2}$ degrees in elevation, as against the 1 degree specified in the characteristics. The average error in measuring the distance was of the order of 700 yards. The equipment was judged useful in all respects except the angular indications. During these tests the thermal element of the radar system proved to be extremely accurate, but since its field of view was limited and since it was estimated that, because of clouds being interposed between the airplane and the radar, the thermal indicator would be useless about 75 per cent of the time, its development was put on low priority; and although not actually abandoned as a research problem, the idea of its use in connection with radar detection of airplanes was given up. During the tests, a B-10B aircraft participating in the tests encountered a wind of 120 miles per hour and was blown out to sea without the pilot's knowledge. The radar discovered this fact. After the identity of the plane was checked by requesting it to circle, the pilot was directed back to the coast. This was the first instance of radar navigation in the United States Army. Also during these tests, it was suggested to the Coast Artillery Board that an attempt be made to detect the bursting of antiaircraft shell. The radar was successful in indicating the burst of 3-inch antiaircraft shells at a range of several thousand yards.

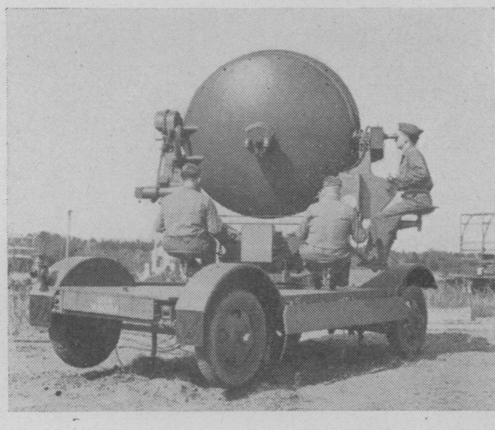

Fig. 14—First service test of the SCR-268-T1. Conducted at Fort Monroe, Virginia, October, 1938. Figure shows the radar control station built around the heat detector which was used for accurate positioning in the experimental model.

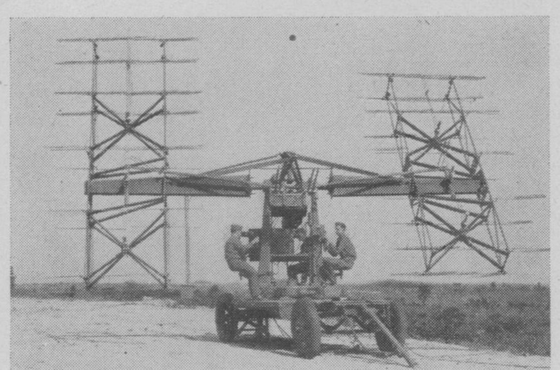

Fig. 15—Elevation antenna SCR-268-T1. October, 1938.

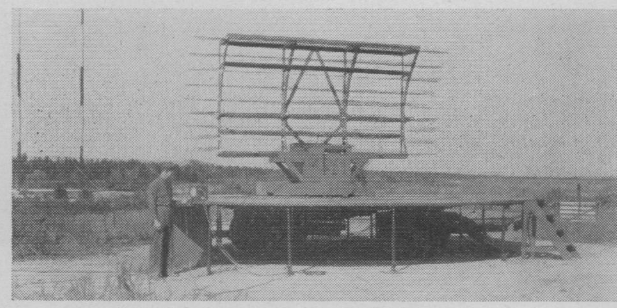

Fig. 16—Transmitting antenna SCR-268-T1. October, 1938.

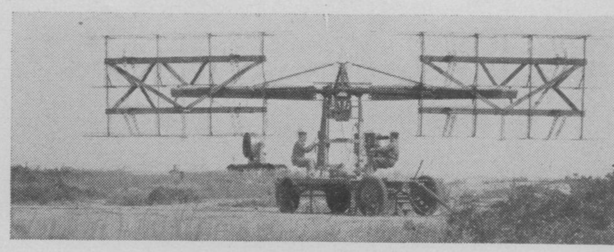

Fig. 17—Azimuth antenna SCR-268-T1. October, 1938.

Figs. 14 to 17, inclusive, show all the units of an SCR-268-T1 radar. Fig. 15 shows an elevation receiving equipment of the SCR-268-T1. In Fig. 16 is shown the transmitting equipment of the SCR-268-T1, and Fig. 17 shows the azimuth receiving equipment of the SCR-268-T1, while the transmitting equipment of the SCR-268-T1 is shown in Fig. 18.

Meanwhile work was under way on the second model, SCR-268-T2, similar in general form but operating at 205 megacycles. The separate mounts for transmitter, azimuth, and elevation arrays were retained. As early as 1937, work was under way at a frequency of 240 megacycles, the purpose being to permit reduction in the size of the arrays. Aircraft echoes were demonstrated to the Secretary of War with 240-megacycle equipment designed by Messrs. Hessel and Slattery, in May of that year.

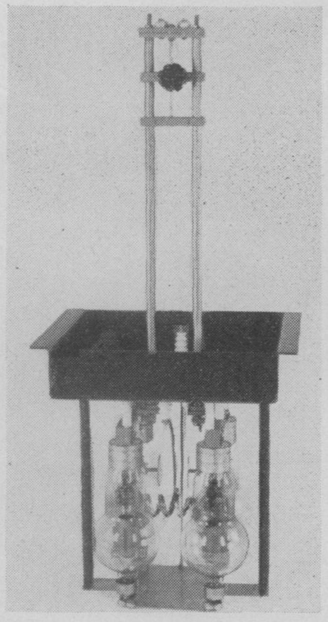

Fig. 18—Transmitter made up of four 806 vacuum tubes, tubes, SCR-268-T1. October, 1938.

An equipment on 240 megacycles, used in May, 1937, is shown in Fig. 19. It had a range of about 6000 yards, and represents the first work in the 200-megacycle band at the Signal Corps Laboratories.

One problem in this development was that of achieving sufficient transmitter power to meet the minimum range requirements. By September, 1939, a 205-megacycle model (SCR-268-T2) similar to the 110-megacycle SCR-268-T1 was ready for service test but was abandoned in favor of the SCR-268-T3, which had all the arrays on a single mount. In addition, a much more powerful transmitter was constructed for the 268-T3 through the use of a "ring" circuit incorporating eight tubes, operating at 205 megacycles and designed by Mr. Baller. The transmitter tubes were Eimac 100TL tubes redesigned. The number of tubes was later increased to 16. The T3 model was completed and service tested by April, 1940, found acceptable in all respects, and standardized for production. In August, 1940, a contract was let to manufacture the T3 model. In December, 1940, the first of 18 preproduction models was completed by the Signal Corps Laboratories, under the supervision of Mr. Vansant, prior to the delivery of production in January.

The first trainload of production models of 268's on

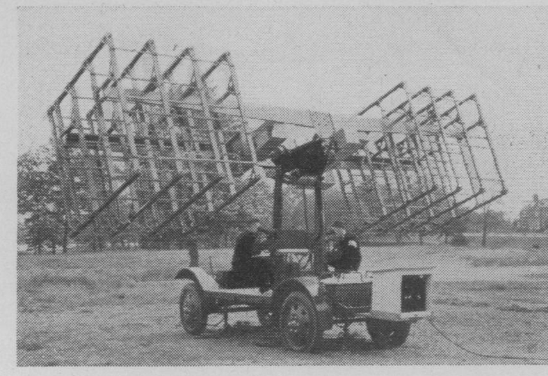

Fig. 19—240-megacycle radar equipment tested in May, 1937.

the way to troops is shown in Fig. 20. By February, 1941, 14 commercial models were delivered and shipped out to Army units. Since then a total of 2974 SCR-268 radar units has been produced. Production engineering and manufacture was by Bell Laboratories and Western Electric. Production was terminated in March, 1944, with the advent of superior equipment.

In July, 1941, seven SCR-268 radars arrived in Panama and were set up for tactical use by October of that year. Two sets arrived in Iceland in August, 1941, with the troops sent there to protect the North Atlantic sea route, and by December, 1941, 16 sets were in use by Coast Artillery troops in Hawaii. Since then the SCR-268 has served in all theaters of War, not only for search-

Fig. 20—First rail shipment of 13 radar sets SCR-268 leaving Fort Hancock for tactical units.

light control but also as a gun-laying set. Inevitably, in view of its wide deployment, SCR-268 was captured, and by 1944 the Japanese had paid us the compliment of copying it.

Detailed Description of SCR-268 Production Model

A view of a production model of the SCR-268 is shown in Fig. 21.

The radar equipment is carried on a trailer on which is mounted a rotatable pedestal. The pedestal carries the three antenna arrays, the transmitter, receivers, and indicators. Reading from left to right are the azimuth receiving array, transmitting array, and elevation receiving array. Behind each receiving array is the corresponding receiver. Near the center are three cathode-ray indicators, with seats in front of each for the operators. The handwheel in front of the elevation operator

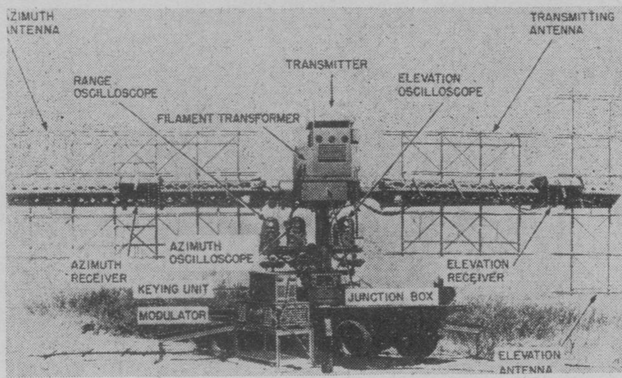

Fig. 21—Broadside view of the SCR-268 radio.

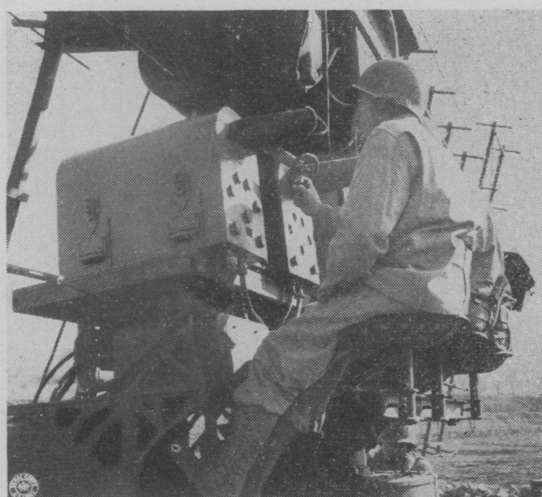

Fig. 22—Oscilloscope operators on an SCR-268 radar maintain watch near Menella, Italy. Nearest the camera is the range scope, next, the azimuth scope, and, at the right, the elevation scope.

Fig. 23—Radio set SCR-268 with 5-man crew in operation on an Italian hillside. The three operators seated on the mount see indications of the airplane echo on cathode-ray oscilloscopes. One operator tracks the aircraft in azimuth (direction in degrees from north); another operator tracks in elevation (angular height); and the third measures the range.

permits him to raise or lower the arrays in elevation. By turning these controls, the operators keep the arrays, including the transmitter array, pointed at the target. The third operator measures the range of the target by turning a range-unit handwheel which displaces the echo on his oscilloscope to the hairline and also transmits the range to the altitude converter. The mount was designed by the Breeze Corporation. In addition to the apparatus shown, a separate trailer carried a Le Roy gasoline-engine generator, a rectifier designed by Bell Laboratories, and frequency-measuring equipment designed by Fred M. Link. Mr. Slattery had charge of system design for the SCR-268-T3.

Fig. 22 is a close-up view of the range oscilloscope, range handwheel, and range operator. Figs. 23 to 27 are views of the SCR-268 in the field.

The original range unit built for the SCR-268 early in 1937 used a resistor-capacitor type of phase shifter,

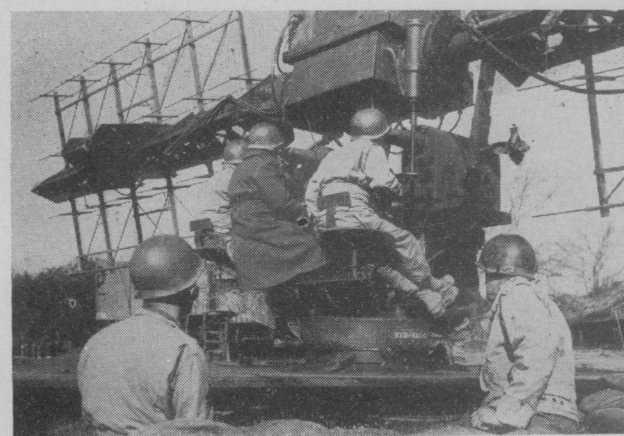

Fig. 24—Radio set SCR-268 in action at Nettuno, Italy, assisting antiaircraft guns to shoot down German night bombers over the Anzio beachhead in 1944.

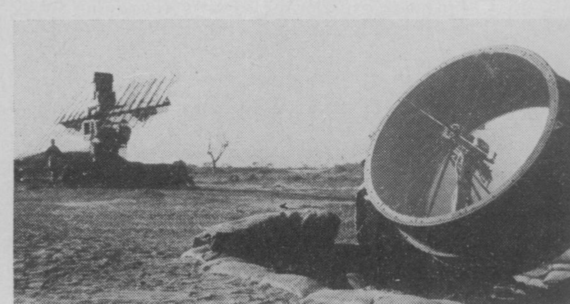

Fig. 25—In North Africa, radio set SCR-268 served to control searchlights like that in foreground, so that when the light is turned on it will flash instantly on an enemy airplane. These sets were used extensively in safeguarding our forces in North Africa.

designed by Rangertone. Later, a Helmholz inductor-capacitor type of phase shifter designed by Dr. Anderson was used.

In operation, the azimuth operator turns his handwheel back and forth, causing the arrays to scan from left to right and back over the sector in which enemy planes may be expected. When he detects an echo, he causes the azimuth array to bear directly on the target by equalizing the double-lobe signals. Thereupon the elevation and range operators go to work, the elevation operator adjusting his wheel until his double-lobe signals are equalized, and the range operator determining the range. The values of range, azimuth, and elevation thereby determined are fed through selsyn drives to the associated searchlight. In the case of antiaircraft-gun control, the target co-ordinates are fed to a director which introduces the necessary "lead" in advance of the target position to allow for the speed of the aircraft and the time of flight of the shells.

In addition to the pedestal trailer, a power-supply trailer was furnished. In later modifications, four trucks were used to supply power and transport the gear. In this case the whole equipment, including trucks and spare parts, weighs about 20 tons, and its power is furnished by a 15-kilovolt-ampere gasoline-engine generator. The weight and bulk of the equipment, while very great compared with more recent sets, have not prohibited rapid installations of the SCR-268. It has been set up, many times, within several hours of being put ashore on a beach.

The transmitter proper, located at the top of the pedestal, generates radio-frequency pulses at a peak power of approximately 50 kilowatts. The transmitter consists of 16 triodes in a ring circuit, the plates and grid of adjacent tubes being connected through half-wave transmission-line tuned circuits. This type of circuit avoids putting the tube capacitances in parallel and permits the high power to be achieved at the frequency of 205 megacycles. The 16 tubes are necessary to obtain sufficient emission to produce the 50-kilowatt pulses.

The pulses themselves are about 5 microseconds long and occur at a rate of about 4100 pulses per second, that is, one pulse every 240 microseconds. The transmitter is on the air, therefore, only about 2 per cent of the time. During the remaining 98 per cent, the receivers are active and listening for echoes. The listening interval determines the maximum range of the set, since the signal must reach the target and return to the receiver between transmitted pulses. Since radio waves travel at a rate of about 330 yards per microsecond, in 240 microseconds

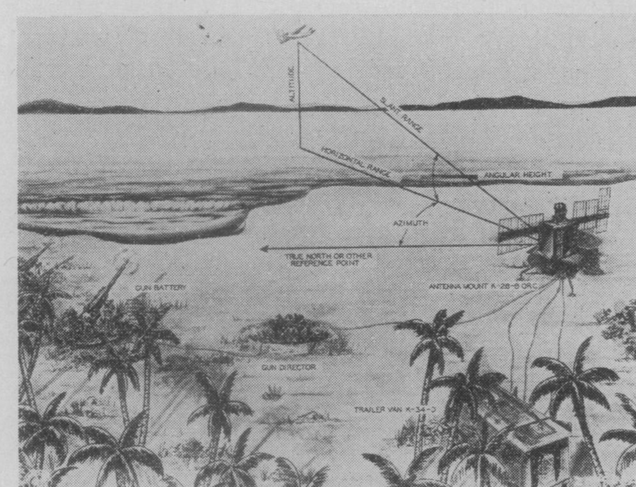

Fig. 26—Radar control of antiaircraft artillery fire is illustrated in this sketch of the SCR-268 radar supplying firing data to a gun director. The electrical impulses from the radar are fed to the gun director, which automatically points the guns and sets the shell fuses for the correct altitude.

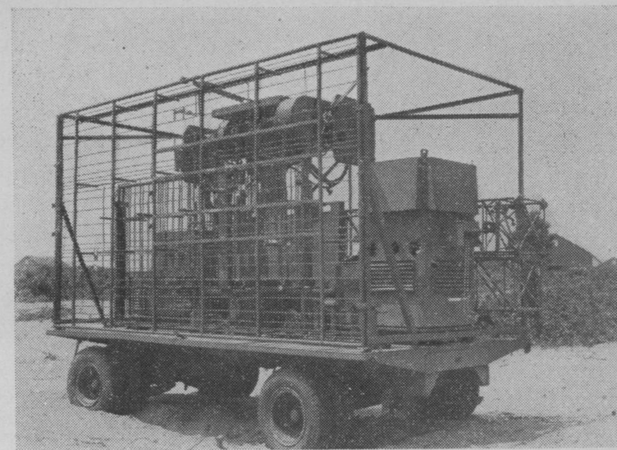

Fig. 27—Late model of radio set SCR-268 trailer packed for transport, less canvas cover.

the signal travels a total of about 80,000 yards; i.e., 40,000 yards to the target and 40,000 yards return trip. If targets are observed at a greater distance than 40,000 yards (23 miles), the echo is obscured by the next transmitted signal or it may arrive during the next succeeding listening interval. In this latter case, the signal may be tracked, but the range measurement is in error by 40,000 yards, a fact which is usually evident from the weak condition of the signal.

In a similar manner, the length of the pulse, 5 microseconds, determines the minimum range at which targets can be detected, since no echoes can be seen while the transmitter continues to transmit. In addition, the recovery time of the receivers is such that targets cannot be seen much closer than about 2000 yards.

The transmitter is keyed and modulated by the units on the ground beside the trailer. These units were designed by Messrs. Vieweger, Moore, Noyes, and Marchetti. The keyer contains a 4100-cycle-per-second sinewave oscillator which establishes the basic pulse rate, and additional tubes which convert the sinewave into a series of sharp pulses. The transmitter tubes are operated at from 8000 to 15,000 volts. The ring circuit is coupled through a loop to the open-wire transmission line which conducts the pulses to the transmitting array, which consists of 16 half-wave radiators and 16 reflectors.

Each receiving array is connected to its respective receiver by two transmission lines taken from opposite ends of the array. Phasing stubs, in the center of each array, adjust the double-lobe pattern. The two terminations are fed to separate radio-frequency stages, which are switched on and off alternately by a rectangular wave of voltage applied to the cathode circuits at 1400 cycles per second. The plate circuits of the radio-frequency stages are connected together, so that in successive stages the double-lobe signals are amplified together in time sequence.

The radio-frequency signal is converted to intermediate frequency at 19.5 megacycles and amplified in four intermediate-frequency stages which display a bandwidth of about 1 megacycle. The gain up to this point is about 20,000 times in voltage, or sufficient to reach the noise level of the input radio-frequency stages. Thereafter the signal is detected and amplified at video frequencies.

The receiver output is then conducted to its associated cathode-ray indicator, where, after further video amplification, the pulse signal is applied to the vertical deflection plates of the cathode-ray tube. The cathode-ray tube and its auxiliary circuits are similar to those of an ordinary test oscilloscope. The horizontal sweep is linear with time and occurs at a rate of 4100 sweeps per second, the rate being established by the sinewave oscillator in the keying unit. In addition, the horizontal sweeps are displaced slightly left and right in synchronism with the switching of the radio-frequency amplifiers in the receiver. Thereby two pulses are made to appear on the cathode-ray tube, one representing the signal from the left-hand lobe of the array, the other from the right-hand lobe. The resulting split image is equalized by the operator in orienting the array. The range indicator does not display a split image, since its function is to indicate simply the time difference between transmission and reception. The sweep circuit in this case is delayed by passing the sinewave from the keyer oscillator through a phase shifter. By adjusting the phase shift, the pulse can be moved across the screen until it falls under the reference hairline.

It may also be mentioned that the SCR-268 included a converter for the purpose of changing slant-range and elevation indications to altitude for use by the gun director, designed for us by Frankford Arsenal.

In all, the SCR-268 employs 110 vacuum tubes.

I would like to call your attention to the soldier operators of our developmental models. These soldiers became expert operators and their commander, First Lieutenant Cassevant, C.A.C., became an expert radar engineer. To them we owe much in military design.

Radars for Long-Range Warning

In 1938, work began on another radar, the SCR-270, to fulfill the requirement for long-distance warning against aircraft. By that time, the basic research at the Signal Corps Laboratories had revealed the means of accomplishing this objective. To obtain long range, the highest possible transmitter power and a large antenna, having high power gain, are required. In the receiver system, high gain in the antenna and the highest possible sensitivity are necessary. As further aids to long-range operation, the pulse energy (pulse amplitude times pulse length) should be high. This implies long pulse. Finally, in order to maintain high energy per unit of time on the cathode-ray tube screen, the spacing between pulses should be no longer than necessary for them to have time to travel to and from distant targets.

These requirements led, after many changes, to the following specifications: the transmitter power is between 30 and 100 kilowatts at a carrier frequency of 110 megacycles according to plate voltages used. The pulses are 15 to 40 microseconds long and transmitted at a rate of 625 per second. At 625 pulses per second, the interval between pulses permits detection out to 150 miles.

A single antenna array is used for both transmission and reception. This "duplex" operation permits the use of a single indicator and one operator. The array consists of 32 half-wave dipoles arranged 8 high and 4 wide, and a reflecting screen or alternately one that is 4 high by 8 wide, mounted on a metal tower.

The array is rotated in azimuth at a rate of about 5 revolutions per minute. The transmitted beam is 28 degrees wide and 11 degrees high between half-power points (or 11 degrees wide by 28 degrees high for alternate antenna). The beam rotates through its own width (28 degrees) in about a second, during which time some 625 radio pulses are sent out. Thus every point in space, surrounding the radar from the horizon to 11 degrees above the horizon, is continually "sprayed" with pulses. Aircraft in this region except for wave-interference spaces, and out to a distance of 100 miles or more, reflect visible echoes. By noting the direction and distance of particular echoes on successive turns of the array, the paths of the aircraft can be followed by plotting, at 12-second intervals, the point representing their position. The angular precision is, of course, poor compared to that of the SCR-268 since no lobe-switching is employed. But since the function of the radar was to warn, rather than to direct gun fire, this lack of precision can be tolerated.

Protection of the receiver is accomplished by the insertion of a spark gap in the receiver transmission line. This gap breaks down during the transmission of each pulse and thereby throws a short circuit across the receiver input. Between pulses, the gap is inactive and the received signal is passed to the receiver. In a later design, three such gaps are used to secure a more perfect short circuit during the transmitted signal.

In the design of the SCR-270, many improvements of an engineering nature were introduced. The transmitter consists of but two tubes (these tubes were developed for us by Westinghouse) operated at between 8000 and 15,000 volts plate potential. These are of the water-cooled variety and possess sufficient emission to reach a 350-kilowatt level from a pair of tubes when series keyed. In the production models, grid modulation was employed, and a 450TH tube, driven by a similar tube, served as the modulator. Under these conditions, 30 to 100 kilowatts is obtained from the transmitter. The receiver has a four-stage intermediate-frequency-amplifier preceded by an orbital-beam tube radio-frequency amplifier especially developed by RCA. The final video amplifier, feeding the cathode-ray indicator, is a beam tetrode. The indicator and range units are very similar to those of the SCR-268.

The reliable range of the SCR-270 is 120 miles on bomber aircraft targets, and about 75 miles on fighters.

The distance to the aircraft is indicated accurately to 2 miles and its direction to about 4 degrees.

A large number of modifications of the basic design were produced for special needs. The SCR-270 is trailer mounted and, with its associated trucks, can be moved over roads and set up quickly. Another series (the SCR-271), was produced for fixed location in permanent or semipermanent buildings. In all 788 radar sets SCR-270/271 were delivered by the prime contractor, the Westinghouse Electric and Manufacturing Company. After five years of use, the SCR-270 is still standard equipment, no radar set yet developed being able to replace it completely.

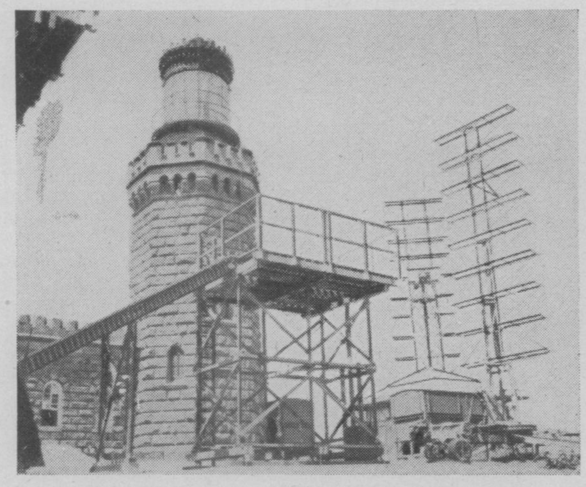

Fig. 28—Early models of both the SCR-270 and SCR-271 installed at Twin Lights, New Jersey.

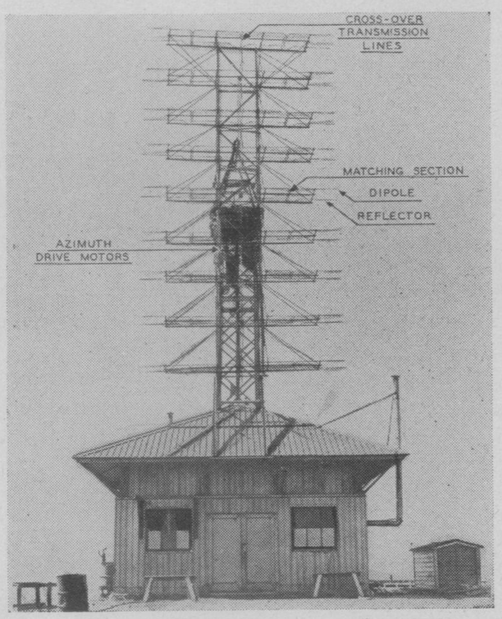

Fig. 29—An early SCR-271 installed at Twin Lights, New Jersey.

A view of a fixed and a mobile version of the SCR-270 is given in Fig. 28, and Fig. 29 is a close-up view of the fixed-station version of the SCR-270, known as the SCR-271. This mount was designed by the Blaw-Knox Company and the electrical fittings by Terpenning. Fig. 30 shows one of the late production models of the SCR-270. This antenna was designed by the Radio Corporation of America and is remarkable for bandwidth and absence of secondary lobes. The mount shown in the

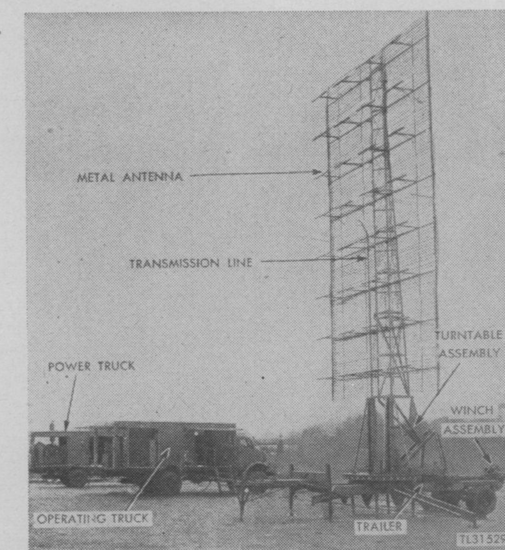

Fig. 30—Radio set SCR-270 set up for operation.

Fig. 31—Radio set SCR-271-D at the Evans Signal Laboratory, showing shelter for components and operating personnel, 100-foot tower, and antenna modified for plan-position-indicator display. Identification, friend, foe (IFF) antenna is shown at top center on radar antenna.

foreground was designed by Couse Laboratories and used in all production models. Fig. 31 shows the high-tower version of the SCR-271. The tower and mount were designed by Blaw-Knox Company.

Components of the 270/271 are indicated in Fig. 32. The receiver and oscilloscope were designed by Mr. Moore; the production engineering and manufacturing were done by Radio Corporation of America. The transmitting tubes, also shown, are two spare transmitting tubes (WL-530), developed by Westinghouse. Figs. 33 and 34 are different views of the SCR-270/271

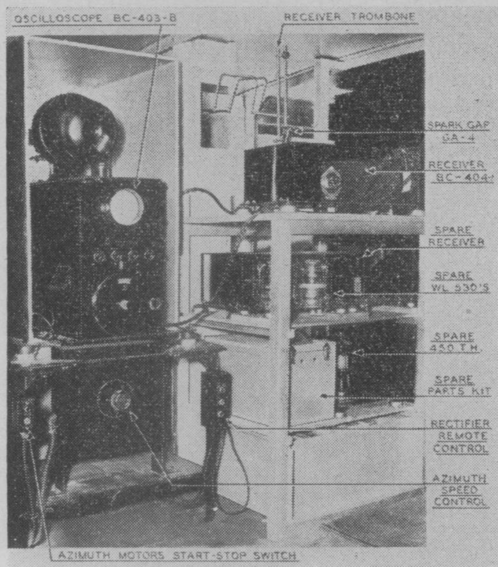

Fig. 32—Parts of an early SCR-270 installed in a K-30 truck.

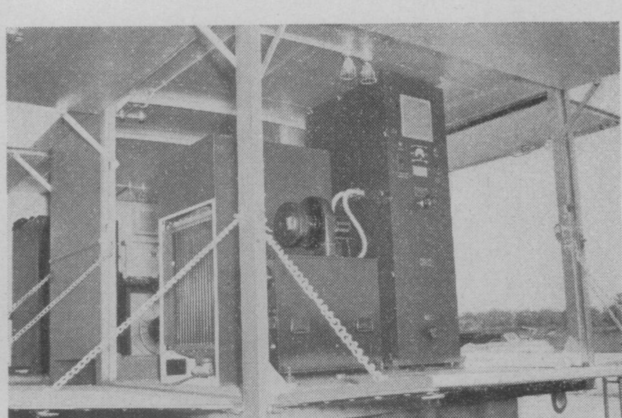

Fig. 33—Rear view of operating van of radio set SCR-270 showing transmitter, water cooler, and spare oscilloscope.

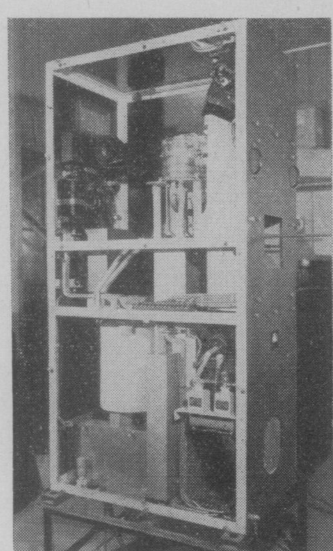

Fig. 34—Transmitter for radio set SCR-271-D.

transmitter. This transmitter was developed by Mr. Watson. The production engineering and manufacturing were done by Westinghouse.

Fig. 35 is a view of a complete SCR-270 as assembled for road transportation. Westinghouse was the prime contractor and had delivered 112 by Pearl Harbor day. From laboratory model to first delivery took only six months.

A most important modification is shown in Fig. 36. This was introduced after our entry in the war, and is a type of indicator known as the plan-position indicator

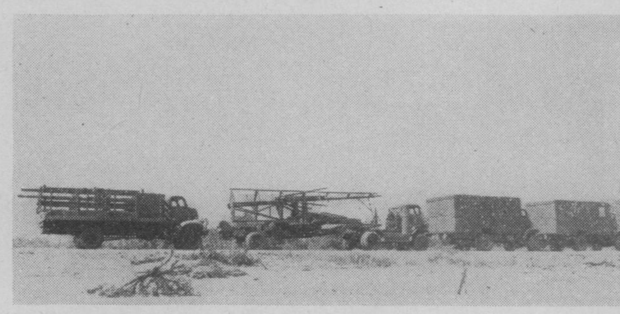

Fig. 35—Radio set SCR-270 packed, ready for transport.

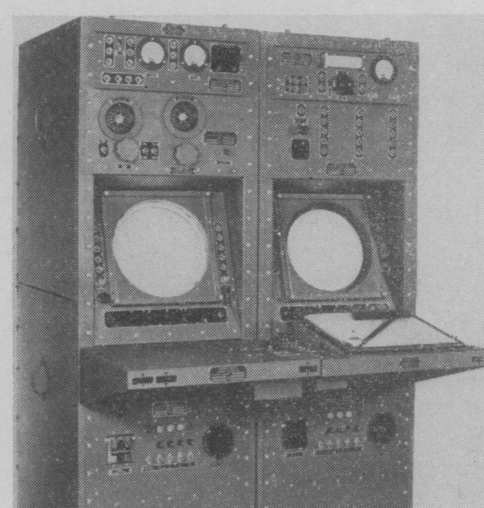

Fig. 36—Receiver indicator used with radio set SCR-270/271 modified for plan-position-indicator display.

(PPI). In this indicator, the cathode-ray beam is deflected radially outward from the center of the cathode-ray tube, with the transmission of the pulses. The cathode-ray beam starts at the center of the tube at the instant the pulse is transmitted and proceeds outward at constant speed, its position corresponding to the position of the pulse in space. When the pulse encounters a target and is reflected, the cathode-ray beam is brightened by intensity modulation and a spot of light appears on the screen, representing the target. Since the direction of the radial motion of the spot is controlled by the position of the array both the distance and the direction of the target are thus indicated. In effect, the screen represents a plan view of the area surrounding the radar, hence the name "plan-position indicator." The advantage of the

PPI is that it can display a large number of echoes simultaneously, whereas the simple indicator previously described (known as type A) is limited to one target at a time. This type of equipment is not unique to the SCR-270/271 but is rather standard to all modern radars. The chief difficulty in its development was obtaining a coating of proper persistence for the face of the oscilloscope. This particular equipment was designed by the General Electric Company.

Conclusion

This story would not be complete without giving due credit to Messrs. Trees, Rauh, Smith, Burtt, and Lewis, and their shop groups who corrected the errors of our engineers and who were responsible for much of the design.

This concludes the story of the 268 and 270/271, jointly developed by the Signal Corps Laboratories, Western Electric Company, Westinghouse Electric Corporation, Bell Laboratories, Radio Corporation of America, Blaw-Knox, Breeze, Couse Laboratories, Eitel-McCullough, Frankford Arsenal, General Electric Company, Le Roy, Fred M. Link, Rangertone, and Terpenning.

Frequency-Modulated Magnetic-Tape Transient Recorder*

HARRY B. SHAPER†

Summary—**A transient recorder having a frequency range of 0.02 to 1000 cycles per second with useful response up to 2000 cycles per second is discussed. The transient is recorded on a loop of magnetic tape and played back synchronously every 0.1 second on an oscilloscope screen. Thus, a steady image of the transient is obtained. Excellent signal-to-noise ratio (40 decibels) is obtained by the use of a 10-kilocycle carrier, which is frequency modulated. Each recording can be obliterated by simply pressing a button, with no material being consumed.**

I. Introduction

THE TRANSIENT behavior of phenomena has always eluded both direct measurement and mathematical analysis. Only in the simpler cases, where all the boundary conditions are known, can the mathematical methods be applied. If they can be applied, these methods are very powerful and illuminating. The great majority of transient phenomena are, however, not clearly defined and must be measured directly.

The instrument to be described is designed to facilitate the observation of transients. Amplifiers and oscilloscopes are now sufficiently well designed to reproduce faithfully the common transients which occur in shock vibrations, lighting, welding, switching, relays, etc. The difficulty is that the phenomenon occurs as a single flash on an oscilloscope, and must be photographed to be observed. Direct-inking pens are available, but these are limited in frequency range, and if high-speed transients are to be observed, then large quantities of paper are consumed. The photographic method is satisfactory but is extremely cumbersome and slow. This is especially true in laboratory investigations where a great number of trials are made and where adjustment of the apparatus is to be made.

A neat way to solve the problem is to record the transient and play it back so that the transient is repeated synchronously. Thus the transient appears as a steady-state signal on the oscilloscope. In this arrangement the signal may be observed conveniently. Such a medium is ideally available in a loop of magnetic tape or wire. No material is used up, and erasing the signal is easy and simple. A new signal can immediately be recorded and observed.

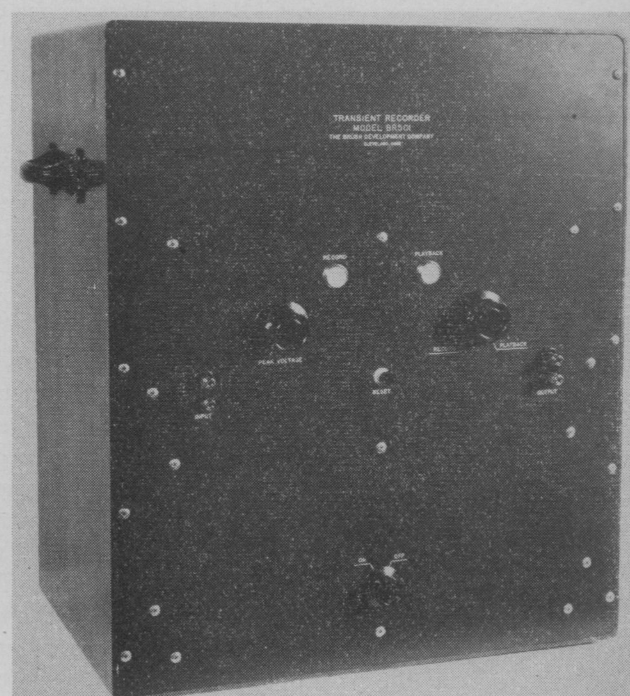

Fig. 1—The frequency-modulated magnetic-tape transient recorder.

This is the basis for the design of the instrument shown in Fig. 1. The instrument stands 23 inches high,

* Decimal classification: R365.3. Original manuscript received by the Institute, December 14, 1944; revised manuscript received, April 25, 1945. Presented, Cleveland Section, Cleveland, Ohio, November 30, 1944.

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