# Short Survey of Japanese Radar—I

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 $\mathbf{R}^{\mathrm{ADAR}}$  IN JAPAN dates back to 1936 when credit is given to Professor K. Okabe of the University of Osaka for devising an electronic method for detecting the presence of passing aircraft.\* At this time Professor Okabe was working under the famous Doctor Yagi,

dean of science at the university. In his method, a radio transmitting station sends a continuous radio frequency signal, with superposed audio modulation in as narrow a beam as convenient, to a distant receiving station. If an object such as an airplane enters the transmission path, the normal uniform signal or tone heard at the receiving station is dis-

solve this problem, but unsuccessfully. In 1938 a large power output set was required to be used; in 1939 a much smaller set was adequate (three watts) and was used experimentally and practically at Hankow. In 1940 various sets with powers

fessor Okabe and his assistants tried long and hard to

The result of a study made immediately following the fall of Japan and recently made available for public information, this 2-part report is designed to present a quick over-all evaluation of Japanese radar, its history and development. As the Japanese army and navy developed their radar equipment independently of each other, Part I of this article concentrates on the army's contributions.

turbed and, instead of being steady, comes in with a strong beat note. This is an application of the wellknown optical Doppler effect.

The Japanese classify their radar sets under two generic headings:

Type A-Continuous wave or Doppler systems. Type *B*—Impulse systems.

According to Professor Yagi, the idea for type-A radar equipment arose following a trip he made to Germany before the first World War during which he became greatly interested in supersonic signaling. Upon his return he performed a number of experiments in this science which led him and Professor Okabe to study the effects of the presence of foreign objects in radio fields. It was not until the middle 1930's, however, that Japanese military people became much interested in such detection problems. They then encouraged Professor Yagi and his associates to apply their knowledge to the advancement of war techniques. Professor Okabe was a leader in the electrical engineering school at Osaka and was given the assignment. He proceeded forthwith to run many laboratory and field experiments on Doppler detection for the army and navy. The method had the great advantage of requiring only very small amounts of power. It had the decided drawback, however, of not giving the definite location of the target along the line between the sending and the receiving stations. Profrom 3 to 400 watts were built. The first Doppler system for aircraft warning was set up in 1941.

It is claimed vehemently by the Japanese that their studies of Doppler detection were conceived quite independently of the suggestions made by Doctor C. W. Rice, of the General Electric Company, whose papers on the

subject appeared in American journals in 1936. Be that as it may, all Japanese radar research and development engineers are familiar with Doctor Rice's writings.

It was not until 1940 that the idea of type-B, or pulsed, radar equipment arose strongly enough for researches on this technique to be initiated. Its advantages were manifested so quickly that the chief effort thereafter was devoted to developing this method.

Unlike American practice, both systems were installed side by side in the army early-warning nets surrounding Japan, and facilities were provided at the information centers for simultaneously displaying the information from both. The Japanese navy also developed a type-A system but never put it into actual operation.

Type-A radar equipments (or detectors, as all earlywarning devices are called in Japan) operating in the 40-80-megacycle band were found to give indications of the passage of aircraft across a fixed line in mountainous places where pulsed types were unsuccessful. They were operable also over much greater distances. The longest type-A line of detection used was from Formosa to Shanghai, a distance of more than 400 miles.

In 1937 the navy research laboratory was experiment-

Wilkinson—Japanese Radar

<sup>\*</sup>The term "radar" first appeared in Japanese papers near the end of 1944. The Japanese were under the imperison that it was used in the United States only to describe the plan position indicator (PPI) search type of set found in B-29's. In-stead of radar, the Japanese call early-warning sets detectors; searchlight and antiaircraft fire control sets are known as locators

Based upon an official report, "A Short Survey of Japanese Radar," prepared by the Second and Third Operations Analysis Sections for Headquarters, United States Army Air Forces, from studies made by the Analysis Sections and the Air Technical Intelligence Group, Far East Air Forces, United States Army.

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Acknowledgment is made of the services of Robert P. Featherstone, formerly captain, Army of the United States, who assisted in the collection of information con-tained in this survey.



Figure 2. Tachi-6 transmitting antenna

Figure 1. Interior view of transmitter and power units of Tachi-6 which corresponds somewhat to the American SCR-270

ing with frequency-modulated continuous-wave radar, utilizing the same principle used in the present American and Japanese low altitude altimeters. In that year a large fleet parade was held in Tokyo Bay, and ranges were obtained up to five kilometers. This was considered unsatisfactory and the experiments were abandoned.

# **RADAR NOMENCLATURE**

Before continuing with a discussion of later developments which will revolve about particular sets, it. will be well to describe briefly the systems of radar nomenclature used by the Japanese army and navy. Japanese radar designations are about as confusing and difficult for the layman to remember as those used in the United States. Over a period of years, Allied radar intelligence people laboriously built up a background in Japanese navy sets, which, in general, were differentiated by four items:

- 1. Mark (Go).
- 2. Model (Kei or Gata).
- 3. Modification (Kai).
- 4. Type (Shiki).

Apparently this was too much for even the Japanese to keep straight, inasmuch as officers and men in their service usually referred to their equipment either by shortened numbers or by nicknames. For instance, the navy's 10-centimeter surface search sets mark 2 model 2 modifications 1 to 4 all were called simply number 22, while the night fighter's prototype 19 air mark 2 model 11 generally was called Gyoku-3.

The official designation system used by the Japanese Navy Technical Department was based on employing the following as the tens digit in the number assigned to any equipment:

- 1. Land-based search.
- 2. Ship-borne search.
- 3. Ship-borne fire control.
- 4. Antiaircraft fire control.
- 5. Panoramic indication.
- 6. Guiding type (ground controlled interception).

The second digit was supposed to be selected according to:

1. Fixed—for instance, number 61 was a fixed-type for guiding or ground controlled interception.

2. Mobile—for instance, number 12 was a land-based search set on a trailer.

3. Portable—for instance, number 13 was a lightweight landbased search set.

In the case of the 2-ship-borne series, however, the second digit refers to a wave length code and not to the degree of mobility. Japanese navy people readily admitted that this system of numbering was far from perfect.

Unofficially, the Japanese navy research laboratory gave each set a name or number as met their whim.

For instance, in the air-borne set FD-1, the "F" stands for "fly," or the German "flutzeig," and the "D" for decimeter wave length. Number 1 was the first one of the series built on the same fundamental designs. The unusual name Gyoku-3 arose from the Japanese word "gyoku-sai," meaning "all-suicide," which may have had considerable appropriateness, inasmuch as this was to have been a night fighter radar set. The letter "K" added to the numbers of certain sets does not refer to the year 1943, as once was suggested in American intelligence, but stands for "kantau" which means simple or simplified.

The Japanese army also had a fairly logical set designation system. The numbers were assigned during development and usually stayed with the set. The type number of each equipment was preceded by one of the following words, in which the prefix "Ta" comes from "Tama Institute" and the. suffix from a characteristic word, giving:

Tachi, meaning land-based ("chi" from tsuchi meaning earth). Tase, meaning ship-borne ("se" from misui meaning water). Taki. meaning air-borne ("ki" from kuki meaning air).

#### ELECTRONICS RESEARCH

Electronics research was handled entirely separately by the Japanese army and navy. Much of the navy work was done by research laboratories directly under the navy ministries. The army, however, assigned more of its pure research to various universities and technical institutes. At the same time several of the larger radio and radar manufacturers were engaged actively in vacuum tube and materials researches, some by direction of the military people, and the rest through their own inspiration. Besides this, of course, the manufacturers were engaged with the problems, many of which bordered on pure research, of trying to meet the specifications for sets ordered by the two services. Incredible as it sounds, engineers and research men in electronics at the large manufacturing companies seldom were told how their equipment worked in the field; they were not allowed to go on shipboard to inspect an installation to say nothing of watching a radar set in operation. Likewise, they were not permitted to visit ground radar installations in the field. Consequently, the men doing much of the designing of the equipment had very little means for observing and correcting their mistakes, an almost insurmountable obstacle in the road of rapid development.

Professor Yagi, well known for his antenna designs, was nominal head of civilian fundamental research. He was outspoken in his criticism of the manner in which the high commands had neglected electronics research on a broad front. In the early days of the war both army and navy officials could not be convinced of the tremendous value that radar might be to them in the defense of their islands. They thought in terms of being always on the offensive, while radar was considered primarily a defensive weapon. Thus they backed only a comparatively leisurely program of radar development. When the top Japanese militarists found they had guessed wrong it was too late to try to catch up with Allied developments.

There was a small number of very able and well trained scientists in Japan, principally in industry and in academic circles. It is of interest to note, however, that in no cases were projects of any great importance turned over to the universities to direct and carry through as they thought best. Usually, small studies, carefully circumscribed by military directives, were parceled out to an individual professor to work on. Often he had no idea of its ultimate use in the radar field. As a result, the utilization of civilian scientific talent, as contrasted



Figure 3. Tachi-2 with transmitting and receiving antennas mounted together on the same mobile trailer mount

with a nearly 100 per-cent mobilization in the United States and Great Britain, was very small and in this way the severe scarcity of first-rate electronics men in Japan was aggravated further by the military's unintelligent direction of their abilities. The meagerness of the program of fundamental electronics research is indicated by the fact that at the close of the war the army had only 39 projects assigned to 13 outside agencies other than the manufacturers.

## DEVELOPMENT OE ARMY RADAR SETS

in 1940 a Japanese technical commission spent several months in Germany and returned with reports of pulsed radar equipment being built in England. This gave new impetus to farseeing officers in the Japanese army and navy to make further studies of its possibilities. Accordingly, the first researches in the army's search radar sets were initiated in 1941.

To co-ordinate the various projects which were beginning to spring up in the army's radar investigations, a research group, called the Tama Research Institute, was formed in 1943 under the leadership of Lieutenant General Suda. This institute was charged with responsibility for all radar research for the army. It also provided a consulting service for the army forces operating the equipment. For example, it assisted in selecting sites in difficult cases. When continuing trouble arose in certain sets, Tama attempted to find the answers.

The institute's laboratories, which were located in the western outskirts of Tokyo, were bombed heavily on April 3, 1945, and about 50 per cent destroyed. Various sections of the research work then were dispersed to other parts of Japan.

The staff of the institute comprised 88 officers and 96 trained assistants. There were an additional 600 persons on the payroll, of whom about half had some technical knowledge. The rest were stenographers, guards, and similar help.

The institute's appropriations for the past three years were:\*

1943—12,000,000 yen

1944—16,000,000 yen

 $1945\mbox{---}16,000,000$  yen (of which only about 7,500,000 yen were spent)

These figures included certain costs for models constructed, and of the remainder, 80 per cent was spent for experimental work and 20 per cent for fundamental research.

A summary of Japanese army radar equipment which had been developed or was under study at the end of the war is given in Table I. The information for this table, furnished by Tama Institute, omitted one notable equipment series known as Taki-24 and 34. microwave airborne extensions of Taki-14, with many features paralleling modern American search equipment. The development of this series was discovered only after considerable tracking down of rumors of its existence.

#### ARMY SEARCH RADAR SETS

As a general rule, Japanese search radar sets were designed for simplicity of operation and presentation. A single A-oscilloscope showing range was the usual case. Bearing was obtainable only roughly through guessing at what point the maximum signal was received. The height-finding radar sets, Tachi-20 and Tachi-35, had more elaborate displays. Resort to pip matching on an azimuth and elevation oscilloscope was the procedure in these cases.

The first army set to be built was the rough prototype of what is now known as Tachi-6. This is the large fixed installation used for primary early warning and corresponds somewhat to the American SCR-270. Frequencies assigned varied from 68 to 80 megacycles. It made use of one transmitter looking either in all directions or over a rather wide fixed arc, with a series of receivers, each looking over a much narrower but movable angle. The first Tachi-6's were produced in 1942 with powers ranging from a 10-kw to 50-kw peak. Figure 1 shows the transmitter and power unit of Tachi-6 while Figure 2 shows the antenna installation at Shimoda. one of the main warning locations, 150 kilometers southwest of Tokyo.

Portable sets were needed to supplement the ponderous Tachi-6 equipment, which was ill adapted for use outside of the home or mandated islands. Accordingly, the mobile Tachi-7, weighing 18 tons including vehicles and operating at 100 megacycles, was developed in the same year. It was ready for service in 1943, and most of the 60 sets manufactured were sent overseas, where mobility and ease of handling were of great importance.

A still lighter set was needed for portable service. For this, work on Tachi-18 was begun early in 1943, and a 100-megacycle set weighing only four tons was completed at the end of the year. These latter sets were retained mainly in Japan, where they provided a standby for Tachi-6 or assisted in reading through Allied jamming signals.

Tachi-6, like the American SCR-270, gave only the barest information on airplane heights. Tachi-20. with lobe switching in both azimuth and elevation, was installed at Choshi in March 1945, and Tachi-35, with goniometer pick-ups from pairs of azimuth and elevation antennas, was installed at Matsuda in May. These sets, working in the 80-megacycle range, were the army's attempt to answer the height problem. They were only partly successful.

In late 1942 the army began studies on a radar set to be installed on transports and other large ships for protection against Allied submarines. This led to the building of the 15.7-centimeter Tase-2 set by the Nihon Musen Company. In February 1943, installations were made on two ships, but the set did not have sufficient power to give satisfactory range, so it was earmarked for use on land. A second marine set, Tase-10, operating at 150 megacycles, was produced in December 1944. This set was designed expressly for use on transport submarines. However, upon its completion, Japan had left only one submarine of size suitable for its installation, and this installation proved abortive when the submarine's power supply was found to be inadequate.

The first army air-borne set, Taki-1, was built by the Nihon Musen Company in 1943, with only six months

<sup>\*</sup> The current military rate of 15 yen to one dollar is likely to be rather misleading as to the magnitude of the budgetary figures. The average factory worker in Japan is paid from one seven to ten yen for a 10-hour day, or, say, one yen per hour. For equivalent work, factory employees in the United States would be paid perhaps one dollar an hour.For a rough estimate of the equivalent American purchasing power allotment for these activities, the figures given might be considered dollars.

elapsing between drawing board and installation. Taki-1 operated at 200 megacycles with a 10-kw peak output, weighed 150 kilograms, and was for use on heavy bombers. Presentation was on a simple A-oscilloscope with a scale laid off by range marker pips. A certain amount of directional searching was obtainable by switching transmitter and receiver to any one of three antennas, a nose Yagi antenna, and a doublet on either side of the fuselage. This set was considered very satisfactory for sea search, giving ranges of 50 kilometers or more on large ships, and more than 1,000 sets were built. Smaller and lighter editions came out from time to time.

It was appreciated that greater definition in the oscilloscope presentation than that given by Taki-1 was desirable. Accordingly, in August 1943, research was started on a centimeter wave length air-borne radar called Taki-14. The first set, operating at 27 centimeters with a triode transmitting tube, was completed in August 1944 under the direction of Major Uozumi of Tama Research Institute. The antenna was a Yagi array with a paraboloid reflector. The set, when in-

stalled on a heavy bomber, gave maximum ranges of only 25–30 kilometers, which was thought, not nearly good enough. By a series of experiments on the transmission lines and the antenna, the ranges were stepped up to 40–50 kilometers by February 1945. Production was made very difficult by the B-29 bombings of the plant doing the manufacturing, so that no sets actually were installed and in use by the end of the war in August. Continued experiments during this period involving the use of cavity tuning had brought the range up to 70– 80 kilometers. The disposition of this latest experimental air-borne equipment is described poignantly by Major Uozumi, project engineer on Taki-14.

"On August 14th in this year, the war situation became too imminent to continue the research in laboratory even for our tech-



Figure 4. Tachi-28 multiple fighter control system

nical officers. We were obliged to prepare as we were able to go to the front to die—I dare say 'to die.' Thus at last we partialized and burnt down all our lovely sets (please pardon me to say 'lovely') with all important documents of investigations or experiments, and then we suddenly met the end of war before we went to the front as you know. I'm very sorry as one engineer that we partialized and burnt down to ashes all the sets and technical documents. I can say with my responsibility that we would have never burnt our lovely sets if we knew the war would end on August 15 at once, and you American Army or Air Forces would land such peacefully as we saw actually."

Paralleling the development of Taki-14 at 27 centmeters were studies at Tama Institute using the identical equipment with the radio frequency circuits altered to accommodate 10-centimeter transmitting tubes, thus producing Taki-24. At the same time, a 5-centimeter



Figure 5. Direction finding antennas

set called Taki-34 was under development which used a magnetron for transmitting and a velocity-modulated tube for the local oscillator. A plan position indicator (PPI) presentation with sweep corresponding to the position of the paraboloid antenna was employed with magnetic deflection coils on the oscilloscope. It was developed after seeing the construction used on B-29's which had crashed over Japan. This set was turned over to Tama engineers in July 1945. It never was test flown, but experiments from a high point of land at Ajiro on the peninsula south of Tokyo showed the disappointing ranges of only 12-15 kilometers on nearby mountains.

#### LOCATOR-TYPE RADAR SETS

In 1942 one Japanese officer and two civilian engineers went to Singapore and Corregidor to inspect captured English and American radars. At Singapore they found the equipment almost entirely demolished. However, according to Japanese accounts, they discovered one complete set of drawings and specifications for a searchlight or fire control radar. At Corregidor several SCR-268's were captured, one of which was in complete operating order.

Tachi-1 and Tachi-2, the first two locators designed by the army, show strong indications of British searchlight control influence. Both are 200-megacycle sets, Tachi-1 having separately mounted transmitting and receiving antennas, while Tachi-2, as shown in Figure 3, has them together on the same mobile trailer mount. A phasing ring is used in both cases to give the receiver lobe generated by the four Yagi antennas a rotary movement. A mechanical distributor is used to switch the received signal at appropriate moments to the azimuth and elevation oscilloscopes. Tachi-3, which became the army's chief fixed position fire control reliance (150 were produced), was patterned after the British gun laying mark II equipment. It was rated at 50 kw at 78 mega-cycles and had a claimed range of 40 kilometers. Color disks were used for pip matching in both azimuth and elevation.

At a typical army antiaircraft defense layout, such as at Kawasaki, ten miles below Tokyo guarding the southern approaches to the capital, both Tachi-2 and Tachi-3 would be installed to control six 120-millimeter guns arranged in characteristic circular positions, and six 88millimeter guns in a semicircular design. Tachi-2 often was camouflaged by a barn which rolled back on railroad tracks when the set was to be used. It is perhaps of interest to note that the Japanese navy acquired a Tachi-3 for experiment and comparison with navy fire control sets at their Chigasaki field laboratory. They found that it had greater range than their own S-3 and S-24 equipments, but that its bearing and elevation accuracies were not as good. Consequently, they considered their navy sets superior for searchlight and fire control purposes.

Tachi-4 was a mobile locator built to replace Tachi-2, but it proved unsatisfactory in operation. In this set the transmitter and receiver were combined to simplify the assembly. Finally Tachi-31 was built from modifications of Tachi-4 and became the standard 200-megacycle radio locator for the army. This 10-kw set used all four Yagi antennas for transmitting and receiving, thereby giving greater range and directional definition (range, 40 kilometers, azimuth and elevation accuracy plus or minus one degree).

At the same time that the 200-megacycle development was going on, slow progress was being made in building an exact copy of the German Small Wurzburg (Tachi-24), which would operate at a 50-centimeter wave length and give a much improved azimuth and elevation accuracy (in the order of one-eighth degree). Plans for this set and the major components had been brought from Germany by submarine in January 1944. Reengineering to Japanese specifications and parts required several months, and the first of three sets to be made by Nihon Musen as models for the Sumitomo and Tokyo Shibaura companies to copy was nearing completion in August 1945.

In all of the foregoing fire control sets, the data are sent to mechanical gun directors by means of a Selsyntype system.

The army just was beginning to produce a locator for use on aircraft as the war ended. This was Taki-2. an 80-centimeter set with a single Yagi transmitting antenna and four similar receiving antennas switched in rotation for azimuth and elevation estimating. It does not seem likely that this set would have given sufficient directional accuracy for much success as a night fighter.

AUGUST-SEPTEMBER 1946

#### Table I. Summary of Radar Equipment Developed by the Japanese Army

Figures Given Indicate Maximum and Minimum for Each Classification

	Number of		Frequency (Megacycles)				Total
Classification	Types Designed	Objective	or Wave Length (Centimeters)	Power Output	Range	Weight	Number Produced
Warning Radar							
Ground		Fixed and mobile air craftwarning systems	. 68–106 megacycles	to 50 kw	to 300 kilometers	. 100 kilograms-18 to (including vehicles	ns. 825
Ship-borne.		Detection of ships, air	15.7 centimeters 150 megacycles	to 50 kw	to 300 kilome	eters 100 kilograms	-4 tons_111
Air-borne.	2	Detection of ship? and . submarines	. 150 megacycles	10 kw	to 100 kilometers	80–150 kilograms	1,000
Locating Radar							
Ground		Fixes firing data for .	78–200 megacycles 50 centimeters	to 50 kw	to 40 kilometers	1.5–4 tons	. 341
Air-borne		Night interception	80 centimeters	2 kw	to 8 kilometers	120 kilograms	in production
Leading Radar							
(Offensive fighter air craft directing)	r-						
For single aircraft		Indicates position of friendly aircraft	175–184 megacycles	to 10 kw	150 kilometers	25 kilograms-1.5 tor	ıs70
For several aircraft Directing equipment .	2	Same Computes intercep- tion course and transmits it to airplane	. 190 megacycles			25 kilograms–500 ton 20-500 kilograms	s 51 models completed
Identification—friend	l	•					
or foe		Identification of aircraft.	. 175-184 megacycles	100 watts (a borne 10kw(groun	ir- 250 kilometers	25 kilograms (ai borne) 1.6 tons (ground	r- 120 1) 50
Navigation Radar							
Hyperbolic curve nav	i-	G		150.1	2 000 111	50.111 (.)	
gation equipment.	2	Computation of two. curved lines for navi- gational purposes	. 1.5 megacycles	150 kw	to 3,000 kilo- meters	50 kilograms (ai borne) 600 tons (ground)	r model
		• • • •			radius 20 kilo-		
Night Radar	4.	Identification of condi tion of terrain for bombing and navi-	. 5-27 centimeters	2 kw	5,000 meters altitude	120 kilograms	completed
Radar altimeter.		Computation of dis tance from aircraft to	. 375 megacycles Fm and pulsed	to 200 watts	to 50 meters and 12.000 meters	25 kilograms	in use
Search Receivers		Detection of enemy . radar	. 3 centimeters-15 meters		to 300 kilome- ters	32–250 kilograms	50 sets in field
Radar jamming		Jamming of enemy radar	0.8–7 meters	continuous 70 watts impulse to 11	to ) kw )	200 kilograms	
Special equipment Special aircraft control.		Guiding of gliders	. 200 megacycles			50 kilograms-2.5 tons	s Under research
Homing equipment	2I	Detection of, and adher ing to, electric waves reflected or sent from shipe	300 megacycles to 7.5 meters	70 watts	to 5 kilometers. (expected)		Under research

#### ARMY LEADING RADAR FOR GROUND CONTROLLED INTERCEPTION

The Japanese were trying hard to solve the problem of ground controlled interception as the war ended. For this they had built a ground interrogator, Tachi-13, transmitting at 184 megacycles per second and receiving at 175 megacycles per second. This was to work with the transponder Taki-15 installed in the airplane both to identify and fix the position of the night fighter. Display was on two *A*-oscilloscopes. one giving range, and the other giving bearing by means of pip matching. This would have been quite similar to using the American RC-184 for guiding an interceptor, something which could be done only with exceedingly skilled plotters and controllers. Presumably the 200-megacycle Tachi-31 or the Wurzburg (Tachi-24) would have been used for fixing the position of the enemy airplane at any moment.

In order to handle more than one air interception at one time, a combination of equipments called Tachi-28 was in the process of being built, by means of which as many as 30 friendly airplanes could be guided simultaneously (see Figure 4). Each airplane to be controlled carries a transmitter (Taki-30) radiating a continuous signal at 190 megacycles and modulated at some assigned frequency between 30 and 60 kc. Two or more direction finder (DF) stations located at intervals of about 50 miles pick up the signals. Their antennas (see Figure 5) rotate steadily at two revolutions per minute, and each is arranged by 50-cycle lobe switching to have a horizontal pattern with two maxima and a sharp minimum between them.

The composite signal picked up by each direction finder station—a mixture of tones from 30 to 60 kcis radioed to a control station on a special 5-meter link. (Some of the central station equipment is seen in Figure 6). In the region below the lowest aircraft signal frequency (from zero to 30 kc) a voice channel and an azimuth signal are transmitted. The latter indicates the position of the direction finder antenna and is in two parts: one. for fine data, is continuously variable and re-

for fine data, is continuously variable and repeats itself every 30 degrees; the other, for coarse data, varies in 12 steps. At the centralstation the coarse azimuth signal lights one of 12 neon lamps, while the fine azimuth signal positions the spot of a cathode ray tube causing it to go through a circle for each 30 degrees of the direction finder antenna's travel. The signal of the particular airplane being observed is selected by a filter and displayed radially on the cathode-ray tube. The minimum in the center of the observed figure which appears on the oscilloscope is at the azimuth of the airplane. The operator locating an airplane has two oscilloscopes before him, one for each of the two outlying direction finder stations. From the data

of both stations he can locate the airplane quite accurately Other operators use the same azimuth signals but select different aircraft signals.

This system was intended for ground controlled interception use and the first units were being installed in the Tokyo area as the war ended. The central station was located at Matsudo; initial direction finding stations were at Choshi and Shiranama. 50 miles east and south, respectively, of Tokyo. In some cases relay stations were be used in the 5meter radio link. This system is of possible interest to American engineers studying airport and airway traffic control as it provides instananous remote indications of a large amount of data:



Figure 6. Tachi-28 central station equipment

Left—Fine indicator, coarse indicator, auxiliary equipment Center—Monitor oscilloscope, equipment to develop circular sweep Right—Filters for airplane signals

two direction finder cuts a minute on each of 30 airplanes.

The transponder used with the Tachi-13 previously mentioned is really an identification-friend-or-foe set and ordinarily would be used with the Tachi-13 or Tachi-17 on the ground as the interrogator-receiver in the pro-



jected identification-friendor-foe system. Tachi-17 is a simplified Tachi-13 giving considerably less directional accuracy.

There is considerable doubt that the foregoing measures would have gone very far toward solving one ofJapan's most urgent problems: how to knock the B-29's out of the sky in such numbers as to interfere seriously with their bombing operations. Even the United States forces, with their much superior plan position indicator oscilloscopes for ground controlled interception, and their 10-centimeter airborne radar interception. would have had great difficulty in slowing down such an attack.

# Short Survey of Japanese Radar—II

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**R**<sup>ESEARCH AND DEVELOPMENT of navy radar and allied equipment were vested in the electronics</sup> section of the Second Naval Technical Institute located near the Yokosuka Naval Base. The section was under the direction of Vice Admiral Nawa, an electrical engineering graduate of Tokyo Imperial University. A rather capable staff of physicists and engineers was employed, some civilians,

some commissioned officers. Doctor Takeyanagi, a name known in television circles, was assistant chief of radar research. The staff received no outside assistance except for one Mr. Brinker, an unwelcome arrival from Germany who came to work in the laboratory at the direction of higher navy officials. The Japanese engineers felt that they were quite able to meet any radar problems that the navy might bring up. Thus the navy handled the majority of its own

electronic research work, while in the army the tendency was to assign various projects to outside research agencies, such as the universities and the manufacturers.

The naval institute's electronics division employed 350 technicians including 80 engineers and scientists. The annual budget amounted to 100,000,000 yen\* which included the costs of making prototypes for all land, air, and ship-borne communications and radar. The actual installation on ships, however, was not handled by the institute. The activities of the radar and communication department of the institute since 1940 include studies on tubes, materials, and test equipment; circuit development; and the testing of many components and complete radar and radio sets.

One development of some interest was apparatus A,

Acknowledgment is made of the services of Robert P. Featherstone, formerly captain, Army of the United States, who assisted in the collection of information con-tained in this survey. by which the Japanese proposed to cause their own shells to explode at predetermined positions or heights by passing them through a strong beam of centimeter radiation. Although the Japanese did succeed in 1944 in generating ten kilowatts of continuous power at a 20-centimeter wave length, the idea failed because of the "lack of an adequate receiving apparatus."

Part II of a Japanese radar survey continues a report based on a study made by the United States Army which was particularly fruitful because of the obvious willingness of the Japanese to volunteer technical information, in spite of the difficulties of interrogating in a foreign tongue or through an interpreter unfamiliar with technical terminology. Because radar research was carried on separately by the army and navy in Japan, this article complements Part I's discussion of army radar with a summary of naval developments in the same field, as well as discussing general factors incidental to the manufacture

and operation of radar equipment.

The work conducted on magnetron research, under the direction of Captain Ito, a former student of Professor Okabe at Osaka University, is of particular interest. It may have come as something of a surprise American intelligence to officers and radar engineers that the navy was producing 10-centimeter magnetrons suitable for use in their ship-borne search sets as early as the fall of 1941. Thus, their microwave studies at that time were but a few months behind similar studies being conducted

in the United States. In the succeeding years, however, American development outdistanced Japanese, inasmuch as the best the latter could do was to produce a tube giving about five or six kilowatts peak output at ten centimeters. Most recent magnetron researches by the navy had resulted, on an experimental basis, in tubes yielding 1.5 kw of pulsed power at 2.7 centimeters and "just observable" powers at 0.7 centimeter. Commercial research organizations displayed magnetrons for which they claimed outputs as high as 26 kw at 2.8 centimeters. A summary of navy radar developments is given in Table I.

# NAVY WARNING RADAR SETS

Research and development work on type B (pulsed radar was begun by the Japanese navy early in 1941). The well-known type 11 (mark 1 model 1) 40-kw 100megacycle set found at Attu and Guadalcanal was developed in the period between April 1941 and March 1942. The Japanese report that the first number 11 set was installed at Rabaul. Altogether, about 80

Basedupon an official report, "A Short Survey of Japanese Radar," prepared by the Second and Third Operations Analysis Sections for Headquarters, United States Army Air Forces, from studies made by the Analysis Sections and the Air Technical Intelligence Group, Far East Air Forces, United States Army.

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<sup>\*</sup> In purchasing power roughly equivalent to 100 million dollars in the United States



Figure 1. Ship-borne 10-centimeter radar set number 22 for surface search

Under bench, left to right: Antenna control handles, rectifier On bench, left to right: Receiver, indicator for warning, receiver control panel, transmitter, transmitter control panel

On wall: Antenna azimuth indicator

of these large early-warning sets were manufactured. Soon after, work was begun on a smaller set which would not require the building of the large number 11 sets on distant islands, and several portable models were developed. Set number 12, of 5-kw power and working at 20 megacycles, appeared at the end of 1942; it later was adapted for ship-borne use also although throughout its life it was troubled with frequency instability. Set number 13, 10 kw at 150 megacycles, followed as a very lightweight unit in 1943, while simplified number 13, that is number 13K, was making its appearance just as the war ended. In the fall of 1944 when the B-29 raids began in earnest, the Japanese decided they needed a set which would give them longer range warning than any of the sets then in use. A long wave 6-meter set was "crash-engineered" and then built in three weeks. Three of these sets eventually were installed, two on the southern shores of Honshu, and the third at the very southeastern tip of Kyushu. Ranges obtained on high flying B-29's were consistently of the order of 300 kilometers.

The first of the long line of number 22-type shipborne 10-centimeter search sets was completed in June 1942. The transmitter is powered by an M-312 magnetron, the anode of which is water-cooled by a motordriven pump. The tube delivers a peak power of approximately six kilowatts with 11,000 volts applied to the anode. Power is transmitted through circular cross section wave guide to a horn antenna. A separate horn

is used for receiving to obviate the loss and complication in a transmit-receive (TR) tube to accomplish electronic switching. A blocking oscillator provides the 10microsecond keying pulse at a rate of 2,500 per second under the control of a tuning fork. The receiver is a superheterodyne with crystal detector and magnetron M-60-S as local oscillator. The intermediate frequency is 14.5 megacycles, the total receiver gain amounting to 120 decibels. The display is on two type-A cathode ray tubes. One tube called the "indicator for warning" shows all target echoes up to 60 kilometers. Range pips generated by shock exciting a crystal appear every five kilometers. A 3-microsecond range pulse is moved along as the range crank is turned. The second, or "range operator's oscilloscope" gives an expanded view

#### Table I. Radar Equipment Developed by the Japanese Navy

Power and range figures given indicate maximum for each classification

Classification	Number of Types Studies	Objectives	Frequency (megacycles) or Wave Length (centimeters)	Power Output	Range
Land-based radar	22 ]	For use in antiaircraft warning, searchlight and antiaircraft fire control, altitude measurement, and identification of aircraft	2 at 60, 6 at 100, 5 at 150, 7 at 200, 2 at 500 megacycles	to 100 kw	to 450 kilometers
Ship-borne radar		For use in antiaircraft and anti- surface warning and fire control	4 at 150, 6 at 200, 1 at 500 mega- cycles; 1 at 28, 8 at 10 centimeters	to 30 kw to	o 100 kilometers
Air-borne radar	11 1	For use in patroling and searching, aircraft identification, altitude measurement, and path finding	6 at 150, 1 at 250, 1 at 340, 2 at 500 megacycles; 1 at 10 centimeters	to 20 kw t	o 150 kilometers
Land-based, ship-borne, ar	nd air 9	earch receivers to determine data	3 centimeters-4 meters	Receivers only	
borne radar counter mea	asures	on enemy radar			

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of about 1,000 meters of the range as selected by the range crank. A magnifying glass in front of the oscilloscope gives it a size equivalent to a 5-inch tube. The true range is read on a dial when the target pip's leading edge is set just even with a vertical line inscribed up the face of the tube. The range obtainable on a battleship was of the order of 25 kilometers. This set was agreed by army and navy alike to be one of the most satisfactory radars used by the Japanese forces. Members of the navy laboratory assembled a 22 set at their Tsukishima test area in Tokyo's eastern suburbs for viewing by United States Army air personnel. Excellent definition was obtained on targets in Tokyo Harbor. Figure 1 shows a bench set up with the transmitter, receiver, and indicator for warning. Figure 2 shows the range unit.

A somewhat simplified version of number 22 called modification-3 was installed in the conning towers of submarines. It used two horns mounted side by side. Presentation was on a single *A*-type 75-millimeter oscilloscope. Range was about ten kilometers on a battleship.

For ship-borne air warning a modification of the number 12 land-based set (renamed number 21) was used, and the number 13 land-based set also was adapted for the same purpose.

The first development work on air-borne radars was done by the navy in November 1941. It resulted in a patrol and search set (number H-6) working at 150 megacycles. During the years that followed, some 2,000 of these sets, which gave excellent satisfaction, were manufactured. The H-6 eventually gave way to the lighter and more compact FK-3 in the latter months of the war.

The navy well appreciated the desirability of obtaining better definition than could be realized from the 150megacycle sets used for sea patrolling if they were to be able to do radar bombing. Some work was done in an attempt to adapt the 10-centimeter number 22 shipborne set for this purpose, but the project was unsuccessful. Meanwhile, design specifications on a 10centimeter air-borne search set called the Rotterdam Gerate had been received by radiotelegraph from Germany. (It now is believed the data came from an early British H2S set shot down by the Germans over Rotterdam.) On the basis of the received data, the navy



Figure 2. Range unit for type 22 radar

electronics laboratory set out to build equipment. The result was the number 51, or Pathfinder, set which is roughly equivalent to the American ASG or SGR-717-B. It is a 10-centimeter magnetron powered set with a north stabilized 150-millimeter plan position indicator oscilloscope tube. The magnetron is the M-314, and can be seen inserted inside the toroidal-type magnet in Figure 3. Arrangement is made for a lubber line to show the heading of the airplane at any instant. A second A-display tube reads altitude. A small M-60-S magnetron is used as the local oscillator. The antenna is the rotating cut parabola type and carries a folded antenna with a parasitic dipole reflector in front of it. Preliminary flight results showed that shorelines could be distinguished at only 20 kilometers, a figure far below what had been hoped.

#### NAVY LOCATOR-TYPE RADAR SETS

The first navy ground-based locator-type radar was based on the American SCR-268's captured at Corregidor in the spring of 1942. Research on the resulting S-3 antiaircraft fire control set was begun in August 1942 and concluded a year later. The Sumitomo Company was provided with drawings of the desired equipment from which they produced about 80 sets, at the very slow rate of five per month. The close resemblance of the copy to the original, the American set, may be

	Tube Characteristics						
Tube Designation	Anode Voltage	Peak Anode Current	Wave Length (centimeters)	Peak Power Input(kw)	Peak Power Output (kw)	Magnetic Field Gauss	
Transmitting:							
M-312	11,000	2.a	9.83-9.92	22 peak	6.6 peak	1,000	
M-314	11,000	.5.a	9.83-9.92			1,000	
S-60	8,000	7.a	5.2	60 peak	18 peak	2,100	
S-51	12.000	6.a	3.15	72 peak		2,200	
Receiving (beat frequency oscillator):	,			1	1	,	
M-60	210 + 20	17  ma + 0.1  (cw)	9.83-9.92			690	
M-2643	540	1.5 ma (cw)	2.8 - 10.0			4.000	
			(Nominal 3 centimeter	rs)			

#### Table II. Nihon Musen Magnetron Characteristics

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recognized in Figure 4. The Japanese had no better luck with these sets in hitting anything than the United States Forces had with the SCR-268. Meanwhile production was started on a searchlight control set L-1 built along the lines of the British searchlight control data obtained at the fall of Singapore. Attempts also were made to adapt the latter for fire control purposes, resulting in the S-23 set. However, the directional accuracy was not good enough, and after making a few sets, the project was abandoned.

Difficulties in building and maintaining the S-3 resulted in the design of a simpler 200-megacycle antiaircraft control set known as the S-24. Inasmuch as this set had both greater range and greater accuracy than the S-3, it became the navy's standard landbased fire control radar equipment. However, its accuracy was still very poor as judged by American standards and, with its susceptibility to jamming, it was thoroughly inadequate to handle the pressing antiaircraft fire control problem.

The navy's initial answer to the jamming problem, as well as the relative inaccuracy of the S-3 and S-24 sets, was to build a higher-frequency set. This was done in the experimental number 61 which, at a wave length of 60 centimeters, has much the appearance of the Small Wurzburg. The navy also had spoken for a share of the production from the army's Wurzburg program.

For ship-borne and coastal defense fire control the navy adapted the number 22 set by switching the receiver alternately to each of a pair of horns with slightly diverging axes. This produced a pair of lobes with a spread of about six degrees. The received signal pips were matched for height on a suitable bearing cathoderay tube to obtain an azimuthal accuracy in the order of plus or minus one-half degree. Experiments also were made with large parabolic reflectors. Here the dipole antenna was oscillated rapidly in a horizontal slot located roughly at the focus of the parabola.

#### NAVY GROUND CONTROLLED INTERCEPTION

The navy plan for controlling friendly fighters was quite similar to that proposed by the army. A ground interrogator with broadband antenna enabling it to operate anywhere from 145 to 155 megacycles trips the transponder in the airplane, which replies at a slightly different frequency (up to three megacycles difference). Radar set number 62 obtains range on an A-oscilloscope and shows bearing on another oscilloscope by matching pips through a mechanical lobe-switching device. It may be noted that the identification-friend-or-foe transponder in the airplane, when not being employed for ground controlled interception work, sweeps a band of 150 plus and minus five megacycles and replies on the interrogation frequency, so that any 150-megacycle radar set such as the navy's number 13 can identify friendly airplanes by the fluctuating increase of the target return at regular intervals. This corresponds exactly to the old American mark 2 identification-friend-or-foe system. For locating the foe airplane, the navy was developing a long-range (200-kilometers) 100-megacycles-per-second lobe-switching radar set to be called number 63. As with the army's proposed scheme for making interceptions by means of separately tracing the friendly airplane and the foe airplane with radar equipments having relatively poor bearing accuracy, it would seem highly likely that the navy's plan would have given very disappointing results unless exceedingly skillful operators were employed.

The navy was developing two night fighter radars at the time the war ended. The 500-megacycle number FD-2 set had a presentation giving azimuthal corrections only with an oscilloscope indication similar to that of the American SCR-521. The other set, working at 150 megacycles per second, was known as Gyoku-3. It employed an unusual fixed antenna built in two forward-facing layers. By feeding them through a rotating goniometer-type coil, a rotating forward lobe was generated and the corresponding display was shown on a plan position indicator oscilloscope. The definition in this set would seem to be very poor, inasmuch as the beam is some 70 degrees in thickness. Japanese navy engineers insisted, however, that such a thick beam is needed or the entire area in front of the airplane could not be searched adequately. Apparently the idea of rapid scanning by a very narrow forward-looking pencil of radiation had not appeared to them to be practicable.



Figure 3. Detail of transmitter of 10-centimeter air-borne "Pathfinder" search set showing electromagnet with magnetron inserted axially

# NAVIGATIONAL AIDS

Both the army and the navy had developed low altitude frequency-modulated altimeters, which they claimed had been of good service during low altitude torpedo bombing attacks on enemy shipping. The army also had a high altitude pulsed altimeter, but it gave so much trouble and read so erratically that the flyers would not rely on it. Neither the army nor the navy had any program for vectoring home lost pilots by means of radar plots. No mention of the use of the identification-friend-or-foe sets in the airplanes to extend their locating coverage for this purpose was made in discussions of the various associated equipments.

The army had plans drawn up and equipment partly installed for a simple hyperbolic navigation system very similar to Loran developed by the United States. The idea for this, although denied by the army, was said by navy personnel to have come from Germany. The equipment carried in the airplane was much simpler than in the American version. The radio operator timed, on a stop-watch, the interval taken by a carefully controlled drift pulse from one of the two ground stations to travel between coincidence with the two regular pulses from the ground stations. Very likely the accuracy does not compare with that obtained by American sets, although it may well be good enough to be of great value to airmen.

#### **RADAR MANUFACTURERS**

The production of radar equipment for both the army and navy was contracted for by a relatively few large manufacturing concerns, who in turn were supplied with parts and minor assemblies by a myriad of small producers. The method of handling was not unlike that used in the United States. The three principal Japanese radar manufacturers were the Nihon Musen Company, the Tokyo Shibaura Denki, and Sumitomo Tsushin Kohgyoh, Each maintained a staff of electronic research workers recruited mainly from the company's





peacetime engineers, physicists, chemists, and metallurgists.

The policy of secrecy enforced by both the Japanese army and navy was a great handicap to production. Often in the same plant similar sets were being developed by company engineers for the two branches of the service, but they were not permitted to exchange the slightest information. For example, the Nihon Musen Company's main plant was divided carefully into two parts, one for manufacturing army equipment and the other for navy equipment. This military policy was criticized strongly by all company officials who saw not only the wastefulness of building two sets to do the same work, but the even more critical loss in engineer and research talent caused by such duplication of design.

The Nihon Musen Company, an affiliate of the German Telefunken electrical interests since 1923, employed some 16,500 workers in its four plants at Mataka (Tokyo suburb), Nagano, Ueda, and Suwa. None of these plants was injured by American bombings. The research section, located at the Mataka plant, had two divisions, one on vacuum tubes which employed 60 scientists and engineers, and one on general matters which employed 40 engineers. Nihon Musen's vacuum tube development under the leadership of engineer Shigeru Nakajima was outstanding. To him is given much credit for the design of the successful magnetrons used in the army and navy's most advanced radar equipment. Experimental magnetrons down to 0.7-centimeter wave length had been built, but their lamp load method of measuring powers was inadequate to determine outputs at such ultrahigh frequencies.

The principal characteristics of Nihon Musen's later magnetrons are given in Table II.

Perhaps Nihon Musen's most interesting commission was, in 1945, to build as quickly as possible three exact copies of the German Small Wurzburg, known in Japan as Tachi-24. These were to be used as models for building 50 sets by the three large radar manufacturers to fill the first joint order of the army and riavy. The first of the models was within one month of completion when the war ended on August 15.

Tokyo Shibaura Denki is the Japanese counterpart of the General Electric Company in the United States, and before the war was affiliated with that company and others for the exchange of certain technical information. The company operated five plants located in Tokyo, Kawasaki, Fuji, and Yobe, with a total of 27,000 employees at their peak of production. The three largest plants which were in the south Tokyo area were estimated to be 70 per cent destroyed by fire and bombings. The general and electronics research laboratories, located in the Koikawa Cho plant both were destroyed completely. The general research section was comprised of 100 engineers and scientists, while the electronics laboratory employed about 150 research workers. In the Tokyo Shibaura electronics laboratory considerable effort was being expended to produce magnetrons at higher and higher frequencies. A 15-centimeter magnetron for the Tase-2 set was the laboratory's highest frequency tube actually in production. However, the research director. Doctor Hamada, had built experimental all-metal types down to three centimeters. For example three of these models shown in Figure 5 have the following claimed performance:

Three centimeters—1-kw peak (air-cooled).

Five centimeters—3-kw peak (air-cooled).

Nine centimeters—10-kw peak (air- and water-cooled).

In general, electromagnets were used for obtaining a strong field for the magnetrons, although experiments with materials for permanent magnets had yielded fields up to 2,000 gausses. Shortages of nickel and cobalt were given as reasons for not developing the permanent magnet program to a fuller extent.

For local oscillators, Tokyo Shibaura engineers had experimented with positive grid Barkhausen tubes to work with crystal detectors. They had tried to build power klystrons five years or more ago at about 20 centimeters but without much success. More recently they had been working with klystrons for receivers at three, five, and ten centimeters.

The Sumitomo Communications Industries Company in peacetime is Japan's leading manufacturer of telephones and automatic and manual switchboards, as well as much wireless and electric testing equipment. It is owned partly by the International Standard Electric Company. Its seven plants in Japan employed 32,500 persons. About half of these were at the Tamagawa plant in Kawasaki which was about 60 per cent destroyed by bombing. The Ikuta research laboratory, 12 miles southwest of Tokyo, is one of the largest electronics research groups in Japan, with a staff of 650 engineers and assistants. During the war most of the talent was devoted to radar research in one form or another.

In November 1944 Tama Institute directed the Sumitomo Company to develop and build a 5-centimeter air-borne search radar set, with the single specification "with as much power and range as possible." At that time they did not know that the American B-29's were equipped with 3-centimeter radar sets or they might have attempted that wave length. The tube research section finally succeeded in devising a 5centimeter magnetron with equalizer ring which developed one kilowatt of pulsed power, but not until Tama Institute had made available, early in 1945. several recovered magnetrons from APQ-13 sets in crashed B-29's. (A number of these were in operating condition, although the Japanese never obtained more than five kilowatts from them.) The antenna and radio frequency "plumbing" were influenced considerably by American design. At the same time a velocity modulated tube with variable frequency was developed



Figure 5. "Rising Sun" type magnetrons built by Tokyo Shibaura Company

Wave lengths from top to bottom: 9 centimeters, 5 centimeters, and 2.7 centimeters

as a beat frequency oscillator to work in the receiver. The size of the metal cavity clamped or soldered to the flanges passing through the glass envelope determines the resonating frequency, which can be varied up to plus or minus five per cent by mechanically compressing the cavity. The voltage on the repeller is varied until maximum output is obtained.

#### **ARMY-NAVY LIAISON**

The great majority of the radar sets installed on the islands which the Japanese invaded were navy types and were operated by navy personnel to protect their own installations. In this way the navy became experienced in early-warning activities near the beginning of the "Pacific War," as the Japanese call it. In the Japanese homeland however, the army was charged with the responsibility for general air raid warning and covered the islands with a network of stations of both types A and B. There was an almost negligible liaison between the army and navy all the way from research and design through manufacture, installation, and operation. As a result, in Japan proper the navy practically duplicated the army's early-warning coverage, but the information so obtained was used almost exclusively for alerting their own air and sea bases and, such antiaircraft and fighter protection as they had available.

The severe loss in efficiency caused by the unwillingness of the two branches of the service to exchange ideas or use any of the same equipment was pointed out strongly by manufacturers, and by others in academic circles who had no military loyalties to defend. The danger of this condition finally was appreciated in certain high quarters, and a joint army-navy committee was set up in August 1943 to correlate the army and navy



Figure 6. The Tokyo Information. Center viewed from the outer moat of the Imperial Palace grounds

The bedspring antennas visible are part of an experimental 60-centimeter frequency modulated communications set

programs. Although the committee met once a month, its ineffectiveness is seen by the fact that it could not obtain agreement between the army and the navy even on using the same identification-friend-or-foe set. The navy adopted a set with transponder sweeping from 145 to 155 megacycles, while the army's set in the airplane received at the spot fre-

quency of 184 megacycles and retransmitted at 175 megacycles. Thus the army could not distinguish Japanese navy airplanes from enemy airplanes, nor could the navy do better for the Japanese army airplanes, and the jealousies between the two services were such that neither seemed to care! The chief contributions of the army-navy joint committee seem to have been to unite the two services on ordering of the Small Wurzburg sets and to obtain agreement that the next air-borne set following the navy's number 51 and the army's Taki-14 would be ajointly sponsored 5-centimeter equipment. Some question exists even as to the co-operation present on this last project, inasmuch as, at the close of the war, the army was experimenting actively with 5-centimeter sets (Taki-34) with apparently no participation by the navy.

### JAPANESE RADAR COUNTERMEASURES

Both the army and the navy appreciated the need for knowing what manner of radar sets was being used against them. Both had developed a line of search receivers with various means of displaying or recording the signals picked up. Some were equipped with oscilloscope presentations whereby homing on a signal was possible. The army, in addition, had built a pair of "wave disturbers," Taki-8 and Taki-23, which were spot jammers of either the impulse or continuous wave type, covering the wave lengths from 7 meters down to 80 centimeters. A magnetron jammer especially designed for the *X*-band of the B-29's was under construction.

Repeated questioning of army and navy radar engineers brought forth emphatic denials that the Japanese ever had installed a captured American identificationfriend-or-foe set in their ships or airplanes. This makes very difficult an explanation of certain observed instances where Allied Forces were sure that their identification-friend-or-foe system had been compromised. The upper end of the navy identification-friend-or-foe M-13 sets' sweep at 155 megacycles nearly would overlap the lower edge of Allied frequencies. However, the Japanese navy maintained that development of this set



Figure 7. View of the north wall of the operations room in the Tokyo Information Center Visible are part of the ground observer display map, the type A detector display board, and part of each of the banks of ground observer display panels

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was completed only in July of 1945, and that of the 50 sets manufactured, none was yet in operational use. The army equipment, with split interrogating and responding frequencies, should not have shown up on American radar equipments at all.

# EFFECTIVENESS OF ALLIED JAMMING

According to all accounts, Allied jamming was so effective that, after May 1, 1945, it was impossible for Japanese antiaircraft guns to shoot unless they had visual tracking. This meant that American bombers had to be picked up first by searchlights which themselves were having a great deal of trouble finding the the target because of the very same electronic jamming on their 200-megacycle frequency.

Inquiry revealed that Allied use of "window" (metal foil strips dropped to create phantom targets), while effective, did not cause nearly the difficulty that the electronic jamming produced. Skilled operators at such places as Kobe were able to distinguish airplanes from the false window targets and to give some rough indications of the locations of the airplanes. However, the electronic jamming created a sea of grass over the entire oscilloscope, and it was impossible to distinguish targets of any kind.

### **RADAR TRAINING**

Both the army and the navy had organized radar training schools for operators and maintenance men. The army's school at Tachikawa was equipped fairly well with several of each type of radar set used by army forces, and could accommodate about 1,200 students at one time. Radar operators here received three months of instruction, maintenance men six months. The navy operated a very large and exceedingly well-equipped school at Chogo, just south of Atsugi airdrome. Courses ran from four to ten months for the 7,000 students who could be accommodated at one time. This school compared very favorably with those set up in the United States for the same purpose.

#### JAPANESE AIR DEFENSE SYSTEM

The Japanese air defense system was an elaborate combination of ground observers and type A and B radar sets. Partly on that very account, it was unwieldy and slow to function. Certain features of the amazingly complex fighter control centers were conceived and built very well. The display of radar information on a lighted gridded map without the use of cluttering stands, for instance, was good. But the equally important ground observer reports appeared at another location and in a quite different presentation form from which no flight tracks were plotted. In addition, there was the problem of using the data from antiaircraft radar systems which came in over a loudspeaker and were plotted on a third display position. It must have been impossible for an ordinary human controller to

co-ordinate and filter in his mind all of the information arriving during a large raid. Figure 6 shows a view of the Tokyo Fighter Control Center, located just inside the outer moat of the Imperial Palace grounds. Japanese military officials flatly denied that the control center had been placed there purposely to increase its immunity to Allied bombs. Whether intentional or not the effect was the same inasmuch as American forces carefully avoided bombing the palace area. Figure 7 shows part of the operations room.

There was also apparently little or no system by which fighters could be directed properly to get into an advantageous position for making an interception as the B-29's arrived, even though in most cases early warning of an hour or more was available. Very poor liaison was maintained between the army and the navy information centers. It would have been a long step forward to have consolidated the two early-warning systems and to have had all stations report to a single information center in the area. Full information would have been had, then, with half the expense and confusion.

Through the fighter control center means for locating friendly aircraft could have been arranged easily by the simplest of direction finding chains. This method would have aided them greatly in developing the techniques necessary for conducting interceptions well before raiders reached the target. Moreover, it would have provided a means for locating pilots in distress and directing them back to friendly bases. As it was, pilots running out of gasoline over the ocean could not be aided inasmuch as their position was too indefinite to warrant sending out rescue craft. This fact further; aggravated the scarcity of good night pilots.

#### **CRITIQUE OF JAPANESE RADAR**

All in all, it must be said that the type A plus the type B equipments gave entirely adequate early warnings of B-29 raids. Occasionally, single bombers flying low and fighters in small formations could slip through the net, but not so often as to present a serious problem. The far-flung system of ground observers tended to fill in any warning shortcomings of the radar equipments.

The good Japanese air raid warning service was useful in that it gave people a chance to seek shelter in time to save their lives. At the same time, the resistance offered to the approaching bombers by antiaircraft fire and by fighter interceptors was pitifully small. This was very largely because the Japanese did not have:

1. Sufficiently accurate fire control radar.

2. Ground and air-borne equipment adequate for ground controlled interception work.

3. An effective system for using what radar they did have this type.

A considerable part of the responsibility for the poor

showing made in resisting American raids must be attributed to the lack of technical development by the Japanese of radar sets accurate enough for good fire control or for fighter direction, that is, the equivalents of the United States forces SCR-584 and SCR-527 and, of course, the AN/CPS-1 (or MEW).

The men in charge of electronics reseach in both the Japanese army and navy well were aware of their deficiencies in fire control and air-borne interception radar. They were pressing their own engineers and those of industrial concerns to overcome these gaps in their defenses at the earliest possible moment.

Much of the Japanese-designed radar equipment examined appeared to be crude both electrically and mechanically in comparison with the later United States sets, although certain equipments were constructed beautifully with no skimping on materials. There is some doubt as to whether the Japanese could have duplicated successfully American modern fire control and ground controlled interception radars even if they had captured them. As a matter of fact, they had obtained fairly good specimens of American identificationfriend-or-foe sets and the APQ-13 from B-24's and B-29's, but, generally stated, they never had been able to put them into complete operation. Admiral Nawa, head of Japanese navy electronics research, stated that their greatest shortcoming in comparison with American radar design was their inability to turn out a highpowered centimeter transmitting tube. Most students of the situation will agree, although, as has been noted, independent Japanese research was well on the way.

Very severe criticism should be leveled by the Japanese people at those military leaders who insisted for so long that army and navy research, development, production, and operation be kept entirely separated. Equally as serious was the neglect to organize the full scientific power of the nation for war research. All this, of course, is realized now by Japanese ex-military leaders. They would not be likely to commit the same mistake another time.