2. Radar for Weather Surveillance

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RADAR FOR WEATHER SURVEILLANCE

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ABSTRACT

A weather radar is one of the most powerful tools to survey typhoons and local downpours, which are responsible for the most of weather-caused damage in Japan. This article first shows the principle of a radar device, and then outline its typical application to such fields as typhoon watch and thunderhead detection. Another important application to flood warning has been described in the 1983 version (Volume 7) by the present author.

1. INTRODUCTION

A weather radar is an electronic device to "see" rainfall or snowfall. Generally, when we see an object, we receive the light from it into eyes and acquire knowledge of its existence and shape. A radar sees an object by emitting electromagnetic waves (microwaves) from itself; raindrops reflect a part of the emitted microwaves if it rains on the direction of emitting, then the radar receives this reflected radio waves by a parabolic antenna which is an "eye" of the radar, and shows the rainfall on a cathode-ray tube through a receiver which corresponds to the optic nerve and the brain.

The measurement of distance, or range, is probably the most distinctive feature of radar. Range is determined from the time taken by the transmitted signal to travel out of the target and back. The direction of the target may be inferred from the angle of arrival of the echo, that is, the azimuth angle of aerial antenna.

The first demonstration of basic radar effects was by Hertz in the late 1880's when he verified Maxwell's electromagnetic theory. Hertz showed that short wave radiation could be reflected from metallic and dielectric bodies. Although the basic principle of radar was embodied in Hertz's experiments, the practical development of radar did not arrive for another 50 years. Practical models of radar appeared in the late 1930's. The rapid advance in radar technology during World War II was aided by the many significant contributions of physicists and other scientists pressed into the practical pursuit of a new technology important to the military.

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In addition to its military application, radar now finds extensive use in air and ship navigation, air traffic control, rainfall observation, typhoon tracking, radar astronomy and others.

One of the main applications of radar in meteorology is in the detection of cloud and precipitation elements. This is used as a direct forecasting aid and detailed studies of the structure of precipitation regions. Since hydrometeors can scatter radio energy, "weather" radars operating on certain frequency bands (generally in the wavelength range from a fraction of a centimeter to some tens of centimeters) can detect the presence of precipitation at distances up to several hundred kilometers from the radar, depending upon meteorological conditions and the type of radar. Evaluation of the echoes that appear on the indicator of a weather radar are made in terms of orientation, coverage, intensity, tendency of intensity, height, movement, and unique characteristics of echoes, which may be indicative of certain types of severe storms (such as typhoons, local heavy rainfalls, or thunderstorms).

In Japan, several tens of weather radar are installed covering almost allover the Islands for meteorological and hydrological use. This article describes the principle of radar, and then general features and status of following systems are outlined; Mt. Fuji radar of the Japan Meteorological Agency for typhoon watch and observation, and Tokyo Electric Power radar for thunderhead detection. A radar raingauge system of Ministry of Construction for flood warning and safe highway utilization has been shown in the 1983 version by the author.

2. PRINCIPLE OF RADAR

2.1 General description for radar set

Radar has been defined as "the art of detecting by means of radio echoes the presence of objects, determining their direction and range, recognizing their character and employing the data thus obtained." In radar meteorology the term "object" is construed to mean anything in the atmosphere which returns to a receiver a detectable amount of power. Thus, in the study of radar meteorology one must consider the reflections by raindrops, cloud droplets, ice particles, snowflakes, atmospheric nuclei, insects, birds, and regions of large index-of-refraction gradients. It is well to point out here that the source of the scattered power, regardless of its properties, may be called a "target".

Radar is based on the principle that an electromagnetic wave is propagated through space at the speed of light, 2.998×10^8 m/sec. The variation in this velocity in the atmosphere is small and predictable, if one knows the distribution of the index of refraction of the medium through which the wave is propagated. In most applications one can consider that the radar wave moves at the speed of light and travels along straight lines. Thus, by means of an antenna producing a narrow beam in the manner of a serchlight beam, one can scan with the antenna until a reflection is obtained and determine the direction to the reflecting object. Also, by measuring the time interval between the transmission of the radio energy and the reception of the reflected signal, one can easily calculate the distance to the object.

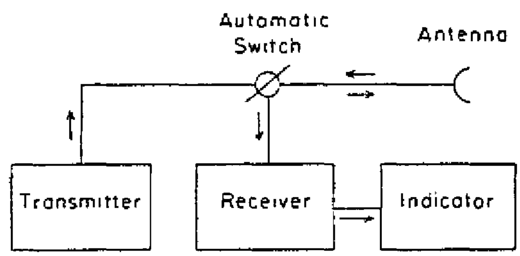


Fig. 1 Block diagram of radar set

For many purposes, a radar set can be considered to consist essentially of a transmitter, which produces power at the radar frequency; an antenna which radiates the power and intercepts the reflected signals; a receiver, which detects, amplifies, and transforms the received signals into video form; and an indicator on which the returned signals can be displayed. The operation of a simple radar set is illustrated in figure 1. Most weather-radar sets employ a single antenna for both transmission and reception. An automatic switch is used to close off the receiver during the short interval when the transmitter is operating and protects the receiver from the tremendous pulse of transmitted power.

With most radar sets, the frequency of operation is fixed, and, generally, the source of the microwaves is a special tube called a "magnetron". For the system to operate properly, the radar receiver must be tuned to the magnetron frequency.

An important characteristic of a radar receiver is its so-called minimum detectable signal, i.e., the smallest signal which can be detected above the noise level. Radar receivers usually are designed to have as low a minimum detectable signal as possible. In many receivers it is of the order of 10^{-13} w. On the other hand, the peak power transmitted is always quite high and may be of the order of 100 kw.

Because of the large range of power dealt with in radar systems. e.g., 10^{-13} to 10^{6} w, it is common to express power in terms of decibels (dB).

The difference in dB between power levels P_1 and P_0 is given as

$$p(dB)=10\ \log_{10}\frac{P_1}{P_0}.$$

Note that the decibel measures a difference in power. It is usual in electronics work to take P_0 equal to milliwatt, and hence p would be the power level of P_1 in decibells with respect to a milliwatt, designated as dBm. The minimum detectable signal of a receiver and peak transmitted power might be -100 dBm and 90 dBm, respectively.

The sensitivity of a radar receiver can be changed by means of the gain control. For any setting of the gain control, the range of signals which can be distinguished on a radar scope is usually small compared with the range of signals received from weather phenomena. If the receiver gain is adjusted so that weak signals are detected, strong ones may saturate the system and be cut off. The range of signal detection is called the "dynamic range" of the radar system. To increase the dynamic range, various schemes have been devised by which weak signals are amplified more than the strong ones.

A radar set such as the one blocked out in figure 1 is called a "noncoherent radar". In such equipment, no account is taken of the phase of the returning radar wave with respect to the phase of the transmitted wave. Most radar sets now in use for weather observations are of this type, and therefore noncoherent radars are sometimes called "conventional radars". As already noted, they supply information on the position of a target and its radar reflectivity. By means of special techniques to be described later, one may obtain limited information about the movements of aggregate targets such as raindrops.

A class of radar sets referred to as "coherent" or "Doppler" radars makes use of the Doppler principle. These instruments, in addition to obtaining the data collected by a noncoherent radar, also measure the velocity of the targets along the radar beam axis. At this point, it is adequate to note that the velocity measurements are made by noting the rate of change of the difference in phase between the outgoing and received signals. As a target moves, the phase changes at a rate proportional to the velocity of the target toward or away from the radar.

In most radar sets, transmitted power is in the form of pulses of radio waves of short duration (e.g., 1 μsec). The frequency at which pulses are emitted is known as the "pulse-repetition frequency", PRF; a typical value is 500 per second. The maximum range of a radar set is specified by half the interval between pulses multiplied by the speed of light.

The frequency of the radio waves used on weather-radar sets ranges from 1,500 to above 30,000 megahertz (MHz). Commonly, meteorologists describe radar sets in terms of wavelength, λ, rather than the frequency. Since these two parameters are related by $c=\lambda f$, the wavelength of the radar set can be calculated quite simply. It is common practice to divide the microwave spectrum into various bands, as shown in table 1.

Table 1 Operating frequencies of weather radar

Frequency (MHz)	Wavelength (cm)	Band	Frequency (MHz)	Wavelength (cm)	Band
~30,000	1	K	~3,000	10	S
~10,000	3	X	~1,500	20	L
~6,000	5	C			

The hydrometeor-detection capabilities of a radar set are critically dependent on the wavelength. It may be stated that, in general, the smaller the size of the particles, the shorter the wavelength required to detect the particles. For example, an S-band radar can generally detect rain but not cloud droplets, while a K-band radar will detect many clouds even though they are not yielding precipitation.

The precision of the measurements of azimuthal and elevation angles to a target is largely a function of the shape of the beam produced by the antenna. Obviously, the sharper the beam - i.e., the smaller the angular width - the better the resolution. Most weather-radar sets use symmetrical beams with widths of one to three degrees. Radar sets designed for measuring heights and vertical dimensions of small targets commonly have narrow vertical beams and wider horizontal beams; large search radar used for detecting aircraft generally have very wide vertical beams. The shape of the beam is governed by the shape and size of the antenna reflector and the wavelength of the radar set. Figure 2 illustrates the beam shapes produced by various types of antenna reflectors.

2.2 Radar indicators

The type of indicator used in a weather radar depends on the information desired. Most indicators consist of a cathode-ray tube in which the beam of electrons is caused to scan across the tube, starting when the transmitter pulse is started and making a discernible indication on the tube when a signal is detected by the receiver. In conception, one of the most elementary indicators is the A-scope, or R-scope. It operates

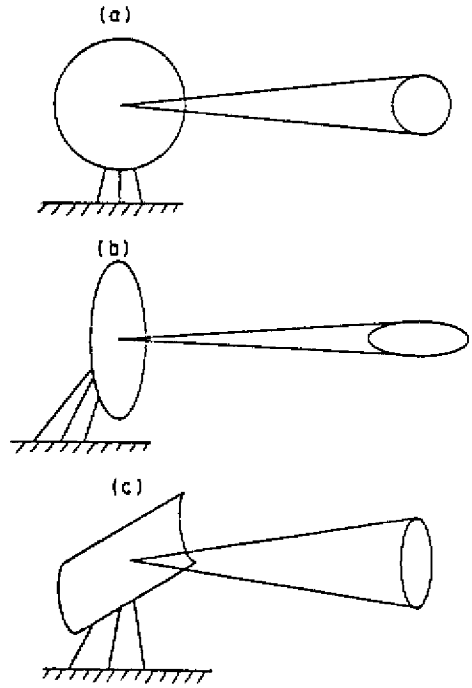


Fig. 2 Various typical antenna reflectors and associated radar beams

like the test oscilloscopes used in physics or electronics laboratories (figure 3).

The beam of electrons scans horizontally across the face of the tube at a fixed speed, and vertical deflections are produced when signals are received. The distance from the start of the sweep to the deflections gives the range of the target. It can be seen that the transmitted pulse also appears on the trace. This is produced by power which leaks through the automatic switch shown in figure 1. The magnitude of the deflections is

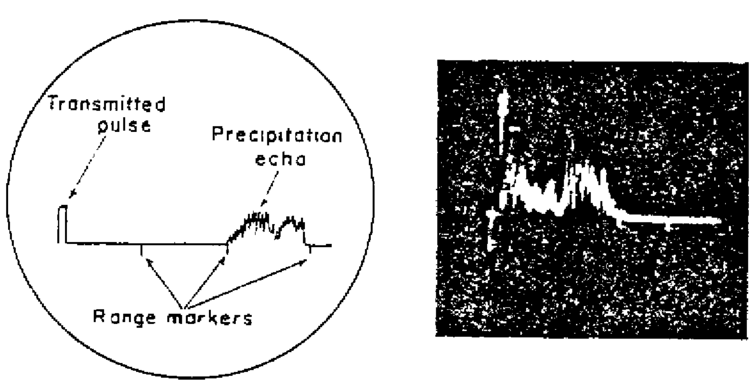
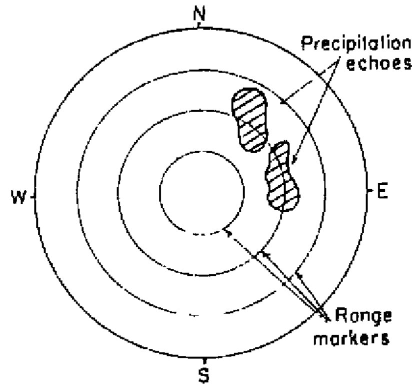


Fig. 3 A- or R-scope

a measure of the strength of the signal received. It is obvious that signals from many targets can be displayed on an A-scope at any one time. In weather radar the A-scope is generally used to identify the source of the backscattered energy, to assist in the tuning of the radar and to make quantitative measurements of returned power.



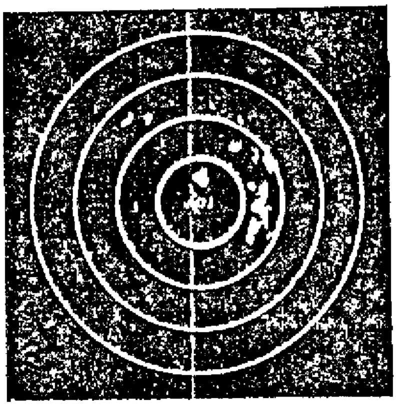


Fig. 4 Plan-position indicator (PPI)

The most extensively used indicator on weather radars is the plan-position indicator, usually designated as PPI (figure 4). As the name connotes, this display presents a plan view of the received signals on a polar coordinate system. It is used on radar sets with antennas which scan azimuthally. In this presentation, the electron beam scans at a fixed speed from the center of the oscilloscope to the outer edge, then returns rapidly to the center of the tube and scans outward again. The beam rotates around the scaope in synchronism with the rotation of the antenna. From the PPI display one can immediately read the range and bearing to the target. The PPI scope is "intensity modulated". This means that the intensity of the bright spot corresponding to the returned signal depends on the strength of the returned signal. A strong "echo" on the scope represents a large amount of returned power. Radar sets with PPI presentations have great application for observations of severe storms and are widely used in weather stations.

Another common radar display is the range-height indicator, usually designated as RHI (figure 5). This type of presentation is used with radar sets whose antennas scan vertically. In this scope the beam scans outward at a particular vertical angle, returns rapidly to the origin, and scans again at a different angle. The vertical angle of the beam is controlled by the vertical angle of the antenna. As can be seen in figure 5, the scope presents the position of the echo on a coordinate system with range as the

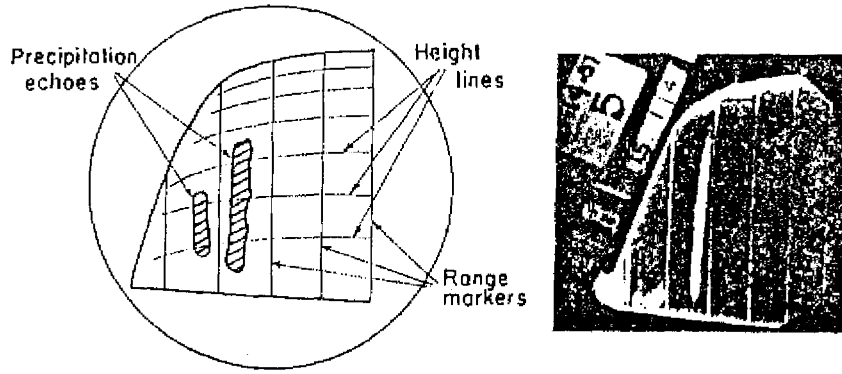


Fig. 5 Range-height indicator (RHI)

abscissa and height as the ordinate. To make height determination easier, the vertical scale is usually exaggerated. Like the PPI scope, the RHI scope uses intensity modulation. It is therefore possible, in some measure, to note the strength of the returned signal by the brightness of the echo, provided the signal is not strong enough to saturate the receiving system. A height-finding radar is particularly useful in studies of cloud and precipitation growth and has been used extensively in cloud physics research.

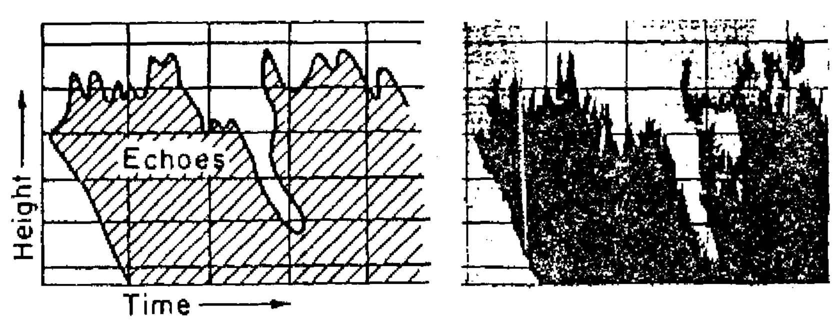


Fig. 6 Height-time indicator (HTI)

Many radar observations of clouds and precipitation have been made by fixing the antenna's position and allowing the weather phenomena to pass through the radar beam. When the antenna points vertically, the data may be displayed in the form of an intensity-modulated height-time section, as shown in figure 6. Such a presentation, called an HTI, is obtained in the following way. The electrom beam of an oscilloscope sweeps along the same line and is intensity modulated at altitudes where echoes are present. By means of a suitable camera, photographic film is pulled across the scope in a direction perpendicular to the trace.

In recent years much use is being made of magnetic tape systems to record radar and subsidiary data. In more advanced facilities, the data are divitized before being recorded on magnetic tape. In this form, they can be fed directly into electronic computers for analysis and interpretation.

3. MT. FUJI WEATHER RADAR SYSTEM FOR TYPHOON OBSERVATION

The Japan Meteorological Agency deploys twenty weather radars at the observing stations and radar stations as shown in figure 8. The radar transmits results to other user stations within its coverage and neighbouring radar stations through FAX transmission. Two ships are equipped with weather radar for observation, other than the ground radars mentioned above. Among these radars, the Mt. Fuji radar is the greatest.

The Mt. Fuji radar is located 3776 m above sea level at the top of the mountain. Mt. Fuji is the highest in Japan and situated at the central part of Japan. Figure 7 shows a grand view of the radar. The power of the radar system is 1,500 kw. Due to its great installation height and high output power, the detectable range is extended to 800 km, permitting a complete coverage of Honshu and Shikoku islands and the greater part of Kyushu. It is also bring the southern waters into the its complete range of coverage. The Mt. Fuji weather radar system displays its full capability as a citadel for protecting Japan's mainland against the disaster of

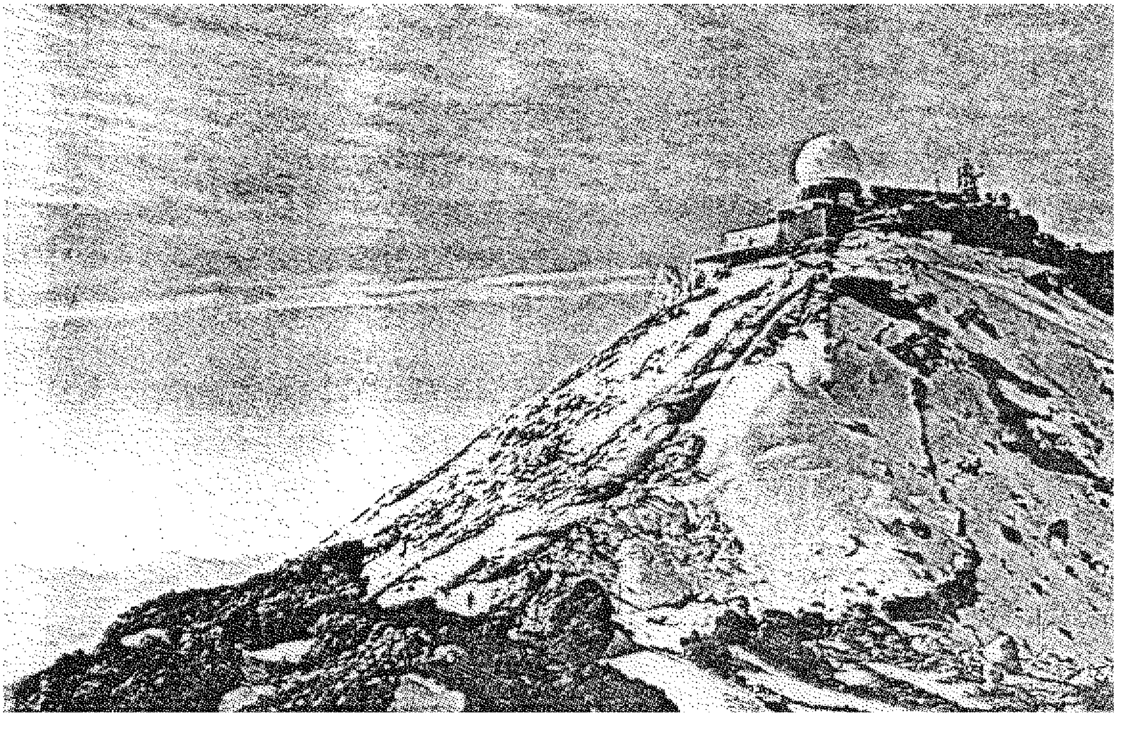


Fig. 7 Mt. Fuji weather radar station on the mountain top