Chapter 3 Microwave Remote Sensing

3.1 Principles of Microwave Remote Sensing

Microwave remote sensing, using microwave radiation using wavelengths from about one centimeter to a few tens of centimeters enables observation in all weather conditions without any restriction by cloud or rain. This is an advantage that is not possible with the visible and/or infrared remote sensing. In addition, microwave remote sensing provides unique information on for example, sea wind and wave direction, which are derived from frequency characteristics, Doppler effect, polarization, back scattering etc. that cannot be observed by visible and infrared sensors. However, the need for sophisticated data analysis is the disadvantage in using microwave remote sensing.

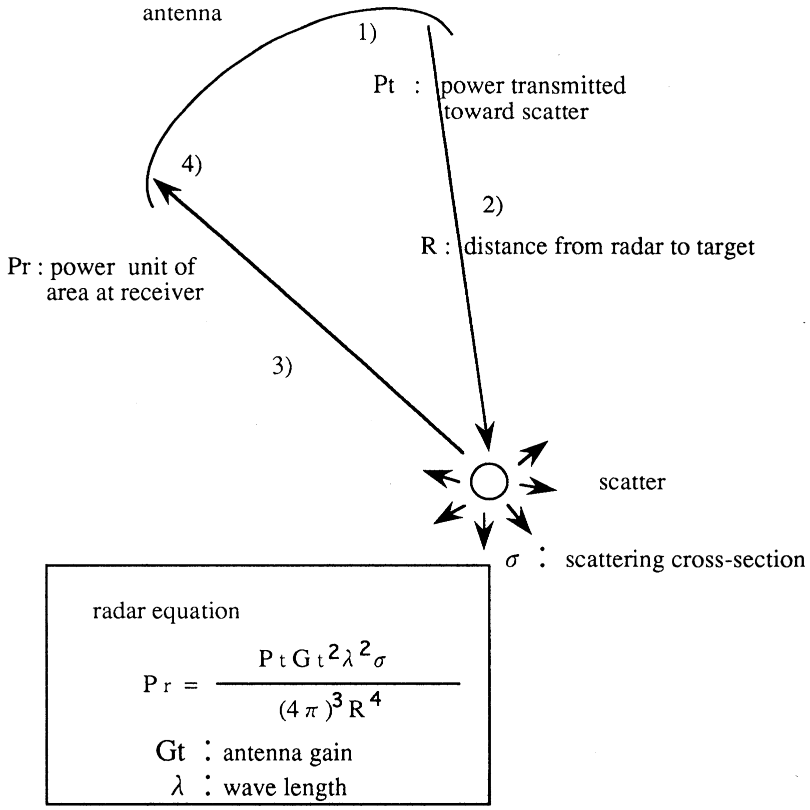
There are two types of microwave remote sensing; active and passive. The **active type** receives the backscattering which is reflected from the transmitted microwave which is incident on the ground surface.

Synthetic aperture radar (SAR), microwave scatterometers, radar altimeters etc. are active microwave sensors. The **passive type** receives the microwave radiation emitted from objects on the ground. The microwave radiometer is one of the passive microwave sensors. The process used by the active type, from the transmission by an antenna, to the reception by the antenna is theoretically explained by the **radar equation** as described in Figure 3.1.1.

The process of the passive type is explained using the theory of radiative transfer based on the law of Rayleigh Jeans as explained in Figure 3.1.2 (see 1.7, 1.12 and 3.2) In both active and passive types, the sensor may be designed considering the optimum frequency needed for the objects to be observed. (see 4.1)

In active microwave remote sensing, the characteristics of scattering can be derived from the **radar cross section** calculated from received power Pr and antenna parameters (A_r, P_t, G_t) and the relationship between them, and the physical characteristics of an object. For example, rainfall can be measured from the relationship between the size of water drops and the intensity of rainfall.

In passive microwave remote sensing, the characteristics of an object can be detected from the relationship between the received power and the physical characteristics of the object such as attenuation and/or radiation characteristics. (see 3.2 and 3.3)



$$Pr = \frac{P_t G_t^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Figure 3.1.1 Concept of radar equation

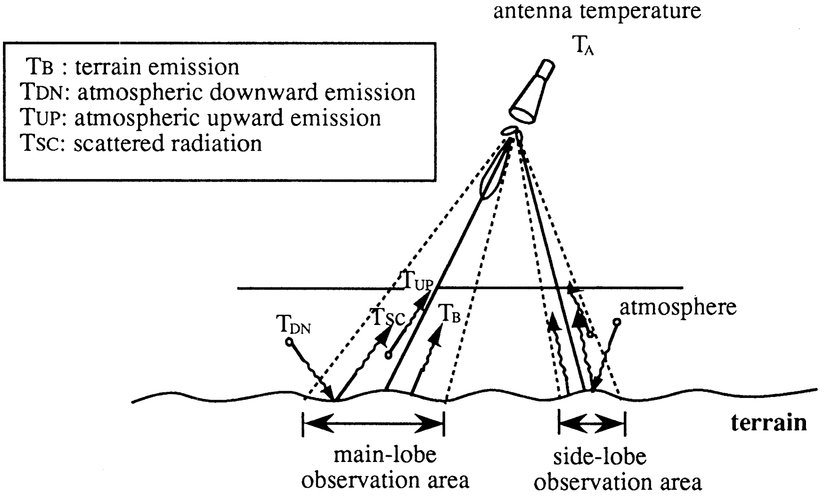


Fig.3.1.2 Principle of passive microwave sensor. The apparent temperature represents the energy incident upon the antenna.

3.2 Attenuation of Microwave

Attenuation results from **absorption** by atmospheric molecules or **scattering** by aerosols in the atmosphere between the microwave sensor on board a spacecraft or aircraft and the target to be measured. The attenuation of the microwave will take place as a function of the exponential with respect to the transmitted distance mainly due to absorption and scattering. Therefore the attenuation will increase in proportion to the distance, under homogeneous atmospheric conditions. The attenuation per unit of distance is called **specific attenuation.** Usually the loss due to attenuation can be expressed in the units of dB (decibel) as follows.

$$dB = K_e B\, dr$$

where K_e: specific attenuation ($dBkm^{-1}$)

B : brightness temperative ($Wm^{-2}\ sr^{-1}$) in the distance of dr

dr : incremental distance

Figure 3.2.1 shows the attenuation characteristics of atmospheric molecules with respect to frequency. From this figure it can be seen that the influence of atmospheric attenuation occurs in the region greater than 10GHz. The intensity of attenuation depends on the specific frequency (absorption spectrum) of the corresponding molecule. This is the reason why the energy of the microwave is absorbed by the molecular motion of the atmospheric constituent. However, if proper frequencies are carefully selected, the attenuation can be minimized because the composition of the atmospheric constituent is almost homogeneous.

In the case of satellite observation, the optical path is usually long in distance, so that attenuation can be influenced by the change in atmospheric conditions. Particularly because the attenuation of vapor (H_2O) is very strong in the specific frequencies, the change of vapor can be detected by a microwave radiometer.

The most remarkable scattering in the atmosphere is due to rain drops. Figure 3.2.2 shows the attenuation characteristics due to scattering of rain drops and mist. The attenuation increases if the intensity of rainfall increases, and the frequency increases until about 40 GHz. However, over 40 GHz the attenuation does not depend on the frequency.

Remarks

1) dB is 1 / 10 bel.
"bel" is logarithmic ratio of two powers P_1 and P_2.
$N = \log 10\ (P_1 / P_2)$ [bel] or
$n = 10 \log 10\ (P_1 / P_2)$ [dB]

2) Specific attenuation K_e is originally expressed as $N_p m^{-1}$ or neepers m^{-1}. But K_e is converted to dB km^{-1} for convenience by multiplying $10^4 \log e = 4.34 \times 10^3$ by $N_p\ m^{-1}$.

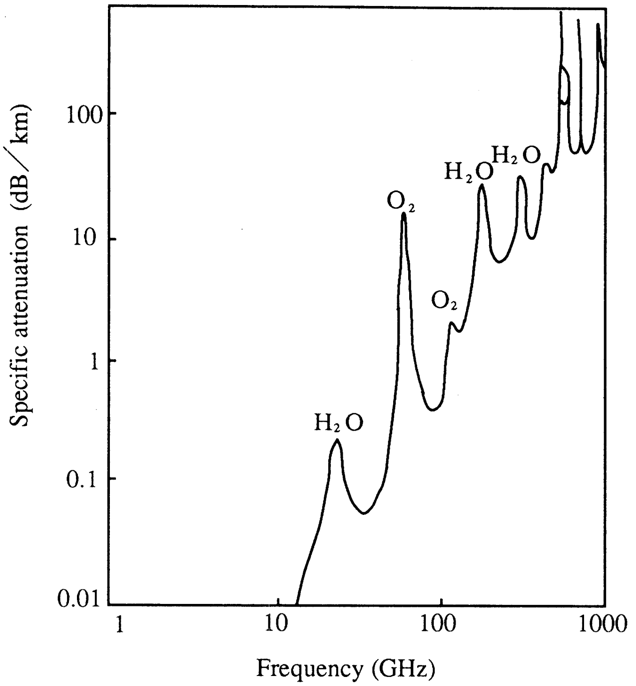


Fig.3.2.1 Microwave absorption due to atmospheric gases

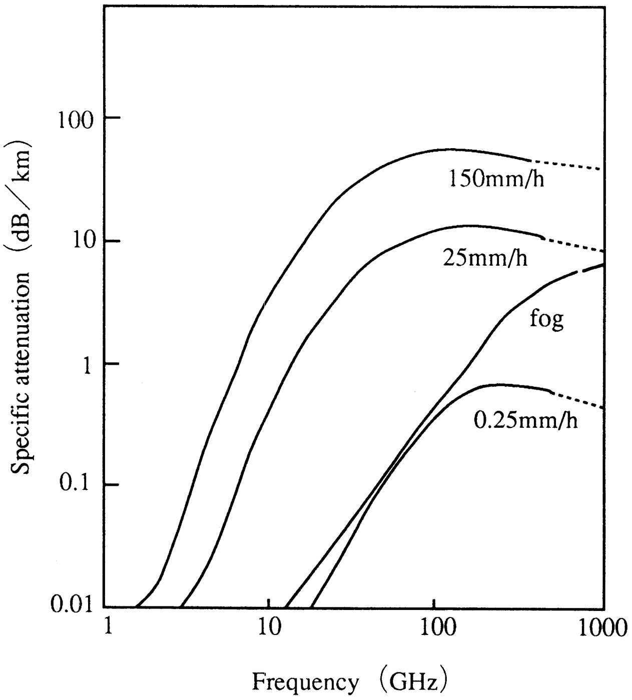


Figure 3.2.2 Microwave attenuation at various rain rate

3.3 Microwave Radiation

The earth surface radiates a little microwave energy as well as visible and infrared because of thermal radiation. The thermal radiation of a black body depends on Plank's law in the visible and infrared region, while the thermal radiation in the microwave region is given by the Rayleigh Jeans radiation law .

Real objects, the so called **gray bodies** are not identical to a black body but have constant **emissivity** which is less than a blackbody . The **brightness temperature** TB is expressed as follows.

$$T_B = \varepsilon T$$

where T : **physical temperature**

ε : **emissivity** $(0 < \varepsilon < 1)$

Emissivity ε of an object changes depending on the **permittivity,** surface roughness, frequency, polarization, incident angle, azimuth etc., which influence the brightness temperature.

Figure 3.3.1 shows the characteristics of emissivity for 3.5 % density salt water with respect to incident angle, polarization and frequency. Figure 3.3.2 shows the emissivity of horizontal polarization (eh) and vertical polarization (ev) for two clay soils with different soil moisture, and a sea water with respect to incident angle.

Table 3.3.1 shows the emissivity of typical land surface covers for two different grazing angles of 30 °and 45 °.

Most users would like to get the physical temperature T instead of brightness temperature T_B, which is measured by microwave radiometers.

Therefore emissivity should be measured or algorithms should be developed to identify the component of atmospheric radiation.

In the case of the receiving antenna of the microwave radiometer, all radiation from various angles are input to the antenna, which needs a correction of the received temperature with respect to directional properties of the antenna. The corrected temperature is called the **antenna temperature**.

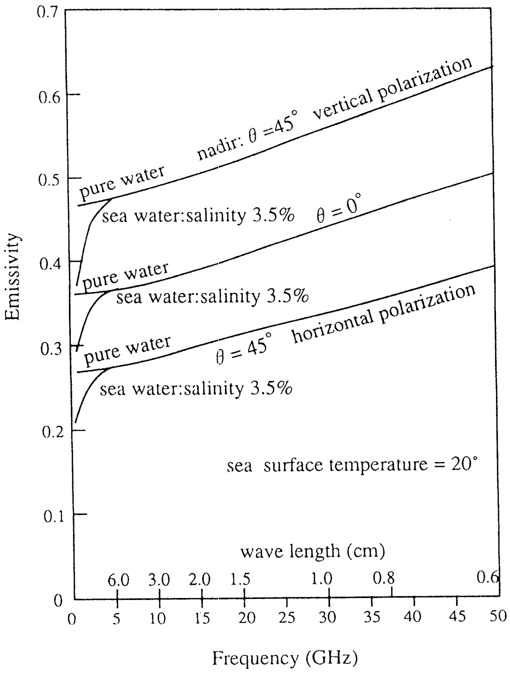


Figure 3.3.1 Emissivity variation of pure water and sea water at 20° C with smooth surface

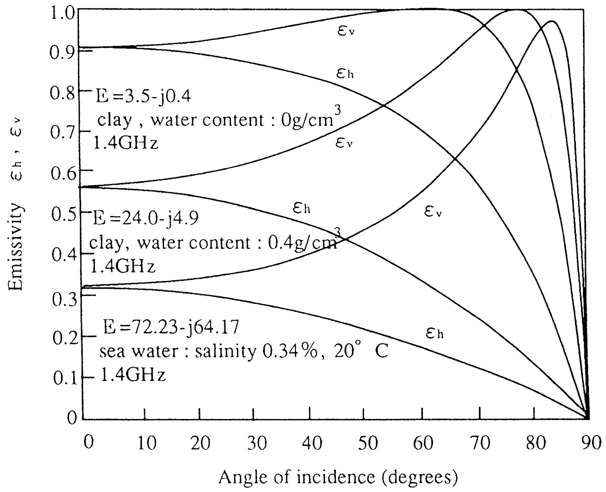


Figure 3.3.2 Emissivity variation of dry clay, wet clay and sea water at 1.4GHz

Table 3.3.1 Emissivity of typical land covers for two different grazing angles of 30° and 45°

land cover	grazing angle 30°	grazing angle 45°
water surface	0.41	0.34
concrete	0.88	0.80
asphalt	0.89	0.82
glass	0.94	0.94
soy beans field	0.96	0.96

3.4 Surface Scattering

Surface scattering is defined as the scattering which takes place only on the border surface between two different but homogeneous media, from one of which electro-magnetic energy is incident on to the other. Scattering of microwave on the ground surface increases according to the increase of **complex permittivity,** and the direction of scattering depends on the surface roughness, as shown in Figure 3.4.1.

In the case of a smooth surface as shown in Figure 3.4.1 (a), there will be a specular reflection with a symmetric angle to the incident angle. The intensity of **specular reflection** is given by Fresnel reflectivity, which increases in accordance with the increase of the ratio of complex permittivity.

When the surface roughness increases a little as shown in Figure 3.4.1 (b), there exists a component of specular reflection and a scattering component. The component of specular reflection is called the coherent component, while that of scattering is called diffuse or the **incoherent component**.

When the surface is completely rough, that is diffuse, only diffuse components will remain without any component of specular reflection as shown in Figure 3.4.1 (c). Such surface scattering depends on the relationship between the wavelength of electro-magnetic radiation and the surface roughness which is defined by the **Rayleigh Criterion** or **Fraunhofer Criterion**.

Rayleigh Criterion : if $\Delta h < \lambda / 8 \cos \theta$, the surface is smooth

Fraunhofer Criterion : if $\Delta h < \lambda / 32 \cos \theta$, then the surface is smooth

where Δh : standard deviation of surface roughness

λ : wavelength θ : incident angle

Generally the scattering coefficient, that is scattering area per unit area, is a function of incident angle and the scattering angle. However in the case of remote sensing, the scattering angle is identical to the incident angle because the receiving antenna of radar or scatterometer is located at the same place as the transmitting antenna. Therefore, in remote sensing only back-scattering may be taken into account.

The radar sectional area $\Sigma\sigma_i A_i$ is given as follows.

$$\sum \sigma_i = \frac{P_r (4\pi)^3 R^4}{P_t G^2 \lambda^2}$$

where P_t : transmitting power G : antenna gain λ : wavelength

P_r : receiving power R : distance between radar and object

A_i : differential area of surface scattering

Scattering area per a unit area σ° is called the **backscattering coefficient**.

$$\sigma = \sigma i / A_i$$

The backscattering coefficient depends on the surface roughness and incident angle as shown in Figure 3.4.2.

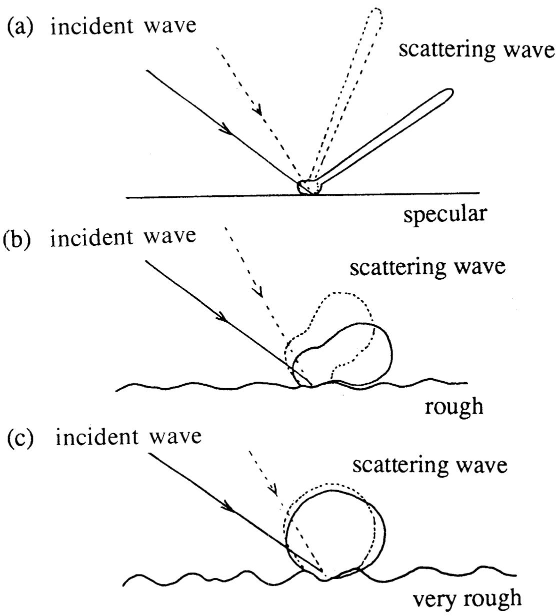


Figure 3.4.1 Surface scattering pattern with different surface roughness

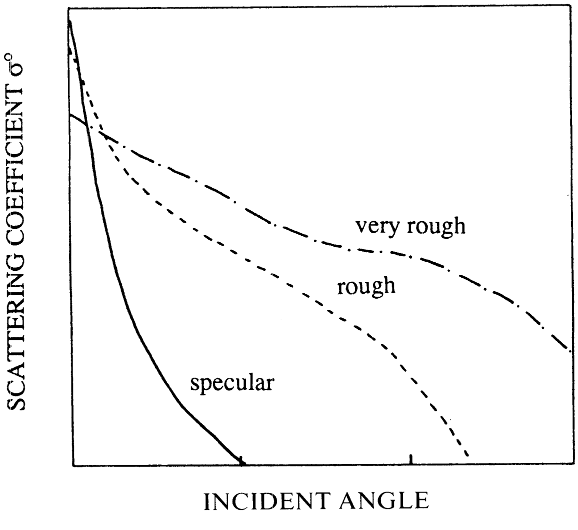


Figure 3.4.2 Backscattering coefficient with respect to the surface roughness and incident angle

3.5 Volume Scattering

Volume scattering is defined as the scattering occurring in a medium when electromagnetic radiation transmits from one medium to another medium. Figure 3.5.1 shows the schematic model of volume scattering for two examples; (a)scattering by widely distributed particles such as rain drops and (b)scattering in uneven media with different permittivities. Scattering by trees or branches, subsurface or soil layers, snow layers etc. are examples of volume scattering.

Volume scattering can be observed if microwave radiation penetrates into a medium. The **penetration depth** δ is defined as the distance when the incident power attenuates to 1/e (exponential coefficient).

The intensity of volume scattering is proportional to the discontinuous inductivity in a medium and the density of the heterogeneous medium. The scattering angle depends on surface roughness, average relative permittivity and wavelength.

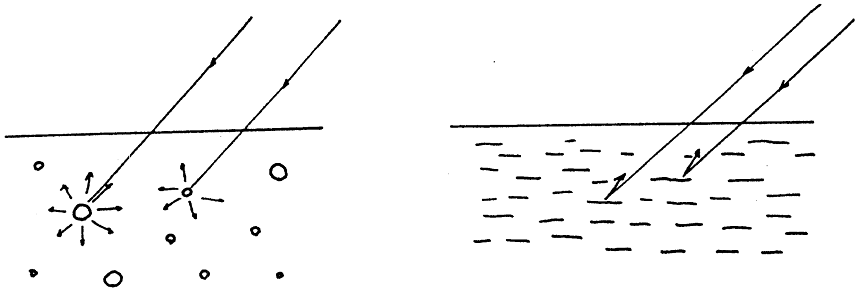
The receiving intensity is proposional to multiplication of the intensity and the volume involved in the region of range gate and beam width as shown in the example in Figure 3.5.2. Volume scattering in the case of rainfall, shown in Figure 3.5.2, is represented as a function of wavelength and Z factor as follows.

$$\sigma = \frac{\pi^5}{\lambda}|k|^2 \sum D_i^6 = \frac{\pi^5}{\lambda}|k|^2 Z$$

where λ : wavelength
D : diameter of rain drop
k : constant ($k = (\varepsilon-1) / (\varepsilon+2)$)
Z : Z factor ($Z = \Sigma D_i^6$)

In the case of soil and snow, volume scattering occurs together with surface scattering, although the surface scattering is small as shown in Figure 3.5.3. There will exist an error for the measurement of surface scattering coefficient because of the effect of volume scattering.

In the case of forest as shown in Figure 3.5.4, it is necessary to introduce a model of the volume scattering by leaves and branches as well as surface scattering by the crown of trees, and corner reflection effects due to the soil and vertical tree trunks.



(a)scattering by widely distributed particles (b)scattering in uneven quality media

Figure 3.5.1 Schematic model of volume scattering

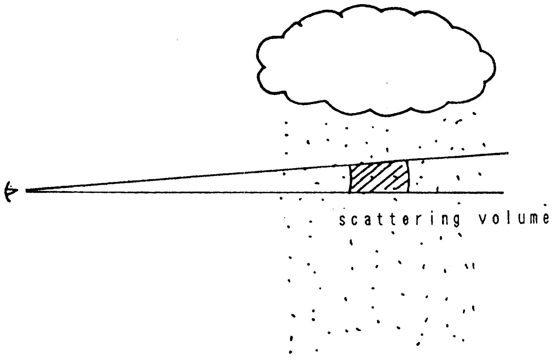


Figure 3.5.2 Volume scattering from rain drop

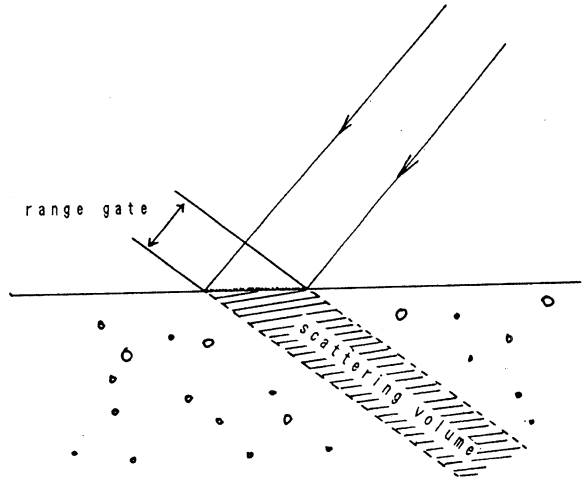


Figure 3.5.3 Schematic model of volume scattering together with surface scattering; in the case of soil and snow

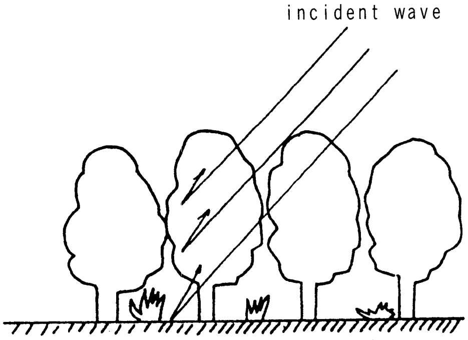


Figure 3.5.4 Schematic model in the case of forest; volume scattering by leaves and branches as well as surface scattering by crown of trees

3.6 Types of Antenna

An antenna is a transducer to transform from a high frequency electric current to radio waves and vice versa. An antenna is used to transmit and receive radio waves. There are many kinds of antenna ranging from very small size (such as a monopoly antenna in a cordless telephone) to very large antenna reflectors of 100 meters in diameter for radio wave astronomy. In this section, antennas used for microwave remote sensing are introduced.

Typical antennas in microwave remote sensing are those of the passive type of microwave radiometer, active types of microwave altimeter, scatterometer and imaging radar.

There are three major types of antenna; horn antenna, reflector mirror antenna and array antenna.

The horn antenna such as the conical horn or rectangular horn is used for power supply to the reflector antenna, calibration of low temperatures for the microwave radiometer in the form of a sky horn looking upward, and calibration for active radar as shown in Figure 3.6.1.

Reflector antenna such as parabolic antenna and Cassegrainian antenna are composed of primary radiator and a reflective mirror as shown in Figure 3.6.2. The reflector antenna is used for microwave radiometers, altimeters and scatterometers. In case of wide angle scanning, all antenna will be controlled, while in the case of narrow beam scanning only the radiometer or reflective mirror will be controlled.

An array antenna is composed of multiple element arrays for example, linear array, area array or nonformal array. The element antennas are half-wavelength dipoles, microstrip patches and wave guide slot. The advantages of array antenna are to enable beam scanning without changing the looking angle of each array antenna and to generate an appropriate beam shaping by selective excitation of current distribution of each element.

The array antenna is used for synthetic aperture radar (SAR) and real aperture radar. Figure 3.6.3 shows a wave guide slot array antenna designed for real aperture radar.

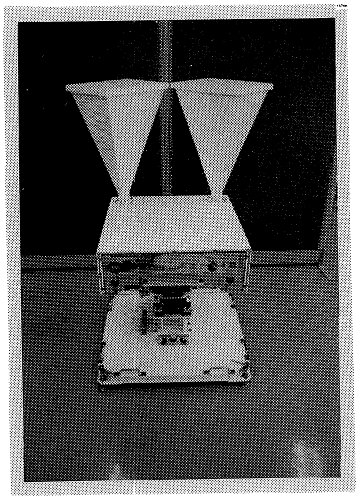


Figure 3.6.1 Horn antennas as used in an active radar calibrator.

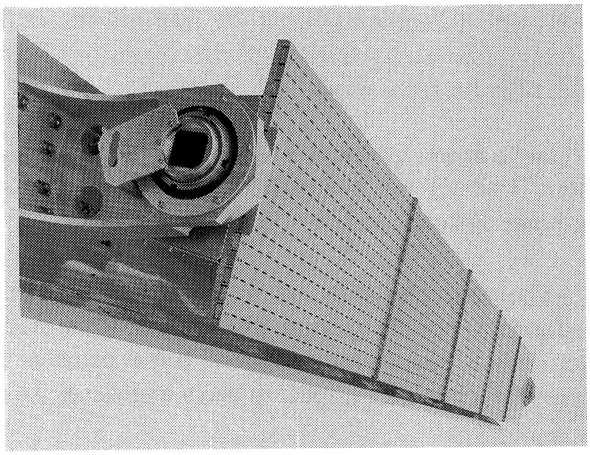
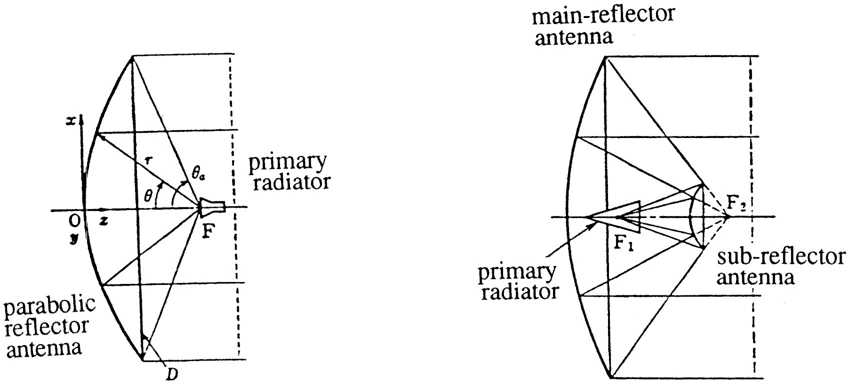


Fig.3.6.3 A waveguide slot array antenna for a real aperture radar.



(a) Parabolic reflector antenna

(b) Cassegrain antenna

Figure 3.6.2 Structure of reflector antennas

3.7 Characteristics of Antenna

An ordinal antenna is used for transmitting radio waves in a specific direction or for receiving radio waves from a specific direction. Therefore it can be said that the antenna is a spatial filter for radio wave.

Relative power, given as a function of the beam angle is called the radiation pattern or beam pattern. Usually the beam pattern is given in an orthogonal coordinate system or polar coordinate system, as shown in Figure 3.7.1.

The characteristics of the beam pattern can be determined by making a Fourier transformation of the aperture distribution. If the size of antenna aperture is infinite, the beam pattern should be an impulse pattern. But as actual antenna are limited in size, the beam pattern has several lobes with respect to beam angles, as shown in Figure 3.7.2.

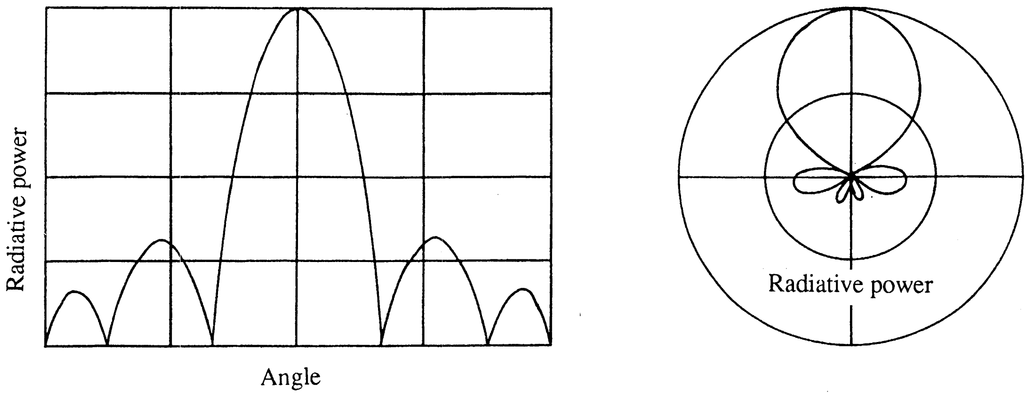
The point with zero power is called the null and the pattern between two nulls is called the lobe. The central biggest lobe is called the main lobe, while the other robes are called sidelobes.

The beam width of the antenna is defined as the beam width at the power level of 3dB downward from the peak of the main lobe (equivalent to the half power beam width). The difference between the peaks of the main lobe and the biggest sidelobe is called the sidelobe level. Antenna gain is given as the ratio of power density of an antenna to the reference antenna with a given constant power at a specific angle. The antenna gain that is obtained by an isotropic antenna as the standard antenna is called standard gain. The ratio of the power density at a specific angle to the average power density determined from all radiative power is called directivity and is given as follows.

$$G_d(\theta, \phi) = \frac{4\pi |E(\theta, \phi)|^2}{\int_0^{2\pi} d\phi \int_0^{\pi} |E(\theta, \phi)|^2 \sin\theta \, d\theta}$$

where E (θ, ϕ) : field strength at the direction of θ and ϕ (horizontal and vertical angles)

Usually characteristics of transmitting antenna and receiving antenna are identical to each other.



X-Y-system

Polar-system

Figure 3.7.1 Radiation pattern of an antenna

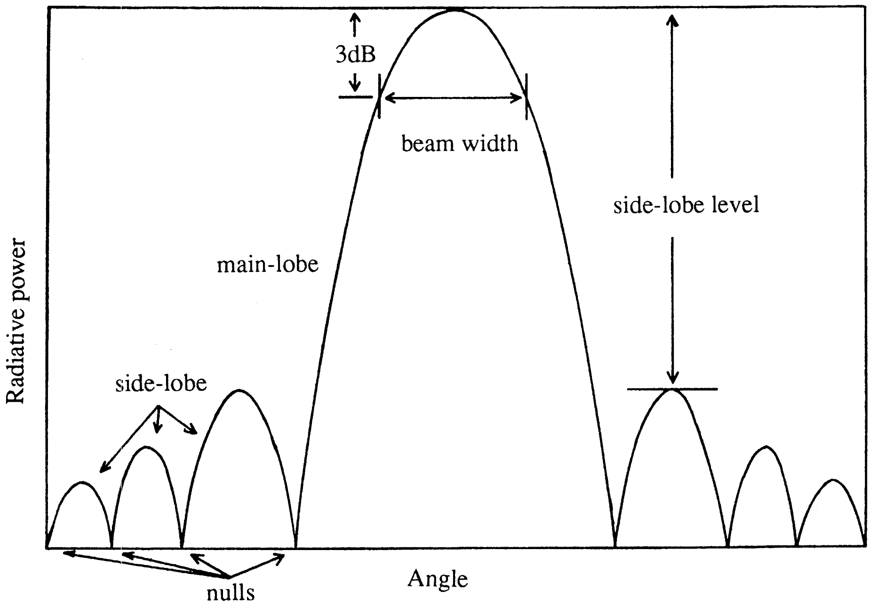


Figure 3.7.2 Terms relating to antenna characteristics as shown on a radiation pattern