CHAPTER III

ANTENNA AND RECEIVER

This chapter is divided in two main sections, antenna and receiver respectively. The former sector is provide the basic concepts for general antenna and the method how to measure the power pattern. The latter part is dedicated to radio receiver in the radio astronomy. The superheterodyne perspective is introduced since it was used in our system.

Definitions

An antenna may be defined as the region of transition between a free-space wave and a guided wave (receiving case) or vice versa (transmitting case) (Kraus, 1986). The antenna is analogous to the lens or mirror in an optical telescope.

The response of an antenna as a function of direction is given by the *antenna pattern*. By the reciprocity this pattern is the same for both receiving and transmitting condition (Kraus, 1988). The pattern commonly consist of a number of lobes as suggested in Fig. 3.1a. The lobe with the largest maximums called the *main lobe*, while the smaller lobe is referred to the *minor lobe* or *side* and *back lobe*.

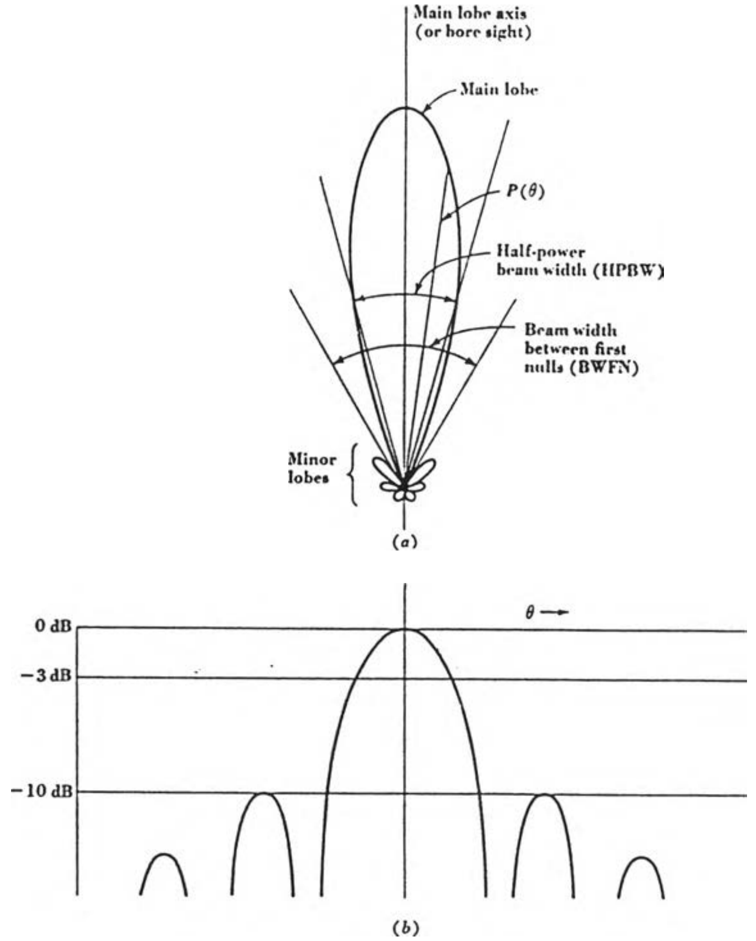

Fig. 3.1 Power pattern of an antenna in polar coordinate (a) and in rectangular coordinate (b) (Kraus, 1986).

If the pattern is measured at so sufficient distance from the source, that increase in the distant cause no change in the pattern, the pattern is the *far-field pattern*. Measurement at lesser distance yield *near-field pattern* which are a function of both an angle and distance since the non-uniform of the electric field from the source.

The pattern may be expressed in term of the field intensity (*field pattern*) or in term of the Poynting vector or radiation intensity (*power pattern*). Fig 3.1a is show a power pattern in polar coordinates. To show the minor-lobe structure in more details the pattern can be plotted on a logarithmic or decibel scale (decibel below main-lobe maximum). Fig 3.1b is an example of the pattern on the decibel scale in rectangular coordinates. The pattern in fig 3.1b. is the same as the one in fig 3.1a.

A single pattern, as in fig 3.1, would be sufficient to completely to specific the variation of radiation with angle if antenna the pattern is symmetrical. In the nonsymmetrical case, a three dimensional diagram is required to show the pattern in its entirety. However, in practice the patterns, one like that in fig. 3.1a through the narrowest part of the lobe an another perpendicular to it though the widest part of the lobe, may suffice. These mutually perpendicular pattern through the main lobe exist are called the *principal-plane patterns*. The above statement assumed that antenna is linearly polarized in one of the principal planes (Kraus, 1986).

Beam Width, Beam Solid Angle, Directivity and Effective Aperture

A useful numerical specification of the pattern can be in term of the angular width of the main lobe at a particular level. The angle at half-power level or the *half-power beam width (HPBW)* is the one most commonly used. *The beam width between first nulls (BWFN)* or the beamwidth at -10 or -20 dB below the maximum value are also useful.

Another way to describe the pattern is in terms of the *solid angle*. Let the relative antenna power pattern as a function of angle be given by $P(\theta,\phi)$ [$E(\theta,\phi) = E(\theta,\phi) * \overline{E(\theta,\phi)}$ where $E(\theta,\phi)$ is the electric field pattern at long distance] and its maximum value by $P(\theta,\phi)_{max}$. The $Pn(\theta,\phi)$ is proportional to the Poynting vector $S(\theta,\phi)$. It may be defined the *beam solid angle* or *beam area* as

$$\Omega_A = \iint_{4\pi} P_n(\theta,\phi)d\Omega \tag{3.1}$$

where Ω_A = beam solid angle or beam area, sr

$P_n(\theta,\phi) = P(\theta,\phi) / P(\theta,\phi)_{max}$ = normalized antenna power pattern

$d\Omega$ = elemental solid angle, sr.

The beam solid angle Ω_A is the angle through which all the power from transmitting antenna would stream if the power (per unit angle) were constant over this angle and equal to the maximum value.

In (3.1), if the integration is restricted to the main lobe as bounded by the first minimum, the main beam solid angle is obtained. Thus

$$\Omega_M = \iint_{\substack{\text{main}\\ \text{beam}}} P_n(\theta,\phi)d\Omega \tag{3.2}$$

where Ω_M = beam solid angle or beam area, sr

In the pattern for which no clearly defined minimum exists, the extent of the main lobe may be indefinite, and an arbitrary level such as -20 dB can be used to delineate it.

The *directivity* of the antenna may be defined as the ratio the maximum radiation intensity (transmitting case) to the average radiation intensity, or

$$\frac{U(\theta,\phi)_{max}}{U_{avg}} \tag{3.3}$$

where $U(\theta,\phi)$ = maximum radiation intensity, W/sr

U_{avg} = average radiation intensity, W/sr.

The average radiation intensity is given by the total power W radiated divided by 4π , and the total power is equal to the radiation intensity $U(\theta,\phi)$ integrated over 4π. Hence,

$$D = \frac{U(\theta,\phi)_{max}}{\frac{1}{4\pi}\iint_{4\pi} U(\theta,\phi)d\Omega}$$

$$= \frac{4\pi}{\iint_{4\pi} \frac{U(\theta,\phi)}{U(\theta,\phi)_{max}} d\Omega}$$

Since the radiation intensity is proportional to the poynting vector, thus

$$D = \frac{4\pi}{\iint_{4\pi} P_n(\theta,\phi)d\Omega} = \frac{4\pi}{\Omega_A} \tag{3.4}$$

The directivity of antenna is a fixed numerical quantity. Multiplying the directivity by the normalized power pattern yields the *directive gain*, a quantity which is a function of angle. Thus,

$$D(\theta,\phi) = D\,P_n(\theta,\phi) \tag{3.5}$$

Antenna pattern may be plotted in term of directive gain, as in fig. 3-2. For a nondirectional antenna the pattern would be everywhere equal to the level $D(\theta,\phi) = 1$. this is called the *isotropic level.*

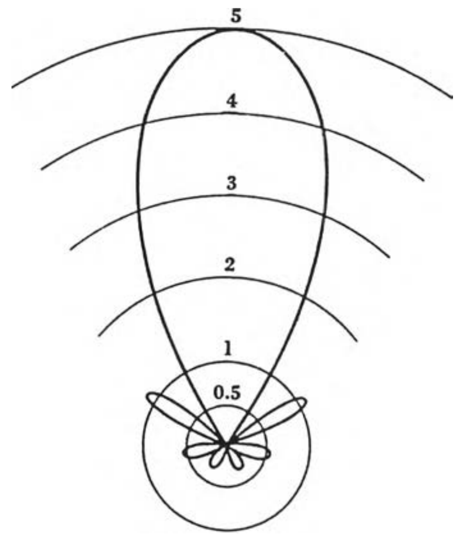

Fig 3.2 Antenna pattern plot in terms of directive gain (Kraus, 1986) .

The directivity has been expressed entirely as a function of the antenna pattern with no reference to the size or geometry of the antenna. To show that the directivity is a function of the antenna size consider the far-electric field intensity E_r at distance r in a direction boardside to a radiating aperture, as in fig. 3-3. If the field intensity in the aperture is constant and equal to E_a (V/m), the power W radiated is given by

$$W = \frac{|E_a|^2}{Z} A \tag{3.6}$$

where A = antenna aperture

Z = intrinsic impedance of the medium,

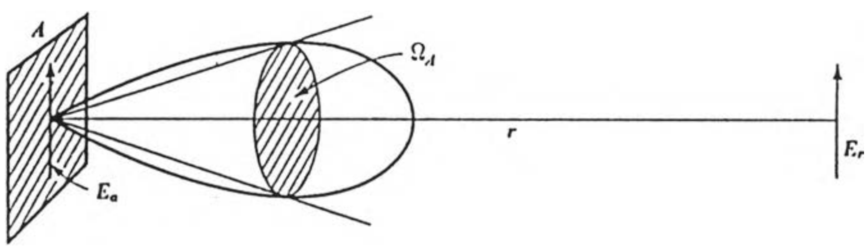

Fig 3.3 Radiation from aperture A with uniform field E_a (Kraus, 1986).

The power radiated may also be expressed in terms of the field intensity E_r at a distance r by

$$W = \frac{|E_r|^2}{Z} r^2 \Omega_A \tag{3.7}$$

where Ω_A = beam solid angle of antenna, sr

In this situation, we have to relate the field intensity in the aperture Ea to the field intensity at distance r (E_r). We consider a continuous current sheet or field distribution over an aperture A. In more general case, we assume that the current or field distribution over the aperture as in fig. 3-4. Assuming that the current or field is perpendicular to the page (y direction) and is uniform with respect to y, the electric field at distance r from an elemental aperture *dxdy* is

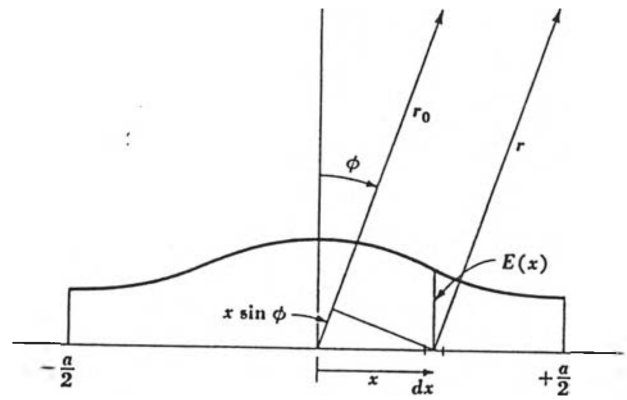

Fig. 3.4 Aperture of width a and amplitude distribution E(x) (Kraus, 1986).

$$dE_y = -j\omega\mu dA_y = -\frac{j\omega\mu}{4\pi r}\frac{E(x)}{Z}e^{-j\beta r}dxdy$$

where A_y = vector potential $[= \frac{\mu}{4\pi}\iiint\frac{J_y}{r}dv$ in general]

J_y = current density , A/m^2

$E(x)$ = aperture electric field distribution, V/m

ω = angular frequency

μ = permeability of medium, H/m

β = wave number, $2\pi/\lambda$

λ = wavelenght, m

For an aperture with a uniform dimension y_1 perpendicular to the page and with the field distribution over the aperture a function only of x, the electric field as a function of ϕ at a large distance from the aperture (r>>a) is ,from above equation,

$$E(\phi) = -\frac{j\omega y_1 e^{-j\beta r_o}}{4\pi r_o Z}\int_{-a/2}^{+a/2} E(x)e^{j\beta x\sin\phi}dx$$

The magnitude of $E(\phi)$ is then

$$|E(\phi)| = \frac{y_1}{2r_o\lambda}\int_{-a/2}^{+a/2} E(x)e^{-j\beta x\sin\phi}dx$$

For a uniform aperture distribution $E(x) = E_a$ and consider when $\phi = 0$, we have

$$|E(\phi)| = \frac{E_a a y_1}{2r\lambda} = \frac{E_a A}{2r\lambda}$$

where A = aperture area (ay_1).

For the unidirectional radiation from the aperture (in direction $\phi = 0$) is twice the value given from above equation which is

$$|Er| = \frac{|E_a|A}{r\lambda}$$

We substitutes the result to (3.7), we have

$$W = \left(\frac{|E_a|A}{r\lambda} \right)^2 \frac{r^2 \Omega_A}{Z}$$

Since the power radiated at distance r have the same value as the power of source from (3.5), we have

$$\lambda^2 = A\Omega_A \tag{3.8}$$

In (3-8) the aperture A is the physical aperture if the field is uniform over the aperture, as assumed, but in general A is the *effective aperture, Ae*. It may be considered the area of energy collected in the case of receiver

Hence, the directivity of the antenna can be written by replacing the Ω_A in (3.4) with λ^2/A_e from (3.8), we obtain

$$D = \frac{4\pi A_e}{\lambda^2} \tag{3.9}$$

Measurement of the Antenna Pattern

It is very important to know the properties of the used antenna if we have intention to evaluate any physical quantity from the observation as discussed in the previous chapter.

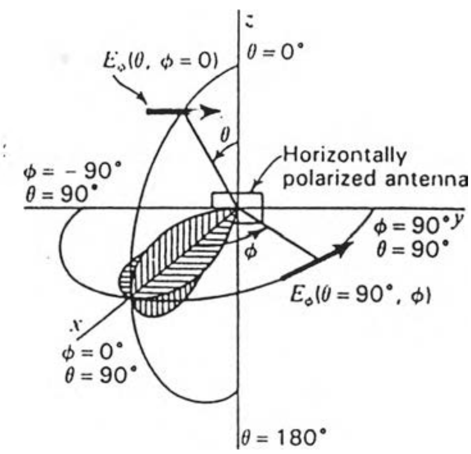

Fig 3.5 Measurement for horizontally polarized antenna power pattern (Kraus, 1988).

The parameter of the antenna, such as power pattern and effective aperture, are the interesting quantity instead of the physical structure of the antenna. In fact, it may be derived directly from the theoretical analysis but it is only the idealized or simplified case of the actual situation in the real world. So while theory is essential to our understanding, experimental measurements determine the actual performance.

The most important characteristic of an antenna is the far-field power pattern, $P_n(\theta,\phi)$. The 3-dimensional pattern have to determine in general case. However, the fewer pattern are frequently sufficient (Kraus, 1988) .

In this thesis, the used antenna is the wide-band log-periodic dipole as discussed in the next section. The antenna of this type are directional and linearly polarized. Thus, suppose that the main beam in the x-direction, as suggested in Fig. 3.5 then two principal-plane patterns bisecting the main beam may suffice. If the antenna is horizontally polarized then xz and xy plane pattern of E_ϕ are measured.

There are two arrangements which is possible to determine the power pattern of the antenna, one by rotating the antenna under test acting as a receiving antenna which a distant separation between the transmitter. Another way is by moving the transmitter around the antenna under test. As the far-field condition, the separation between transmitting and receiving antenna have to be sufficient for the pattern unchanged by the distant between source and receiving antenna.

This condition is met when the field at the antenna under test approximates a uniform plane wave. Consider the antenna's element with the physical size a as show by fig. 3-6.

If the point source situate at P, the field on all parts of element is arrived in the same phase at an infinite distance. If the separation is finite distance r the field at the edge must travel a distance $r+\delta$. Hence, there are phase different between the center and the edge of the elements, which is $2\pi\delta/\lambda$. If δ is comparably smaller than the wavelength of the incident wave, the measured pattern will approach appreciably to the true far-field pattern (Kraus, 1988). Referring to fig. 3-6,

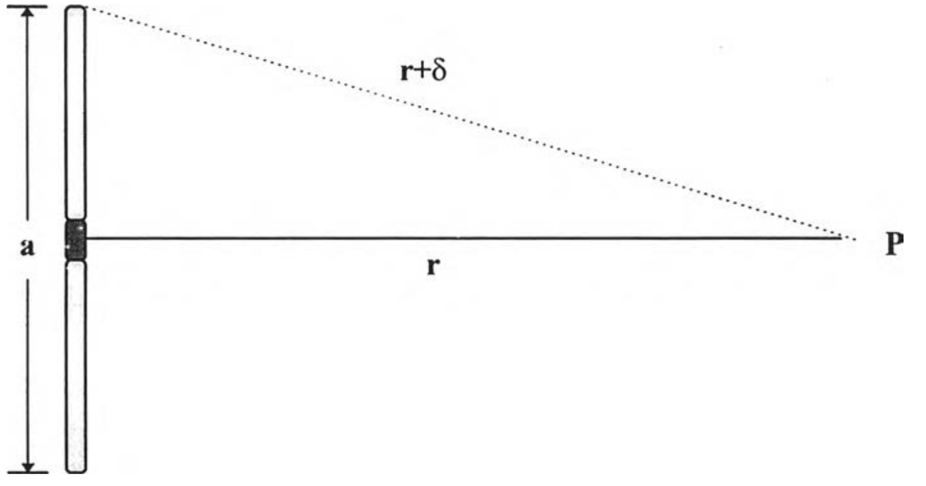

Fig 3.6 The longest element of an antenna in the electric field of the point source .

$$r^2 + 2r\delta + \delta^2 = r^2 + \frac{a^2}{2}$$

$$r = \frac{a^2}{8\lambda} - \frac{\delta}{2}$$

If $\delta << a$ and $\delta << r$

$$r \cong \frac{a^2}{8\delta}$$

Thus, the minimum distance r are depends on the maximum value of δ which can be tolerated. C.C. Cutler, A. P. King and W.E. Kock* recommended that δ be equal to or less than λ/16, Hence

$$r \geq 2\frac{a^2}{\lambda} \tag{3.10}$$

The phase difference for $\delta = \lambda/16$ is 22.5°. These value is satisfactory for the most case (Kraus, 1988).

When the arrangement as discussed in set and the antenna under test is connected to the receiver to monitor the power from the transmitter, we obtain the power pattern by rotating antenna or by moving antenna around the source in any direction. Also when we complete a plane we can be done in the same way for another plane.

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* Cutler, C.C., King, A.P. and Kock, W.E. Microwave Antenna Meaturemmts. Proc. IRE. 35 (December, 1947): 1462-1471 cite in Kraus, J.D. Antennas. 2nd ed. Singapore: McGraw-Hill, 1988.

Log-Periodic Dipole Antenna

As the discussion in the chapter II, the energies developed by the radio telescope system depend on the bandwidth of the system. Hence, the antenna of the wider bandwidth respond is one of the primary requirement (Heiserman, 1975).

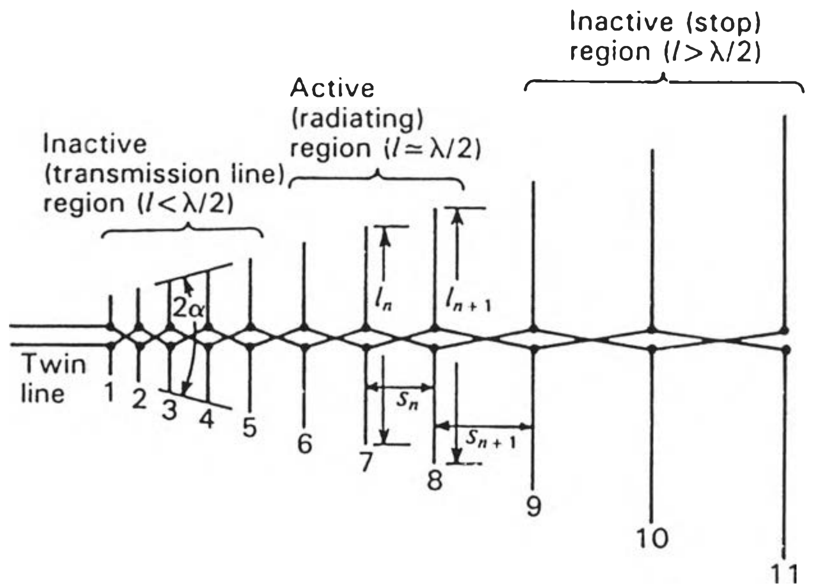

Fig. 3.7 Log-periodic dipole antenna (Kraus, 1988).

In this thesis we chose the broadband log-periodic dipole antenna as shown by fig. 3-7. This antenna was designed by Raymond DuHamel and Dwight Isbell in 1957. The physical principle is the fact that the characteristic of the antennas of same type but different size remain the same when operate at proper frequency. For example, there are two dipole antenna which are different in physical size by the ratio s. If the small one operate at frequency f, the input impedance of both antenna is the same when the large one operate at frequency f/s. When the such antenna is combined to array, the broadband characteristic is accomplished. The power pattern of this antenna is shown in fig. 3-8.

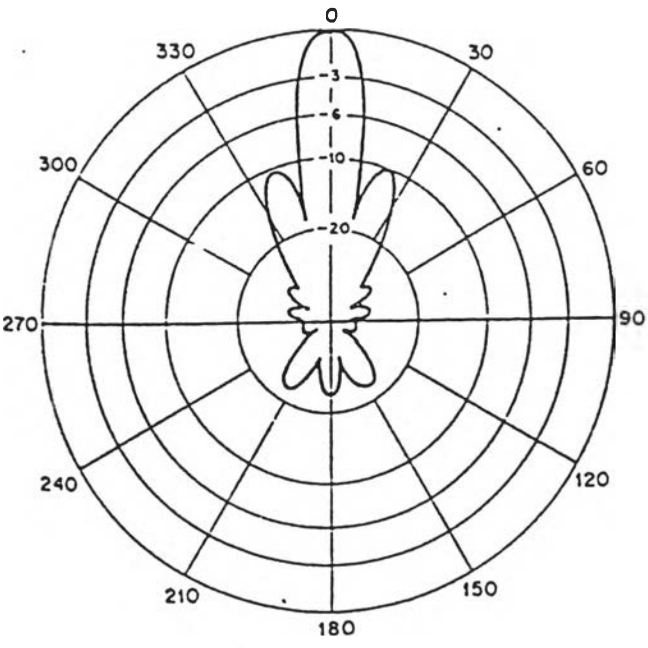

Fig 3.8 Power patern for a log-periodic dipole antenna (ชัยวัฒน์, 2536).

Radio Telescope Receivers

The radio receiver has the function to detect and measure the emission from the celestial object. In general, the measured signal has not the physical property difference from the terrestrial or receiver's noise. The output signal is the composition of many part as follow.

(1) The signal itself. The thermal radiation from the blackbody cause the fluctuation in the antenna which behave like the resister of the temperature over the absolute zero. It is important to note that the fluctuation at the output terminal is not only from the thermal agitation but also the non-thermal process. However the statistical properties are the same. The signal from any direction is selected by the directional antenna. However, the signal from source may be absorbed by the medium before reaching the antenna and before fed to the input terminal of the receiver (by the transmission line).

(2) Man-made and natural interference. The effect of the antenna minor lobes cause the induction of the unwanted signals to the antenna. It can be classified in two type, natural and man-made interference. The natural interference may be caused by the electrical discharge in the Earth's atmosphere such as lightning or thunderstorms, thermal emission from the ground, or the rest of the sky itself. The intensity of the atmospheric discharges decreased at the high frequency and in practice it does not present a significant problem at the wavelenght shorter than two or three meters. The man-made interference come from many sources such as the automobile ignition system, electrical machinery (e.g. motor) or communication system. The interference of this type are sometimes carried from the power line or the communication cable and connector. Many measures should be applied to reduce the effect.

(3) Receiver noise. The various circuit in the receiver generate some noise to the output. These fluctuation also have the statistical properties as the thermal fluctuation received from the target source. It is major contribution to the high frequency receiver. However, for the lower frequency, the signal from sky have so intense that the receiver noise became less importance (Brown and Lovell, 1958 ; Christiansen and Hogbom, 1985).

(4) Instabilities in the equipment. These are troubles described as *gain variation*, *drifts*, etc. The requirement of stability is very important The long-term recording so suffer from the instability.

Radio telescope receiver are basically similar in construction to the communication receiver, but the purpose of the reception is differ. The radio astronomer is interested in the average energy but not in the actual form of the signal.

Thus, the measurements are made for long period of time which is long enough to give a sufficient accurate value of the average power. Since the instability of the receiver, the calibration will be used as much as possible.

Superheterodyne Receiver and Mixer

The most common type of receiver is the superheterodyne which block diagram is shown in Fig. 3.9.

The signal from antenna is fed through the Radio Frequency (RF) Amplifier. The radio signal will be confined to the specific frequency with an arbitrary bandwidth and amplified with the gain of the order 10 to 30 dB (Kraus, 1986). The weak amplified RF signal is mixed with a strong Local Oscillator (LO) to translate the signal spectrum to the Intermediate Frequency (IF) which power is directly proportional to the RF signal power. The IF signals are amplified with the gain in order to 60-90 dB at the IF amplifier sections and then detected and integrated before sent to the readout device. The signal. In general the used detector type is the square law which the output is corresponding to the signal power.

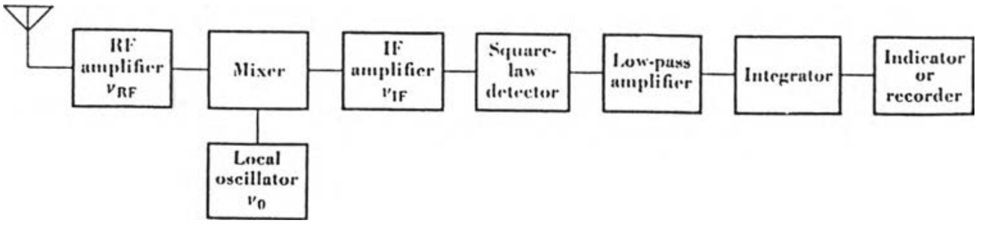

Fig 3.9 A superheterodyne radio telescope receiver (Kraus, 1986) .

The readout device depend on the purposes of the detection. For the common radio receiver, it is connected to the audio amplifier which is connected to the speakers. The readout device in radio telescope may be the simply as a multimeter, the more complex apparatus such as pen recorder or computer control acquisition system.

The section before and after the detector is called the *predetection* and the *postdetection* respectively (Kraus, 1986). However, the section before and after the mixer may be called the *frontend* and *backend* according to the operation frequency respectively (Rohlfs, 1990). The radio receiver which measure the total noise of the antenna including the receiver itself is called a *total power receiver*.

The single stage amplifier is impossible to amplify the small signal induced by the antenna since the high gain amplifier suffer from the limitation of bandwidth. However, it is possible to be replaced by multistage amplifiers, but the stability is another considered requirement. When a small amount of power leaking from the output feed back to the input of the any previous stages, the system will be oscillating violently. The situation may be avoid by heavy shields, but the more effective measure can be applied by translate the signal spectrum to the band which is the previous amplifiers cannot be operated. The superheterodyne receiver is the application from this principle. This frequency is usually translated to the lower frequency since it is easier to build than the stable amplifier in high frequency.

Now it is useful to consider the frequency conversion in more detail. The mixer may be devised by the non-linear circuit, but derivation of its properties are most simple for a pure quadratic characteristic (Rohlfs, 1990). The relation for such a mixer can be given by

$$V = \alpha(V_s + V_l)^2 = \alpha(V_s^2 + V_l^2 + 2V_sV_l)$$

where V = output voltage

α = mixer gain

V_s = input voltage

V_l = local oscillator voltage

The input voltage Vs and the local oscillator V_l may be written as the sinusoidal wave which are

$$V_s = A_s \cos(\omega_s t)$$

$$V_l = A_l \cos(\omega_l t)$$

Substitute to the mixer equation, we have

$$\begin{aligned} V &= \frac{\alpha}{2}\left(A_s^2 + A_l^2\right) \\ &+ \frac{\alpha}{2}(A_s^2 \cos(2\omega_s t) + A_l^2 \cos(2\omega t)) \\ &+ \alpha A_s A_l \cos(\omega_s + \omega_l)t \\ &+ \alpha A_s A_l \cos(\omega_s - \omega_l)t \end{aligned}$$

We can see that the first and second term on the right hand side are DC and the double frequency of the input and LO voltages, respectively. The frequency of the third is the summation of their frequencies and the last term is corresponding to the different. If we apply the bandpass filter to eliminate all component except the last, hence

$$V_o = \alpha A_l A_s \cos(\omega_s - \omega_l)t$$

From this relation, the non-linear mixer will give the linear result. The signal is translated to the lower frequency and the amplitude is directly proportional to the gain of mixer, amplitudes of the local oscillator and the input signals.

As the result, the input signal is amplified and its frequency is converted. If the LO frequency is chosen to the band which the RF amplifier cannot operated, The violently oscillation do not occur. However, the stable oscillator can be designed easily than the heavy shielding, the deviation of the LO amplitude cause variation of gain in the receiver. The calibration should be made to recover it.

Calibration of the Rceeiver

Since the instability of the receiver, it is important to calibration the system. The calibration should be made regularly as much as possible for the long-term recording. The noise source can be used as the standard signal. By switching between the antenna and the noise source, the calibration is accomplished. The noise source may be the resistor of the same resistance of the antenna impedance (Heiserman, 1975).