CHAPTER II

THEORY

2.1 MODIFIED EFFECTIVE EARTH'S RADIUS

A ray that propagates through the earth's atmosphere encounters variations in atmospheric refractive index along its trajectory that cause the ray path to become curved. The radio refractive index of the atmosphere, n, always has a values slightly greater than unity near the earth's surface and approaches unity with increasing height. Thus ray path usually have a curvature that is concave downward.

The classical method of accounting for the effects of atmospheric refraction of radio waves is to assume an effective earth's radius, $a_e = ka$, where a is the true radius of the earth and k is the effective earth's radius factor. This method, advanced by Schelleng, Burrews and Ferrell,[*(2)] assumes an earth suitably larger than the actual earth so that the curvature of the radio ray will be absorbed in the curvature of the effective earth, thus the radio ray can be drawn as straight lines over this earth rather than curved rays over the true earth.

The expression relating the curvature of radio rays to the gradient of refractive index can be derived as follow:-

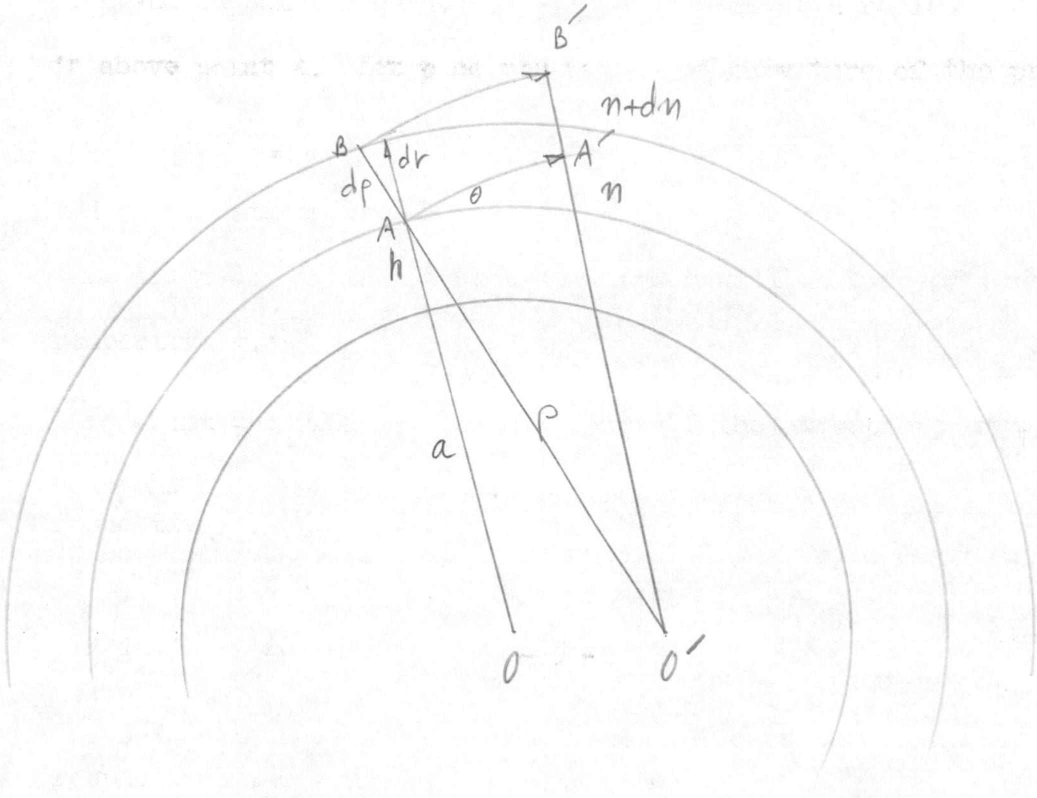

Fig. 1 Differential geometry used in the derivation of the effective-earth's radius model atmosphere.

In Fig. 1 Let AB represent a wavefront moving in a direction AA' in the atmosphere of height h above the earth surface. After a time interval dt, the two points A and B will move to A' and B' respectively.

Let the radio refractive index of the atmosphere at point A be n and at point B be n+dn. The point B is at a radial distance dr above point A. Let ρ be the radius of curvature of the path AA'.

The reciprocal of radius of curvature is the curvature of the path. Thus the curvature of the path AA' is $1/\rho$

If the phase velocity along AA' and BB' are v and v+dv respectively, then the angular velocity of points A and B are equal.

$$\frac{v}{\rho} = \frac{v + dv}{\rho + d\rho} \qquad \text{..........(1)}$$

or

$$\frac{dv}{v} = \frac{d\rho}{\rho} \qquad \text{..........(2)}$$

The phase velocity, v, is related to the index of refraction , n, by the expression

$$v = \frac{c}{n} \qquad \text{..........(3)}$$

where c is the velocity of light in vacuum.

From equation (3) one can derive that

$$\frac{dv}{v} = -\frac{dn}{n} \qquad \text{..........(4)}$$

Substitute equation (4) into (2) one obtain

$$\frac{1}{\rho} = -\frac{1}{n}\frac{dn}{d\rho} \qquad \text{..........(5)}$$

If the ray path makes an angle θ with the surface of constant refractive index, then

$$dr = d\rho \cos \theta$$

Consequently equation (5) can be rewritten as

$$\frac{1}{\rho} = -\frac{1}{n}\frac{dn}{dr}\cos \theta \qquad \text{..........(6)}$$

The curvature of the effective earth is defined by the relation.

$$\frac{1}{a_e} = \frac{1}{a} - \frac{1}{\rho} \qquad \text{..........(7)}$$

where $1/a - 1/\rho$ is the curvature of the earth relative to that of the ray. The a_e and a are the effective and true earth radii respectively, and they are related by the effective earth's radius factor, k, as

$$a_e = ka \qquad \text{...........(8)}$$

From the equations (6), (7) and (8) one can solve for the factor k and obtain

$$k = \frac{1}{1 + \frac{a}{n}\frac{dn}{dh}\cos\theta}$$

For wave propagation in the troposphere where the ray path is approximately tangential to the surface of constant refractive index of air ($\theta = 0$) and n is very close to unity, the effective earth radius factor becomes

$$k = \frac{1}{1 + a\frac{dn}{dh}}$$

In temperate zone, the observed gradients of n is close to $- 1/4a$ and this gives $k = 4/3$.

2.2 Radio Refractive Index of the Atmosphere

The propagation of electromagnetic waves around the earth is influenced by the properties of the earth and its atmosphere. The earth is an inhomogeneous body whose electromagnetic properties vary considerably as we go from one point to another. The atmosphere over the earth is dynamic medium, its properties vary with temperature and humidity: turbulence creates blobs that scatter radiation.

The radio energy at frequency above 30 MHz is not normally reflected by the ionosphere, the characteristics of the received field is therefore attributed to variations in the lower atmosphere and, in particular, to the radio refractive index of air.

The radio refractive index is defined as the ratio of the speed of propagation of radio energy in a vacuum to the speed in a specified medium. The refractive index of the troposphere is of central concern in the propagation of radio waves at frequencies above 30 MHz.

According to the scatter theory of H.G. Booker and W.E. Gordon,*[3] the air is not uniform; turbulence is always present and the temperature and humidity are constantly fluctuating due to the turbulence. Therefore the refractive index also continually fluctuates both in time and space. When the primary electric field is projected into this type of air, the turbulence appears to be several dipoles radiating in random directions and the field of reception is thus determined by this scattering process.

Radio wave travel in straight lines through any isotropic, homogeneous medium with a velocity $v = c/n$, where c is the velocity of light in a vacuum and n is the index of refraction of the medium. If the index of refraction changes the velocity of the wave changes and the direction of its travel may be changed. The index of refraction of air is slightly greater than unity and varies with the state of the atmosphere. At the earth's surface the refractive index is at greatest value and approaches unity with increasing elevation.

Many experiments previously conducted have led to a conclusion that for radio wave the empirical formula for the refractive index of the atmosphere in the troposphere is very closely approximated by *(4)

$$(n - 1) \times 10^6 = \frac{77.6}{T}\left(P + \frac{4810e}{T} \right)$$

where	n	=	refractive index of the atmosphere
	P	=	atmospheric pressure in mb
	e	=	water-vapor pressure in mb
	T	=	absolute temperature in ^oK

The refractive index of air, as expressed by the above formula, is effectively nondispersive for frequency below 50 GHz.

The equation $N = (n-1) \times 10^{-6}$, where N is radio refractivity, is widespread use by radio scientist and communication engineers through out the world.

2.3 Measurement of the Radio Refractive Index

There are two approaches to the measurement of the radio refractive index. One is the method by which the refractive index is directly measured. The other is the indirect method by which the meteorological data is measured and the refractive index is evaluated from the formula given previously.

The direct method employs radio frequency refractometer to determine the refractive index. The resonant frequency of a microwave cavity is a function of its dimensions and the refractive index of its contents. If the cavity is open to the atmosphere, the resonant frequency change as the refractive index of the air passing throught it changes. If a sealed reference cavity is used for comparison, the difference between the two resonant frequencies becomes a convenient measure of the refractive index variations in the sampling cavity.

The indirect measurement is conducted by measuring temperature, pressure, and humidity with subsequent conversion to the refractive index as indicated previously. This method employs standard weather observations and are generally used because of high accuracy and convenience to conduct.

2.4 Measurement of Temperature

In order to obtain the temperature profile of air above the earth surfase with high accuracy, care should be taken concerning the selection of the type of thermometer. For measuring and recording temperature accurately with great sensitivity, electrical methods are best. Two general type of electric thermometers are in use; the thermocouple and the resistance thermometer.

The thermocouple is based on the fact that a current will flow between two junctions of two metals if one junction is kept hotter or colder than the other. The junctions, made of such pairs of metals as copper and constantan, may be made so small that they can be fitted or fused into a small space and, being almost massless, their sensitivity is high and time lag very small. For use in meteorology, the thermocouple is often arranged with the cold junction in a bath of dry ice and acetone, or of liquid nitrogen and the other junction in the place where the measurement is needed. The current which is a function of temperature measured may be amplified and recorded on a recorder either by direct wire or by a radio transmitted signal.

Resistance thermometers are based on the principle that the electrical resistance of a conductor varies with its temperature. The platinum wire thermometer is of this type. Recently it has been recognized that high sensitivity and highly satisfactory results can be obtained from ceramic resistors which have negative resistance coefficient; that is, the resistance decreases with the increasing temperature. This is contrast to the metals which have positive resistance coefficient. One type of ceramic resistor in use, called the thermistor, has a very high negative coefficient, varying from approximately 20,000 to 2,000,000 ohms for the temperature rangs from + 60 °C to - 90 °C. This makes it very suitable for meteorological measurements. It is made 0.02 inch in diameter and 1 inch in length and is coated with a pigment which makes it more than 90 per cent reflective to the solar radiation. Its small-mass assures good sensitivity. It is widely used for upper-air measurements, with the readings radio-telemetered to a ground recorder.

Temperature measurement is a standard of the world's weather service. Thermometer protected by radiation shield are usually accurate to within ± 0.1 °C. The platinum resistance thermometer an international standard, is capable of measuring temperature in still air to within ± 0.05 °C. If used in a well-compensated bridge cricuit. The platinum resistance thermometer is velocity sensitive in a moving air stream. Thermocouples avoid this problem and yield short-term accuracies of approximately ± 0.1 °C with time constants measured in milliseconds.

2.5 Humidity Measurement

Humidity is a measure of the quantity of water in vapor or gaseous form contained in a given portion of the atmosphere. This may be expressed directly as a number of grams of water vapor in a cubic meter of air, or it may be expressed in terms of the contribution of the water vapor to the total of the pressure of all the atmospheric gases. The latter is called the vapor pressure. It may also be stated in terms of specific humidity, temperature of the dew point, or possibly some other quantities. The instrument that is sensitive to changes in the humidity or water-vapor content of the atmosphere is called hygrometer.

The most obvious way to measure the water-vapor content is to pass a sample of known volume or mass of the atmosphere through chemicals that absorb all the water vapor. By weighting the absorbing material before an after the absorption, the mass of the water vapor in the sample can be determined. Certain salts, such as $CaCl_2$, P_2O_5, $MgCl_2$ are well suited to this type of measurement. The chemical-absorption method of measuring humidity, which supposedly quite accurate, is difficult in practice. The major disadvantage of chemical absorption method is that it require so much time, i.e. may be over an hour or perhaps a whole day to accurately take a reading of mean value of humidity. Another type of absorption hygrometer is based on electrical changes produced by the absorption of water on electrical-conducting materials. This hygrometer measures the electrical resistance of a film containing lithium chloride, LiCl, which is hygroscopic. The resistance also depends on the temperature, so that a correction of the reading due to temperature is necessary.

The other way to measure humidity is by using dew-point apparatus. For every value of the water-vapor content, there is a temperature at which this quantities will produce saturation. This temperature is called the temperature of the dew point, and it may be achicved by cooling the air at constant pressure and without allowing the total water-vapor content to change. When a solid body is cooled to the dew point, dew begins to condense on it. If the temperature of the surface of such a body can be measured it would provide a means of obtaining the dew-point temperature. Some forms of the dew-point apparatus are simple. A small reservoir of ether is placed behind a silvered disk or in a silvered tube. By bubbling air through the ether, it is made to evaporate and cool, and the silvered surface is suppose to cool at the same rate. The surface is so highly polished that one notices immediately the dulling of reflections caused by the condensation of dew. The temperature of the ether is read on a thermometer immersed in it, and if the instrument is properly construct and the thermometer is read just at the beginning of condonsation, the reading will be the temperature of the dew point. A modern recording dew-point hygrometer substitutes a photoelectric cell for the human eye and employs suitable electronic circuitry. A tiny mirror is fused to the outside end of a copper rod, the main part of which is immersed in a refrigerant in a flask. The temperature of the mirror can be kept constant by induction heating from a heating circuit to balance the conduction cooling due to the refrigerant. As dew forms on the mirror, the diminution of a light beam reflected from the mirror causes the photocell to actuate the heating circuit. The system can be made to supply just the right amount of heat to hold a steady condition in which the dew point is neither thickening nor disappearing. The temperature is obtained through a thermocouple junction fastened to the back of the mirror, and recorded electronically.

Relative humidity requires the greatest care in measurement. It is also a standard measurement of the world's weather service. The common lithium chloride strip is accurate to within $\pm$ 5 per cent in relative humidity. In general, the lag constant is of the order 8 to 10 second for temperature in excess of 0 $^{\circ}$C.

2.6 The Measurement of Pressure

The pressure is defined as the force per unit area exerted by the air.

$$P = F/A$$

If the acceleration of gravity g is the only acceleration present and if M is the total mass of the overlying atmosphere, then

$$F = Mg$$

which is the weight of the atmosphere. Under these conditions, the atmosphere is said to be in static equilibrium, and the pressure is defined as the weight per unit area or the weight of a column of air of unit cross section to the top of the atmosphere.

$$P = Mg/A$$

In the cgs system of units, the pressure is expressed in terms of dynes per square centimetre. For meteorological purposes, this unit is too small, so 1,000 times this unit, the milliber, is used. A bar is one million dynes per cm^2 and a millibar is one thousandth of that, or 1,000 dynes per cm^2.

The apparatus used for pressure measurement in radiosonde is aneroid barometer. It consists of an evacuated chamber and spring. The spring keeps the chamber from collapsing under the pressure of the atmosphere and restores the chamber to a larger shape when the pressure is reduced. The chamber is of thin metal that can expand or contract the chamber as the pressure changes. The spring may be in the form of either spring arm outside the chamber or a helical spring inside. The deflection of the spring and chamber are multiplied by levers so that they may operate a pointer on a dial marked with pressure readings. The aneroid has a temperature correction due to temperature effects on the characteristics of the spring and on the small amount of gas contained in the chamber.

Pressure is also a standard measurement of the world's weather service. The total atmospheric pressure can be measured by a variety of electrical sensors. The simplest device is the pressure potentiometer where an aneroid capsule is mechanically linked to a potentiometer. One or two millibar can be considered the limit of accuracy in a differential device operating over a range of $\pm$ 100 mbar with reference to an average value with time constants of perhaps 5 msec.

2.7 Upper - Air - Observations

Soundings of the troposphere and lower stratosphere with meteorological instruments are made every day by the Meteorological Department, sounding balloons carrying instruments called radiosonde that continuously telemeter the reading of temperature, pressure and humidity back to the earth by the radio signals. These signals are recorded by thermograph, barograph and hygrograph respectively. The radiosonde signal is also used for direction finding by ground equipment, making it possible to follow the drift of the balloon and enable one to compute the wind velocity at various level through which the balloon rises.

In order to determine the state of the atmosphere at rest at any given point, three quantities must be measured, i.e., pressure, temperature and humidity. The relationship between pressure and height is such that, if the three quantities just named are measured, the altitude can be obtained. Therefore metorological sounding instrument consist of apparatus for recording pressure, temperature, and humidity.

2.8 The Radiosonde

The radiosonde equipment involve special problems of engineering. In addition to the meteorological unit, the radiosonde must have a light weight, cheap radio transmitter. The needs are best met by use of ultrahigh radio frequency, which required a minimum of power. Extremely small dry-cell or storage batteries may be used for the energy supply. Two systems of modulation are in use, one in which the audiofrequency is modulated and the other with amplitude modulated. The latter is favored for direction finding, at least when used of a 1680-MHz transmitter. Both types are controlled by what is known as a blocking oscillator

The meteorological unit consists of a slowly rotating contact point, driven by clockward or some other constant - speed motor. Instead of making contact with fixed points, it operates with points that change their position in the cycle of rotation. The pressure, temperature, and humidity sensing elements cause these contact points to move as the measured value change. Two fixed points, easily identifiable because they are close together, are include for reference. As the measured quantities change, the time interval between the fixed reference and the variable sensing contacts changes. The signal transmitted at each contact is recorded on a chronograph at a receiving station where the spacing of the signals is calibrated in terms of meteorological quantities.

A special pressure-measuring and actuating system is used. An aneroid moves a contact arm over a series of strips. These strips are spaced in accordance with set intervals of pressure so that the pressure change steps can be added together by counting the contacts. The temperature and humidity readings are transmitted with each set of contacts. The conducting strips are separated by insulating bands. When the switch arm is on an insulating portion, the signal modulated by the tiny signal is actuated. Every few strips transmitt reference signals.

For sensing the temperature, a ceramic 'thermister' is used, while the humidity element is the lithium chloride - coated slide.

The lag constants of the radiosonde sensors are also of importance. Since the sonde is rising at a relative rapid rate, it passes into regions of changing refractivity before the sensors are aware of it. The lag coefficient associated with the radiosonde introduces an error in the estimation of the true gradient.

The determination of N from radiosonde data is subject to all of the errors inherent in the radiosonde observation. It is concluded that the time lag of the sensing elements is the most serious source of error. The lag coefficient of the lithium chloride strip is a function not only of the temperature, but also of the absolute value of the relative humidity, as well as of the size and direction of the gradient.*(5) The radiosonde samples temperature and humidity in sequence rather than simultaneously. To correct this deficiency the cycling time in one radiosonde is decreased so that many more samples of each parameter were produced per unit time. The correction of time lag for the temperature element yields a twofold correction to N due to the actual error in temperature and the ancillary correction in vapor pressure resulting from the more correct estimate of the true saturation vapor pressure. This arises from the fact that when the lithium chloride element measures relative humidity it must be used with the saturation vapor pressure. Since the saturation vapor pressure of water is a function of temperature, an error in temperature produces an error in the estimated water vapor pressure. The lag constant of the lithium chloride humidity element becomes significantly larger for temperature below $0^{o}C$.

The environmental value of the measuring of variable, θ, can be determined from (6)

$$\theta_{e,k+1} = \theta_{i,k+1} + R\lambda \frac{\theta_{i,k+1} - \theta_{i,k}}{h_{k+1} - h_k}$$

Where θ is the measuring variable, λ the appropriate lag constant and subscripts i, and e stand for the indicated and environmental values respectively. R is the ascension rate of the radiosonde (m/min.). The k th and the (k+1) st are the boundary layer considered. The above equation assumed that θ_e varies exponently with time and θ_i varies linearly between reported values. In applying the equation one generally assumes that time lags are always known and that the environmental and indicated values are indentical at the base of each layer.

2.9 Troposphere And Influences On Radio Wave Propagation

The troposphere is the lowest region of the atmosphere. It begins at the earth's surface and ends at the tropopause approximataly 10-16 kilometers above the earth surface. The significant feature of the troposphere is the temperature decrease with height. But in layers of little vertical extension is the normal temperature decrease is a transition layer between the troposphere and the stratosphere. Sounding made at single stations show a sharp delineation between the normal rate of temperature decrease occuring in the troposphere and the approximately isothermal distribution of the stratosphere. In Thailand the tropopause is found at average height of 16.5 km.*(7)

The main permanent constitutes of troposphere are the gases oxygen, nitrogen, argon and carbondioxide. The percentage by volume are.*(8)

Nitrogen	78.088 %
Oxygen	20.949 %
Argon	0.93 %
Carbondioxide	0.03 %

The important variable atmospheric gases in the troposphere are ozone and water vapor. Ozone is thought to be formed by photochemical reduction of organic pollutants in the lower atmosphere. In the upper atmosphere it is produced by mean of the photochemical dissociation caused by ultraviolet radiation from the sun. Generally its concentration is low in the troposphere and higher amount in the upper atmosphere.

Contrary to the behavior of ozone, the highest amount of water vapor are found near the earth's surface. The parameter is very important for radio wave propagation. Especially in the frequency range of 100 to 50,000 MHz. The variation of abosorptions with pressure, frequency, temperature, and humidity are described by the Van Vleck theory of absorption.*(9) The water vapor absorption is directly proportion to the absolute humidity. Water is supplied to the troposphere by evaporation from the surface of the earth, i.e., from the land as well as from the ocean. Precipitation returns water to the surface. The percentage of water vapor in the atmosphere is quite small compared with other gases.

2.10 Temperature Inversion

The causes of temperature variations are:- radiation of the sun, heat conduction, convection, adiabatic changes and advection.

Heat is transmitted by infrared radiation. The earth's surface absorbs the sunray very well. The absorbing or reflecting property of the earth depend on the nature of the ground. The ground is a bad heat conductor and has a low specific heat, It is rapidly heated by incoming sun radiation. This heating takes place in very. thin layers of the soil and increases with the rising sun. At noon the soil is warmest. When the sun sets the incoming radiation become weaker and so the soil become cooler. This cooling is strongest during clear nights. The lowest temperatures are reached at sunrise. The outgoing radiation is caused by the fact that the earth it self radiates according to its temperature. The outgoing radiation is over compensated by the sun radiation during the day but is fully effective during the night hours. The incoming radiation may be completely screened by a cloud cover. Then cooling caused by the outgoing radiation in also diminished by reflection at the clouds.

The earth's surface is heated by radiation. Air touching the earth's surface is heated by heat conduction in a very thin layer. The heated air has less density, consequently, convection starts and brings the heat up to higher level.

The opposite takes place during the night. As the earth's surface is cooled for outgoing radiation the touching air is also cooled by heat conduction. The denser air is below and has no intention of upward movement. Only a thin layer of the air is cooled. Above this cooled level the temperature increase with height because this air is not affected by the outgoing radiation. At some hundred metres above the earth's surface the temperature distribution with height is inverse to the normal decrease. This layer is called a surface inversion of temperature.

2.11 Atmospheric Turbulence

It is a matter of experience that air currents do not flow in parallel streams but usually this so-called laminar flow does not exist and the atmosphere is in a state of turbulence motion. The atmosphere is an inhomogeneous medium, althought mean values of refractive index usually have some horizontal homogeneity. The inhomogeneities are produced and supported by turbulence motion.

Turbulence may be defined*(10) as an irregular motion which generally makes its appearance in fluids, i.e. gaseous or liquid, when they flow past solid surfaces, when neighboring streams of the same fluid flow past or over one another, or when thermal instability is present. While the air has a mean speed and a mean direction which are reasonably constant for periods of hours, the instantaneous speed and direction at a particular point may differ widely from the mean values. There is no clear idea of how or why turbulance arises, or of the exact nature of the eddies which form in a fluid in turbulent flow. It is thought that the main causes of turbulence are convection and friction. The index or refraction of the atmosphere is a function of temperature and humidity and these two parameters by themselves are partly function of the wind. The friction between the air and the earth's surface causes the turbulence of the wind and diminishes its speed.

2.12 The influence of the atmosphere on radio wave propagation

In the case of rectilinear propagation the spherical shape of the earth would cause very limited ranges of the transmitters. In the lowest surface layers of the troposphere diffraction originates a deflection to the earth's surface.

Refraction and reflection of electromagnetic waves occur at inversions of temperature and sudden decreases of humidity which enlarge the range of transmitter. But, as meteorological conditions change in time and in space large ranges do not last permanently. Apart from the meteorological conditions the wavelength plays an important role in this respect.

Absorption by air particles causes a loss of energy of electromagnetic waves so that the received signal is weaker than that transmitted in a perfect vacuum. This weakening is especially caused by the oxygen and the water vapor content. Measurements of these weakening processes are very difficult because the absorption ability of the atmosphere is also subject to the temperature. If the composition of air is constant the temperature can change the attenuation of the transmission up to 60 percent in the range of possible temperature.

Another factor is the scattering by which small particles suspended in a medium of different refractive index diffuse a portion of the incident radiation in all directions. Along with absorption, scattering is a major cause of the attenuation of radiation. The electromagnetic wave running through the atmosphere are weakened by scattering. On the other hand a part of the wave energy may return to the transmitter by back scattering. So principally a difference must be made between forward and back scattering. For the problems of radio wave propagation the forward scattering is important whereas in the field of radar meteorology the back scattering must by considered.