Mitigation of Effects of the Atmosphere on Radio Wave Propagation.

A.S. Adegoke, M.Sc., MNSE

Department of Computer Engineering, Yaba College of Technology
Yaba-Lagos, Nigeria.

E-mail: adegokeas2000@yahoo.com

ABSTRACT

Radio waves traveling through free space have little or no external influence on them. But when such signals are traversed through the atmosphere, their effective propagation will be determined by atmospheric factors. Some of these atmospheric factors are variations in geographic height, differences in geographic locations, and changes in time (day, night, season, etc.). This paper has critically looked into these factors and investigated their effects. Five cases of atmospheric phenomenon were considered and solutions to mitigation effects suggested. The result of this study will provide useful information to telecommunications operators in making necessary adjustments, where possible, for optimum result.

(Keywords: telecommunications, radio waves, atmospheric factors, absorption, signal attenuation)

INTRODUCTION

When radio wave signals are propagated through the atmosphere, their transmission capacity is greatly influenced by atmospheric conditions at that point. Within the atmosphere, radio waves can refract, reflect, diffract, and even be ducted. For example, in our recent work, it was demonstrated that when signals are propagated through the atmosphere, they may be refracted. This refraction tends to further lengthen the ray path thereby increasing the propagation time, which in turn lead to late arrival time of the signal at the receiver circuit. This phenomenon is called propagation delay.

Also, wind, air temperature, and water content of the atmosphere can combine to either extend radio communications or to greatly attenuate wave propagation making normal communications extremely difficult. So, due to the non homogeneous nature of the atmosphere, little changes in atmospheric constituents can produce dramatic changes in ability to communicate.

LITERATURE REVIEW AND HISTORICAL BACKGROUND

In 1899, a scientist named Nikola Tesla made a breakthrough by making the first attempt of using the atmosphere to transmit radio wave signals. In his experiments, he transmitted extremely low frequencies between the earth and upper part of the atmosphere (ionosphere). This was further buttressed in December 12, 1901 by Guglieno Marconi who established the first transatlantic communication between Poldhu and Canada. In his experiment, he used a 400-foot kite–supported antenna for reception. The transmitting station in Poldhu, Cornwall used a spark-gap transmitter to produce radio wave signal with a frequency of approximately 500khz and a power of 100 times more than any radio signal ever produced.

In 1902, O. Heaviside and A. Kennelly discovered the presence of permanent electrically conducting layer high in the atmosphere. Between 1903 and 1906, J.E. Taylor and J.A. Fleming among others suggested that the conducting properties of this layer were produced by ionization action of ultraviolet light from the sun on the upper atmosphere. This means that the sun controlled radio propagation, which was confirmed as soon as commercial communications were established across the Atlantic Ocean.

After these tremendous achievements were discovered, scientists began to notice some impediments posed by the atmosphere on transmitted radio wave signals. To this effect, G.W. Pierce, in 1910, noticed that waves do reflect in the process of getting to ionized layers and this interferes with direct or ground waves thereby canceling or amplifying the signal.

The final experimental proof of this came in 1924 with an experiment conducted at Cavendish Laboratories using the BBC transmitter at Bournemouth. They calculated the signal strength and fade variation and deduced that reflection occurred at a height of about 100km.

THEORETICAL CONSIDERATIONS

When radio waves are propagated, it is customary to experience problems caused by certain atmospheric conditions. These problem-causing conditions results from a lack of uniformity in the earth's atmosphere. Many factors can affect atmospheric conditions either positively or negatively. Before we proceed further here, it is pertinent to clearly examine the composition of earth's atmosphere.

The earth's atmosphere is divided into three major separate regions. These are troposphere, stratosphere, and the ionosphere. The troposphere is the lowest part of the atmosphere extending from the surface up to 10km (6 miles) see Figure 1. Almost all weather phenomena takes place in the troposphere.

Temperature in this region decreases rapidly with altitude. There is formation of cloud and also a lot of turbulence because of variations in temperature, pressure, and density. All these conditions have profound effects on radio waves.

The stratosphere is located between troposphere and ionosphere. Temperature throughout this region is almost constant and there is little presence of water vapor. Because of its relatively calm nature with little or no temperature change, stratosphere has almost no effect on radio wave signals.

The ionosphere refers to the upper region of the atmosphere where charged gas molecules have been produced by energy of the sun. The degree of ionization varies with intensity of the solar radiation. It is the most important region of the atmosphere used for long distance and point-to-point communication.

The ionosphere is not a homogeneous region but consists of rather distinct layers which have their own individual effects on radio propagation. The layers of distinct interests are D, E, F_1 and F_2.

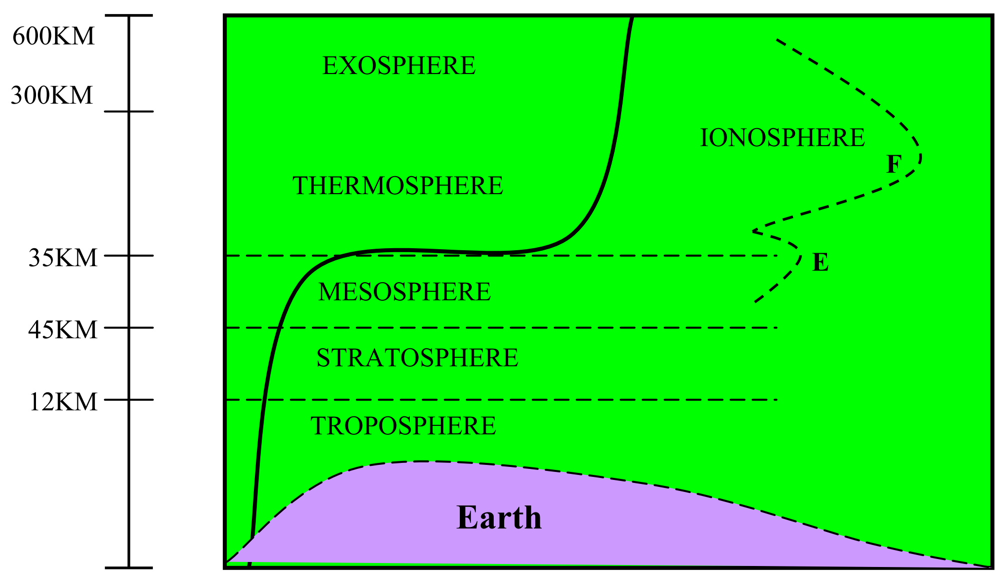

Figure 1: Layers within the Atmosphere.

ANALYSIS

Rain Attenuation

This is the interference caused by raindrops on electromagnetic signals traveling through the atmosphere. When this phenomenon occurs, the transmission is weakened by absorption and scattering of the signal by raindrop. When a raindrop causes attenuation by absorption, it technically means that the raindrop acts as a poor dielectric thereby absorbing power from the radio wave and dissipating it in form of heat loss (Figure 2). The size of a raindrop usually varies greatly, but on the average, it has a diameter of about 1mm and occur roughly 100mm apart [5].

How long a transmission will be affected by rain attenuation and how deep the attenuation will be is determined by the amount of rainfall.

Absorption of electromagnetic energy by these droplets is dependent on upon signal frequency. For waves up to 10cm wavelength, the absorption is negligible. This is because rain attenuation increases rapidly with an increase in frequency. Also, precipitation in the atmosphere has its greatest effect on higher frequency (H.F.) range signals. Frequencies in the H.F. range and below show little effect from this condition. In a simple arithmetic form, rain attenuation can be calculated from the ratio of power flux "IN" [$P_{in}(f)$] to the power flux "OUT" [$P_{out}(f)$]. This can be written as:

$$P_{out}(f) = P_{in}(f)\, e^{-\beta r}$$

where β = reciprocal of the range.

Expressing it in decibel form,

$$\text{LOSS} = 10 \log \frac{P(o)}{P(r)} = 4.434\alpha r \ \text{dB}$$

The value 4.34α is called specific attenuation (γ). This specific rain attenuation γ which is usually expressed in dB/km can be calculated from E.M theory if the drop size and shape distribution of the rain are known. But it is easier to take the standard model based on rainfall rate,

$$\gamma = aR^{b} \ \text{dB/km},$$

where a and b are coefficients for both vertical and horizontal polarization provided in Table 1 and Figure 3 as presented by Mike, Willis, et al. [5].

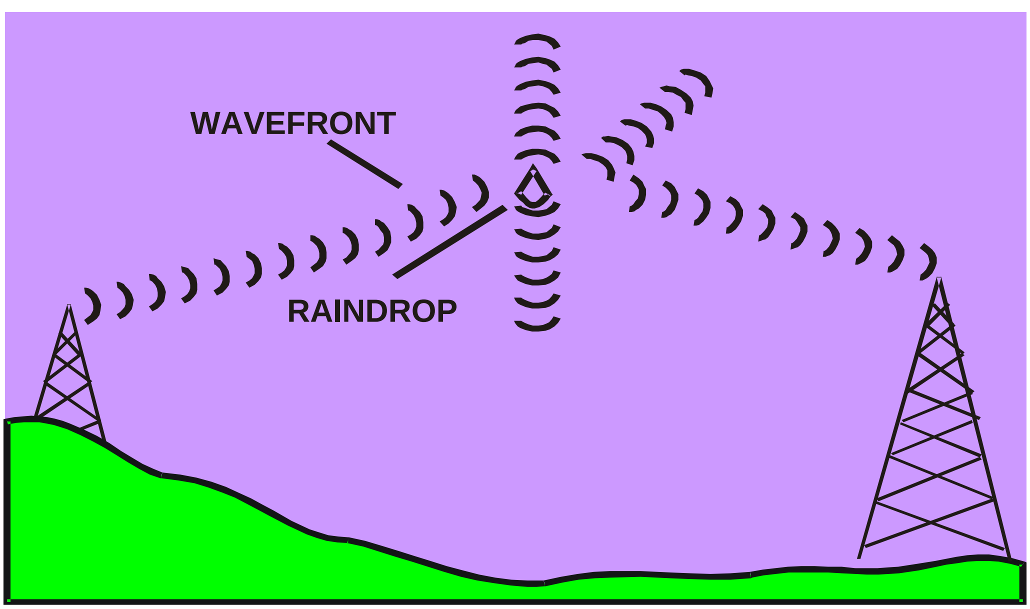

Figure 2: Radio Frequency Energy Loss from Scattering.

Table 1: Standard Rainfall Model

F (GHZ)	A	B
1	0.0000387	0.912
10	0.0101	1.267
20	0.0751	1.099
30	0.187	1.021
40	0.350	0.939

Note as shown above that "a" increases with frequency while "b" varies less, confirming that rain attenuation is much higher at high frequencies.

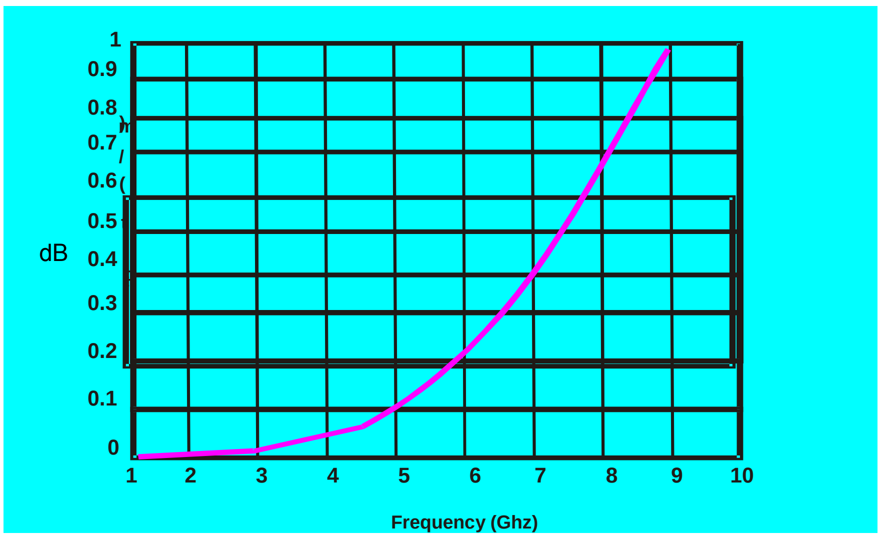

Figure 3: Attenuation Due to Rain. (Attenuation in dB Vs frequency)

<u>Tropospheric Ducting</u>

Tropospheric ducting is a phenomenon that is brought about as a result of a dramatic increase in temperature at higher altitudes. Under normal atmospheric conditions, the warmest air is found near the surface of the earth. The air gradually becomes cooler as altitude increases. At times, unusual situations may develop in which layers of warm air are formed above layers of cool air. This condition is known as "temperature inversion".

This temperature inversion causes ducts of cool air to be sandwiched between the surface of earth and a layer of warm air [7]. Now, if a radio wave enters the duct at a very low angle of incidence, VHF and UHF transmission may be propagated beyond normal line-of-sight. When ducts are present as a result of temperature inversion, propagation ranges of VHF and UHF are extended (Figure 4).

This extension is as a result of different densities and refractive qualities of warm and cool air. The duct acts like an open–ended waveguide. Signals trapped in it can travel thousand of miles. Indeed, there is no theoretical limit to the distance a signal can travel via tropospheric ducting.

As a result, a distant station may be heard in favor of a closer station on the same frequency band (a situation similar to "far away condition" in E.M. theory). Sometimes, conditions are such that multiple ducts are formed, bringing in distant stations from many different areas at the same time.

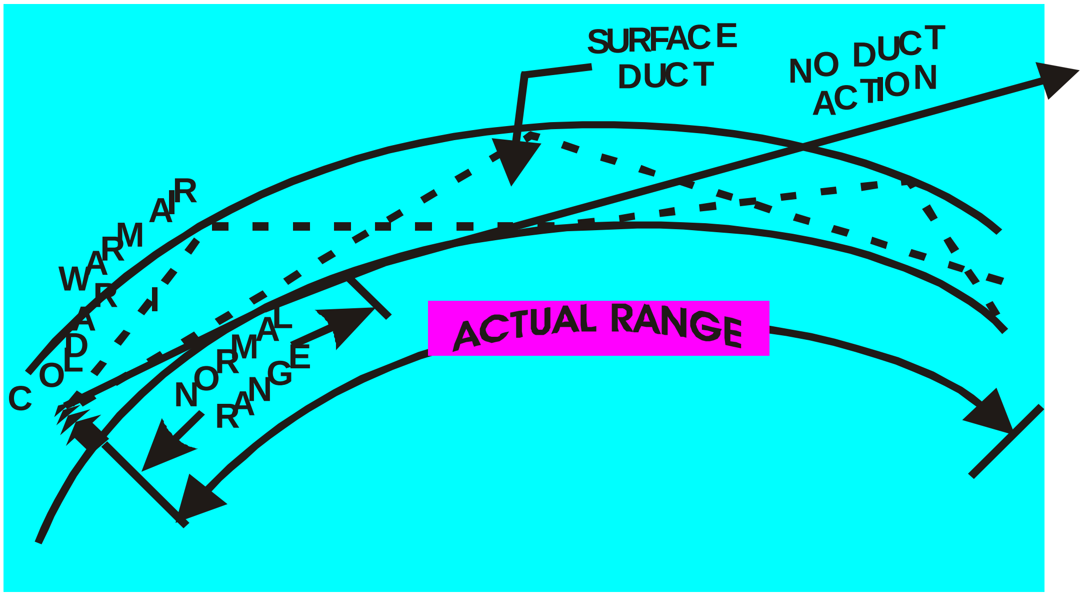

Figure 4: Duct Effect Caused by Temperature Inversion.

Ionospheric storms

Ionospheric storms are caused by particle emissions from the sun generally α and β rays. Since these takes about 36 hours to reach the earth, some warning is possible after large sunspots or solar flares are noticed. The effects of ionospheric storms are turbulent ionosphere and very erratic sky wave propagation.

The storm affects mostly the F2 layer, reducing its ion density and causing the critical frequencies to be lower than normal [4]. When storms occur, frequencies that are normally used for communication will tend to be too high; to the extent that the wave penetrates the ionosphere.

The technical implication of this in radio communication is that the range of frequencies on a given circuit will be smaller than normal. Also, communication will be possible only at lower working frequencies. In order to reduce storm effects, lower frequencies should be used where possible. Since higher frequencies are most affected by these storms.

SUDDEN IONOSPHERIC DISTURBANCE

Sudden ionospheric disturbances (SID) are caused by solar flares which are gigantic emissions of hydrogen from the Sun. Such flares are sudden and unpredictable, but more likely during peak solar activity than when the Sun is quite. X-ray radiation accompanying solar flares tremendously increases ionization density down the D layer. This layer now absorbs signals that would normally go through it and be reflected from the F layer.

The technical implication of this is that short wave radio signals (in the H.F. range) are absorbed by the increased particles in the low altitude ionosphere causing a complete blackout of radio communications. These fadeouts lasts for a few minutes to few hours. Radio operators listening during this time may believe his or her receiver has gone dead.

SPORADIC “E”

This is associated with the formation of highly ionized particles or “clouds” in the E region of the ionosphere at altitudes between 50 and 70 miles (Figure 5). It is interesting to note that after almost 70 years of the study of sporadic E, its exact cause is still not known and its occurrence can not be predicted. However, sporadic E is known to vary significantly with latitude. Sporadic E clouds are usually fairly small in size, but larger clouds or multiple clouds often form during substantial openings.

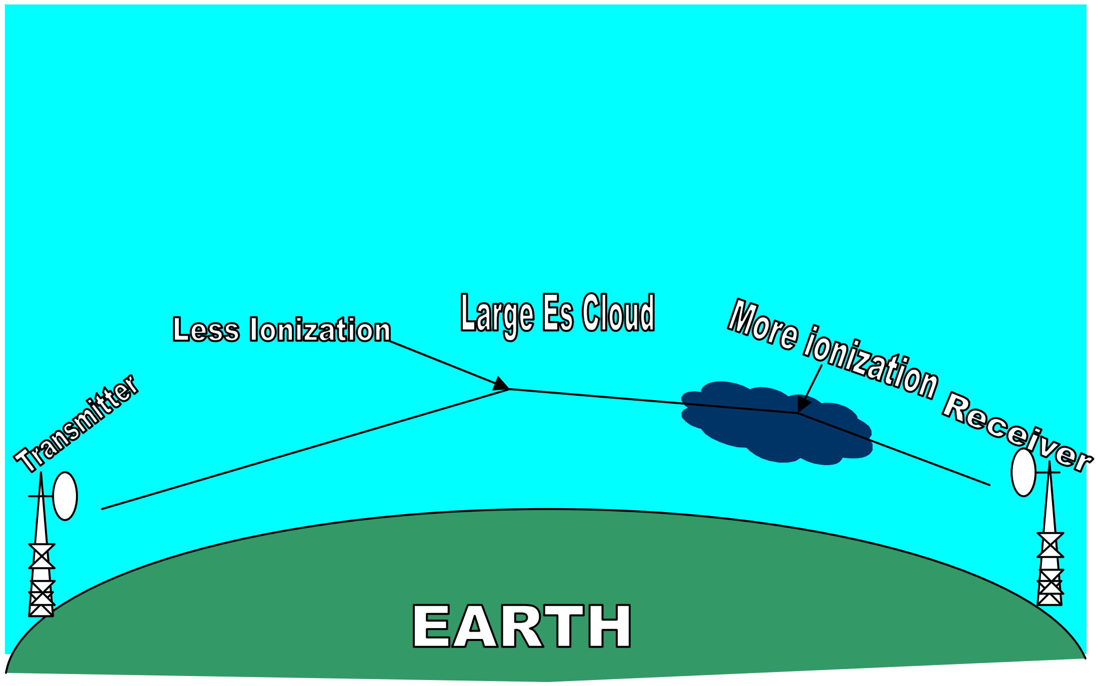

Figure 5: Illustration of Sporadic "E" Cloud.

DISCUSSION

It is evident from the analysis so far that radio waves are always subjected to certain unavoidable mitigating effects when propagated through the atmosphere. The propagation capacity is determined by atmospheric conditions at the time of transmission. At times, propagation distances are greatly extended. While in some cases they may be reduced or totally eliminated.

Irrespective of the nature of atmosphere, radio waves must be propagated on daily basis. Since telecommunication is part of the human daily routine, for effective passage of information, business transactions, entertainment, etc., in order to ensure effective signal propagation in the presence of some atmospheric phenomenon, the following solutions are suggested based on occurrence of different events (Table 2).

As contained in Table 2, the ability to forecast space weather conditions at any point in time is a pre-requisite in proffering solutions to atmospheric hazards to radio wave signals. However, in some cases engineering solutions to problems may be very costly and almost impossible to implement.

When properly harnessed, significant economic and societal benefits will be realized if designers of emerging technology can:

(i) anticipate the properties of space weather to which the hardware will be subjected.

(ii) Depend on accurate and timely predictions of space weather.

(iii) Take advantage of post–event analysis to determine the source of system anomalies and failures and build a database for future planning.

CONCLUSIONS

Communications at all frequencies are affected by space weather. H.F. radio wave is more routinely affected because its frequency depends on reflection from the ionosphere. Ionospheric irregularities contribute to signal fading, highly disturbed conditions, extension of propagation range, etc.

Table 2: Suggested Solutions to Atmospheric Hazards to Radio Waves.

S/N	EVENT	CAUSES	TYPICAL DURATION	EFFECTS	SUGGESTED SOLUTION
1	Rain attenuation (γ)	Rain, Fog	Few minutes to 70 hours	Weakening of RF signal. Absorption and scattering of radio waves	Upon transmission, radio wave signals could be boosted by increasing its transmitting power. This will compensate for possible attenuation caused by weather precipitation.
2	Tropospheric Ducting	Temperature Inversion	Indeterminate	Propagation Range of UHF & VHF signal is extended beyond line of sight.	Measure duct boundaries to know appropriate signal to be transmitted. Since lower duct boundaries allows higher freq. to be transmitted perfectly (and vice versa).
3	Sudden Ionospheric disturbance	Emission of Ultraviolet & X- ray	20 minutes to few hours	Complete blackout fading of radio communication (short fadeout)	Avoid transmission during peak solar activity. Preferably, transmit at nights, since SID does not occur at night.
4	Ionospheric storm	Emission of α and β rays from the sun	2-4 days	Drop in signal strength, erratic sky wave propagation, and turbulent ionosphere.	Increasing the critical frequency of the signal. Also if possible, frequency adjustment can be made. Proper monitoring of transmission.
5	Sporadic E	Formation of wind shear, thunder storm & cosmic debris.	Few minutes to few hours	Preventing long distance HF communication, multi-path problems, and delay in arrival time.	The MUF should be adjusted accordingly to counter the effects of Es. Since the amount of signal refraction caused by Es depends on the intensity of ionization and signal frequency.

Telecommunication companies increasingly depend on propagation of higher frequency radio waves that penetrates into the ionosphere and are relayed via satellite to other locations. These signal properties can be changed by atmospheric condition so that they can no longer be accurately received, a situation that can lead to catastrophe in some critical cases like search and rescue efforts, military operations, etc.

The ability to carefully observe and monitor conditions of the atmosphere and characterize, in detail, the nature of problems, would allow forecasters to provide timely warnings and forecast likely weather events. These accurate and timely forecasts will give telecommunication operators the opportunity to have proper planning and make the necessary proactive decisions based on available database information. This investigation is recommended for further research work to cater to other atmospheric effects not highlighted in the current study.

REFERENCES

1. Adegoke, A.S., Ezebuiro, I.I., and Ogunlewe, A.O. 2007. “RF Signal Interference on Wireless Communication System”. *Journal of Research in Engineering*. 4(2):39-43.

2. Cummer, S.A. 2000. "Modelling Electromagnetic Propagation in the Earth – Ionosphere Waveguide". *IEEE Transactions on Antennas and Propagations*. 8(9):1420-1429.

3. Cummer, S.A. and C. Zhenggang. 2005. "Broadband VLF Measurements of Lightning-Induced Ionospheric Perturbations". *Geophysical Research Letters*. 32:L08804.

4. Kennedy, G. and B. Davis. 1999. *Electronic Communication System, 4th edition.* Tata Mc-Graw Hill Publishing: New York, NY.

5. www.mike-willis.com/Tutorial/PF10.htm

6. www.humanuniverse.com/anttheory1.html.

7. www.tpub.com/neets /book10/40j.htm.

8. www.ofcm.gov/nswp-sp/text/d-sec2.htm.

ABOUT THE AUTHOR

A.S. Adegoke, M.Sc., MNSE, is a postgraduate researcher in the Department of Computer Engineering, Yaba College of technology, Yaba-Lagos, Nigeria where he serves as a Lecturer. He holds a B.Sc.(Hons) and M.Sc. in Electronics and Computer Engineering, earned in 1996 and 2002, respectively, from Lagos State university. He is a writer and publishes widely in journals and conferences. He is currently working towards his Doctoral degree in the area of radio wave propagation.

SUGGESTED CITATION

Adogoke, A.S. 2008. "Mitigation of Effects of the Atmosphere on Radio Wave Propagation". *Pacific Journal of Science and Technology*. 9(1):5-12.

Pacific Journal of Science and Technology