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Microwave Signal Attenuation in Harmattan Weather Along Calabar-Akampkpa Line-of-Sight Link

O. E. EYO, A. I. MENKITI, S. O. UDO
Department of Physics, University of Calabar, Calabar-NIGERIA

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Abstract

Line-of-sight (LOS) attenuation at 6.44GHz was measured at Calabar (4° 58′ N, 8° 17′ E) for ten months (Aug '93-May '94) using the Nigerian Telecommunications radio signal. The measurement was made with the intent of highlighting microwave signal attenuation in Harmattan weather conditions. The results are presented in terms of mean signal level and fog attenuation, fade rate distribution, fade depth distribution and scintillation index. The observed attenuation values due to Harmattan (fog) and the calculated (using Altshuler's model) are in fairly good agreement. Also, the statistics of fade distribution show fast fading of longer duration of the order of 15 to 38 fades per hour during this period (Harmattan). This shows that microwave LOS link in this region and regions with similar climatic characteristics are prone to signal degradation as well as fading in the Harmattan season.

Key Words: Harmattan, Radio signal, Fog attenuation, Statistics of fade, Calabar.

1. Introduction

The presence of the various forms of precipitation such as rain, snow, cloud and fog in a radio wave path are always capable of producing major impairments to terrestrial communications. According to Gibbins [1], the hydrometeors can introduce significant attenuation, together with a degree of depolarization, through their ability to absorb and scatter radio waves.

The effects of precipitation on the propagation of radio waves have been studied by a number of workers [1-11], among others. Many results of these studies have shown serious attenuation at frequencies in the micro wave region above 10 GHz. Attenuation is less pronounced at frequencies around 3 GHz. However, to a communication system designer, attenuation due to precipitation and atmospheric gases at frequencies above 1 GHz is important.

This work was carried out to assess the extent of signal attenuation noticed from the annual routine monitoring of the received signal level recorded at the carrier station of the Nigerian Telecommunications (NITEL) situated in Calabar (4°58'N, 8°17'E). A preliminary investigation of the recorded data of the line-of-sight (LOS) link revealed severe signal degradation during the months of November through February with the months of December and January showing very high fade margins. In the West African sub-region, December through January is a period that is referred to as Harmattan. The Harmattan period is the period when cold and dust-laden North-East trade winds from the Saharan desert keep the atmosphere over the entire West-African sub-region heavily overcast for days, with characteristic hazy and cloud free weather conditions with low relative humidity, degradation of visibility, depletion of solar radiation, attenuation of radio signals and discomfort to the respiratory system and associated ailments [12]. However, it should be noted that the area under study is close to the Atlantic Ocean, so the effect of the Harmattan there is not as severe as in the Northern part of the country, but does still cause significant effect on radio signals. The Harmattan period falls within the dry season [12-13] when a lot of bush burning activities take place; hence the contribution to the hazy condition by bush burning is not unexpected. This preliminary assessment of the attenuation along the link is indicative of fog attenuation statistics.

Most of the work cited on the effects of precipitation on the propagation of radio waves dwell on statistics of rain attenuation. Fog, unlike rain has not enjoyed the benefit of numerous studies and the statistical effects are relatively unknown. A few fog attenuation measurements have been carried out by Haroules and Brown [2] at 8.17 and 35 GHz, Lo et al. [4] at 35 and 95 GHz and by Altshuler et al. [5] at 15 and 35 GHz. With the exception of Altshuler [14], none of the reports presents comprehensive statistics of fog attenuation. Altshuler [14] has developed a simple expression for calculating fog attenuation in the microwave and millimeter wavelength regions. The expression, given in terms of fog density M (gm^{-3}) is

$$A = M\left(00.6f + \frac{11.2}{f} - 0.022T - 1347\right)\ \mathrm{dB\ km}^{-1}, \tag{1}$$

where the fog density M is given in terms of visibility V, (in km) by

$$M = \left(\frac{0.024}{V}\right)^{1.54}\ \mathrm{g}^{-3}. \tag{2}$$

From available literature, no work seems to have been done on the effect of this peculiar phenomenon, the Harmattan, on the propagation of radio waves. So this work sets out to find out the statistics of Harmattan (fog) attenuation and to see the extent of signal degradation and fading caused by it. This, we hope, will be useful to the communication system designers, especially, in designing appropriate systems for the region.

2. Terrain Profile and System Characteristics of the Link

The line-of-sight microwave link used for the study is situated between Akamkpa, located at Latitude 4° 12′ N; Longitude 8° 17′ E (Transmitting end) and Calabar located on Latitude 4° 58′ N; Longitude 8° 17′ E (Receiving end) over a path length of 43 km. Figure 1 shows the path profile between Akamkpa and Calabar LOS link. The ray path is prepared from the profile graph of [15] using the effective earth radius factor k = $^4/_3$.

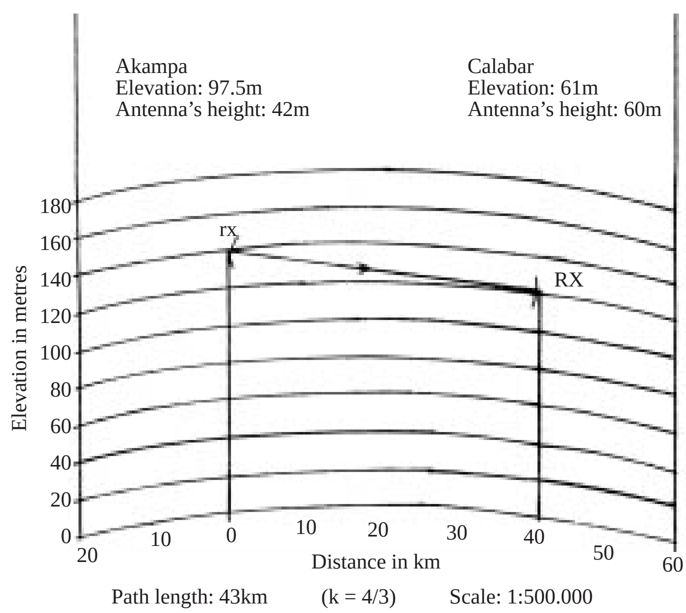

Figure 1. Terrain Profile between Akamkpa and Calabar LOS link

The important features of this link are that it is a short hop and is surrounded by no hills as the area is characterized with low terrain. It is also evident from Figure 1 that the ray reaching the receiving antenna has sufficient Fresnel zone clearance as there are no obstructions between the transmitting and receiving antennas.

Table 1 shows the system characteristics of the micro wave link.

Table 1. System characteristics of Calabar-Akamkpa LOS link (after NITEL).

System parameters	Transmitting station	Receiving station
Transmitting Frequency:	6.44 GHz	6.44 GHz
Antenna's Type:	Parabolic dish of 1.4m diameter with horn feed	Parabolic dish of 1.4m diameter with horn feed
Antenna's gain: (1.4m diameter, 55%)	35.7 dB (linear)	35.7db (linear)
Standard Power received:	-	-62 dBm
Antenna's Height	42m	60m

3. Data Base

The radio signal data used for the present analysis are for the period August 1993 to May 1994. The field strength variations were recorded for both diurnal and seasonal behaviour at the receiving end, Calabar once a week on 24 hours basis. The recording was carried out manually at a time constant of 60 seconds. According to Eyo [16], the period was classified into three seasons, namely:

(i) period before fog (PBF) - August to October
(ii) period of fog (FOG) - November to February
(iii) period after fog (PAF) - March to May

Periods PBF and PAF are meant to provide baseline data on the fading pattern of the link.

Information on some meteorological parameters like air temperature, relative humidity and water vapour pressure during the fog season (Nov-Feb.) were obtained from the daily visibility records of the Federal Civil Aviation Authority (FCAA) at the Calabar airport, situated about 2.5 km from the site of the radio signal measurement. Figure 2 shows the distribution on the number of occurrences of fog during the study period.

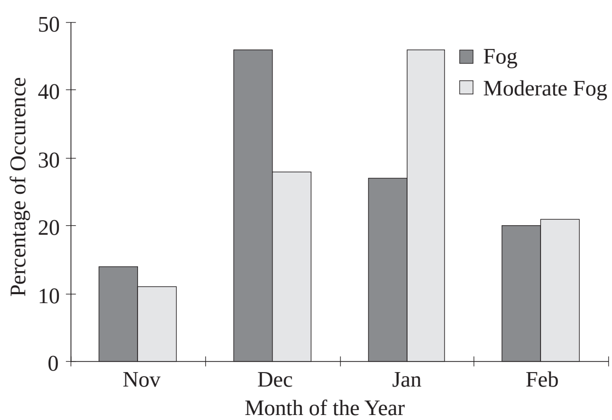

Figure 2. Distribution of fog observed at Calabar between Nov'93 and Feb'94.

Although a ten-month data seems inadequate for any major climatologically related conclusion to be drawn, extensive comparison of data on meteorological parameters mentioned above in terms of duration and spread, within the West-African sub-region, showed that the data presented here are quite representative of this region climate. Hence the small duration posses no major limitations to the conclusions derivable.

4. Results and Discussions

The recorded signal strength data were statistically computed into hourly averages for each month. Using the hourly averages, attenuation values pertaining to fog and propagation characteristics of the link were obtained.

4.1. Mean Signal level and Fog attenuation

The diurnal variations of the mean signal level for the three classified seasons are shown in Figure 3. To arrive at attenuation values pertaining to fog, the difference in field strength between FOG and PBF seasons (called type 1 attenuation) and that between FOG and PAF seasons (called type 2 attenuation) are computed. Figure 4 shows the diurnal variation for type 1 and type 2 attenuations. Fog attenuations are also obtained by calculation using Equations (1) and (2). The results are shown in Table 2.

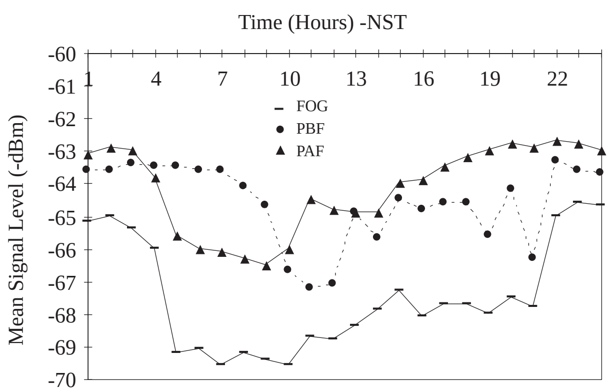

Figure 3. Diurnal variation of mean signal level for all seasons.

Table 2. Calculated fog attenuation.

Transmitted Frequency (GHz): 6.44			
V = 400m M = 0.013 gm^{-3}		V = 999m M = 0.0032 gm^{-3}	
Temperature/Attenuation		Temperature/Attenuation	
22.4 °C	24.0 °C	22.4 °C	24.0 °C
3.7 dB	3.3 dB	0.92 dB	0.80 dB

Figure 3 shows that during the months of the Harmattan (FOG), the amplitude variation of the signal is much higher compared to periods before and after the Harmattan (i.e. PBF and PAF). In the months of Harmattan, the signal is 6.5 to 8 dBm below the normal level between 0500 and 1200 hours, and between 1300 and 2100 hours, the decrease in signal is from 5 to 6 dBm. The variation however, appears low between 2200 and 0400 hours, varying from 2.2 to 4 dBm below the normal signal level.

In PBF months, the signal level is almost steady at -1.5 dBm between 2100 and 0700 hours, and for the rest of the day, the signal fluctuates between - 2 and -5 dBm. In PAF months, the signal level is also steady between 1800 and 0300 hours, having a variation of only 1 dBm below the normal level. For the rest of the day, the level drops between -1.5 and -4.5 dBm.

The calculated fog attenuations from Table 2 lie between 0.9 and 3.7dB at the lowest fog temperature of 22.4 °C, whereas the observed attenuations for both type-1 and type - 2 attenuations are between 1 and 6 dB, as seen in Figure 4. These results show that the lower values of attenuation representing higher visibility value of 999 m for moderate fog seem to be in good agreement, while the upper values representing the lower visibility value of 400 m for moderate fog show a disparity. This disparity is not unexpected. It may be attributed to the fact that measurement of visibility is very subjective. The observed attenuation with values above 4 dB implies the occurrence of thick fog with visibility value of less than 400m.

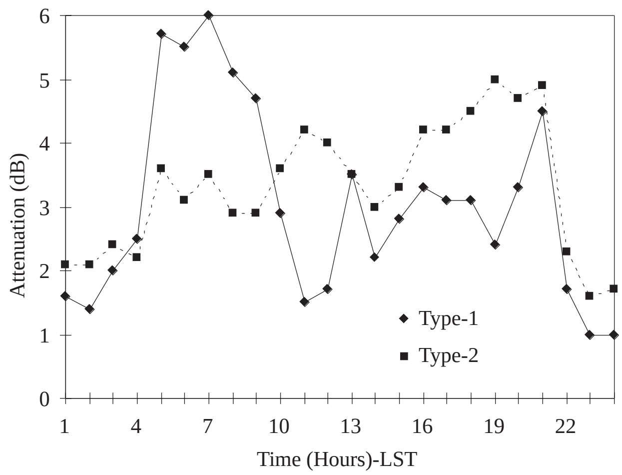

Figure 4. Diurnal variation of Fog Attenuation.

4.2. Fade rate

Fade rate is the number of fades in a specified time interval. In microwave communication, fade rate limits the digital data transmission rate and also defines the size of the irregularities in the atmosphere. From the daily hourly fade rates, the average fade rate per hour for each month is computed. Figure 5 shows the diurnal variation of fade rates distribution. The distribution shows that the months of November and February are transitional months. This is expected as Harmattan effects are not intense in early November and late February; sometimes its effects are not felt at all. Figure 6 is drawn to show seasonal effect on diurnal variations of fade rates.

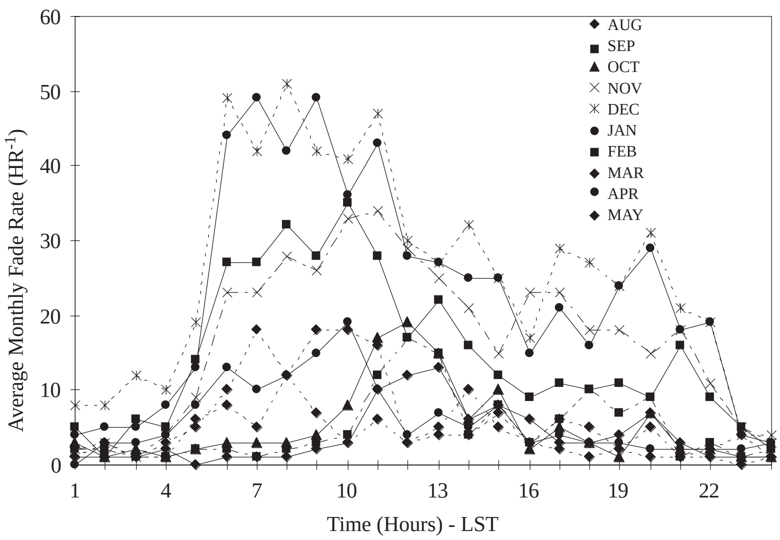

Figure 5. Diurnal variation of Fade Rate.

In the months before the Harmattan (PBF), the diurnal variation in fade rate is between 1 and 15 fades per hour; the maximum occurring from 1100 to 1300 hours and the minimum which remains fairly constant is observed during 2100 to 0800 hours. In PAF months, the observed fade rate is 10 to 13 fades per hour between the hours of 0600 and 1100, and 1 to 7 fades per hour during the day and night times. In the Harmattan months (FOG), the observed fade rate is of the order of 26 to 38 fades per hour between the hours of 0600 and 1300. This remains between 15 and 23 fades per hour during the day time and early hours of the night, exceeding the night time fade rate of 3 to 7 fades per hour.

These results show that there is very little variation in fade rate in the months before and after the Harmattan season, but prominent variation of up to 38 fades per hour in the FOG months, with maximum always occurring during morning hours. This is indicative of the presence of some atmospheric irregularities along the microwave link during Harmattan season; the effect of Harmattan is normally seen to be intensed in the monthly hours.

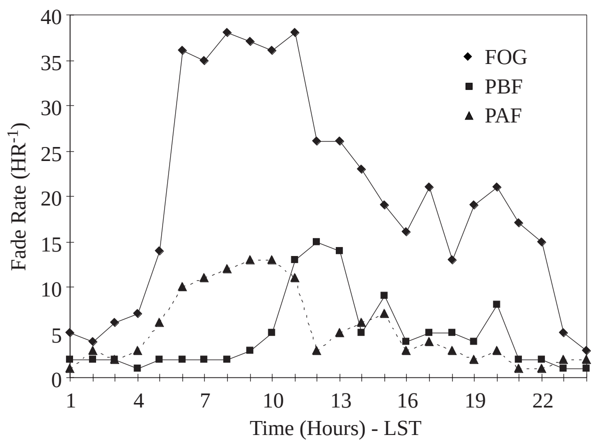

Figure 6. Seasonal Effect on Diurnal variation of Fade Rate.

It could also be observed that maximum fades always occur during morning hours for all the three seasons. This may be because during the transition period, atmospheric layers, which are usually present, start to move up while heated air mass close to the earth's surface starts ascending and causes appreciable fading to tropospheric propagated signal. The decrease in the observed fade rate during day time hours may be due to the fact that the atmosphere is well mixed.

4.3. Fade depth

The atmospheric irregularities along the radio rays path usually affect the velocity of propagated signal and consequently fading occurs. Fading is usually expressed in terms of fade depth. This is the difference between the maximum and minimum signal strength over a certain interval of time, usually over a very small interval. In this work, the hourly fade depth was computed for each season from the hourly averages of the signal strength. Figure 7 shows the distribution of seasonal effect on diurnal variations of the hourly fade depth.

From Figure 7, fade depth fluctuates round the clock giving an average fade depth of 3.5 dB in the PBF and PAF seasons. In the FOG season, fade depth values are much higher, varying between 5 and 10 dB on the average, with the maximum values occurring between 1600 and 1900 hours and the minimum at night time.

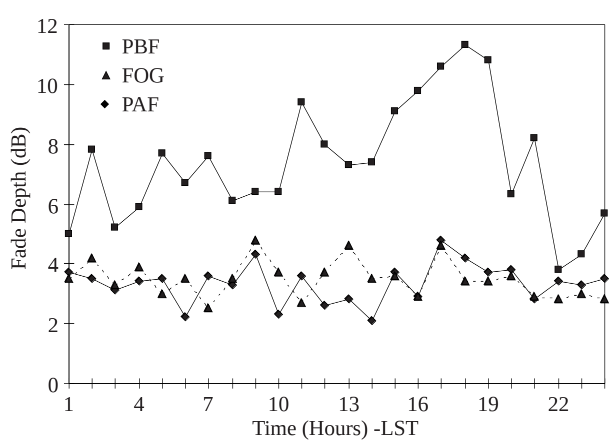

Figure 7. Seasonal Effect on Diurnal variation of Fade Depth.

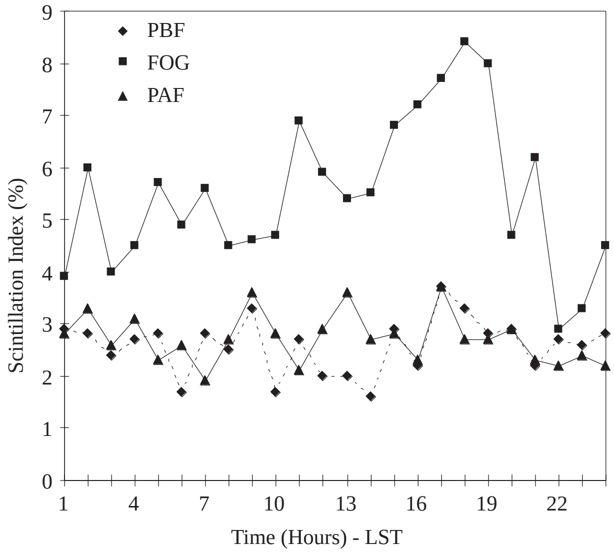

Figure 8. Seasonal effect on Diurnal variation of Scintillation Index.

4.4. Scintillation index

The intensity of fluctuations in signal strength is measured by a quantity called the scintillation index (S.I). The scintillation index was calculated for each season using the expression

$$S.I\,(\%) = \frac{Power_{\max} - Power_{\min}}{Power_{\max} + Power_{\min}} \times 100 \tag{3}$$

Figure 8 shows the distribution of seasonal effect on diurnal variation of the scintillation index observed for the three seasons.

For all seasons, scintillation occurs round the clock. During the seasons PBF and PAF, it varies from 1.5 to 3.5% while in the FOG season, scintillation index is observed to vary from 3 to 8%.

5. Conclusion

This work has provided the statistics of fog effects on a line-of-sight (LOS) microwave link situated in south - eastern Nigeria for the first time. For the 10-month database of the link, the calculated fog attenuation has been found to give fairly good agreement with the experimental results. From the propagation characteristics of the link, the various statistics of fading caused by fog along the link show fast fading of longer duration of the order of 15 to 38 fades per hour; higher fade depth values varying between 5 and 10dB, and a scintillation index of 3 to 8%.

Comparison of these statistics with those of the seasons before and after fog shows that the Calabar-Akamkpa microwave LOS link is prone to signal degradation as well as fading in the Harmattan season.

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