EXPERIMENTAL STUDIES ON MILLEMETER WAVE PROPAGATION IN ARID CLIMATE: SCINTILLATION AND MULTIPATH FADING

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INTRODUCTION

A field study on wave propagation covering a wide range of the electromagnetic spectrum has been actively running for the last four years in the city of Riyadh, Saudi Arabia. The region can be considered a typical arid climate where the rate of evaporation is higher than the rate of precipitation. The study involves the operation and continuous, computerized, monitoring of two microwave radiolinks operating at 12 GHz, three millimeter wave links with radio frequency of 40 GHz, and an infrared link with 0.88 μm wave length. A meteorological station is operated and monitored as well.

The first set of data obtained by measuring the received signal variations on the 40 GHz links and on the 0.88 μm infrared link were reported in (1). Such data included the analysis of several sand storms and rain events. More details on the parameters of sand storms were reported in (2,3).

This paper presents new data and analysis of scintillation and fading observed on various links during the last four years. Amplitude scintillation has been measured on 14-km, 40-GHz links, with average path clearance of 50 meters along the path. Various types of amplitude scintillation vis., i) dry, ii) quasi-wet and ii) wet scintillation are presented and compared. Amplitude scintillation distributions are obtained and reported for various types of scintillation.

Fading of signal level over line-of-sight links strongly depends on the hop length, frequency, terrain and climate. For short hops the probability of occurence of deep fades becomes diminishingly small. However, since an extended hop length of 10 to 20 km is possible for regions with rare rain activities, clear weather fading can affect the link reliability in a similar way as rain and sand storms. Fade events were observed during the course of measurements with fade durations ranging from a fraction of a minute to several hours. The recorded fade shapes indicates the possibility of power fading as well as multipath fading. Atmospheric layers, ground reflections and strong refraction gradient are among possible mechanisms of such fades.

A complete record of fade events observed during the year 1987 is given with statistical analysis of fade depth. It is particularly shown that fade depth did not exceed 6 dB, with strong durinal dependence, and that scintillation often accompanies fading. Monthly variations and amplitude probability density are reported as well.

MEASURED SCINTILLATIONS

During the period from January to April 1986, more than 35 events of amplitude scintillation have been recorded on the 40 GHz, 14 km path link. It is believed that the selected recording period is representative of other similar events which occurred during most of the year. Three main types of scintillations were observed, viz:

i) dry type; which occurred during clear atmosphere, i.e. neither rain, fog nor duststorms, Fig.(1).

ii) wet type; which occurred simultaneously during rain-induced fade, Fig.(1).

iii) quasi-wet type; which occurred between successive rain-induced events, or just before or after the rain event, Fig.(1).

Several investigators have reported dry amplitude scintillations on a 36 GHz, 4 km links (4,5) and on low elevation angle, 4 to 28 GHz satellite paths (6). Wet type has been also observed by Ortigies (7) on 11 GHz satellite links. However, quasi-wet type on 40 GHz, 14 km link is reported here for the first time.

Comparison of the Three Types

Table 2 presents a summary of comparing the peak-to-peak amplitude, rate and duration for the various types of scintillations.

TABLE 1 – Comparison between peak-to-peak amplitude, rate and duration for the various types of scintillations

Type	Peak-to-peak amplitude (dB)	Rate (Hz)	Duration (min)
Wet	0.5 to 3.0	0.2	5 to 200
Quasi-wet	0.5 to 6.0	< 0.1	30 to 100
Dry	1.0 to 5.0	< 0.1	5 to 150

It is noted that the rate of wet type is relatively higher than the other two types and generally lower than the value (0.37 Hz) reported by Vilar and Mathews (9). The peak-to-peak amplitude range of the quasi-wet type is twice as much as the wet type, and it is relatively larger than the dry type. This may be attributed to the effects of increasing water vapour and speed of updrafts and down drafts during rain cell development which can cause more turbulence.

This is supported by an observation of extreme 6 dB peak-to-peak of scintillation fading in a day just before raintall. In addition, sun shines usually between rain storms heating earth rapidly which results in steep changes of potential temperature (θ) and specific humidity (Q) with height (H). This leads to greater variation of refractive index packets which follows the velocity fields variation. However, in some cases, such as neutral atmosphere ($d\theta/dH$ = constant, i.e. $dT/dH = 0.98°k/100$ m), strong velocity variation of air may exist with little effect on refractive index. The dry type occurred mostly in early morning and increases with sun rise. This is probably because tropospheric heat exchange is greatest during such period. Similar fading of about 3 dB peak-to-peak has been reported on a hot day with moist ground for 116 GHz, 1.4 km link (8).

Ortiqies (7) showed that the mathematical relationships and power spectra of wet type scintillations are the same as those of dry, and assumed that tropospheric turbulence is the predominant process. However, our measurements indicates that there is a difference in the value of frequency for both types. A distinction has been claimed between clear air turbulence (CAT) and turbulence associated with rainstorms, which unlike CAT, is characterized by an increase in the vertical transport of moist/warm air parcels. Consequently, vertical cross-path wind speed may be increased leading to higher rate of fading. Wet type scintillation can be considered as a result of two scattering processes (1) from atmospheric turbulence, (2) from rain drops. The first scattering is in the direction of propagation while the second is isotropic. However, measurements show that generally the peak fading of wet type is small in comparison to that from atmospheric turbulence. Similar findings have been reported for rain induced scintillations on 11 and 30 GHz satellite down links. Moreover, such a result is supported by the general low rainfall rate (of the order of 30 mm/h or less) in the City of Riyadh.

Amplitude Statistics:

To study the behaviour of the three various types of amplitude scintillations, and assess a model for predicting communication performance with regard to scintillation phenomena, it might be useful to quantify the amplitude distribution based on a relatively longer-term than usually carried in literature (months rather than minutes). Figure (4) depicts the percentage of time p% against A_p using the least squares method. The best fit models (least residuals sum of squares) for the three types are given in Table 2. It is found that lognormal distribution model of peak fading A_p (dB) can adequately describe both wet and dry types, which is in agreement with weak-scattering theories. Similar lognormal distribution has been reported in Atlanta, Georgia, for frequencies of particular interest in imaging system (116 GHz to 230 GHz) and 1.4 km path (8). Also, it is claimed (9) that apart from Rayleigh distribution of multipath fading, the distribution of small signal fluctuation during non-multipath periods is lognormal. On the other hand, the quasi-wet type is best described by exponential distribution, which provides probabilities for the time between successive events occurring in a Poisson process.

TABLE 2 - Best fit model for the three types of amplitude scintillations

Scintillation	Model	Equation
Dry	Lognormal	$p\% = (\frac{0.07}{A_p})\exp[\frac{(\ln A_p - 7.4)^2}{0.06}]$
Quasi-wet	Exponention	$p\% = 2.75 \exp[-78.6 A_p]$
Wet	Lognormal	$p\% = (\frac{0.05}{A_p})\exp[\frac{(\ln A_p - 2.4)^2}{0.06}]$

Scintillation measurements with OTS satellite and 3 m and 8.5 m earth station antennas in Germany (7), indicated that the mean amplitude of both wet and dry types can not be described by Gaussian distribution, and is approximated by:

$$p(A) = \int_0^\infty p(A,\sigma) \cdot p(\sigma) d\sigma$$

where, $p(A,\sigma)$ is a normal distribution of amplitude A(dB) for a given standard deviation σ, and $p(\sigma)$ is lognormal distribution function for 1 min distribution.

As is shown in Fig.(1), the wet type scintillation is superimposed on rain-induced fades. the later has been measured on the same link, and can be modelled by a power law:

$$P(F)\ \% = 6.69\ F^{-1.183}$$

where P(F) is the percentage of the year during which F is exceeded and F is the rain-induced fade depth in dB. Consequently, beside its effects of degrading usable bandwidth and BER, scintillation distribution modifies the overall distribution. Since both are occurring during the same time, then the overall probability is the sum of the two distributions. The contribution of wet scintillation to the overall time percentage is of the order of 10% for the indicated amplitude range (3.0 dB peak-to-peak), which may cause a complete outage if F is less than the fade margin by few dB's.

Duration Distribution

In this section new measurement of duration distribution of scintillation on MMW terrestrial link in arid climate is presented and investigated. Duration distribution is useful for assessing MMW link performance besides amplitude distribution of scintillation. A larger number of scintillations of short durations have different effects on communication links than fewer scintillations of long duration. For example, analog or television signal may not be affected seriously by short duration outages which are not tolerable for digital service.

Duration is defined here as the time interval during which scintillation amplitude falls within given limits of amplitude thersholds. In this measurement, durations D are quantized in 4 minutes intervals from 4 minutes to 200 minutes. A group of amplitude scintillation which last for an interval (multiples of 4 minutes) is considered as an event. The number of events $N(D,A_p)$ within amplitude levels 0.5 to 1.0 dB, 1.0 to 2.0 dB, and 2.0 to 3.0 dB are counted, and their time invervals are measured.

Table 4 gives the total number of events $N_t(D,A_p)$ with duration D equals to or exceeds 4 minutes per time of observation, at different amplitude A_p for dry, wet and quasi-wet scintillation.

TABLE 3 - Total number of events with duration D > 4 minutes

Scintillation	$N_t(D,A_p)$ with the shown levels		
	0.5 to 1.0 dB	1.0 to 2.0 dB	2.0 to 3.0 dB
dry	330	90	15
wet	60	80	20
quasi-wet	85	50	-

It is seen that the number of events $N(D,A_p)$ increases with the decrease in scintillation amplitude A_p. However, an exception is the wet type, which shows fewer number at A_p = 0.5 to 1.0 dB than that at increased level of A_p = 1.0 to 2.0 dB. This exception may be attributed to the steep sides of rain-induced fade where most of small amplitudes of scintillation are usually observed.

MULTIPATH FADING

Fading of the received signal for periods of minutes have been observed on the millimeter wave link. The fade was repeated for hours with occasional enhancement, or scintillation, or with power fading. The shape of this fade indicates the possibility of multipath propagation due to atmospheric layer with strong refraction gradient or due to ground reflection. Table 4 shows the number of minutes during which fades exceed 1 to 6 dB per time of measurement and the different types of multipath fade. The average temperature and relative humidity during the period of occurrence of multipath event are also given. Months during which no events have been observed are omitted. Figure (2a - 2g) shows the percentage of time during which the fade depth exceeds abscissa for each month (February-December) of the year 1987. Figure (3) shows the distribution of the fade depth for the total period of measurements.

From the above measurement on the 40 GHz, 14 km during the year 1987, it can be seen that:

1) Multipath fade did not exceed 6 dB.

2) Multipath propagation occurred during the period from midnight to noon time. Probably non-uniform distribution of temperature and relative humidity occurred in this time.

3) Scintillation occurred simultaneously with multipath fade. Signal enhancement and power fading are relatively rare.

4) The probability of multipath propagation is higher in winter (November, December and February) than in summer (March to June). this may be explained by the fact that the winter is characterized by relatively moderate temperature (of the order of 15°C) and high relative humidity (50 to 78%). On the other hand, summer is hot (20 to 48°C) but dry.

5) For 2% and 1% of the time, multipath fades may exceed 2.8 dB and 4.8 dB respectively.

6) The distribution of multipath fade may be described by Rayleigh distribution.

CONCLUSION

From this study, it can be concluded that in arid climate:

1. Three types of amplitude scintillation occurred; during dry climate: (dry), during rain events: (wet), and during the period in between rain evenbt: (quasi-wet).

2. The amplitude of quasi-wet type is as twice as the other two types.

3. Atmospheric turbulence is generally stronger in arid than in non-arid regions. Turbulence during wet conditions is relatively weaker.

4. The contribution of wet scintillation to the overall probability is of the order of 10% which can not be neglected when considering system reliability.

5. Although multipath fading is a hot weather phenomena, more fades were recorded in winter time. This is because winter has warm temperature and high humidity in Riyadh. Summers, although hot, but very dry.

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