EXPERIMENTAL STUDIES ON MILLEMETERWAVE AND INFRARED PROPAGATION IN ARID LAND: THE EFFECT OF SAND STORMS

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INTRODUCTION

A field study is presently underway in Riyadh city, Saudi Arabia, to study the effects of rain, sand storms and multipath-fading on millimetric wave propagation. The study involves computerized monitoring of five radio links and a meteorological station. Detailed description of the system layout, equipments and measured parameters is found in (1,2).

This paper summarizes the measured sand/dust storm parameters and its effect on the radiolinks. Nine sand storms were experienced in the city of Riyadh during the year 1987, and were observed both by the meteorological sensors and by the radio links. Our purpose of the measurements of sandstorms is twofold. First, we use the measurements to determine the prominent storm parameters which have considerable effects on wave propagation into such storms. Such parameters include 1) particle concentration, 2) particle size and size distribution, 3) refractive index of such particles, or its dielectric constant. For dry sand and dust particles, the value of permittivity is well known and the effect of dry particles on propagation is rather small. As the moisture content of sand/dust particles increases, attenuation increases markedly. The second aim of the present measurements is to compare the measured attenuation, as the millimetric-waves propagate through sand storms, with the calculated value of attenuation. Such calculated attenuation is found by using an attenuation model which relates attenuation to visibility, frequency and particle size and refractive index.

EXPERIMENTAL RESULTS

The data, local Time (LT), visibility (V_O), temperature (T), relative humidity (RH), vapour pressure (e), wind direction and speed (WD, WS) barometric pressure (p), were measured during nine duststorm events occurred during 1987 in Riyadh. Vapour concentration (w) and refractivity N_O were calculated employing the relations:

$$w = 213.6\ (e/T)\ g/m^3 \qquad (1)$$

$$N_O = 77.64(p/T) + 71.7(e/T) + 4149(e/T^2) \qquad (2)$$

where, the units of the meteorological variables are:

e (mb),

T (k),

$$P_d = p - e \text{ (mb)} \qquad (3)$$

where p_d is the dry air pressure.

Table (1) (at the end of the paper) gives the result of measurements and calculations of such radiometeorological parameters as shown in columns (1) to (10) and (11), (12) respectively. In column (13) visibility data observed at King Khalid International Airport (K.K.I.A) Meteorology station, which is about 20 km NE of K.S.U. are also given.

An interesting observation is the simultaneous occurrance of high rate of change in meteorological parameters with airborne dust. As an example, consider the blown dust event on November 11, 1987 at 7 pm, when visibility (V_O), temperature (T), relative humidity (RH), and wind speed (WS) have changed in 10 minutes as summarized in Table (2).

TABLE 2 - Meteorological changes accompanied by visibility raduction on November 11, 1987.

Parameter (y)	Change (y_1 to y_2)	Relative Changes
Visbility (km)	20 to 3	- 85%
Temperature (°C)	27 to 30	+ 11%
Relative Humidity(%)	37 to 42	+ 13%
Wind Speed (m/s)	1.5 to 7	+ 37%

Relative change/minute = $[(y_2-y_1)/10y_1].100$

After the cessation of the blown dust event, the changes in (T) and (RH) continued, but with low rate of ± 0.6% respectively. This observation emphasizes the importance of radiometeorological changes accompanied by airborne dust events.

These radiometeorological changes result in corresponding changes in the calculated water vapour concentration w(g/m^3) and air refractivity N_O which accompanied the duststorm events. As shown in column (12) of Table 1, in most events, N_O has decreased by about 1.5% within 10 minutes. The impact of such changes on millimetre wave propagation will be discussed latter.

Generally, the observed visibilities at K.K.I.A. are of the same order as those measured at K.S.U. Therefore, it can be said that the cell size of the nine duststorm events exceeds 20 km.

Table 3 gives the total number of minutes for the year 1987 during which visibility was less than the value shown in column (1). The cumulative percentage of the year is shown in column (3).

TABLE 3 - Visibility distribution (1987).

V_O (km)	No. of min./year	p%
1.25	256	5×10^{-2}
1.4	297	5.8×10^{-2}
1.6	410	8×10^{-2}
1.9	615	1.2×10^{-1}
2.8	718	1.4×10^{-1}
3.75	795	1.55×10^{-1}
5.6	871	1.7×10^{-1}
6.4	1025	2×10^{-1}

Dust Attenuation for the 40 GHz, 14 km Link:

Table 4 gives the total number of minutes per the year 1987 during which path attenuation for the 40 GHz, 14 km link was exceeded due to duststorm events. The cumulative percentage of the year is given in column (3). Figure (1) depicts such cumulative distribution. For example, path attenuation of 1.5 dB and 4.0 dB was exceeded 0.1% and 0.01% of the year respectively.

TABLE 4 - Duststorm attenuation distribution 40 GHz 14 km link

A(dB) at 40 GHz	No. of min./year	p%
0.5	1577	3×10^{-1}
1.0	788	1.5×10^{-1}
1.4	578	1.1×10^{-1}
2.0	394	7.5×10^{-2}
3.0	242	4.6×10^{-2}
3.5	105	2×10^{-2}
4.0	58	1.1×10^{-2}

Dust Attenuation for the 0.88 µm,0.75 km Link

Table 5 shows the total number of minutes for the year 1987 during which dust attenuation for the near infrared link was exceeded due to duststorm events. In column (3), the cumulative percentage of the year is given. For 0.2% and 0.1% of the year, the 0.88 µm wave attenuation exceeded 1 dB and 6.5 dB respectively on 0.75 km path.

TABLE 5 - Dust attenuation distribution for 0.8 µm link

A(dB/km) at 0.88µm	No. of min./year	p%
1	1025	2×10^{-1}
2	871	1.7×10^{-1}
3	769	1.5×10^{-1}
4	753	1.47×10^{-1}
5	738	1.44×10^{-1}
6	615	1.2×10^{-1}
7	410	8×10^{-2}
8	297	5.8×10^{-2}
9	256	5×10^{-2}

COMPARISON WITH THEORY

To compare the measured dust attenuation at 40 GHz with calculation, the following formula is employed to calculate path attenuation A_C(dB), (3,4):

$$A_C = [1.8899(10)^{-3}\ (a_e/V_O)\ f.G"]\ \text{dB}$$

where, a_e = effective particle radius (m)
f = frequency (GHz)
V_O = visibility (km)
$G"$ = $\varepsilon"/[(\varepsilon'+2)^2+(\varepsilon")^2]$, permittivity factor
$\varepsilon',\varepsilon"$ = real and imaginary parts of permittivity of dust.

From our previous measurements, it was found that the effective particle radius of dust particles rarely exceed 20µm at typical antenna height of 21 m. The dust permittivity at 37 GHz are assumed according to the measurement of Geiger and Williams (3). Table 6 gives three various values of permittivity $\varepsilon^* = \varepsilon' - j\varepsilon"$ for dry condition, 10% and 20% moisture content. The corresponding permittivity factors G" are also shown in row (2) of Table 6. The considerable increase of G" with moisture increase is evident, consequently attenuation increases proportionally.

Table 7 gives the measured visibility, V_O, path attenuation A_m(dB) in columns (1) and (2) respectively. Columns (3), (4) and (5) give the calculated A_C(dB) for dry, 10%, 20% moisture conditions respectively.

Comparing A_m and A_C at the same visibiltiy, it is found that the measured attenuation exeeds calculated attenuation, in general. Even for 20% moisture in dust particles, A_m is larger than A_C by about one order of magnitude. However, the 20% moisture condition is unlikely to occur. Moisture gained by dust particles does not exceed 10% for extreme relative humidity of 90%.

TABLE 6 - Permittivity factor G at 40 GHz

	Permittivity @ 37 GHz		
m_w%	dry	m_w = 10%	m_w = 20%
ε*	2.52-j0.074	3.29-j0.73	0.59-j4.77
G"	$3.6(10)^{-3}$	0.0256	0.0382

TABLE 7 - Comparison with theory.

V_o (km)	A_m (dB)	A_c (a_e = 20µm) (dB)		
		dry	m_w = 10%	m_w = 20%
1.42	1.0	0.05	0.382	0.569
1.25	1.4	0.06	0.434	0.646
5.56	0.5	0.014	0.097	0.116
3.75	1.5	0.020	0.144	0.215
1.61	2.0	0.047	0.337	0.502
2.05	1.4	0.037	0.264	0.394
3.75	0.7	0.020	0.144	0.215
2.14	1.0	0.036	0.253	0.378
0.625	2.0	0.122	0.867	1.293
0.682	2.5	0.111	0.795	1.184

CONCLUSION

It is concluded that the measured attenuation is considerably higher than the estimated attenuation using typical sand particles moisture content of up to 10%. Measuring such a parameter during a storm is a rather formidable task. A close agreement between theory and measurements is obtained at a sand particle moisture content of about 20%. However, a larger moisture content is unlikely to occur during a storm, since moisture gained by dust particles does not exceed 10% for a relative humidity of 90%.

Moreover, it is also noticed that the measured attenuation differs from storm to storm for the same visibility. Such change may be attributed to sharp, sudden change in temperature, pressure, and himidity during a storm which may result in a severe variation in the refractive index.

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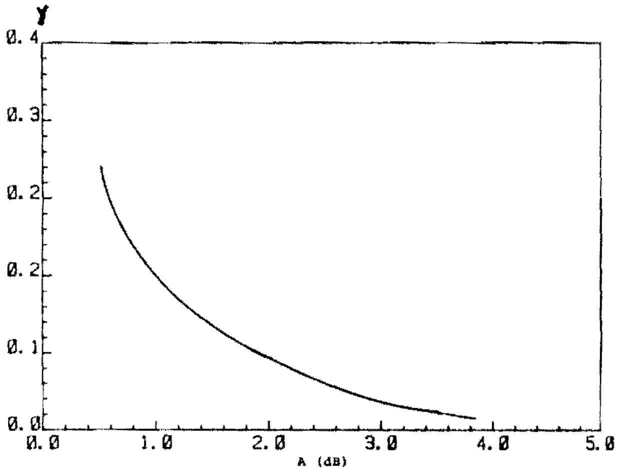

Y: P % percentage of year attenuation > abscissa

Fig.(1) - Distribution of Dust Attenuation A (dB) for MMW Link.