EFFECT OF MULTIPATH FADING ON MILLIMETER WAVE PROPAGATION-A FIELD STUDY

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ABSTRACT

A field study on wave propagation covering a wide range of the electromagnetic spectrum was actively running for 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 millimitric wave links with radio frequency of 40 GHz, and an infrared link with 0.88 μm wavelength. A meteorological station is operated and monitored as well.

This paper presents a description of the experiment, and reports results of measuring multipath fading as it affects the radiowave propagation at 40 GHz and at near infrared. Statistical characterization of multipath fading is given and compared with well known results at microwave frequencies.

I. INTRODUCTION

The present trend in radio design calls for the use of frequencies above 30 GHz for short links carrying wide-band digital communication signals. A hop length of 3 to 5 km may be considered for climatic regions dominated by heavy rain. Site (route) diversity and frequency diversity [1,2] are expected to provide protection against attenuation by rainfall. A major problem with the short hop system is due to the noise accumulated in the tandem repeaters. However, digital modulation with regeneration at each repeater will solve the problem. Here the limiting design factor may not be rainfall attenuation, rather, equipment reliability will set the limit on system performance.

In Saudi Arabia and similar areas with little rainfall, much longer hops may be feasible. Besides rainfall, propagation of millimetric waves is marked by many other phenomena such as bandwidth decoherence [3], and depolarization or polarization rotation. Since all of the above phenomena are weather dependent, their effect on propagation should be evaluated for the particular transmission climate.

Unfortunately, almost all the data reported in the published literature are taken in climatic regions that differ widely from the arid land climate of Saudi Arabia. In order to efficiently utilize the new frequency band, a propagation study in aridland is urgently needed. Such a study should be run over a span of several years, to obtain a sufficient statistical data.

A glance over the rain data available for Riyadh city shows that, for most of the year, rainfall is very little [4], and hence rain attenuation may not be the dominant propagation factor. On the other hand, sand and dust storms may be experienced several times each year. Particle sizes may range from a fraction of a micron to few hundred microns in radius. Due to the heavy particles of sand storms which are never less than 0.04 mm in radius [5!, the air - 2 meters above the earth's surface - could be clear of sand. Hence we may expect that radio links will not be affected by sand storms. However, dust storms comprising much smaller particles (less than 0.01 mm in radius) may be found at as high as hundred meters or more. This will reduce the visibility and affect the propagation in millimetric wave band [6-12]. Multipath fading due to temperature and pressure gradients is also expected to affect the propagation in Saudi Arabia. Our findings on the effect of rain sand/dust storms on propagation in arid land are reported elsewhere [13-16], however, the effect of multipath fading on propagation is reported here.

II. EXPERIMENTAL SYSTEM DESCRIPTION

A block diagram of the experimental system is shown in Figure 1. The system comprises: (1) a set of five transmission links operating at microwave (~12.5 GHz), millimeter wave (~40 GHz) and near infrared (0.880 μm) with different path distances of 14 km, 10 km and 0.75 km. (2) Meteorological instrumentation situated at the receiving site; which includes dust passive collectors (DPC) and high volume samplers (HVS) at different heights above ground, along with dust particle-size analysis (PSA). Visibility reduction is measured using the near infrared link. A rainfall rate gauge (RRG) and meteorological station (MS) for the measurement of temperature (T), relative humidity (RH), wind speed and direction (WS,WD) and barometric pressure (P). (3) a data collection and processing laboratory which includes a minicomputer (μc), tape (p), printer, data acquisition system (DAS), 40 GHz spectrum analyzer (SA) with supporting hardware and multichannel recorder (MCR). Table 1 lists the basic parameters of the different links.

III. MEASURED ATTENUATION DUE TO MULTIPATH FADING

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 dimenishingly small. However, since an extended hop length at 10 to 20 km is possible for regions with rare rain activities, clear weather fading can effect 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. 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 2 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.

From the above measurement on the 14 km, 40 GHz links, 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 mid-night 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 to 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 80%). 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.

a) Fade Occurence Factor

Based on three years of measurement, the average yearly probability of fading is calcualted as 0.033 for the 14-Km, 40 GHz links. The well known fading occurence factor, used at microwave frequencies is given by [17].

$$R = 2.5 \times 10^{-6} \times a \times b \times f \times D^3 \qquad (1)$$

where R is the fade occurence factor (probability of fading), f is the center frequency in GHz, D is the hop length in miles and a,b are terrain and climate factors, respectively, given by:

a = 4; 1; 1/4 for very smooth (including overwater); average with some roughness; and very rough for very dry terrain, respectively.

b = 1/2; 1/4; 1/8 for gulf coast or similar hot humid area, normal interior temprature mountainous or very dry, respectively.

For the 14 Km links operating at 40 GHz an occurence factor of ~ 0.03 in calculated using the above expression with a = 2 and b = 0.25. Such values of a,b are the proper values for the path, and the meaured occurence factor (0.033) is fairly close to the calculated 0.03. Hence it seems that the formula (1), which is well in use for microwave frequencies is still holding accurately at extremely high frequency band.

b) Amplitude and duration statistics

i) 40-GHz links

The probability Y(F) that fade depth exceeds F dB, during fading is well approximated by an exponential or a normal distribution. For the 40 GHz links such distributions are given by:

$$Y(F) = \exp(-0.284 \times F) \qquad (2\text{-a})$$

$$Y(F) = 9.52 \exp(-0.0054(F + 20.43)^2) \qquad (2\text{-b})$$

Equation (2) gives the conditional probability of exceeding a fade depth of F dB. The probability P(F) of exceeding a fade depth of F dB during the year, based on the average of the two links over the entire period of experiment is given by Y(F) of equation (2) multiplied by the fade occurence probability, hence,

$$P(F) = 0.033 \exp(0.048 \times F) \qquad (3\text{-a})$$

or

$$P(F) = 0.033 \times 9.494 \exp[-0.0054(F+20.43)^2] \qquad (3\text{-b})$$

It is also interesting to note that the experienced fade over the 14-Km links can be approximated by a Rayleigh distribution in the form:

$$P(F) = 0.033 \times 10^{-F/10} \qquad (4)$$

Fade duration is essentially of exponential distribution, however, small fade has a normal distribution of fade duration. The probability Y(t) that fade duration exceeds t minutes is given by:

$$Y(t) = \exp(-t/T_0) \qquad (5)$$

where T_0, the average fade duration is an inverse linear function of fade depth in the form:

$$T_0 = 5 + \frac{37}{F} \qquad F < 15 \text{ dB} \qquad (6)$$

where T_0 and F are in minutes and dB, respectively and the above equations were derived for the 14-Km, 40-GHz, hop in Riyadh.

ii) Near infrared link

Even for the short hop of 0.75 Km operating at 0.88 μm wave length, multipath fading was observed with an occurence probability of about .01, one third of the occurence probability of multipath fading over the 14-Km, 40 GHz links. Fade depths are exponentially or log normal distributed and the yearly average probability P(F) of a fade depth in excess of F dB is

$$P(F) = \exp(-.15\,F) \qquad F \leq 12 \text{ dB} \qquad (7)$$

Fade duration for fade depths of 3,5,7,9 and 11 dB occured with an exponential distribution of about 10 minutes average duration, hence the probability that a fade duration exceeds t minutes is written as

$$Y(t) = \exp(-t/10) \qquad (8)$$

From the measurements of multipath, it has been observed that multipath propagation occured during the period from midnight to noon time, probably non-uniform distribution of temperature and relative humidity occured in this time. Scintillation occured simultaneously with multipath fading. Signal enhancement and power fading were relatively rare. It is also observed that the probability of multipath propagation is higher in winter than in summer. This may be explained by the fact that winter is characterized by relatively moderate temperature (in the order of 15°C) and high relative humidity (50-80%). On the other hand, summer is hot (35-48°C) but dry.

IV. CONCLUSION

A field study aimed at studying the propagation of millimeteric waves in aridland was underway in the city of Riyadh for a period of four years. The paper presented the results of measuring signal attenuation caused by multipath fading at 40-GHz and near infrared frequencies. Various meteorological parameters were simultaneously measured and statistically analyzed. The essense of the results can be summarized as follows:

i) Multipath path fading was experienced by the 40-GHz links during the experiment. It is interesting that the Rayleigh amplitude distribution and the well-known occurence factor for the microwave band [equation (1)] still hold accurately at 40-GHz.

ii) Even at the short hop of 0.75 km operating at near infrared frequency, multipath fading was experineced. Fade amplitude and duration statistics are given for both the 40-GHz and the infrared links.

Although reliability and outage analysis are not included in this paper, such analysis can be easily pursued based on the complete statistics of rain attenuation, sand storms and multipath fading. It can also be verified that the three factors viz. sand storm, rain and multipath fading may play equally important roles in determining the link reliablity for the long hops in arid climate.

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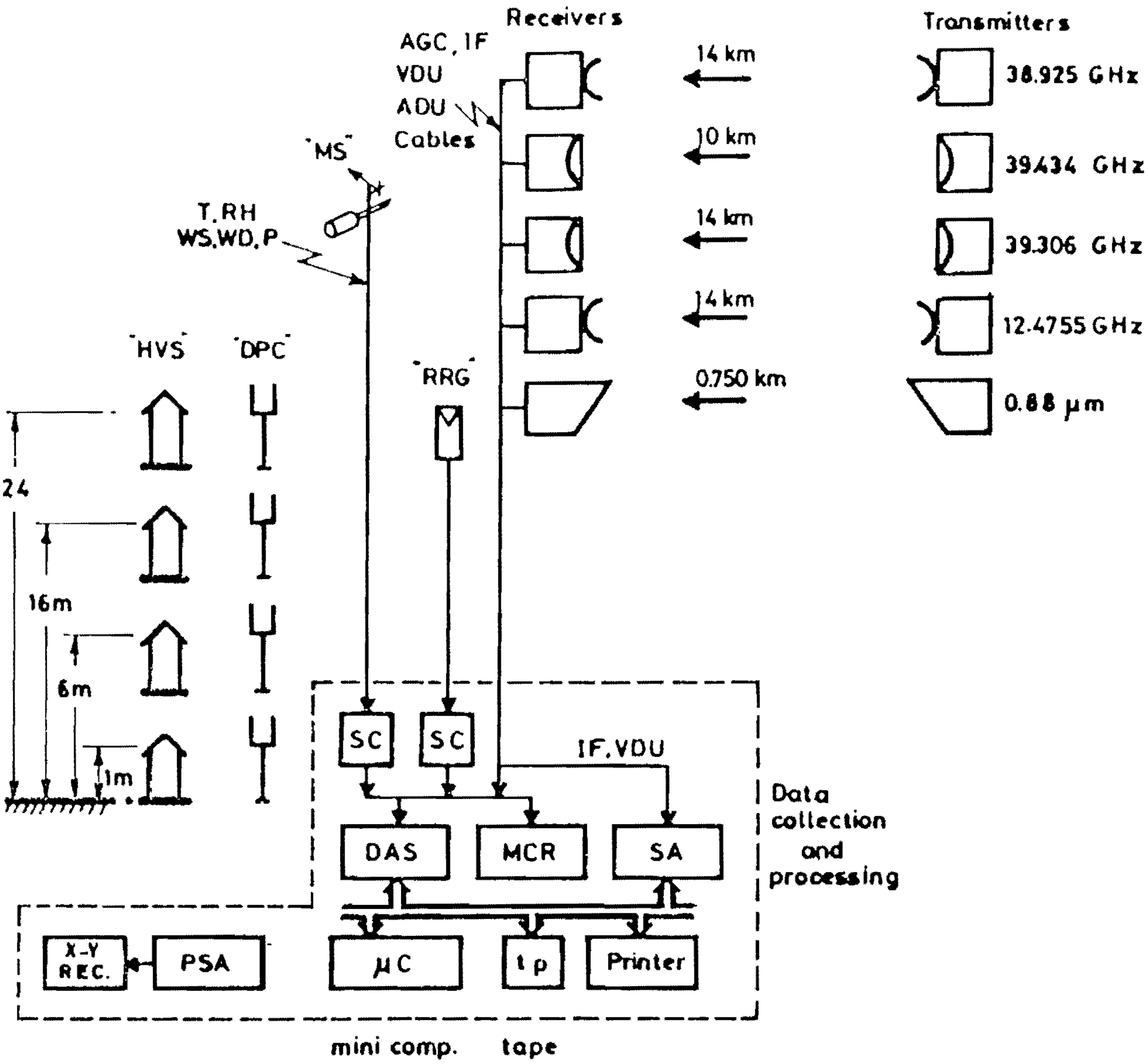

Figure 1 : Block diagram of the experimental system

Table 1. Parameters of the Link Systems

Link / Parameter	BKM	HUK/HUP	NEC	IR
Transmitter frequency (GHz)	12.4653	39.306/ 39.434	38.925	0.880 μm
Transmitted power (dBm)	+20	+23	+10	+14.77
Transmitter	x-tal	DRO & Impatt	Impatt	Ga Aℓ As
Polarization	Vertical	Vertical	Vertical	Random
Antenna type,	Parabola	Cassegrian	Cassegrian	Fresnel lens
Antenna size, "	23' 5/8	9"	14"	6" x 6"
Antenna gain (dB)	35	35	40	-
beamwidth (°)	3.0	2.5	1.6	0.17 divergent
Receiver type	SH	SH	SH	Silicon Avalanche diode
Radome	No	Kapton (0.005")	No	Glass
First IF (GHz)	0.430	1.142/1.2	1.70	-
Second IF (MHz)	70	300	70	-
Band width (MHz)	19	42.5	35	40 nm
AGC range (dB)	45	30	50	30

DRO : Dielectric Resonator Oscillator
SH : Superhetrodyne

Table 2: Number of events and type of multipath fading on the 40 GHz, 14 km link, in Riyadh, during 1987.

Month	Time of measurement x 10^3 (min)	Period of fade occurence	Average temperature	Average relative humidity RH%	Number of minutes of fade events during which exceeds 1 to 6 dB			
					with scintillation	with enhancement	with power fade	Total number of minutes
February	40.32	DN	16	46.5	1730	-	-	1730
March	28.8	DN	14	78.0	735	-	-	735
April	43.2	MD	22.5	40.0	590	-	500	1090
May	28.8	DN/MD	29.5	33.0	740	-	-	740
June	28.8	DN/NS	25	26.0	500	-	-	500
November	43.2	DN/MN	16	50.0	1342	213	-	1555
December	44.64	MD	14	68.0	826	290	-	1116

r : fade depth (dB)
DN : day period from dawn to moon
MD : day period from midnight to dawn.
NS : day period from noon to sunset