CLEAR-AIR SIGNAL LEVEL MEASUREMENT FOR MICROWAVE LINE-OF-SIGHT LINK APPLICATION IN SOUTH AFRICA

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Abstract: This paper presents an analysis of the 19.5 GHz clear-air signal level measurement variations over a line of sight link set up between two campuses of University of KwaZulu-Natal in Durban, South Africa. The measurement over the link spans a period of eleven months. An analytical expression for fade depth exceedance is proposed for KwaZulu-Natal, in South Africa. The link outage probability is compared with the results obtained from two ITU-R models as per Recommendations P.530-8 and P.530-12, Morita's model for Japan, and the model of Vigants used in the United States. The Morita model over sea and coastal regions gives an outage probability of 0.060%, compared to 0.037% obtained from the measurements, with the two ITU-R models also giving close values of 0.027% and 0.024%, respectively. However, Vigants' model is found to be the least appropriate for outage estimation in South Africa.

Keywords: Radioclimatic Model, Microwave Line-of-Sight Link.

1. INTRODUCTION

According to Olsen [1], predictions based on global radioclimatic models of the ITU-R can be made for three significant clear-air propagation effects on terrestrial line-of-sight (LOS) links: fading, distortion, and depolarization. In addition, such predictions can also be made for very low angle satellite links. All these predictions use worldwide contour maps of refractive index gradient statistics for the first 100 m of the troposphere. The current efforts in modelling is attributed to the establishment of an ITU-R Group in 1994 to develop new global radio-climatic models in clear-air conditions; with a parallel effort in Europe via the COST-235 Project being initiated, which was later expanded into the COST-255 framework. However, due to the sparcity of modelling data, Lystad et al [2] reported on the deployment and testing of various interpolation techniques for clear-air parameters at non-regular observation locations; they concluded that the kriging approach, with a little improvement, would be the best tool to map global data sets.

For clear-air propagation LOS prediction, the main types of impairment are diffraction fading and multipath fading. Diffraction or k-type fading in LOS links arises owing to the variation of the effective earth radius factor (k-factor) due to the time-varying nature of the primary tropospheric parameters of temperature, pressure, and water vapour pressure [3]. The statistics of the vertical gradient of radio refractivity, N, in the lowest atmosphere are important parameters for the estimation of path clearance and propagation-associated effects such as ducting, surface reflection, and multipath fading on terrestrial LOS links. Since most terrestrial LOS towers are within the height range of 20-100 m above ground level, refractivity gradient statistics for the lowest 100 m a.g.l are used to estimate the probability of occurrence of ducting phenomena and multipath conditions. Where more reliable local data are not available (as is the case in many African regions), Recommendation P.453-9 gives global plots of the percentage of time that the refractivity gradient, dN/dh, falls below -100 N-units/km (this is defined as β_o). The plots give the following percentages in the eastern part of South Africa, including Durban: 10-20% in February; 2-5% in May; 2-5% in August; and 10-20% in November. This compares well with the values obtained by Dabideen et al for KwaZulu-Natal, including Durban, with values ranging between 6-13%, as shown in Fig.1. [4].

Atmospheric ducts may cause deep slow fading, strong signal enhancement, and multipath fading on terrestrial LOS links [3]. The ITU-R therefore gives statistics on duct occurrence tendencies globally, incorporating both surface ducts and elevated ducts. The plots give surface duct occurrence probability of about 10% for South Africa. The corresponding values obtained by Dabideen et al for KwaZulu-Natal give a probability range of 2-6% for surface ducts, and 1-2% for elevated ducts, as shown in Fig.2 [4].

With regard to predicting multipath fading, Olsen, Tjelta et al [5, 6] provide a summary of worldwide techniques for predicting multipath fading distribution on terrestrial LOS links. They refer to two ITU-R methods: Method 1 requiring the knowledge of only three link parameters – the path length, d (km), the operation frequency, f (GHz), and the magnitude of the path inclination $|\varepsilon_p|$ (milliradians); and Method 2, which requires the additional link variable, the average grazing angle, ϕ (milliradians), which is the average grazing angle corresponding to a 4/3 earth radius model for refraction. By comparing the revised ITU-R method with regional

Table 1: k-factor median and effective values exceeded 99.9% of the time for KwaZulu-Natal [8]

Period	*Median value of k*	*Effective k exceeded 99.9% of the time*
February	1.21	0.2
May	1.15	0.3
August	1.27	0.9
November	1.20	0.5
All Year average	1.21	0.5

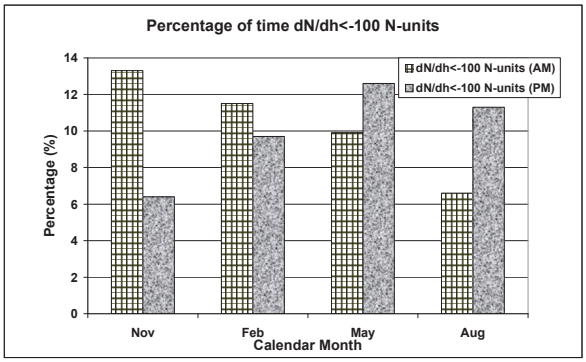

Fig.1. Percentage of Time dN/dh<-100 N-units/km for KwaZulu-Natal [4]

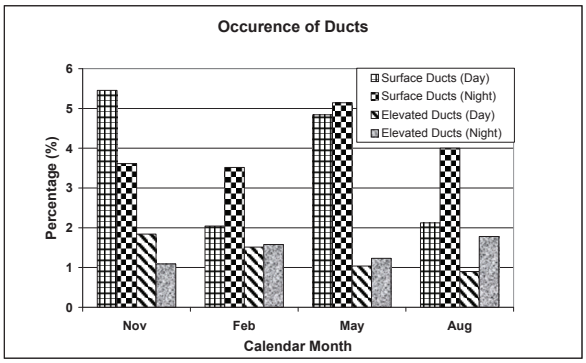

Fig.2. Duct Occurrence Frequency for KwaZulu-Natal [4]

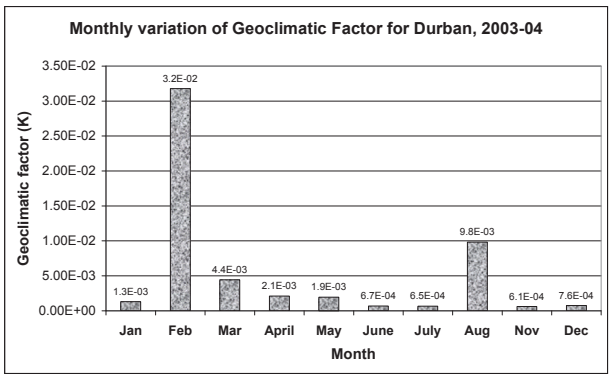

Fig.3. Monthly Geoclimatic Factor values for KwaZulu-Natal

methods (the Barnett-Vigant's method in the United States, and the Morita method used in Japan), they conclude that the ITU-R method performs significantly better than the other two methods for both overland and coastal/over water links.

As far as diffraction fading is concerned, ITU-R Rec.P530-12 [7] states that *k*-factor statistics for a single point can be determined from measurements or predictions of the refractive index gradient in the first 100 m of the atmosphere (see Recommendation ITU-R P.453 on effects of refraction [3]). These gradients need to be averaged in order to obtain the effective value of *k* for the path length in question, k_e. Values of k_e exceeded for 99.9% of the time are discussed in terms of path clearance criteria. For KwaZulu-Natal, Afullo and Odedina have determined the median value of k to be1.21, and the value of k_e exceeded 99.9% of the time for the worst month is 0.2, as shown in Table 1 [8].

This submission presents measurement results over a 6.73 km LOS link operating at 19.5 GHz, in Durban, KwaZulu-Natal. Section 2 gives a background to current fade exceedance methods. The link details are presented in section 3, the received signal analysis in section 4, and the link fade depth exceedance probability is modelled in section 5, which also presents the comparison between the outage probability with the corresponding analytical models of Morita, ITU-R, and Vigants. Section 6 presents the conclusions.

2. FADE OCCURRENCE ESTIMATION

Olsen et al used the percentage of time p that fade depth, A, (in dB) in deep-fade range, is exceeded in the average worst month (given by ITU-R Recommendation P.530-8) as [6]:

$$p = Kd^{3.6} f^{0.89} \left(1 + \left|\varepsilon_p\right|\right)^{-1.4} 10^{-A/10} (\%) \tag{1}$$

However, in the latest version P.530-12, p is given by [7]:

$$p = Kd^{3.2} \left(1 + \left|\varepsilon_p\right|\right)^{-0.97} 10^{0.032 f - 0.00085 h_L - A/10} (\%) \tag{2}$$

Here h_L is the altitude of the lower of the two antennas (a.s.l.). K is the geoclimatic factor, estimated by [7]:

$$K = 10^{-4.2 - 0.0029 dN_1} \tag{3}$$

Here, dN_1 is the point refractivity gradient for the lowest 65 m of the atmosphere not exceeded for 1% of the average year. For KwaZulu-Natal, Dabideen et al [4] have found the worst-month value of K to be 0.0318, as shown in Fig.3 [4].

For the antenna heights h_e and h_r ((m) above sea level, the path inclination, ε_p in milliradians, is given by:

$$|\varepsilon_p| = |h_r - h_e| / d \tag{4}$$

In this paper, we compare the fade depth distributions for a LOS link in Durban, KwaZulu-Natal, with Olsen's model (ITU-R P530-8), the ITU-R P530-12 model, Morita's model, and Vigants' model. In the Vigants' model, the fade occurrence probability for deep fading is given by [9]:

$$p = C(f/4)d^3 10^{-5}$$
$$C = \begin{cases} 4 & \text{for overwater and Gulf coast} \\ 1 & \text{for average terrain and climate} \\ 0.25 & \text{for mountains and dry climate} \end{cases} \tag{5}$$

Here f is frequency in GHz, and d is distance in miles (1 mile=1.6 kilometres). To obtain the occurrence probability as a percentage, multiply the above equation by 100.

A further modification of equation (5) is proposed by Vigants if a terrain roughness factor, ω, is incorporated into the formula. He explains that applicable values of ω range from 20 ft or 6.09 m (smooth surface) to 140 ft or 42.7 m (rough surface). Thus, when modified for surface roughness, the equations for C become:

$$C = \begin{cases} 2(\omega/50)^{-1.3} & \text{for coastal areas} \\ (\omega/50)^{-1.3} & \text{for average climate} \\ 0.5(\omega/50)^{-1.3} & \text{for dry climate} \end{cases} \tag{6}$$

Note that, ω, the surface roughness, is in feet in equation (6), and should be converted into metres.

Morita's probability of Rayleigh fading model for LOS microwave links was developed after studying over 80 microwave systems in Japan [16]. He derived the following empirical formula for the occurrence probability of Rayleigh fading as a result of propagation tests in the worst season for many years in Japan (for path length d in km and frequency, f in GHz):

$$P_R = \left(\frac{f}{4}\right)^{1.2} Q d^{3.5}$$
$$Q = \begin{cases} 2.0x10^{-9} & (\text{over mountains}) \\ 5.1x10^{-9} & (\text{over plains}) \\ 3.7x10^{-7}\sqrt{1/\sqrt{\bar{h}}} & (\text{over sea or coastal region}) \end{cases} \tag{7}$$
$$\bar{h} = \text{average path height in metres}$$

In fact, the above Rayleigh fading formula by Morita was picked up for each hop by counting the total signal interruption time due to fading which was confirmed by the operation of the squelch circuit at the receiver. Thus the P_R above defines the probability of outage over the hop. In our link below, it corresponds to the probability that a fade depth of about 40 dB is attained. This submission presents measurement results over a 6.73-km LOS link operating at 19.5 GHz, in Durban, KwaZulu-Natal. The link details are presented in Section 3, the received signal analysis in Section 4, and the outage probability is modelled in Section 5. Section 5 also gives a comparison between the outage probability on a monthly basis with the corresponding analytical models used by Olsen, Morita, ITU-R, and Vigants. In our link, the average path height, h, in metres is 114.2; and the surface roughness factor, ω=32.1 m or 105.3 ft.

3. EXPERIMENTAL LOS MICROWAVE LINK OPERATIONAL DETAILS

In this section, the signal attenuation measurements over a period of one year in 2004 in Durban by Naicker et al [10] is presented to model clear-air fading on a typical terrestrial line-of-sight link in South Africa. These discussions are the clear-air counterpart of the rain-attenuation modelling in Fashuyi and Afullo [11]. The line-of-sight link was established between the Howard College and the Westville campuses of the University of KwaZulu-Natal, Durban. The transmitter station was setup on the roof of the Science building at the Westville campus on the azimuth angle of 30.980° and about 178 m above sea level; while the receiver station was mounted on the roof of the Electrical Engineering building at Howard College campus, on the azimuth angle of 30.943° and about 145 m above sea level [10, 11]. The path clearance from the first Fresnel ellipsoid and the line-of-sight path are shown in Fig. 4.

Note that for Durban, it has been established by Afullo et al [8] that the median value of k=1.21, rather than the temperate zone value of k=1.33. In addition, for the worst month (February), the value of k exceeded 99.9% of the time is 0.2, compared to 0.9 for the month of August. Therefore, to incorporate the appropriate value of the earth bulge, we have plotted the earth profile charts for k=1.33, 1.21, 0.9, and 0.2. One observes that even in the worst month, with k=0.2, the first Fresnel zone radius is cleared by over 20 m everywhere along the path. Thus we can conclude that diffraction fading is negligible over the link, since Δh=0 within the first Fresnel zone.

Table 2: Terrestrial link parameters for the LOS SHF system [10]

Parameter	Description
Path Length	6.73 Km
Height of transmitting antenna above the ground	24 m
Altitude of transmitter station	178m
Height of receiving antenna above the ground	20m
Altitude of receiver station	145m
Carrier frequency	19.5 GHz
Bandwidth under investigation	200 MHz
Transmitting power	10-100 mW
Transmitting/receiver antenna gain	38.6 dBi
Transmitting/receiver antenna beamwidth	1.9 degrees
Free space loss	135 dBm
Total cabling and connection losses	≈2.2dB
Clear air attenuation	≈1 dB
Receiver Bandwidth	100 kHz to 1 GHz

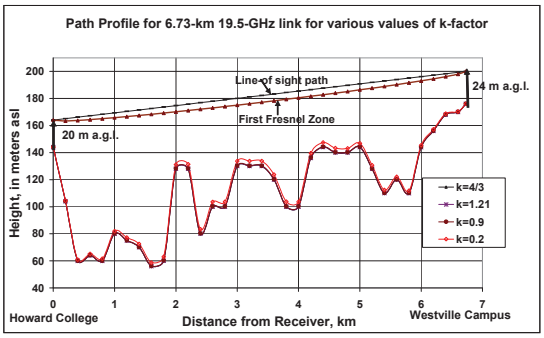

Fig 4: The path profile for the 6.73 km terrestrial line-of-sight link from the Howard College campus to the Westville campus [10], [11]

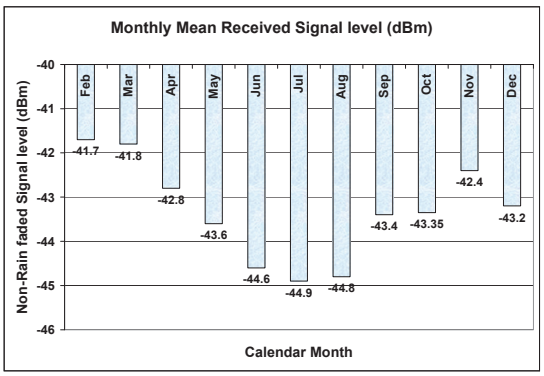

Fig.5: The average non-rain faded signal values for 10 months in 2004 [11]

The link is horizontally polarized and centred at an operating frequency of 19.5 GHz. In addition, two Oregon Scientific WMR928N wireless professional weather stations were used along the path at both the receiver and the transmitter end to record the rainfall rate, outdoor temperature, relative outdoor humidity, outdoor dew point temperature, outdoor pressure, wind speed and wind direction under the link [10].

Two Valuline® WR42/R220 parabolic antennas, each of 0.6-meter diameter, were mounted at the receiving and the transmitting stations. The antennae can operate within the 17.7-19.7 GHz and 21.2-23.6 GHz bands and provide a gain of 38.6 dBi and a 3 dB beam width of 1.9 degrees at 19.5 GHz [10]. These parabolic antennae are protected by a weatherproof material (the radome) which prevents ice and freezing rain from accumulating directly onto the metal surface of the antenna. The cabling consists of FSJ1-50A superflexible coaxial cable which produces an attenuation of 2.2 dB per 100 m.

At the transmitter, an Agilent E8251A signal generator is used to provide the source signal and this can operate between 250 KHz-20 GHz. This was used in conjunction with an Agilent 83018A microwave system amplifier which can operate from 0.5 GHz to 25 GHz and provides a gain of up to 27 dB [12]. This setup produces unmodulated continuous wave signals at the operating frequency of 19.5 GHz. At the receiver, another Agilent 83018A power amplifier is used to produce additional gain before feeding the signal into the Rhodes & Schwarz FS1Q40 spectrum analyser. More details on the link setup at receiver and transmitter ends can be seen in [10]. The terrestrial link parameters are shown in Table 2.

The expected noise power in the receiver when no signal is transmitted lies between -80.5 to 80.2 dBm. This defines the noise floor. This is determined from the noise temperature of the antenna of 206°K (with an estimated efficiency of 63.4%, equivalent background temperature of 150°K [13], and a maximum physical temperature of 303°K); the transmission line noise temperature of 93.4°K (with an attenuation of 22 dB per 100 m); and the 83018A Agilent Amplifier (with a gain of 27 dB, and noise figure of about 9.5 dB at 19.5 GHz [12]) with noise temperature of 2398.5°K. This therefore results in total receiver noise temperature of 3470.4°K, or noise power of -80.2 dBm [13]. At the lower temperature of 287°K, the noise power is -80.5 dBm. In the measurements, this squelch value varied from -79.5 dBm to -82 dBm.

Calculating the expected power received P_r, we have [11]:

$$\begin{aligned} P_r &= P_t - FSL + G_{rant} + G_{\tan t} - Losses \\ &= 20dBm - 135dB + 38.6dBi + 38.6dBi - 2.2dB - 1dB \\ &= -41\ dBm \end{aligned} \tag{8}$$

Where:

P_t = Power transmitted (taken as 100mW=20dBm)

FSL = Free space loss

G_{rant} = Receive antenna gain

$G_{\tan t}$ = Transmit antenna gain

Thus the received power P_r expected at the receiver end of the link when a transmitting power of 100 mW is employed between Howard College and Westville campuses should be *-41 dBm* when there is no rain to cause any rain attenuation, no losses due to fog and water vapour, no multipath fading, and no diffraction fading. However, due to the other possible sources of loss, the actual received signal levels falls below this ideal value. Due to the coastal nature of Durban, as well as the surrounding industries, fog attenuation cannot be ignored: at the link operating frequency of 19.5 GHz, an average fog attenuation of 0.1 dB/km is expected, resulting in a value of 0.7 dB along the propagation path [14]. Water vapour is another main contributor of attenuation, with an average pressure of 27 mb in the summer, resulting in an attenuation of 0.34 dB/km, or 2.2 dB over the path in summer. During winter, the water vapour pressure is about 13 mb, giving an attenuation of 0.13 dB/km, or 0.9 dB over the LOS path. Thus water vapour attenuation varies from 0.9 dB to 2.2 dB over the link; and the combination of water vapour and fog attenuation together contribute an attenuation of 1.5 dB to 3.0 dB (see [11,15]). The mean value of the clear-air received signal level is shown in Fig. 5.

4. DAILY AND MONTHLY SIGNAL LEVEL ANALYSIS

Figures 6-8 give sample plots of the time series of the measured received signal for three typical days with extreme fading (total outage), low fading, and negligible fading, respectively. In Fig. 6a, the signal is practically squelched over the entire day, as shown in the corresponding probability density function shown in Fig. 6b. Similarly, Fig 7a shows a signal with some deep fading, as again shown in the signal's pdf of Fig. 7b. Finally, Fig. 8a and 8b show the signal when there is very low fading. Note that the mean clear-air levels in Fig.5 are taken to be the reference values in the determination of multipath fade depth.

For the purpose of this analysis, the measurement days are categorized into six different fade depth levels. These fade depth levels are: fade depth A(dB) ≥ 5 dB; fade depth A(dB) ≥ 10 dB; fade depth A(dB) ≥ 15 dB; fade depth A(dB) ≥ 20 dB; fade depth A(dB) ≥ 30 dB; fade depth A(dB) ≥ 40 dB. Before starting the analysis for each fade depth level for different months, all the available measurement data for the month in question are pooled together. We then determine the probability that a certain fade depth A is exceeded for a given month by summing all the measurement minutes during which that fade depth is exceeded, and dividing this by the total measurement minutes for the month. However, in cases where the signal was in squelch for an extended period – for example more than 30 minutes non-stop – then that period's data is excluded, for it might imply either power outage at the transmitter or ducting. For example, the data for 31st March 2004 was excluded, as there was total outage over that period. On the other hand, the data for 31st May was accepted, as the fade depth was not unacceptably high over an extended period.

The fade depth for a given month, M, for a signal level P_{Mj} measured in the jth minute of that month is determined as:

$$A_{Mj} = P_M - P_{Mj} \tag{9}$$

where P_M is the median clear-air signal level for month M. For example, for February, P_M=-41.7 dBm; for March, P_M=-41.8 dBm; for April, P_M=-42.8 dBm; et cetera. The resulting exceedance plots are shown in Figures 9a and 9b. As expected, the lower the value of A, the higher the probability of exceedance. In Fig.9a, the months with the best performance for A=10 dB are April and August, which each give an exceedance probability of 0.001%. The poorest performers for this value of A are the months of May and June, with exceedance probability levels of 5%.

For A=30 dB, the best performance is obtained in the months of April, July and August. March and December give miserable percentages above 0.1%, with February only slightly better. Yet again, the greatest culprits are the months of May and June, which each give a probability of exceedance value of about 5%. This implies that there is something else occurring during these two months, which needs further investigation. Finally, for A=40 dB, all the other months perform well save for the months of May and February, which give exceedance probabilities of 0.4% and 0.03%, respectively. In fact, one would expect that for a fade margin as high as 40 dB, the link should no longer suffer at all from multipath fading. Thus, as before, we may only surmise that some other events, different from multipath (or diffraction) fading must be playing a role here.

5. ANALYTICAL EXPRESSIONS FOR PROBABILITY OF EXCEEDANCE

For the exceedance plots shown in Fig.9, we now proceed to develop analytical expressions as a function of A (dB). These are given by the following expressions, for a given fade depth A:

$$\begin{aligned} P_{May}(A) &= 0.00002A^4 + 0.0012A^3 - 0.0259A^2 + 0.2197A + 3.7117 \\ P_{June}(A) &= -0.00002A^4 + 0.0012A^3 - 0.0275A^2 + 0.2341A + 3.3218 \\ P_{Year}(A) &= -0.000004A^4 + 0.0002A^3 - 0.0042A^2 0.0225A + 1.1478 \end{aligned} \tag{10}$$

Table 3: Analytical expressions of percentage exceedance probabilities for the different months

Month	Analytical Expression
February	$P_A = 0.000001A^4 - 0.0001A^3 + 0.004A^2 - 0.057A + 0.3309$
March	$P_A = -0.0000008A^4 + 0.00005A^3 - 0.0011A^2 + 0.0096A + 0.138$
April	$P_A = 0.5868A^{-2.1162}$
May	$P_A = -0.00002A^4 + 0.0012A^3 - 0.0259A^2 + 0.2197A + 3.7117$
June	$P_A = -0.00002A^4 + 0.0012A^3 - 0.0275A^2 + 0.2341A + 3.3218$
July	$P_A = 0.00009A^4 - 0.0085A^3 + 0.2656A^2 - 3.2166A + 12.165$
August	$P_A = 0.00005A^4 - 0.0042A^3 + 0.1293A^2 - 1.554A + 5.7859$
December	$P_A = 0.000003A^4 - 0.0003A^3 + 0.0091A^2 + 0.1067A + 1.0428$
Whole Year	$P_A = -0.000004A^4 + 0.0002A^3 - 0.0042A^2 + 0.0225A + 1.1478$

Table 4: Outage probability for the measurement compared with semi-empirical models

Model	Outage Probability (%)
ITU-R P.530-8 (K=0.0318)	0.027%
ITU-R P.530-12 (K=0.0318)	0.024%
VIGANTS plain & average terrain	0.363%
VIGANTS mountain & dry climate	0.091%
VIGANTS over water	1.451%
VIGANTS average climate (roughness factor ω=105.3 ft)	0.138%
VIGANTS dry climate (roughness factor ω=105.3 ft)	0.069%
VIGANTS coastal area (roughness factor ω=105.3 ft)	0.276 %
MORITA over mountains	0.011%
MORITA over plains	0.027%
MORITA over sea or coastal region (mean h=114.2 m)	0.060%
THIS LINK (measurements over the year)	0.05%

It is observed that over the link, the percentage of time that a certain fade depth A(dB) is exceeded can be modelled as a fourth order polynomial for May, June and whole year. These and other expressions, for all the measurement months of the year, are presented in Table 3. Finally, we compare these fading probabilities with the semi-empirical expressions due to ITU-R Recommendation P530-8 (as presented by Olsen et al), ITU-R Rec. P.530-12, the Morita model, and the Vigants' model.

For the current measurements, the median signal level over the year is about -43 dBm, while the estimated noise level is about -82 dBm. Morita's example in Fig.1 [16] shows the median received signal level of -30 dBm, and squelching or outage is achieved at -70 dBm. Thus a fade depth of approximately 40 dB gives complete outage, as the received signal is completely embedded in noise. Thus we use the given models to estimate the probability of link outage. In addition, note that the revised or improved Vigants' model incorporates a terrain roughness factor, ω. This is defined as the square root of the average square of the deviation from the mean, given by [9]:

$$\omega = \sqrt{\frac{1}{13}\sum_{i=1}^{13}\left(x_i - M\right)^2} \tag{11}$$

In this case, x_i is the height above sea level of the i-th terrain point in the intervening path between transmitter and receiver, and M is the mean terrain height for the link. In this example, we have used 13 points for the link in Fig.4, resulting in a mean terrain height M=114.2 m, and terrain roughness ω=32.09m =105.3 feet. The results are summarized in Table 4.

We should also note that Morita performed his tests in the 4-GHz band, and surmises that the formula be best applied in the frequency band between 2 to 15 GHz. Thus while the measured link outage probability of 0.05% is comparable to Morita's value of 0.060% over water and coastal areas, we should bear in mind the above caution. We also note that the ITU-R model of Recommendation P.530-8 gives an outage probability of 0.027% for this link, which is practically close to the measurement value obtained for our link. On the other hand, ITU-R Recommendation P.530-12 gives a marginally lower probability of 0.024%. All the Vigants's models (with and without the surface roughness factor) are seen to perform rather poorly in estimating the link outage. This may partly be due to the fact that they are not global, as compared to the ITU-R models.

Finally, we also note that the Geo-climatic factor (K) used in the ITU-R models in Table 4 is a local one obtained by Dabideen et al [4]; and it is the worst-month value of 0.0381, which is the value for February. We note that the actual ITU-R value of K for the region is 9.12×10^{-4}, which could have resulted in at least slightly

different results for the outage probability. Also note in Table 1 that the effective value of k exceeded 99.9% of the time in the worst month is 0.2, and this also takes place in February. Thus, for KwaZulu-Natal, February is the month for the highest probability of multipath fading as well as diffraction fading.

6. CONCLUSION

From the 11-month measurement campaign in KwaZulu-Natal over a line-of-sight microwave link, we determine the analytical models for fade exceedance probability. The measured outage probability of 0.05% compares well with the value of 0.06% due to Morita's model for sea and coastal areas. It also compares reasonably well with outage values of 0.027% and 0.024% obtained from the models of ITU-R Recommendations P.530-8 and P.530-12, respectively. However, it is observed that the Vigants' model of the United States for coastal and over-water regions does not present a reasonable prediction for link outage in South Africa, even with surface roughness incorporated. Finally, while the above models present a good start, a longer measurement campaign in South Africa will ensure a refinement of the model.

7. REFERENCES

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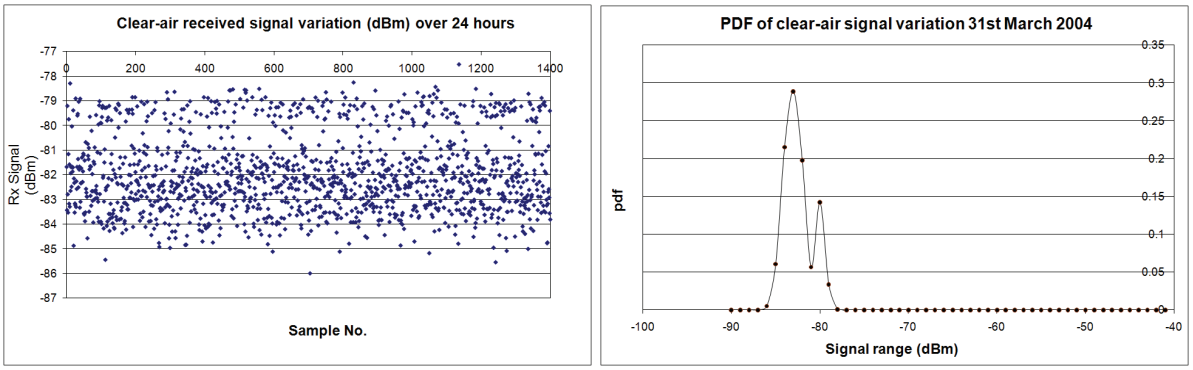

Fig 6: Clear-Air Signal Level Variation over 24 hours, 31st March 2004 a) Time series, b) pdf

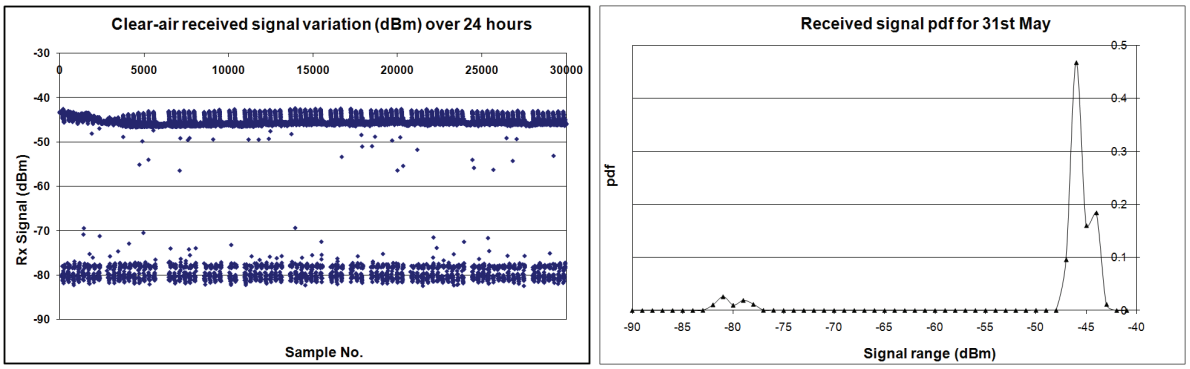

Fig 7: Clear-Air Signal Level Variation over 24 hours, 31st May 2004, a) Time series, b) pdf

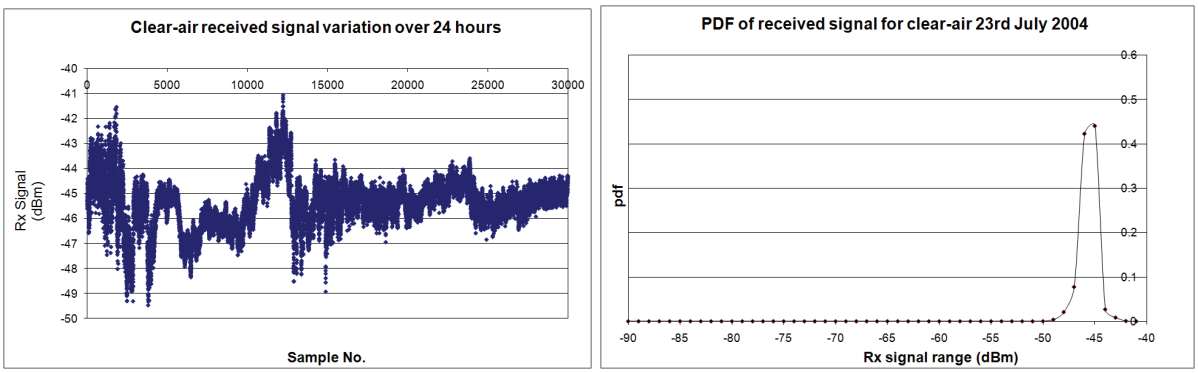

Fig 8: Clear-Air Signal Level Variation over 24 hours, 23rd July 2004, a) Time series, b) pdf

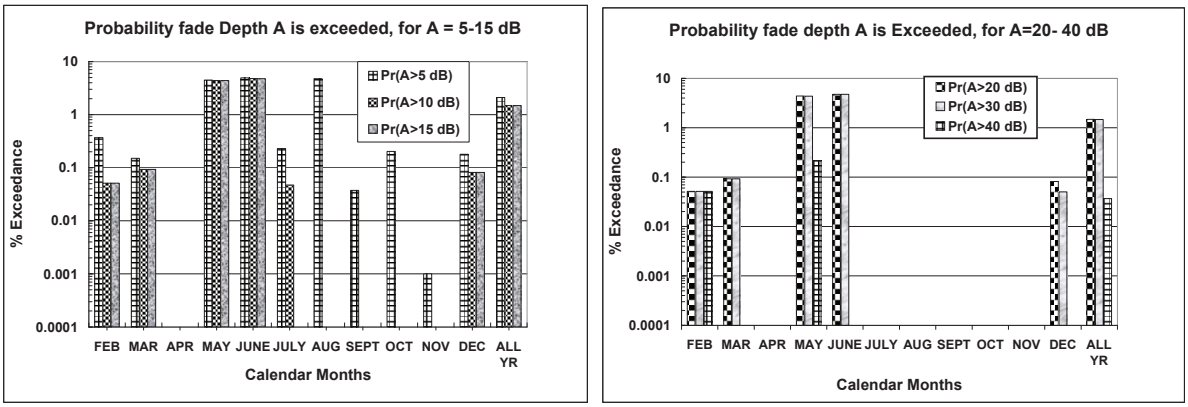

Fig 9: Probability that fade depth, A, is exceeded for the ranges a) A=5-15 dB, and b) A=20-40 dB