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Analysis of the Fading Problem on Microwave Links Along the West Coast of Saudi Arabia

Abdulaziz S. Al-Ruwais and Adel A. Ali

Electrical Engineering Department, King Saud University,
P.O. Box 800, Riyadh 11421, Saudi Arabia

ABSTRACT. An analysis of the fading problem encountered on a microwave link along the Red Sea coast of Saudi Arabia is presented. The analysis is based on field measurements of two received signals at 4 and 6 GHz. Obstruction and multipath fading are identified to be the main types of fading which cause the outage of this link. Analyses of possible diversity improvement are presented for both frequency and space diversity. It is shown that modified antenna system design or practical increase in tower heights are unlikely to bring a satisfactory solution to the problem. Moving some of the tower sites away from the coast will lead, possibly, to more reliable system performance.

Fading of signals transmitted using line of sight (L.O.S.) microwave links is a common problem. It is caused mainly by the variations in the refractive index profile of the lower troposphere. Several modes of anomalous propagation may occur according to many possible values of the refractive index gradient. At moderate positive values of the refractive index gradient (subrefraction, for example) the earth's surface obstructs (bulge) partially the microwave beam which then misses the receiving antenna. Super-refraction is produced by moderate negative values of the gradient causing the beam to reach the receiving antenna at an angle outside the main beamwidth, and thus antenna decoupling may occur. In extreme atmospheric conditions a receiving antenna may become in a shadow area, and therefore a complete black-out fade occurs. Such a fade is produced by either extremely negative or positive gradients close to the earth's surface. Ducting occurs when microwave beams are trapped in a duct either at the earth's surface or at an elevated level. Ducting causes deep fading or enhancement by several dB of the received signal which may last for a long period of time causing interference with other nearby communication systems.

Elevated atmospheric layers with steep refractive index gradients, when formed, give rise to simultaneous different ray trajectories causing multipath propagation. The signal components along the different paths sum up vectorally to give an enhanced or dehanced received signal. Multipath propagation results essentially in depression of the received signal power (or falt fade). Multipath fading (mpf) is also frequency selective in that different frequencies within the transmitted signal band are affected differently. Frequency selective fading has significant effects on medium and high capacity digital radio system (Barnett 1979). Fading problems are commonly encountered along some of the microwave routes in Saudi Arabia as documented by reports from the Ministry of P.T.T. (1983). For the year 1983, for example, the total outage time due to effects of fading was 5538 min. The average outage time was 23.9 min per occurrence for a total of 231 reported fading events. The number of routes affected that year was twelve. Among these twelve routes, route 04 accounted for the highest total outage time. It had a total outage time of 3590 min. or 64% out of the overall outage time of 5538 min. Route 04, which consists of 12 hops, originates at Jeddah (Station 059) and ends in Medina (extending over 404.3 km total length) Fig. 1. It was placed into service in April 1979, but its performance did not meet the design objectives and CCIR recommendations.

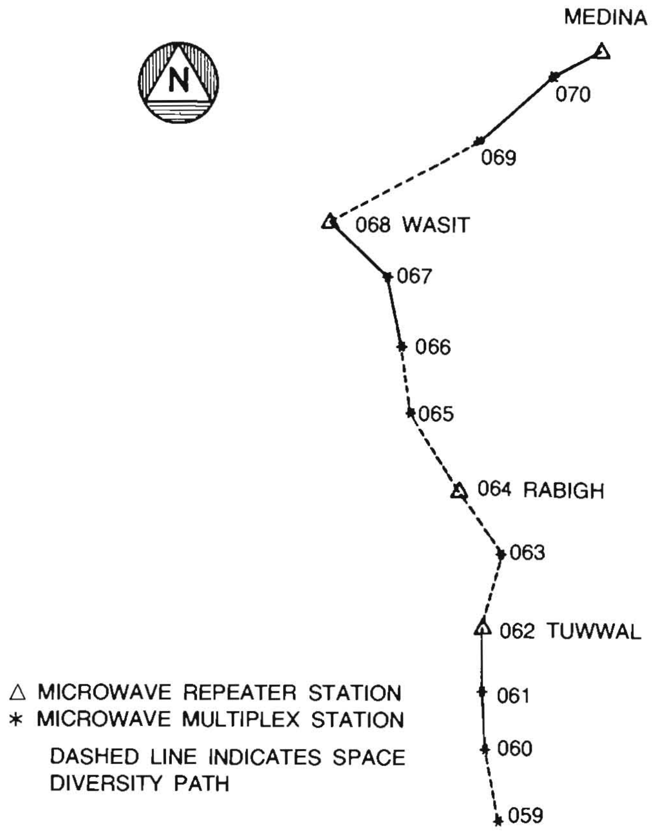
The aim in this paper is to provide quantitative analysis of the fading problem on this route.

Section I, of this paper, defines route 4 and describes the data. It also summarizes the problem from the P.T.T. reports. Section II provides an analysis of the fade events. We then discuss some suggested solutions in section III. Section IV contains the conclusions.

1. Fade Data for Route 4

Route 4 is used to provide telephone services between Jeddah and Medina. Only one hop of this route is considered for investigation. This hop extends from Station 63 to Rabigh (Station 64), 31 km away. The path profile of this hop and the antenna heights are shown in Fig. 2 (P.T.T. 1979).

The data, in this paper, are chart recordings of the automatic gain control (AGC) signals received along both the 4 and 6 GHz channels. The test period extends over 15 days during August and September, 1984. This test period falls in the high fade season and recordings were taken on two different channels. The obtained data are adequate in isolating clearly the frequency selective fades from power (non-selective) fades. Usually, further long term measurements are needed to separate between the two types of fades where only one channel is available for data measurements.



STATION	Lat.			Long.			Alt. (m)
MEDINA	24°	29′	0″	39°	35′	0″	594
070	24	23	0	39	24	0	895
069	24	8	0	39	7	0	1172
068 WASIT	23	49	50	38	33	0	25
067	23	37	0	38	46	0	47
066	23	20	56	38	49	9	23
065	23	5	33	38	51	22	15
064 RABIGH	22	48	2	39	1	52	7
063	22	33	22	39	11	45	23
062 TUWWAL	22	16	51	39	7	0	1
061	22	2	0	39	7	0	7
060	21	48	43	39	7	40	56
059	21	31	53	39	10	44	5

Fig. 1. Route 4 of the Kingdom microwave network

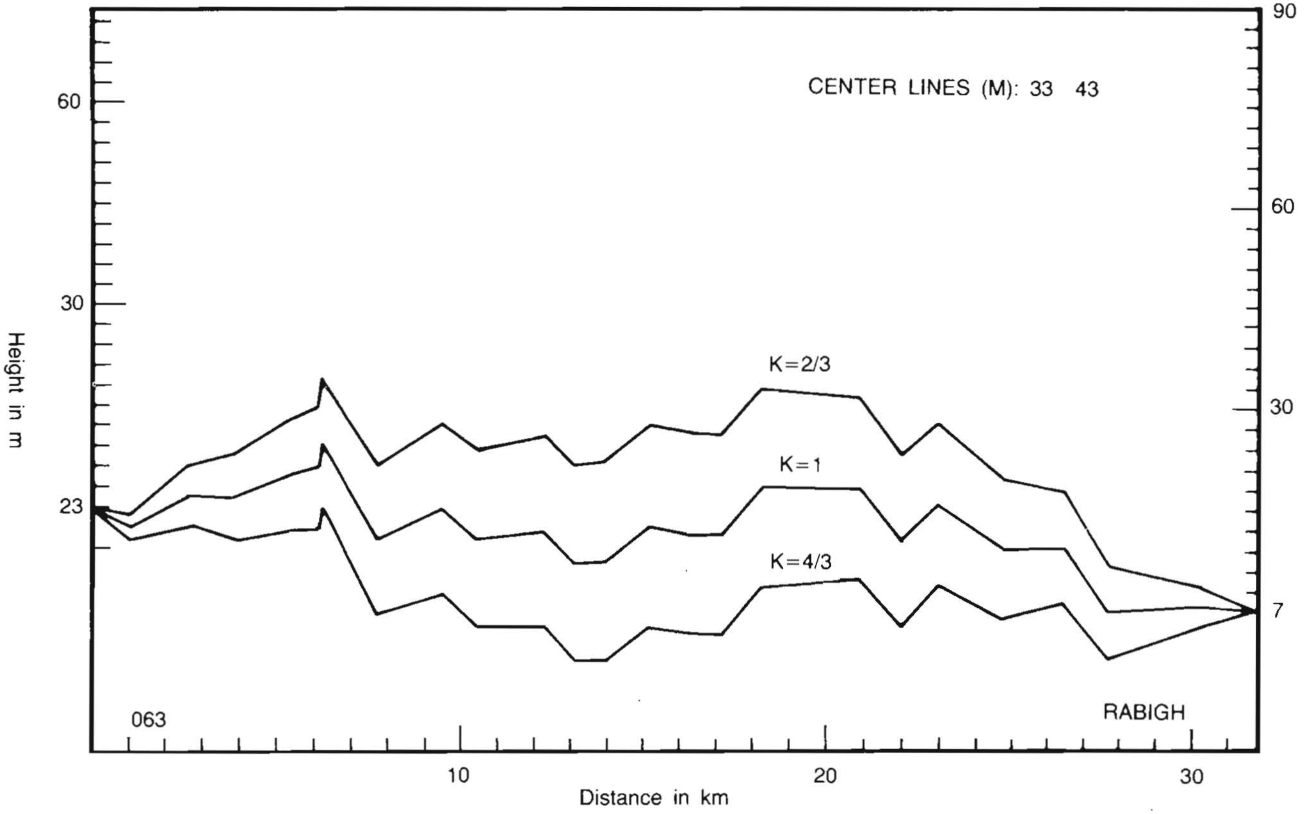


Fig. 2. Path profile 063-Rabigh.

Due to the simultaneous recording of the received signal levels with time over the 4 and 6 GHz channels, we will be able to characterize (as will be discussed in Section 2) the fading variation over the two carrier frequencies. Before we do so, it may be useful to review the previous work that the Ministry of P.T.T. has undertaken.

A measuring system (ARPAS) is used to monitor simultaneously the meteorological data and the received signal levels at the site. The meteorological data recorded are four temperature values, three humidity values, wind speed, and direction all taken at different positions along the microwave tower. Meteorological measurements were conducted with sensors located at hights varying from about 4 to 100 m above mean sea level. Furthermore, there is no indication of any major differences of readings over that range nor is there any indication that fading differs systematically, as reported by the P.T.T. team. It is thus, assumed that readings indicating meteorological events measured at the tower sites can give a qualitative indication of the events which can occur anywhere along the paths. The data are stored on magnetic tapes and processed on a HP 9845 Computer to present a graphical or tabular display of the measured parameters. The results of 20 days' recordings were analysed in detail by some specialists (Ministry of P.T.T. 1979). The group of specialists arrived at the following physical explanations based on the measured meteorological data. There is a nocturnal pool of cool damp air resting on the coastal plain bounded by an elevated "dome" at the junction of this pool and more normal air. The best estimate for the height of this dome in the vicinity of the microwave route is 120-250 m. There are extensive warm dry air intrusions both into the cool damp air pool and above the "dome", emanating from the mountain valleys. These intrusions pass through the radio paths and cause severe fading on all radio channels simultaneously. Anomalous refractive index gradients have been detected for approximately 90% of the time although they are not always associated with fading.

The P.T.T. team concentrated their effort on trying to correlate the fade events encountered on the microwave links with meteorological parameters measured along the repeater sites. The meteorological environment was studied in depth in order to explain the fading mechanism, but no specific fade statistics were obtained or discussed.

These specialists were also doubtful whether there is any simple solution to the problem. Modified antenna system design or increase in tower heights are unlikely to result in a system that would meet the CCIR performance targets.

2. Analysis of Fade Events

2.1 *Fade Statistics*

A continuous record of the automatic gain control (AGC) signal is the data source for the 4 GHz and 6 GHz channels. The AGC signal is proportional to the depth of fade, and fades of up to 45 dB can be detected. Our purpose is to analyze fade events, obtain various fade statistics and distinguish the fade type as frequency selective or nonselective.

For both, the 6 GHz and the 4 GHz channels, fade duration and depth have been recorded. Two types of fading can be distinguished, *viz.* frequency selective and nonselective. Fade events occurring simultaneously over both channels are non-selective. On the other hand, fade on one channel accompanied by a nominal signal on the other channel is considered as frequency selective fading. Six cases are outlined as follows:

i) Selective fade on 4 GHz channel,
ii) non-selective fade on 4 GHz channel, and
iii) total fade on 4 GHz channel.

Three similar cases are also generated for the 6 GHz channel. Fade events with a fade depth smaller than 10 dB are neglected.

Figure 3 depicts the number of minutes during the 15-day test for which a given fade depth was exceeded. Frequency selective fading, which occurred on one frequency only, and nonselective fading, which occurred simultaneously on the 4 GHz and 6 GHz links are shown, together with total fading comprising both types of fades. The non-diversity annual outage probability for the 4 GHz and 6 GHz links of route 04 is shown in Fig. 4. Selective fading, non-selective fading and both types of fading are included.

2.2 *Outage on Unprotected Hops*

When the fade depth on a microwave radio channel exceeds the channel's fade margin, an outage occurs. During an outage, the received RF level is below the FM improvement threshold and a squelch circuit is used to mute the receiver. Such action will cause a service interruption and reduce reliability if traffic is not switched on to a spare "hot-stand-by" channel. The reliability can be defined as:

$$\text{Reliability} = 1 - \text{outage probability} \qquad (1)$$

The nominal received signal level for the hop under consideration is -30 dBm and the FM improvement threshold is -70 dBm. Hence, a fade margin of about 40 dB is available. For a heavy route long haul reliability of 99.98%, the total outage time allowed would be 106 min/ year. Assuming that all the allowed outage budget is kept for propagation, the propagation outage can be prorated over the hope of 31 km as:

$$\text{Allowed outage time} = \frac{31}{4000} \times 106 = 0.82 \text{ min/year}$$

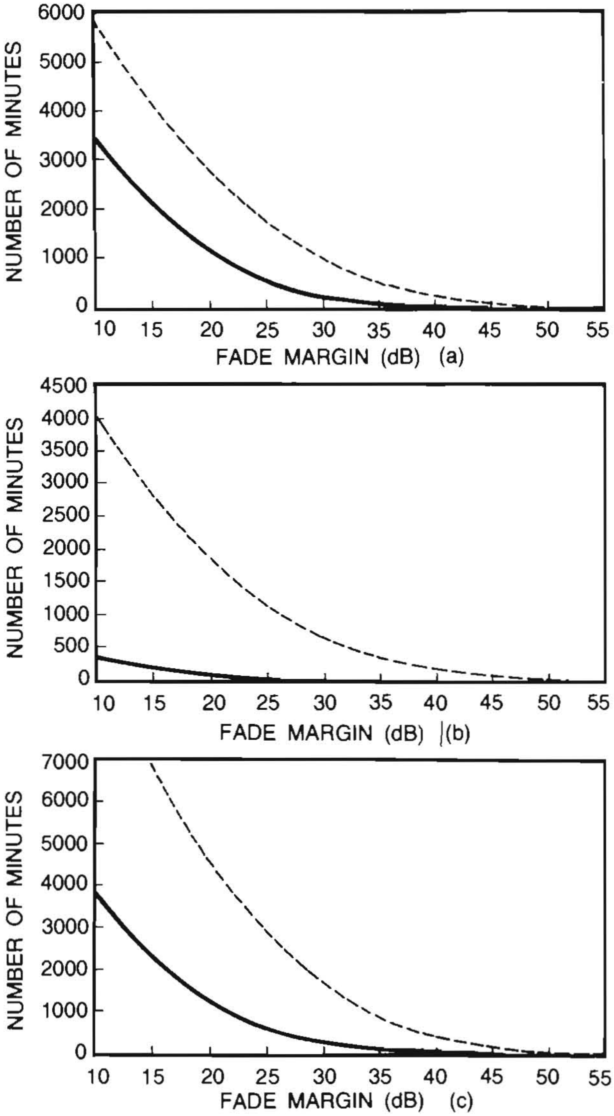


Fig. 3. Number of minutes during the 15-day test for which a fade-depth was exceeded. a) Non-selective, b) selective, and c) both. —— 4-GHz --- 6/GHz.

The number of minutes for which a given fade depth was exceeded is given in Fig. 4 for the observation period of 15 days during the heavy fading months of August and September. To estimate the expected fade over a one year period we first note that the number of minutes for the worst fading month will be 2 × number of minutes of fade during the experiment. The total time per year may be

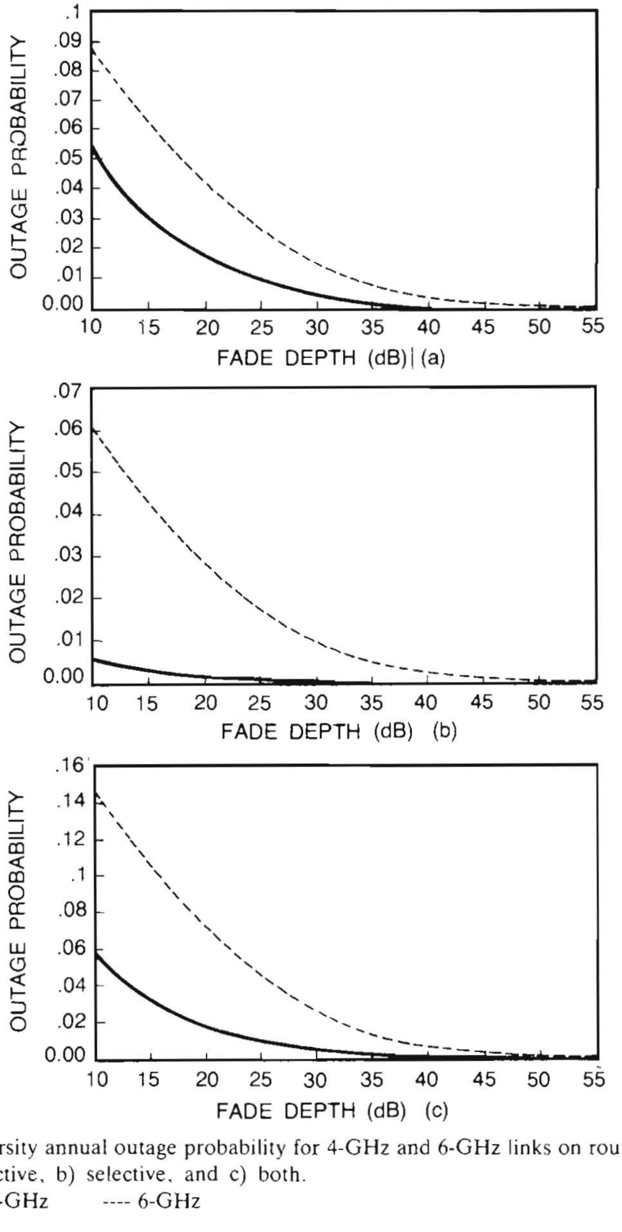


Fig. 4. Non-diversity annual outage probability for 4-GHz and 6-GHz links on route-04 caused by: a) Non-selective, b) selective, and c) both.
——— 4-GHz ---- 6-GHz

estimated as 4 × fade of the worst month, hence, fade time per year can be calculated from Fig. 4 by scaling each fade duration by a factor of 8.

Let us now calculate the prorated outage time per year. We get:

i) 45 × 8 = 360 min of non-selective fading and 3 × 8 = 24 min of frequency selective fading over the 4 GHz link.
ii) 305 × 8 = 2440 min of non-selective fading and 180 × 8 = 1440 min of frequency selective fading over the 6 GHz system.

This shows that annual outage caused by selective fading is relatively small compared to that caused by non-selective fade. The same conclusion can be observed from Fig. 3-b. It shows that the number of minutes for which a fade-depth of 25 dB or more was exceeded is relatively small especially at 4 GHz.

As the above figures are far more than the allowed 0.82 min per year, diversity must be employed.

2.3 *Diversity Improvement*

The practice of improving propagation reliability using frequency and space diversity capitalize on the frequency and space selective of fading. Multipath fading is known to be both frequency and antenna selective. On the other hand, non selective fading, in clear-air-conditions, is mostly due to severe bending or ducting.

For the frequency selective fading the use of diversity reception is bound to improve reliability by an order of several hundreds for typical design parameters (Vigants 1975). On the other hand, obstruction fading (non-selective) may require added clearance, use of less directional antennas or path rerouting. The improvement factor for frequency diversity I_{fd} and space diversity I_{sd}, are given as the ratio of outage time without and with diversity, (Vigants 1968 and Barnett 1972). Hence

$$I_{fd} = \frac{1}{2} \left(\frac{\Delta f}{f}\right) \times 10^{F/10}; \text{4 GHz} \tag{2}$$

$$I_{fd} = \frac{1}{4} \left(\frac{\Delta f}{f}\right) \times 10^{F/10}; \text{6 GHz} \tag{3}$$

$$I_{sd} = 7 \times 10^{-5} \times f \times \frac{S^2}{D} \times 10^{F/10} \tag{4}$$

where Δf is the frequency diversity spacing, f is the frequency in GHz, F is the fade margin in dB, S is the antenna separation in feet, and D is the hop length in miles.

3. Suggested Solutions Based on Data Analysis

In the previous section, it has been shown that the outage time on both the 4 and 6 GHz links exceed the allowed time. Hence, diversity must be employed as follows:

3.1 *Diversity Reception for the 4 GHz Link*

The mpf on the 4 GHz link can be overcome by using the proper diversity. The required improvement is 24/0.82 = 30 times, hence $I_{sd} = 30$. For a fade margin of 40 dB, the required antenna separation is found from equation (4) with f = 4 GHz, D = 15 miles as:

$$S = 4 \text{ meters}$$

On the other hand, frequency diversity may also be used. The frequency separation can be found from (2) as:

$$\frac{\Delta f}{f} = 60 \times 10^{-4} = 0.6\%$$

It is evident that either type of diversity can be employed to reduce selective fading to an acceptable level. For refractive fading, however, a different approach has to be used as discussed in Section 4.

3.2 *Diversity Reception for the 6 GHz Link*

The 6 GHz channel fade occurrence exceeds that of the 4 GHz both for the selective and non-selective fading. For a fade margin of 40 dB, the outage time due to frequency selective fading is 1440 min. Since the allowed fade duration is only 0.82 min/year, a diversity improvement of 4000 times is needed. With space diversity, the required antenna separation can be found from equation (4) as S = 25 m. Similarly, a frequency separation $\Delta f/f = 72.5\%$ is required if frequency diversity is used. However, with such a large improvement, space diversity seems more appealing. From the previous discussion, it becomes clear that frequency selective fading caused by multipath propagation can be overcome by the use of space diversity. The more complicated problem is that of obstruction fading identified as a simultaneous fade lasting for tens of minutes.

3.3. *Non-selective Fading*

Service outage caused by frequency selective fading can be kept within the acceptable 0.66 min/year per hop using space diversity reception. On the other hand, combatting flat fading caused by obstructed transmission, is not as simple for two reasons. First, the improved propagation reliability offered by diversity reception has been based on multipath transmission. No similar results are available for diversity protection against obstruction fading. Even, if we assume that the formulae (2) – (4) derived for multipath propagation are valid for obstruction fading, then, for the 4 GHz link an improvement of 48 × 8/0.82 = 485 is needed, while the 6 GHz improvement is 485 × 8/0.82 = 4900 is needed.

From the above discussion, it is clear that non-selective, obstruction fading is the major cause of outage on the link under consideration and simple diversity techniques may not bring the link reliability to an acceptable level.

3.4 *Results of Antenna Diversity Experiment*

An extensive study of the fading section has been carried by the Ministry of P.T.T. during which meteorological parameters, together with the AGC signal, proportional to the fade depth on the 4 GHz links were monitored. A data acquisition system and a microcomputer have been used to analyse the received signal from the main antenna and from the space diversity antenna.

The results of 20 days of measurements were analysed in detail. Fading was observed in various degrees on all nights with fades of greater than 40 dB being observed on fifteen nights. It is also observed that fading is correlated on both the main and space diversity antennae, although the deeper fades are more severe on the diversity receivers. Such results are in agreement with a similar study by Vigants (1981).

Meteorological measurements have detected the formation of atmospheric layering resulting in an anomalous refractive index gradient for approximately 90% of the time. It is evident from both experiment, *viz.* space diversity and frequency diversity (4 and 6 GHz) that non-selective fading may occur. Depending upon the geometry of the path and the aerial system used, the microwave path may experience extreme subrefractive conditions, super-refractive conditions and layers, all of which cause severe fading which is independent of frequency or of fine structure geometry (spaced diversity).

4. Conclusion

Analysis of two types of fading, experienced on the microwave network in Saudi Arabia has been presented. The analysis has been used on two sets of measurements:

i) Fading on two received signals at 4 GHz and 6 GHz, and

ii) fading on two diversity antenna at 4 GHz.

Frequency selective fading alone will not cause a severe reliability problem since space and/or frequency diversity can be used to attain the required system reliability. On the other hand, obstruction fading, lasting for larger intervals on both antennae and on all frequencies is making the system unreliable. Obstruction fading is more severe on the lower antenna and on the higher (6 GHz) frequency. It may be concluded that:

1. Attenuation fading due to potential path obstruction in a substandard atmosphere is non-selective. Increased fade margin and antenna hights are prime solutions, although outages are usually caused by the accompanying severe multipath fade and not by the diffraction fade alone.
2. Because ducts are often narrow, space diversity may provide some remedial action. Frequency diversity is of little use except as protection against the accompanying multipath fading.
3. It is doubted that there is any simple solution to the problem. Modified aerial system design or a practical increase in tower heights are unlikely to result in a system which would meet the performance targets. It is quite possible that at least some of the sites will have to be moved closer to the mountains.

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تحليل لظاهرة الخفوت على وصلات الموجات الدقيقة الممتدة على الساحل الغربي للمملكة العربية السعودية

عبدالعزيز سالم الرويس و عادل أحمد علي

قسم الهندسة الكهربائية - جامعة الملك سعود - الرياض - ص. ب ٨٠٠ - المملكة العربية السعودية

يتناول هذا البحث تحليلاً لظاهرة الخفوت التي تتعرض لها وصلات الموجات الدقيقة الممتدة على ساحل البحر الأحمر للمملكة العربية السعودية. ويقوم هذا التحليل على قياسات عملية لإشارتين كهربائيتين ترددهما ٤ و ٦ ألف ميجاهيرتز. وتبين من هذا التحليل أن هناك نوعين رئيسيين من أنواع الخفوت اللذين ظهرا بشكل جلي. أولهما الخفوت الناتج عن احتجاب الإشارة، وثانيهما هو الخفوت الناتج عن تعدد مسارات الإشارة.

وقد نوقشت إمكانية استخدام طريقتي التنوع الترددي والتنوع الفراغي لغرض تحسين البث على هذه الوصلة. وتبين أن فكرة تعديل تصميم الهوائيات، أو زيادة ارتفاعات بعض أبراج الموجات الدقيقة زيادة معقولة يشك في قدرتها على الإتيان بحل مقبول للمشكلة. ولعل تحريك مواقع بعض الأبراج تجاه الداخل وبعيداً عن الشاطيء قد يؤدي إلى تحسن أداء وصلة الموجات الدقيقة هذه.