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Frequency Diversity Improvement Factor for Rain Fade Mitigation in Malaysia

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***Abstract*— Microwave communication systems in tropical region like Malaysia, operating at higher frequency ranges, are degraded its performance severely during rains. Hence, the rain fade must be taken in consideration for the MW link design to track the service outage and quality. This paper aims to develop and propose frequency diversity Improvement Factor prediction model for rain fade mitigation from 5 – 40 GHz. The rain attenuation is predicted based on ITU-R rain attenuation prediction method using measured rain rate in Malaysia. The predicted data are analysed to develop and propose a prediction for the improvement factor. The proposed improvement factor model is investigated according to the fade margin where the frequency separation is set to 5 GHz only.**

Keywords—frequency diversity; diversity improvement factor; rain fade mitigation.

I. INTRODUCTION

The evolution of telecommunication technology and the increasing number of user require a large bandwidth, high speed and reliable system designs. These demands resulted in highly saturated lower frequency bands together with the fast growth in capacity requirements pushing the frequency range limits into higher bands, which have enough band-widths to support these needs. Above a certain threshold of frequency, attenuation due to rainfall becomes one of the most important limits on the performance of line-of-sight (LOS) microwave links especially in tropical regions like Malaysia which experience heavier rainfall intensities, so the link quality and availability may be affected, To counteract this degradation and make efficient and economic use of these bands, different techniques have been proposed which are called fade mitigation techniques.

Rain fade is the reduction of the signal power level due to rain rate leading to low quality system, it is considered as the major problem facing microwave links design in tropical climate country like Malaysia where the rain intensity is very high, but telecommunication development demands higher frequency bands where rain has larger fade attenuation effect on the microwave frequencies. Rain attenuation estimation is the main step in counter measuring this effect, by using either ITU prediction model [1] or Crane's model [2], which based on large amount of empirical data.

Fade mitigation technique (FMT) defined as an adaptive communication systems that compensate tropospheric attenuation effects affecting the signal quality in real time. Designing a fade mitigation technique to countermeasure the rain attenuation requires analysing the effect of the rain rate on the microwave link using a prediction models. ITU proposed prediction model used to estimate the rain attenuation level related with each frequency, hence the fade mitigation technique is based on these estimations to meet specific quality of service requirements.

Improving the reliability and quality of the transmission system by using diversity schemes is considered the most effective technique in rain fade mitigation where two or more communication channels with different characteristics are used to deliver the signal through faded channels and decreases the outage percent of time of the link. Frequency diversity scheme uses multiple frequencies as different communication channels, under the condition that each frequency is uncorrelated with others in term of propagation effects. Thus, rain attenuation estimation by ITU used to define the best frequencies to consider as diversity frequencies for the system base frequencies.

II. RAIN FADE MITIGATION TECHNIQUES

Rain fading is the dominant propagation impairment affecting high frequencies in microwave system links and rain fade mitigation is the key element in the design of that system. Fade mitigation techniques; refer to adaptive communication systems that avoid atmospheric attenuation effects on the communication links in real time. The main objective for implementing FMT is to counteract these signal impairments to improve the communications availability and reliability of the microwave link and to design a systems that compensates for channel effects only when required, while at the same time maintain the desired minimum quality of service (QoS) under clear sky conditions [3].

Based on the different characteristics related with mitigation of the signal impairments due to atmospheric propagation, fade mitigation techniques are classified into three main techniques as:

- Adaptive Power control techniques.
- Adaptive transmission techniques.
- Diversity protection schemes.

Where some of these techniques follow the same procedures to maximize the link availability like observing the link quality by measuring the propagation conditions, then they provide a prediction model of the communication link and finally change some parameters of the microwave system according to the prediction model [4].

A. Adaptive Power Control Techniques

Power control is the process of varying the effective isotropic radiated power EIRP, either by increasing the carrier power or the antenna gain on one of the link terminals to maintain a desired power level at the receiver to compensate the signal quality after degradation due to propagation effects (Pan et al., 2008). The overall availability of the connection is improved if the link power is boosted in raining conditions according to the magnitude of rain induced fade, and so adaptive power control.

The adjustment of the carrier power can be either by uplink power control (UPC) at one of the link sites (earth station in case of satellite system) or by downlink power control (DPC) called at the other site (satellite station). In addition, spot beam shaping (SBS) technique which is only for satellite communication system where it is carried by switching a satellite antenna with narrower beam-widths The UPC considered the simplest way in mitigating the rain fading, this is because of the easy idea of increasing the transmission power proportionally with the attenuation level and back into the normal power after the rain effect is gone [5]. This approach is implemented as:

- Open loop system: where the transmitted signal power is varied according to a beacon signal or based on measurements on recently received signal.
- Closed loop system: the adjustment is made directly when the end site receives the degraded signal level via a dedicated control channel.
- Feedback loop system: this system depends on a central control station that monitors all levels of all carriers (for satellite system).

B. Adaptive Transmission Techniques

These techniques focus on varying the way in which signals are processed and transmitted by each site in the communication link, where it apply the most efficient coding rate , encoding technique or modulation technique to avoid rain attenuation on the signal. Mainly these techniques consist of adaptive coding AC, adaptive modulation AM and data rate reduction techniques.

Adaptive coding technique used for the detection and correction of the resulted errors from the propagation effects like forward error correction (FEC), it is implemented by introducing some redundant bits in a digital communication system.

Adaptive modulation technique aims to change the modulation scheme between two states, under clear air conditions a high spectral efficiency modulation scheme and under faded channel link where lower efficient but more robust modulation scheme is used.

Data rate reduction where the rate should be matched with propagation effects level, thus the bandwidth of the information signal at transmission can be reduced during high attenuation levels resulting in an increase in the available signal to noise ratio.

These techniques are implemented with limitations as the cost and the information rate variation leading to different service quality [4-5].

C. Diversity Protection Schemes

Countermeasures against attenuation due to impairment of propagation, primarily rain fades by using two or more communication channels with different characteristics related with fading levels, these schemes are the most efficient fade mitigation techniques because rain attenuation is the main impairment affecting the availability and performance of a microwave communication link operating above 5 GHz. Diversity techniques are effective when the channels are considered to be independently or uncorrelated faded [6].

There are two factors used to describe diversity performance: the diversity gain G (dB), which is defined as the difference between the attenuation without diversity reception and attenuation with diversity reception, for the same probability level. The Improvement factor I, which is defined as the ratio of the non-diversity outage probability to diversity outage for the same attenuation value [7].

Diversity schemes consist of three main techniques according to their implementation on the communication link as:

Site Diversity (SD): for satellite communication system where the satellite beam covers a large geographical area, two or more earth stations are distributed along this area separated by a distance which is calculated according to the rain cell so that the rain fade at each site is different than the other as shown in Fig. 1 [8,11]. A gain and improvement factor models for this scheme is proposed by ITU [9] and Hodge model [10].

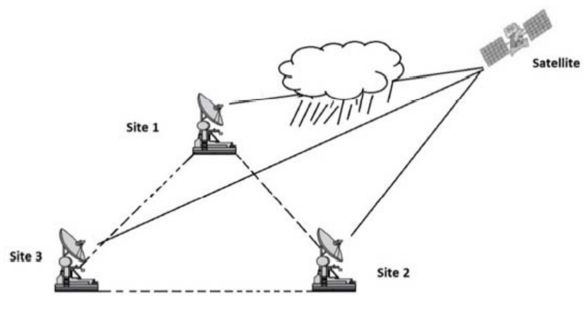


Fig. 1. Block diagram of site diversity scheme.

Time Diversity (TD): transmit the desired signal in different periods of time. The intervals between transmissions of the same symbol should be at least the coherence time which is related with the fade rate, so that different copies of the same symbol undergo independent fading. This technique uses propagation prediction model to estimate the most appropriate time to re-send the message without repeating the request.

Frequency Diversity (FD): The same information signal is transmitted on different carriers, the frequency separation between them being at least the coherence bandwidth.

III. FREQUENCY DIVERSITY IMPROVEMENT FACTOR

The diversity performance could be described in terms of outage percentage of time; the Improvement factor $I_D(P)$ is defined as the ratio between outage percentage of time with a specific fade margin P(A) and the outage percentage with the same margin at the diversity frequency $P_D(A)$, represented by:

$$I_D(P) = \frac{P(A)}{P_D(A)} \quad (1)$$

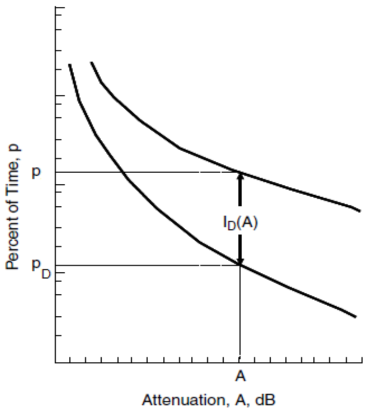


Fig. 2. Diversity Improvement Factor Definition.

Since the improvement definition in equation (1) depends on the outage level at the required attenuation (fade margin), frequency separation, and the diversity (or base) frequency; the rain specific attenuation with respect to the frequency is considered as the milestone to the Improvement factor development.

IV. DEVELOPMENT OF IMPROVEMENT MODEL

The proposed model is for 5GHz separation only at any fade margin, and due to very small attenuation the frequency is in the range of 10 GHz to 40 GHz. Starting from the specific rain attenuation; equation (2), provided by ITU-R model [1,9] we have:

$$\gamma_R = kR_{\%P}^{\ \alpha} \ \text{dB/km} \quad (2)$$

Where k and α are the scattering coefficients and $R_{\%P}$ is the rain rate at outage of P percentage. The measured rain rate in Malaysia 118 mm/hr at 0.01% is used to predict the specific rain attenuation for 5 to 40 GHz using equation (2) and shown in Fig. 3.

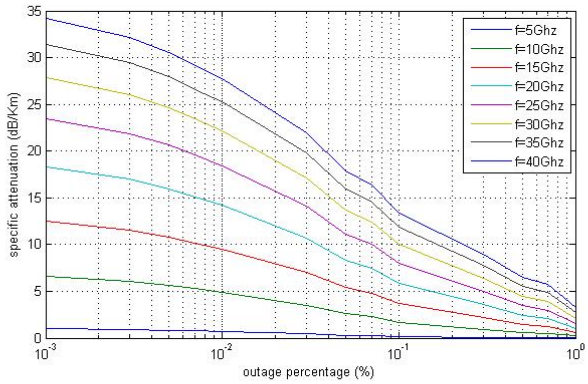


Fig. 3. Specific rain attenuation (dB/Km) predicted for 5 GH to 40 GHz based on measured rain rate in Malaysia.

Fig. 3 shows the variation in the outage percent with respect to the specific rain attenuation which corresponds to the fade margin required for the system. For 5 GHz frequency separation, applying equation (1) to the results shown in Fig. 3, at different fade margins F from 3 to 7 dB/ km and the improvement factors are estimated and presented in Table I.

TABLE I. IMPROVEMENT FACTOR FROM DEFINITION WITH 5 GHZ SEPARATION

f_d (GHz)	f_b (GHz)	IMPROVEMENT FACTOR $I_D(P)$				
		3 dB	4 dB	5 dB	6 dB	7 dB
10	15	4.5	4.5	6.67	11.76	60
15	20	2.16	2.78	2.67	2.45	2.6
20	25	1.8	1.68	1.875	2.14	2.1
25	30	1.17	1.62	1.44	1.619	1.625
30	35	1.18	1.176	1.395	1.32	1.423
35	40	1.24	1.125	1.33	1.33	1.216

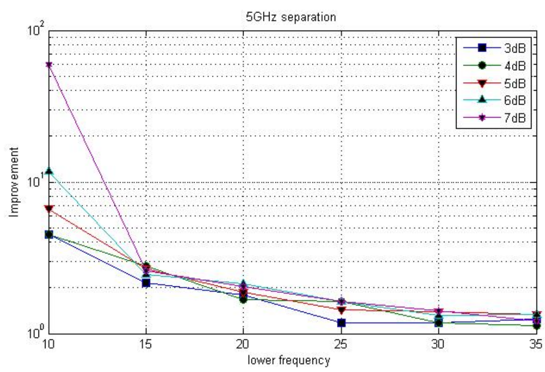


Fig. 4. Improvement Factors for 5 GHz Separation in frequency diversity scheme.

In order to develop prediction model, each graph in Fig. 4 represents an equation between the Improvement factor and the diversity frequency. To come out with one model combining these equations, all curves are fitted with respect to the fade margin (F) as shown in Fig. 5.

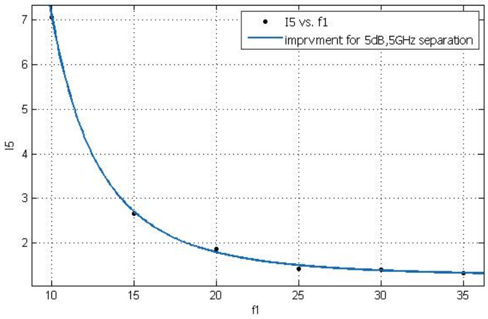


Fig. 5. Estimated improvement factor fitting at 5 dB/km fade margin.

Fig. 5 shows the general frequency diversity Improvement factor model and can be represented by equation (3) as best fit.

$$I = a(f_d)^{-b} + c \tag{3}$$

Where a, b and c are fading related coefficients, each has a value for different fade margins which are estimated and presented in Table II. The coefficients a and b are also plotted in Fig. 6 which provides the best fit equations as (4).

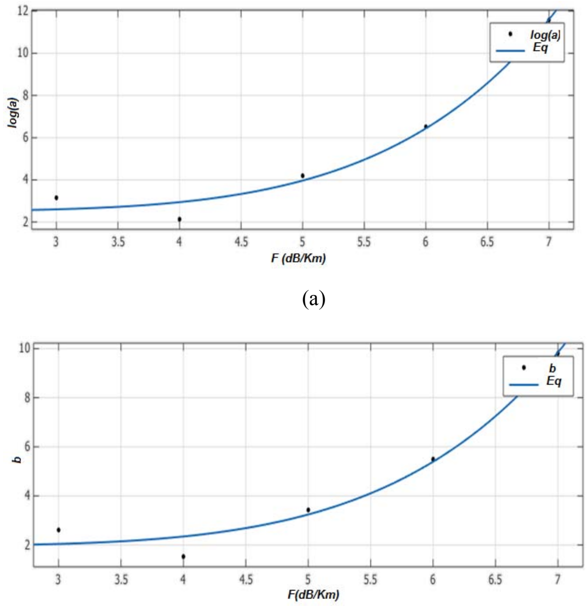
TABLE II. MODEL COEFFICIENTS

F dB/Km	a	b	c
3	1422	2.613	1.029
4	135.7	1.528	0.4911
5	15650	3.431	1.252
6	3246000	5.5	1.488
7	3.759E+11	9.808	1.549

Hence the proposed frequency diversity improvement factor model for 5GHz separation and 1 km microwave path length is proposed as equation (4).

$$I = a(f_d)^{-b} + c$$
$$a = 10^{(2.2252*10^{-4}*F^{5.48}+2.515)}$$
$$b = 1.885 * 10^{-4} * F^{5.467} + 2$$
$$c = 1.1618 \tag{4}$$

Using eq(4), the improvement factors model are predicted for the same specific rain attenuation and shown in Fig. 7.



(a)

(b)

Fig. 6. Best curve fitting (a) coefficient a and (b) coefficient b.

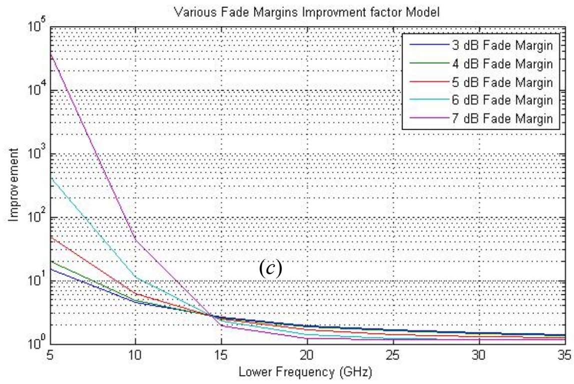
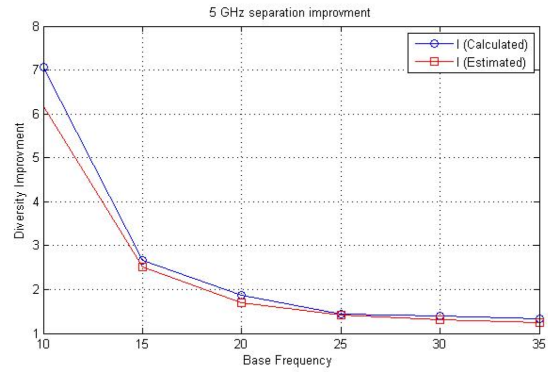


Fig. 7. Improvement factors based on proposed model.

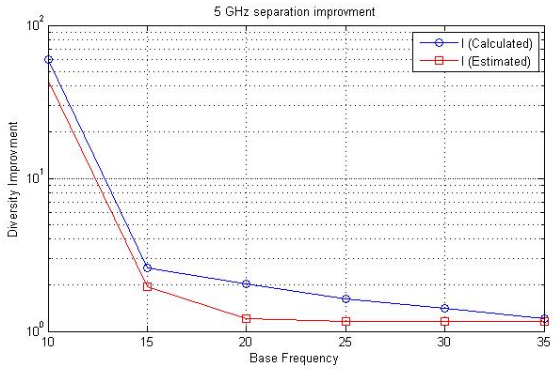
As noted from Fig. 7, the fade margin effect is divided into two regions according to the diversity frequency. First region before 14 GHz where the higher the fade margin the higher the Improvement is, the second region where the improvement changes with the fade margin in a nonlinear form and this effect can be neglected due to relatively small change in the improvement.

V. VALIDATION

Comparison between Fig. 7 and Fig. 4 shows the differences between the calculated improvement factor by the general definition and the estimated from the proposed prediction model. For fixed fade margin, Fig. 8 represents the validation comparison for 5 GHz separation improvement at 5-7 dB/km margins for predicted (estimated) and ITU-R calculated based on measured rain rate. From Fig. 8, the difference is clear due to the nonlinear coefficient of the proposed model.



(a)



(b)

Fig. 8. Predicted and calculated frequency diversity improvement factor at (a) 5dB/Km and (b) 7dB/Km.

The validation is also supported with measured rain attenuation at 14.6, 21.95, 25 and 37 GHz [12-14]. The frequency diversity improvement factor based on one year rain attenuation measurement at four frequencies are estimated and compared with predicted values using proposed model in (4) and presented in Table III.

TABLE III. COMPARISON BETWEEN PREDICTIONS AND MEASUREMENTS

f(GHz)	I(7)	
	Measured	**Predicted**
14.6-21.95	1.318	2.28
21.95-25	1.379	1.8
25-37	1.037	2.2

VI. Conclusion

Frequency diversity can be implemented using a proposed diversity improvement factor model for 5 GHz frequency separation based on the fade margin needed for the system design. It is observed that the improvement changes rapidly within the frequency range of 5-15 GHz and it is almost no improvement at this separation above 15 GHz.

The proposed frequency diversity model is very useful tool in designing a reliable microwave communication links in a tropical country like Malaysia, where the diversity system's reliability may be achieved according to amount of improvement between the base frequency and the diversity frequency. Further investigations are needed to provide a model for any frequency separation and any path length for the microwave links.

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