The Analysis of Protection Ratio and Its Effect of Interference-to-Noise Ratio for Digital Microwave System with Diversity

Kyoung-Whoan Suh[1] · Won-Gyu Jang[2]

Abstract

In this paper, the derivation of the protection ratio for the digital microwave system with diversity is newly suggested for a basic guidance of initial planning for frequency coordination, and computational results are presented for an actual radio frequency band. The net filter discrimination has been also examined to see the effect of the adjacent channel protection ratio caused by adjacent channel interference. In addition, the protection ratios for the space or frequency diversity system are analyzed in terms of diversity improvement factors to find out an equivalent allowable noise-to-interference ratio (*N/I*) from degraded fade margin. According to results for 6.2 GHz system, with the space diversity of 25 m distance between antennas or the frequency diversity of $\triangle f/f$=0.05, under 64-QAM and 60 km at BER 10^{-6}, the protection ratio can be greatly reduced in comparison to the non-diversity system. So, assuming that only the same protection ratio as the non-diversity system is kept, it is shown that the system with diversity may get more interference level of *N/I* allowing from 9.0 to −5.9 dB or from 6.0 to −4.3 dB for the space or frequency diversity. In consequence, it is concluded that the diversity system is more robust or tolerable for interferences or fades, which may play an important role in overcoming *N/I* to some extent.

Key words : Digital Microwave System, Protection Ratio, Fade Margin, Space or Frequency Diversity, Net Filter Discrimination.

Ⅰ. Introduction

As a basic method of frequency coordination in the wireless network, some criteria based upon the concept of a protection ratio have been adopted with a generic interference management methodology. The protection ratio(*PR*) defines a minimum relative power ratio of wanted to unwanted signals in the interfered receiver [1],[2]. So, to achieve proper frequency coordination for new wireless service systems in conjunction with existing wireless networks such as radio relay, cellular, satellite, and radar, the protection criteria for interference analysis must be performed in advance to meet good quality of service recommended by International Telecommunication Union Radiocommunication(ITU-R) Sector.

Since the mid 1990's, two main outputs relevant to protection from interference in the digital microwave network have been studying in view of defining a maximum permitted interference level and a predictable protection ratio based upon a fade margin[3],[4]. Some associations such as Federal Communications Commission(FCC), European Telecommunications Standards Institute(ETSI), and Radio Authority(RA) have illustrated practical applications based upon system parameters such as EIRP, noise figure, occupied channel bandwidth, transmission capacity, and signal degradation due to interference. On the other hand, Australian Communications Authority(ACA) has shown the initial frequency coordination method based upon the protection ratio by using the fade margin including interference limit, and however, *S/N* of modulation was not taken into consideration as a variable even though it actually varies from modulation schemes.

Recently, to generalize and compensate the limited previous works, an efficient and comprehensive derivation of PR has been introduced[5]. Also, the criteria of error performance and availability degradation objectives from interference from emission/radiation of other sources have been studying under a co-primary basis including diversity system[6]. Even though the digital microwave system with diversity is usually used for overcoming the multi-path or rain fading, the protection ratio for the diversity system is required to see how the diversity improvement factor has an effect on the protection ratio for a given availability.

In this paper, the derivation of the protection ratio for the digital microwave system with diversity is newly suggested and computational results are presented for an actual radio frequency band applicable to basic guidance

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of initial planning for frequency coordination. The net filter discrimination(NFD) has been examined to see the effect of the adjacent channel protection ratio caused by adjacent channel interference. In addition, the protection ratios for the space or frequency diversity system are investigated in terms of diversity improvement factors and fade margin to derive how the protection ratio is directly related with equivalent allowable noise to interference ratio(N/I).

Ⅱ. Formulation of Protection Ratio

2-1 Protection Ratio(PR)

Fig. 1 depicts a typical case of a potential interference scenario for one direction of transmission with a single frequency. Provided that link AB means an existing service and link CD is a proposed new service, the potential interference paths of AD and CB marked by dotted lines are also presented with the corresponding transmit and receive antenna discrimination angles (Φ and Θ) relative to the respective antenna bore-sight azimuth. For the input of a potential interfered receiver, the power ratio of wanted-to-unwanted signal can be expressed by $C/I=P_{wntd}-P_{unwntd}$ in dB. In order to make successful frequency coordination, C/I is compared with the relevant protection ratio. Therefore, the power ratio of wanted-to-unwanted signal should be greater than the protection ratio(PR), which is given by $C/I \geq PR$. The co-channel protection ratio caused by co-channel interference is expressed as a function of S/N of modulation scheme, interference-to-noise ratio, multiple interference allowance, fade margin of multi-path or rain attenuation [7],[8]. On the other hand, the adjacent channel protection ratio associated with adjacent channel interference includes the NFD as well as variables of the co-channel protection ratio. The NFD depends upon Tx spectrum mask and overall Rx filter response[9].

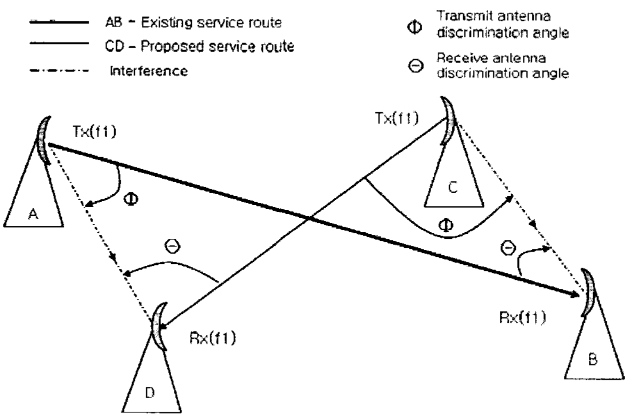

Fig. 1. Wanted signal (AB, CD) and interference (AD, CB) paths.

The protection ratio is given by [5]

$$PR = S/N(BER = 10^{-y}) + N/I + MIA + FM - NFD \quad (1)$$

where S/N is the power ratio of signal to noise in dB depending upon the modulation and coding scheme at a given BER of 10^{-y} and therefore, ITU-R F.1101 is referenced for S/N of M-ary QAM at BER 10^{-6}. N/I is the power ratio of noise to interference such as 10, 6 or 3 dB which brings about 0.5, 1 or 2 dB degradation in the receiver threshold signal level due to interference, respectively. MIA is multiple interference allowance related with multiple interference sources, which usually permits 4.0 dB. FM is the fade margin of dispersive or flat fade. To understand parameters related with Eq. (1), the pictorial concept for the protection ratio is characterized in Fig. 2[5], where I_t means a total noise power in the interfered receiver.

For a given link, the required fade margin due to multi-path fading is equal to fade depth exceeded for the percentage of time (p_w) in the average worst month. The probability that the received power p is less than or equal to p_0, at the frequency f (GHz), in the worst month, is given by[7]

$$P(p \leq p_0) = Kd^{3.6} f^{0.89} (1 + |\varepsilon_p|)^{-1.4} \times \frac{p_0}{p_n} \times 10^{-2} \quad (2)$$

where p_n is a received power at no fading, and $|\varepsilon_p| = \frac{1}{d}|h_r - h_t|$ is the absolute value of the path inclination in milliradians where d is path length in km, f is frequency in GHz, and h_t and h_r are altitude of the transmitter and receiver antennas in meters, respectively. The geoclimatic factor k is described in ITU-R Rec. P. 530-10 for the average worst month from p_L based upon empirical relation ship.

From Eq. (2), FM can be expressed by[5]

$$FM = 10\log_{10}[Kd^{3.6} f^{0.89} (1 + |\varepsilon_p|)^{-1.4}] - 10\log_{10}(p_w) \quad (3)$$

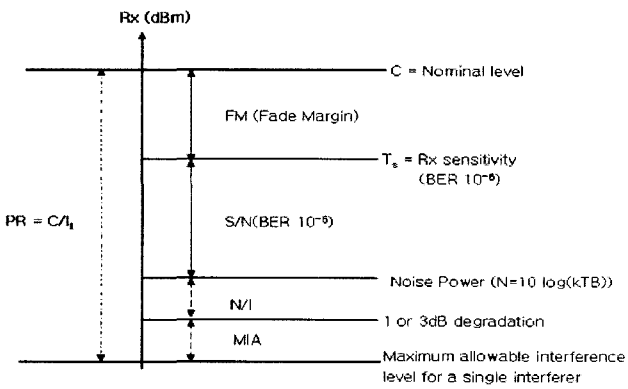

Fig. 2. Pictorial concept for the protection ratio.

where $FM = 10\log\left(\frac{p_n}{p_0}\right)$ and $p_w = P(p \le p_0)\times 100(\%)$.

On the other hand, it is well known that a flat fade margin for attenuation due to rain is dominant in the millimeter wave band. So, according to ITU-R Rec. P.838[8], for any given path, the attenuation caused by rain exceeded for percentage of time $p_w(0.001 \sim 1)$ of the worst month is

$$A_{p_w} = A_{0.01}\times 0.12\times P_w^{-(0.546+0.043\log_{10}p_w)} \tag{4}$$

where $A_{0.01}$ is the attenuation due to rain exceeded for 0.01 % of the worst month. Eq. (4) is valid for radio links located in latitudes (North or South) equal to or greater than 30 degrees. For other latitudes, A_p is also given in ITU-R Rec. P.838.

2-2 Net Filter Discrimination(NFD)

The definition of NFD is given by[5]

$$NFD = 10\log\left(\frac{P_c}{P_a}\right) = 10\log\left(\frac{\int_0^\infty G(f)|H(f)|^2 df}{\int_0^\infty G(f-\triangle f)|H(f)|^2 df}\right) \tag{5}$$

where P_c is the total power received after co-channel RF, IF, and base band filtering, and P_a is the total power received after offset RF, IF, and base band filtering. The functions of $G(f)$ and $H(f)$ are Tx spectrum mask and overall Rx filter response, respectively, and $\triangle f$ denotes the frequency separation between a desired signal and an interference signal. As pointed out in ITU-R Rec. F.746, this value is produced purely by Tx spectrum and by the overall Rx filtering, and it does not comprise any other decoupling such as antenna discrimination or the actual interfering power level.

2-3 Fade Margin with Diversity

In analog or narrow band digital links, in the worst month, the probability that the received power, without diversity, is equal or less than p_0, where $p_0 \ll p_n$ is given by[10]~[12]

$$P(p \le p_0) = F\times\left(\frac{p_0}{p_n}\right) \tag{6}$$

where F is a constant, depending upon the method chosen, which is often known as the deep fade occurrence factor mention in ITU-R Rec. P.530-10.

If the system adopts double space diversity, with a selection combiner as shown in Fig. 3 and receiver antennas vertically spaced, the probability p_r that the output signal is equal or less than p_0 is

$$P_r(p_r \le p_0) = \frac{P(p \le p_0)}{i_0} \tag{7}$$

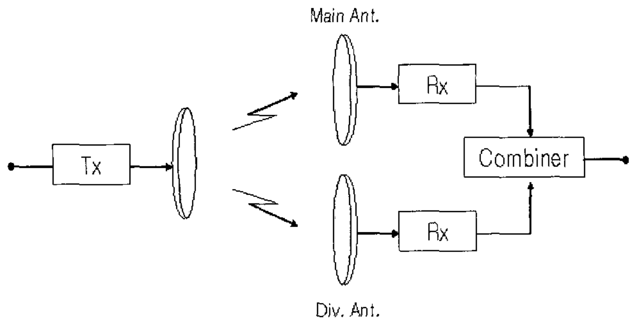

Fig. 3. Simplified block diagram of digital microwave system with space diversity.

where i_0 is the space diversity improvement factor which is given as

$$i_0 = 1.21\times 10^{-3}\times\frac{d_c^2 f}{d}\frac{g_s}{g_p}\left(\frac{p_n}{p_0}\right) \tag{8}$$

where g_s and g_p are the gains of the main and the diversity antennas, respectively, f is the operating frequency in GHz, d is the path length in km, and d_c is the distance between antenna centers in meters. Eq. (8) is valid for the range of parameters: $0.25 \le g_s/g_p \le 1$, $2 \le f \le 11$, $5 \le d_c \le 25$, $10^{-5} \le (p_0/p_n) \le 10^{-3}$, and $10 \le i_0 \le 200$.

Substituting Eqs. (2) and (8) into Eq. (7), the resultant fade margin is given by[13]

$$FM = \frac{1}{2}\left(10\log\left(\frac{Kd^{3.6}f^{0.89}(1+|\varepsilon_p|^{-1.4})}{1.21\times 10^{-3}\times\frac{d_c^2 f}{d}\frac{g_s}{g_p}}\right) - 10\log(p_w)\right) \tag{9}$$

Also, let's consider the fade margin for the frequency diversity. Providing that we use double frequency as shown in Fig. 4 with a selection combiner, the improvement factor becomes[10],[12]

$$i_0 = \frac{80}{fd}\frac{\triangle f}{f}\frac{p_n}{p_0} \tag{10}$$

where $\triangle f$ is the frequency difference between carriers in GHz. When $\triangle f > 0.5$ GHz, then one should use

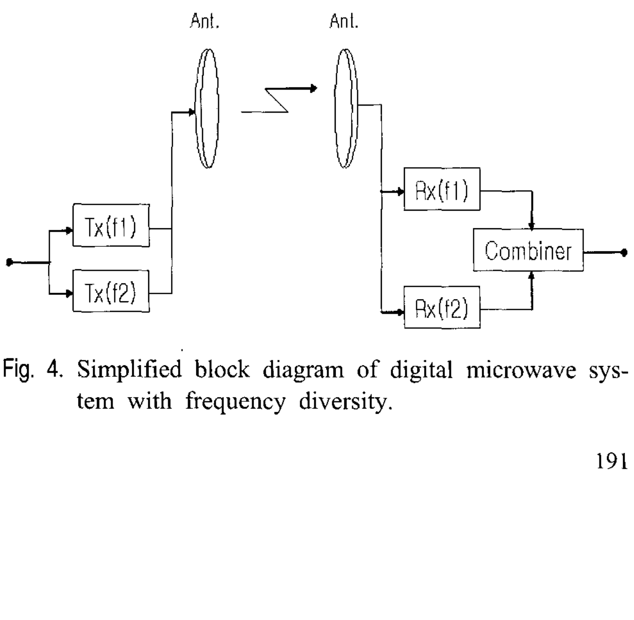

Fig. 4. Simplified block diagram of digital microwave system with frequency diversity.

Δf=0.5 GHz. Eq. (10) is valid for the range of parameters: $0.25 \le g_s/g_p \le 1$, $2 \le f \le 11$, $30 \le d \le 70$, $\Delta f/f \le 0.05$, and $5 \le i_0$.

Substituting Eqs. (2) and (10) into Eq. (7), the fade margin for the frequency diversity is given by[13]

$$FM = \frac{1}{2}\left\{10\log\left(\frac{Kd^{3.6} f^{0.89}(1+|\varepsilon_p|^{-1.4})}{\frac{80}{fd}\ \frac{\Delta f}{f}}\right) - 10\log(p_w)\right\} \tag{11}$$

In addition, as can be expected, from Eqs. (9) and (11), the resultant fade margins are greatly reduced in comparison to that for the non-diversity system based upon Eq. (3). The reduced fade margin can be expressed by a margin degradation (ΔM) or margin loss in dB, which may lead to an equivalent allowable interference of N/I. For the interfered receiver system with N/I, the margin degradation is given by

$$\Delta M = 10\log(1 + 10^{(-N/I)/10}) \tag{12}$$

where N and I are noise and interference powers in the same receiver. Then, the change of N/I can be found from the margin degradation due to the adoption of the diversity system.

Ⅲ. Simulated Results and Discussion

3-1 Non-diversity System

Let's examine the protection ratio for the non-diversity system of 6.2 GHz. The values of parameters taken here are N/I=6 dB, MIA=4.0 dB, p_L=10, p_w=0.01 %, and ε_p=0. Signal-to-noise ratio(S/N) is referred from ITU-R F.1101, and it gives 23.8 dB for 64-QAM at BER 10^{-6}[14]. N/I of 6.0 dB equals 1.0 dB degradation in receiver threshold signal level due to interference.

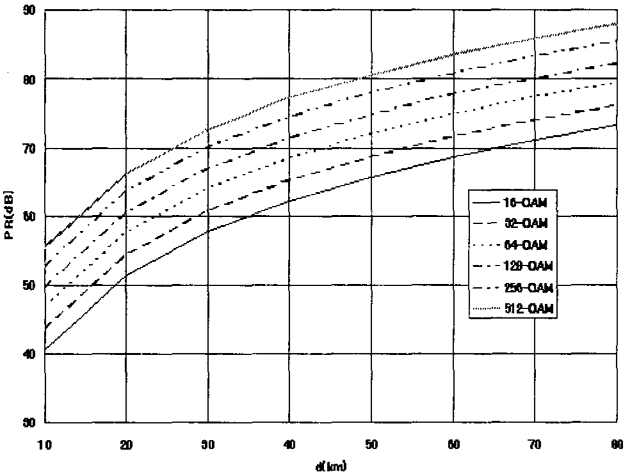

Fig. 5. Co-channel protection ratio at 6.2 GHz.

Fig. 5 shows the protection ratios for the co-channel interference as a function of distance and M-ary QAM, and it illustrates the protection ratio of 74.9 dB for 64-QAM and 60 km. The physical meaning of this value is that C/I of the interfered receiver in the existing network should have more than 74.9 dB to assure coexistence for a new digital microwave system.

To calculate the adjacent channel protection ratio, it is necessary to examine the net filter discrimination. According to channel allocation of ITU-R F.383-5, 29.65 MHz per channel is allocated for high capacity transmission in 6.2 GHz band. For instance, the transmitter spectrum mask used for the net filter discrimination is the response of (a) in Fig. 6[15] and the receiver spectrum mask noted by, $|H(f)|^2$, is the square of the magnitude of overall receiver filter response, which is also taken as the same transmitter spectrum mask with a view to illustrating the calculation procedure for the sake of convenience.

The calculated NFD for frequency offset Δf is shown in Fig. 7 and gives about 26.5 dB at offset frequency 30 MHz for integration interval from −30 MHz to +30 MHz. The adjacent channel protection ratio, 48.4 dB at the first adjacent channel 30 MHz can be easily obtained by subtracting 26.5 dB from the co-channel protection ratio of 74.9 dB. Hence, if one applies the same procedure to the remaining QAM as well as other modulation schemes, a variety of the protection ratio are readily obtained by means of adding or subtracting S/N difference with respect to S/N of 64-QAM.

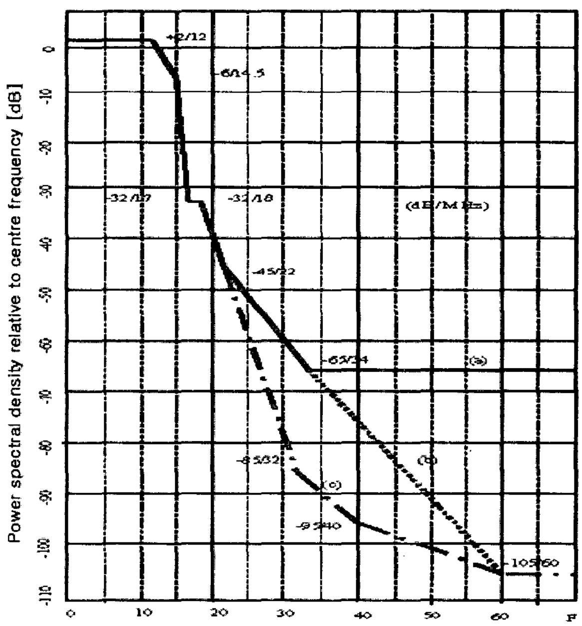

Fig. 6. Transmitter spectrum mask with 29.65 MHz channel bandwidth.

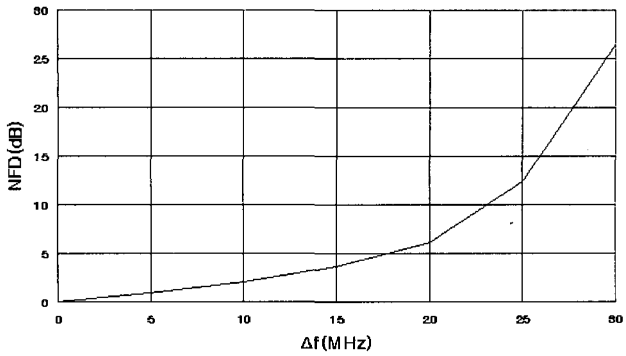

Fig. 7. NFD as a function of offset frequency.

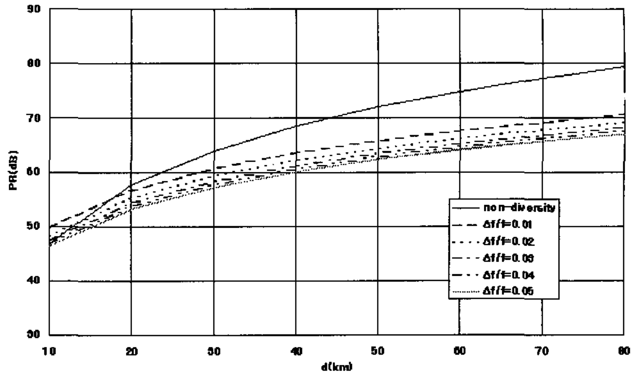

Fig. 9. Protection ratio of frequency diversity for $\triangle f/f$.

3-2 Diversity System

First, let's consider the protection ratio for the space diversity system. As an example, Fig. 8 shows the co-channel protection ratios as a function of distance between main and diversity antennas with the same antenna gain, while other variables keep the same ones as Fig. 5 except for N/I=9 dB. Due to the space diversity the compound N/I at the combined IF receiver yields 6 dB, which is the same value as the non-diversity system. Assuming that the system with the space diversity is operated, the protection ratio is greatly reduced as the parameter d_c is increased up to 25 m in comparison to the non-diversity system. This means that the space diversity system is less sensitive to interference, resulting in more improved transmission quality or availability.

Second, to check the protection ratio for the frequency diversity system, Fig. 9 shows the resultant output for 6.2 GHz with $\triangle f/f$ from 0.01 to 0.05 while conserving the same conditions as Fig. 5. It is shown that if $\triangle f/f$ increases up to the limit, the protection ratio is gradually decreasing due to the frequency diversity improvement factor. In case of 60 km distance, the protection ratio is about 10.7 dB less than that for the non-diversity system, which implies that the frequency diversity system provides better performance for interferences or fades by getting more sufficient protection ratio.

Finally, to draw the value of equivalent allowable interference due to the use of the diversity system, Fig. 10 illustrates degraded fade margin resulting from the difference of fade margin between the non-diversity and the diversity systems.

Fig. 11 shows the variation of N/I to derive the equivalent allowable interference. If one takes the degraded

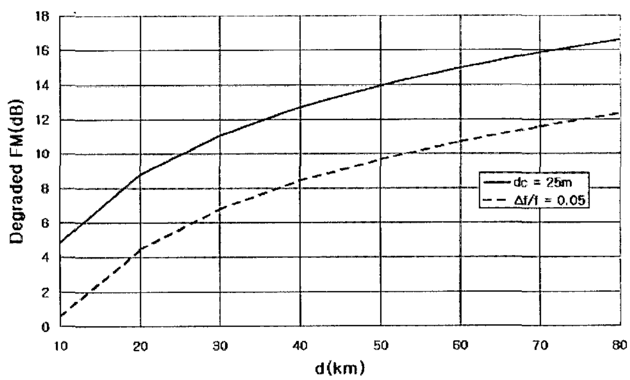

Fig. 10. Degraded fade margin due to diversity use.

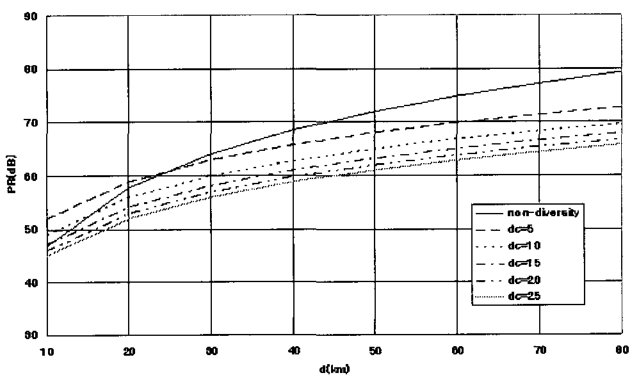

Fig. 8. Protection ratio for a distance between antennas.

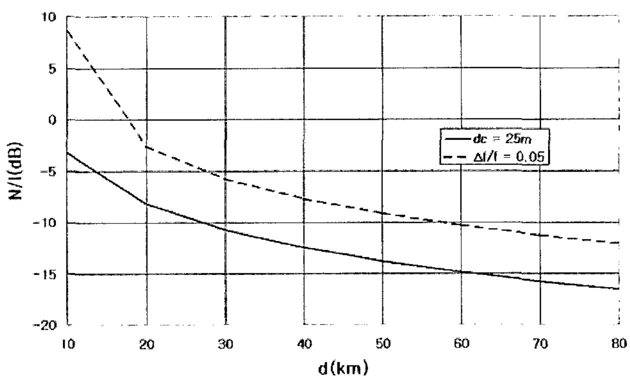

Fig. 11. Variation of N/I due to degraded fade margin.

fade margin for the space diversity in Fig. 10, it gives 15.0 dB for 60 km distance. It is noted that the degraded fade margin of 15.0 dB is equal to the degraded *N/I* of -14.9 dB as shown in Fig. 11. Therefore, the space diversity may permit more interference level of *N/I* from 9.0 to -5.9 dB so long as the same PR for the non-diversity system is maintained. In the similar way, the *N/I* change for the frequency diversity can be calculated and the degraded fade margin of 10.7 dB for 60 km distance is equal to the degraded *N/I* of -10.3 dB in Fig. 11. So, this may permit more interference level of *N/I* from 6.0 to -4.3 dB.

Ⅳ. Conclusions

In this paper, the derivation of the protection ratio has been newly presented for digital microwave systems with diversity, and simulated results were presented for an actual radio frequency band applicable to initial planning of frequency coordination. Also, the protection ratios were investigated in terms of diversity improvement factors, fade margin, and *N/I* for the digital microwave system with the space or frequency diversity.

According to results for 6.2 GHz system with 64-QAM at 60 km and BER 10^{-6}, it was shown that fade margin and co-channel protection ratio reveal 41.1 and 74.9 dB, respectively. For net filter discrimination with respect to 30 MHz channel bandwidth, it provided 26.5 dB at the first adjacent channel of 30 MHz, and this resulted in the adjacent channel protection ratio of 48.4 dB. In addition, the co-channel protection ratio for the space diversity system provided about 62.9 dB for distance of 25 m between two antennas, which was 12 dB less than that for the non-diversity system. On the other hand, the co-channel protection ratio for the frequency diversity system yielded about 64 dB for $\Delta f/f=0.05$, which is 10.7 dB less than that for the non-diversity system. It was interesting to note that the PR needed to keep the same availability can be greatly reduced in comparison to the non-diversity system. Therefore, if only the same PR as the non-diversity system is maintained, the diversity system may get more interference level of *N/I* allowing from 9.0 to -5.9 dB or from 6.0 to -4.3 dB for the space or frequency diversity system. As the results, the diversity system is more robust or tolerable for interferences or fades, which may play an important role in overcoming *N/I* to some extent.

The presented method gives a comprehensive solution for calculating the protection ratio and can be applied to the basic guidance for initial planning of frequency coordination in the digital microwave networks up to millimeter wave band.

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