A MODEL OF FREQUENCY DIVERSITY IMPROVEMENT FOR DIGITAL RADIO

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1. Introduction And Summary

Figure 1 shows the comparison of the frequency diversity improvement factors (FDIF) measured recently from Georgia [1] and Wyoming [2,3] in the U.S.A. for 6-GHz 90-Mb/s systems to the predictions from the existing model [4]. The FDIF is the factor by which the outage time of a digital radio channel is reduced by a frequency diversity protection system. It is seen that the existing model is too pessimistic by about a factor of 10 for digital radio applications. The existing frequency diversity model was based on analog radio experience and does not properly account for the sensitivity of the digital radio to multipath dispersion effects.

In this paper, we present a broad band ($\geq$ 250 MHz), three-ray model to analyze the FDIF for digital radio subjects to dispersive multipath fading on microwave line-of-sight paths. The calculated FDIF for digital radio by this three-ray model agrees well with the measured data. The model further shows that a smaller frequency separation provides a larger 1-by-1 FDIF and is in sharp contrast to that of analog radio experience. The use of this new model will provide substantial cost savings to digital radio users by avoiding unnecessary space diversity protection or by allowing longer radio hop lengths.

2. Broad Band Modeling of Multipath Dispersion

2.1 Digital Radio Outages Caused by Multipath Dispersion

In the recent few years, the adaptive equalization technology, including amplitude and transversal equalizers, advanced so rapidly that the multipath dispersion caused digital radio outages can occur only if a notch of the multipath dispersion falls inside the channel occupied by the digital signal. In other words, the slope and the minor higher order curvatures in the channel transfer function produced by a notch falling outside of a digital radio channel are so well equalized by the advanced adaptive equalizers that no outage occurs.

Therefore, for a 1-by-N frequency diversity protected system, a dispersion caused outage can occur only if two or more channels are hit by notches simultaneously. The analysis of FDIF for digital radio, thus, requires a broad band model of multipath dispersion covering an entire common carrier band. For example, for the North American 6-GHz common carrier band, the model must cover the 250-MHz band occupied by the seven working channels plus the protection channel transmitting in the same direction.

The available experimental data [5, 9] indicate that the number of the propagation paths on a line-of-sight microwave radio hop during multipath condition can be greater than two and that the probability distributions of the relative delays are approximately exponential.

2.2 Limitations of The Two-Ray Model for Broad Band Applications

In modeling multipath dispersion within a radio channel (e.g., 30 MHz), many authors [6,7,8] have used various forms of two-ray model to study the effects of multipath dispersion on digital radio performance. Although the actual number of propagation paths can be greater than two [5], Rummler [7] shows that a two-ray model with a fixed relative delay of 6.3 nanoseconds (ns) is adequate to represent about 95 % of the measured multipath dispersion events within the 30-MHz channel bandwidth of a 6-GHz channel on the 26-mile, Atlanta-Palmetto path in Georgia in the Summer of 1977. However, the two-ray model with the fixed relative delay of 6.3 ns is found to be inadequate to represent the dispersion statistics measured on a 64-mile path in Wyoming [2, 8]. To overcome this deficiency, M. H. Meyers [8] generalized the two-ray model to allow the delay to be a random variable and the mean delay to be a function of hop length and geographic location. The mean delay was found to be about 0.4 ns for the 26-mile path in Georgia and about 1.5 ns for the 64-mile path in Wyoming [6, 8].

The 1982 experimental data [1] from the 26-mile path indicates an FDIF of 45 for the 1-by-1 diversity case with a carrier frequency separation of 60-MHz. In the two-ray model, a relative delay of 12 ns or longer is required to create a notch frequency separation of 90 MHz or smaller to hit the two channels simultaneously with 60 MHz carrier frequency separation. The exponential distribution of the delay in the two-ray model with a 0.4 ns mean delay yields an extremely small probability of 10^{-12} for the delay to exceed 12 ns. This implies an unrealistically large FDIF in the order of 10^{12} for the 1-by-1 case with the 60-MHz separation. This gross inconsistency with the measured data, clearly, indicates that the two-ray model is inapplicable to the broad band frequency diversity modeling. This conclusion leads us to adopt a three-ray model for the broad band analysis discussed in the next section.

2.3 The Three-Ray Model for Frequency Diversity Analysis

The three-ray model consists of a main ray with unity amplitude and zero reference delay and two additional rays with randomly varying amplitudes and delays. The amplitudes of the second and the third rays are assumed to be uniformly distributed within the range of zero to unity, and the delays are assumed to be exponentially distributed. The FDIF of the three-ray model is calculated by using a computer Monte Carlo simulation process. Essentially, the simulation process computes the probability of two radio channels being hit simultaneously by two notches with respect to the pobablity of a notch in a channel. For the 26-mile path, the mean delay of the second ray is assumed to be 0.4 ns according to References [6] and [8]. The FDIF predicted by the three-ray model is a strong function of the remaining model parameter, namely: the mean delay of the third ray. The simulation results indicate that a mean delay of 2 ns for the third ray yields an FDIF in close agreement with the measured data from the Georgia 26-mile path.

3.0 Results and Discussion

With the parameters of the three-ray model determined in Section 2.3, we calculate the 1-by-1 FDIF for the Georgia 26-mile path as a function of the frequency separation as shown in Figure 2. Also shown in Figure 2 as a dashed line is the prediction of FDIF by the analog radio model. It is seen that: (1) The FDIF predicted by the analog radio model is too pessimistic, especially for small frequency separation, and (2) as the frequency separation decreases, the digital radio FDIF increases whereas the analog radio FDIF decreases.

An intuitive explanation for the increasing digital radio FDIF with decreasing frequency separation is that the frequency separation between notches is inversely proportional to the delays among the rays. The longer delay, corresponding to smaller frequency separation between notches, has a smaller occurrence probability which leads to the smaller probability of simultaneous outages on two channels with small frequency separation. Therefore, for digital radio routes, we recommend minimizing the frequency separation between the working channel and the protection channel to maximize the FDIF. The computer simulation program has also been used to calculate the FDIFs of 1-by-N systems and will be published in the future.

We are also applying a similar concept to model the space diversity for digital radio. It is anticipated that the space diversity improvement factor for digital radio may increase as the antenna spacing decreases, again in sharp contrast to the analog radio experience.

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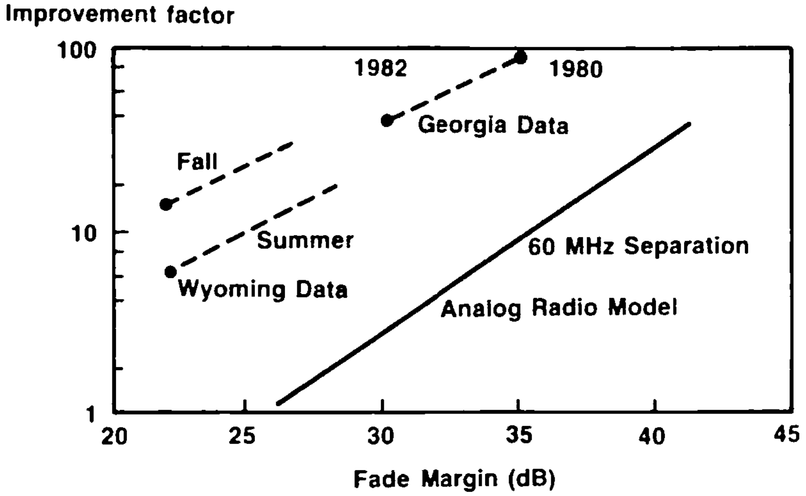

Figure 1 - Comparison of measured frequency diversity improvement factors for digital radio in Georgia and Wyoming with those predicted by the existing analog radio model.

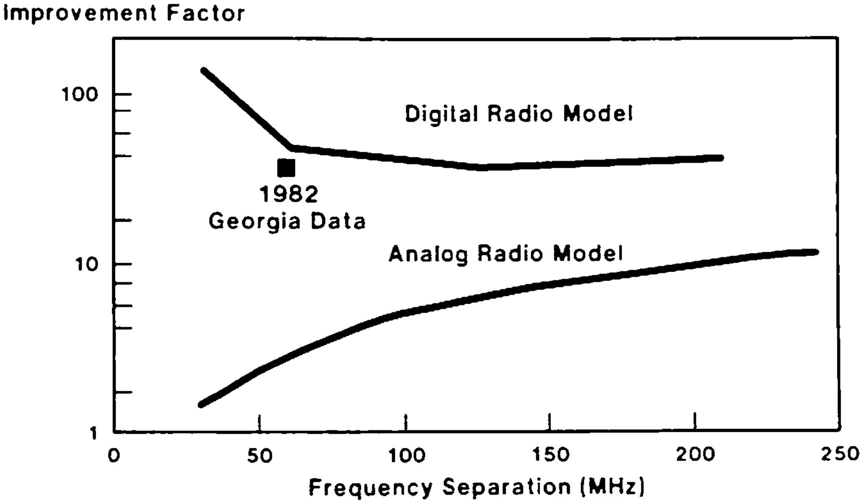

Figure 2 - Dependence of 1-by-1 frequency diversity improvement factor on frequency separation.