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| Source | John Liebetreu<br>SiCOM, Incorporated<br>7585 East Redfield Road<br>Scottsdale, AZ 85260<br>Voice: 480-607-4830<br>Fax: 480-607-4806<br>E-mail: john@sicom.com |
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| Abstract | This paper describes a radio equipment "signature," a means of comparing different digital radio designs in their sensitivity to multipath fading, and reviews the concept of DFM, dispersive fade margin, as a measure of the expected outage due to selective fading. Since dispersive fade margin accounts for all contributions to sensitivity of a digital radio operating in a frequency-selective fading environment, it provides an ideal metric for comparing digital radios with one another. |
| Purpose | The radio equipment signature, described in this document is proposed for consideration as a performance metric to facilitate comparison of different digital radio designs, each of which may comply with emerging air interface standards. Although different radios may each be standards-compliant, applying performance metrics such as DFM and radio signatures such as those identified herein will provide a valuable discriminant among vendor offerings. |
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# Dispersive Fade Margin: A Physical Layer Performance Metric

*John Liebetreu*
*SICOM, Incorporated*

## Introduction

The study of channel distortions during periods of multipath fading has a history extending to early deployments of microwave long-haul radio links. Early researchers found intersymbol interference to be the main source of channel-induced degradation in emerging digital radio links, so it made little sense to consider traditional flat fade margin as a performance metric.

In these early deployments, the need was recognized for estimating link performance during periods of frequency selective (multipath) fading. In addition, a metric was needed that provided good correlation between laboratory tests and field measurements, to enable assessment of the performance of a radio design prior to its field installation.

Early research by Lundgren and Rummler[1] formed the basis of a statistical model for the transfer function of the dispersive channel, which can cause severe intersymbol interference in digital radio systems. In addition to their statistical channel characterization, Lundgren and Rummler related this model to the probability of outage due to selective fading; this outage probability can be computed with data that is easily generated from a simple and direct set of digital radio performance measurements.

This paper describes a radio equipment "signature," a means of comparing different digital radio designs in their sensitivity to multipath fading, and reviews the concept of DFM, dispersive fade margin, as a measure of the expected outage due to selective fading.

## *Digital radio signatures: W-curves*

Computation of DFM relies on measurement of the robustness of the digital radio and modem to frequency selective fading to obtain a "signature" for the digital radio and modem combination These signatures, known as W-curves (or dispersion signatures), measure the robustness of a communications system to frequency selective fading as a function of frequency. The tests for robustness are based on a two-ray multipath model (Rummler model) with 6.3 ns delay between the main (stronger) and secondary path rays. Note that no loss of generality results from using a fixed value for ray delay, and it has no associated physical interpretation, although signatures can be measured for values other than 6.3 ns. A simple scaling rule relates signatures created with different ray delay values: the width of the signature is independent of ray delay, and the amplitude of the signature is proportional to the ray delay value[2].

In the Rummler model, the main path may either lead or lag the secondary path. The case where the main path leads the secondary path is referred to as the minimum-phase multipath case, and the case where the main path lags the secondary path is referred to as the non-minimum-phase multipath case. Both the non-minimum phase W-curve and the minimum-phase W-curve signatures must be measured to obtain a true picture of a digital radio's robustness to frequency-selective multipath fading.

The procedure used to construct the W-curve signature for a digital radio requires that a notch be created at a given frequency offset from the carrier frequency; the notch depth is increased until a specified BER is attained (typically between $10^{-3}$ and $10^{-6}$). The depth of the notch is then plotted at this frequency offset. The shape of the resulting plot of notch depths versus frequency offset is responsible for its name. Two typical examples of the W-curve are depicted in figure 1; one of these W-curves corresponds to a BER specification of $10^{-3}$, and one corresponds to a BER of $10^{-4}$; both W-curves are for the minimum phase multipath case. Both the minimum dispersion signature and the non-minimum-phase dispersion signature are used to compute DFM, since some equalizers behave very differently under minimum-phase conditions than for non-minimum-phase conditions.

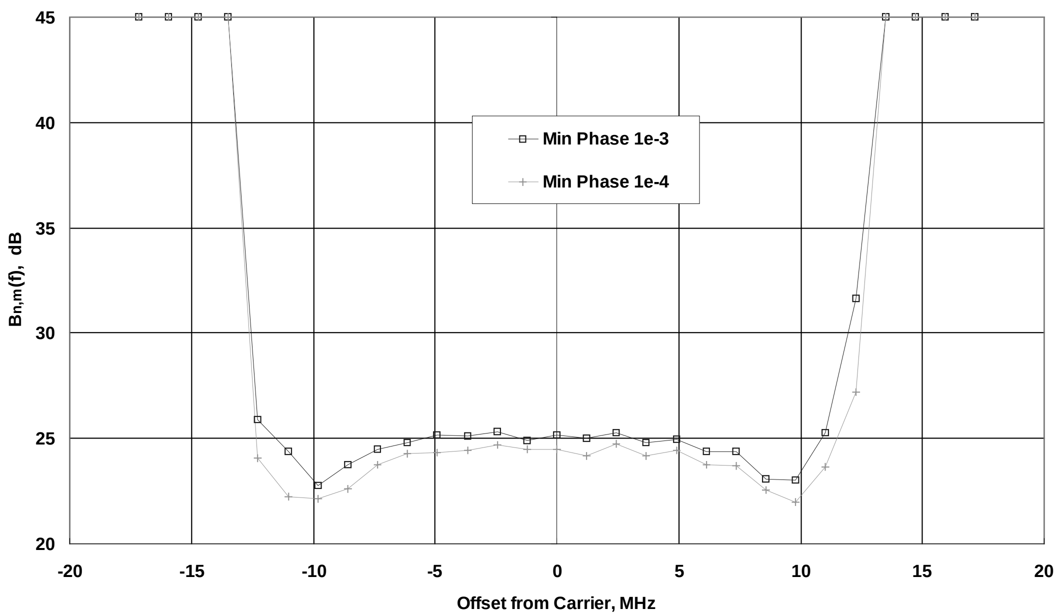


Figure 1. Tyical dispersion signatures

## Dispersive fade margin definition

DFM (Dispersive Fade Margin) is defined to be the fade depth exceeded for the same number of seconds at a threshold error rate (the threshold error rate is defined to reside at the value of interest for which the dispersion signatures were created).

DFM is calculated based on the W-curves using the computation[3]

$$DFM = 17.6 - \log_{10}\left(\frac{S_w}{158.4}\right)$$

where,

$$S_w = \int_{-f_1}^{f_1}\left(e^{\frac{-B_n(f)}{3.8}} + e^{\frac{-B_m(f)}{3.8}}\right)df$$

where $B_n(f)$ is the W-curve for non-minimum phase fade, $B_m(f)$ is the W-curve for minimum phase fade, and $f_1$ sets the signal-occupancy bandwidth, which is the bandwidth of interest. Notice that the expression for $S_w$ is that of a statistical expectation, computed with the assumptions that the distribution of the notch frequency is statistically independent of the other parameters and of uniform distribution over frequency, and the notch depth is exponentiallydistributed.[4] In this expression, it is assumed that minimum-phase and non-minimum-phase fades occur with equal probability; thus the two signatures are given equal weighting in computing DFM. In general, a digital radio with a dispersion signature that falls above that of another radio will result in less outage.

## Conclusion

Since dispersive fade margin accounts for all contributions to sensitivity of a digital radio operating in a frequency-selective fading environment, it provides an ideal metric for comparing digital radios with one another. It also serves as a valuable tool in evaluating the effects modem signal processing techniques, such as adaptive equalization, have on link performance in selective fading. Finally, DFM serves as a means of comparing the relative robustness of single-carrier and multi-carrier modulation systems in selective fading environments. It is unlikely to be productive to attempt to standardize on any specific equalization technique, or even on any particular value of DFM. However, it would be of considerable value to the service providers to standardize on a single metric which facilitates comparison of modems using alternative methods to deal with signal distortion induced by propagation in the millimeter-wave bands.

[1] C.W. Lundgren and W.D. Rummler, "Digital radio outage due to selective fading—observation vs. prediction from laboratory simulation," Bell System Technical Journal, pp.1073-1100, May-June 1979.

[2] M. Emshwiller, "Characterization on the performance of PSK digital radio transmission in the presence of multipath fading," ICC'78 Conference Record, Toronto, Ontario, CANADA, Paper 47.3.

[3] Microwave digital radio systems criteria, Bellcore Technical Reference TR-TSY-000752, October 1989.

[4] W.D. Rummler, R.P. Coutts, and M. Linger, "Multipath fading channel models for microwave digital radio," IEEE Communications Magazine, November 1986, pp.30-42.