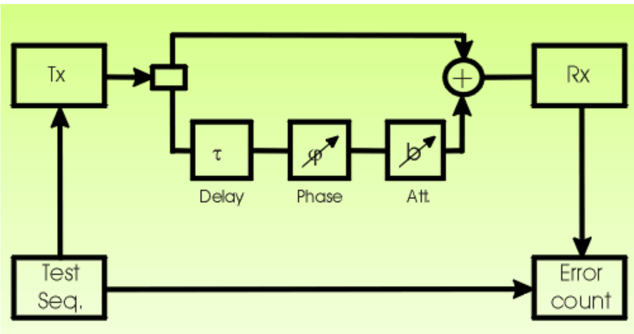
Training Program : Point-to-Point Radio Link Design

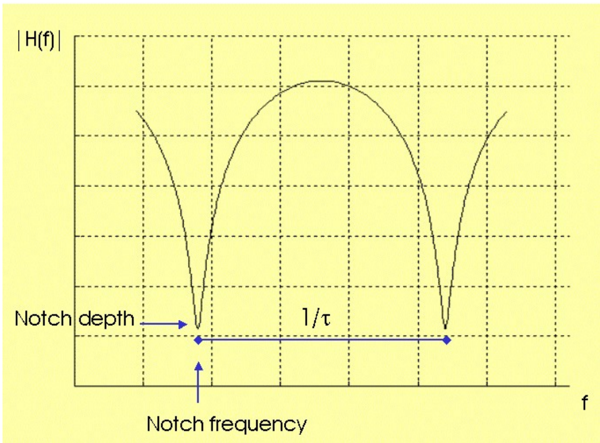
Course : Multipath Fading

COMPLEMENTS to Lesson 3 : Multipath Outage and Countermeasures

Signature Measurement

The equipment signature gives a measure of the sensitivity of radio systems to channel (amplitude and group delay) distortions as produced during multipath propagation events [1]. The measurement set-up is shown in the figure. The Tx signal is modulated by a test sequence and is transmitted through a simulated multipath channel, modeled as a two-path channel (the direct path plus the echo delayed path).





Signature measurement setup and Two-path channel transfer function

The power level and the phase of the delayed signal can be adjusted by means of a variable attenuator and a variable phase shifter. Assuming a normalized signal amplitude equal to 1 in the direct branch and b (< 1) in the delayed branch, then the Two-Path Channel Transfer Function is:

$$H(f) = 1 - b \cdot \exp[-j(2\pi f\tau - \varphi)] = 1 - b \cdot \exp[-j2\pi\tau(f - f_0)]$$

where : τ = Echo delay, assumed as constant;

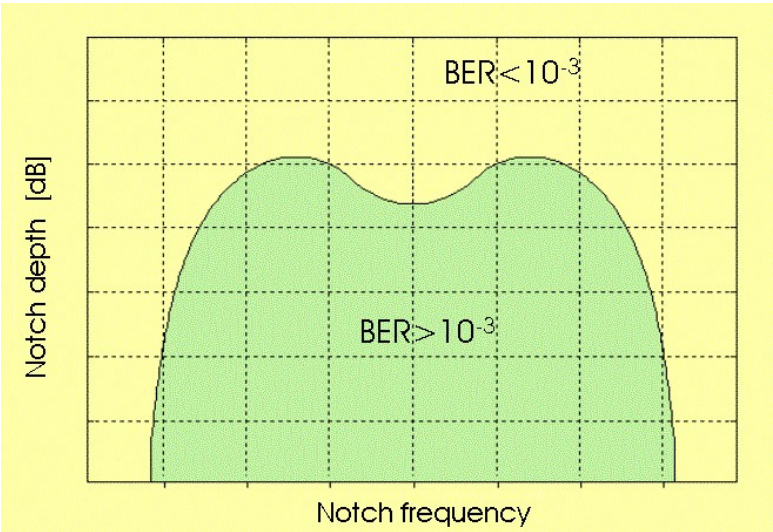
$f_o = \varphi / 2\pi\tau$ = Notch Frequency;

B = Notch depth (in dB) = $-20 \, Log_{10}(1 - b)$ (maximum attenuation in the transfer function).

The above definition refers to a Minimum-Phase Transfer Function. Otherwise, if the signal amplitude is b (< 1) in the direct branch and 1 in the delayed branch, then similar definitions apply, but a Non-Minimum-Phase Transfer Function is obtained.

The first step in the measurement procedure is to adjust the phase shift φ, so that Notch Frequency f_o is set to a given value, with echo amplitude close to zero. Then, the echo amplitude is increased, with increasing Notch Depth B (transmission channel more and more distorting). Consequently, the Bit Error Rate (BER) will increase. The echo amplitude is increased, up to the "Critical Notch Depth B_C", corresponding to BER = 10^{-3} (or any other desired threshold). The point [B_C, f_o] is a signature point.

The same steps are repeated for different notch frequencies f_o, in order to plot a complete signature curve in the Notch Depth vs. Notch Frequency plane.



Example of Equipment Signature in the Notch Depth / Notch Frequency plane.

In that plane each point corresponds to a pair of notch parameters, so it is representative of a particular channel state. The points below the signature show the channel states for which BER > Threshold. Therefore, the area below the signature gives a measure of the receiver sensitivity to multipath distortions. For an unequalized signal, typical signature width may be of the order of 1.5 times the symbol rate, while using equalization it is significantly reduced.

The procedure is carried out with Minimum- and Non-Minimum-Phase Transfer Functions, in order to produce Minimum- and Non-Minimum-Phase Signatures.

More on Outage Prediction

The ITU-R outage prediction model [2], taking account of frequency selective fading, gives:

$$P_{OUT} = P_{NS} + P_S$$

where P_{NS} is the outage probability due to signal attenuation (non-selective outage component, same formula as for narrowband systems), while P_S is the outage probability due to signal distortion.

The selective component P_S depends on the receiver sensitivity to signal distortion. The Signature measurement characterizes a radio equipment under this aspect. The signature template is approximated as a rectangle, with τ, W, and B, defined as the measurement delay [ns], signature width [GHz], and depth [dB], respectively. P_S is given by :

$$P_S = P\ 2.15 \cdot \eta \cdot [\ W_M \cdot 10^{-BM/20}\ (\ \tau_m^{\ 2} / \tau_M\ )\ +\ W_{NM} \cdot 10^{-BNM/20}\ (\ \tau_m^{\ 2} / \tau_{NM}\ )\ ]$$

where : $\eta = 1 - \exp[-0.2\ Po^{0.75}]$ is the Multipath Activity (directly related to the Multipath Occurrence Factor Po);

$\tau_m = 0.7 \cdot [\ D / 50\ ]^2$ is the mean time delay [ns] of multipath echo components (a function of hop length D in km);

W, B, τ have subscripts "M" or "NM" depending on Minimum- or Non-Minimum Phase channel in signature measurement.

Overall Performance and Fade Margin

The usual rule in compiling the Link Budget is to take account of obstruction loss expected for most of time, that is obstruction loss OL_S with Standard k-factor value (generally 1.33). Under this assumption, "Nominal Received Power" (that is Rx power expected for most of time) and Fade Margin are computed and Outage caused by multipath is predicted.

A useful complement to the above analysis is to extend performance evaluation to include also the obstruction loss OL_E in extreme sub-refractive conditions, that is with the minimum k-factor (usually estimated for 0.01 or 0.001% of time).

To do so, a reduced Fade Margin (FM_E) is computed, with OL_E instead of OL_S included in the link budget. It is recognized that path obstruction is caused by propagation trajectories and refractivity conditions associated to specific atmospheric stratification. On the other hand, in "the case of multipath fading, a different type of atmospheric stratification temporarily creates multiple transmission paths" [3]. Therefore, the two propagation impairments can be considered as mutually exclusive and it should be not appropriate to estimate multipath outage with the reduced FM_E.

The appropriate design procedure is to check if FM_E > 15 -20 dB, in order to guarantee a sufficient margin for moderate Rx power fluctuations, even with minimum k-factor.

Useful References

[1] ITU-R Rec. P.1093-2, " Effects of multipath propagation on the design and operation of line-of-sight digital fixed wireless systems", 2006

[2] ITU-R Rec. P.530-18, "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems", 2021

[3] Vigants A., "Microwave Radio Obstruction Fading", BSTJ, vol. 60, n. 6, 1981