Source: **Motorola**
Title: **SCM Fading Model**
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1. SUMMARY

This contribution investigates further details of the fading behavior of the spatial channel model, which is characterized by narrow angle spreads. In a previous contribution[1], the fading behavior was analyzed from 0-5λ, and further work described here increases the lag distance to 20 λ. An additional model is also considered.

The fading effects, from narrow angle spreads are examined and compared using the autocorrelation function, and the length of the simulated segment is considered.

2. AVERAGE FADING BEHAVIOR

When correlating over numerous time profiles of the complex fading envelope, the result is a classical Bessel function when all AoAs are sampled. This characteristic remains evident even with the larger lag distances. When averaging across uniformly random AoAs, the average behavior converges to the classical Bessel function for each of the fading models that were examined. Figure 1 illustrates the case where models a, b, c, and e (described below), are evaluated with random AoA for each sampling interval, and where the lag distance extends now to 20 λ. The results are all real-valued and indicate that the current SCM model, or models with additional randomization in angle or power are all comparable and produce a sufficiently good match to the ideal Bessel function when evaluated across the various possible angles of arrival.

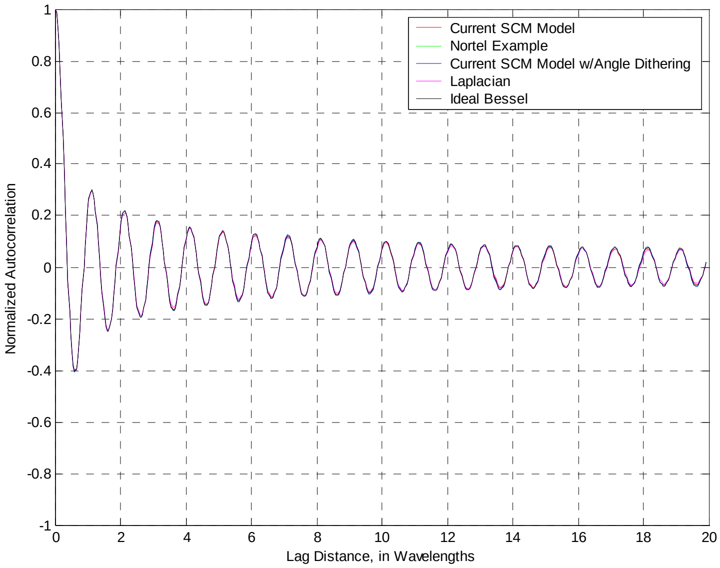

Figure 1, Fading Autocorrelation, σ_{AS}=35º, AoA=Random, with different sub-ray configurations

When limited to a restricted range of AoAs, the correlation plot may be very much higher, and be real or complex as shown in [2]. The magnitude of the autocorrelation increases as the angle spread decreases, and it is a function of the AoA.

In order to evaluate the SCM fading behavior and compare to different models, the following three cases were defined in [2] and comparisons were illustrated. These same models will be used for further comparisons, with an additional model added. They are:

a.) The SCM model with 20 sub-ray of equal power and Laplacian in angle with $\sigma_{AS} = 35°$

b.) The Nortel example[3] is shown where an equal angle spacing is used with a Laplacian power per sub-ray. The angles are randomly perturbed by a uniform distribution within a bin around each sub-ray, and the powers are correspondingly set with a Laplacian envelope according to the angles that were used.

c.) This example uses the SCM model with 20 equal power sub-rays, but includes a uniform randomizing of each of the angles within a bin around each sub-ray. The powers remain constant.

d.) Ideal correlation from an integral[4]. (The plot is shown corrected below.)

e.) Laplacian AoA. This fourth case is added for comparison. This case draws 20 sub-rays with an AoA with a Laplacian PDF and AS = 35˚. For each experiment, a random draw is made of using this distribution of angles with 20 equal amplitude sub-rays.

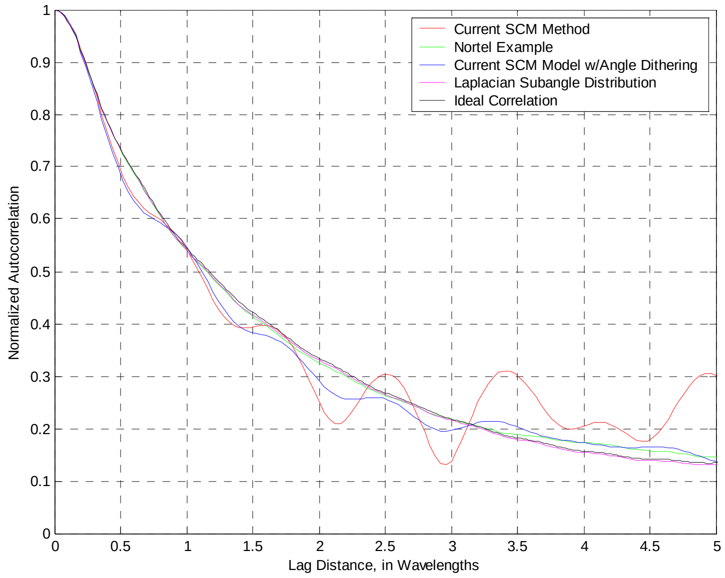

Figure 2, Autocorrelation (Magnitude), σ_{AS}=35º, AoA=30º with different sub-ray configurations

Figure 2 shows an updated autocorrelation plot, where the "ideal" line has been corrected, and the new model, case (e) is shown. This plot compares the correlation for the different techniques when the AoA = 30º. Although the results are complex valued, only the magnitude is shown in this result.

The deviations from ideal are mainly due to the quantizing effect of having only 20 components. It should also be noted that the variations in correlation will be different for every AoA that is evaluated, but when averaging over the AoAs, the result converges to the ideal Bessel function as shown in Figure 1.

In the cases shown, the Nortel example, and the new Laplacian technique have the most randomness per draw, and these converge better to the ideal average value, with the Laplacian technique appearing slightly better. The SCM model is relatively close, but deviations from the ideal are evident.

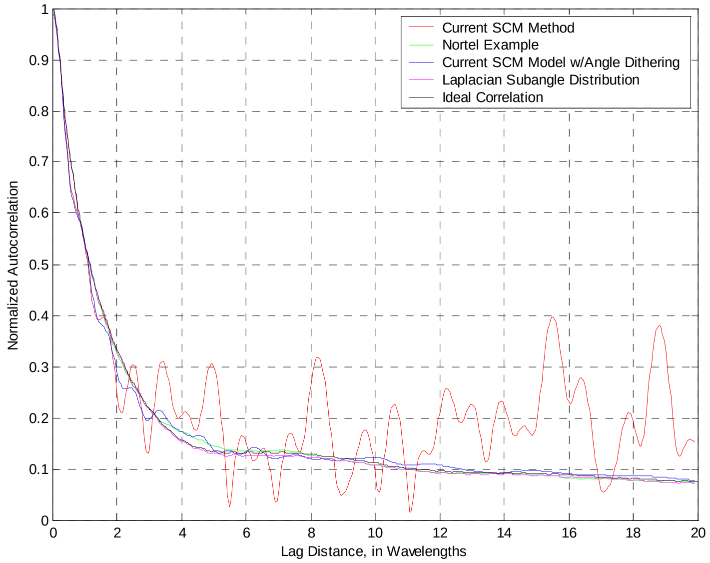

Figure 3, Autocorrelation (Magnitude), σ_{AS}=35º, AoA=30º with different sub-ray configurations

Figure 3 investigates the autocorrelation when larger lag distances are used. The models with more randomness tend to approach and stay closer to the ideal average at all the lag distances shown. Although the SCM experiences significant variations, this is primarily at very low correlations. Also when averaging over various AoAs, the result was shown to be a good match to the ideal Bessel shown in Figure 1.

3. CORRELATION FOR SHORT SEGMENTS

When fading profiles of limited duration are sampled, the fading correlation does not as closely resemble the average, but is more noisy. This is true for all types of fading models including the SCM.

In order to evaluate the variations expected for short fading segments, the following experiments were made using the four fading approaches given above by models a, b, c & e. In each case, numerous 100λ fading segments were evaluated for their complex autocorrelation. To compare the results, the correlation magnitude was used as a statistical measure. The following figures plot the mean, 10% and 90% values of the correlation magnitudes. Note that the mean value (solid line) of the correlation magnitudes is different than the magnitude of the mean value of the complex correlation (dashed line), which was used previously in [2], and in Figures 1, 2 & 3. This new measure is introduced since it is difficult to compare %-tiles of complex numbers without taking their magnitudes first.

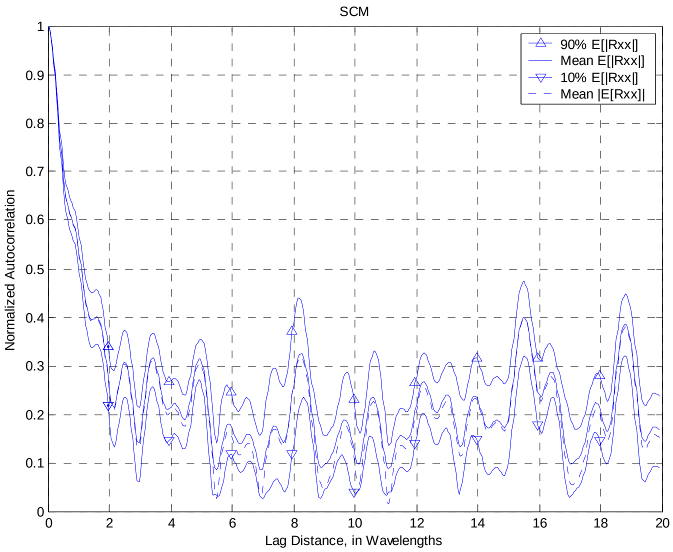

Figure 4, Standard SCM, AoA = 30 deg, 100λ fading segments

In Figure 4, the SCM model, which is characterized by 20 sub-rays of equal power and spaced with a Laplacian angle spacing is shown. The mean values using both averaging techniques produced nearly the same results as shown. The 10% and 90% bounds are relatively tight compared to other models.

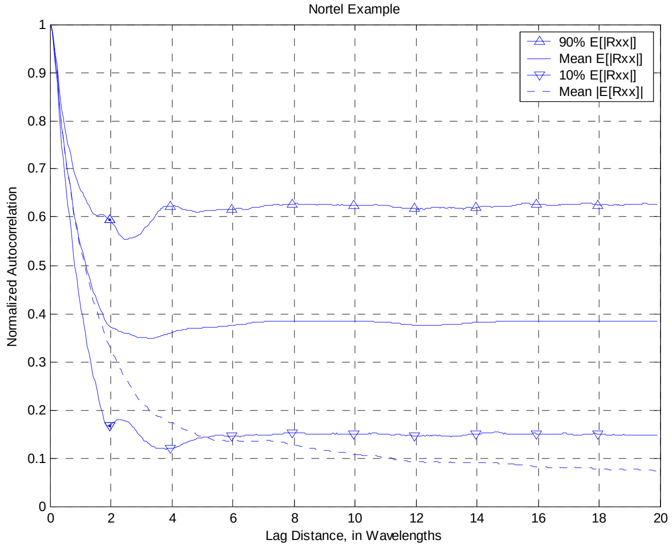

Figure 5, Nortel Example with 20 sub-rays, AoA = 30deg, 100λ fading segments

In Figure 5, the Nortel example[3] is shown to have a much larger 10%-90% deviation from the average, even at λ/2 compared to other models. Note also that the average of the magnitudes is much different than the average of the complex values. This is also evident in the 90%-tile being much higher than in the other models. It is believed that the difference in the averages is due to most of the power being concentrated in a few rays near the zero degree Laplacian center, which produces a higher spread of correlations for the individual channel realizations. When averaging in the complex domain, these larger magnitudes are cancelled by similar large magnitudes with opposing phases, whereas averaging in the magnitude domain retains a larger value.

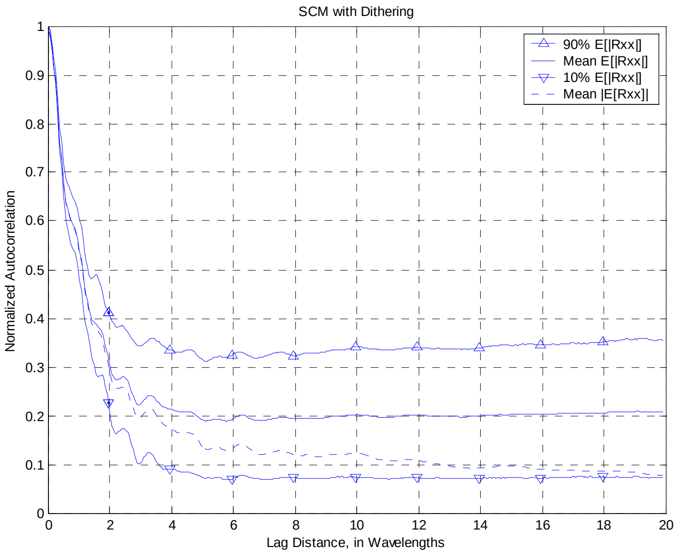

Figure 6, SCM model with Angle Dithering, AoA = 30 deg, 100λ fading segments

Figure 6 illustrates the third model being compared which extends the basic SCM with dithered AoAs for each of the 20 sub-rays. This model is somewhat more smooth at larger lag wavelengths, and do not have as much variation compared to the SCM model, although the 10%-90% bounds are somewhat larger. The performance of this model appears to be similar to the SCM model at λ/2.

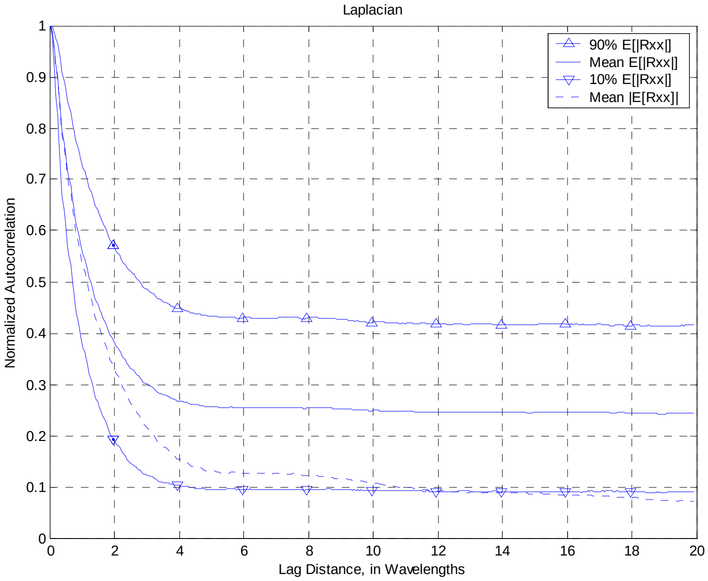

Figure 7, 20 Equal power Sub-rays, Laplacian distribution of angles, 100λ fading segments

Figure 7, describes the fourth model being compared, characterized by 20 sub-rays chosen from a Laplacian distribution of angles of arrival. This technique produces an average autocorrelation that is monotonic, and very smooth at all lags. The 10%-90% bounds are somewhat better than previous models at higher lags, but not as low as the SCM over most of the lag distances, including especially λ/2. The complex average correlation is a good match to ideal.

Conclusions

Additional details regarding the length of the fading segment have been characterized for the SCM by comparing statistical measures of correlation, with lag distances increased to 20λ to observe the far out behavior.

An additional model (e) was described and compared, which has very good average performance, but requires some extra complexity by drawing sub-rays from a Laplacian distribution for each drop. The variations seen in short segments appear large at short lags such as λ/2 where the 10-90% bounds are much larger than for other models.

The standard SCM model appears to still be a reasonably good approach due to its simplicity, even though it is not as smooth across the various lag distances. At the low correlations involved, < 0.4, the variation is not expected to be an issue to simulations.

4. REFERENCES

[1] Motorola, SCM-093, "SCM Fading Models", San Diego, CA, January 8th, 2003.

[2] Motorola, SCM-086, "SCM Fading & Path Loss", Teleconference, December 19th, 2002.

[3] Nortel Networks, "SCM Model Correlations," SCM-065_v2, Teleconference, October 10th, 2002.

[4] J. Salz and J. H. Winters, "Effect of Fading Correlation on Adaptive Arrays in Digital Mobile Radio,''IEEE Tr. on Veh. Tech., Vol. 43, No. 4, pp. 1049-1057, November 1994.