4. SUMMARY AND CONCLUSIONS

A simple model of wideband HF noise/interference has been developed, based on analyses of measured data. In contrast to previously developed models, which provide descriptions of the statistical characteristics of the noise/interference (for example, the amplitude probability distribution), the present model describes the noise/interference waveform itself, and can therefore be used to simulate the noise/interference process. The statistical characteristics of the process have been investigated to guide the model development and to check the validity of the model.

In Part I of this series, the first-order statistics of the noise/interference were examined, and it was shown that the quantities generated from the simulated data closely resemble the corresponding measured quantities for a variety of measured data. Thus, the time-averaged behavior of the amplitude and phase of the simulated noise/interference was shown to be consistent with that of the measured data.

In the present report, certain higher-order statistics of the noise/interference have been analyzed. These analyses are necessary to investigate the relationships between the noise/interference process at different instants in time. In particular, the autocorrelation function and the pulse width and spacing distributions of the voltage envelope have been investigated.

An analytic expression for the autocorrelation function of the simulated noise/interference was derived, and, using this expression for guidance, it was shown that the wide variety of autocorrelation functions of the measured data can be simulated using the proposed model with appropriate choices for the amplitudes and frequencies of the dominant narrowband interferers. However, the nonstationarity of the noise/interference, which is evident in some of the measured data, has not yet been incorporated into the model.

Pulse width and pulse spacing distributions were computed for both measured and simulated noise/interference, and it was shown that, in the absence of impulsive noise, the measured and simulated distributions are qualitatively similar. However, it was found that, in the presence of impulsive noise, the model as previously formulated (with a uniform distribution for the times of arrival of the impulses) does not generate all the observed features in the measured distributions. Accordingly, the model was refined by developing a "bursty" distribution for the times of arrival of the impulses, whereby the impulses are correlated in time. It was shown that the refined model does indeed generate features in the distributions that are similar to those in the measured distributions.

The comparisons of measured and simulated statistical quantities in this work (as well as in Part I) are of a qualitative nature. Quantitative comparisons are difficult because one is dealing with an infinite variety of waveforms generated by random processes. Ultimately, the validity of any model for the simulation of noise/interference can only be established by quantitative comparisons of radio performance using simulated and measured waveforms.

Conspicuously absent from the model development is the incorporation of a waveform for wideband HF atmospheric noise. The development of such a waveform requires the analysis of additional data containing atmospheric noise. However, the fact that the impulsive noise investigated thus far can be modeled as a train of filtered impulses using an appropriate time of arrival distribution suggests that atmospheric noise, as well as other manmade impulsive noise, can also be modeled as a train of filtered impulses, appropriately distributed in time. The pulse width and spacing distributions should enable one to model the distributions of times of arrival in a manner analogous to the modeling of the impulsive noise discussed in the present work. These investigations are currently under way and will be reported elsewhere.

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6. REFERENCES

Abraham, L.G., M.I. Clune, D.C. Rogers, and B.G. Thornton (1989), Stationarity of wideband HF noise after interference excision, IEEE 1989 Military Commun. Conf., Boston, MA, Paper No. 48.3.

CCIR (1974), HF ionospheric channel simulators, XIIIth Plenary Assembly, ITU, Geneva, Switzerland, Vol. III, Report 549, pp. 66-72.

Cox, D.R. and H.D. Miller (1965), The Theory of Stochastic Processes (Chapman and Hall, New York, NY).

Ehrman, L., L.B. Bates, J.F. Eschle, and J.M. Kates (1982), Real-time software simulation of the HF radio channel, IEEE Trans. Commun. Com-30, No. 8, pp. 1809-1817, Aug.

Girault, R., J. Thibault, and B. Durand (1988), Software ionospheric channel simulator, IEE Fourth Intl. Conf. on HF Radio Systems and Techniques, London, UK, IEE Pub. 284, pp. 321-325.

Hall, H.M. (1966), A new model of "impulsive" phenomena: application to atmospheric noise communications channels, Electron. Lab., Stanford Univ., Stanford, CA, Tech. Rep. 3412-8 and 7050-7, SU-SEL-66-052, Aug.

Hoffmeyer, J.A. and L.E. Vogler (1987), Measurement, modeling, and simulation of LOS microwave channels, NATO AGARD Conf. Proc., No. 419, Scattering and Propagation in Random Media, Rome, Italy, May, Paper No. 31.

Hoffmeyer, J.A. and L.E. Vogler (1990), A new approach to HF channel modeling and simulation, IEEE 1990 Military Commun. Conf., Monterey, CA, Paper No. 60.2.

Hoffmeyer, J.A., L.E. Vogler, J.F. Mastrangelo, L.E. Pratt, and C.J. Behm (1991), A new HF channel model and its implementation in a real-time simulator, IEE Fifth Intl. Conf. on HF Radio Systems and Techniques, Edinburgh, UK, IEE Pub. 339, pp. 173-177.

Lemmon, J.J. and C.J. Behm (1991), Wideband HF noise/interference modeling, Part I: First-order statistics, NTIA Report 91-277, May (NTIS Order No PB 91-208454).

Le Roux, Y.M., G. Savidan, G. DuChaffaut, P. Gourvez, and J.P. Jolivet (1987), A combined evaluation and simulation system of the HF channel, IEE Fifth Intl. Conf. on Ant. and Prop., York, UK, IEE Pub. 274, pp. 171-175.

Longuet-Higgins, M.S. (1962), The distribution of intervals between zeros of a stationary random function, Phil. Trans. Roy. Soc., London, 254, p. 557.

Mastrangelo, J., J. Hoffmeyer, C. Behm, and L. Pratt (1991), A new wideband HF simulation system for testing HF radios, IEEE 1991 Military Commun. Conf., McLean, VA, Paper No. 49.5.

McFadden, J.A. (1956), The axis crossing intervals of random functions, IRE Trans. Information Theory, IT-2, pp. 146-150.

McRae, D.D. and F.A. Perkins (1988), Digital HF modem performance measurements using HF link simulators, IEE Fourth Intl. Conf. on HF Radio Systems and Techniques, London, UK, IEE Pub. 284, pp. 314-317.

Mooney, O.J. (1985), Implementation of an HF ionospheric channel simulator using a digital signal processor, IEE Third Intl. Conf. on HF Commun. Systems and Techniques, London, UK, pp. 27-31.

Perry, B.D. and R. Rifkin (1989), Measured wideband HF mid-latitude channel characteristics, IEEE 1989 Military Commun. Conf., Boston, MA, Paper No. 48.1.

Rice, S.O. (1944 and 1945), Mathematical analysis of random noise, Bell System Tech. J., 23, pp. 282-332, July 1944; 24, pp. 46-156, January 1945.

Uman, M.A. (1987), The Lightning Discharge (Academic Press, Orlando, FL).

Vogler, L.E. and J.A. Hoffmeyer (1988), A new approach to HF channel modeling and simulation, Part I: Deterministic model, NTIA Report 88-240, Dec. (NTIS Order No. PB 89-203962/AS).

Vogler, L.E. and J.A. Hoffmeyer (1990), A new approach to HF channel modeling and simulation, Part II: Stochastic model, NTIA Report 90-255, Feb. (NTIS Order No. PB 90-200338/AS).

Vogler, L.E., J.A. Hoffmeyer, J.J. Lemmon, and M. Nesenbergs (1988), Progress and remaining issues in the development of a wideband HF channel model and simulator, NATO AGARD Conf. Proc., Propagation Effects and Circuit Performance of Modern Military Radio Systems with Particular Emphasis on those Employing Bandspreading, Paris, France, Oct., Paper No. 6.

Watterson, C.C. (1981), HF channel-simulator measurements on the KY-870/P FSK burst-communication modem - set 1, NTIA Contractor Report CR-81-13 (NTIS Order No. PB 82-118944).

Watterson, C.C. (1982), HF channel-simulator measurements on the KY-879/P FSK burst-communication modem - set 2, NTIA Contractor Report CR-82-20, Dec. (NTIS Order No. PB 83-194738).

Watterson, C.C. and R.M. Coon (1969), Recommended specifications for ionospheric noise simulators, ESSA Tech. Report ERL-127-ITS-89.

Watterson, C.C., J.R. Juroshek, and W.D. Bensema (1969), Experimental verification of an ionospheric channel model, ESSA Tech. Report ERL-112-ITS-80.

Watterson, C.C., J.R. Juroshek, and W.D. Bensema (1970), Experimental confirmation of an HF channel model, IEEE Trans. Commun. Technol. COM-18, pp. 792-803.