6. SUMMARY AND CONCLUSIONS

Since communications systems are seldom interfered with by classical white Gaussian noise, it has been the object of this report to apply Middleton's physical-statistical model of impulsive interference to real world signal detection problems.

The main impulsive interference models that have been proposed to date were summarized in chapter 2 and Middleton's model was specified in some detail, giving the statistics required for the solution of signal detection problems. Comparison of these statistics with measurements was shown to be quite excellent.

In general, optimum detection algorithms were obtained for coherent and incoherent binary detection, for the three basic digital signaling waveforms; i.e., antipodal, orthogonal, and ON-OFF keying. Performance bounds were obtained for these signaling situations. Since it is known that in order to gain significant improvement over current receivers, the number of independent samples of the received interference waveform must be large, the performance results are obtained parametric in the number of samples, or equivalently, in the time bandwidth product. Performance of the current suboptimum receivers was obtained and compared to the optimum performance. It was shown that substantial savings in signal power and/or spectrum space can be achieved.

Since physical realization of the completely optimum detection algorithms cannot, in general, be economically obtained, the corresponding locally optimum or threshold receivers were derived and their performance specified. These threshold receiver-structures are canonical in nature in that their structure is independent of the form of the interference. Locally optimum structures were given for coherent and incoherent detection with various kinds of fading signals. The case in which phase estimation is used (partially coherent) was also treated.

The particular detection problems treated and results obtained are summarized in table 6.1. All the performance results, including the performance of correlation receivers in class A interference, are now results. In addition, many of the LOBD receiver structures are thought to be new. Specifically, it has been shown that the LOBD for NCFSK with slow fading signal is different than the LOBD with fast fading signal if the threshold $K \neq 1$. If $K = 1$, the LOBD structure has been known for some time and is the same (e.g., fig. 5.1) for constant, slow fading, or fast fading signals. [This result has recently been shown for m level NCFSK by Nirenberg (1975), who also shows that if the desired signals contain desired amplitude modulation, additional nonlinear processing is required in the LOBD structure. The techniques used by Nirenberg to obtain these results are quite different from those used in this report.] If $K \neq 1$, the LOBD structure

Table 6.1 Summary of Results

Class A Interference		
Signaling Situation	**Detector Structure**	**Performance**
Coherent (ϕ known) H_1: $X(t)=S_1(t)+Z(t)$ H_2: $X(t)=S_2(t)+Z(t)$ Antipodal, orthogonal and ON-OFF	Likelihood ratio, Schwartz algorithm (sec. 4.1)	Performance bound, $\hat{P}_e$ (sec. 4.2)
Antipodal, orthogonal and ON-OFF	LOBD (sec. 4.4.1)	Performance estimate, P_e (sec. 4.4.1)
	Correlation receiver (optimum in Gauss)	"Exact" P_e (sec. 4.3)
Interference Discrimination	LOBD (sec. 4.4.2)	
Incoherent (ϕ unknown) H_1:$X(t)=S_1(t;\underline{\theta})+Z(t)$ H_2:$X(t)=S_2(t;\underline{\theta})+Z(t)$ NCFSK, $\underline{\theta}=\{a,\phi\}$ K arbitrary, ϕ uniform		
a; constant	LOBD (sec. 5.1.1)	Performance estimate, (K = 1), P_e (sec. 5.3.1)
a; slow fading	LOBD (sec. 5.1.1)	
a; fast fading	LOBD (sec. 5.1.1)	
NCFSK with phase estimation	1st and 2nd order LOBD's (sec. 5.1.1)	
NCFSK	Correlation receiver	"Exact" P_e (sec. 5.3.3)
ON-OFF	LOBD (sec. 5.1.2) Approximation of $\Lambda(\underline{X})$ (sec. 5.2)	Performance estimate, P_e (sec. 5.3.2)
	Correlation receiver	"Exact" P_e (sec. 5.3.3)

for slow fading signals also involves the second moment of the fading distribution (i.e., the signal power), whereas, for fast fading signals, the LOBD structure involves the mean of the signal fading distribution as well (e.g., 5.18). Also, the LOBD for ON-OFF incoherent signaling was shown to be a special case, requiring the inclusion of higher order terms in the expansion of the likelihood ratio to insure consistency (sec. 5.1.2). In addition, the LOBD structure for NCFSK with phase estimation was shown to be canonical (as are the other LOBD structures) and to involve a weighted linear combination of the coherent and incoherent LOBD's (e.g., fig. 5.4).

While an upper bound on the performance of the completely optimum receiver for coherent signals was obtained in section 4.2, corresponding general results for incoherent signals are much more difficult to achieve. For incoherent signals, the only performance result obtained for the completely optimum receiver was the performance estimate for incoherent ON-OFF signals in class A interference (sec. 5.3.2).

In this report, all performance calculations were performed with the pdf of the interference in normalized form, so that the noise power is unity and the SNR is given by the signal power S. In actual situations, the performance of the optimum and locally optimum receivers is not a function of the SNR alone, because of the required nonlinear processing. That is, for actual problems of interest, the performance algorithms developed here must use the pdf of the interference in unnormalized, or absolute, form. Performance will, in general, depend on the absolute interference level as well as the SNR. In this sense, then, these receivers are adaptive; i.e., must be able to adjust to the parameters (level, etc.) of the interference. Spaulding et al. (1969) give examples of this for the Hall receiver.

There are, of course, many problems remaining, the most obvious probably being to extend the results to include class B and class C (a combination of class A and class B) interference. Others include the following: Important digital signaling situations, such as minimal shift keying and differential phase shift keying have not been treated, and the performance of some of the LOBD structures which have been derived has not been explicitly determined (e.g., NCFSK with phase estimation). Some important characteristics of the LOBD's, such as ARE (asymptotic relative efficiency), have also received little attention. That is, how "small" is a small signal in the threshold receiver development? Since the optimum and locally optimum receivers must be adaptive, techniques by which an actual receiver can estimate the required and changing interference parameters must be developed. Multiplicative interference, such as frequency selective fading, must also be considered for real world communications channels.

7. ACKNOWLEDGMENTS

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