

A NEW MODEL OF HF IMPULSIVE ATMOSPHERIC NOISE:  
APPLICATION TO DIGITAL COMMUNICATION SYSTEMS



by

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CERTIFICATE

This is to certify that the dissertation, "A New Model of HF Impulsive Atmospheric Noise: Application to Digital Communication Systems", which is being submitted by Maruti Pandurang Shinde for the award of the degree of Doctor of Philosophy to the Indian Institute of Technology, New Delhi, is a record of bonafide research work. He has worked for the period of more than three years under my supervision.

This dissertation has reached the standard fulfilling the requirements of the regulations relating to the degree. The results obtained in this dissertation have not been submitted to any other University or Institute for the award of any degree or diploma.

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*Maruti P. Shinde*

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ABSTRACT

At tropical latitudes atmospheric radio noise (ARN) is the principal source of interference to radio communications in the HF band. Determination of an optimum receiver or detector or design of signal depends upon noise characteristics and mathematically tractable model of noise. Taking into consideration the known properties of impulsive ARN in tropics, it is modelled here as the product of a narrowband Gaussian noise and reciprocal of a nongaussian random process. This model yields finite values of first and second moments thus qualifying to represent a physical process. This model leads to observed probability distributions of noise. The first order statistics of amplitude probability distribution of noise are obtained. An expression for the probability that the received noise envelope exceeds a given level is obtained for the new model and compared with the measured data. Higher order statistics of distribution of envelope level crossings are derived; and further it is shown that the noise pulses are dependent and they have tendency to cluster that is in confirmation with the observed correlation between noise pulses. The new ARN model is used to derive probability distributions of amplitude and phase of an FSK signal immersed in noise. The amplitude probability distribution is used to evaluate the performance of an FSK system with and without nonlinear processing. Effects of

clipping and square-law noise blanking with FSK system are analysed. This analysis shows that the square-law noise blanking gives an advantage of about 15 dB in SNR at the practical values of probability of error. Probabilities of errors of a phase-coherent binary detector in ARN with and without above nonlinear processing are determined and plotted for comparison. Orthogonal symbol error probabilities of a noise-reduction phase-coherent receiver in ARN are determined that show significant improvement possible by signal-design. The model is used to derive hypothesis testing statistics for detection of known signals with the aid of Bayes' strategy and prewhitening transformation. Probability of error is calculated and plotted for receiver structures for HF atmospheric noise, viz. linear matched filter and  $(-1/\log)$  correlator and inverted  $(\log)^2$  correlator receivers. It is shown that these nonlinear processing techniques result in considerable improvement in system performance over that of the linear matched filter. The statistics of burst noise are applied to PSK signal design for improved reliability and general constraints emerging out of this analysis are indicated. Possibility of constructing a teletype signal with coded orthogonal Walsh pulses is also analyzed.

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LIST OF SYMBOLS

$a_i$	random amplitudes of noise
$A_c$	clipping level
$B$	bandwidth of observation
$2B$	receiver radio-frequency(r f) bandwidth centred about $f_0$
$B(t)$	nongaussian random process $1/Z(t)$
$c(t)$	clipped envelope
$\overline{c^2}$	mean squared value of the clipped noise envelope
$E_{rms}$	root-mean-square (rms) spectral amplitude of noise
$E_{quasi-peak}$	quasi-peak spectral amplitude of noise
$E \left[ v \right] \}$ $E \{ v \} \}$	expected value of $v$
$E$	energy of the signal
$F(jv)$	characteristic function of a random variable $x$
$f(\  \underline{x} \ )$	a monotonically decreasing function of $\  \underline{x} \ $
$h(t)$	impulse response of a filter
$H(\omega)$	transfer function of a filter
$H_1$	hypothesis under which the observable $\underline{x} = \underline{S} + \underline{z}n$
$H_0$	hypothesis under which the observable $\underline{x} = \underline{z}n$
$K_{3/2}$	modified Bessel function of the second kind
$m$	number of black pulses
$n_o(t)$	output noise
$N$	number of pulses in noise bursts; also mean noise power or noise variance at the output of the narrow-band filter
$N(t)$	zero-mean Gaussian noise component
$n(t)$	noise model

$p$	duration of the noise impulse
$p_B(b)$	pdf of non-Gaussian random process $B(t)$
$p_c(x)$	distribution of clipped waveform
$P_e$	probability of error
$P_e^U$	upper bound on probability of error
$p_N(x)$	pdf of Gaussian noise component
$p_v(v)$	pdf of envelope of noise
$p_Y(y)$	pdf of $Y(t)$
$p_z(z)$	pdf of $z=1/B$
$p_\phi(\phi)$	uniform phase distribution
$p(\underline{x} H_1)$	pdf of received signal under the hypothesis $H_1$
$p(\underline{x} H_0)$	pdf of the observable under the hypothesis $H_0$
$p(r)$	pdf of $r$
$p(\phi)$	pdf of $\phi$
$P_o(v)$	probability that the envelope intensity exceeds level $v$ -
$P(T_o)$	probability that the separation time $T$ between successive noise bursts exceeds $T_o$
$p_y(\underline{y})$	pdf of the observable $\underline{y}$
$p_{y,\hat{y}}(y,\hat{y})$	joint pdf of $(y,\hat{y})$
$q$	duration of noise burst
$q(T-\tau)$	impulse function of matched filter
$r$	pulse repetition period
$r(t)$	instantaneous envelope voltage function of $r'(t)$ ; also $S(t)+n(t)$
$r'(t)$	signal plus noise when the amplitude of the signal is not zero
$R_o$	Signal-to-noise ratio at the output of a filter

$s(t)$	input signal
$s_o(t)$	output signal
$S_j(t)$	set of orthogonal binary symbols
$S(t)$	amplitude of $S_j(t)$
$S(w)$	spectrum of the signal
$S$	signal strength
$T$	Burst duration; also separation time between a downcrossing and the next upcrossing of the level $v_o$ by the envelope of the received noise
$T_o$	$1/2B$
$T_s$	period of the transmitted signal
$u(t)$	deterministic waveform
$u(x)$	unit step at $x=0$
$v$	$(y^2 + \hat{y}^2)^{1/2}$ , envelope
$\bar{v}$	first moment or mean value signifying noise amplitude
$\overline{v^2}$	second moment or mean square value indicating noise power level
$w_j$	$w_c \pm w$
$w_c, w_o$	carrier frequency in radians per second
$\underline{W}$	a nonsingular "whitening" transformation matrix
$\underline{W}^T$	transpose of matrix $\underline{W}$
$wal(j, \theta)$	Walsh functions
$(\underline{x} - \underline{S})^T$	transpose of $(\underline{x} - \underline{S})$
$\  \underline{x} - \underline{S} \  \phi^{-1}$	$(\underline{x} - \underline{S})^T \phi^{-1} (\underline{x} - \underline{S})$
$Y(t)$	$Z(t)N(t)$ -also the narrowband received noise
$y$	inphase component corresponding to $Y(t)$
$\hat{y}$	quadrature component corresponding to $Y(t)$
$\underline{y}_w$	$\underline{w}y$

$\underline{Y}_{ws}$	component of $\underline{Y}_w$ in the direction of $\underline{S}_w$
$Z(t)$	$1/B(t)$
$\alpha$	$A_c/S$ , clipping level in terms of signal strength
$\beta$	factor by which the noise power is reduced in the output due to nonlinear processing
$\delta(x)$	Dirac-delta function
$\theta$	phase of the narrowband received noise; also $\cos^{-1}(S/v)$
$\Lambda(\underline{x}_w)$	likelihood ratio, $\frac{p(\underline{x}_w   H_1)}{p(\underline{x}_w   H_0)}$
$\rho_{12}$	mark-space crosscorrelation function for PSK signals
$\sigma$	standard deviation
$\sigma^2$	variance of noise
$\tau$	duration of the transmitted signal
$\phi$	covariance matrix of noise
$\phi^{-1}$	inverse of covariance matrix of noise
$\phi(t,s)$	autocovariance function of noise
$\underline{\phi}$	spectral density of noise
$\psi_n(\omega), \psi_n^*(\omega)$	conjugate factors of the noise spectral density
$\omega_c$	carrier frequency

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