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Correlation techniques for the detection of frequency-hopping signals

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In this paper, an overview, basic principles and analysis of the correlation detection of frequency- hopping (FH) signals are given. Based on theoretical results for relationships among detection probability, false alarm rate and certain signal parameters, the detection performances of correlation methods are presented graphically, analyzed, verified and compared.

Key words: **frequency-hopping, detection, interception, correlation detection.**

Introduction

FREQUENCY-HOPPING signals, and spread-spectrum signals generally, have low probability of interception (LPI), i.e. these signals are intentionally designed to make the detection process as difficult as possible for unintended receivers (interceptors). Difficult detection of FH signals is a consequence of the use of a very large number of hopping channels (carrier frequencies) and particularly of the use of the pseudonoise (PN) sequence for determining FH pulse carrier frequencies. The impossibility of the PN sequence prediction is crucial in improving protection against interception and detection of these signals.

The detection of FH signals is achieved by using energy detection [3,4,13,14] and correlation techniques [1,6,7,9]. Energy detection, inferior to more complex correlation techniques, is easier for implementation.

There are two basic approaches to energy detection of FH signals: a wideband radiometer (energy detector) matched in the bandwidth (W_{FH}) and the integration time (T_{FH}) to the entire FH transmission; and canalized pulse detection systems with a set of narrowband radiometers that individually cover subbands of the total FH bandwidth and match the bandwidth (W_H) and the integration time (T_H) to the FH pulse bandwidth and duration, respectively. An ideal wideband radiometer, where a single rectangular filter having the bandwidth $W=W_{FH}$ and an integrate and dump (I+D) energy detector having the integration time $T=T_{FH}$ are used to detect FH signals in the $T_{FH}W_{FH}$ time-bandwidth cell, is referred to as a referent FH detection system.

Pulse detection systems can be worse to energy integration over the FH transmission in the case of higher T_HW_H values. However, for lower T_HW_H values, pulse detection can have advantages over a wideband radiometer, disregarding the system detection complexity. The reason for this is the fact that the probability of FH signal detection in the wideband radiometer case, with the integration time equal to the emission time T_{FH}, does not depend on the FH pulse parameters T_HW_H.

The analysis of the joint probability of FH signal interception and detection shows that it is possible to successfully intercept and detect FH signals by means of search receivers with associated energy detectors [13,14]. The increase of the scan speed and the number of parallel receiver channels (multichannel receiver) improves the performances of FH pulse interception as well as their detection. Increasing probability of intercept by the scan speed, when the detection time is shortened, is limited by reduced selectivity to narrowband adjacent-channel signals and broadband interfering signals [14]. The presence of narrowband interfering signals does not introduce significant degradation of detection performances, but makes the problem of the detection threshold adjustment more complex. It can be shown that the degradation of detection performances by increasing the number of narrowband interfering signals from 0 to 2048 is not larger than 5 dB for a typical signal-to-noise (SNR) ratio $E_{NB}/N_0 \approx 30$ dB (E_{NB}- narrowband signal energy, N_0- one-sided noise power spectral density) and the probability of the false alarm of 0.001. In the same way, the misalignment of the integration interval in detection with respect to the hop period degrades the detection performances less than 2 dB [3,13,14] in this case.

In the set of the correlation methods of FH signal detection, optimum coherent and noncoherent average likelihood (AL) detection, suboptimum coherent and noncoherent maximum likelihood (ML) detection and autocorrelation-domain detection methods are usually considered. The papers [1,6] are excellent references for LPI detection techniques of FH signals.

In this paper, optimum and nonoptimum correlation methods of FH signal detection are analyzed, under the assumption of their sinewave modeling with uniform discrete distribution of possible random frequencies.

Coherent and noncoherent FH signal detector structures are based on the Neyman-Pearson detection theory [5,11]. Under the assumption of the existence of only single frequency hop per the detection interval T, the optimal FH signal detection system is realized by the summation of the outputs from the bank of N parallel correlators, one correlator for each of possible random hopping frequencies. This AL detection is optimal for slow frequency hopping (SFH) where the symbol interval T_S and the detection interval T are equal, i.e. $T=T_S$. The coherent ML detector, which is a suboptimum version of the AL detector, is obtained by testing the presence of signals at each of the N correlator out-

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The structure of the optimum coherent AL detector is shown in Fig.1 [1].

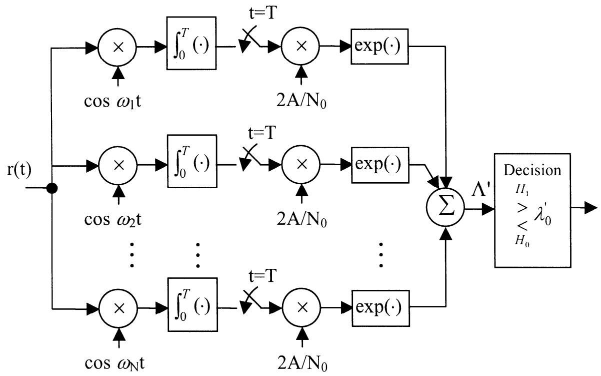

Figure 1. Optimum coherent AL detector of FH signals

In the case of noncoherent FH pulse detection, the initial phase of FH signals (2) is uniform in $[0,2\pi]$, i.e. $w(\theta)=1/(2\pi)$, $\theta\in[0,2\pi]$, and the AL ratio has the following form

$$\Lambda=\sum_{n=1}^{N}\int_{0}^{2\pi} w(\theta)\cdot\exp\left(\frac{2A}{N_0}\int_{0}^{T} r(t)\cos\left(\omega_n t+\theta\right)dt-\frac{E_S}{N_0}\right)d\theta \quad (8)$$

With $w(\theta)=1/(2\pi)$, $\theta\in[0,\,2\pi]$, the AL ratio test, in the case of noncoherent detection, is

$$\Lambda'=\sum_{n=1}^{N}\frac{1}{2\pi}\int_{0}^{2\pi}\exp\left(x_{cn}\cdot\cos\theta-x_{sn}\cdot\sin\theta\right)d\theta \underset{H_0}{\overset{H_1}{\gtrless}} \lambda_0\cdot N\cdot e^{d^2/2}=\lambda_0' \quad (9)$$

where

$$x_{cn}=\frac{2A}{N_0}\int_{0}^{T} r(t)\cdot\cos(\omega_n t)dt\ ;\ x_{sn}=\frac{2A}{N_0}\int_{0}^{T} r(t)\cdot\sin(\omega_n t)dt \quad (10)$$

The integral in the sum in (9) is recognized as a modified Bessel function of the first kind of zero order, defined by

$$I_0(x)=\frac{1}{2\pi}\int_{-\pi}^{\pi}\exp\left(x\cdot\cos(\theta)\right)d\theta=\frac{1}{2\pi}\int_{0}^{2\pi}\exp\left(x\cdot\cos(\theta)\right)d\theta \quad (11)$$

By using the former definition of the Bessel function, the AL ratio test (9), in the case of noncoherent detection of FH signals, can be presented in the following form

$$\Lambda'=\sum_{n=1}^{N} I_0(q_n) \underset{H_0}{\overset{H_1}{\gtrless}} \lambda_0\cdot N\cdot e^{d^2/2}=\lambda_0' \quad (12)$$

where

$$q_n^2=x_{cn}^2+x_{sn}^2 \quad (13)$$

and, the correlation values x_{cn} and x_{sn} are given in (10).

Also, one should notice that random variables, which present the summands in (9) or (12), are statistically independent because of the assumed spacing $\Delta f=1/T$ between FH pulse frequencies, that provides the orthogonality of these signals in the noncoherent case.

The structure of the optimum noncoherent AL detector is shown in Fig.2 [1].

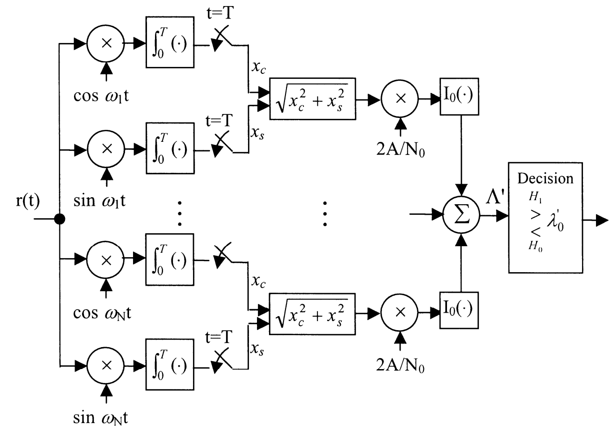

Figure 2. Optimum noncoherent AL detector of FH signals

ML detection of FH signals

The suboptimum ML (Maximum Likelihood) detector is obtained by testing the output of every correlator, instead of testing the sum of all outputs, as in the case of the optimum AL detector.

The essence of the suboptimum ML detection is in determining the presence or absence of FH signals at each of the N possible frequencies, ignoring the other (N-1) frequencies. The overall decision as to whether a FH signal is present is made if the test detects the presence of signals at one or more of the N possible frequencies. This version is a so-called suboptimum hard-limited version of the AL detector. The optimum AL receiver may then be viewed as a soft combining of the signal tests for individual frequencies where the combining is done with exponential weighting (expression (6)).

Therefore, in the case of the ML detection, the decision about the presence or absence of signals at nth frequency is obtained on the basis of (6) for N=1, i.e.

$$e^{x_n} \underset{H_0}{\overset{H_1}{\gtrless}} \lambda_0\cdot e^{d^2/2}=\lambda_0' \quad (14)$$

or

$$A\cdot\int_{0}^{T} r(t)\cdot\cos(\omega_n t)dt \underset{H_0}{\overset{H_1}{\gtrless}} \frac{N_0}{2}\cdot ln\lambda_0+\frac{E_s}{2}=\gamma \quad (15)$$

Therefore, the ML detection test may be written in the form of (6) by assuming that the random variable e^{x_n} takes values 0 or 1 at nth frequency, when the signal is present or absent, respectively. Then, in the coherent case of the FH signal detection, the ML ratio test has the following form 1 in Fig.3 [1].

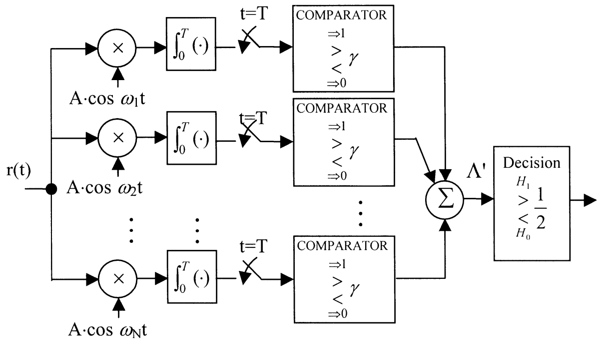

Figure 3. Coherent ML detector of FH signals

The orthogonality of the FH signal pulses at different frequencies f_n, n=1,2,…,N, causes the Gaussian random variable $y_n = A\cdot\int_0^T r(t)\cos(\omega_n t)\,dt$, in (15), under the hypothesis of H_1 (FH pulse present at f_n) to have the mean m_y and the variance δ_y

$$\begin{aligned}
&H_1 : m_y = A\int_0^T\left[A\cos\omega_n t+\overline{n(t)}\right]\cdot\cos\omega_n t\;dt = E_s\\
&\sigma_y^2 = \overline{y_n^2} - E_s^2 =\\
&= A^2\int_0^T\int_0^T\overline{\left[A\cos\omega_n t+n(t)\right]\cdot\left[A\cos\omega_n u+n(u)\right]}\cos\omega_n t\cdot\\
&\cdot\cos\omega_n u\;dtdu - E_s^2 =\\
&= A^2\cdot\int_0^T\int_0^T\overline{n(t)n(u)}\cdot\cos\omega_n t\cdot\cos\omega_n u dtdu =\\
&= A^2\cdot\int_0^T\int_0^T\frac{N_0}{2}\delta(t-u)\cdot\cos\omega_n t\cdot\cos\omega_n u dtdu =\\
&= A^2\frac{N_0}{2}\cdot\int_0^T\int_0^T\cos^2\omega_n t dt = \frac{E_s N_0}{2}
\end{aligned}\tag{18}$$

and, under the hypothesis H_0 (only the noise is present, or the FH pulse is present at f_i, $i\neq n$) in an analogous way, it is possible to obtain

$$H_0 : m_y = 0\;;\;\sigma_y^2 = E_s N_0/2 \tag{19}$$

where $\overline{(\cdot)}$ denotes expectation.

Therefore, the normalized Gaussian random variable $y'_n = \left(A\cdot\sqrt{2/(E_s N_0)}\right)\cdot\int_0^T r(t)\cos\omega_n t dt$, under the hypothesis H_1 (FH) has the mean $d=\sqrt{2E_s/N_0}$ and the variance 1, and under the hypothesis H_0 ($\overline{FH}$) the mean is 0 and the variance is 1. Based on (15) and the well-known relation for the probability of the Gaussian random variable to exceed a certain threshold ($Pr\{V>V_T\} = Q((V_T-m)/\sigma)$), it is possible to obtain the expression for the probability of FH pulse detection at nth frequency ($Q_D = Pr\{y_n>\gamma\mid FH\}$)

$$Q_D = Q\left(\frac{ln\lambda_0}{d}-\frac{d}{2}\right) \tag{20}$$

and the probability of the false alarm for FH pulses at nth frequency ($Q_F = Pr\{y_n>\gamma\mid\overline{FH}\}$) is

$$Q_F = Q\left(\frac{ln\lambda_0}{d}+\frac{d}{2}\right) \tag{21}$$

These probabilities are independent of n ($Q(x)$ function is defined in Appendix 1).

If we suppose that the FH signal is detected when its presence is detected at least at one of the N frequencies, and that the false alarm assumes one or more exceedings of the detection threshold at some of the N frequencies in the absence of FH pulses, the probability of detection P_D and the probability of the false alarm P_F have the following form in the case of ML detection

$$P_D = 1-(1-Q_D)(1-Q_F)^{N-1} \tag{22}$$

$$P_F = 1-(1-Q_F)^N \tag{23}$$

The noncoherent ML detector is a suboptimum version of the noncoherent AL detector. Therefore, in analogy to the coherent case, the random variable l_n (in analogy to (16)) takes the values 1 or 0, according to the FH signal detection optimum test at nth frequency in the noncoherent case (derived from (12) for N=1), i.e.

$$q_n \underset{l_n=0}{\overset{l_n=1}{\gtrless}} I_0^{-1}\left(\lambda_0\cdot e^{d^2/2}\right)=\gamma \tag{24}$$

The test of the noncoherent ML detector has also the form (16), as in the case of the coherent ML detector, but the probability of detection Q_D and the probability of the false alarm Q_F at nth FH pulse frequency, obtained from (24), are [11]

$$Q_D = Q_M\left(d,\gamma/d\right) \tag{25}$$

$$Q_F = e^{-\gamma^2/(2d^2)} \tag{26}$$

where $Q_M(\alpha,\beta)$ is the Marcum Q-function (Appendix 1).

The structure of the suboptimum noncoherent ML detector is shown in Fig.4 [1].

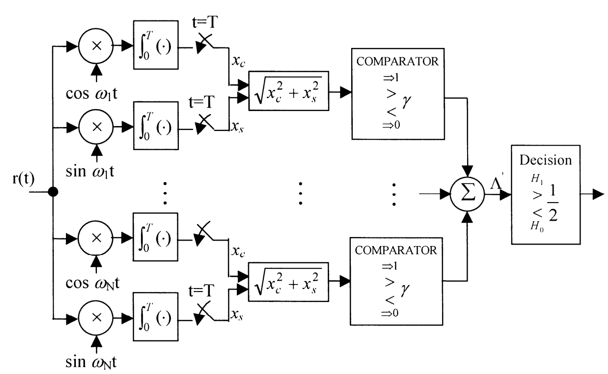

Figure 4. Noncoherent ML detector of FH signals

Analysis of ML detection performances

To analyze the detection performances of optimum AL detectors, it follows from (6,7) that the distribution of a sum of independent, lognormal random variables is required. This is an unsolved problem and it is possible to use only certain approximations. However, the suboptimum ML detectors have slightly different performances comparing to optimum detectors, and their analysis is possible and much easier.

In the case of the coherent ML detector, it follows from (20)-(23) that the probability of detection P_D has the following form

$$P_D = 1 - \left[1 - Q\left(Q^{-1}\left(1-(1-P_F)^{1/N}\right) - d\right)\right] \cdot \left(1-P_F\right)^{\frac{N-1}{N}} \quad (27)$$

where P_F is the probability of the false alarm, and $d^2=2E_s/N_0$ is the SNR.

In the same way, but by using (25) and (26) instead of (20) and (21), respectively, the probability of FH signal detection in the case of the noncoherent ML detector is obtained

$$P_D = 1 - \left[1 - Q_M\left(d, \sqrt{-2 \cdot ln\left(1-(1-P_F)^{1/N}\right)}\right)\right] \cdot \left(1-P_F\right)^{\frac{N-1}{N}} \quad (28)$$

Expressions (27) and (28) give the probability of FH signal detection, P_D, in the cases of coherent and noncoherent ML detection, respectively, as a function of the probability of the false alarm P_F and the SNR given by $d^2=2E_s/N_0$. In the case of the energy detection of FH signals, the probability of detection depends on the product TW (the product of the detection time and the bandwidth) in the detection cell [15], as well as on the P_F and SNR ratio. In order to compare the energy and correlation methods of FH signal detection, the following relation among $d^2=2E_s/N_0$, TW and the ratio of the FH signal average power (S) to the average noise power (S_N) in the detection cell, ($\partial^2=S/S_N=S/(N_0W)$) is quite useful

$$d^2/2 = TW \cdot \partial^2 \quad (29)$$

Based on (27) and (28), the analysis of detection performances in the cases of the coherent and the noncoherent ML detector, respectively, is performed in the MATLAB software package. Fig.5 shows the probability of detection P_D, as a function of $E_{FH}/N_0=d^2/2$ (or S/S_N for TW=100) in the case of the coherent ML detector for P_F=0.01, P_F=0.001 and P_F=0.0001 and N=256 frequencies. The noncoherent case is shown in Fig.6 for the same parameters.

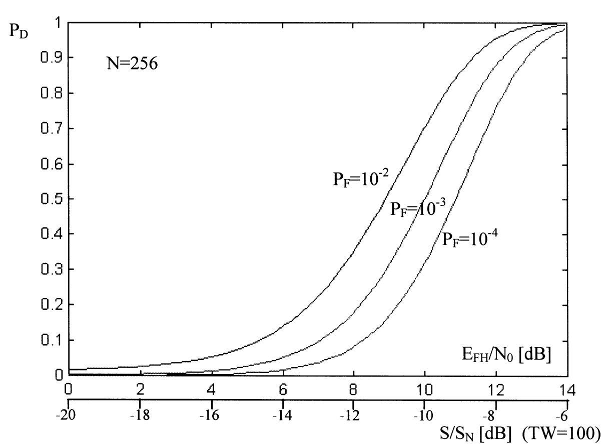

Figure 5. Detection performances of the coherent ML detector of FH signals

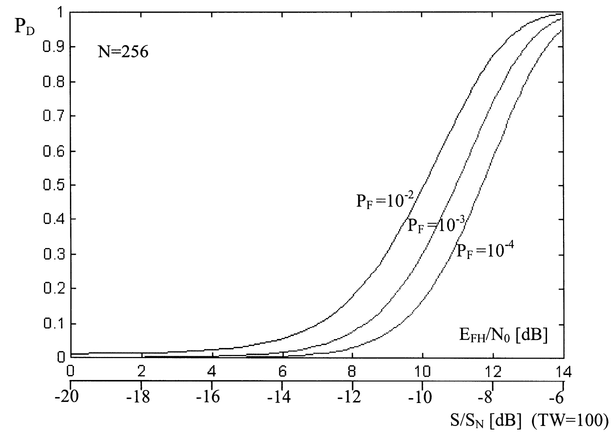

Figure 6. Detection performances of the noncoherent ML detector of FH signals

The results in Fig.5 and Fig.6 show that the noncoherent ML detector, because of its simpler realization, has performances that are somewhat worse (although insignificantly (≈1dB)) comparing to the coherent ML detector.

ACD method of FH signal detection

The autocorrelation-domain (ACD) method of FH signal detection improves the detection performances comparing to other classic energy (radiometer) methods. The ACD detection is somewhat inferior to the optimum AL and suboptimum ML detection of FH signals, but the complexity of realization is significantly reduced. This method is especially interesting with modern achievements in the technology of real-time correlators and convolvers with a large time-bandwidth product (TW).

The mathematical model of the real-time autocorrelation detector is shown in Fig.7 [6].

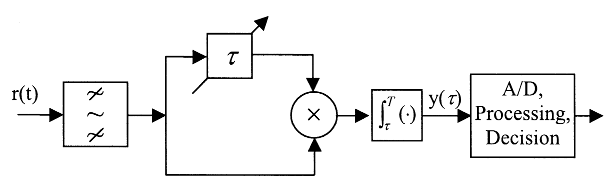

Figure 7. Mathematical model of the real-time ACD detector

Therefore, if the total bandwidth of FH signals (W_{FH}) is divided into subbands W ($W \geq R_C$), then, in the ACD method, the signal processing and the decision about signal presence in the bandwidth W are performed on the basis of the ACD detector shown in Fig.7, instead of the energy detector. The real-time autocorrelator performs transformation from the time-domain (t) to a new, so-called correlation domain (τ), where it is expected that the appropriate autocorrelation function $y(\tau)$ improves the separation between the signal and the interference.

If the output of the correlator $y(\tau)$ is sampled at the multiples of the reciprocal value of the bandwidth W, i.e. at the moments τ_k=k/W, then the ACD detector decision rule in the bandwidth W can be presented in the following form [6]

$$\Lambda = \sum_{k=1}^{TW-1} a_k V_k \underset{H_0}{\overset{H_1}{\gtrless}} \text{threshold} = \lambda_0 \quad (30)$$

where $TW=T_HW=G_P$ is the processing gain in the ACD detector cell, and

$$V_k=y^2(\tau_k),\ \ k=1,2,\ldots,TW\text{-}1 \tag{31}$$

The parameters a_k in (30) are chosen according to the optimization method. Their number (TW-1) is limited in practice to $p\cdot TW$, where $0<p\leq 1$, and its selection depends on the signal processing algorithm. The following choice for the parameters a_k is convenient

$$a_k=\begin{cases}\left(T_H-\tau_k\right)^{-2},\ k=1,2,...,p\cdot TW\\ 0\ ,\ \ k=p\cdot TW+1,...,TW\end{cases} \tag{32}$$

Under the assumption of the Gaussian approximation of Λ from (30) (this assumption is acceptable because Λ presents the sum of a large number of random variables), the following expression for the detection probability of FH signals in the ACD detection cell $T_H\cdot W$ (Appendix 2) is obtained

$$Q_D=Q\left[\frac{E\{\Lambda/H_0\}-E\{\Lambda/H_1\}+\sqrt{var\{\Lambda/H_0\}}\cdot Q^{-1}\left(Q_F\right)}{\sqrt{var\{\Lambda/H_1\}}}\right] \tag{33}$$

where $E\{\Lambda\mid H_i\}$ and $var\{\Lambda\mid H_i\}$ are the mean and the variance of the Gaussian random variable Λ, respectively, under the hypothesis H_i, i=0,1 and they are given by the following approximate forms [6]

$$\begin{aligned}
E\{\Lambda/H_0\}&=(N_0W)^2\cdot ln\left(\frac{1}{1-p}\right)\\
E\{\Lambda/H_1\}&=p\cdot TW\cdot S^2+\left[2S\cdot N_0W+(N_0W)^2\right]\cdot ln\left(\frac{1}{1-p}\right)\\
var\{\Lambda/H_0\}&=\frac{1}{TW}\cdot\left(\frac{p}{1-p}\right)\cdot(N_0W)^4\\
var\{\Lambda/H_1\}&=\frac{1}{TW}\cdot\left(\frac{p}{1-p}\right)\cdot(N_0W)^4+p^2\cdot TW\cdot(N_0W)^4\cdot\left(\frac{2S}{N_0W}\right)^3+\\
&\quad+2p\cdot(N_0W)^4\left(\frac{S}{N_0W}\right)\cdot\left(1+4\cdot\frac{S}{N_0W}\right)
\end{aligned} \tag{34}$$

One should emphasize that Q_D and Q_F are related to the probability of detection and the probability of the false alarm only regarding the decision in one detection cell of the bandwidth W, and not regarding the overall decision about FH signals in the bandwidth W_{FH}.

By applying (33) and (34), the probability of ACD detection in the cell TW, is obtained. For example, for p=1/2,

$$Q_D=Q\left[\frac{\frac{1}{\sqrt{TW}}Q^{-1}(Q_F)-\frac{1}{2}\partial^4-2\partial^2 ln2}{\sqrt{\frac{1}{TW}+2TW\cdot\partial^6+\partial^2+4\partial^4}}\right] \tag{35}$$

where $\partial^2=S/S_N=S/(N_0W)$, and the relation between ∂^2 and $d^2/2=E_s/N_0$ is given by (29).

Therefore, for the ACD detection method of FH signals, where p=1/2, and where the overall decision about the presence of FH signals at some of the N possible frequencies assumes that at least one decision about the presence of the signal has happened, and where the false alarm assumes that at least once the threshold was exceeded at some of the N channels when there is no FH pulse present, the total probability of FH signal detection can be obtained on the basis of (22) and (23) as

$$P_D=1-(1-Q_D)(1-P_F)^{\frac{N-1}{N}} \tag{36}$$

where Q_D is given by (35).

By applying the MATLAB software package and the obtained analytic expressions, the dependence of the ACD (p=1/2) detection probability versus $E_{FH}/N_0=d^2/2$, or versus $S/S_N=\partial^2$, is examined for TW=100, the probabilities of the false alarm P_F=0.01, P_F=0.001, P_F=0.0001 and N=256 frequencies. The results are shown in Fig.8.

From the results of the detection performances of the ACD detector (Fig.8) and the ML detector (Fig.5 and Fig.6) it can be seen that the ML detector is better for higher S/N ratios. For lower S/N ratios (∂^2<10dB at TW=100) the ACD detector has better performances. Besides, it is important to emphasize that the ACD detector is much simpler than the ML detector and more robust regarding unknowing and variations of FH signal parameters, like power levels or frequency offsets [6].

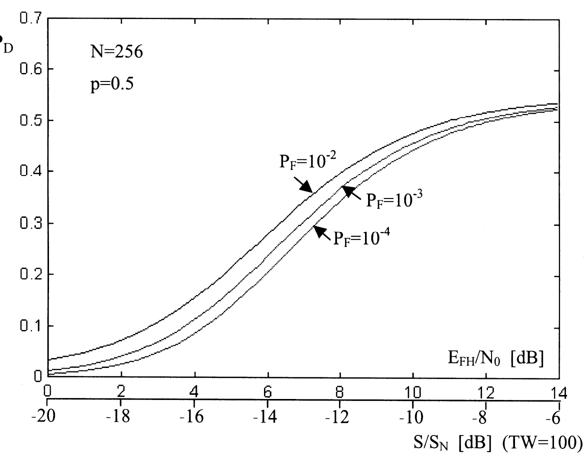

Figure 8. Detection performances of the autocorrelation detection (p=0.5) of FH signal.

Conclusion

Optimum AL and suboptimum ML methods of FH signal detection, which use a bank of correlators as a receiver, have superior performances comparing to energy methods of detection, but they are very complex for realization. The ML detector has similar performances as the AL detector, and it is easier for implementation. Among optimum and suboptimum complex methods of detection, the noncoherent ML detector is the simplest, with characteristics that are slightly worse (≈1dB) comparing to the coherent ML detector. However, the autocorrelation (ACD) method of detection is relatively easy for realization, and its performances are much better comparing to energy methods of detection, and somewhat worse than ML detection performances. Besides, the ML detector has better detection performances only in the case of a high SNR, while in the case of a lower SNR (S/S_N<10dB, at TW=100) the ACD detector has better performances. Also, it is important to emphasize that the ACD detector is more robust regarding unknowing and variations of FH signal parameters, like power levels and frequency offsets.

Appendix 1.

Q-function, $Q(x)$, and the complementary error function (*coerror function*), $erfc(x)$, are defined as

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-u^2/2}du\ ,\ erfc(x)=\frac{2}{\sqrt{\pi}}\int_x^\infty e^{-u^2}du$$

It can be seen that $erfc(x)=2Q(x\sqrt{2})$, $Q(x)=(1/2)\cdot erfc(x/\sqrt{2})$.

The Marcum *Q*-function, $Q_M(\alpha,\beta)$, is defined as

$$Q_M(\alpha,\beta)=\int_\beta^{+\infty} x\cdot e^{-\frac{x^2+\alpha^2}{2}} I_0(\alpha x)\ dx$$

and for $\beta>>1$ and $\beta>>\beta-\alpha$ it is possible to use the following approximation:

$$Q_M(\alpha,\beta)\approx\frac{1}{2}\cdot erfc\left(\frac{\beta-\alpha}{\sqrt{2}}\right)$$

Appendix 2.

From the detection theory of the Gaussian random variable Λ, with the detection threshold λ_0, it is known that the probability of detection can be obtained as

$$Q_D=Pr\{\Lambda>\lambda_0\mid H_1\}=Q\left(\frac{\lambda_0-E\{\Lambda\mid H_1\}}{\sqrt{var\{\Lambda\mid H_1\}}}\right)=$$

$$=\frac{1}{2}erfc\left(\frac{\lambda_0-E\{\Lambda\mid H_1\}}{\sqrt{2\cdot var\{\Lambda\mid H_1\}}}\right)$$

and the probability of the false alarm is

$$Q_F=Pr\{\Lambda>\lambda_0\mid H_0\}=Q\left(\frac{\lambda_0-E\{\Lambda\mid H_0\}}{\sqrt{var\{\Lambda\mid H_0\}}}\right)=$$

$$=\frac{1}{2}erfc\left(\frac{\lambda_0-E\{\Lambda\mid H_0\}}{\sqrt{2\cdot var\{\Lambda\mid H_0\}}}\right)$$

By eliminating of λ_0 from these expressions it is possible to obtain (33).

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Korelacione metode detekcije signala sa frekvencijskim skakanjem

U radu je dat pregled, izloženi su osnovni principi i izvršena je analiza korelacione detekcije signala sa frekvencijskim skakanjem. Na bazi teorijskih rezultata za zavisnost verovatnoće detekcije od verovatnoće lažnog alarma i parametara signala, izvršen je grafički prikaz, analiza i poređenje performansi detekcije razmatranih korelacionih metoda.

Ključne reči: **signali sa frekvencijskim skakanjem, detekcija, presretanje, korelacione metode.**

Techniques de corrélation de la détection de signaux à saut de fréquence

Les principes de base et l'analyse de la détection de corrélation de signaux à saut de fréquence sont donnés. Les performances de la détection des techniques de corrélation traitées sont présentées par la voie graphique, analysées et comparées suivant les résultats théoriques pour la dépendance entre la probabilité de détection et la probabilité de la fausse alarme et des paramètres de signaux.

Mots-clés: **signaux à saut de fréquence, détection, interception, techniques de corrélation.**