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CFAR adaptive threshold for ESM receiver with logarithmic amplification

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Abstract

An adaptive threshold with constant false alarm rate (CFAR) property is proposed to be used in a channelized electronic support measures (ESM) system with logarithmic video amplification. For this purpose, two CFAR processors are designed which are in fact modified excision (MEx) and adaptive MEx (AMEx) processors, previously presented by authors, but modified for the logarithmic amplification case. In the case of relatively small variations in the noise power, MEx-LOG/CFAR is proposed. This processor exhibits a good robustness against interfering pulses, which cause the major difficulty in the estimation of noise statistics. In the case of relatively large variations in the noise power, AMEx-LOG/CFAR processor is proposed. Thanks to a feedback loop in its structure, this processor can easily adapt itself with any change in the background noise power to assure the CFAR property and false alarm rate regulation. Furthermore, in the steady state (constant noise power), its detection performance is independent of the noise power. Methods to determine the design parameters of the proposed processors are discussed, and their performance analysis is studied using Monte Carlo simulations.

Keywords: CFAR thresholding; ESM receiver; Electronic warfare; Logarithmic detection; False alarm rate control

1. Introduction

Electronic support measures (ESM) systems try to identify the existing radar pulses in the environment by measuring the parameters of the received pulses and to classify them. By remaining passive, an ESM system can monitor threats without being detected itself, while possessing a range advantage over any given radar, because only one-way signal propagation loss is involved. By correctly monitoring and locating (finding the angular position of) enemy microwave emitters, the ESM system yields data allowing one to deduce associated threats, and commands use of appropriate electronic counter measures (ECM) or weapon delivery against these threats [3,17,24,30].

In an ESM receiver, a threshold is used to declare the reception of a radar pulse. After such a declaration, parameters of the corresponding received pulse such as frequency, pulse-width, angle of arrival, etc. are measured. These parameters are then delivered to the "host" data processing unit, where it is decided if the received pulse corresponds to a pre-surveyed radar or not. In the latter case, a new radar presence is

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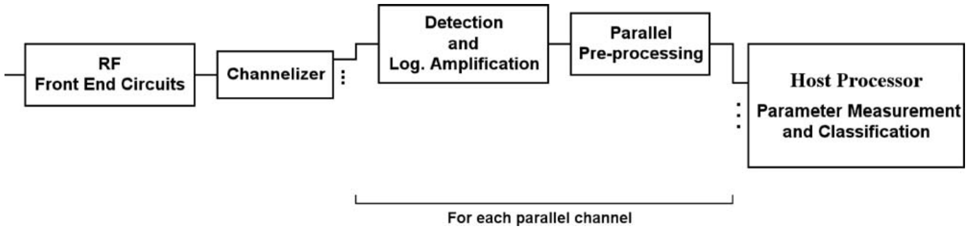

Fig. 1. Block diagram of a channelized ESM receiver.

decided and thereafter, the receiver tries to confirm/deny this decision by processing next received data [3,17]. The parameters measurement process and the classification take the major part of the computation of the system.

In this work, we propose a constant false alarm rate (CFAR) adaptive threshold to be applied in an ESM receiver. CFAR processors are usually used for the detection of radar pulses in radar application, when the background noise statistics are unknown and/or time-varying [25]. Under such conditions, the use of a fixed detection threshold cannot result in a controlled false alarm rate (FAR). Using a CFAR processor, the detection threshold can be set adaptively, based on local information of the background noise power. Notice that the thresholding of the received signals in an ESM receiver is somewhat different from that in the radar application as will be explained.

In this paper, we consider a channelized-type ESM receiver. Before dealing with the design of appropriate CFAR processors conformable to our ESM system, let us first consider two associated topics, the channelizer structure and the thresholding task.

1.1. Channelized receiver

The interest of use of channelized receivers comes from the need to intercept, measure, and classify many signals per unit time. Use of channelized receiver results in a much lower probability of overlap of signals at high signal densities, as compared to other types of electronic warfare (EW) receivers. This (relatively) high probability of intercept (POI) and high throughput rate can be achieved with a reasonable (simplified) architecture. Channelized receivers are also preferred in surveillance applications because of their low acquisition time and high sensitivity [1,6,18,33].

The block diagram of the receiver is shown in Fig. 1. At the receiver front end, signals are de-multiplexed (channelized) with respect to frequency or direction of arrival, for example. Next, the de-multiplexed signals are down-converted to an intermediate frequency (IF) band, and are then segmented into the appropriate parallel frequency bands.

These "raw" signals contain unneeded/redundant information, while the processing capability of the host digital processor is limited, regarding the wide frequency band under surveillance. So, it is essential to optimize and minimize the information rate that this host computer should process. That is why after detection and logarithmic amplification, signals are submitted to a *pre-processing*. In this way, only the desired information is passed to the host. Typical signal processing functions performed in this pre-processing level are, thresholding, inhibition of signal reporting from selected channels, centroiding, and compression [1].

1.2. Thresholding

Let us now concentrate on the thresholding task of the pre-processor. Input signals must exceed the threshold before a signal presence is recognized. The higher this threshold, the lower the FAR, but also the lower the detection probability and the receiver sensitivity [2]. In most ESM systems, a fixed threshold is used (or it is changed by the operator manually). If the receiver is RF noise limited and $BW_{RF} \gg BW_{Video}$ (BW_{RF} and BW_{Video} are the RF and video bandwidths, respectively), setting the threshold in about 13–20 dB above the noise level may result in a reasonable probability of detection without causing an excessive FAR [1].

However, this setting may not result in suitable false alarm regulation when variations occur in the background noise power and that we want to reduce the amount of human intervention for an autonomous ESM system. When noise power changes considerably, if the threshold is set (incorrectly) too high, it results in a very low probability of detection, and inversely, if the threshold is set too low, noise signals exceeding this threshold will be taken for arriving radar pulses. Notice that although due to the host data processor treatment, these "signals" (which are in fact false alarms) may not be finally taken into account, a considerable part of data processing is devoted to process them [16,28]. The occurrence of too many false alarms (noisy threshold crossings) may result in the *saturation* of the host processor. This situation is more crucial when broad band noise jammers exist in the scenario. Notice that additive broadband noise jamming can also be modeled as Gaussian [11]. In such a case, the receiver noise in some channels can be augmented considerably and careful setting of the pulse detection threshold in each parallel channel is necessary when the system is in the automatic detection mode. [1]

1.3. Smart processing

Most current ESM systems do not use a CFAR adaptive threshold, but they use a fixed threshold together with some logic-based processing before a pulse arrival is declared. For example, the start of a pulse may be decided when the pulse rise time is short enough, that is, if the pulse amplitude rises significantly. Also a minimum pulse-width criterion may be used, depending on the surveillance conditions; a pulse arrival is declared if its pulse-width is greater than a pre-decided value. When processing is performed on sampled data, a pulse reception decision may be conditioned to the reception of two successive threshold crossings.

These logic-based methods may not function as efficiently as a CFAR threshold, especially under critical conditions. In other words, by smart processing we can limit the false alarms, but we cannot control them as when we use a CFAR threshold.

Recently two CFAR processors, named as modified excision (MEx) and adaptive MEx (AMEx) have been proposed to be used in an ESM system for the linear detection case [16]. In this paper, our aim is to design a CFAR processor for an ESM system which uses logarithmic amplification of the received signals. To do this purpose, two concepts should be taken into account: special characteristics of ESM systems and logarithmic detection (subject of Section 2). Notice that logarithmic amplification is widely used in EW receivers to provide a large dynamic range [13]. After studying the general concepts concerning our problem, we begin by describing the system assumptions and statistical models in Section 3. In Section 4, excision LOG (Ex-LOG) processor is introduced, which will be used as a primary idea for the design of appropriate CFAR processors in our application. Next, we consider two cases of small and large variations in the background noise power in Sections 5 and 6, respectively, where MEx-LOG and AMEx-LOG CFAR processors will be introduced and described. In these two sections, methods for the determination of the processors' design parameters are discussed, assuming a particular characteristic equation for the logarithmic amplifier. In Section 7, the modification of the design parameters for a new characteristic equation is discussed. Conclusions and some discussions are given in Section 8.

2. ESM system considerations

As mentioned previously, a channelized ESM receiver is considered in this paper. The block diagram of one of receiver channels is shown in Fig. 2. As it is seen, in our system, parameter measurement is performed on analog (continuous-time) signals. The effect of A/D (analog to digital converter) and D/A (digital to analog converter) is discussed in [15].

Here the frequency measurement is performed on RF signal, separately by an instantaneous frequency measurement (IFM) receiver. [2] We will consider the

[1] Notice that usual electronic counter counter measures (ECCM) techniques employed in radar systems against noise jamming such as sidelobe canceling (SLC), sidelobe blanking (SLB) [7], and look through cannot be used in an ESM system.

[2] IFM receivers are common components in EW systems which quickly measure a signal's frequency to command appropriate ECM techniques such as jamming, or ECCM techniques such as blocking, to take place [4].

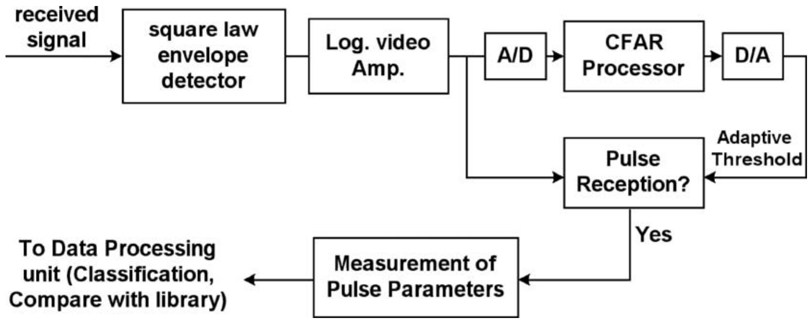

Fig. 2. Block diagram of a typical receiver corresponding to one of channels.

design of the CFAR processor as it is usual in radar applications, but firstly we remind the important points that should be taken into account, that is, special specifications of ESM systems and the logarithmic amplification.

2.1. Special specifications

Since ESM systems do not have the problem of clutter, there is no need to determine the detection threshold in real time, and this relatively simplifies the design of a CFAR processor. However, an ESM system is subject to various transmissions, since it receives the signals in a relatively wide frequency band. [3] For our adaptive thresholding section, these pulses are as interferers, which interfere with the operation of CFAR in noise, that is, they may raise the threshold incorrectly. So, an important problem is to have a set of reference noise samples to estimate the noise power.

2.2. Logarithmic detection

ESM systems need to have a large dynamic range, because they should regard far and nearby emitters (low power received signals and signals coming from more local higher power emitters) simultaneously. Usually logarithmic video amplification is used in order to increase the receiver dynamic range (as shown in Fig. 2). Here, the dynamic range and the frequency bandwidth of the receiver is limited by the detector. The usual technique in the design of logarithmic characteristics for radar and electronic warfare receivers is the parallel summation technique [13]. The amount of compression depends on system requirements, channelizer circuit capabilities and number of bits used in A/D.

Most of CFAR algorithms proposed for the linear detection case are also applicable to the logarithmic detection case, with some modifications. For the cell averaging (CA) family of CFAR processors [9], logarithmic amplified samples can be processed in a similar way. For these processors, the use of logarithmic data results in an increased robustness against interferers [25,26]. Nevertheless, logarithmic processing causes some additional CFAR loss [12,25].

3. System description and statistical models

The input–output characteristic of the logarithmic amplifier is considered according to (1), where z and x are the output and input of the amplifier, respectively, and log is in base 10:

$$z = a \log x + b, \quad (1)$$

where a (the compression factor) and b are the parameters of the logarithmic amplifier. Obviously, this ideal characteristic is not practically obtainable, and the actual characteristic does not match it exactly [13]. In an ESM system, the RF bandwidth is much larger than the video bandwidth, and hence, the Gaussian distribution can be considered for the input noise [16,35].

[3] In a typical EW environment, about several thousands of signals or emitters may be present in radar frequency bands at any instant [1]. Although their frequencies do not fall in all channels of the channelizer, the problem of interfering pulses still is important for the adaptive thresholding system within each channel.

Moreover, in most practical systems, statistically independent noise samples can be considered [16]. Therefore, assuming Gaussian distributed independent identically distributed (IID) samples in the detector input, the probability density function (PDF) of noise samples at the output of the detector is

$$f_{nx}(x) = \frac{1}{2\sigma^2} \exp\left(-\frac{x}{2\sigma^2}\right), \quad x \geqslant 0, \tag{2}$$

where σ^2 is the variance of samples. Note that additive broadband noise jamming can also be modelled as Gaussian [11].

On the other hand, we consider constant amplitude for the received pulses, which is equivalent to considering non-fluctuating (Swerling case 0) targets in radar application [31]. So, if the amplitude of a received pulse equals A, the PDF of signal plus noise samples at the detector output is given by

$$f_{sx}(x) = \frac{1}{2\sigma^2} \exp\left(-\frac{x + A^2}{2\sigma^2}\right) I_0\left(\frac{A\sqrt{x}}{\sigma^2}\right), \quad x \geqslant 0, \tag{3}$$

where $I_0(.)$ is the modified Bessel function of the first kind and zero order.

4. Ex-LOG/CFAR processor

In order to design a CFAR processor for our special application, as a primary idea, we begin with Ex-CFAR processor [11]. This processor has been proposed to work under the presence of several interferers among the reference samples and can be regarded as a member of CA family CFAR processors. The block diagram of this CFAR processor for the case of logarithmic amplification (named as Ex-LOG) is shown in Fig. 3. Samples at the output of the logarithmic amplifier are compared to a primary threshold B_E in order to remove probable interferer samples (function of the excisor block on the figure). Then, the final detection threshold B_D, is obtained via the addition of the average of the survived samples V, with a threshold parameter γ_D. When $B_E \to \infty$, the processor reduces to CA-LOG [12]. An important parameter, called as *excisor coefficient*, is defined for the

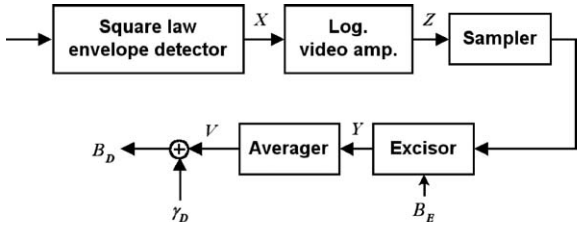

Fig. 3. Block diagram of the Ex-LOG/CFAR processor: V—average of survived samples, B_E—excision threshold, γ_D—threshold parameter, and B_D—detection threshold.

processor as

$$\alpha = B_E - E\{Z\}, \tag{4}$$

where regarding (1),

$$E\{Z\} = a \log(2\sigma^2) + b - a\gamma \log e \tag{5}$$

with γ the *Euler* constant, defined as

$$\gamma = -\int_0^\infty e^{-x} \ln x \, dx \approx 0.57721. \tag{6}$$

In other words, B_E can be calculated using the following equation:

$$B_E = a \log(2\sigma^2) + b - 0.2507a + \alpha. \tag{7}$$

The performance of Ex-LOG processor is similar to Ex-CFAR, which is extensively discussed in [10,11], except that it suffers from more CFAR loss due to the use of logarithmic amplification [14]. In the presence of interfering targets, assuming constant γ_D, any increase in the number of interferers results in an increase in P_{fa} (false alarm probability). However, assuming constant P_{fa} (correcting γ_D with respect to the number of interferers), any increase in the number of interferers results in a decrease in P_d (detection probability), due to the increased CFAR loss.

5. Adaptive thresholding in situations of relatively small variations in noise power

5.1. MEx-LOG/CFAR processor

As it was previously explained, in our application the major difficulty in the estimation of background noise statistics is the problem of interfering pulses. Considering a set of reference samples, it is possible that most of them correspond to interfering pulses, and are removed by the excisor (see Figs. 2 and 3). So, the estimated statistics would be based on a very small number of noise samples, which results in a great CFAR loss. Therefore, similar to the case of MEx processor [16], as a modification to the Ex-LOG algorithm, we fix the number of samples remained after the excisor. In other words, the processor should wait until taking K samples smaller than B_E. The resulted algorithm is named MEx-LOG (Modified Ex-LOG).

A brief comparison is made between the performances of Ex-LOG and MEx-LOG processors, as follows. It is similar to the case of Ex and MEx processors, for which a detailed comparison is made in [16].

Considering the conditions of *benign* environment (i.e. additive Gaussian noise plus possibly additive broad band jamming), for small values of α, Ex-LOG processor suffers from more CFAR loss. However, for relatively large values of α, two processors endure almost the same CFAR loss. In the presence of interference, considering a constant γ_D, any increase in the number of interferers would result in an increase in P_{fa} of Ex-LOG, but has almost no effect on the FAR of MEx-LOG. Here, MEx-LOG takes its advantage over Ex-LOG, particularly for small α values. An interesting point is that, given a constant number K of non-excised reference samples, the CFAR loss of MEx-LOG processors is almost independent of α.

Due to logarithmic amplification, performance analysis of MEx-LOG processor by means of analytical methods is very complicated. Alternatively, numerical methods may be used. For instance, the PDF of V (see Fig. 2) may be obtained via K-times convolution of the PDF of Y with itself, or via using Gram–Charlier series with Edgeworth grouping [29]. However, as we will see, we will choose a large K in our analyses and use of these methods becomes computationally hard. So, we have used Monte Carlo simulations for the performance analysis of the processor.

5.2. Determining MEx-LOG design parameters

Three important parameters of the processor are K, B_E, and γ_D. Considering almost constant noise power, we will discuss the determination of α instead of B_E. Moreover, unless otherwise mentioned, the characteristic equation of the logarithmic amplifier is considered according to (1), with $a = 0.68$ and $b = 2.5$. Correction of processor's design parameters for arbitrary a and b will be discussed in Section 7.

5.2.1. Determination of K

Since in our application, it is not necessary to determine the detection threshold in real time, K can be chosen as a large value, so that a small CFAR loss would result. However, the choice of K should also result in a reasonable *sampling time* (the time needed to get K non-excised samples from the input). We choose $K = 100$ in our analyses.

5.2.2. Determination of α

To determine α, three criteria should be taken into consideration. The first criterion is the sampling time in a benign environment. The total number of input samples, taken to extract K non-excised reference samples, has a negative binomial distribution. Considering its expected value with respect to α, values of $\alpha > 0.3$ are concluded to be suitable.

The next criterion is the endured CFAR loss in the noise only environment. As it was explained previously, simulation results show that the detection performance has a negligible sensitivity to α. Therefore, no limitation arises from this point of view.

The other criterion is the capability of excision of interferer samples. As an example, Fig. 4 shows the effect of an interfering signal with $r_i = \text{INR}$ (interference to noise ratio) on the detection of a signal with $r_s = \text{SNR}$ (signal to noise ratio). $r_i/r_s = -6$ dB and $P_{fa-d} = 10^{-4}$ (design P_{fa}) are considered. The density of the interference is such that for each 6 samples taken from input, 5 correspond to noise and one to interference. This fact is denoted as density$(i/n) = 1/5$. From Fig. 4, values of $\alpha < 0.5$ seem to be suitable. On the whole, $0.3 < \alpha < 0.5$ is an appropriate interval.

5.2.3. Determination of γ_D

γ_D is determined with regard to the values of α and P_{fa-d}. For instance, Fig. 5 shows values of γ_D versus α, obtained by means of simulation for $P_{fa-d} = 10^{-4}$.

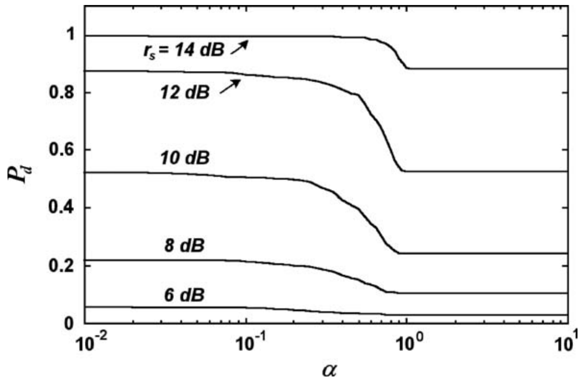

Fig. 4. Effect of interference on the detection performance of MEx-LOG/CFAR processor; $P_{fa-d}=10^{-4}$, $K=100$, $r_i/r_s=-6$ dB, density$(i/n)=1/5$.

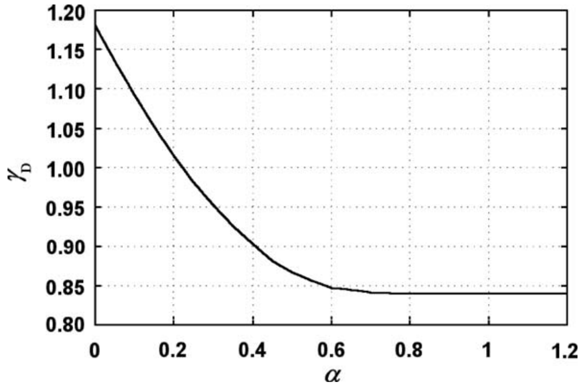

Fig. 5. MEx-LOG/CFAR processor, design curve of γ_D versus α, $P_{fa-d}=10^{-4}$, $K=100$.

6. Adaptive thresholding in situations of large variations in noise power

6.1. AMEx-LOG/CFAR processor

If noise power has relatively small variations, use of MEx-LOG processor with fixed B_E and γ_D (setting them to *middle* values with regard to the variation range of the noise power), results in satisfactory CFAR and detection performances. However, if relatively large variations occur in

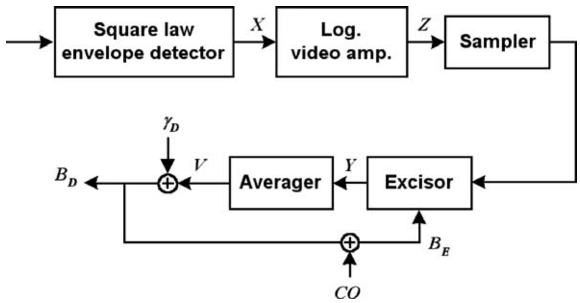

Fig. 6. Block diagram of the AMEx-LOG/CFAR processor.

the noise power,[4] adaptive B_E and B_D should be used [16].

For a large K, B_D has a small variance. So, considering B_D as a suitable reference value, B_E can be set as the summation of B_D and a constant CO (the notation stands for threshold COefficient). In this way, the excision threshold can change appropriately with any variation in the noise power. The block diagram of the resulted processor, named AMEx-LOG (Adaptive MEx-LOG) is shown in Fig. 6.

Similar to the case of MEx-LOG processor, most of the results to be presented are obtained by means of simulations. Here, in addition to logarithmic detection, the existence of feedback in the processor's structure makes its analytical analysis very complex.

On the other hand, since γ_D and CO both affect the feedback loop, their mutual effect on the function of the processor should be taken into consideration.

As it was the case for AMEx [16], the performance of AMEx-LOG processor in the "steady state" (that is, when the noise power remains unchanged) is independent of the noise power [14]. With any change in the background noise level, the algorithm undergoes a *transient behavior*. Unless otherwise mentioned, the results to be presented are for the *steady state* of the algorithm. Some simulation results concerning the properties of AMEx-LOG processor will be presented in the following subsections.

[4] It may arise from broadband noise jammers being present in the scenario. Notice that noise jamming may be used against the enemy ESM system in order to mask from it the radar signals [34]. Our aim here is just to correct the threshold to prevent excessive false alarms resulting from such an ECM operation.

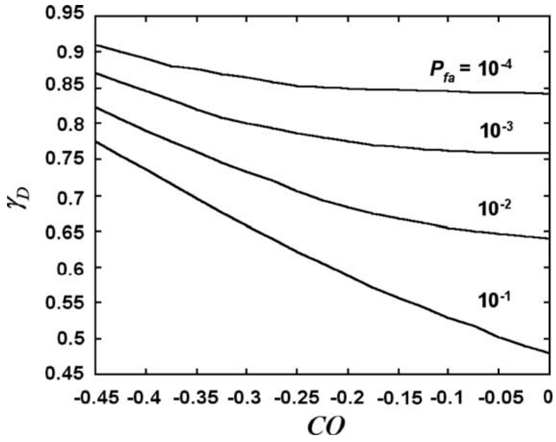

Fig. 7. AMEx-LOG/CFAR processor with $K = 100$, design curves of γ_D versus CO.

6.2. Determining AMEx-LOG design parameters

Similar to the case of MEx-LOG processor, $K = 100$ is chosen and results to be presented, are based on this assumption. Determination of γ_D and CO is discussed in the following.

6.2.1. Determination of γ_D

γ_D is determined with regard to P_{fa-d} and CO. For example, Fig. 7 shows curves of γ_D versus CO obtained via simulation for several P_{fa-d} values.

6.2.2. Determination of CO

A very small CO not only causes a long sampling time, but may also result in the divergence of the algorithm because of consequent decrease in B_E and B_D. Remembering the mutual effect of γ_D and CO on the function of the algorithm, larger P_{fa-d} cause more limitation on the choice of CO. Assuming $\max(P_{fa-d}) = 10^{-2}$, values of $CO > -0.40$ are suitable, regarding this criterion. On the other hand, a large CO weakens the capability of the excisor in removing probable interferer samples. Based on simulation results, values of $CO < -0.25$ are suitable from this point of view.

Simulation results show that CFAR loss of the algorithm has almost no sensitivity to CO, and hence, does not impose any limitation on its choice.

Taking into mind the appropriate interval of $-0.40 < CO < -0.25$, the last criterion to be considered, is the time required by the algorithm to reach its steady state, as the result of a variation in noise power. The discussion over this criterion is left for the next subsection.

6.3. Transient behavior of AMEx-LOG processor

As explained previously, with any change in the background noise power, the CFAR algorithm undergoes a transient behavior, until it adapts itself to the new noise level. To study the transient behavior of AMEx-LOG algorithm, we consider two cases of increase and decrease in the noise power.

6.3.1. Increase in the noise power

Assume that the noise power is almost constant, and the processor has reached a steady state. By any increase in the noise power σ^2, V, B_D, and B_E increase gradually, until the processor reaches its new steady state. Greater CO and/or γ_D helps B_E to increase more rapidly.

In order to investigate the effect of CO and γ_D on the transient response, we take use of simulation results. Fig. 8(a) shows P_{fa} curves versus cycles of the algorithm runs, for several values of CO, belonging to the interval $-0.40 < CO < -0.25$ deduced in the previous subsection. [5] $P_{fa-d} = 10^{-3}$ is considered. Furthermore, effect of γ_D (or equivalently P_{fa-d}) on the transient response is considered in Fig. 8(b). In both cases, it is assumed that at first (cycle 0), $\sigma = 20$ mv. The algorithm has reached its steady state, and at this moment, σ increases to 100 mv suddenly (notice that such a abrupt increase in σ is rarely happened, but this permits us to study the transient behavior). As expected, with any increase in CO or γ_D, a faster transient response results. [6]

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[5] To obtain this figure as well as other simulation results presented in this paper that concern the computation of P_{fa}, the number of independent trials used, has been to obtain at least 500 false alarms.

[6] Notice that for the first cycles after the increase in the noise power, the processor takes a long time to take K non-excised samples from the input. As a solution, we may impose that (taking into account the maximum probable interference density) if sampling time is too long, B_E be increased about 20%, for example, to permit the processor to reach more rapidly its steady state under such severe conditions.

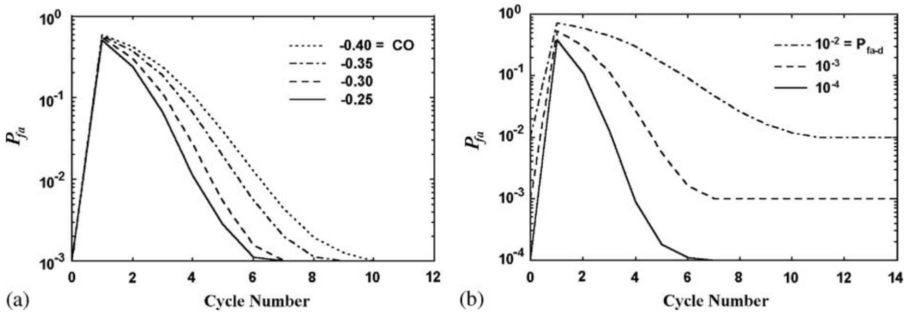

Fig. 8. AMEx-LOG processor, transient behavior of P_{fa}; Increase in σ of noise from 20 to 100 mv, $K = 100$, (a) $P_{\mathrm{fa-d}} = 10^{-3}$, (b) $\mathrm{CO} = -0.3$.

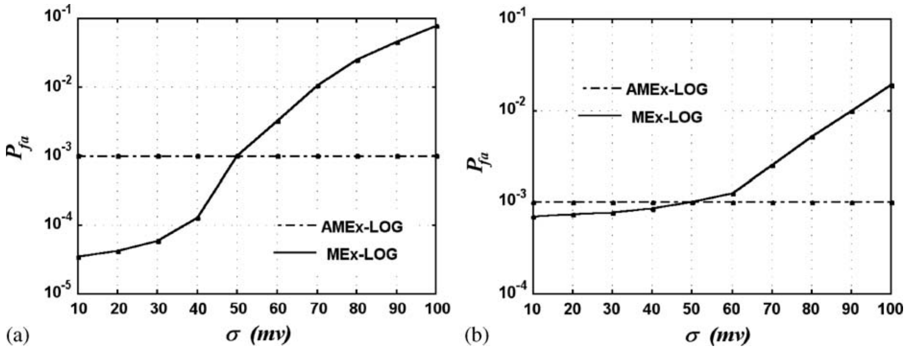

Fig. 9. P_{fa} of MEx-LOG and AMEx-LOG processors for different σ of noise; $K = 100$, design-$\sigma = 50$ mv, $P_{\mathrm{fa-d}} = 10^{-3}$: (a) $\alpha = 0.3$ and (b) $\alpha = 0.6$.

6.3.2. Decrease in the noise power

In this case B_{E} and B_{D} are initially high, and hence, any decrease in noise power will cause a quick decrease in V, B_{D}, and B_{E}. As a result, the algorithm reaches its steady state rapidly. It has been verified that the presence of interfering signals does not prevent the algorithm to converge properly [14].

On the whole, with attention to the results of the previous subsection, $\mathrm{CO} = -0.30$ is proposed as a suitable value with the assumption of $\max(P_{\mathrm{fa-d}}) = 10^{-2}$.

6.4. Performance comparison between MEx-LOG and AMEx-LOG processors

Assuming $\alpha = 0.30$ and $\mathrm{CO} = -0.30$ as suitable parameters for MEx-LOG and AMEx-LOG processors, respectively, Fig. 9 shows P_{fa} of the two processors for different values for noise power, σ^2. For AMEx-LOG, P_{fa} values are for the steady state of the processor. In the design of processors' parameters, $\sigma = 50$ mv and $P_{\mathrm{fa-d}} = 10^{-3}$ are considered. As it was explained previously, AMEx-LOG has a considerable advantage over MEx-LOG, when important variations are possible in the background "noise+noise jamming" power. Notice that although for a greater α, MEx-LOG has a better FAR regulation, it undergoes a degradation in the interference rejection capability.

The effect of interferers on the detection performance of the two processors is shown in Fig. 10, where curves of P_{d} versus INR are shown. $\alpha = 0.30$, $\mathrm{CO} = -0.30$, and $P_{\mathrm{fa-d}} = 10^{-4}$ are considered. It can be seen that MEx-LOG processor has more robustness against interfering signals. That is because for AMEx-LOG processor, B_{E} is not fixed and is determined according to B_{D}. So, any increase in V and B_{D}

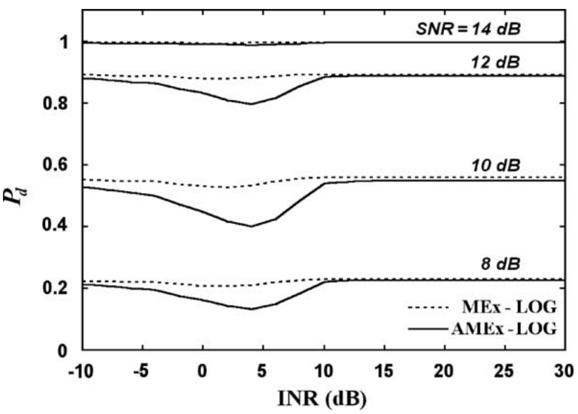

Fig. 10. IZ characteristic curves of MEx-LOG ($\alpha = 0.30$) and AMEx-LOG ($\mathrm{CO} = -0.30$) processors; $P_{\mathrm{fa-d}} = 10^{-3}$, $K = 100$, density$(i/n) = 1/5$.

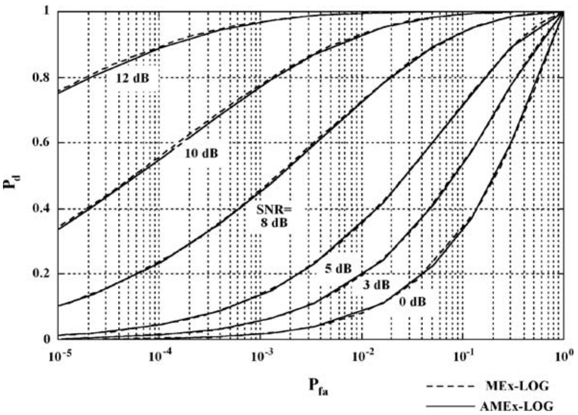

Fig. 11. ROC curves of AMEx-LOG and MEx-LOG processors.

due to non-excised weak interferer samples, will result in a higher B_{E}. AMEx-LOG processor is said to have a wider ineffectiveness zone (IZ). IZ is defined as the range below B_{E} in which the interferers are not excised and thus influence the setting of the detection threshold [11].

On the other hand, receiver operating characteristic (ROC) curves of two processors are shown in Fig. 11. As expected, AMEx-LOG processor suffers from more CFAR loss as compared to MEx-LOG. This additional CFAR loss is evaluated as 0.12 dB by means of simulation, under the conditions of $P_{\mathrm{d}} = 0.8$, $P_{\mathrm{fa}} = 10^{-4}$ and $K = 100$. Note that since the detection performances of the processors have almost no sensitivity to B_{E}, these results are independent of α and CO.

7. Correction of design parameters for a new logarithmic amplifier characteristic equation

Up to now, the characteristic equation of the logarithmic amplifier was considered according to (1), with $a = 0.68$ and $b = 2.5$, and Figs. 5 and 7 were obtained for this special case. An important concept is to correct the design parameters of the presented CFAR processors, as a result of a change in a and/or b. Considering the new characteristic equation parameters as a' and b', the method of modification of the processors' design parameters is discussed in the sequel. All *primed* quantities to be used, are for the case of the new logarithmic amplifier characteristic equation.

7.1. Correction of α of MEx-LOG processor

With any change in a or b, α (and in fact B_{E}) should be modified so that the same probability of excision of noise samples (P_{ex}) results. Remembering statistical assumptions made in Section 3, we have

$$P_{\mathrm{ex}} = \mathrm{Prob}(Z > B_{\mathrm{E}}) = \exp\left(-\frac{10^{B_{\mathrm{E}}/a}}{2\sigma^2 10^{b/a}}\right), \qquad (8)$$

where Z is sample at the output of the logarithmic amplifier. To have the same P_{ex}, we should have

$$B'_{\mathrm{E}} = \frac{a'}{a}(B_{\mathrm{E}} - b) + b'. \qquad (9)$$

Replacing B_{E} from (7),

$$\alpha' = \alpha \frac{a'}{a}. \qquad (10)$$

7.2. Correction of CO of AMEx-LOG processor

Similar to (8), we have

$$P_{\mathrm{fa}} = \mathrm{Prob}(Z > B_{\mathrm{D}}) = E\left\{\exp\left(-\frac{10^{B_{\mathrm{D}}/a}}{2\sigma^2 10^{b/a}}\right)\right\}, \qquad (11)$$

where the expected value $E\{.\}$ is with respect to B_{D}. In order to have the same P_{fa}, it can be seen that as a sufficient condition we should have

$$B'_D = \frac{a'}{a}(B_D - b) + b'. \quad (12)$$

Moreover, to have equal P_{ex}, as a sufficient condition (9) should be satisfied (P_{ex} in this case is the expected value of (8) w.r.t. B_E). From (9) and (12),

$$CO' = B'_E - B'_D = CO\,\frac{a'}{a}. \quad (13)$$

7.3. Correction of γ_D

Again, our criterion is to have equivalent excision and detection functions. Considering a set of samples $\{x_i\}$ at the input of the logarithmic amplifier, Eq. (14) shows the relationship between $\{z_i\}$ and $\{z'_i\}$, the logarithmically amplified samples in two cases of old and new characteristic equations, respectively.

$$z'_i = \frac{a'}{a}(z_i - b) + b'. \quad (14)$$

Assuming the same excision function in two cases, for the corresponding surviving samples ($\{y_i\}$ and $\{y'_i\}$) we have

$$y'_i = \frac{a'}{a}(y_i - b) + b'. \quad (15)$$

After taking the average of these samples,

$$V' = \frac{a'}{a}(V - b) + b'. \quad (16)$$

Considering (16) together with (12) (the condition for P_d), it can be concluded that

$$\gamma'_D = B'_D - V' = \gamma_D\,\frac{a'}{a}. \quad (17)$$

As expected, the correction of the design parameters depends only on the compression factor of the characteristic equation, a.

8. Conclusion and discussion

The need to precisely and simultaneously intercept and receive many time-coincident signals in the increasingly dense electromagnetic environments without loss of information leads us to the use of channelized receivers. Several aspects of research have concerned *adaptive* ESM systems in the past few years [5,19–23,27,32]. One of the important research areas for the improvement of the channelized technology is the use of efficient and high speed preprocessing circuits so that in addition to accurate and precise signal interception, only useful and reliable information be passed to the host digital computer (see Fig. 1). One of these preprocessing steps is the signal thresholding; that is, taking only the signals exceeding an appropriately set threshold as possible radar signals. In this paper, we suggested the use of an adaptive threshold with CFAR property to be used in the thresholding circuit of each parallel channel in a channelized receiver. This has the advantage of regulating the FAR when the ESM is functioning in an automatic mode (without operator intervention).

In this perspective, two CFAR processors were designed to be used in an ESM receiver using a logarithmic video amplifier. In the design of these processors, special specifications of ESM receivers as well as logarithmic amplification were taken into account. Under the conditions of relatively small variations in noise power, MEx-LOG processor was proposed. This processor exhibits a good robustness against interfering signals and can preserve its detection performance in situations of severe interference. However, if large variations occur in the noise power, it can provide neither a good FAR regulation nor a narrow IZ.

In situations that relatively large variations in the noise power are probable, AMEx-LOG processor was proposed. In steady state (unchanged noise level), the detection and CFAR performances of this processor have almost no sensitivity to the noise power. In fact, the feedback loop in the structure of the processor permits it to adapt itself to new background noise level. The feedback loop parameter CO, can be set appropriately in order to provide a suitable (fast enough) transient behavior as a result of any variation in the noise power. AMEx-LOG processor suffers from a little more CFAR loss and a wider IZ, as compared to MEx-LOG. Yet, these are reasonable costs for the excellent CFAR property of this processor.

Methods for the determination of the design parameters of two processors were discussed, assuming a special characteristic equation for the logarithmic amplifier; and conversion equations were provided for the correction of these design parameters for an arbitrary characteristic equation. So, although the analysis of the proposed CFAR processors was based on simulation results for the special case of $a=0.68$ and $b=2.5$, the presented curves can be utilized in a general case, using the correction equations.

For the proposed AMEx-LOG processor, feedback was taken from B_D to B_E (see Fig. 6) to permit adaptive setting of these parameters. In this form, as explained previously, the mutual effect of γ_D and CO should be taken into account, for example on the transient behavior of the processor. However, the feedback can be taken from V to B_E, where the feedback and threshold parameters will have no mutual effect on the processor performance.

In the system considered, pulse detection (adaptive thresholding) and parameter measurement is performed in continuous time, i.e. on analog signals (see Fig. 2). From an implementation point of view, the effect of data quantization on the detection and CFAR performances of the thresholding system should be taken into consideration. In spite of the compression of the input data, as a result of logarithmic amplification, a reasonable number of quantization bits is required to achieve an appropriate CFAR performance, even if a large variation range is considered for the noise power [15]. Note that here the effect of clamping of possible signal samples is not important, as it is the case in radar application [8].

Notice that the proposed adaptive thresholding imposes a relatively small complexity to the system, and can be employed together with other smart false alarm rejection processings such as minimum pulse-width test, etc.

Although the suggested improvement may be considered as moderate, as compared to the challenges and research areas on channelized receivers, it may have considerable interest in a non-stationary environment and when efficient false alarm control is desired in the automatic detection mode of an ESM system.

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