Designing a New CVR Receiver and Investigating the Problem with Simultaneous Signal with Applying Approach in Electronic Warfare

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ABSTRACT:
In order to launch different receivers in electronic warfare, side-circuits are required to detect the presence of a pulse at the receiver input and to report it after making sure that the receiver output is not due to system noise alone. In practice, a crystal video receiver (CVR) is used for this purpose. This receiver provides the required time information (or domain related information) to the other part of an electronic warfare receiver by extracting the received RF signal wave envelope. In this paper, after a conceptual overview of the structure of this receiver, the analysis of its function (sensitivity) will be dealt with. Moreover, some important issues in its design will be discussed. In addition, since the IFM and CVR receivers are not capable of processing simultaneous pulses or pulses coupled with the CW, some further steps are taken to maintain system efficacy under such conditions.

KEYWORDS: Electronic Warfare, Function, Crystal Video Receiver, Signal.

1. INTRODUCTION

Crystal Video Receiver is the simplest and most primitive receiver to use in electronic warfare systems and is a constant part of almost all electronic warfare receivers due to its simplicity and low volume. The determination of time of arrival (TOA), the pulse width, or the extraction of information from its domain are used. In addition, using multiple CVRs and comparing their domain is the simplest way to measure a signal TOA angle [1]. To simply describe the performance and sensitivity of the CVR, first, the concerned analog receiver model will be explained. In the following, after referring to the digital equivalent system, it will be shown that all results are easily generalized to the digital domain.

(Fig.1) shows the simplest case of the CVR receiver structure.

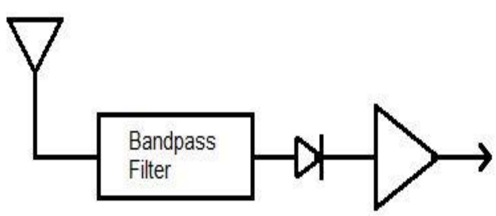

Fig. 1. CVR receiver structure [2].

In this structure, the received signal passes through the video detector at the desired bandwidth and will eventually amplify the resulting video signal. The sensitivity of this receiver structure is determined by the noise characteristics of the video detector and amplifier. To improve sensitivity, a low-noise RF amplifier (LNA) is often used prior to the detector, which will dramatically increase the CVR sensitivity (Fig.2). In this state, the sensitivity of receiver will limit the noise digit of LNA [3].

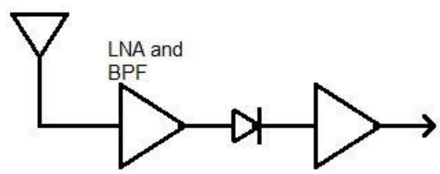

Fig. 2. CVR Receiver Structure Using RF Amplifier [3]

Conventional analog implementations employ a diode detector that, depending on the operating conditions, often behaves as a linear (rectifier) or quadratic (energy detector) detector. In the first case, the relationship between input voltage (V_i) and output (V_o) is $V_o=kV_i^2$, $V_o = kV_i$, $V_i> 0$ ($V_o = 0$, $Vi <0$) and in the second case, $V_o=kV_i^2$. Low pass filters in the video amplifier and detector circuit prevent high frequency passages and only pass the video signal. Bandwidth of this video filter along with RF input bandwidth play a major role in receiver sensitivity. In order to properly select the receiver parameters, one must first determine the impact of each on the receiver performance (sensitivity) [4].

2. FUNCTION EVALUATION CRITERIA

One criterion for measuring the capability of an ESM receiver is the lowest level of signal reception power that can be processed by the receiver "appropriately" and is often referred to as sensitivity. Appropriately is defined here depending on the application and purpose of the involved processing. For example, in older systems where the presence of the signal was determined by the operator visually from the scope, the tangential sensitivity criterion was widely used and it is referred to the surface of received pulse power that the lower edge of the noise mounted on the signal was placed equal to the upper edge of the single noise. Based on the experimental observations, the required signal-to-noise ratio is about 8 dB. Since today, the signal presence detection and processing is done automatically by digital adapters, such criteria have lost their effectiveness and are rarely used [5].

Today, the ability of a receiver to detect the presence of a signal is determined by the amount of detection probability (pd) and probability of false alert (pfa), and it is necessary to obtain the sensitivity of the receiver with respect to the values given for these two quantities. Hence, extracting the pd and pfa relationships will greatly facilitate the design and analysis of the receiver performance.

It should be noted that in practice, instead of false probability, the alarm rate may be expressed in a timely manner, such as a false alarm per minute. In this case, if we call the false alert rate R (the distance of both false alarms are equal to 1 / R), since in each false alert the average of time duration that the signal is above the threshold is equal approximately to 1/ 2B (B Detection Output Bandwidth). The amount of corresponding false alarm probability can be obtained by using the $Pta = R/2B$ relation.

3. ANALYSIS OF RECEIVER PERFORMANCE (SENSITIVITY)

To obtain the detection probability and false alarm probability values, one must first calculate the probability density functions of the receiver output, which can be very difficult in general. However, since in practice the RF input signal bandwidth is much greater than the video receiver bandwidth, using the central limit theorem can show that the output probability distribution is very close to the normal (Gaussian) distribution [6]. Therefore, we will see that in this case it is enough to calculate the first two torque of the receiver output.

Relationships with CVR sensitivity are found in most references to electronic warfare receivers [7]-[8], but since they are rarely mentioned in how to extract these relationships, in order to complement the discussion, below we will explain the process of obtaining the first two output torques in the CVR receiver. With these two quantities, the signal-to-noise ratio of the output and the probability of false detection and alert can be easily calculated. If m1 and m2 are the first two torque of the video output, then the output SNR is equal:

$$SNR = \frac{m_1^2}{m^2 - m_1^2} \tag{1}$$

The first (average) torque is usually easy to calculate. To obtain the second output torque (the filtered process), we first need to find the spectral power density (or equivalent R_τ auto correlation function) of the filter input. Then the second torque is obtained from this relation. [9].

$$m_2 = \overline{z^2} = \int S_z(\int (f) df = \int S_y(f)|H(f)|^2 df \tag{2}$$

Where H(f) is the function of the video filter conversion, y is its input with spectral power density $S_y(f)$ and z is its output with spectral power density $S_z(f)$. As mentioned above, the CVR receiver can be modeled as a single or dual nonlinear element located between two filters (BF video). The complexity of analyzing the performance of this receiver and other similar structures all results from the nonlinear characteristic of the element. For example, at these receivers for 1 dB, the increased SNR of the input would not be equal to 1 dB [9].

First, we consider the receiver with a nonlinear grade 2 element. The received signal can be expressed as follows:

$$S(t) = a(t)\cos(2\pi f_0 t + \varphi) \tag{3}$$

Where a(t) is the shape of the received pulse f_0 is the central frequency φ of its phase. After passing the RF transmitter and amplifier filter and Gaussian thermal noise, the input signal to the detector will be in the form of r(t) = s(t) + n(t), where n (t) is the white Gaussian noise with the power of σ^2. (Fig.3) shows the spectrum of the received power:

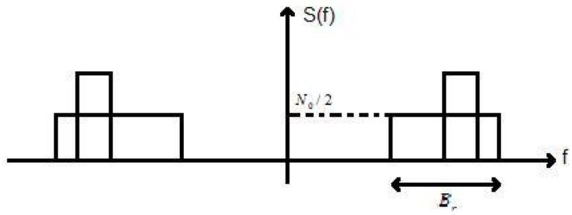

Fig. 3. Input power spectrum [9].

In this figure, for the sake of simplicity, we neglected the effect of the transmitter filter on the received pulse shape. The output of the nonlinear element will be $y = (t) = s^2(t) + 2s(t)n(t) + n^2(t)$. The last two sentences form the input noise of the video and, as can be seen, due to the presence of sentence of multiplication of signal noise in the output, the output noise power is dependent on the input pulse power. If the RF amplifier gain is large enough and the video segment noise is low, the video segment noise can be ignored and the input noise from the RF segment will be the sole major source of system noise. As is the case in most modern systems, we continue to ignore the noise generated by the video component elements.

As mentioned above, it is enough to calculate the first torque (average) and the second torque (power) for the performance check. When there is no signal (noise only), and assuming the video filter gain is normalized to 1, one can easily see that $m_1 = \overline{n^2(t)} = N_0 B_r = \sigma^2$. In this case considering that [10].

$$R_y(\tau) = R_{n^2}(\tau) = E\left(n^2(t+\tau)\right) = \sigma^4 + 2R_n^2(\tau) \quad (4)$$

The spectral density of the input power of the low pass filter (video) is obtained by taking Fourier from the above relation:

$$S_y(f) = \sigma^4\delta(f) + 2S_n(f) * S_n(f) \quad (5)$$

Given the noise in the white bandwidth RF input, the video filter input pass will be as follows [11]:

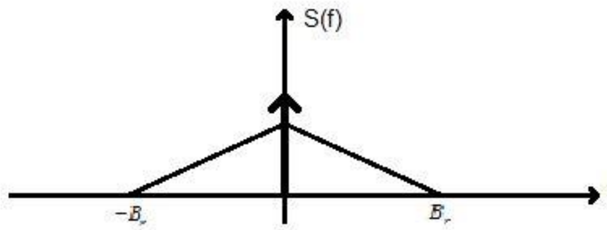

Fig. 4. Filter input [11].

In addition, assuming the video filter bandwidth (B_v) is less than (B_r), using the relation (2) the output noise power equals [12]:

$$m_2 = \int_{-B_v}^{B_v} S_{n^2}(f)df = \sigma^4 + 2N_0^2(B_rB_v - B_v^2/2) = \sigma^4 + 2\sigma^4(B_r/B_v - B_v^2/2B_r^2) \quad (6)$$

When there is also a signal input, given that the individual noise moments are equal to zero:

$$m_1 = E\left(s^2(t) + 2n(t)s(t) + n^2(t)\right) = a^2/2 + \sigma^2$$

$$R_y(\tau) = R_{(s+n)^2}(\tau) = E\left(s^2(t)s^2(t+\tau) + n^2(t+\tau) + 4n(t)n(t+\tau) + n^2(t)s^2(t)n^2(t+\tau)\right) \quad (7)$$

Where a is the received pulse amplitude, and assuming the signal bandwidth is much less than the noise bandwidth (RF input), it can be shown that the low pass downstream component of the quadratic element output spectrum is as follows [13].

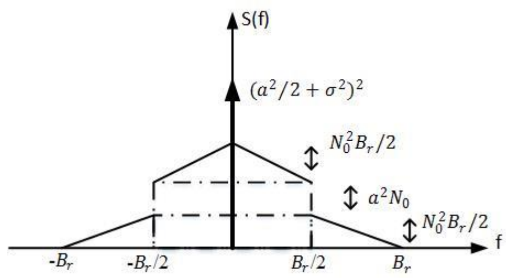

Fig. 5 Low pass component of the output spectrum.

As a result, the second torque of the video filter output will be as follows (with $B_v < B_r/2$, which is almost always the case in our intended use):

$$m_2 = \int_{-B_v}^{B_v} S_{(s+n)^2}(f)df = (a^2/2+\sigma^2)^2 + 2N_0B_v(\sigma^2 + a^2 - N_0B_v/2) = (a^2/2+\sigma^2)^2 + 2\sigma^2B_v/B_r(\sigma^2 + a^2 - \sigma^2B_v/2B_r) \quad (8)$$

Therefore, as stated above, the probability density function of CVR output in single noise mode, p_0, in signal plus noise mode, p_1, will be as follows:

$$p_i(x) = \frac{1}{\sqrt{2\pi\sigma_i^2}} e^{-\frac{(x-\mu_i)^2}{2\sigma_i^2}} \quad (9)$$

$$i = 0,1$$

Where μ_i and σ_i^2 are averages and variances in state i, respectively, and are:

$$\begin{aligned}
&\mu_0 = \sigma^2 \\
&\sigma_0^2 = 2\sigma^4 (B_v / B_r - B_v^2 / 2B_r^2) \\
&\mu_1 = a^2 / 2 + \sigma^2 \\
&\sigma_1^2 = 2\sigma_0^2 + 2a^2\sigma^2 B_v / B_r
\end{aligned} \tag{10}$$

Therefore, if V_T is the decision-making threshold level (i.e., if the output is greater than V_T the signal presence is declared), the probability of false alert and detection is obtained from the following relationships:

$$\begin{aligned}
&P_{fa} = Q\left(\frac{V_T - m_0}{\sigma_0}\right) \\
&P_d = 1 - Q\left(\frac{m_1 - V_T}{\sigma_1}\right)
\end{aligned} \tag{11}$$

The famous function Q (x) represents the tail surface of the Gaussian density function and is defined as follows:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{u^2}{2}} du \tag{12}$$

Available as a graph or table of values.

As the above results show, the narrower the bandwidth of the video filter, the lower the output noise power and the better the receiver performance. On the other hand, the filter bandwidth must be large enough to exceed the expected pulse width minimum. Therefore, the maximum expected bandwidth of the received pulse would determine the lower bandwidth of the video filter. In practice, usually the filter bandwidth is set too low to accelerate the triggering of IFM receiver by decreasing the Rise Time of the video output.

If a nonlinear element is a rectifier, similar results can also be obtained, but given the more complex nonlinear nature of this element, obtaining these results is not as easy as the former case, and here it is avoided. [13]. It is enough to say that the performance (sensitivity) of a CVR with two power two element and rectifiers is very close and the CVR is very close with a rectifier, and the CVR with a rectifier is only slightly better than the CVR with a power 2 element [14].

4. DIGITAL DESIGN AND IMPLEMENTATION OF CVR

In digital implementation, a similar receiver structure is used. Each RF sub band (channelized receiver outputs) is transferred to the baseband after being fitted with the LNA, sampled and provided to the digital processor as I and Q. The desired nonlinear characteristic in the digital domain can be created easily (and without the limitations of a diode detector). The low pass filter (video) can also be implemented in the simplest form as a collector.

5. THE PROBLEM OF SIMULTANEOUS SIGNALS

One of the important issues in the design of high bandwidth receivers without the capability of separating signals, such as IFM and CVR, is the problem of simultaneous signals. If there is more than one signal at the IFM receiver input, depending on the used frequency estimation algorithm, the receiver output can have either many errors or be even generally invalid.

Although, it can be shown that if there is a difference of more than 6 dB at the received signal power level, the IFM receiver is able to report a higher power pulse frequency with a relatively small error [15]. Due to the receiver's lack of prior knowledge of each of the signals requires a mechanism to detect and announce the existence of concurrent signals in order to determine and report the frequency of each signal separately, using the more sophisticated separation and estimation methods.

In addition, since the presence of a long-range pulse (with a CW signal) can interfere with the receiver's performance in general, special attention should be paid in this regard. Since in practice, and especially in our intended application (due to the channelized receiver and the relatively low RF bandwidth of each channel), the probability of more than two pulses per channel is very low. In the following, we consider the two pulse and pulse synchronization modes and CW and come up with solutions to the problem. It is also possible to generalize by integrating some of these methods for rare states with more than two simultaneous signals.

A. Two simultaneous pulses:

Different methods have been proposed to detect the presence of concurrent pulses in the IFM receiver so far. Most of these methods are intuitive, have been suggested for use in the IFM receiver by analogue implementation, and have major weaknesses [6]-[9]. Therefore, we will not deal with detail and their function here. However, we also introduce and investigate one relatively new method of detecting simultaneous signals that has the proper performance, digital implement-ability and simple mathematical formulation [15].

To explain this method, we note that if only one signal enters in a CVR receiver having two channels I and Q and a quadratic nonlinear element ($s(t) = ae^{j2\pi ft}$), the output is equal to the amplitude of this signal, overtime, the pulse presence will be constant. Nevertheless, if we take the received signal as

$s(t) = a_1 e^{j2\pi f_1 t} + a_2 e^{j2\pi f_2 t}$, the output of the CVR will no longer be a constant because:

$$\left|a_1 e^{j2\pi f_1 t} + a_2 e^{j2\pi f_2 t}\right| = a_1^2 + a_2^2 + 2a_1 a_2 \cos 2\pi\Delta f t \quad (13)$$

As a result, the output amplitude will be variable over time and more than one signal can be recognized by detecting these changes. Since these changes are in the form of a sinusoidal waveform with a difference in the frequency of the two received signals, a simple way to detect these changes of passing time of the CVR output through a high pass filter (which only removes DC and its proximity) is the investigation of the output of this filter. If the filter output energy exceeds the threshold level, more than one signal is declared.

B. Pulse and simultaneous CW

When a CW signal is present in the IFM receiver, there will be a DC signal at the output of the phase detector (video) correlator. Therefore, it is necessary to separate the CW from the other signals in order to allow for a proper measurement of the frequency of the pulse signals.

The most primitive way to solve this problem is to insert a notch filter file at the receiver input to remove the CW signal. Initially, by detecting the presence of the CW signal and measuring its frequency by IFM, the notch filter is set to the CW frequency and prevents its entry into the receiver. Since implementing this method and placing such a adjustable filter on any of the outputs of the channelized receiver would be extremely complicated, it would not be scientific in our intended receiver.

Another common solution is coupling the AC output of the correlator and amplifier and video. This will remove the DC signal from the output and only process the pulse output. But then the system will not be able to measure the frequency of long pulses or CW signals. Therefore, by separating the AC and DC paths after the phase detector correlator output, it is possible to measure the frequency of both sets of signals. In analog IFM systems, analogs of the (Fig.6) structure are usually used for:

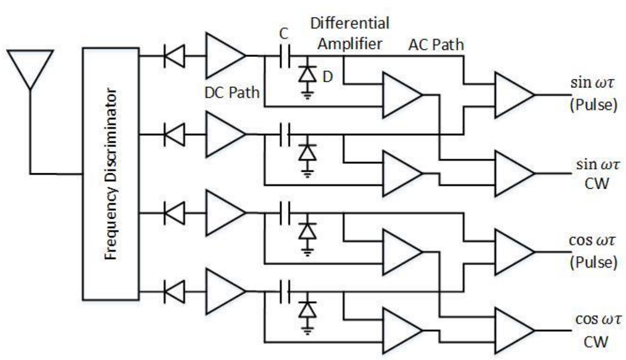

Fig. 6. Phase Detector [11].

In the structure of Fig. 6, the video output of the phase detector correlator is divided into two paths, one with AC coupling and the other with DC coupling (capacitors are used to prevent the passage of CW signals as DC voltage at the output of the detecting correlators that appear). The DC path contains both pulse and CW signals, while the AC path contains only pulse signals. AC path diodes have also been used to set the reference voltage to zero (in places where there is no pulse). In the differential amplifiers, the distance of two AC and DC paths is reduced and the components of the pulse signals common to both are eliminated, leaving only the CW signal in their outputs. This way the receiver is able to separate the CW signals from other signals.

A similar idea can be applied to digital IFM implementation, though the structure would be a bit simpler in digital mode. In this case, there is no need to use a differential amplifier because the time samples of the signal are in memory, after separating the two AC and DC paths (by means of a simple digital overpass filter) and detecting the location of the pulse. Using the AC path, it is easy to determine the presence or absence of a CW signal by comparing samples of a DC path that do not contain a pulse with a threshold level.

6. EVALUATION OF THE PROPOSED CVR

The task of this section is to detect the presence of a pulse and set up other parts at the right time. In this paper, we simulate the CVR receiver in a simulation as an energy detector whose low pass Filter is chosen for simple implementation of an N-length circuit breaker. If the bandwidth for the video segment BV and the A / D sampling frequency is equal to fs, the filter length will be:

$$N = \left[\frac{f_s}{B_v}\right] \quad (14)$$

As stated above, the lower the bandwidth of the BV, the better the CVR performance; on the other hand, the low bandwidth is equivalent to a high rise time resulting in a low speed and delay in detecting the presence of a pulse as well as the lack of separation of two consecutive pulses is with short distance. Therefore, considering these considerations, we will obtain BV equal to the current value of 50 MHz.

If the CVR input is a complex signal f (n), its output is:

$$y(n) = \frac{1}{N} = \sum_{i=0}^{N-1} \left|x(n-i)\right|^2 \quad (15)$$

And the output value is constantly compared to a threshold level. Whenever the value exceeds the threshold level, the flag of the pulse becomes one and the location of the pulse initiation (sample index) is also reported. The threshold level will be determined by the false alert rate (p_{ta}). Since the sum of squares is N, it is sufficient to determine the threshold level:

$$Th = \sigma^2 x_{2N}^{2\ \ -1}(1 - P_{fa}) \tag{16}$$

Where σ^2 is the noise power, $x_2^2 N$ denotes the cumulative distribution function of the central chi square distribution with degree of freedom 2N, and the superscript 1 - denote the inverse function. It should be noted that the assumption of independent random variables is not a precise assumption here, since sampling takes place at a frequency greater than the Nyquist frequency and consequently, the interval between successive samples will be less than the input process time. However, the above approximation can be a good starting point for estimating the threshold level. Also, therefore, the approximation, where pulse is present (Gaussian mean is non-zero), will be the distribution of the decentralized chi-square output. Therefore, the probability of detection (Pa) comes from this relation:

$$P_d = 1 - x'_{2N}(NA^2/\sigma^2, Th/\sigma^2) \tag{17}$$

Where $\acute{x}_{2N}(\frac{NA^2}{\sigma^2} \text{and} \frac{Th}{\sigma^2})$ is a function of the cumulative distribution of a 2N decentralized chi-square variable of degree of freedom and a decentralized parameter NA^2/σ^2 at the point Th/σ^2 is calculated ($A_2/2$ is the received pulse power).

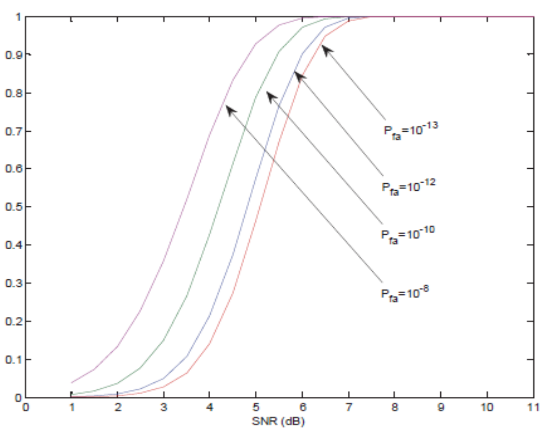

Fig. 7. The probability of detection in the system with the parameters given above in terms of $SNR = \frac{A^2}{2\sigma^2}$ for the Pfa value.

The false alert rate is 1 hour, which is approximately equal to the probability of a false alarm of 10-12 as stated in the preceding article. For this value of probability of false amount, the proportion of signal to noise equal to 8 dB will result in a detection probability of more than 0.9999, which will reach 0.99999999 in 9 dB.

7. CONCLUSION

In this paper, the design of a new CVR receiver is investigated and the problem of signals synchronized with the approach used in electronic warfare is examined. The requirements for CVR design as well as the issue of simultaneous signals were raised. Moreover, to solve this challenge, a corresponding solution was provided. In the designed CVR, the probability of false alert signal-to-noise ratio of 8 dB will be more than 0.9999 detection probability, which will reach 0.99999999 at 9 dB.

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