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RESEARCH ARTICLE

Automatic Identification of Communication Signals Using Zero-Crossing Based Techniques

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ABSTRACT

The identification of different types of modulation for any intercepted communication signal out of the vast hierarchy of possible modulation types is a key fundamental before advising a suitable type of demodulator, where this process is usually a manual option. This technique is extremely important for the purposes of communication intelligence. In this paper, a proposed methodology is suggested, validated, and tested (through computer simulations) for the automatic identification of the modulation type (analog and digital) of the intercepted communication signals. The methodology is based on the zero-based representation of signals and utilization of new algorithms for such identification.

Keywords: Zero-Crossing, communication signals, modulation, digital signal, analog signal, algorithms

INTRODUCTION

The analysis of zero-crossing technique describes one of the several techniques, which make the use of the information pertaining to the locations in time of successive zero-crossing of a time waveform. Such techniques have found applications for several signal processing and pattern recognition tasks. Some of these tasks include speech analysis and recognition communications applications.[1] Each of these applications has its specific features regarding the nature of the zero-crossing data measurements and the features extracted from such data. Some applications utilize the number of zero-crossing, the other may count the time interval between successive zeros. By all means, the work of Voelcker[2,3] remains the standard source for clearing the essence of zero-based representation of signals. Inspired aspirants working under his directions (e.g. Takayuki Arai and Yuichi Yoshida)[4] and Sekey[5] cleared out some difficult mathematical problems such as uniqueness, sufficiency, and completion, in addition to characterizing several classes of entire functions (EF) amenable to such representations.

In this paper, we will try to extend the prowess of zero-based representations to cover important utilities in the field of communication intelligence, namely, the identification of unknown modulation of intercepted signals. Further, a tested modulation scheme, based on manipulating the zeros of the baseband and carrier waveforms, will be illustrated. This scheme has been mathematically and experimentally verified to emulate most analog and digital modulation schemes.

FUNDAMENTALS OF ZERO-BASED REPRESENTATION OF SIGNALS

This subject warrants a due introduction owing to the fact that these techniques have not been very current due to the special mathematics (mainly the theory of EF) and to the difficult problem of interpolating (reconstructing) a signal by virtue of its zero-crossings. In this paper, a brief illustration introduction of zero-based techniques exemplified by displays of actual signals generated and processed by the author by configuring the Hewlett-Packard Spectrum Analyzer and the Waveform Recorder under the control of the HP Computer. The author developed the software to affect all the displayed signals illustrated in this paper.

A band-limited (BL) signal $s(z)$ is an EF[6] which can be described by the location of its zeros

$$s(z) = s(o)\prod_{(n=1)}^{\infty}(1-\frac{z}{z_n}) \quad (1)$$

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Where $z = t + J\,u$; a complex variable whose real axis coincides with the real-time axis $s\ (z)$ along the real axis coincides with $s\ (t)$), z_n is the location of the n^{th} zero.

The time waveform wholly real zero BL signal $s\ (t)$ corresponding to the Equation (1) can be expressed[7] as

$$S(t) = A * \prod_{(n=1)}^{2M} sin(\frac{w_o}{2} - 2(t - tn)) \quad (2)$$

Where A is a scale factor.

Equation (2) was utilized to effect the reconstruction of the BL signal shown in the first trace of Figure 1. The second trace displays the hard-limited signal of the first trace. The third trace displays the real zeros of the signal, we can express these zero locations as

$$Z = \sum_{k+1}^{N} [1 - sgn)(s_{(k+1)})sgn(s_k)] / 2 \quad (3)$$

Where N = the number of samples, s_k is the digitized input signal K^{th}

In all our experimentation, the number of samples was chosen to be 400 (for due consideration to anti-aliasing). Equation (2) was utilized to reconstruct the signal [the fourth trace of Figure 1].

CONVERSION OF COMPLEX ZEROS INTO REAL ZEROS

We note that Equation (2) is valid for real zeros only, while real signals can contain, in general, complex zeros. The occurrence of complex zeros affect the "dimensionality[8] of the signal, meaning that the signal cannot be reconstructed by virtue of its real-zeros only without due consideration to its complex zeros, a methodology must exist to transform complex zeros into real zeros to allow signal reconstruction by merit of its real-zero locations.

Fortunately, several such methodologies do exist. One such method is to add a sine waveform which frequency is equal or greater than the highest frequency component present in the BL signal. The composite signal $x(t)$ can be expressed as

$$x(t) = s(t) + A\ cos2n\ (w + 1)t,\ 0<t<T \quad (4)$$

Where w is the single-sided bandwidth. It is easy to show that the composite signal $x(t)$ will have 2 $(wT+1)$ zeros in the time interval between 0 and T.

The original signal, $s(t)$, can be recovered by subtracting the added sinusoid from the reconstructed signal

$$s(t) = x(t) - A\ cos2\pi\ (w + 1/T)t \quad (5)$$

The previous methodology is illustrated in Figure 2.

REAL-ZERO INTERPOLATION

The technique of interpolating a minimum – bandwidth waveform to a set of real zero-crossing on the time axis was first described by Voelcker[7,3] and dubbed RZI. The real-zero interpolator RZI suggested in the reference quoted, ingenious as it stands. It has been very difficult to implement practices, and the original set comprised more than 300 shift-register chips was very difficult to construct that limited zero-based technique applicability. One of the aims of this paper is to introduce a computer-simulation version, based on the same principle, easy to implement practices to reconstruct wholly real-zero signals from there zero-crossing. We shall base our simulation on the RZI version Figure 3.

Consider the following representation[9] of the real zero signals $S_{RZ}\ (t)$

$$S_{(RZ)}(t) = Re(S_{RZ}(t)e^{j\varphi}(S_{RZ}(t)) \quad (6)$$

Assume $\tau_o, \tau_1, \tau_2 \ldots\ldots \tau_i$. is a sequence of points on "the real-time axis representing the zero-crossing of the BL real zero signal $S_{RZ}\ (t)$. The signal which shall be reconstructed from the real zero locations is the real zero component $S_{RZ}\ (t)$ of the original signal $s(t)$. The original signal $s(t)$ can be considered as composed of two components $S_{RZ}\ (t)$ and $S_{cZ}\ (t)$ as follows

$$s(t) = S_{RZ}\ (t) * S_{cZ}\ (t) \quad (7)$$

where

$S_{RZ}\ (t)$ is the real zero signal, $S_{cZ}\ (t)$ is the complex zero signal.

Hard limiting the signal $s(t)$ destroys its envelope and produces

$$sgn\ [S_{RZ}(t)] = \begin{cases} +1, S_{RZ}\ (t) > 0 \\ -1, S_{RZ}\ (t) < 0 \end{cases} \quad (8)$$

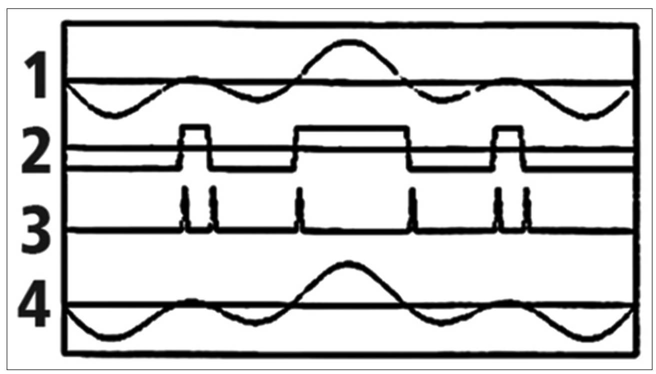

Figure 1: Waveform regeneration. (1) Input signal, (2) hard clipped, (3) real zeros, (4) reconstructed signal

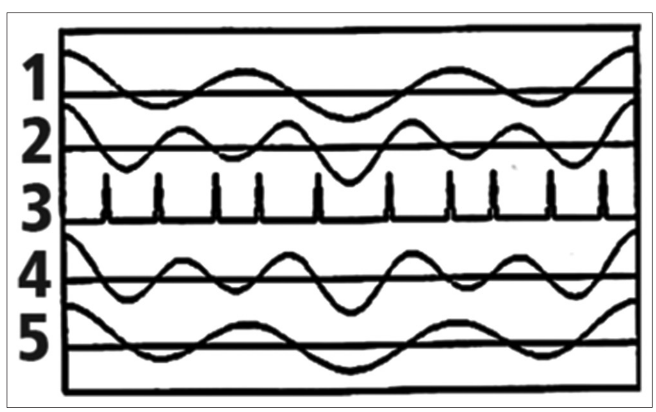

Figure 2: Reconstructing signal from zero-crossing. (1) Original signal $S(t)$, (2) composite signal $x(t)$, (3) zeros of $x(t)$, (4) reconstructed $x(t)$, (5) reconstructed signal $s(t)$

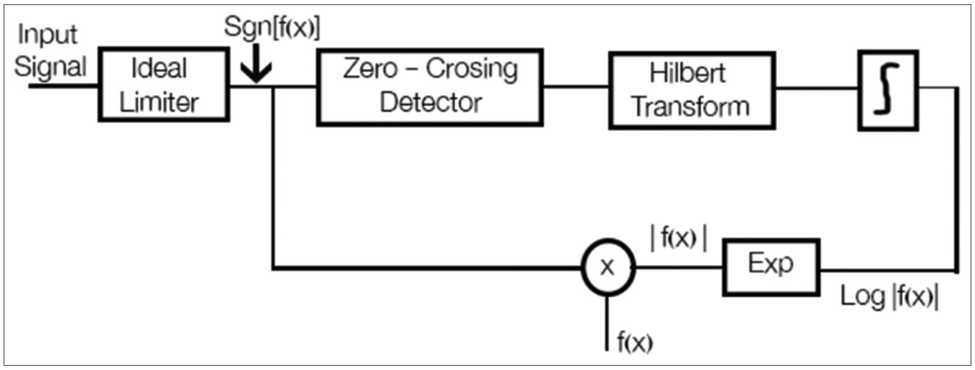

Figure 3: A real zero interpolator

We can write Equation (5) in the following form

$$S_{RZ}(t) = S_{RZ}(t)\, cos\phi\, (S_{RZ})\,(t)) \quad (9)$$

where $\phi\,(S_{RZ})$ is the 'instantaneous phase' of $S_{RZ}(t)$.

Each zero-crossing is represented by a delta function" at its location, then the following equation holds

$$\varphi(S_{RZ}(t\ \ )) = \sum\nolimits_{2nR} n\delta(t-\tau_i) \quad (10)$$

Since $S_{RZ}(t)$ is an EF; its phase and modules are a Hilbert Transform pair,[6] thus

$$H(\varphi(S_{RZ}(t\ \ )) = H\,\delta(t-\tau_i\ ) \quad (11)$$

$$= \frac{1}{n}\int_{-\infty}^{\infty} \frac{\delta(t-\tau_i\ )}{(t-\tau_)} \quad (12)$$

$$= \frac{1}{t-\tau}$$

Applying the general phase-envelope relationships[9] follows that

$$ln^{\cdot} S_{RZ}(t\ \ ) = \sum\nolimits_{2nR} \frac{1}{t-\tau_n} \quad (13)$$

$$=H\,(\phi, S_{RZ})\,(t)) \quad (14)$$

Thus integrating the output of the Hilbert Transform network, exponentiating its output and then multiplying it by $sgn\,(S_{RZ}(t))$ yields the interpolated signal.

The previous description of the RZI versions of Voeicker and Sekey is limited practically by the difficulty of realization of a wideband Hilbert transform network. Computer simulation provides a suitable answer to this problem.

COMPUTER SIMULATION OF THE RZI

Figure 4 illustrates the developed flowchart describing the methodology for realizing real zero interpolation of a minimum bandwidth waveform fitting the real zero input sequence.

Figure 5 illustrates the simulation results. The first trace is a sinusoidal input clipped to yield the second trace. Impulses are added to characterize the third trace. The fourth trace is the Hilbert transform output. The reconstructed clipped signal is shown in the fifth trace. It is clear that it coincides with the clipped input signal.

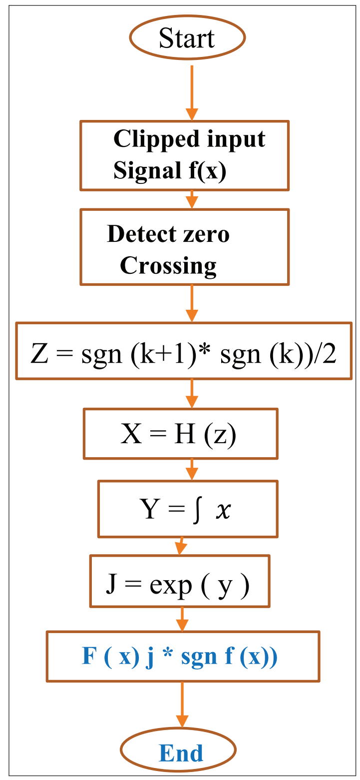

Figure 4: Flowchart for the RZI

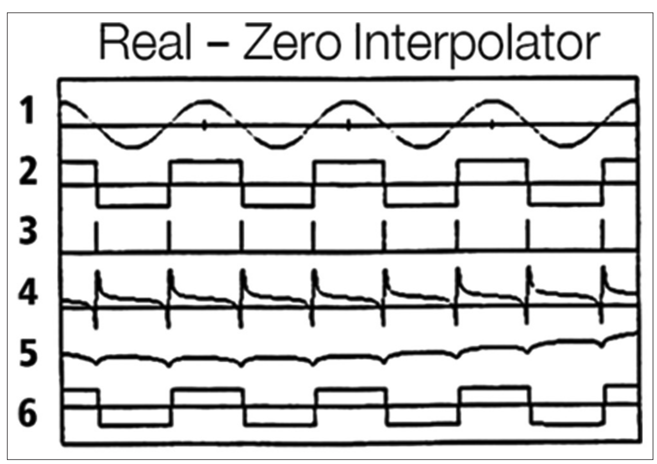

Figure 5: Temporal waveforms in real zero interpolation. (1) Input signal, (2) clipped input signal, (3) real zeros, (4) Hilbert,[4] (5) integral,[5] (6) EXP,[6] (7) SGN[2]

For practical applications, it would be of consequence to relate the processing (computational) load to the number of zeros necessary for the interpolation procedure and further to evaluate the effect of change of the sample size (N) on this processing time. Practical results of such experimentations are exemplified in Figure 6. The processing time is approximately linearly related to the zero count.

MODULATION IDENTIFICATION METHODOLOGY BASED ON ZERO-PATTERN CHARACTERIZATION

Segmenting an input intercepted communication signal into time windows encompassing a sufficiently large number of cycles of the lowest frequency present; corresponding to sufficient sample size, enables us to correlate the time-dependence of the number of intercepted zero-crossing with the type of modulation. Correctly and automatically identifying the type of modulation of unknown interceptions has been and will always be a subject of paramount importance in both civil and military communications. In this section, the aspirant wishes to present this contribution which is computer methodological processing of received signals (digitized and handed over to the computer), processing them in the manner described in the last section to arrive at the decision characterizing the type. Of modulation; provided that it coincides with a pattern stored in a special library. change to In modulation, each coincides signal with a pattern ins stored in special library. By this means effective switching to a

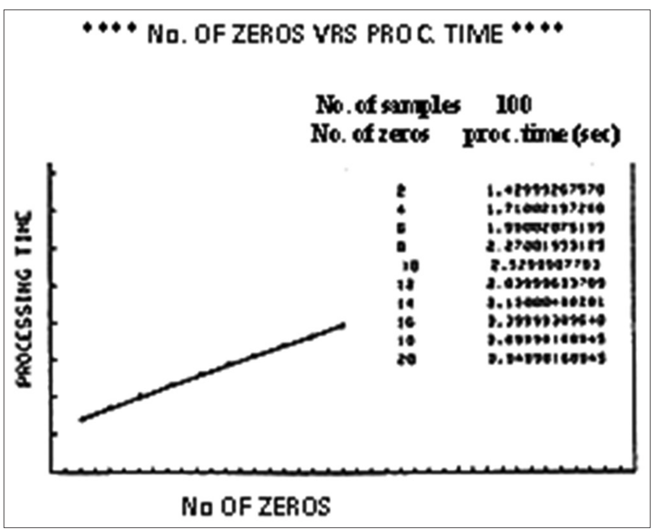

Figure 6: Processing time VRS number of zeros of interception

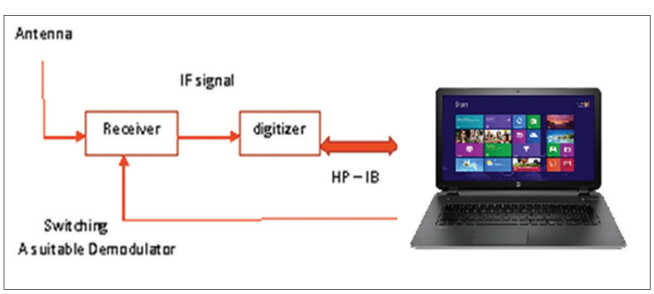

Figure 7: Block diagram of automatic demodulation

suitable demodulator can be automatically affected. Figure 7 illustrates the conceptual proposed configuration which may affect automatic demodulation of unknown interceptions.

To experimentally evaluate the concept illustrated above, the following procedure and algorithms were adopted:

a. Most widely known classical analog and digital modulation waveforms have been computer-simulated, they are zero-crossing processed in the described manner and the identification "feature" extracted; namely, the zero-pattern time course. Figure 8 illustrates the results obtained. It is clear from the different processed modulation types (both analog and digital) that a unique zero-pattern is associated with each modulation type unless in some situation they have similar zero-pattern. A library of zero-pattern displays corresponding to each modulation type is thus constructed and stored.
b. The real intercepted communication signal is first processed to obtain the relevant zero-pattern, as explained in the previous step. Then, the displayed pattern is normalized for the same frequency as the reference pattern.
c. The identification is effected automatically by comparing the interception zero-pattern display with

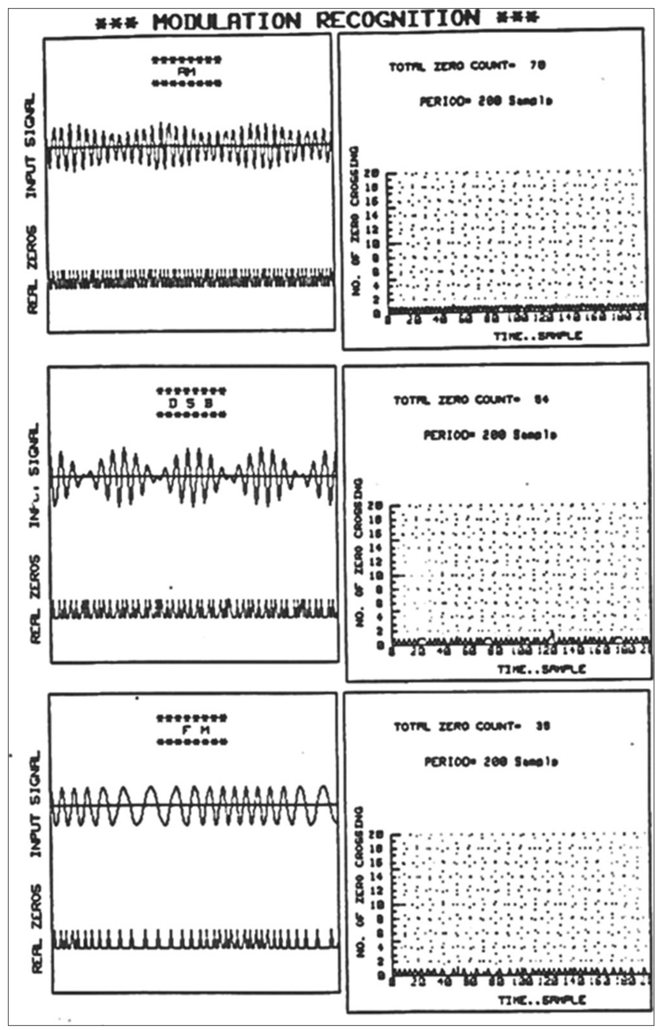

Figure 8: Method of modulation recognition based on zero-pattern time course

the corresponding zero-patterns of the constructed modulation-type library in step (a). The algorithm adopted here for identification is the least square approximation. Figure 9 illustrates the experimental results obtained.

MODULATION/DEMODULATION BY ZERO MANIPULATION

Another contribution presented here is a methodology for affecting different modulation/demodulation schemes using zero manipulation. Figure 10 illustrates the methodology for generating an AM (DSB) modulated waveform. The first and second traces in this figure illustrate computer-simulated base-band (modulating) and carrier waveforms, respectively. The third trace illustrates the processed zero-crossing of the carrier signal. The zeros of the baseband signal are added in the fourth trace, and the resulting zero sequence is applied to the proposed computer-simulated version of the real zero interpolator to yield the Am (DSB) modulated waveform shown in the last trace.

The same procedure is repeated for ASK and PSK. The results and procedures are shown in the subsequent Figures 11 and 12. It is evident that such methodologies

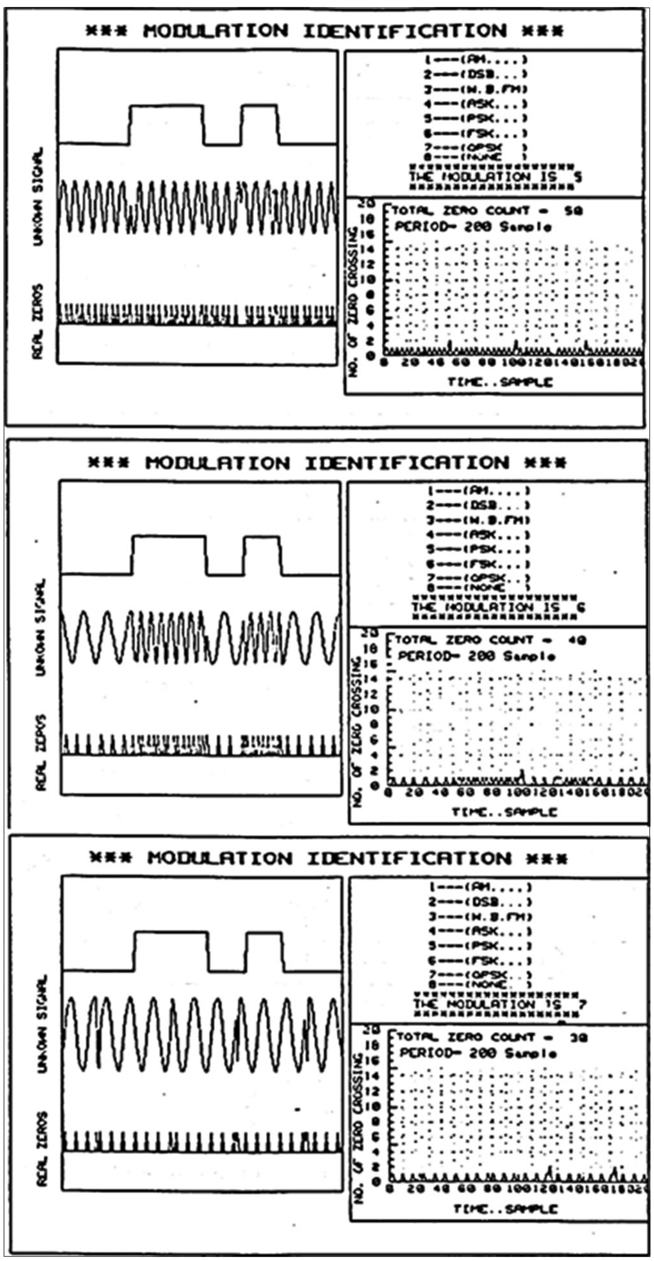

Figure 9: Modulation identification

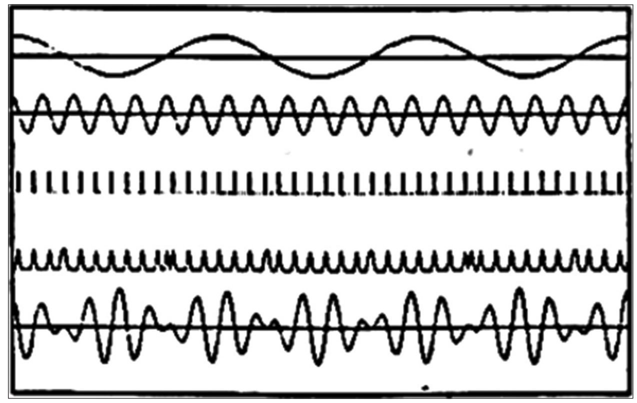

Figure 10: DSB signal generation. (1) Modulating signal,(2) carrier signal, (3) real zeros, (4) padding zeros, (5) modulation signal

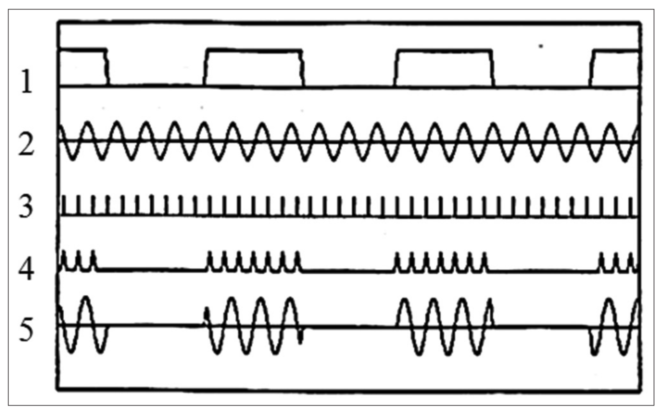

Figure 11: ASK signal generation. (1) Binary sequence, (2) carrier wave, (3) real zeros, (4) deleted zeros, (5) ASK signal

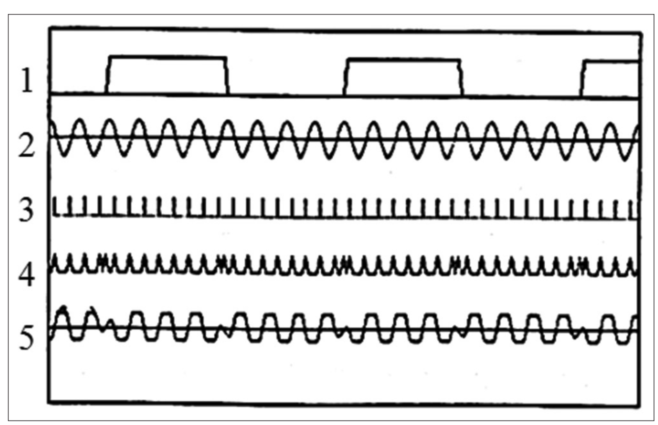

Figure 12: PSK signal generation. (1) Binary sequence, (2) carrier wave, (3) real zeros, (4) deleted zeros, (5) PSK signal

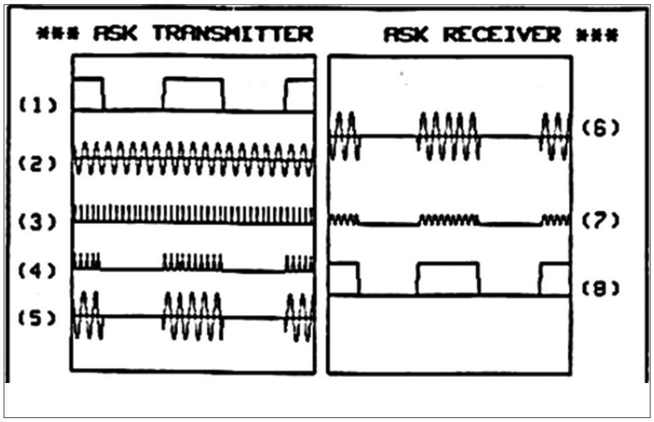

Figure 13: Zero-based ASK MODEM operation. (1) binary sequence, (2) carrier wave, (3) real zeros, (4) deleted zeros, (5) ASK signal, (6) ASK signal, (7) real zeros, (8) binary sequence

alleviate the need for complex schemes traditionally employed in conventional modulation schemes.

The process of demodulation can be affected in an inverse manner by deleting/or adding the zeros of the carrier waveform and real zero interpolating the resulting zero sequence. Figure 13 illustrates the methodology and results obtained for demodulating ASK-modulated signal. Figure 13 is configured in a manner to illustrate the possibility of incorporating such methodology in the design of modems for data transmission.

CONCLUSION

This paper shows the potency of zero-based techniques in a wide variety of applications. The success in introducing a computer-based version of the RZI may open the door easily implementing schemes, which could otherwise be very complicated and cumbersome. It is left to the reader to evaluate the impact of the ideas presented here for automatic demodulation of intercepted communication signals (without the need for manual switching of a modulation type switch).

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