MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

1- # ZERO-CROSSINGS BASED AUTOMATIC MODULATION IDENTIFICATION

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4- ## ABSTRACT

Identification of the type of modulation of an intercepted communication signal out of the vast hierarchy of possible modulation types is fundamental before advising a suitable type of demodulator. This process is usually manual. In this paper, a new methodology is suggested and validated (via computer simulations) for automatic identification of the modulation type (analog and digital) of intercepted communication signals[1]. The methodology is based on zero-based representation of signals and utilization of new algorithms for such identification. Another contribution presented in this paper is a novel ASK modulation and demodulation scheme utilizing zero-manipulation.

Zero-crossing analysis describes any of several techniques which make use of information pertaining to the locations in time of successive zero-crossings 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 [2], communications applications [3],...etc. 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-crossings, the other may count the time interval between successive zeros.

In this paper we shall try to extend the prowess of zero-based representations to cover important utilities in the field of identification of unknown modulation of intercepted signals. Further, a novel modulation scheme, based on manipulating the zeros of the base band and carrier waveforms, is illustrated. This scheme has been mathematically and experimentally verified to emulate most analog and digital modulation schemes.

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## 2. FUNDAMENTALS OF ZERO-BASED REPRESENTATION OF SIGNALS:

This subject warrant a due introduction owing to the fact that these techniques have not been very current until lately due to the special mathematics (mainly the theory of entire functions) and also to the difficult problematics of interpolating (reconstructing) a signal by virtue of its zero-crossings. In this paper we shall introduce a brief illustration of zero-based techniques exemplified by displays of actual signals generated and processed by the authers by configuring the Hewlett Packard HP54201D Digitizing Oscilloscope or the HP5182A Waveform Recorder under the control of the HP9836CU Computer. The authors developed the software to affect all the displayed signals illustrated in this paper.

A band-limited signal can be represented by a set of amplitude sample values taken at Nyquist rate. yet another way of representing such signals is by means of their real and complex zeros [4]. A zero-based representation is shown to be valid for band-limited signals which is usually the case of interest. The real zeros of the waveform are its conventional zero axis crossings and are easy to determine using the following relationship.

$$z = \sum_{k=1}^{N} [1-\mathrm{sgn}(s_{k+1}) * \mathrm{sgn}(s_k)]/2 \qquad \ldots\ldots(1)$$

Where N= the number of samples
$s_k$ is the digitized input of samples,

Usually, the complex zeros are not easy to identify, except through a numerical factorization of a trigonometric polynomial. An alternative procedure is to preprocess the signal prior to the zero extraction by means of an invertible transform which converts all the complex zeros into first-order zeros.

A band-limited (BL) signal s(z) is an entire function (EF)[5] {functions that are analytic over a complex plane are called *entire functions*. BL signals are EF's because their Fourier transforms have bounded support (by definition). Similarly, the impulse response of a BL channals and systems are entire}; It can be described by the location of its zeros

$$s(z) = s(o) \prod_{n=1} \left( 1 - \frac{z}{z_n} \right) \qquad \ldots\ldots\ldots\ldots(2)$$

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 band-limited signal s(t) corresponding to eqn(2) can be expressed [3] as

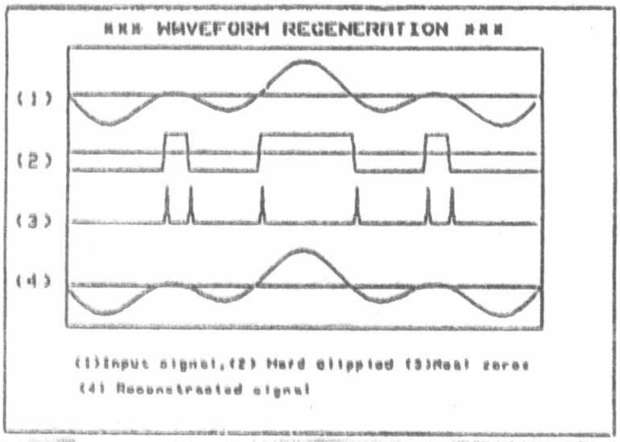
$$s(t) = A * \prod_{n=1}^{2M} \sin \left[ \frac{w_o}{2} (t - t_n) \right] \quad .........(3)$$

where A is a scale factor.

Eqn(3) was utilized to affect reconstruction of the band-limited signal shown in the first trace of fig[1]. The second trace displays the hard-limited signal of the first trace. The third trace displays the real zeros of the signal, which can be extracted from eqn(1).

In all our experimentation, the number of samples was chosen to be 400 (for due consideration to anti-aliasing).

Eqn(3) was utilized to reconstruct the signal (see the fourth trace of fig[1]).

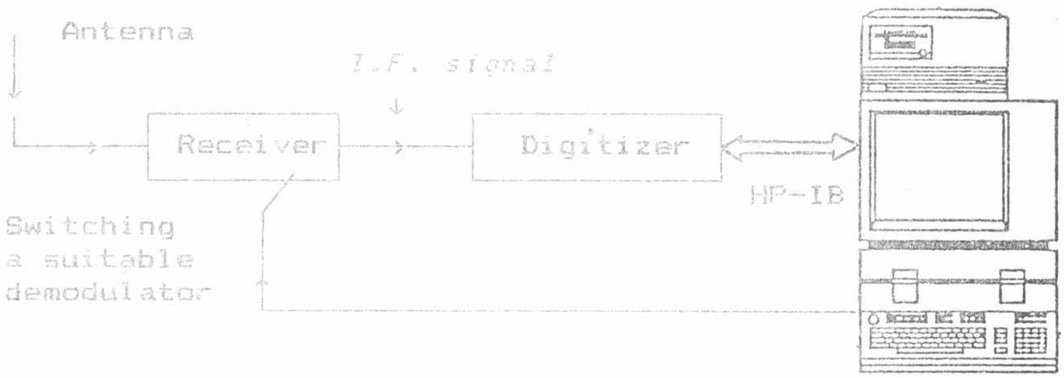



Fig[1]: Waveform Regeneration

## 2. MODULATION IDENTIFICATION METHODOLOGY BASED ON ZERO-PATTERN CHARACTERIZATION:

Segmenting an input intercepted communication signal into time windows encompassing sufficiently large number of cycles of the lowest frequency present; corresponding to a sufficient sample size, enables us to correlate the time-dependence of the number of intercepted zero-crossings 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 authors wish 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. By this means effective switching to a suitable demodulator can be automatically affected. Fig [2] illustrates the conceptual proposed configuration which may affect automatic demodulation of unknown interceptions.

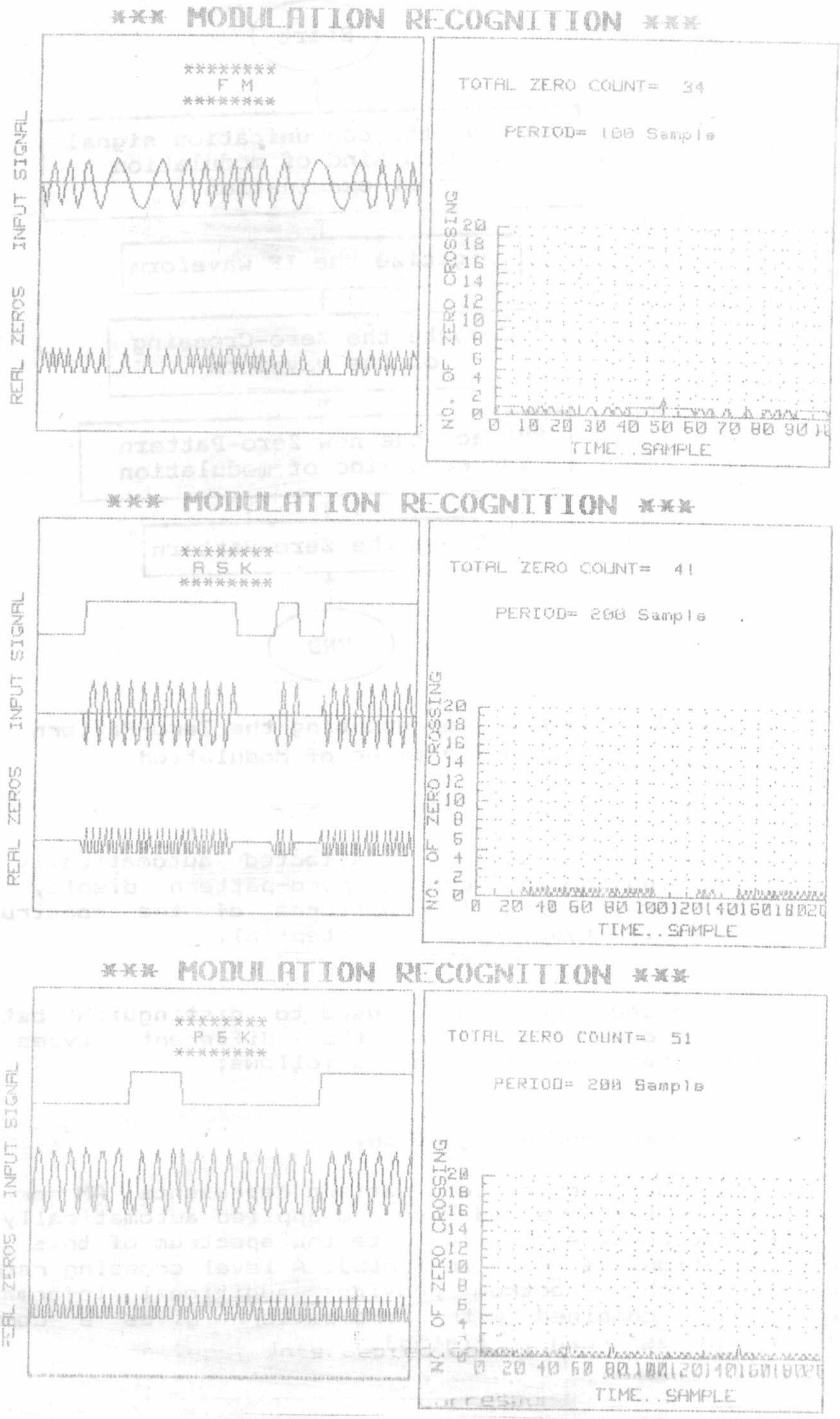



Fig[2]: Block Diagram of Automatic Demodulation of Interceptions.

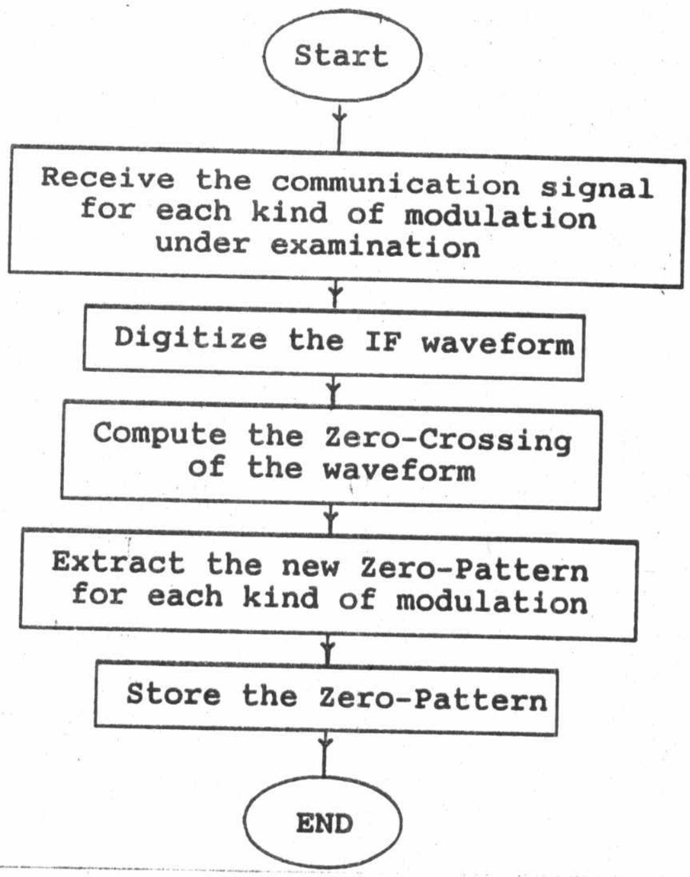
In order to experimentally evaluate the concept illustrated above, the following procedure and algorithms were adopted:

(a)- Most widely known classical analog and digital modulation waveforms[4] have been computer-simulated, their zero - crossings processed in the described manner and the identification "feature" extracted ; namely the zero-pattern time course. Fig[3] illustrates the results obtained[1]. 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-patterns. A library of zero-pattern displays corresponding to each modulation type is thus constructed and stored. Fig[4] shows the flowchart representig developed program.

(b)- The real intercepted communication signal is first processed to obtain the relevant zero-pattern as explained in the previous steps. Then the displayed pattern is normalized for the same frequency as the reference pattern. i.e. the same I.F. frequency. The zero locations of the received waveform are sufficient to preserve all the information about the input signal




Fig[3]: Method of Modulation Recognition Based on Zero-Pattern Time Course



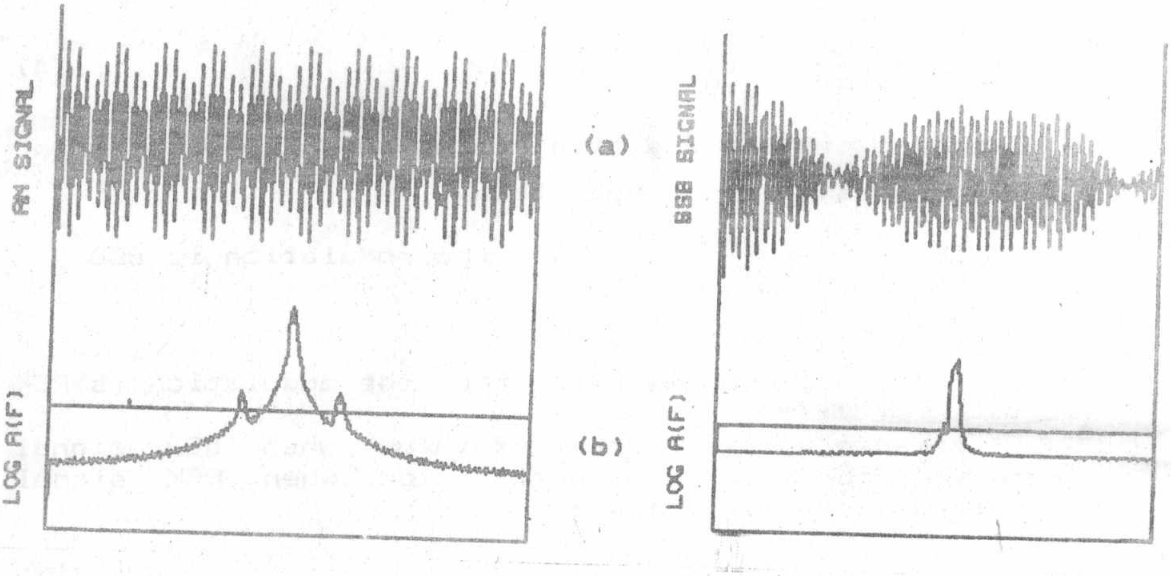

Fig[4]: Flowchart Representing the Zero-Pattern for standard types of Modulation

(c)- The identification is affected automatically by comparing the interception zero-pattern display with the corresponding zero-patterns of the constructed modulation-type library in step (a).

A proposed algorithm was used to distinguish between similar zero-patterns for the different types of modulation, and this was done as follows;

(1) AM and SSB Recognition;

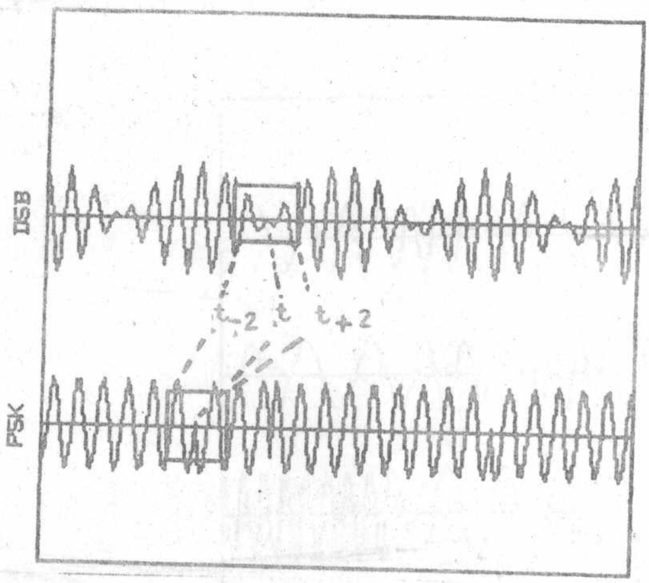
When the proposed zero pattern represents AM or SSB modulation, the received waveform applied automatically to the FFT subroutine to illustrate the spectrum of this type of modulation. as shown in fig[5]. A level crossing rate is applied to this spectrum provides additional information which when combined with zero-pattern gives a correct decision. as shown in fig[5b].




Fig[5]: AM and SSB Recognition

(2) DSB and PSK Recognition;

For some kind of traffic with DSB modulation and some different sequences with PSK, these two kind of modulation may they have the same zero-pattern as shown in fig[6]. In order to distinguish between them we measure the maximum value $v_{max}$ of the I.F. waveform and the minimum value $v_{min}$ at a point equal to interval $\Delta t$, where




Fig[6]: DSB and PSK Recognition

$$\Delta t = t_{n+2} + t_n \qquad .....(4)$$

and $t_n$ is the position of the zero-crossing when the waveform change its phase, then

IF $v = \dfrac{v_{max}}{v_{min}} >> 1$ then the modulation is DSB

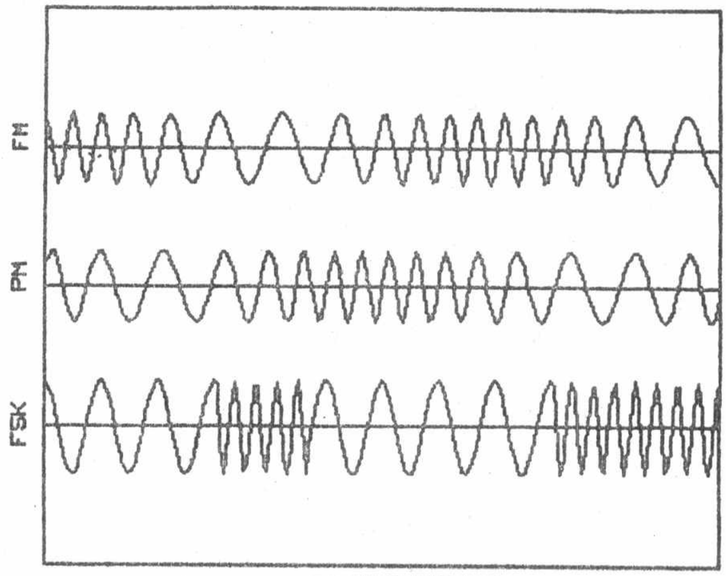
and,

IF $v$ = approximately 1 then the modulation is PSK

because v have a greatest value when DSB signal is received and have a lowest value when PSK signal is received. (see fig.(6)).

(3) FM, FSK, and phase Modulations;

Analysis of the waveform of an FM signal, at the receiver I.F. frequency. should indicate the frequency of the waveform changes with the modulation. For the FSK, the traffic will cause discrete changes in frequency. However, the phase modulation has a similar characteristic. Thus for linear FM, the waveform alone does not always correctly show the type of modulation. Fig[7] shows FM, FSK, and Phase modulations, all the types of modulations have similar waveform, and hence, identical zero=patterns. In order to distinguish between them we make the following proposed;




Fig[7]: FM, FSK, and Phase Modulations

For the FM waveform, the carrier's frequency is maximum at the peak of the modulating time waveform. Additionally, the FM carrier's frequency is a minimum at the valley of modulating waveform. For PH, the carrier's frequency is greatest when the rate of change of the modulating waveform is increasing at the greatest rate, and is lowest when the rate of change of the modulating signal is decreasing at the greatest rate. For a standard sine wave, the greatest positive change of a signal occurs when the waveform crosses the zero-axis, going in the positive direction. Thus, the expected frequency changes of the carrier should peak at this time. Likewise, the modulating sine wave has its greatest negative going change when it is at the zero axis, traveling in the negative direction, this is where the carrier frequency should be at its lowest frequency value.

Angle modulated signals have the general form

$$X_c(t) = A_c \cos(W_c t + \varphi(t)) \qquad \ldots\ldots(5)$$

where $A_c$ and $W_c$ are constants and the phase angle $\varphi(t)$ is a function of the base band signal $X(t)$. We can express the angle modulated signal as [6]

$$X_c(t) = \begin{cases} A_c \sin(W_c t + K_p\, X(t)) & \text{for PM} \\ A_c \sin(W_c t + K_f \int_{-\infty}^{t} X(\tau)d\tau) & \text{for FM} \end{cases} \qquad \ldots(6)$$

The relationship between the amplitude of the normalized modulating signal g(t) and any two successive zero-crossing instants $t_{i-1}$ and $t_i$ of the modulated FM carrier

$$Y_{FM}(t) = A_c \sin [W_c t + \Delta W \int_0^t X(u)du ] \qquad \ldots\ldots(7)$$

can be easily shown to be given by

$$W_c(t_i - t_{i-1}) + \Delta W \int_{t_{i-1}}^{t_i} X(t)dt = \pi \qquad \ldots\ldots(8)$$

The function of Eqn.(8) has zeros when

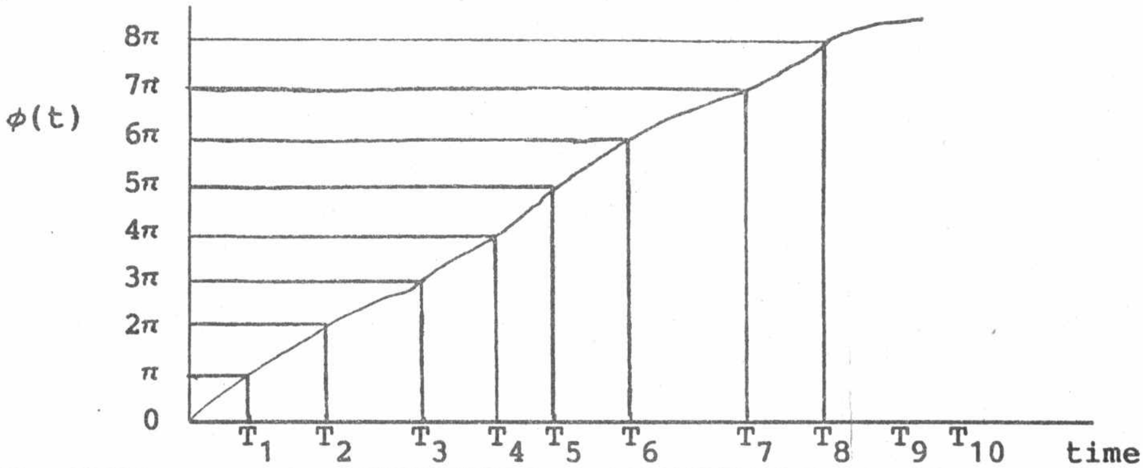
$$\Phi(t) = Wt + \varphi(t) = n\pi \qquad n = 0, \pm 1, \pm 2 \qquad \ldots(9)$$

For an FM signal, the total phase $\phi(t)$ must be a monotonic increasing function in order that the instantaneous frequency be positive. From fig[7], the total phase function appears as shown fig[8], with the zero-crossing noted. Note that, the zero-crossings correspond to the times shown (labeled $T_1$ through $T_{10}$). For frequency-modulated waveform, the times will not be equally spaced[7].

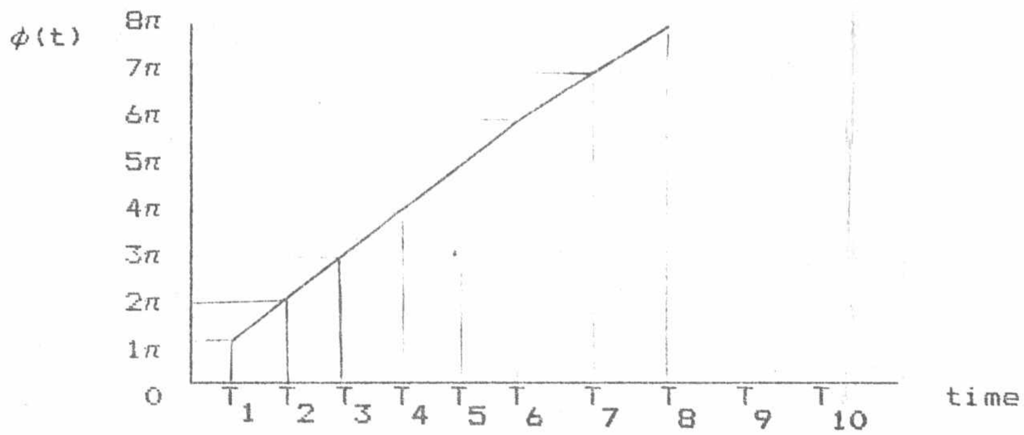
In the binary FSK signaling scheme, the waveforms

$S_1(t) = A\cos(w_c t - w_d t)$ and
$S_2(t) = A\cos(w_c t + w_d t)$ are used to convey binary

digits 0 and 1, respectively. The information in an FSK signal is essentially in the frequency of the signal. The binary FSK waveform is a continuous phase constant envelope FM waveform. The total phase function appears as shown in fig[9], with the zero-crossing noted. The time appear will be equally spaced for each binary signaling scheme.

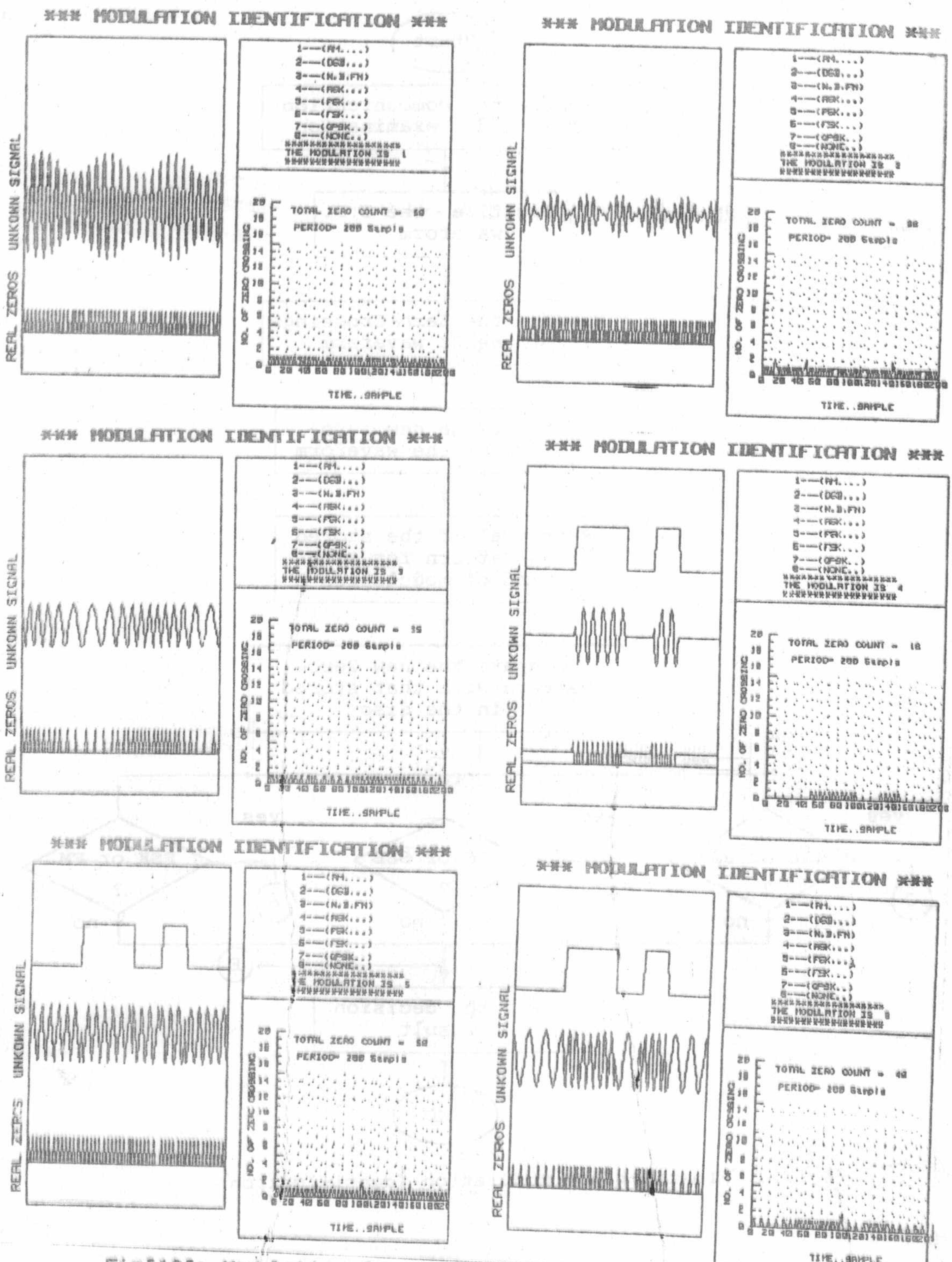



Fig[8]: Total Phase versus Time for FM

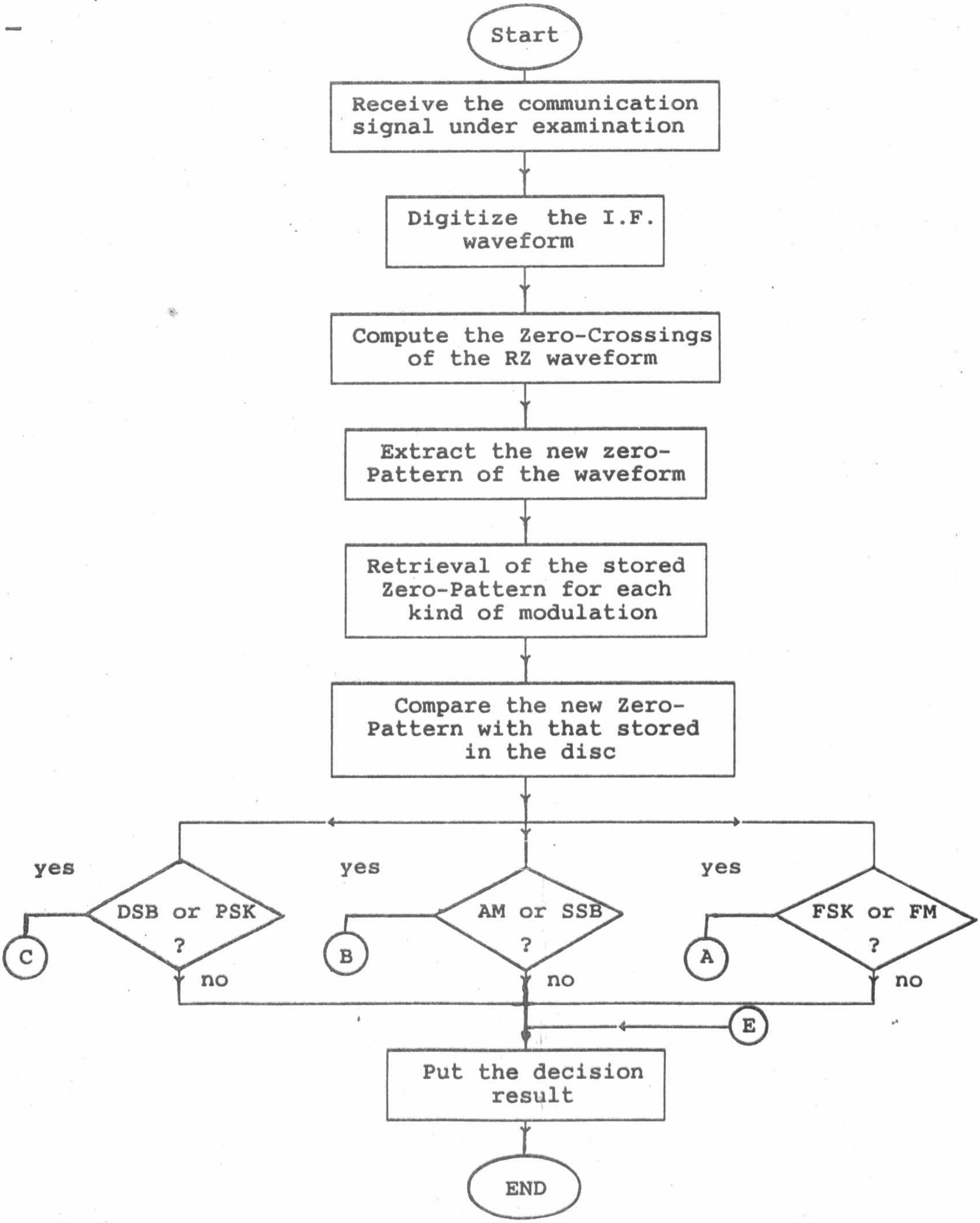



Fig[9]: Total Phase versus Time for FSK

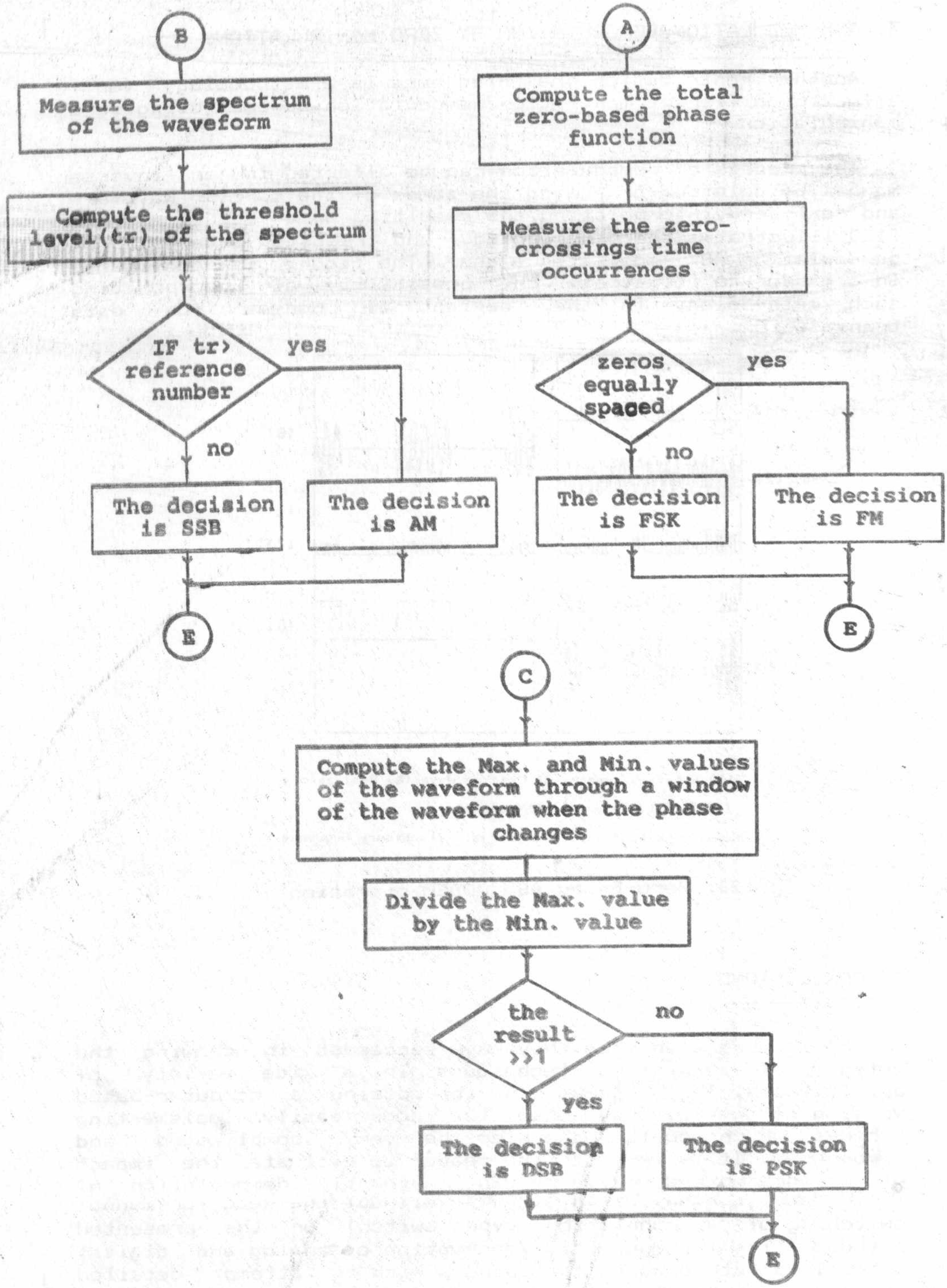
The algorithm adopted here for identification is the least-square approximation. Fig[10] illustrates the experimental results obtained. Fig[11] shows the flowchart for modulation identification.




Fig[10]: Modulation Identification



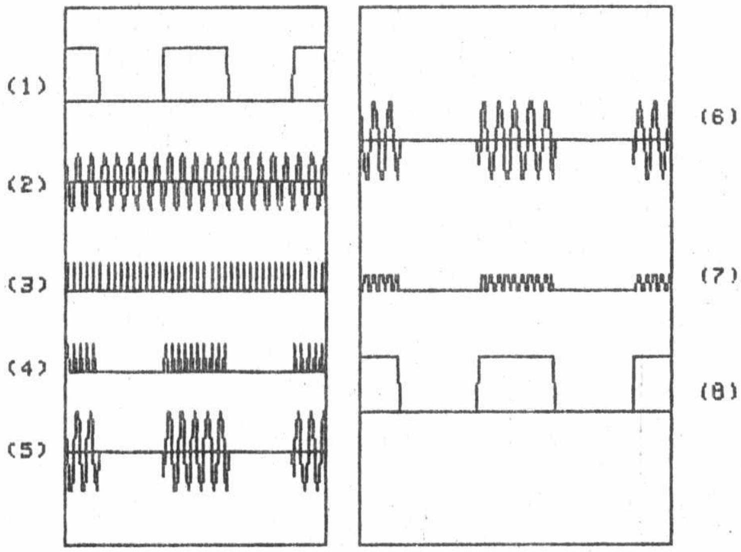

Fig[11]: Flowchart for Modulation Identification


B
Measure the spectrum of the waveform
Compute the threshold level(tr) of the spectrum
IF tr› reference number
yes
no
The decision is SSB
The decision is AM
E
A
Compute the total zero-based phase function
Measure the zero-crossings time occurrences
zeros equally spaced
yes
no
The decision is FSK
The decision is FM
E
C
Compute the Max. and Min. values of the waveform through a window of the waveform when the phase changes
Divide the Max. value by the Min. value
the result ››1
no
yes
The decision is DSB
The decision is PSK
E

## 3. ASK MODULATION/DEMODULATION BY ZERO MANIPULATION:

Another contribution presented here is a methodology for affecting different modulation/demodulation schemes using zero manipulation.

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. Fig [12] illustrates the methodology and results obtained for demodulating ASK -modulated signal. The figure is configured in a manner to illustrate the possibility of incorporating such methodology in the design of Modems for data transmission.




(1) Binary sequence, (2) Carrier wave, (3) Real zero

(4) Deleted Zeros, (5) ASK signal

(6) ASK signal, (7) Real Zeros, (8), Binary Sequence

Fig[12]: Zero-Based ASK MODEM operation

## 4. CONCLUSIONS:

The authors wish that they have succeeded in showing 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) or the presented methodologies for encryption/decryption of analog and digital data. In a future work ,the authors wish to attempt detailed comparative evaluation of these ideas.

## 5. REFERENCES:

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