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ANALYSIS OF SYMMETRICAL COMPONENTS OF HARMONICS FOR THREE PHASE POWER SYSTEMS

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I dedicate this thesis to
my parents and Térèsa
for their Love, Encouragement
and Inspiration.

Kwan L. Shum

C O N T E N T S

A C K N O W L E D G E M E N T

I express my sincere gratitude to the large number of individuals without whose help this project could not have been accomplished. I am indebted to them for their constructive contribution and verbatim review of the contents of the thesis and in particular to my supervisors, Professor N. Enslin and Mr. K. P. Hoffman for their continued supervision during the course of this work.

Mr. Watson, come here, I want you.

Alexander Graham Bell

A B S T R A C T

Harmonic distortion of three phase power systems is caused by large amounts of electric power consumers using power electronic installations (e.g. drives and rectifiers). It has a number of undesirable consequences and has become an increasingly important problem with the rapid growth and ready availability of the power electronic devices and installations.

A famous mathematical technique called "symmetrical components" was used to model the fundamental components of three phase systems. This method was extended to various harmonics.

The aim of this thesis is to measure both the magnitudes and phase angles of various harmonics which exist in three phase power systems, and to express them in symmetrical components.

A digital electronics and microprocessor- based instrument was designed and constructed using the novel signal modulation technique called "+1 and -1" which was developed by the author of this thesis. This instrument was employed to achieve the above objectives.

L I S T O F I L L U S T R A T I O N S

L I S T O F T A B L E S

L I S T O F S Y M B O L S

This list does not include all symbols used, since all symbols were already clearly defined in the thesis. Instead this list displays the symbols which may create confusion.

$\bar{U}0, \bar{U}+, \bar{U}-$ Zero, positive and negative sequence components

$\bar{V}0, \bar{V}+, \bar{V}-$ Sequence components of Voltages

$\bar{I}0, \bar{I}+, \bar{I}-$ Sequence components of Currents

Ua0(t), Ub0(t), Uco(t) Instantaneous zero sequence components

Ua1(t), Ub1(t), Uc1(t) Instantaneous positive sequence components

Ua2(t), Ub2(t), Uc2(t) Instantaneous negative sequence components

$\hat{U}_K$ Peak amplitude

U_K Mean level of output

$\bar{U}_K$ Mean level of output

$_0\bar{U}_K$ Mean level of output modulated at 0 deg. phase shift clock

$_{90}\bar{U}_K$ Mean level of output modulated at 90 deg. phase shift clock

k Order of harmonic

θ , ϕ , α , β Angles

Hn Rms value of amplitude of nth harmonic

L I S T O F A B B R E V I A T I O N

ADC	Analogue-to-digital Convertor
CT	Current Transformer
DET	Dual Edge Triggered
FF	Flip Flop
FFT	Fast Fourier Transform
IIR	Impulse Response Filter
PLL	Phase Lock Loop
ZC	Fundamental Filtered Zero-crossing

CHAPTER ONE

" Where shall I begin, please your Majesty ? " he asked. Begin at the beginning, the King said, gravely, " and go on till you come to the end: then stop. "

Alice's Adventures in Wonderland,

Lewis Carroll

The last thing one knows in constructing a work is what to put first.

Blaise Pascal

1 Introduction

1-1. An introduction to harmonic distortion .

The aim of an electric power system is to provide a supply of electricity to large numbers of consumers. Ideally this electricity is supplied as a perfectly sinusoidal voltage of constant amplitude and frequency. In practice the operation of the supply system and the use made of the supply by the consumers causes various deviations from the ideal. One form of deviation is distortion of the waveform. This problem has become increasingly important with the ready availability of power electronic devices.

1-2. Causes of harmonics.

If a power system is to supply a good sinusoidal voltage the generators themselves must generate a sinusoidal waveform. Starting at the generator terminals the first components to affect the waveform are the transformers. Partial saturation of the iron causes the magnetising current to differ significantly from a sine wave, which is to say that it contains harmonic components [1]. The contribution of harmonics of the magnetising current to the distortion of the supply voltage depends on the source impedance of the supply and the magnitude of the harmonic currents.

Larger amounts of harmonic distortion are more usually caused by various types of rectifying load. For a rectifier of a given size, the harmonic currents are affected by the pulse number and the possible application of phase angle control [2]. Loads containing saturated iron cores also draw distorted current. Significant amounts of harmonic distortion may arise, not only from large installations, but also from the combined effect of a large number of small installations. The manufacturers of household appliances should adopt power supply circuits that do not cause large switch- on transients, for examples as in TV receivers, heaters and boilers [3]. These transients are equivalent to injecting a substantial amount of harmonic currents into the supply as well as in some cases direct currents.

1-3. Harmonic currents and their effects on system voltages.

The harmonic voltage distortion can be found as the product of the harmonic current and the impedance at that frequency of the component or components through which it flows. The harmonic voltage distortion is liable to reach unusually high values when the harmonic current encounters a parallel or series resonant circuit [4]. Since a parallel combination of inductance and capacitance presents a high impedance to current, the harmonic voltage distortion will be increased. A series resonant circuit provides a low impedance path for currents which will in turn cause increased voltage distortion across the inductive and capacitive branches. An electricity distribution network

contains inductive components, usually in the form of the leakage reactance of transformers. Capacitors are often connectsd for power factor correction and in cable networks, the cable capacitance can also form part of a tuned circuit.
The maximum voltage distortion on a power system does not necessarily occur at the point of connection of the distorting load. Magnification may very well be caused at relatively remote points on the network and this must always to be kept in mind when connecting distorting loads.

1-4. The disadvantages of harmonic distortion.

Harmonic distortion has a number of undesirable consequences. Harmonic distortion increases the current carried by capacitors connected to the system, particularly when they unexpectly form part of a resonant circuit. Such current may operate a protective device causing the capacitor to be disconnected, or may, over a period, reduce the life of the capacitor [4].
The most serious effect upon a.c. machines of system harmonics is an increase in machine losses [5, 6, 7]. The major component of extra loss occurs in the rotor. Harmonic voltage distortion has little effect upon the torque or power developed by a machine but can give rise to torque pulsations which could be significant [6, 7].
Some electronic equipment uses the supply voltage waveform direct -ly to control the switching instant of thyristors and similar components. Distortion of the voltage wave can adversely affect

the performance of such devices, particularly when the distortion is severe, and the voltage may cross the zero line or some other level more than twice per cycle [2]. Since the ear is most sensitive to sounds having frequences around 1 KHz, the introduction of voltages of this frequency into a telephone system will lead to a disturbing hum [2]. Such disturbances can occur when telephone lines run parallel with power lines carrying distorted currents with appreciable high frequency conponents [2]. Distorted currents will also increase the losses in the supply system both because a given power supply requires a larger r.m.s. current and as a result of additional skin effect losses [2].

1-5. Harmonic elimination.

Most of the information on harmonic control relates to the three-phase a.c.- d.c. or a.c.- a.c. power convertor. There are in general two accepted ways in which the harmonics developed by the convertor can be controlled. The first method is to increase the pulse number of the convertor and the second is to install harmonic filters [2]. In the first case the orders of the characteristic harmonic for a waveform with pulse number p are $pq \pm 1$, where q is an integer. Therefore, the higher the pulse number, the higher the frequency of the lowest order harmonic produced. Moreover as the harmonic order increases, its amplitude decreases. On the other hand, harmonic filters connected to a.c. system generally have two functions, i.e. to

reduce harmonic voltage and current below the permitted levels and also the to provide of some of the reactive power absorption. There have been several attempts to achieve harmonic control by other means. Three of these are:

1. Magnetic flux compensation for power transformers.
   A current transformer is use to detect the harmonic components coming from the non-linear load and these are fed through an an amplifier into the tertiary winding of a transformer in such a manner as to cause cancellation of the harmonic current concerned [8].
2. Harmonic re-injection for low pulse-number convertors to emulate the qualities of higher pulse-number convertors. The d.c. ripple output of 6-pulse convertor and the output of its feedback convertor can be combine together to produce a 12-pulse waveform on the d.c. side [9] .
3. Multi-layer cables are composed of different materials with higher values of resistance on the outside layers. This is to eliminate the higher harmonics which propagate along the outside layers due to the skin-effect for d.c. transmission lines. This method was utilized in the d.c. transmission lines between coal enriched Siberia and the industrially dense European part of USSR [10].

All the methods mentioned above are generally complicated and expensive, to implement practically.

1-6. Measurement of Harmonic Distortion.

For many years the standard method of measuring harmonic distortion was to select the appropriate frequency component from the distorted wave by means of a tuned circuit. Another approach is to use the sampling circuits to store the instantaneous values of the waveform at successive instants during the cycle and to compute a Fourier analysis on- line. Signal modulation technique is also one of the alternative way, which separates the various frequencies components of the signal by means of modulating them with a special modulating waveform.

1-7. Aim of this thesis.

The principle objective of this project is to design and construct an instrument capable of measuring both magnitude and phase of harmonic power flow. The method adapted in this thesis is the signal modulation technique.

There are six main areas which need close examination with reference to harmonic monitoring techniques of this project. Primarily, the electronic components used in building the instrument must be highly precise, e.g. the input scaling circuits must employ very low offset type operational amplifers and the analogue- to- digital convertor must be stable and should have high resolution quality. Secondly, the meters connected to the harmonic generators, which are used to calibrate the readings of the instrument, must be very accurate. It will be perfect for testing accuracy if electronic programm-

able harmonic generators are employed instead of the traditional synchronous rotating generators. The electronic generators consist of high resolution and precise digital-to-analog convertors. The shapes, amplitudes and angles of their output waveforms can also be programmed. Since the output waveforms, amplitudes and angles are known and are highly stable, it is not necessary to rely on analogue meters and oscilloscopes, etc. Analogue meters often generate inaccurate readings. Thirdly, the frequency response and accuracy of the current transformers is important. Large input current signals will have to be stepped down, so that their amplitudes are compatible with the electronic equipment. Fourthly, the type of analytic technique must be considered to give maximum accuracy and potential of real-time speed of measurement. Fifthly, the instrument must be designed to have the capability of communication with other instruments or controllers. Finally, the results must be interpreted correctly by the equipment and presented in a meaningful manner.

CHAPTER TWO

For every problem there is one solution which is simple, neat and wrong.

H. L. Mencken

2 Mathematical Model of Harmonics

2-1. Symmetrical Components Analysis.

The electrical power system normally operates in a balanced 3 - phase sinusoidal steady state mode. However, there are certain situations which can cause unbalanced operation. The most severe of these is a short circuit or fault. Less severe conditions are the presence of large amount of single phase loads and their unequal distribution. A long untransposed transmission lines inherently also causes unbalance [11, 12].

Arbitrarily unbalanced three phase voltages or currents can be transformed into 3 sets of balanced 3-phase components or symmetrical components [13]. We can transform an arbitrarily unbalanced condition into symmetrical components, compute the system response by straight- forward circuit analysis on simple circuit models, and transform the results back into the original phase variables.

In a general 3-phase circuit, we must deal with a minimum of three voltages and three currents. The specific definitions are shown in Fig. 2.1 . Each voltage and current is considered as being a sinusoidal steady state waveform and therefore may be expressed using phasor notation as shown in Fig. 2.2 [14].

Modern technique in the calculation of system unbalanced conditions demands a knowledge of the theory of symmetrical components and the phase sequence characteristics of the individual parts of the system.

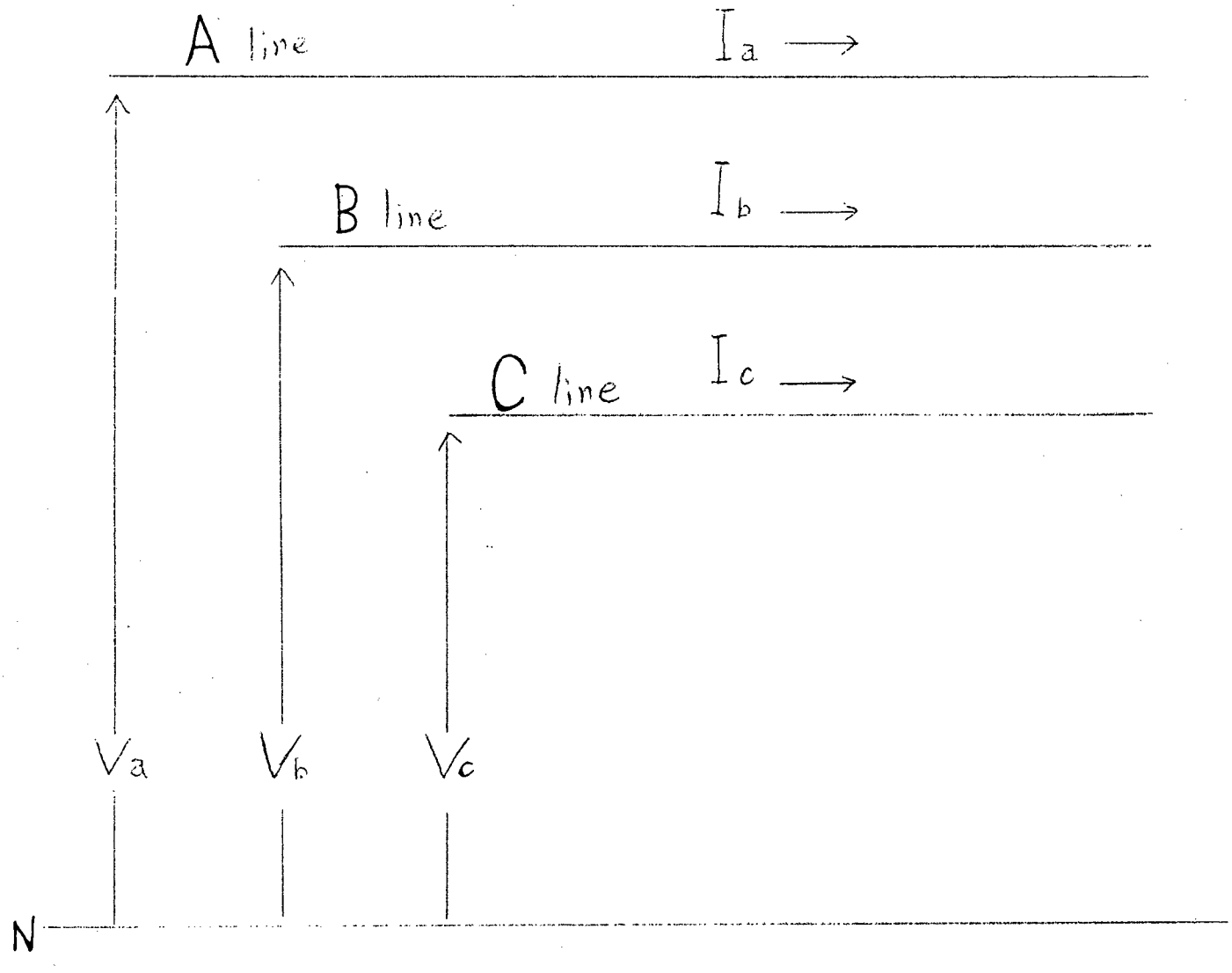
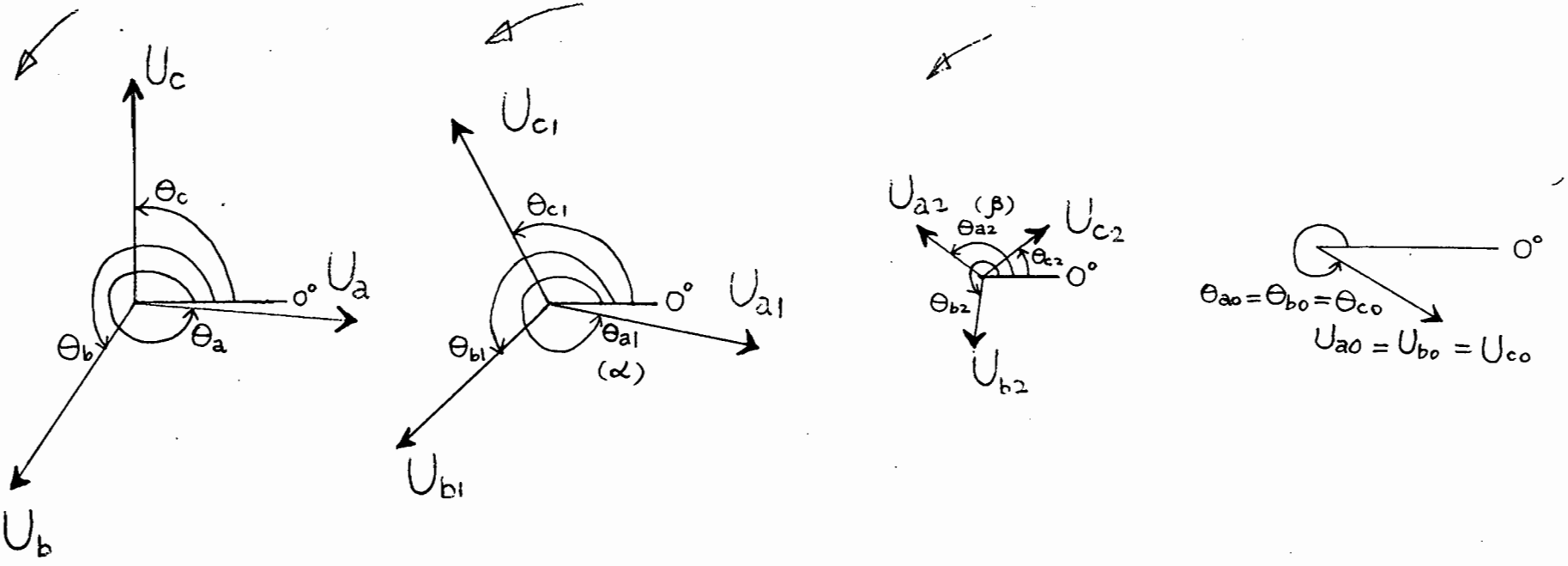


Fig. 2.1 Definition of phase voltage and currents in 3-phase circuit.



Real system (a) | +ve seq. (b) | -ve seq. (c) | zero seq. (d)

Fig. 2.2 Real system and corresponding symmetrical components.

It is possible to analyse any given system of three- phase unbalanced phasors into three other balanced phasor systems which are called positive , negative and zero phase sequence phasors respectively .

The positive phase sequence system is that in which the phase (or line) voltages and or currents reach their maxima in the same order as do those of the normal supply.

It is conventionally assumed that all phasors rotate in a counter- clockwise direction , and the positive phase sequence system is that in which the phase maxima occur in the order ABC [15].

Conversely , the negative phase sequence system is that in which the phasors , while rotating in the same direction as the positive phase sequence phasors , namely , counter- clockwise , reach their maxima in the order ACB [15].

The zero phase sequence system is a single- phase phasor , and it represents the residual voltage or current which is present in three- phase circuit under fault conditions when a fourth wire is present either as a direct metallic connection or as a double earth on the system [15].

The positive phase sequence systems of voltages and currents are those which correspond to the normal load conditions [16].

The negative phase sequence systems of voltages and currents are those which set up in the circuit by the fault , and their magnitudes are a direct measure of the superposed fault conditions between phases . The individual voltages and currents of this system are confined to the three lines [16].

The zero phase sequence systems of voltages and currents are set up in the circuit by the fault, and their magnitudes are a direct measure of the superposed fault conditions to earth . The voltages and currents of this system embrace the fourth wire (or ground) in addition to the three line wires [16].

The fundamental frequency positive- and negative- sequence impedance of machines rotating close to synchronous speed differ considerably. This is due to the fact that the stator developed rotating flux field set up by the positive-sequence voltages component is largely magnetizing, only small currents are induced in the rotor. However, negative-sequence currents of double frequency are induced in the rotor and the impedance is determined largely by the leakage fluxes of the stator and rotor [17].

As has been stated above, the method is applicable for quantities which may be represented by sinusoidal voltages and currents. For problems in which higher harmonics play an important part the method is also applicable.

2-2. Symmetrical components of various harmonics.

A distorted current or voltage waveform can be represented by the well- known Fourier series which is the sum of a fundamental and a series of harmonic components. For this to be be valid, the distorted waveform has to have the same wave shape for an indefinite number of cycles or persist for a reasonable length of time.

Distorted waves of a periodic nature can be resolved into a Fourier series consisting of a fundamental and higher harmonics. The result can be expressed in the general form

$$u(t) = \sqrt{2}\,[\,H1 \cos (wt + \phi 1) + H2 \cos 2(wt + \phi 2) + H3 \cos 3(wt + \phi 3) + \ldots\ldots\,] \qquad (2.1)$$

in which H1, H2 ,....,represent the r.m.s. values of amplitude and $\phi 1$, $\phi 2$, $\phi 3$, ... represent the phase angle of the respective harmonics. This relation can also be expressed in exponential terms as :

$$u(t) = \mathrm{Re}\,\sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \phi n) =$$

$$= \mathrm{Re}\,\sqrt{2}\,[\,H1 \exp j\,(wt+\phi 1) + H2 \exp j2(wt+\phi 2) + H3 \exp j3(wt+\phi 3) + \ldots\ldots\,] \qquad (2.2)$$

The phase relationship between the fundamental and the harmonic components is always important. When several different sources combine together, the phase angle of the harmonic components may differ considerably and the resulting distortion may be emphasised or reduced.

The advantage of this method of representing a distorted wave as being made up of a fundamental and a series of harmonics is that, in a linear system each harmonic component may be considered separately, and the final distortion may be found by superposition of the various components.

2-2-1. Positive- sequence System .

Considering first the symmetrical system of three- phase currents or voltages Ua1, Ub1 and Uc1 in Fig. 2.2 . Being balanced, Ua1, Ub1 and Uc1 have equal amplitudes , are displaced 120 deg. relative to each other other , and

$$Ua1(t) = Re\ \sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \alpha n) \exp jn(0)$$

$$= Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\alpha 1) + H2 \exp j2(wt+\alpha 2) + H3 \exp j3(wt+\alpha 3) + \ldots\ldots\ ] \qquad (2.3.a)$$

$$Ub1(t) = Re\ \sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \alpha n) \exp jn(4\pi/3)$$

$$= Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\alpha 1+4\pi/3) + H2 \exp j2(wt+\alpha 2+4\pi/3) + H3 \exp j3(wt+\alpha 3+4\pi/3) + \ldots\ldots\ ] \qquad (2.3.b)$$

$$Uc1(t) = Re\ \sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \alpha n) \exp jn(2\pi/3)$$

$$= Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\alpha 1+2\pi/3) + H2 \exp j2(wt+\alpha 2+2\pi/3) + H3 \exp j3(wt+\alpha 3+2\pi/3) + \ldots\ldots\ ] \qquad (2.3.c)$$

or, by substituting $a = \exp j(2\pi/3)$ and $a^2 = \exp j(4\pi/3)$

$$Ua1(t) = Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\alpha 1) + H2 \exp j2(wt+\alpha 2) + H3 \exp j3(wt+\alpha 3) + \ldots\ ] \qquad (2.4.a)$$

$$Ub1(t) = Re\ \sqrt{2}\ [\ a^2\ H1 \exp j\ (wt+\alpha_1) + a\ H2 \exp j2(wt+\alpha 2) + H3 \exp j3(wt+\alpha 3) + \ldots\ ] \qquad (2.4.b)$$

$$Uc1(t) = Re\ \sqrt{2}\ [\ a\ H1 \exp j\ (wt+\alpha_1) + a^2\ H2 \exp j2(wt+\alpha 2) + H3 \exp j3(wt+\alpha 3) + \ldots\ ] \qquad (2.4.c)$$

Thus it will be seen that the fundamental terms (H1) possess a positive-sequence (as do the fourth and seventh, etc. harmonics), the second harmonic terms (H2) possess a negative-sequence (also fifth and eleventh, etc.) and the third harmonic terms (H3) possess a zero-sequence (also all multiples of three). These results are summarized in Table 2-1.

2-2-2. Negative-sequence System.

Likewise, consider system of three phase currents or voltages Ua2, Ub2 and Uc2 in Fig. 2.2 .

$$Ua2(t) = Re\ \sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \beta n) \exp jn(0)$$

$$= Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\beta 1) + H2 \exp j2(wt+\beta 2) + H3 \exp j3(wt+\beta 3) + \ldots\ldots\ ] \qquad (2.5.a)$$

$$Ub2(t) = Re\ \sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \beta n) \exp j(2\pi/3)$$

$$= Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\beta 1+2\pi/3) + H2 \exp j2(wt+\beta 2+2\pi/3) + H3 \exp j3(wt+\beta 3+2\pi/3) + \ldots\ldots\ ] \qquad (2.5.b)$$

$$Uc2(t) = Re\ \sqrt{2} \sum_{n=1}^{\infty} Hn \exp jn(wt + \beta n) \exp j(4\pi/3)$$

$$= Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\beta 1+4\pi/3) + H2 \exp j2(wt+\beta 2+4\pi/3) + H3 \exp j3(wt+\beta 3+4\pi/3) + \ldots\ldots\ ] \qquad (2.5.c)$$

or, again by substituting a = exp j(2π/3) and a^2 = exp j(4π/3)

$$Ua2(t) = Re\ \sqrt{2}\ [\ H1 \exp j\ (wt+\beta 1) + H2 \exp j2(wt+\beta 2) + H3 \exp j3(wt+\beta 3) + \ldots .\ ] \qquad (2.6.a)$$

$$Ub2(t) = Re\ \sqrt{2}\ [\ a\ H1 \exp j\ (wt+\beta 1) + a^2\ H2 \exp j2(wt+\beta 2) + H3 \exp j3(wt+\beta 3) + \ldots .\ ] \qquad (2.6.b)$$

$$Uc2(t) = Re\ \sqrt{2}\ [\ a^2\ H1 \exp j\ (wt+\beta 1) + a\ H2 \exp j2(wt+\beta 2) + H3 \exp j3(wt+\beta 3) + \ldots .\ ] \qquad (2.6.c)$$

The fundamental terms (H1) have a negative-sequence (as do the fourth and seventh, etc. harmonics), the second harmonic terms (H2) have a positive-sequence (also fifth and eigth, etc.) and the third harmonic terms (H3) have a zero-sequence (also all multiples of three). These results are also summarized in Table 2-1 .

2-2-3. Zero- sequence System .

If a purely zero- sequence system is considered with phasor diagram as shown in Fig. 2.2.d . Ua0(t), Ub0(t) and Uc0(t) are equal in magnitude and in phase so that the fundamental and all the harmonic terms (Hn) are of zero-sequence.

Harmonic	Sequence		
	Positive	Negative	Zero
[Hn]	[Ua1,Ub1,Uc1]	[Ua2,Ub2,Uc2]	[Ua0,Ub0,Uc0]
H1	+ve	-ve	0
H2	-ve	+ve	0
H3	0	0	0
H4	+ve	-ve	0
H5	-ve	+ve	0
H6	0	0	0
H7	+ve	-ve	0
H8	-ve	+ve	0
H9	0	0	0
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TABLE 2-1. SEQUENCE OF HARMONICS IN THREE-PHASE SYSTEMS

2-3. Relationship between line and phase voltages and currents with harmonics.

When substantial harmonics are present the $\sqrt{3}$ relation between line and phase quantities (i.e. V line = $\sqrt{3}$ V phase) of the star- connection of a 3- phase system no longer holds. Harmonic voltages in successive phases are $\pm 2\pi n/3$ out of phase with each other and the resulting line voltage becomes

$$Vab(t) = Va(t) - Vb(t)$$

$$= \mathrm{Re}\ \sqrt{2} \sum_{n=1}^{\infty} Vn \left[\exp jn(wt + \phi n) - \exp jn(wt + \phi n + 4\pi/3) \right]$$

$$= \sqrt{2} \sum_{n=1}^{\infty} Vn \left[\cos n(wt + \phi n) - \cos n(wt + \phi n + 4\pi/3) \right]$$

$$= -\sqrt{2} \sum_{n=1}^{\infty} Vn \left[2 \sin n(wt + \phi n + 2\pi/3) \sin n(2\pi/3) \right]$$

When n = 3,6,9, etc. Vab becomes zero, i.e. no triple harmonics exist in the line voltages. Similarly, for the delta- connected three phase system , a complete path for the triple harmonic currents is formed. These currents flow in phase around the loop and the relation of I line = $\sqrt{3}$ I phase also no longer holds.

When analysing the penetration of harmonics into a power network it is usual to assume that the effective inductive reactance for the nth harmonic is n times the fundamental value ($Z_l = j\ nW_f\ L$) and the capacitive reactance is 1/n times ($Zc = 1/j\ nW_f\ C$) [14].

CHAPTER THREE

There is a Turkish proverb to the effect that ' the world belongs to the dissatisfied. '

I believed in this saying absolutely.

For me the one great underlying principle of all human progress is that ' divine discontent ' makes men strive for better conditions and improved methods.

Charles P. Steinmetz

3 HARMONIC MONITORING

There are three areas which need close examination with reference to harmonic monitoring. These are the current transformer, signal processing equipment and interpretation of results.

3-1. Character of Current Transformer.

The simplified equivalent circuit of current transformer is shown in Fig. 3.1. [18].

Defining

L_2 = Leakage reactance referred to secondary

Le = Magnetising reactance referred to secondary

L_ℓ = Terminating reactance of secondary

Cw = Reactance due to wire capacitance referred to secondary .

For low frequencies, the effect of wire capacitance (Cw) can be neglected and therefore

$$I_2' = (N1/N2) I_1 \qquad (3.1)$$

$$Ie = E_2 / W Le \qquad (3.2)$$

$$I_2 = I_2' - Ie \qquad (3.3)$$

$$E_2 = W I_2 (L_2 + L_\ell) \qquad (3.4)$$

Substituting equations (3.1) and (3.3) into equation (3.4) :

$$E_2 = W (L_2 + L_\ell) [(N1/N2) I_1 - Ie] \qquad (3.5)$$

To predict I_2 for a given I_1 with known termination (L_ℓ) , equation (3.5) has two unknowns (E_2 and Ie) . The second relation between E_2 and Ie is the magnetization curve (E_2 versus Ie : Fig. 3.2) . If equation (3.5) is plotted

on the same coordinates as the magnetization curve (Fig.3.2), the intersection of the two plots will represent a solution for E_2 and Ie . Knowing Ie , now I_2 can be solved . The error of CT is the deviation of I_2 from I_2' as expressed as a percentage of I_2' .

CT error = (I_2' - I_2) / I_2' = Ie / I_2'

CT error increases with increasing CT current and is further increased by high terminating impedance . The optimum termination of CT would be a perfect short circuit . Even at short circuit the CT error is not zero , due to the internal leakage reactance of the CT .

The typical freguency response of a CT is plot of the magnitude of the current ratio, that is, |Output current| / |Input current| = |G(jWe)| , as a function of radian frequency We , that is , as the frequency of forcing function We change for a fixed load. [19]. The magnitude of the force function is maintained constant during the process of taking data for the |G(jWe)| versus We plot (Fig. 3.3) .

When a current transformer operating at 50 or 60 Hz carries very low current, the absolute error increases because the magnetising current becomes more significant. The better the CT quality, the smaller is the effect. As frequency increases, magnetising reactance increases and magnetising current decreases (see equation 3.2) , so that for small current a CT produces a higher output of current at high frequencies than at low frequencies. Errors due to core losses and secondary leakage inductance and winding capacitance are only significant at frequencies

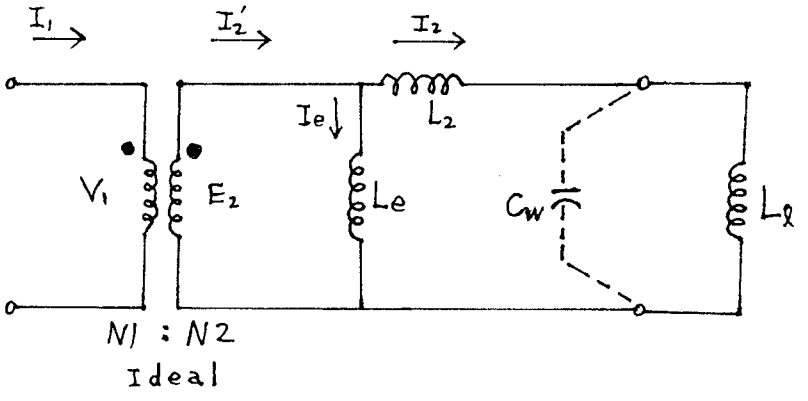


Fig. 3.1 Simplified Equivalent Circuit of CT.

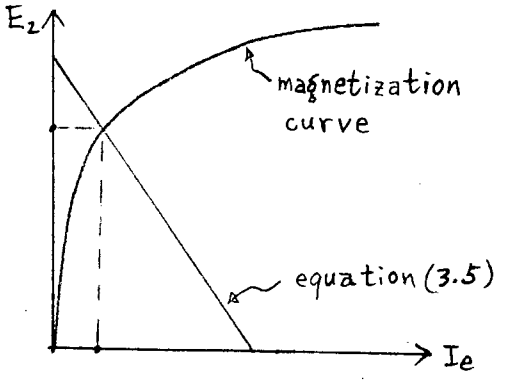


Fig. 3.2 Magnetization Curve of CT.

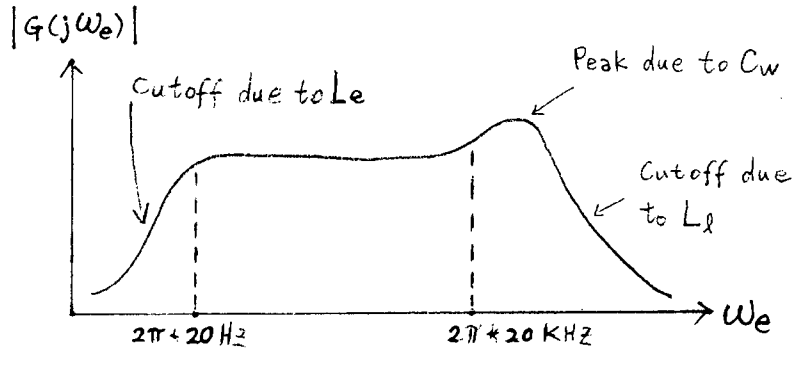


Fig. 3.3 Typical Frequency Response of CT.

of above 20 KHz generally. Below 20 KHz commercially available CTs are reported [20] to be adequate for harmonics monitoring . However, the following precautions should be taken :

1) The CT burden should be very low impedance , to reduce the required CT voltage and , consequently , the magnetising current .

2) It is recommended that twisted- pair or coaxial leads from the CT to the test equipment as short as possible to minimize unwanted pickup .

3) If the CT is a multi- winding type, use the highest ratios of secondary/primary . Higher ratios require lower magnetising current and tend to be more accurate .

3-2. Signal processing techniques.

There are, basically, three different approaches to analysis of harmonic distortion. They are

(i) Filtering

(ii) Fourier transform

(iii) Modulation

Each of the above can be implemented by analogue or digital techniques. The digital approach supersedes the analogue one in new designs as a result of digital devices are relatively much cheaper and can be programmable.

3-2-1. Filtering.

With the filtering technique both random transient and steady state harmonics can be measured if the relative phase relationships of the harmonics are of no concern. Phase shifts at different frequencies can be compensated by use of tunable all pass filter, which unfortunately also have different amplitude responses to different signals carrying different frequencies. A filter bank is required to deal with different frequencies. A six-pole Butterworth bandpass filter is a suitable choice because of its monotonically flat amplitude response. Even if the frequency of the input signal shifts slightly from the centre frequency of the filter, there is no need to re-calibrate [21]. In its digital implementation, it is referred to as an Infinite Impulse Response filter. The design of IIR filters has traditionally been based upon the transformation of an analogue filter approximation to a digital filter [21].

3-2-2. Fourier Transform.

The Fourier Transform can be approximated by the discrete Fourier transform which can speeded up by using Fast-Fourier-transform algorithms. Although the Fast-Fourier-transform algorithm was developed for use on general-purpose computers, some dedicated digital signal processors with FFT-based spectrum analyzers like TI's TMS 320, TRW's TDC 1028 and ITT's UDPI 01, on a single PC board, have recently become available on the market. The FFT operates on whole blocks of data at a time in order to

transform the signals from the time domain to the frequency domain. It is essential that analogue signals be bandlimited before sampling. Even if the signal is naturally bandlimited, since additive noise may have a much broader spectrum than the signal, analogue lowpass filtering is almost always necessary prior to sampling. The phase information obtained after the transform of a filtered signal have some degree of phase shift comparing with the original signals. The analogue signals pass through an antialiasing filter, sampler and A/D converter. The next step is windowing, which involves multiplying each sample point in the frame by a weighting coefficient. A discrete window, called a Dolph-Chebyshev window, is a suitable choice. This particular window has a very narrow main lobe. Windowing is required to account for the finite length of sample, since the FFT should operate on an infinitely continuous signal. After weighting, the data passes through the FFT algorithm, which involves squaring and summing of each spectral point [22].

3-2-3. Signal Modulation ____ " +1 and -1 " Technique.

There are various types of modulation methods. The following method, developed by K. L. Shum from an idea in a paper by Dr. M. L. Meade [23], represents a new attempt at measuring components (amplitude and phase) of harmonics in a waveform.

Let a signal be $\sum_{k=h}^{\infty} \hat{U}_k \sin (KW_S t + \theta_k/K)$, where $\hat{U}_k$ is the peak amplitude, θ_k is the angle , K is the order of harmonics referred to W_S (the fundamental angular frequency of the signal) and h can be any positive integer.

Let the gain be switched from +1 to −1 at a reference frequency,

so that the gain = +1 ; $0 < t < \pi/W_r$

-1 ; $\pi/W_r < t < 2\pi/W_r$

where W_r is the angular reference frequency .

Let the mean level of output over one reference period be $\underline{U}_K$

$$\underline{U}_k = \sum_{K=h}^{\infty} \hat{U}_K W_r \left[\int_0^{\pi/W_r} \mathrm{SIN}\,(KW_S t + \theta_K/K)\,dt - \int_{\pi/W_r}^{2\pi/W_r} \mathrm{SIN}\,(KW_S t + \theta_K/K)\,dt \right] / 2\pi$$

$$= \frac{\sum_{K=h}^{\infty} \hat{U}_K W_r \left\{ \left[-\cos(KW_S t + \theta_K/K)\right]_0^{\pi/W_r} - \left[-\cos(KW_S t + \theta_K/K)\right]_{\pi/W_r}^{2\pi/W_r} \right\}}{2\pi K W_S}$$

$$= \sum_{K=h}^{\infty} \hat{U}_K W_r \left\{ \left[-\cos(\pi K W_S/W_r + \theta_K/K) + \cos(\theta_K/K) \right] - \left[-\cos(2\pi K W_S/W_r + \theta_K/K) + \cos(\pi K W_S/W_r + \theta_K/K) \right] \right\} / 2\pi K W_S$$

Let $N = KW_S / W_r = Kf_s / f_r$, then

$$\underline{U}_k = \sum_{K=h}^{\infty} \hat{U}_K [\cos(\theta_K/K) + \cos(2\pi N + \theta_K/K) - 2\cos(\pi N + \theta_K/K)] / 2\pi N$$

When <u>N is an even number</u> , $\underline{U}_k = 0$.

When <u>N is an odd number</u>, $\cos(\theta_K/K) = -\cos(\pi N + \theta_K/K)$, then

$$\underline{U}_k = \sum_{K=h}^{\infty} 2\hat{U}_K \cos(\theta_K/K) / \pi N = \sum_{K=h}^{\infty} (2\hat{U}_K/\pi)(f_r/Kf_s)\cos(\theta_K/K)$$

$$= \sum_{K=h}^{\infty} A_K (f_r/Kf_s)\cos(\theta_K/K) \; ; \quad \text{where } A_K = 2\hat{U}_K/\pi N \qquad (3.6.1)$$

When $f_r = Kf_S$, $\underline{U}_K = \sum_{K=h}^{\infty} A_K \cos(\theta_K/K) = \sum_{K=h}^{\infty} X_K \qquad (3.6.2)$

Shifting the reference frequency to 90 degrees lag, causes the mean level of output over one reference period to equal

$$\underline{U}_k = \sum_{K=h}^{\infty} A_K \text{COS}\ (\theta_k/K - \pi/2) = \sum_{k=h}^{\infty} A_K \text{SIN}\ (\theta_k/K) = \sum_{k=h}^{\infty} Y_K \qquad (3.6.3)$$

When N is a fraction , the situation becomes more complicated . Consider a distorted waveform which has a fundamental and harmonic frequencies .

The radian frequency (W_r) of the reference clock is given by

$W_r = L\ W_S$ for $L > 1$.

The frequency of Mth harmonic is M times the frequency of fundamental .

Let the mean level of output over one fundamental period be $\underline{U}_M$.

For $L > M$ and $M = 1, 2, 3, \ldots\ldots, \infty$,

$$\underline{U}_M = \sum_{M=1}^{\infty} \hat{U}_M \sum_{Q=1}^{L} \{ \int_{(2Q-2)*2\pi/2L}^{(2Q-1)*2\pi/2L} \sin\ (M\ Wt + \theta_M/M)\ d(Wt)$$

$$- \int_{(2Q-1)*2\pi/2L}^{2Q*2\pi/2L} \sin\ (M\ Wt + \theta_M/M)\ d(Wt)\ \}/2\pi$$

$$= \sum_{M=1}^{\infty} \hat{U}_M \sum_{Q=1}^{L} \{ [- \cos\ (M\ Wt + \theta_M/M)\ ]_{(2Q-2)\pi/L}^{(2Q-1)\pi/L}$$

$$- [- \cos\ (M\ Wt + \theta_M/M)\ ]_{(2Q-1)\pi/L}^{2L\pi/L}\ \} / 2\pi M$$

$$= \sum_{M=1}^{\infty} \sum_{Q=1}^{L} \{ <- \cos\ [(2Q-1)\pi M/L + \theta_M/M] + \cos\ [(2Q-2)\pi M/L + \theta_M/M] >$$

$$- <- \cos\ [\ 2Q\pi M/L + \theta_M/M] + \cos\ [(2Q-1)\pi M/L + \theta_M/M] >$$

$$\}\ \hat{U}_M / 2\pi M$$

$$= \sum_{M=1}^{\infty} \hat{U}_M \sum_{Q=1}^{L} \{ -2\cos[(2Q-1)\pi M/L + \theta_M/M] + \cos[(2Q-2)\pi M/L + \theta_M/M] + \cos[2Q\pi M/L + \theta_M/M] \} / 2\pi M$$

Let $P = Q-1$, then

$$\underline{U}_M = \sum_{M=1}^{\infty} \{ \hat{U}_M \sum_{P=0}^{L-1} \langle -2\cos[(2P+1)\pi M/L + \theta_M/M] + \cos[2P\pi M/L + \theta_M/M] + \cos[(2P+2)\pi M/L + \theta_M/M] \rangle / 2\pi M \}$$

Let $\phi = \pi M/L + \theta_M/M$, then

$$\underline{U}_M = \sum_{M=1}^{\infty} \{ \hat{U}_M \sum_{P=0}^{L-1} \langle -2\cos(2\pi MP/L + \phi) + \cos(2\pi MP/L + \phi - \pi M/L) + \cos(2\pi MP/L + \phi + \pi M/L) \rangle / 2\pi M \}$$

$$= \sum_{M=1}^{\infty} \{ \hat{U}_M \sum_{P=0}^{L-1} \langle -2\cos(2\pi MP/L + \phi) + 2\cos(2\pi MP/L + \phi)\cos(\pi M/L) \rangle / 2\pi M \}$$

$$= \sum_{M=1}^{\infty} \{ 2\hat{U}_M' [\cos(\pi M/L) - 1] [\sum_{P=0}^{L-1} \cos(2\pi MP/L + \phi)] / 2\pi M \}$$

$$= \sum_{M=1}^{\infty} \{ 2\hat{U}_M [\cos(\pi M/L) - 1] \mathrm{Re}[\sum_{P=0}^{L-1} e^{j(2\pi MP/L + \phi)}] / 2\pi M \}$$

$$= \sum_{M=1}^{\infty} \{ 2\hat{U}_M [\cos(\pi M/L) - 1] \mathrm{Re}[e^{j\phi} \sum_{P=0}^{L-1} e^{j2\pi MP/L}] / 2\pi M \}$$

$$= \sum_{M=1}^{\infty} \{ 2\hat{U}_M [\cos(\pi M/L) - 1] \mathrm{Re}[e^{j\phi} \sum_{P=0}^{L-1} (e^{j2\pi M/L})^P] / 2\pi M \}$$

If $\exp j\pi M/L \neq 1$ (which implies $L \neq M$) , then

$$\underline{U}_M = \sum_{M=1}^{\infty} \{ 2\hat{U}_M [\cos(\pi M/L) - 1] [1/2\pi M] * \mathrm{Re}\langle [e^{j\phi}] [1 - (e^{j2\pi M/L})^L] / [1 - e^{j2\pi M/L}] \rangle \}$$

$$= \sum_{M=1}^{\infty} \{ 2\hat{U}_M [....] [....] \mathrm{Re}\langle [....] [1 - e^{j2\pi M}] / [....] \rangle \}$$

$$= \sum_{M=1}^{\infty} \{ 2\hat{U}_M [....] [....] \mathrm{Re}\langle [....] [1 - 1] / [....] \rangle \}$$

$$= 0$$

Modulating the signal for one fundamental period, with a clock frequency ranging from the fundamental to it's nth harmonic (where n can be infinity), gives us a mean level of output. This mean level of output can be represented by the equation (3.6.1) with different f_r/Kf_s ratios, which must be an odd number. Unfortunately this modulation technique does not allow the direct measurement of the magnitude of individual harmonics, since the presence of higher harmonics also contributes to the mean d.c. output (see equation 3.6.1) . These higher harmonics result in smaller d.c. components as the order of the harmonics increases. If the d.c. components arising from harmonics higher than the 25th are neglected, then a set of equations (3.7) can be obtained from equations (3.6.2) and (3.6.3) .

Referring to equations set (3.7) ,

$\hat{U}_K$ is the peak amplitude of the signal.

θ_K is the angle of signal with respect to the reference (usually taken as the zero crossing point of the fundamental) .

${}_oU_K$ is the mean level of output modulated at the reference frequency.

${}_{90}U_K$ is the mean level of output modulated at the frequency with 90 deg. phase shifted.

k is the order of the harmonics.

$$
\begin{aligned}
{}_{o}U_1 &= \frac{2}{\pi}\hat{U}_1 \cos\theta_1 + \frac{2}{3\pi}\hat{U}_3 \cos\theta_3 + \frac{2}{5\pi}\hat{U}_5 \cos\theta_5 + \\
&\quad - - - - - - - - + \frac{2}{23\pi}\hat{U}_{23} \cos\theta_{23} + \frac{2}{25\pi}\hat{U}_{25} \cos\theta_{25} \\
{}_{90}U_1 &= \frac{2}{\pi}\hat{U}_1 \sin\theta_1 + \frac{2}{3\pi}\hat{U}_3 \sin\theta_3 + \frac{2}{5\pi}\hat{U}_5 \sin\theta_5 + \\
&\quad - - - - - - - - + \frac{2}{23\pi}\hat{U}_{23} \sin\theta_{23} + \frac{2}{25\pi}\hat{U}_{25} \sin\theta_{25} \qquad (3.7.1)
\end{aligned}
$$

$$
\begin{aligned}
{}_{o}U_2 &= \frac{2}{\pi}\hat{U}_2 \cos\theta_2 + \frac{2}{3\pi}\hat{U}_6 \cos\theta_6 + \frac{2}{5\pi}\hat{U}_{10} \cos\theta_{10} + \\
&\quad - - - - - - - - + \frac{2}{9\pi}\hat{U}_{18} \cos\theta_{18} + \frac{2}{11\pi}\hat{U}_{22} \cos\theta_{22} \\
{}_{90}U_2 &= \frac{2}{\pi}\hat{U}_2 \sin\theta_2 + \frac{2}{3\pi}\hat{U}_6 \sin\theta_6 + \frac{2}{5\pi}\hat{U}_{10} \sin\theta_{10} + \\
&\quad - - - - - - - - + \frac{2}{9\pi}\hat{U}_{18} \sin\theta_{18} + \frac{2}{11\pi}\hat{U}_{22} \sin\theta_{22} \qquad (3.7.2)
\end{aligned}
$$

$$
\begin{aligned}
{}_{o}U_3 &= \frac{2}{\pi}\hat{U}_3 \cos\theta_3 + \frac{2}{3\pi}\hat{U}_9 \cos\theta_9 + \frac{2}{5\pi}\hat{U}_{15} \cos\theta_{15} \\
&\quad \frac{2}{7\pi}\hat{U}_{21} \cos\theta_{21} \\
{}_{90}U_3 &= \frac{2}{\pi}\hat{U}_3 \sin\theta_3 + \frac{2}{3\pi}\hat{U}_9 \sin\theta_9 + \frac{2}{5\pi}\hat{U}_{15} \sin\theta_{15} \\
&\quad \frac{2}{7\pi}\hat{U}_{21} \sin\theta_{21} \qquad (3.7.3)
\end{aligned}
$$

$$
\begin{aligned}
{}_{o}U_4 &= \frac{2}{\pi}\hat{U}_4 \cos\theta_4 + \frac{2}{3\pi}\hat{U}_{12} \cos\theta_{12} + \frac{2}{5\pi}\hat{U}_{20} \cos\theta_{20} \\
{}_{90}U_4 &= \frac{2}{\pi}\hat{U}_4 \sin\theta_4 + \frac{2}{3\pi}\hat{U}_{12} \sin\theta_{12} + \frac{2}{5\pi}\hat{U}_{20} \sin\theta_{20} \qquad (3.7.4)
\end{aligned}
$$

$$
\begin{aligned}
{}_{o}U_5 &= \frac{2}{\pi}\hat{U}_5 \cos\theta_5 + \frac{2}{3\pi}\hat{U}_{15} \cos\theta_{15} + \frac{2}{5\pi}\hat{U}_{25} \cos\theta_{25} \\
{}_{90}U_5 &= \frac{2}{\pi}\hat{U}_5 \sin\theta_5 + \frac{2}{3\pi}\hat{U}_{15} \sin\theta_{15} + \frac{2}{5\pi}\hat{U}_{25} \sin\theta_{25} \qquad (3.7.5)
\end{aligned}
$$

$$ {}_{0}U_{6} = \frac{2}{\pi}\hat{U}_{6} \cos\theta_{6} + \frac{2}{3\pi}\hat{U}_{18} \cos\theta_{18} $$

$$ {}_{90}U_{6} = \frac{2}{\pi}\hat{U}_{6} \sin\theta_{6} + \frac{2}{3\pi}\hat{U}_{18} \sin\theta_{18} \qquad (3.7.6) $$

$$ {}_{0}U_{7} = \frac{2}{\pi}\hat{U}_{7} \cos\theta_{7} + \frac{2}{3\pi}\hat{U}_{21} \cos\theta_{21} $$

$$ {}_{90}U_{7} = \frac{2}{\pi}\hat{U}_{7} \sin\theta_{7} + \frac{2}{3\pi}\hat{U}_{21} \sin\theta_{21} \qquad (3.7.7) $$

$$ {}_{0}U_{8} = \frac{2}{\pi}\hat{U}_{8} \cos\theta_{8} + \frac{2}{3\pi}\hat{U}_{24} \cos\theta_{24} $$

$$ {}_{90}U_{8} = \frac{2}{\pi}\hat{U}_{8} \sin\theta_{8} + \frac{2}{3\pi}\hat{U}_{24} \sin\theta_{24} \qquad (3.7.8) $$

$$ {}_{0}U_{9} = \frac{2}{\pi}\hat{U}_{9} \cos\theta_{9} $$

$$ {}_{90}U_{9} = \frac{2}{\pi}\hat{U}_{9} \sin\theta_{9} \qquad (3.7.9) $$

$$ {}_{0}U_{10} = \frac{2}{\pi}\hat{U}_{10} \cos\theta_{10} $$

$$ {}_{90}U_{10} = \frac{2}{\pi}\hat{U}_{10} \sin\theta_{10} \qquad (3.7.10) $$

$$ - - - - - - - - - - - - - \qquad (3.7.11) $$
$$ - - - - - - - - - - - - - $$
$$ - - - - - - - - - - - - - \qquad \sim $$
$$ - - - - - - - - - - - - - \qquad (3.7.23) $$

$$ {}_{0}U_{24} = \frac{2}{\pi}\hat{U}_{24} \cos\theta_{24} $$

$$ {}_{90}U_{24} = \frac{2}{\pi}\hat{U}_{24} \sin\theta_{24} \qquad (3.7.24) $$

$$ {}_{0}U_{25} = \frac{2}{\pi}\hat{U}_{25} \cos\theta_{25} $$

$$ {}_{90}U_{25} = \frac{2}{\pi}\hat{U}_{25} \sin\theta_{25} \qquad (3.7.25) $$

For h = 9, ..., 25 , equations (3.7.9) to (3.7.25) can be solved simultaneously for the absolute values of A_k and θ_k to give:

$$A_k = \sqrt{X_k^2 + Y_k^2} \qquad (3.8.1)$$

$$\theta_K = K \arccos (X_k / A_k) \qquad (3.8.2)$$

Equations (3.7.6) to (3.7.8) each have two d.c. terms . The second terms arising from higher harmonics could be eliminated by dividing equations (3.7.18), (3.7.21) and (3.7.24) by a factor of 3 and then subtracting the results from equations (3.7.6) to (3.7.8) respectively. Equations (3.8.1) and (3.8.2) can now be applied to find A_6 , θ_6 , A_7 , θ_7 , A_8 and θ_8 .

Based on the same procedure, the d.c. terms existing in equations (3.7.1) to (3.7.5) can be eliminated and A_1 to A_5 and θ_1 to θ_5 can also be obtained .

The values of each θ_k from the equation (3.8.2) are the absolute values and the quadrants to which they belong is determined according to Fig. (3.4) . Fig. 3.4 shows the relationship between X_k, Y_k and θ_k for each individual harmonic. Fig. (3.5) shows the X_k _Y_k _θ_k curves for the fundamental and the third harmonic.

3-2-4. Aspects of the different methods.

Both digital filtering and discrete Fourier Transform algorithms have been developed for use on minicomputers. There are large amounts of software for implementing a digital filter in many digital filters and signal processing books. Most of the programs are written in Fortran-77. In one book [24] ,

X_K _ Y_K _ θ_K Relationship

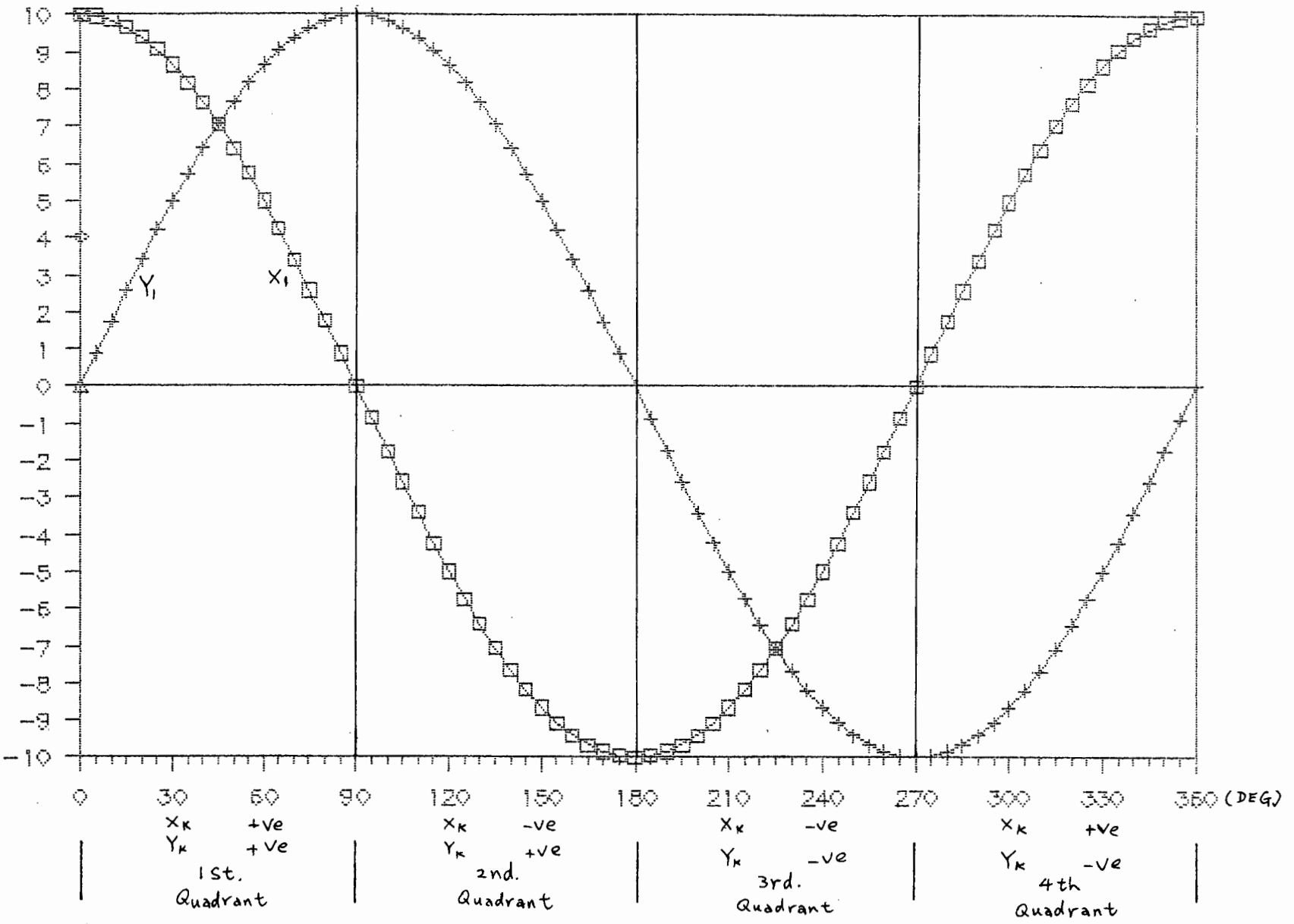


Fig. 3.4 Relationship between X_K, Y_K and θ_K

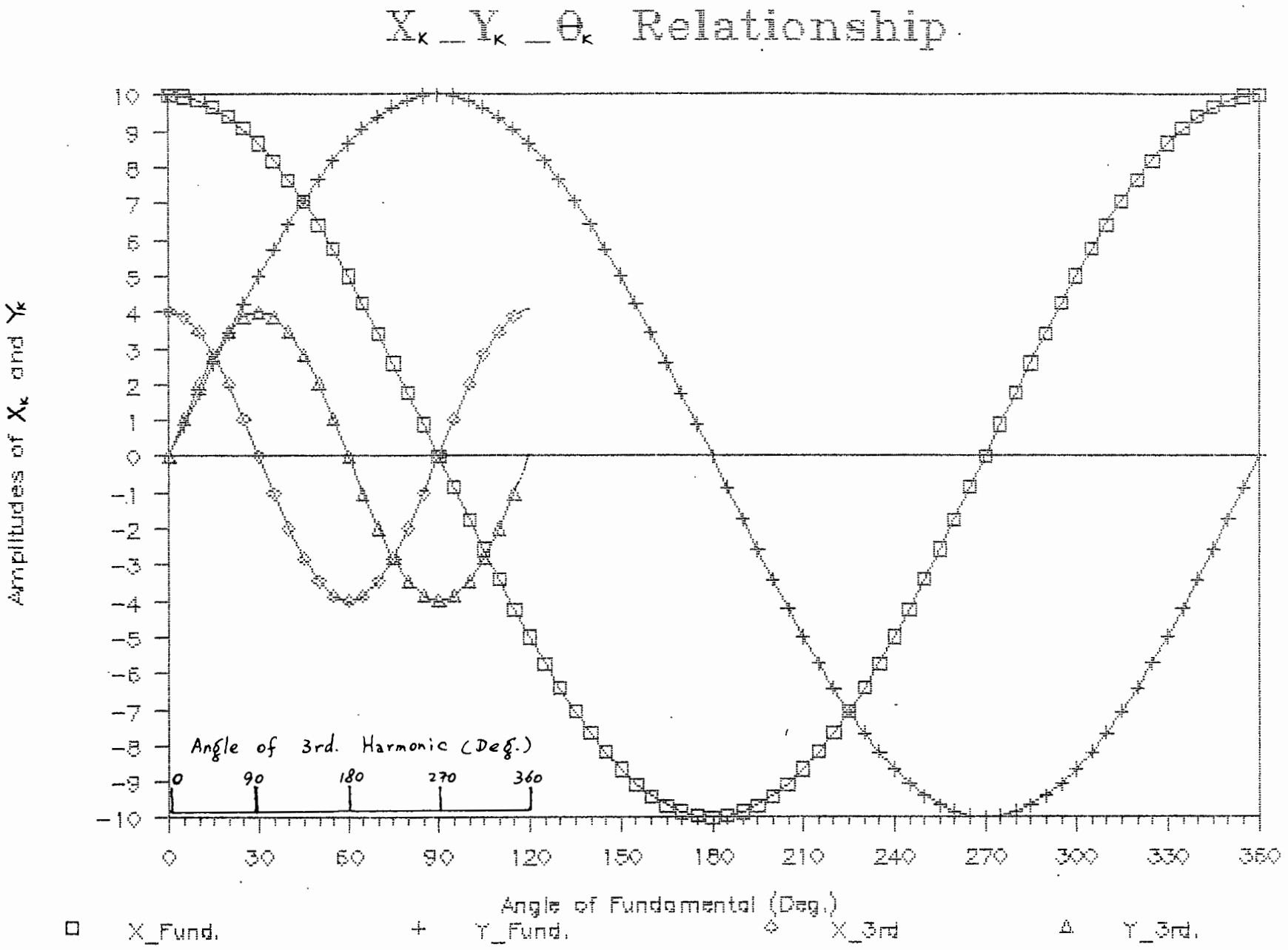


Fig. 3.5 X_k _ Y_K _ θ_K Curves of Fundamental and 3rd. Harmonic.

the authors collected several special programs written in assembly langauges of several of the most common 16_ bit microprocessors ,i.e. 8086, MC68000, Z8000, TMS9995, and 9445 respectively for the implementation of real_ time software filters in digital form. A similar situation exists for the handling of DFT 's. GEÇKİNLİ and YAVUZ, in their book [22] , published a special program for measuring the harmonics on the mains.

It is difficult to translate this software into the Basic language and run it on microcomputers because most of microcomputers using the Basic language are slow, especially on input routine. Unfortunately, in measurement of harmonics, a high sample rate is demanded.

One of the principle objective of this project was to design and construct an instrument capable of measuring the magnitude and phase of the harmonic components of both voltage and current accurately and quickly. The signal modulation method described above is the most attractive choice. This method is better than the filtering and Fourier transform methods because it preserves both magnitude and phase information of all harmonics involved. It also has the advantage that any shapes of waveform can be analyzed as in the filtering and Fourier transform methods. This is a more generalized method than the one developed recently by the Russian born Israeli engineer M. A. Slonim and his colleagues P. P. Biringer and I. Rapoport [25, 26] which can handle only a limited number of known waveforms.

Another advantage is that it can be easily implemented by digital

circuitry and software, as described in the rest of this thesis.

3-3. Interpretation of results.

Harmonic measurements of a substantial mains power which has multiple frequencies, resonances, fluctuating amplitudes and multiple sources nature, are complicated.

Strange phenomena can be present if overheating or instabilty occures in the system during measurement. In this case, measurements of harmonics alone are inadequate and may be misleading.

A non-linear load supplied by a noisy source can cause the net power flow to be away from or towards the load depending on the relative magnitude of the harmonic source in the load and the supply. The magnitude is usually too small to be of concern, otherwise measurements can be postponed until the supply gets quieter.

CHAPTER FOUR

The fancy is indeed no other than a mode of memory emancipated from the order of time and space.

Samuel Taylor Coleridge

4 INSTRUMENTATION

4-1. Introduction

One of the aims of this thesis is to design an instrument based on the " +1 and -1 " signal modulation technique to measure both magnitude and phase of voltage and current, which forms a major part of the work involved in this project.

This instrument should run fast and preferably have the capacity to run in real time. The new trend in electronic system design is to minimize the use of analogue circuitry, especially analogue filters, and instead maximize the use of digital circuits and software. Unfortunately, due to limited funds, a low- cost design is the only choice.

The basic design principle, the actual hardware development, the practical problems encountered and their solutions will be explained in the following paragraphs.

4-2. Basic design philosophy.

Fig. 4.1 shows the basic layout of the instrument. It is convenient to divide it into eight major functional blocks.

4-2-1. Part 1 Scaling.

The maximum inputs to the instrument are defined as :

V - 240 V a.c.

I - 1 A a.c.

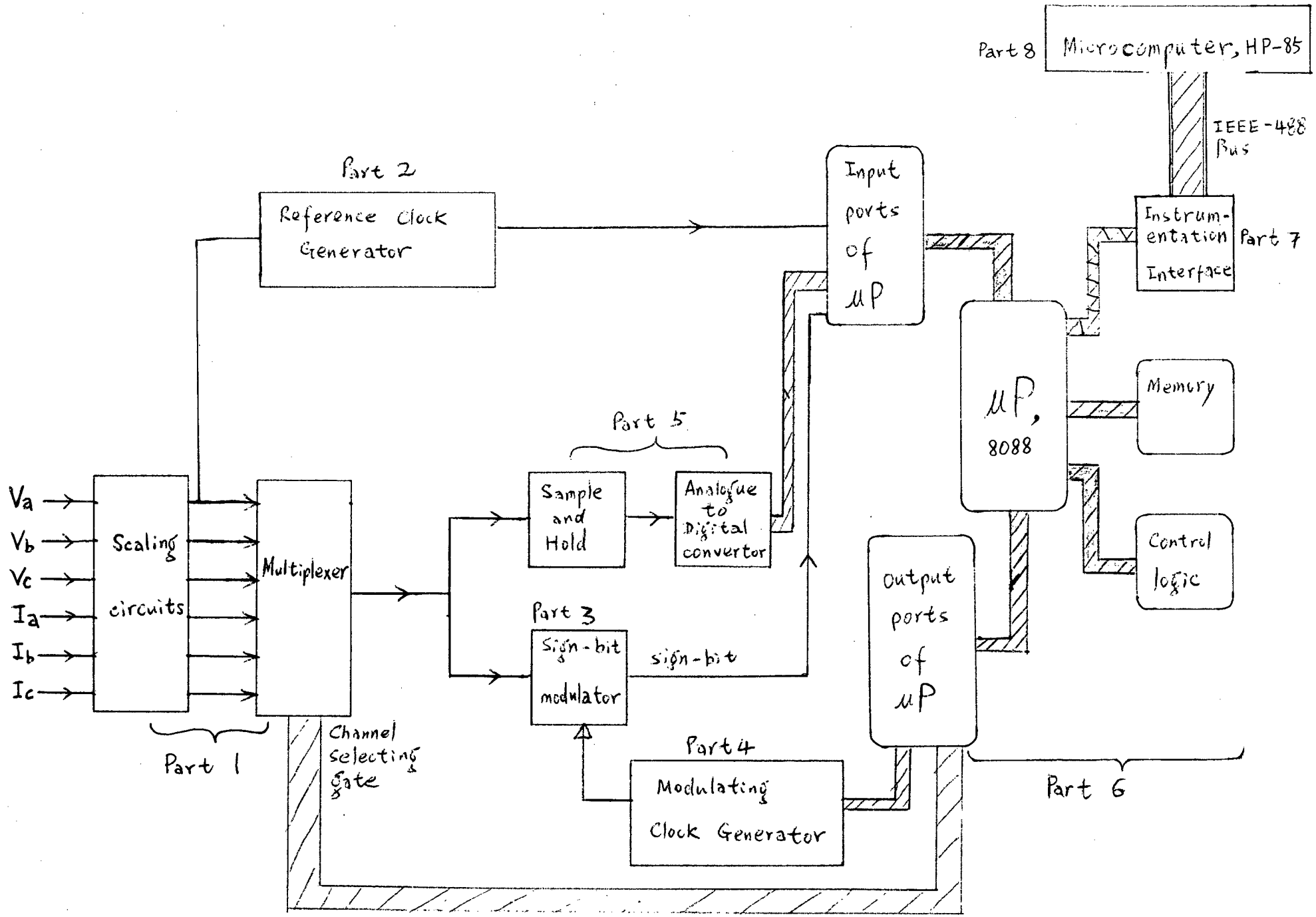


Fig. 4.1 Basic layout of the overall system.

A LED indicator on the front panel of the instrument will light up if any input signal exceeds these values. The signals pass through a scaling circuit made up of high wattage resistors, restricting the amplitude of the signals to within -5 V and +5 V. Scaling down 240V a.c. maximum input voltage to 5V a.c. requires the circuit shown in Fig. 4.2 .

The resistors used are at least half-watt each and 1% accurate.

The total gain of this passive circuit is :

Vout/Vin = 5/(330 + 10) = 1/68

If the input voltage signals are larger than 240 Va.c., the values of resistors of voltage scaling circuit should be recalculated to suit the new specification. It is not recommended that potential transformers be used for scaling purposes because their frequency response characteristics depend on such factors as stray inductance, capacitance of the windings and the frequency dependent core losses.

Input current signals must be converted to voltages. The circuit in Fig. 4.3 is employed.

The resistors here are 10-watt each and 1% accurate.

The total gain of this passive circuit is:

Vout/Iin = (4.7 + 2.2) V/A = 6.9 V/A

Over- range current signals can be stepped down using current transformers with 0.1% rated accuracy.

Thereafter the signals are fed to an analogue multiplexer which is controlled by the microprocessor. The multiplexer chooses one of six channels (Va,Vb,Vc,Ia,Ib,Ic) and feeds this to the

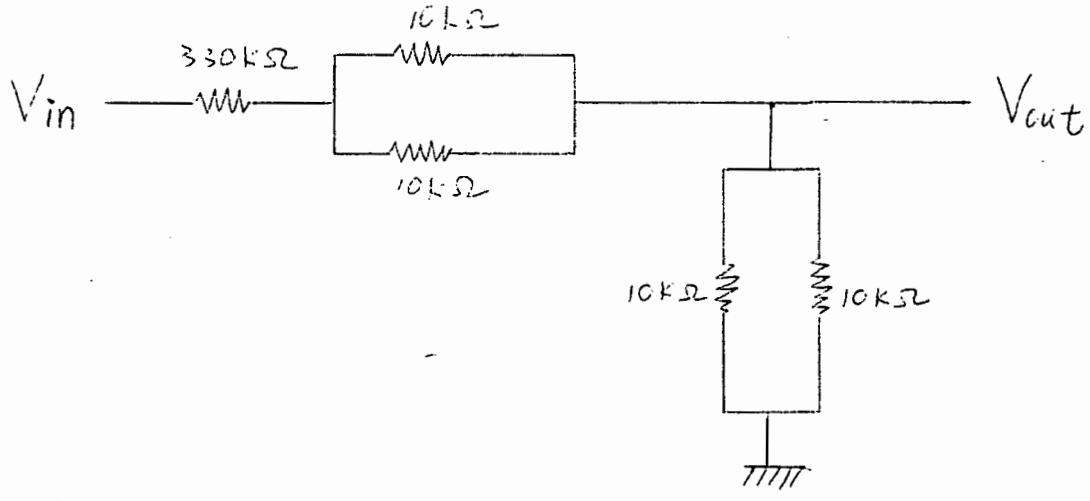


Fig. 4.2 Voltage Scaling Circuit

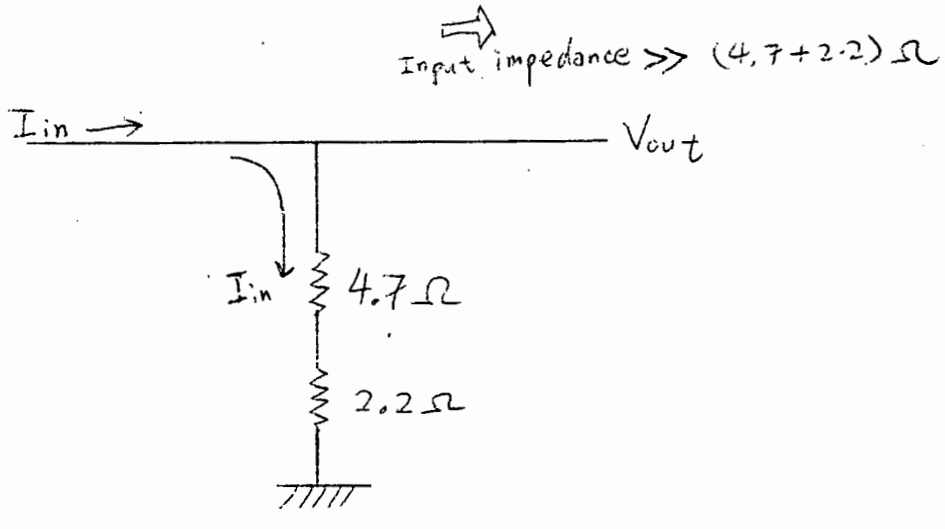


Fig. 4.3 Current Scaling Circuit

high input impedance buffer and then to the inputs of the sign-bit modulator and the sample and hold.

The analogue multiplexer is implemented with cmos analogue gates and a digital decoder. The cmos analogue gates used were IH 5052 which have 150 ohms on-resistance and 60 dB cross coupling rejection. The latter parameter is small enough to be neglected and the former can be compensated. The IH5052 is directly controlled by TTL logic levels. Unfortunately, IH5052 is not a device designed for precision applications. It has voltage and current offsets and on-off switching noise which may degrade the accurracy of the measurement. A better device should be used to replace the IH5052 if funds become available. The decoder causes the multiplexer to route one of the input channels to the buffer. It is controlled by the microprocessor. Fig. 4.4 shows the circuit diagram of the multiplexer.

4-2-2. Part 2 Reference clock generator.

The fundamental of Va is chosen as the reference clock of the whole system. The signal from channel Va is noisy and contaminated by harmonics because it comes from the mains. There are two methods of recovering the fundamental from the input signal, namely :

1. Low pass active filter.
2. Phase-locked loop with exclusive-or gate input to eliminate noise.

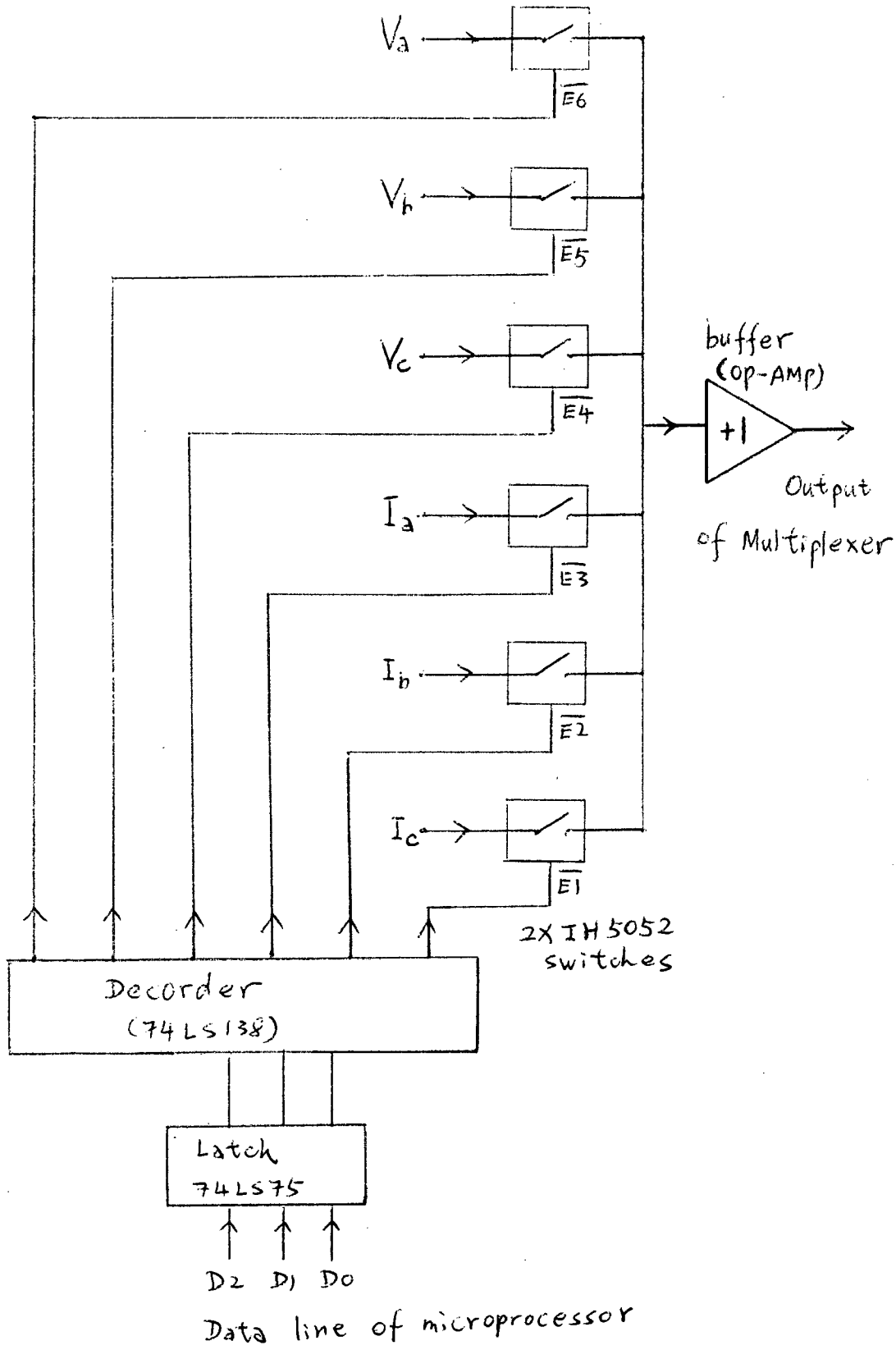


Fig. 4.4 Multiplexer

Both methods generate phase shift which could be compensated for by an analogue phase-shifter. The input impedance of such a phase-shifter must be very high to avoid loading which will have an effect on the accuracy of the signal Va. One of the disadvantages of a PLL is that it can also lock onto an harmonic of the signal [27]. The filter is thus left as the only option. Unfortunately, neither the low-pass filter nor the phase compensation circuit have a high value of input impedance, so the Va input signal first has to be buffered using a voltage follower circuit which has an input impedance of several mega-ohms. The low- pass filter is a second order active Tschebyshev type. The 2nd harmonic has 20 dB attenuation relative to the fundamental frequency. Fig. 4.5 shows the circuit [21]. The 2K2-ohm trim pot in Fig. 4.5 has to be adjusted with the help of an oscilloscope until the input signal (50 Hz) of the phase-shift compensator is in phase with the output of low-pass filter. The signal passes through the lowpass filter and is fed to a zero-crossing detector.

A zero- crossing detector, implemented by analog comparator LM319, would detect the fundamental filtered signal as it crosses the zero value. Noise will cause multiple zero crossings. Thus another detector must be used in conjuction with the zero-crossing detector to detect the first rising edge. A non-retriggerable one-shot 74LS221 is suitable for this application. Once triggered, its output is independent of further transitions of the input and it will be reset after a preset time. The output of the one-shot will be a clean and well defined reference

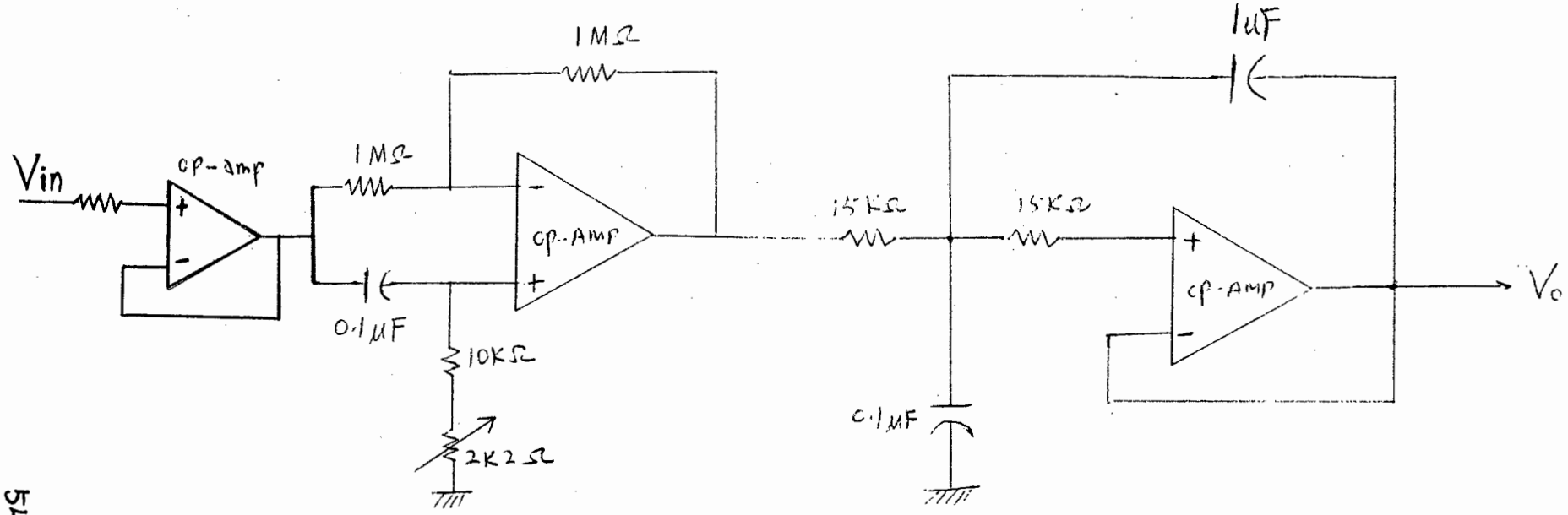


Fig. 4.5 Phase-shift compensator and low-pass filter

clock. This reference clock need not have a 50% duty cycle, because only the period of the reference clock is of importance. The reference clock generator circuit diagram is shown in Fig. 4.6 .

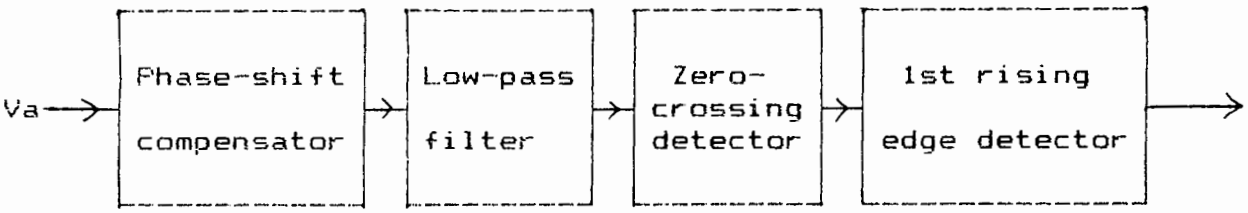


Fig. 4.6 Reference Clock Generator.

4-2-3. Part 3 Sign- bit modulator

The function of the sign- bit modulator is to multiply the amplitude of the input signal by +1 or -1 within a specified period . This operation is controlled by the modulating clock. This procedure has first been implemented by software on a computer. The computer gets the samples directly from the ADC and then multiplies them by +1 or -1 according to the reference clock which is also simulated by software. This method of implementation was attempted, but is impractical, because it uses too much processing time, i.e. it delays the measurement time. Some additional hardware is required to speed up the operation. The output of the modulator feeds a sign detector LM311 to generate a reference clock. The clock will be in a high state if the amplitude of the signal from the modulator is negative and the clock will be in a low state if the signal is positive. The output of the sign detector is assigned to the sign- bit of

the ADC and the ADC therefore only measures the absolute amplitude of the signal and not its sign.

Care must be taken in the design of a sign- bit modulator. The multiplier function of the modulator needs to be symmetrical about the zero voltage reference to generate output values with a positive and negative gain of one during a specified period. It can only allow small errors due to the offset of the ground reference voltage and the switching noise at the time the signal switches from +1 to -1 or vice versa.

The circuit diagram (Fig. 4.7) and procedure to design a sign- bit modulator is as follows :

The modulating clock is derived from a modulating clock generator, its frequency being controlled by the microprocessor. When the switch 1 is on, the output voltage will be equal to the inverse of the value of the input. When the switch 1 is off, the output will be equal to the input voltage.

Switch 2 is always on and is built in the same IC package as switch 1. The on- resistance of switch 1 and that of switch 2 is therefore always the same even if the temperature changes.

The next step is to look for optimal values of resistances R1, R2, and Rf in Fig. 4.7 .

Let the on-resistance of switch 1 and 2 be r ohms and its off-resistance be infinite.

According to Fig. 4.8 ,

$$e1 = (Vo - Vin)R1 / (R1 + Rf + r) + Vin$$

$$= Vo\ R1/(R1 + Rf + r) + Vin\ [\ 1 - R1/(R1 + Rf + r)\ ]$$

$$e2 = Vin\ R3 / (R2 + R3)$$

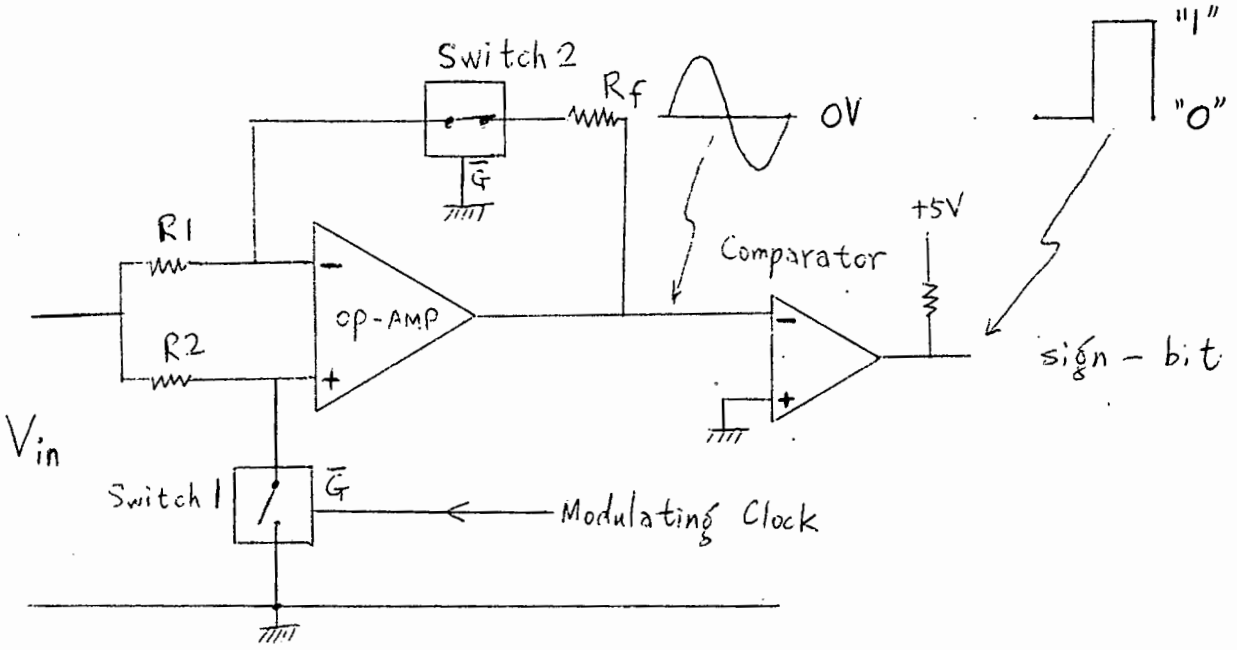


Fig. 4.7 Sign - bit modulator

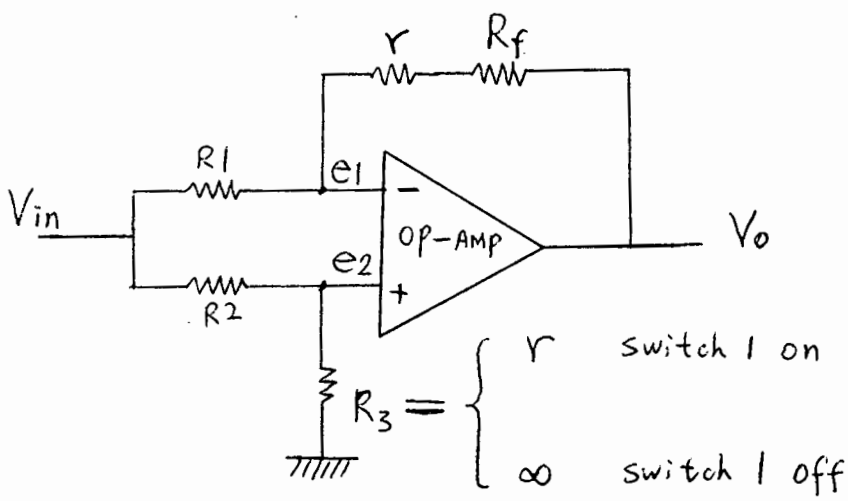


Fig. 4.8. Equivalent circuit of Sign - bit modulator

When the open loop gain is very large, e1 = e2 , therefore

$$Vo\ R1/(R1+ Rf+ r) = Vin\ [\ R3/(R2 + R3) + R1/(R1+ Rf+ r) - 1\ ]$$

$$Vo/Vin = [\ R3/(R2+R3) - (Rf+r)/(R1+Rf+r)\ ]\ (R1+Rf+r) / R1 \qquad (4.1)$$

When switch 1 is off, R3 is equal to infinity.

Equation (4.1) becomes

$$Vo/Vin = (R1 + Rf + r)\ [\ 1 - (\ Rf + r\ )\ /\ (R1 + Rf + r)\ ]\ /\ R1$$

$$= (R1 + Rf + r)\ [\ (R1 +Rf +r -Rf -r)\ /\ (R1 +Rf +r)\ ]\ /\ R1$$

$$= 1$$

When switch 1 is on, R3 is equal to r ohms and Vo/Vin is expected to be -1.

Equation (4.1) becomes

$$(R1 + Rf + r)\ [\ r/(R2 + r) - (Rf + r)/(R1 + Rf + r)\ ]\ /\ R1 = -1$$

$$r(\ R1 + Rf + r\ )/[\ R1\ (\ R2 + r\ )\ ] - Rf/R1 - r/R1 = -1$$

$$r[\ (\ R1 + Rf + r\ )/(\ R2 + r\ ) - 1\ ]/R1 - Rf/R1 = -1$$

$$r[\ (\ R1 + Rf - R2\ )/(\ R2 + r\ )\ ] - Rf/R1 = -1$$

Taking R1 + Rf - R2 = 0 , the expression becomes Rf = R1 and then R2 = 2 R1 = 2 Rf. The modulator is implemented by a precision operational amplifier (OP-27) [28], a cmos analogue switch IH5052 and metal film precision resistors. Choosing R1=100k ohms the other values can be derived as, R2=200k ohms and Rf=100k ohms. The circuit in Fig. 4.9 is the actual modulator .

4-2-4. Part 4 Modulating clock generators.

The modulating clock generator is a programmable square wave generator. It must be possible for the microprocessor to set

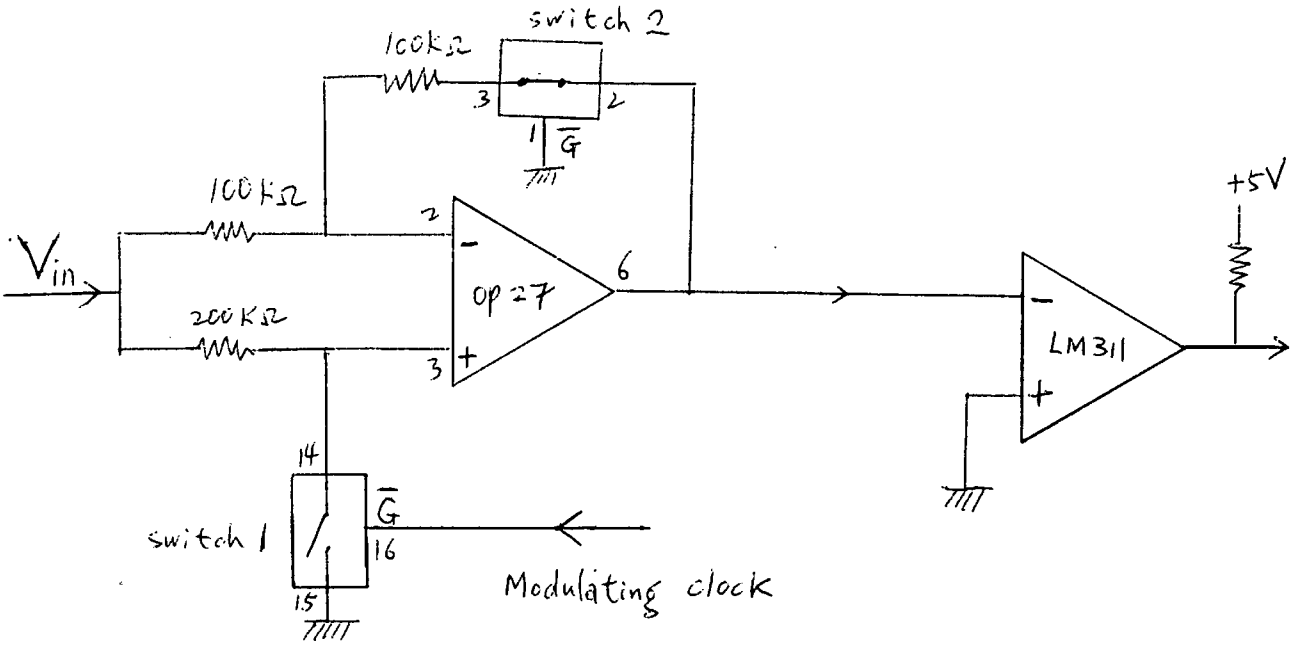


Fig. 4.9 Actual Sign-bit Modulator circuit

its output frequency to the fundamenal or any of the harmonics of the reference clock from the zero-crossing detector. One important point is that it must have the capability to synchronize with the input reference clock with very little phase shift error, ideally zero- phase shift. Another clock generator operating at the same frequency, but with a 90 degree phase shift is required to run in parallel with the zero- phase-shift one. This could be implemented in software, but the use of a digital phase shifter is preferable in order to save computing time in the microprocessor. The Intel chip 8254 [29] is chosen as the in- phase clock generator. Its operating clock frequency is 2.5 MHz . The 8254 has three programmable interval count- down counters. When counter 0 operates in mode 3, it behaves as a square wave generator. When counter 1 operates in mode 2, it behaves as an automatic reloaded counter. To calculate the frequency of the Nth order harmonic of the input signal counter 1 must count the duration between two successive rising edges of the fundamental filtered zero- crossing (ZC) signal, i.e. the duration of one cycle of the fundamental component of the input signal. The microprocessor will then read the value of the count from counter 1 and divide it by N . After dividing the value of the count by N, the microprocessor sends this value to counter 0 to generate a modulating square wave clock which is of the same period as the Nth harmonic of input signal. In order to obtain the value of the count from counter 1, the clock input of counter 1 must be inhibited by using the GATE1 input of this

counter. Otherwise, the count may be in the process of changing when it is read, giving an undefined result. Counter 0 also has a GATE0 input which is used to sychronize it with the rising edge of the ZC signal. Fig. 4.10 shows the controlling circuit and timing diagram of counter 1. An innovative device, called the dual edge triggered flip- flop (DET FF) is used to allow counter 1 to operate in counting mode between two assigned successive rising edges of the ZC signal. Unfortunately, in order to prevent counter 1 from operating repeatedly, the first rising edge of the ZC signal cannot be directly applied to the DET flip-flop. Instead, the microprocessor has to poll the ZC signal until it detects a change state low to state high. It then issues a GATE0 signal which in turn activates the GATE1 input line of counter 1. This will become inactive again after the second successive rising edge of the ZC signal. Whenever the GATE1 input line is inactive, the final value of the count is latched and the microprocessor can read it from counter 1.

Another modulating clock has a 90 degree phase-lag in relation to the first one. This clock generator is implemented using a phase- lock loop (PLL) technique. The chip chosen was a cmos 4046 [30]. The PLL was designed to lock to the input clock signal with a frequency range from 35 Hz to 1.5 KHz. This circuit is programmed to have a fixed 90 degree phase- shift between the input and output clock signals by setting the B inputs of a cascaded 8-bit BCD magnitude comparator chip 74C85 to 89. Fig. 4.11 shows the circuit of the digital phase

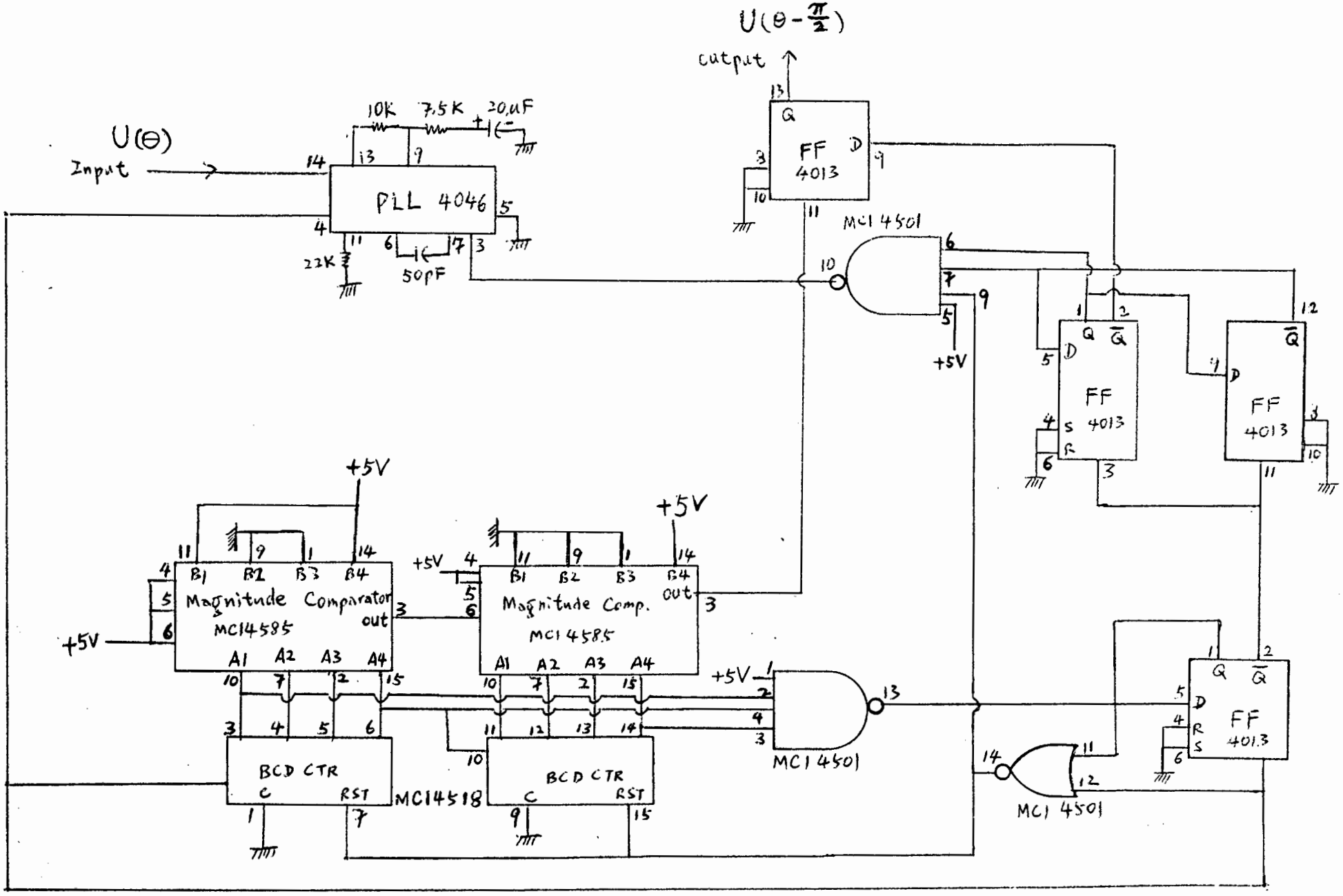


Fig. 4.11 Digital phase shifter (set to 90°)

shifter. Both clocks feed an analogue multiplexer (cmos 4051) and one of them is selected by the microprocessor as a modulating clock. Fig. 4.12 shows a modulating clock generator.

4-2-5. Dual- edge triggered flip- flop (DET FF) .

Before further discussion of other circuits, a commercially unavailable device, called a dual- edge triggered flip-flop has to be mentioned, because it will appear frequently later on. There are occasions when the design of discrete logic circuits can be simplified if DET FFs are utilised. The DET FF is developed with the use of a controlled glitch and its circuit and timing diagram are shown in Fig.4.13.

Referring to Fig.4.13 , the output goes to the 1 state on every positive transition of the input A line and the output goes to the 0 state on every positive transition of the input B line. The output of the flip- flop is capable of being reset by another A line transition immediately after being cleared, regardless of the level of B line. A controlled glitch occurs whenever the B line makes a positive transition. The circuit's operation is as follows :

1. Qa is set by every positive transition of line A.
2. If Qa is set, FFB is enabled and set on a positive transition of line B;
3. this causes FFA to clear, which now clears FFB via its clear input.
4. Thus FFB is only set for the time it takes itself to set,

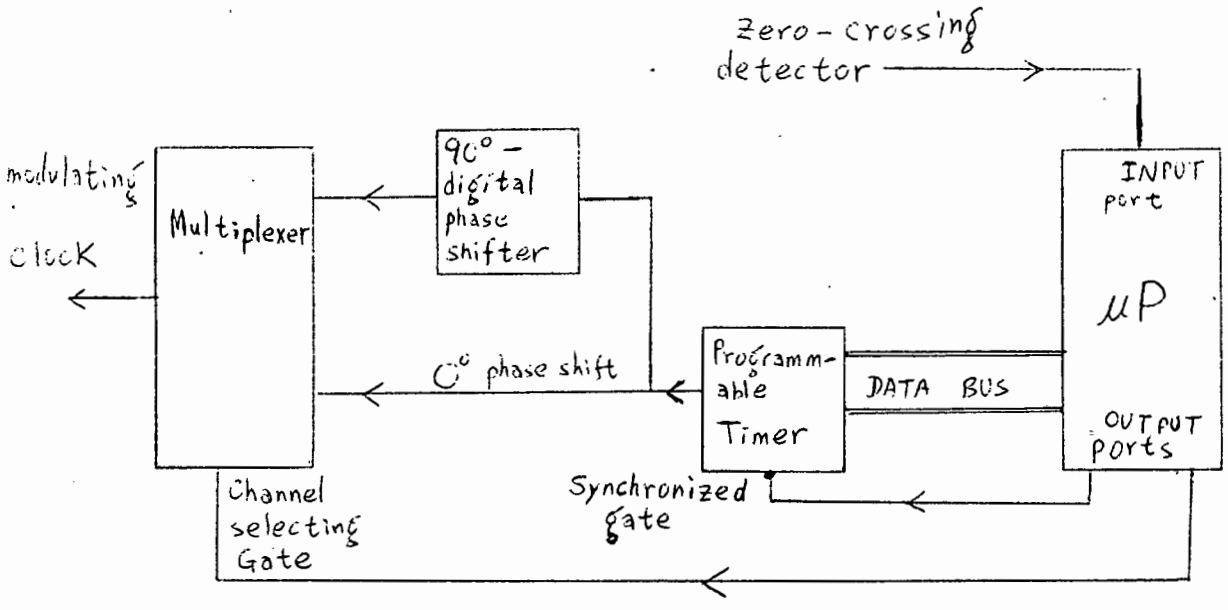
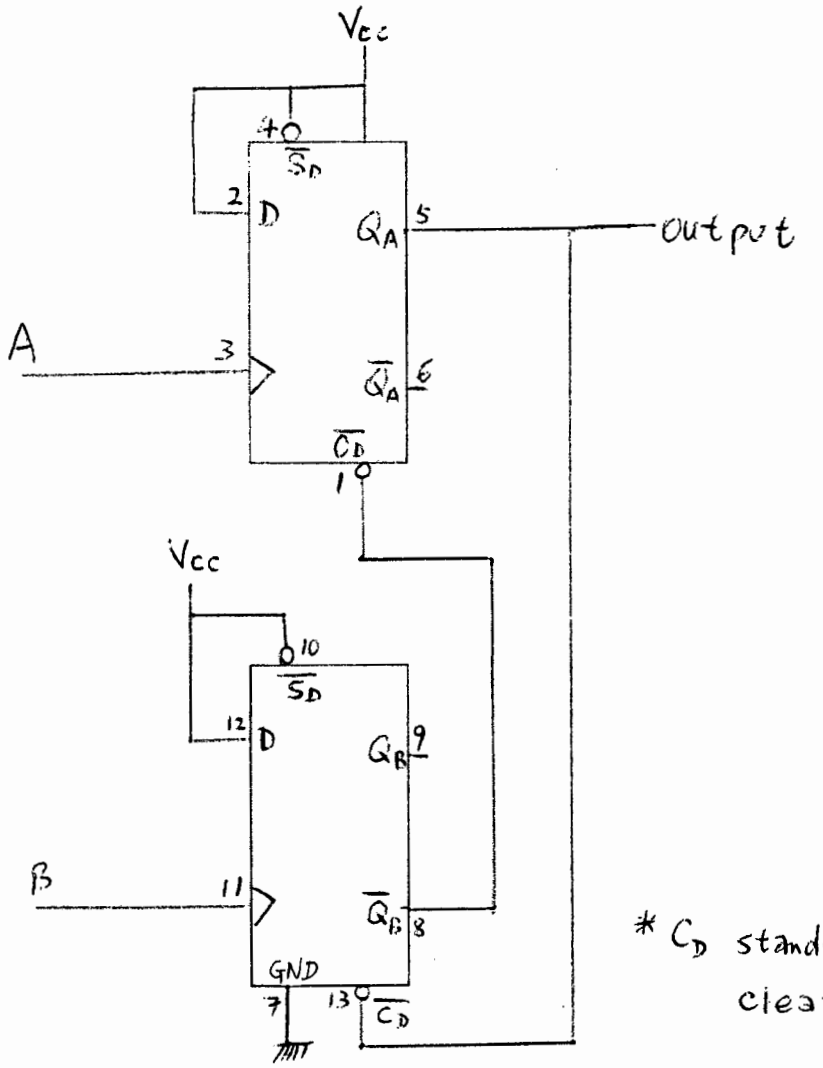


Fig 4.12 Modulating Clock Generator



74LS74

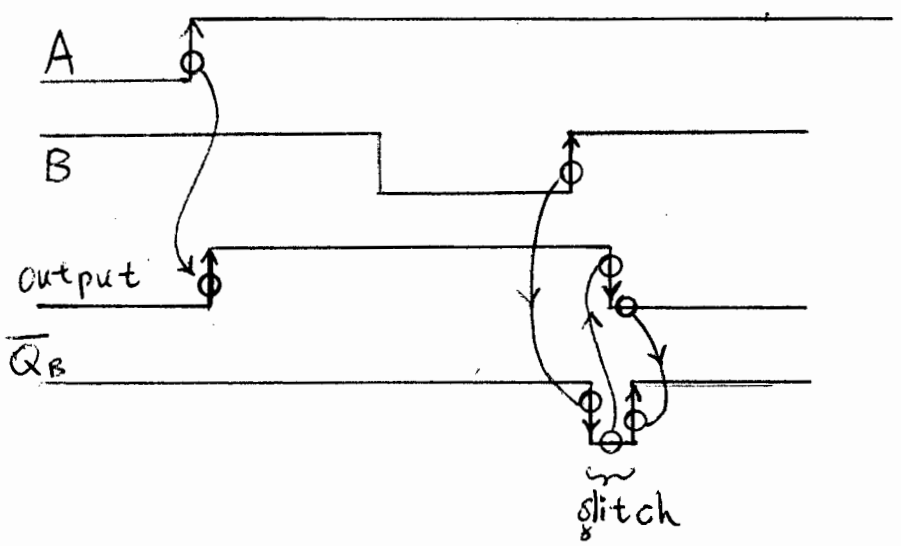


Fig. 4.13 Dual-edge triggered Flip-Flop (DET FF)

plus the time it takes for FFA to clear. Since this is about two propagation delay times, FFB creates a glitch of perhaps 40 ns maximum.

5. The positive transition of the line B causes the glitch, which is the setting of FFB.
6. When FFB is set, it causes the clearing of FFA, and when FFA clears, it clears FFB terminating the glitch.
7. In summary, the positive edge of the B line causes the output to rise, and the positive edge of the B line causes the glitch, which causes the output to fall.

4-2-6. Part 5 Sample- and- Hold and Analogue- to- Digital Convertor (ADC).

It is necessary to locate a sample and hold device LF398 in front of an analogue to digital convertor, even if the ADC has a very fast conversion speed. Its function is to hold the input signal constant for the duration of the sampling of the ADC . It has a storage capacitor to store the input signal value and also to smooth very short spikes which are fatal to the accuracy of an ADC. A small value of storage capacitor is preferable for high sample rate applications and the capacitor used should have a very low loss. Polyethylene type capacitors are employed. The sample and hold device has a FET type input with a very high input impedance to prevent the leakage of charge from the storage capacitor. It should also have a fast slew rate to follow the change of input signal during sampling. Access times also need

to be short for high speed applications.

The ADC was based on a 12-bit successive approximation register 74C905, a fast analogue comparator LM361 and a R-2R resistor ladder. A homemade ADC system was used instead of a commercially available one, because high speed 12-bit ADCs are expensive and the cheap ones are too slow [31]. If there are enough funds, a commercially available fast ADC should be employed to ensure the accuracy of the measurement.

The principle of the successive approximation type ADC will not be discussed further here. There is extensive literature concerning data conversion and acquisition which explains in detail how such ADC 's work.

In order to drive the 12-bit 50K/100K resistor ladder network and achieve + or - 1/2 LSB resolution, two cmos 74HC244 chips [30] are used as buffers. The power supply of the 74HC244 is regulated. Fig. 4.14 and Fig. 4.15 show the ADC system and its timing diagram respectively.

The successive approximation register has such inputs as a clock line, a start line ($\overline{S}$) and a data line (D) . The outputs are data lines D0 to D11 and a conversion complete line ($\overline{CC}$) .

The operation clock frequency, derived from the 15 MHz of the clock generator of the microprocessor, is 1.25 MHz, (15/12 = 1.25) .

The sampling rate is 13.2 μS. In 20 ms, the ADC can take 1470 samples. According to Sharon's Theorem the minimum sampling frequency should be 2*25*50 Hz = 2.5 KHz. By increasing the sampling frequency a more accurate result of measurement is

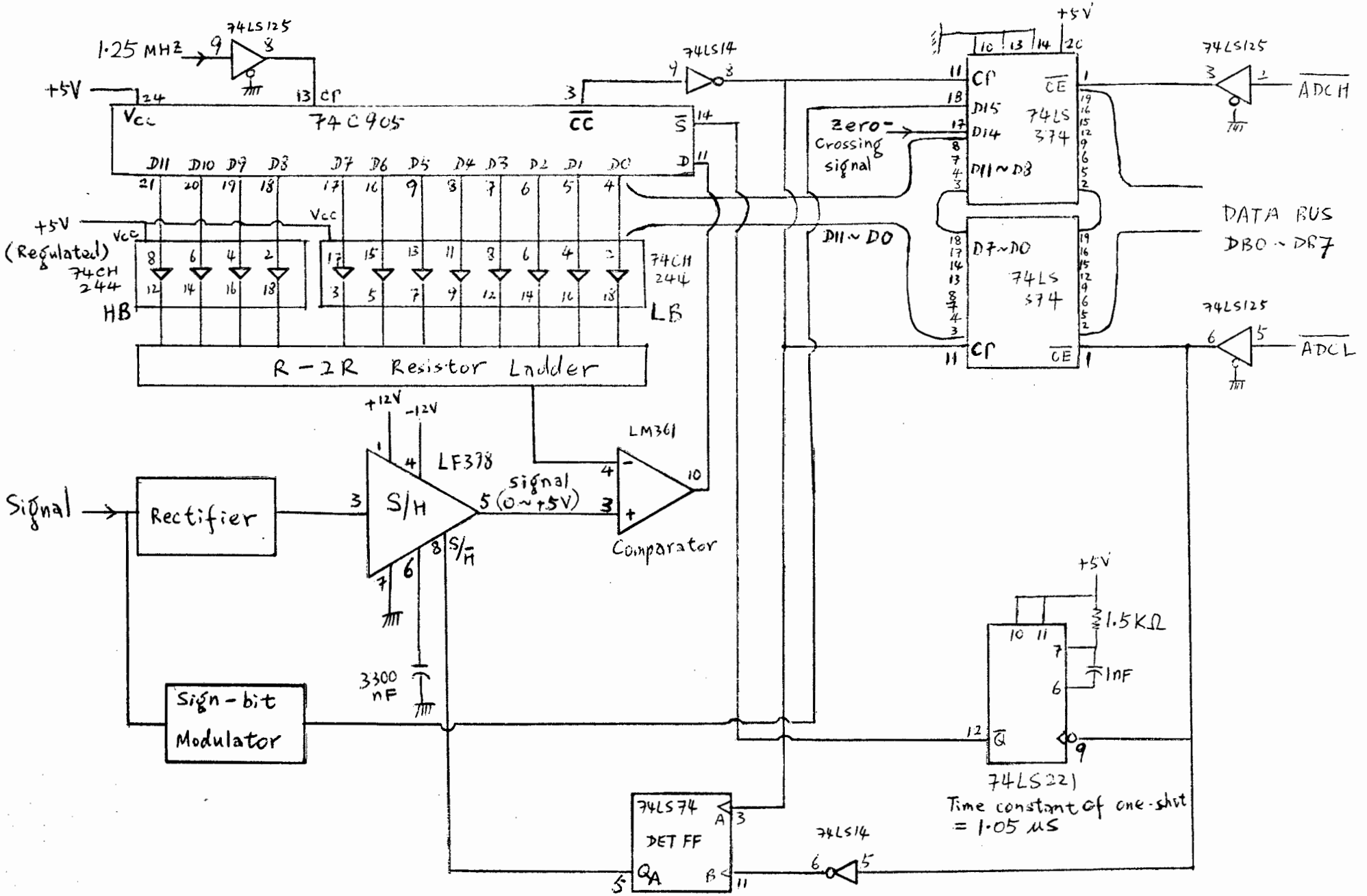


Fig. 4.14 Analogue-to-Digital Convertor system

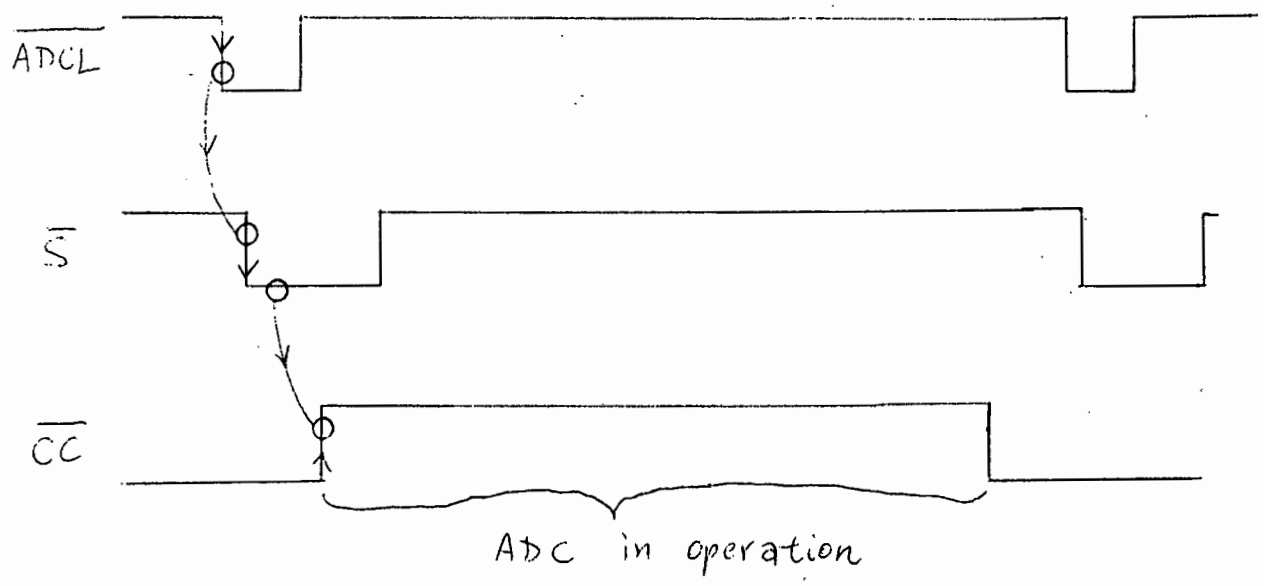


Fig. 4.15 Timing diagram of ADC.

obtained. It should be realized that the settling time of the ADC must be less than the sampling time between two successive samples.

The $\overline{ADCL}$ line feeds the one- shot circuit to create the $\overline{S}$ signal of the ADC which starts at the rising edge of $\overline{ADCL}$ and ends after one operational clock period of the ADC.

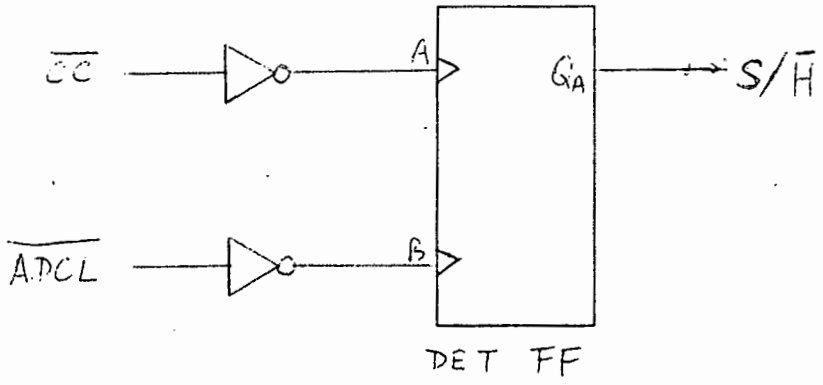
Both the CC and ADCL signals feed a DET FF to set up the control logic input ($S/\overline{H}$) of the sample- and- hold device. Fig. 4.16 shows the circuit and timing diagram.

During the period between the rising edges of control signals "ADCL" and "CC" , the sample- and- hold device operates in hold mode and the rest time in sample mode.

$\overline{S}$ is derived from a monostable with a period of 1.05 μS, which ensures that $\overline{S}$ is held in the 0 state for at least one operational clock period of the ADC, this being necessary to initiate a conversion. The monostable is triggered when the low byte of the ADC is read, and the sample- and- hold device is switched to hold mode, ready for the next conversion. The data input (D) comes from the output of the comparator. The conversion complete output ($\overline{CC}$) goes high whenever the conversion begins and remains at the 1 state during a conversion.

After a maximum of 13 cycles it goes to the 0 state and the conversion is complete. This latches the data outputs into two eight- bit latches to be read by the microprocessor. It also switches the sample- and- hold device back to sample mode.

When the microprocessor reads the 16- bit port ADCP, the chip select line for the ADC (from decoder 74LS138) goes low. This,



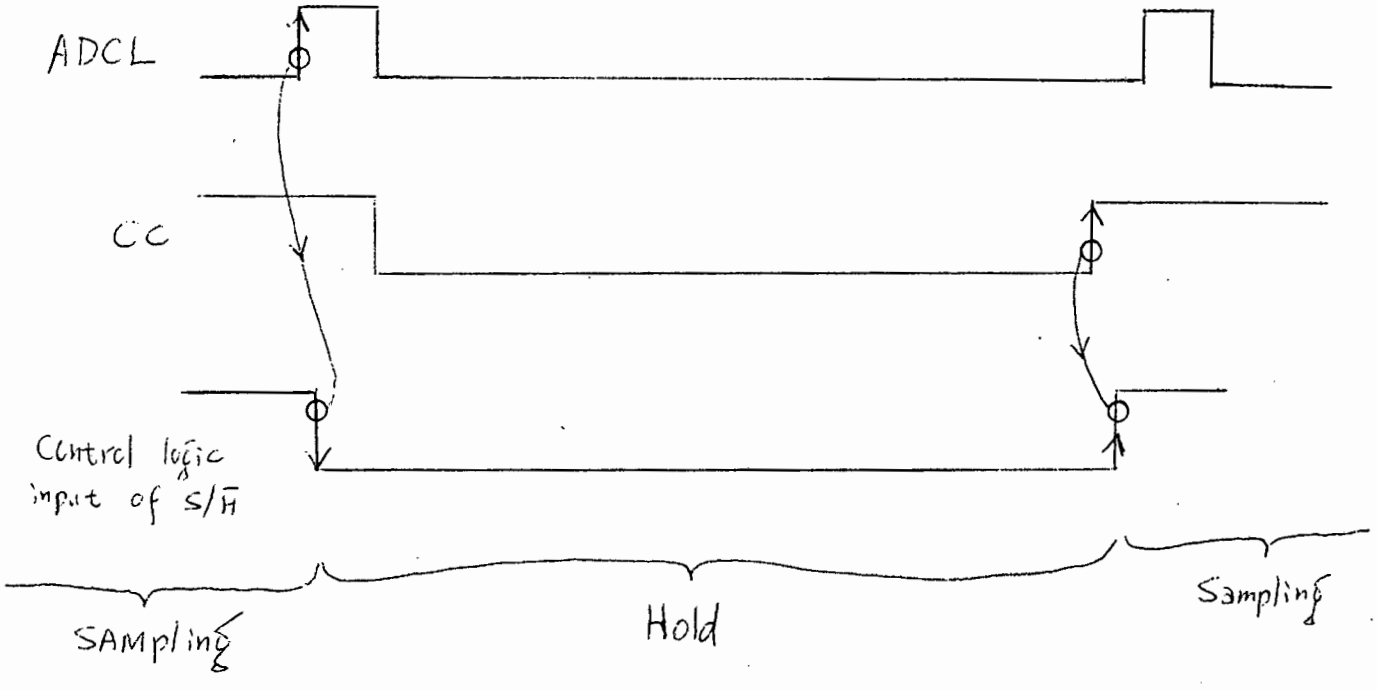


Fig. 4.16 Controlling circuit of S/$\bar{H}$ device and its timing diagram.

together with the read strobe and A0 being low, generates $\overline{ADCL}$, which enables the low byte from the latch onto the data bus. The microprocessor then issues a second read with A0 high to read the second byte. This ensures $\overline{ADCH}$ to go low, allowing the second latch to put the high byte onto the data bus.

Fig. 4.17 shows its circuit and timing diagram.

Only 5 bits of the MSB are used to represent the input signal in digital form, i.e. D8 to D11 and D15. D12 to D13 are permanently tied to ground and D14 is tied to the zero- crossing detector's output. In other words D14 is used as a semaphore to show when the zero crossing occurs.

D15 is the sign bit of the data which is generated from the sign-bit modulator. If it is low, the data is positive; if high, the data is negative.

The input signal of the ADC cannot go beyond the range of 0 to 5 volts, because the ADC operates only within these limits.

A.C. input signals have to be rectified before they can be fed to the ADC. The rectifying circuit is exactly the same as the one used as the modulating clock generator. Fig. 4.18 shows the circuit. Referring to Fig. 4.18, whenever the input signal is positive, the output of comparator LM319 goes high. This switches off the switch IH5052, so the output signal follows the input signal. Whenever the input signal is negative, the output of LM319 goes low to turn on the switch, so that the circuit has a gain of -1, rectifying the signal.

Data expressed in this form is better than in 2's complement form because it gains one more bit, i.e. 13-bit accuracy.

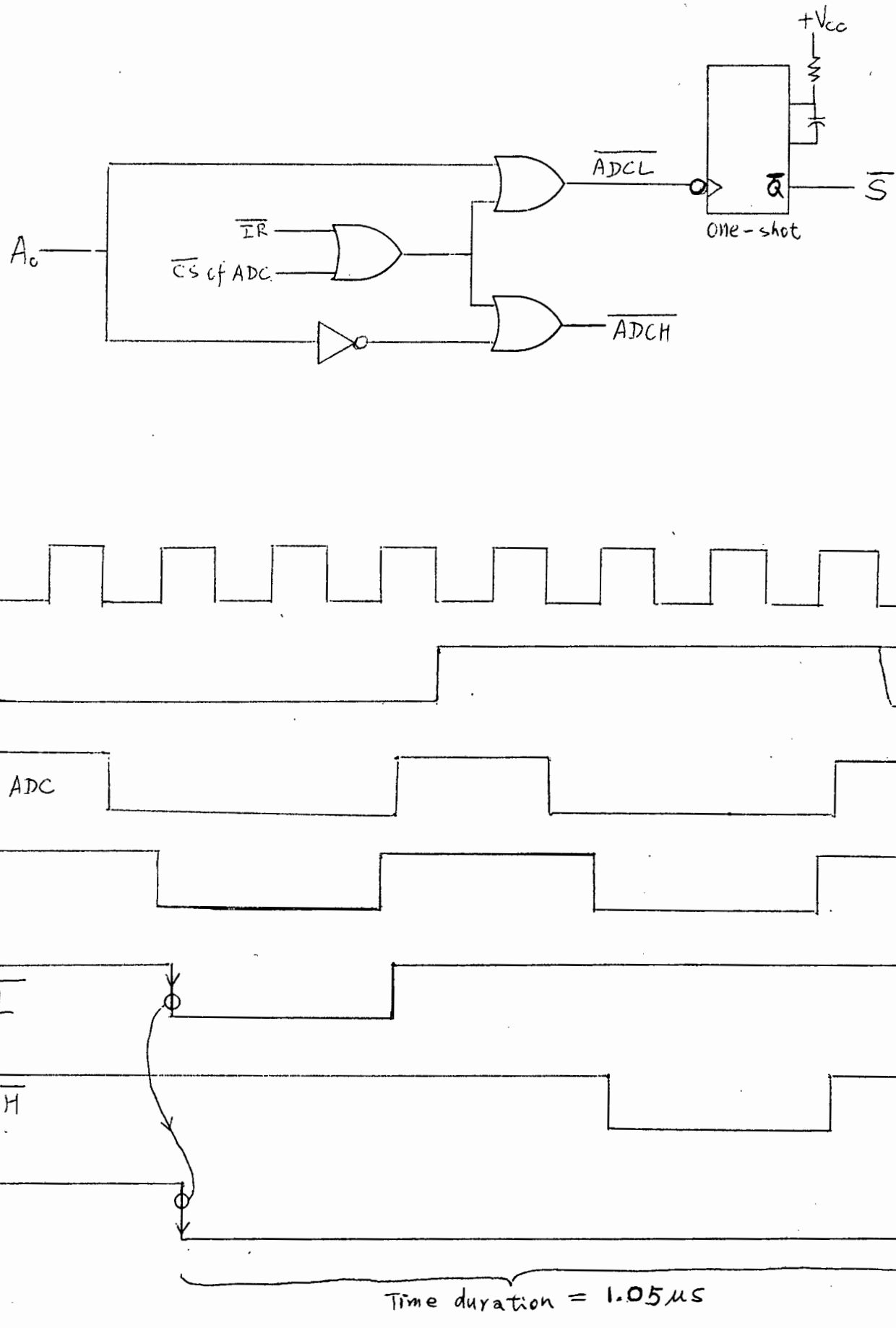


Fig. 4.17 Circuit diagram of signals $\overline{ADCL}$, $\overline{ADCH}$, $\overline{S}$ and their timing diagram.

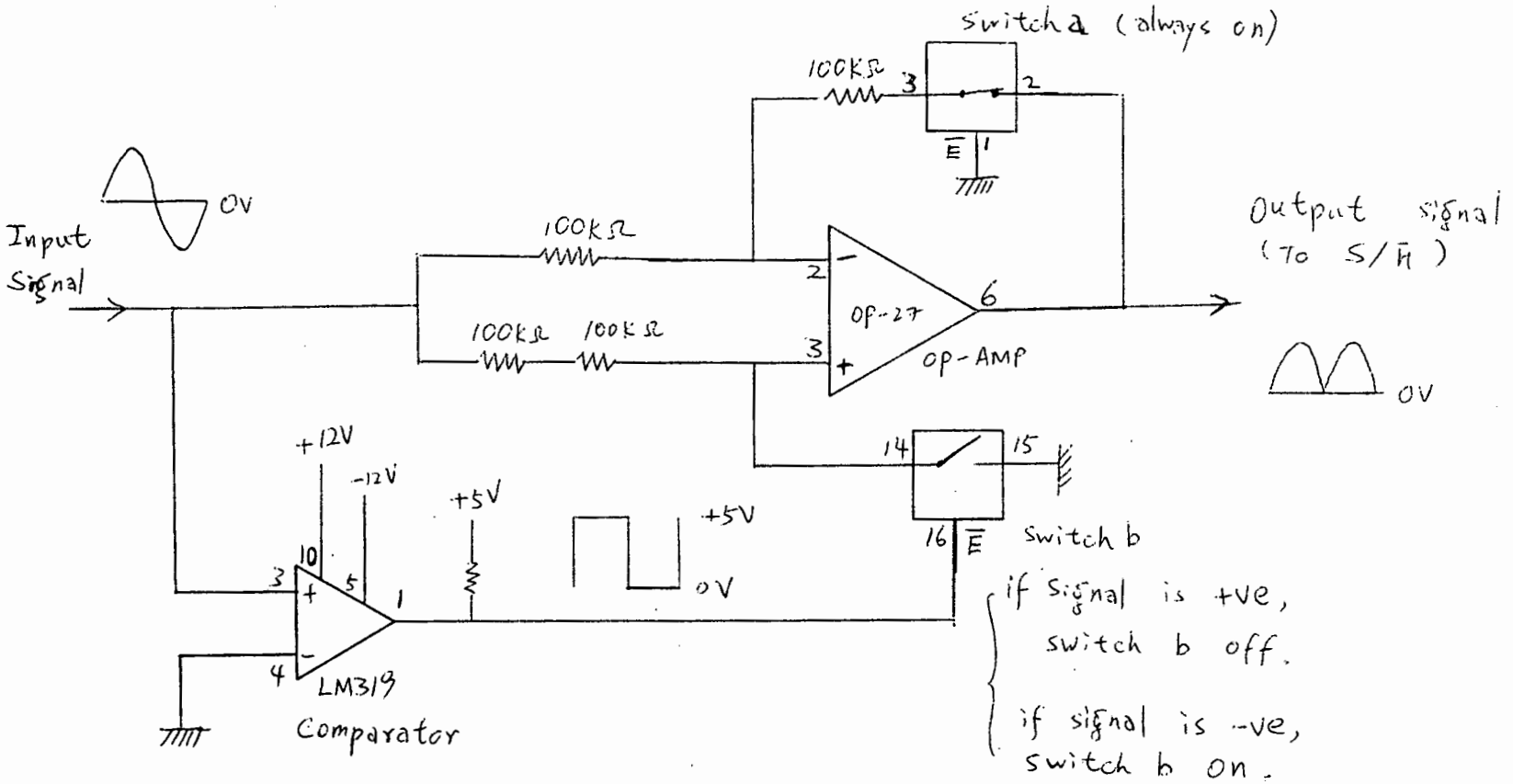


Fig. 4.18 Rectifier circuit

Thus, depending on the sign- bit, the input signal is modulated in software, which is faster than the traditional hardware modulator.

4-2-7. Part 6 Microprocessor unit.

The microprocessor is the central unit of the system. It links all other units of the system through its data, address and control lines. The micropocessor unit includes input-output ports, memory and control logic.

In order to facilitate the arithmetic processing, eliminate the requirements for writing long software routines and accelerate the measuring time, a hardware numerical processor is desirable. Owing to the economic factor, some algorithms for arithmetic processing has to be developed instead.

The Intel chip 8088 was used as the microprocessor unit of the system because of the microprocessor development facilities for the Intel 8088 available. The Intel MDS III computer, the IBM PC with Microsoft Assembler and the PDP-11 with an 8086 Cross Assembler are good examples.

The Intel functions of the 8088 processor are quite different from its predecessor, the 8085, and circuits designed for the 8085 would not be compatible to the 8088 system. The 8088 has an instruction stream queuing mechanism which is lacking in the 8085. This queuing mechanism allows the 8088 efficient use of bus bandwidth. Whenever there is space for at least 2 bytes in the queue, the bus interface unit of the processor will

attempt a word fetch memory cycle. This greatly reduces dead time on the memory bus. The queue acts as a first-in-first-out buffer, from which the execution unit executes instruction bytes as required. Because of the presence of the queuing mechanism, the address lines of the microprocessor are always busy. This is the most important key point for designing the peripheral interfacing circuits of the 8088.

The chip-select lines ($\overline{CS}$) of the memory and peripherals, including the timer, the ADC and the intrumentation interface controller, come from the address bus. Chip-select lines can stay active until very late in the bus cycle, resulting in bus contention elsewhere in the system. A new chip-select ($\overline{NCS}$) signal needs to be generated, starting at the falling edge of the address latch enable (ALE) control signal of the processor and terminating when either the write ($\overline{WR}$) or read ($\overline{RD}$) control signal goes high. This could easily be implemented with one DET FF.

When the input or output instruction of I/O port is executed by the microprocessor, signal $\overline{S2}$ becomes active. The inverted $\overline{S2}$ together with the falling edge of the ALE causes the DET FF to generate the falling edge of $\overline{NCS}$ of peripherals.

Fig. 4.19 shows the new chip select circuit of peripherals and its timing.

Referring to Fig. 4.19, whenever the $\overline{S2}$ signal is activated, the present cycle accesses an input or output port. The new chip select ($\overline{NCS}$) signal determines the active period of the decoder 74LS138. Address lines A5, A6 and A7 decide which

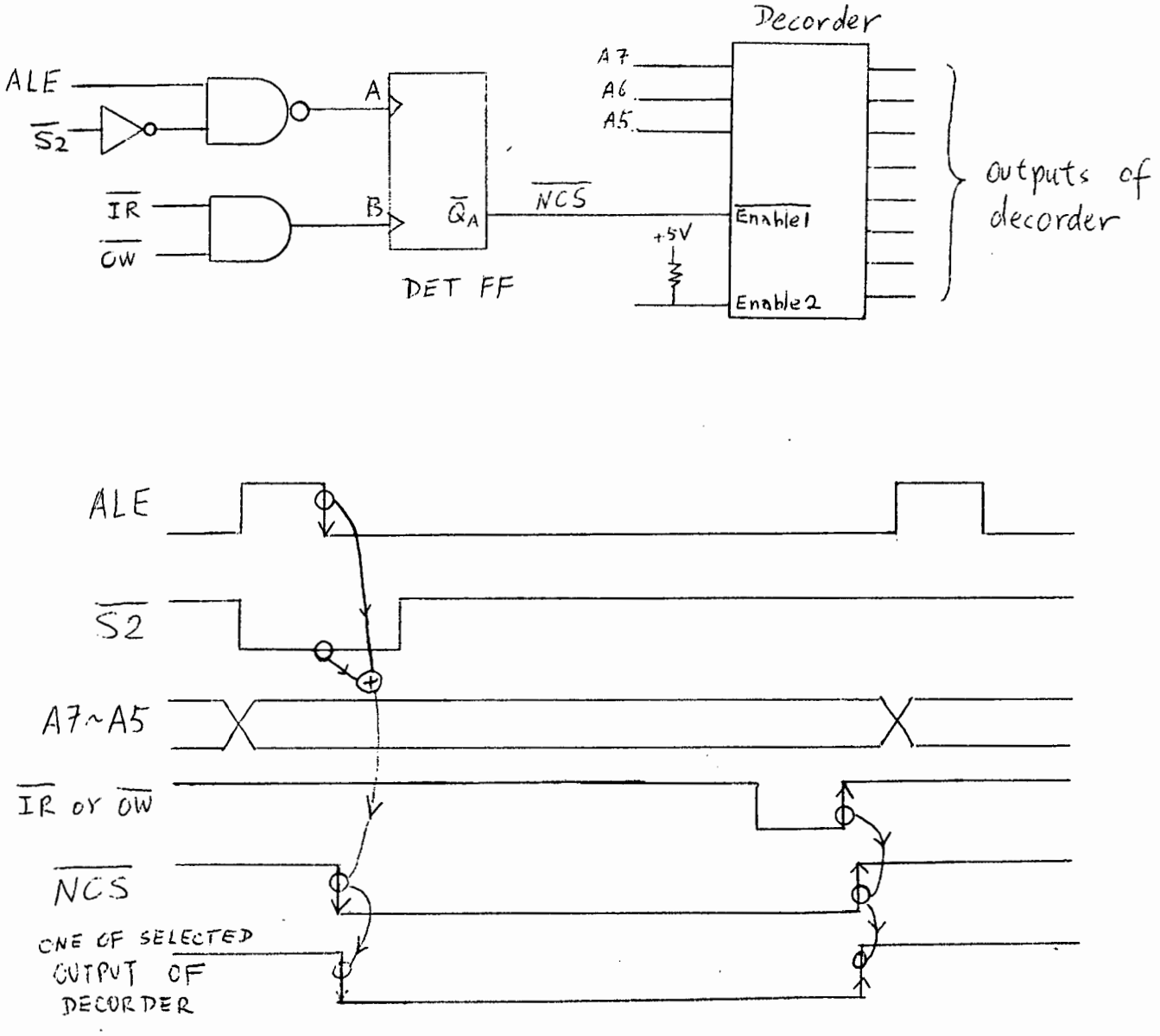


Fig. 4.19 New chip select ($\overline{NCS}$) circuit of non-memory peripherals and its timing diagram.

one of the eight output lines of the decoder which has same duration as $\overline{NCS}$, is to be active. Table 4.1 shows the address of each new chip select line and which chip is activated by the $\overline{NCS}$ line.

Fig. 4.20 shows the new chip select of the erasable programmable read only memory (EPROM) and the timing diagram. The EPROM can be addressed from 0FC000H up to 0FFFFFH, 16K bytes altogether.

Address	new chip select
0E0H to 0FFH	HPIB talker and listener
0C0H to 0DFH	LED and Multiplexer
0A0H to 0BFH	ADC
80H to 9FH	1. Manual switches 1 to 5 decide the maximum order of harmonic to be measured (maximun up to 25th) . 2. Zero-crossing signal
60H to 7FH	Programmable interval timer.
40H to 5FH	Modulating clocks selector.
20H to 3FH	Synchronizing signal for modulating clock.

Table 4.1 Address of each new chip select.

Fig. 4.21 shows the new chip select circuit of random access memory (RAM) and its timing diagram. The RAM can be addressed from 0000H up to 1FFFH; 8K bytes space altogether.

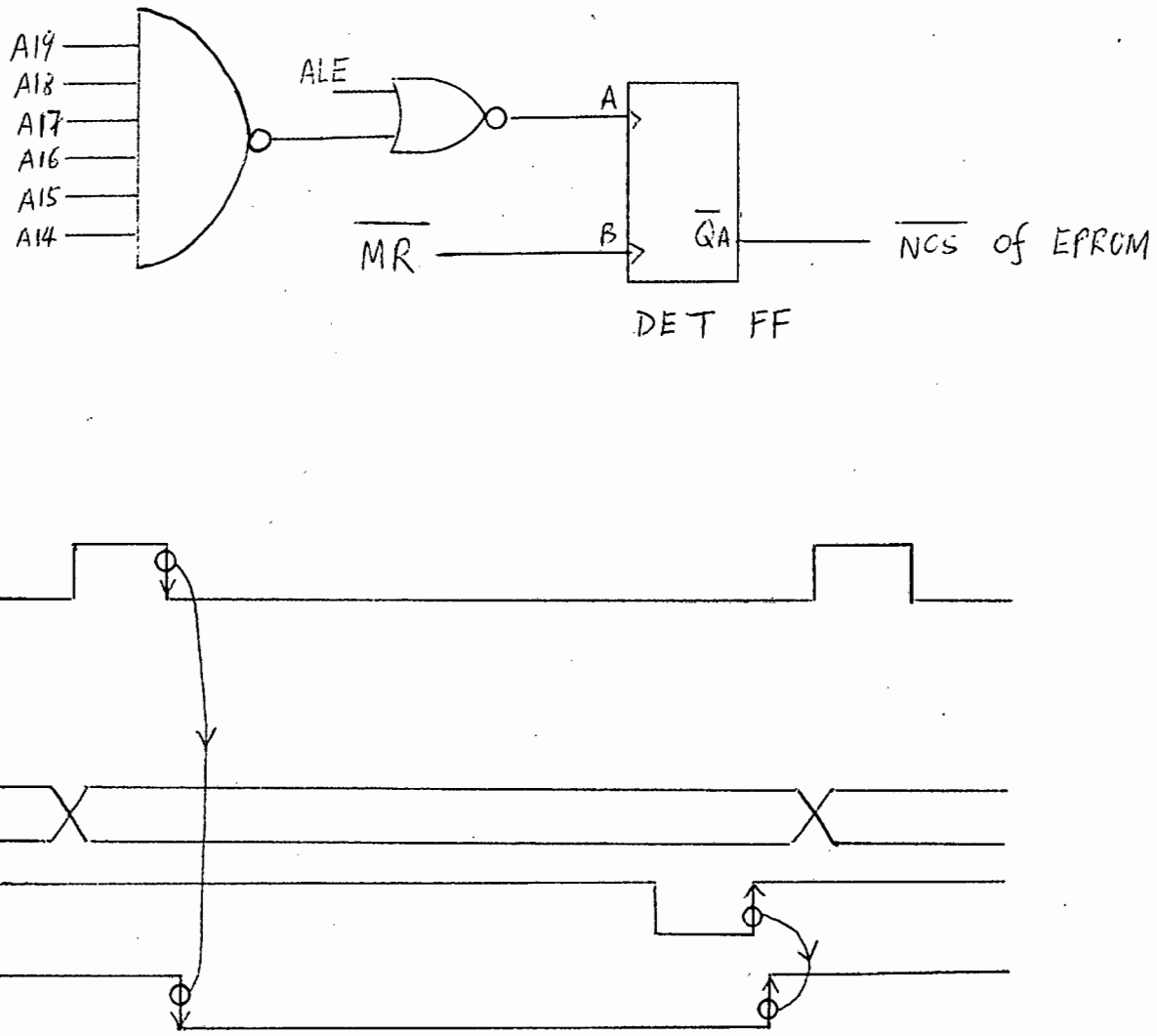


Fig 4.20 New chip select circuit of EPROM and its timing diagram

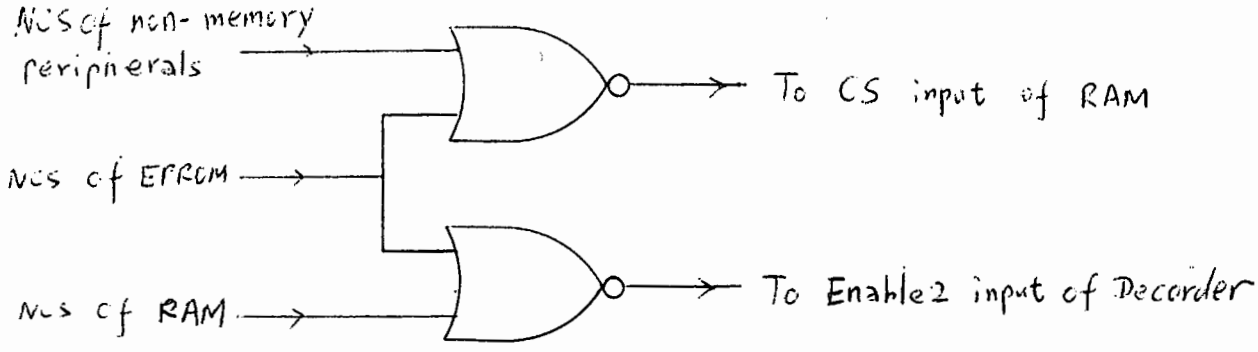


Fig. 4.22 Circuit secures New chip select signals

This signal can be generated with the circuit of Fig. 4.23 . MC68488 also has R/$\overline{W}$ signal line. This signal can be implemented with the circuit of Fig. 4.24 .

According to the specification of the 8088, $\overline{IR}$ and $\overline{OW}$ only last minimumly for 325 ns. On the other hand, the E signal must have a minimum duration of 450 ns. Therefore a wait state generator for the 8088 is needed in order to lengthen the E signal to more than 450 ns duration. Since one wait state can only generate 100 ns extra time, which does not match the specification of the MC68488, a triple wait state generator is employed. Fig. 4.25 and Fig. 4.26 show the triple wait state generator and its timing and state diagrams respectively.

Referring to Fig. 4.26, the system's $\overline{WAIT}$ line is driven low whenever a device requiring three wait states is selected. The flip- flops are cleared when either $\overline{ALE}$ or the $\overline{CS}$ of the GPIA is high, forcing system $\overline{wait}$ line high, which is connected to the RDY1 line of the system clock generator 8284.

If no wait state is required, the flip- flops do not change. If a wait state is required, the CLR pins of the flip- flops are released and the output of the generator toggles on the falling edge of the system clock at the beginning of T2 to force three wait states according to the state diagram of outputs Q1 and Q2 of FF1 and FF2 (Fig. 4.26) . After 3 wait states, the $\overline{WAIT}$ signalis removed, indicating readiness and allowing the completion of the bus cycle. Further changes in the state of the flip flop will not affect the bus cycle. The circuit allows approximately 600 ns for the chip to select, decode and

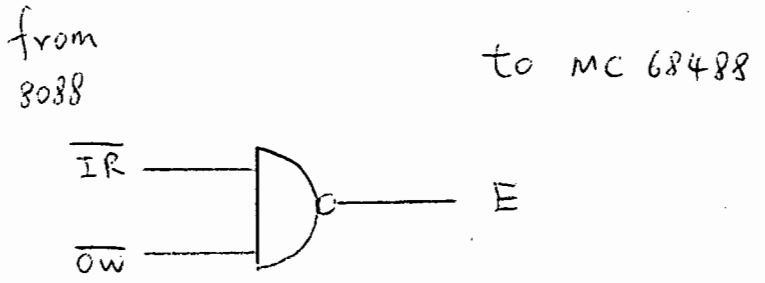


Fig 4.23 E signal circuit

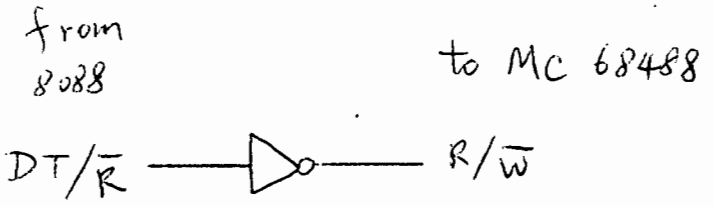


Fig. 4.24 R/W signal circuit

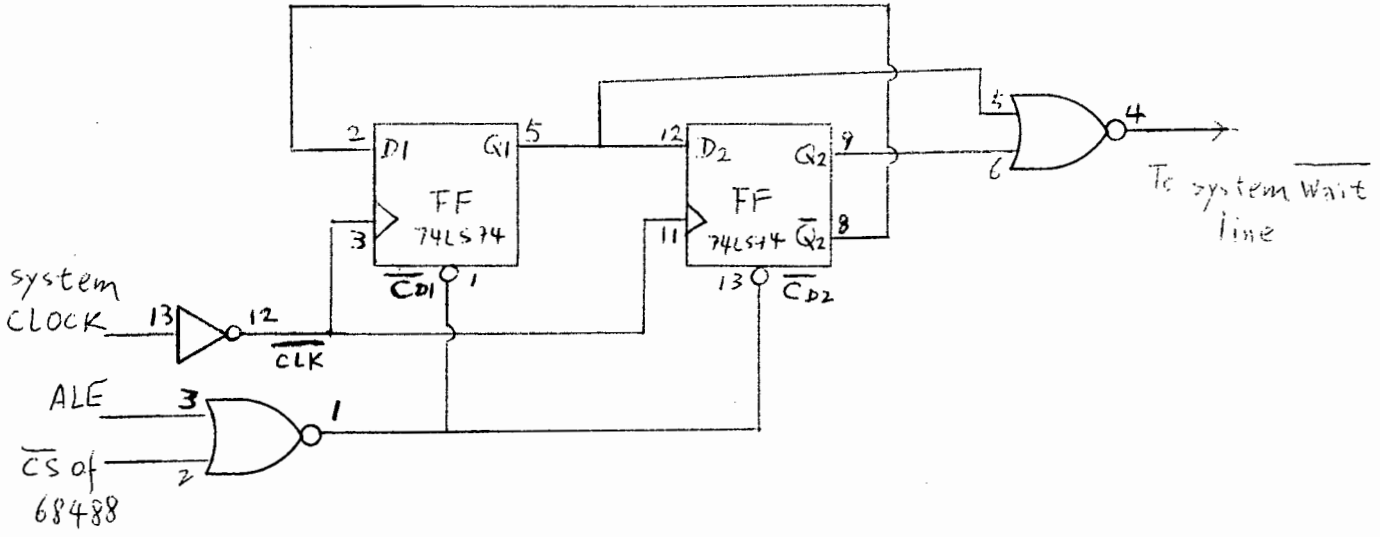
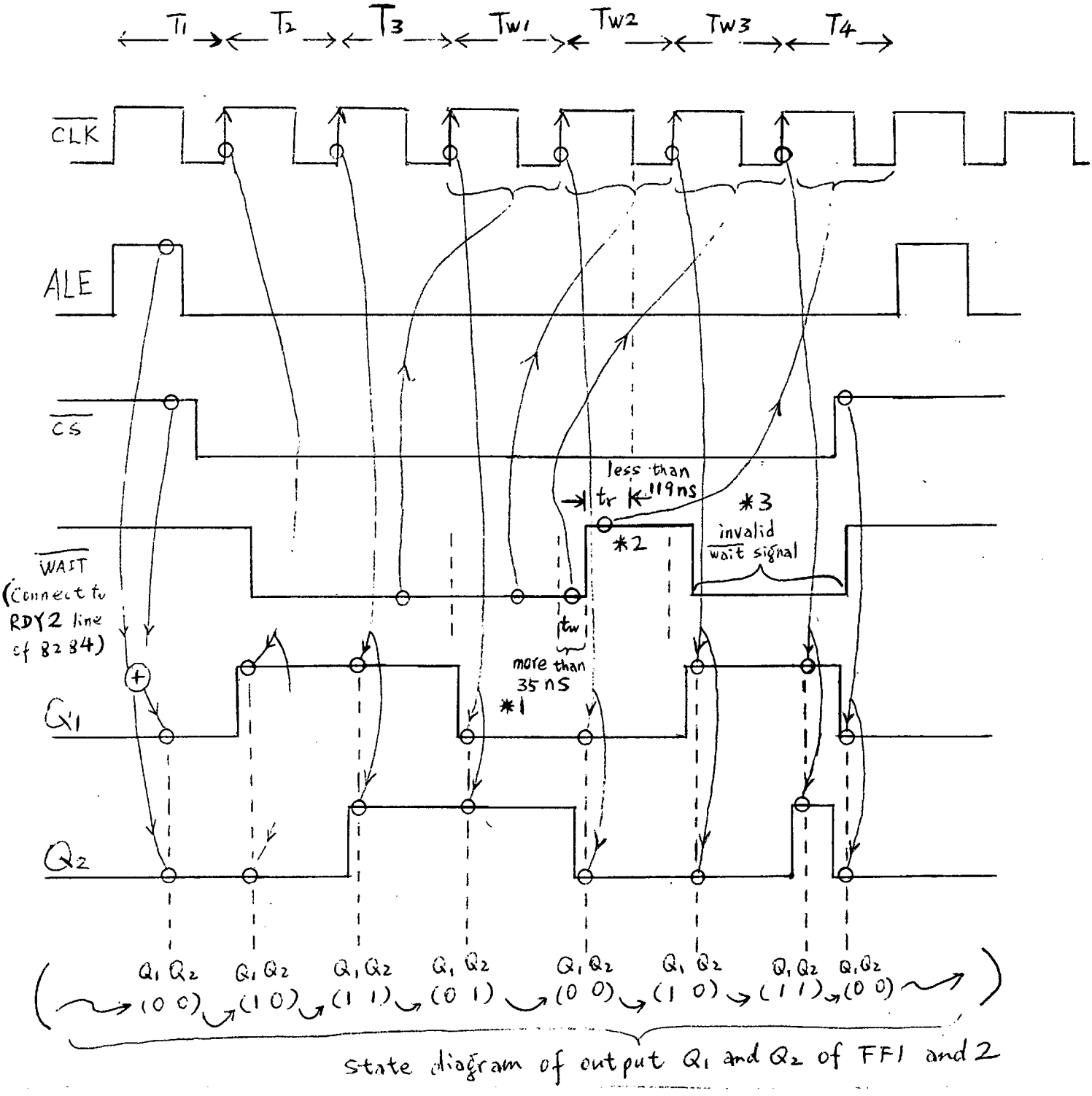


Fig. 4.25 Circuitry of Triple Wait-state Generator



According to the Specification of 8284 :

*1. One wait state Tw3 sets up because tw > 35 ns .

*2. T4 cannot be issued after Tw2 because of tw > 35 ns and tr < 119 ns , instead T4 is issued after Tw3 .

*3. This $\overline{\text{wait}}$ signal is invalid and ignored by 8284 because it is not issued by the end of T2 or start of T3 .

Fig. 4.26 Timing and state diagrams of Triple Wait - State Generator

condition the system's ready signal.

4-2-9. Part B Microcomputer.

The purpose of using a microcomputer (HP 85) is mostly for scaling the raw results and expressing them in symmetrical components, then to utilize its screen and printer to display the results. It is also used as a controller to control other potential instruments running in parallel with the system by means of its instrumentation interface.

4-2-10. Overall operation.

Finally, consider the overall action of the system. After passing through the scaling circuit, the input signal from Va goes into the reference clock generator. The reference clock generator recovers the fundamental of the input signal in the form of a clean and well defined rectangular wave. This signal is then fed to the input port of the microprocessor. The microprocessor always polls the input-port to see whether the input rectangular wave changes from a low state to a high state. If this happens, the microprocessor immediately sends out a signal from its output port to the modulating clock generators in order to synchronize the reference clock. There will be a phase shift between the reference clock and modulating clock, caused by the time gap between the time when the microprocessor catches the change of state of reference clock and when the

microprocessor issues a synchronizing signal. This phase shift will be negligible if the polling frequency of the microprocessor is very much higher than the frequency of the reference clock. The modulating clock signal feeds the sign- bit modulator and modulates one of the six input channels of the analogue multiplexer which is selected by the microprocessor cyclically, in order to generate the sign-bit for the ADC. The output of the buffered multiplexer is fed to the sample and hold device and then the ADC. The sample and hold samples the input analogue signal at a specified time and then holds this value until it takes the next sample point. The ADC converts the analogue values held in the sample and hold into digital code and then feeds it to the input port of the microprocessor. The microprocessor fetches the data from the ADC and then processes it according to the program stored in the memory. The microprocessor deals with each input channel for one cycle of fundamental period time and then switches to the next channel until all six channels have been served. After serving all six input channels, the microprocessor continues to calculate all the required data and then passes it to the instrumentation interface. The microcomputer picks up the data from the instrumentation interface and then multiplies it by the scaling factors and expresses it in symmetrical components. It then transfers the data to its display unit or uses it for other purposes.

4-2-11. SH-64 Bus.

Because many electronics components are incorporated in the system, it was impossible to fit all the components on one card. The SH-64 bus was utilized to help the distribution of the components onto several cards. The assignment of the function of every line is shown in Appendix [A]. One of the most fatal disadvantages of the SH-64 bus is its backplane which has undershoot and ringing transients. All the wires in the backplane behave as transmission lines, in which unwanted transients exist.

Several attempts were made to eliminate these transients and the following conclusions obtained.

1. All the input and output lines of each card have to be secured by the drivers or buffers.
2. The 74ALS or 74F series of TTL drivers and buffers are highly recommended, because the 74ALS and 74F series IC's outputs include clamping diodes to limit undershoot and control ringing on long signal lines. As with the input diode clamps, these diodes are intended for transient suppression [35] .
3. Deploy active terminators at both ends of the backplane.

4-2-12. Layout of circuitry.

The system has been constructed using a modular approach. Each module resides on a standard Eurocard, 100 mm by 220 mm. These

cards then plug into an SH_64 backplane using a rack mounting system . There are three cards in the system: Card A, Card B and Card C.

Card A contains all analogue circuits and the ADC .

Card B contains the microprocessor, memory, counter and control circuits.

Card C contains the IEEE-488 interface and digital phase shifter circuits.

These individual circuit diagrams are appended in Appendix B.

CHAPTER FIVE

It is important to note that probably no large operating system using current design technology can withstand a determined and well-coordinated attack, and that most such documented penetrations have been remarkably easy.

B. Hebbard et al.

It is necessary to point out that there is almost no writings composed in non-parent language of the author which is not subject to criticism if any defect therein is purposively sought.

Kwan Leung Shum

5 SOFTWARE

5.1. The procedure of developing an operating system for the instrument .

The operating system of the instrument was developed using the editing, assembling and in-circuit emulation facilities of Intel's Microprocessor Development Series III System (MDS-III) . This system allows easy and rapid development and debugging of assembly language (ASM 86) programs, the language used for writing the operating system of the instrument . Each routine is created as a file using the editor called "Alter" of the MDS-III . The editor creates what is known as a source code, which must then be assembled by ASSEMBLER_86 to form the microprocessor compatible machine code of 8088. The MDS_III linker program called "LINK 86" is then use to link all the routines together without assigning absolute addresses. All the routines are now specified at relocatable addresses and are ready to be debugged using the in-circuit- emulator (ICE_86) facilities. These are particularly powerful facilities which allow users to trace the execution of a program, thus allowing programming errors to be located and corrected. Perhaps more important is that this can be done using combination of the MDS-III hardware features and/or the hardware of the instrument being developed. Thus the software can be initially tested using MDS-III hardware only. As more of the system hardware is developed, so it is incorporated into the test

procedure, thereby ensuring that all testing and debugging is carried out on a unit as close to the final product as possible. After the debugging procedure, a system program of the MDS-III called "LOC 86" is employed to locate the software at absolute addresses. Another system program of MDS_III called "OH 86" is used to convert the binary absolute object module into Intel's standard hexadecimal format. This hexadecimal file is then transferred to the host computer (PDP-11/23) . Unfortunately, the Intel's standard hexadecimal format is not used by the EPROM programmer, which is connected to the PDP-11/23 . Therefore, a system program on the PDP-11/23 called "CON" is used to convert it into compatible form . The final step is to down-load the compatible hexadecimal code developed in PDP-11/23 to the EPROM programmer and program the code into the EPROM .

5-2. The operating system.

The operating system controls all the functions of the harmonic analyser. There are two diagrams of concern. The first is Fig. 5.1 which is the flowchart outling the operating system. Fig. 5.2 shows the priority of the various procedures and nesting procedures and where they fit into the overall operating system and the sequence in which they are called.

The program listing of the operating system in the Appendix C includes comments for the purpose of demonstrating the function of each section of the code.

It must be stressed that the software currently used was composed

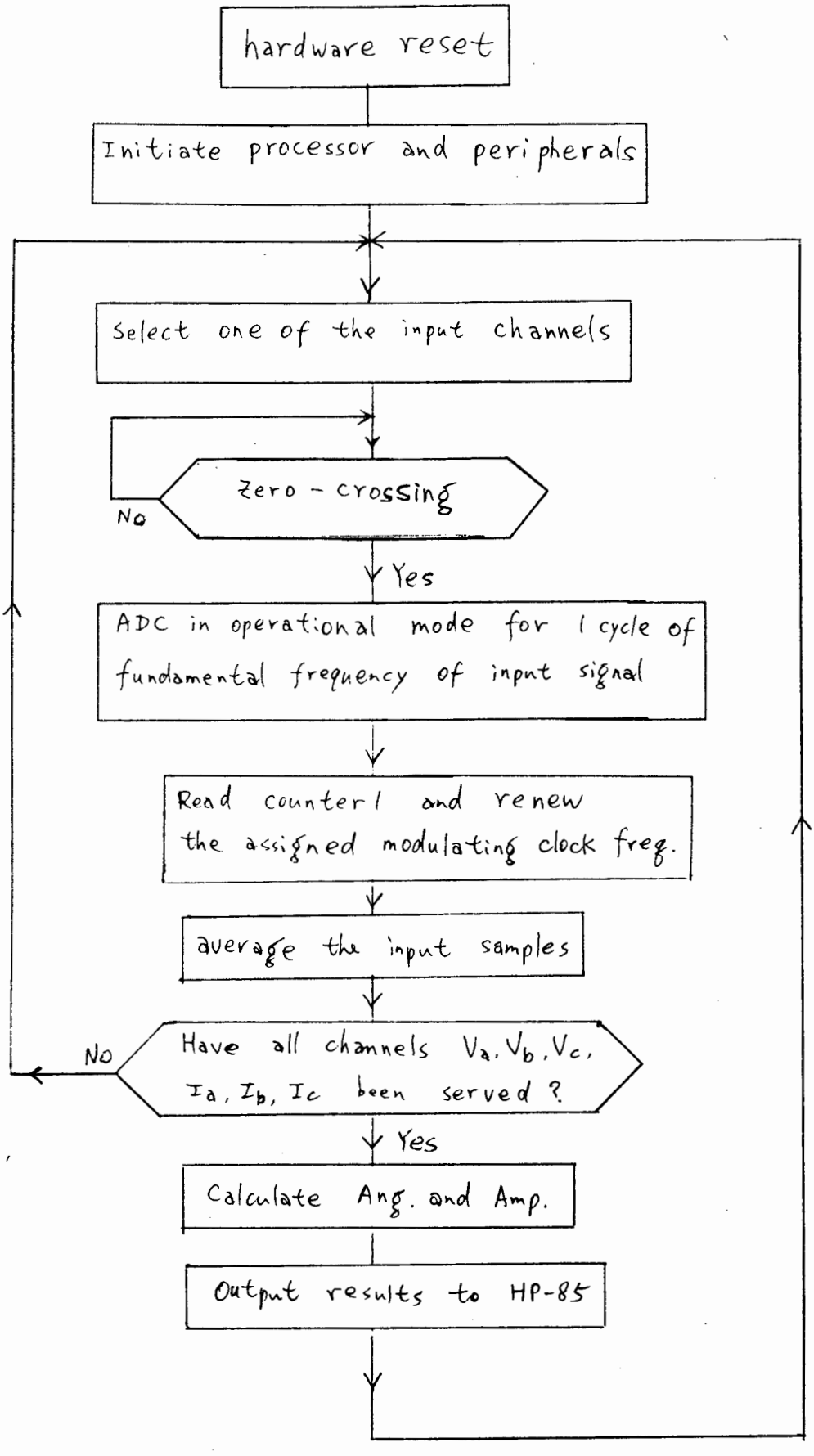


Fig 5.1 Flowchart of the operating system.

BEGIN		
	MOD_CLK_SYN	
	MOD_CLK_UPDATE	
	DUMMY_READ	
		ZC_ADC
		MOD_CLK_UPDATE_1
	ZC_ADC	
	MOD_CLK_UPDATE_1	
	AVERAGING	
		LED
	ZC_ADC	
	MOD_CLK_UPDATE_1	
	AVERAGING	
	MOD_CLK_UPDATE_1	
	THREE_7_8	
		DEHA
	THREE_7_7	
		DEHA
	THREE_7_6	
		DEHA
	THREE_7_5	
		DEHA
	THREE_7_4	
		DEHA
	THREE_7_3	
		DEHA
	THREE_7_2	
		DEHA
	THREE_7_1	
		DEHA
	DIV_32	
	SROOT	
		QUE
		QUE
	DIV_32	
	FANG	
	GPIB	
	GPIB	
	GPIB1	

Fig. 5.2 Order of Execution of the Procedure of Operating System.
(Read from the left and down).

with the objective of achieving maximum speed because real- time signal processing speed is required.

5-2-1. Initialization.

The operating system was divided into 8 parts, Part 0 to Part 7. Part 0 consists of the "SAMP" segment, "ATCS" segment and "STACK_SEG" segment.

The "SAMP" segment sets up the storage area for the temporary data and scratch pad registers.

The "ATCS" segment stores the whole arc_cosine look_up table.

The "STACK_SEG" segment preserves the memory space for the system stack.

5-2-2. The operation of the software.

Following a hardware reset program, which is inside the "RES" segment located at the end of the program, execution is transferred to the "BEGIN" procedure. The "BEGIN" is the main procedure which is divided into seven parts, parts 1 to 7.

<1> Part 1 starts the code segment and defines the addresses of all the I/O ports, and initialises all the segment registers and stacks.

<2> In Part 2 the microprocessor turns off the overflow LED and selects channel 6 which accesses Va as the first channel to be processed. Counter 0 and counter 1 are then initialised. It selects the 0_deg. phase modulating clock to modulate the input signal. The microprocessor then reads the external switch port

"SWP" , which must be set manually before the program commences in order to determine the maximum order of harmonics (from 1 to 25) to be measured. Counter 0 of the chip 8254 provides the modulating clock to the sign- bit modulator. This is initially set to 50 Hz. Once the measuring process starts the counter assigned frequency is updated to a new harmonic frequency before the microprocessor commences to process the new channel during the measurement.

Procedure "MOD_CLK_SYN" is then called. This procedure polls the ZC port until the fundamental filtered zero_crossing (ZC) signal is detected. When this is completed it synchronizes the modulating clock by reseting counter 0.

Procedure "MOD_CLK_UPDATE" is now called and polls the ZC port until the ZC signal is again detected (i.e. one fundamental cycle later) .

The value of counter 1 is read. This value is decremented until one fundamental cycle has passed. This value is used to update counter 0, which generates the modulating clock.

Procedure "DUMMY_READ" is now executed; this is a pilot procedure which leads the ADC into the normal operation. The channel pointer (R6) is initialised with channel 6 which accesses Va.

The microprocessor now calls procedure "ZC_ADC" with a zero degree phase shift modulating clock. This procedure lets the CPU first poll the ZC port until the rising edge of ZC signal is detected after which the analogue- to- digital convertor (ADC) starts converting the analogue signal into the digital form. The microprocessor stores the samples in the memory for one

period of the zero_crossing signal, and then checks each sample to determine whether its value is out of the 0 to 5V range. If it is, the CPU lights the LED to show the overflow status of the input signal. While checking overflow operation, the CPU also modulates each sample according to its sign_ bit, D15, which comes from the sign_bit modulator. If the D15 contains "0" , the CPU will not change the sample, which means the sample is multiplied by one. If the D15 contains "1" , the CPU will convert the sample into 2's complement form, which means the sample is multiplied by negative one. After modulating all samples, the CPU sums them up and then averages them by dividing the summation value with the total number of samples involved in the summation. After averaging, the mean level values of output $_{0}U_{k}$ and $_{90}U_{K}$ are obtained. The $_{0}U_{K}$ and $_{90}U_{K}$ are obtained by modulating at 0_ and 90_ degree phase shift reference clock respectively. The $_{0}U_{K}$ and $_{90}U_{k}$ are then stored at address XY in memory.

The ADC does have offset error which must be eliminated by the following procedure :

Let Pi be the absolute value of sample with +ve sign-bit .

Let Qj be the absolute value of sample with -ve sign-bit .

Let Ri and Rj be the absolute values of offset error of the ADC,

$i = 1, 2, \ldots\ldots, M$

$j = 1, 2, \ldots\ldots, N$

$k = i + j$

where k is the total number of input samples in one fundamental period.

Take approximation, Ri or Rj = R which will be equal to the minimum absolute value of samples, i.e. , R = Min (Pi or Qj).

Sum of samples = Summation [(+Pi + Ri)] + Summation [(-Qj - Rj)]

= Summation [Pi] - Summation [Qj] + (M-N)*R

Therefore,

Summation [Pi] + Summation [Qj] = Sum of samples - (M-N)*R

where (M-N) is the difference of the number of samples with +ve and -ve sign bit.

Procedure "MOD_CLK_UPDATE_1" is called and counter 0 generates modulating clock with its assigned harmonic frequency. This assigned frequency is stored in register R14. The microprocessor chooses the 90_deg. phase shift modulating clock before modulating the input signal so that the modulating clock can have longer time to stabilise.

Procedure "AVERAGING" is called and checks for overflow of input signal and modulates samples with gain +1 or -1 according to sign-bit. It also eliminates the offset error according to the method described above in the "ZC_ADC" .

Procedures "ZC_ADC" and "MOD_CLK_UPDATE_1" are again called but at a 90_deg. phase shift modulating clock. The next channel (i.e. channel 5) is then selected.

Procedure "AVERAGING" is again called to process those samples derived at the 90_deg. phase modulating clock.

The whole cycle is then repeated. This cycle is repeated for each channel (channel 6 down to channel 1, each with two sets of data, one at 0_degree and the other 90_degree phase shift

modulating clock) .

After all six channels have been accessed the contents of register R14 is decreased by one. It is then checked to see if it is zero. If not, the cycle is repeated using the new harmonic frequency. If it is zero then Part 3 is started.

<3> Part 3 processes equation set (3.7) and is programmed to calculate D.C. terms of $2U_K \cos \theta_K/k(p+1)\pi$ and $2U_K \sin \theta_K/k(p+1)\pi$ in equation (3.7) based on the method described in the section (3-2-3) . Equation (3-7-6) to (3-7-8) each have two D.C. terms. The 2nd term arising from the higher harmonics can be eliminated by dividing equation equations (3.7.18), (3.7.21) and (3.7.24) by a factor of 3 and then substracting them from equations (3.7.6) to (3.7.8) respectively. By repeating the same procedure, those D.C. terms which exist in equation (3.7.1) to (3.7.5) can be eliminated.

The D.C. terms are stored in memory in the following order :

($_0V_{ak}$ $_{90}V_{ak}$

$_0V_{bk}$ $_{90}V_{bk}$

$_0V_{ck}$ $_{90}V_{ck}$

$_0I_{ak}$ $_{90}I_{ak}$

$_0I_{bk}$ $_{90}I_{bk}$

$_0I_{ck}$ $_{90}I_{ck}$)

where subscript k is the order of the harmonic.

The values of D.C. terms are stored in memory, starting with those related to the fundamental and going up to those related to the highest harmonic.

According to the above data structure, each set of values related

to a particular harmonic occupies 12 words (or 24 bytes). This means that the starting address offset of each set of data related to a particular harmonic is a multiple of 24 .

Part 3 processes 8 procedures, namely procedure "THREE_7_8" down to "THREE_7_1" .

Procedure "THREE_7_8" begins by initializing the starting environment for calculating equation (3.7.8) . The microprocessor first reads the switch port (SWP) to determine the maximun order of harmonic that needs to be measured.

If the order of the harmonic is less than or equal to 23, the procedure terminates and returns to the main routine. If it is greater than 23, a factor 3 is stored in register R6. Thereafter the routine DEHA is called and executes the following procedure :

It retrieves the set ($_{0}U_{24}$ $_{90}U_{24}$) and divides it by the content of R6 , which is 3 . It then subtracts the result from set ($_{0}U_{8}$ $_{90}U_{8}$). The new set of results is $2U_8$ COS θ_8/π and $2U_8$ SIN θ_8/π . This set is stored back in ($_{0}U_{8}$ $_{90}U_{8}$). All the results are expressed in the two's complement form.

Procedures "THREE_7_7" down to "THREE_7_1" operate on the same basis, each using a different set of data, a different dividing factor stored in R6 and a different address pointer according to equation set (3.7) .

<4> Part 4 calculates the average input fundamental frequency of 6 channels based on the first 12 input values from counter 1, which are stored in the memory location "ZCC" using the following equation :

FREQ * 10 = 10*12*2.5E6 / SUM [ZCC] ,

where 2.5 is the operational frequency of counter 1 in MHz , 10 a scaling factor and SUM [ZCC] the summation of the first 12 input values.

<5> Part 5 calculates $A_K = \sqrt{X_K^2 + Y_K^2}$ and

$$\theta_K = \text{ARC\_COS} (X_K / A_K) .$$

It also calculates the quadrant of θ_K according to Fig. 3.4 .

It uses procedure "DIV_32" , which is a 32_bit by 32_bit division procedure, using the substract_and_test method.

Another procedure involved is "SROOT" which has a nesting procedure called "QUE" . "SROOT" calculates the square root of a 32_bit binary number involved in the calculation of $\sqrt{X_K^2 + Y_K^2}$. The algorithm of calculating square roots is from an old Chinese formula which is expressed in verse form for decimal numbers modified for binary numbers.

It first divides the 32_bit number into two groups of 16_bit each. The procedure called "QUE" calculates both the most and the least significant words of the data. The result of a square root of a 32_bit number is 16_bit .

After "SROOT" is completed, "DIV_32" is called to work out X_K/A_K. Procedure "FANG" is called to determine the absolute value of θk in binary form. The arc_cosine value (or θ_K) is contained in the DI register. The angle determined is only in the range 0 to 90 degree with scaling factor 10, that is, 0 to 900. Its quadrant has to be established by other procedures. This procedure uses fast searching method to determine the angle from the looking_up table defined in the "ATCS" segment. The

accuracy (resolution) of this look_up table is 0.2 degree. The speed of this procedure using a look_up table inconjunction with a searching technique is much faster than numerical processors. The quadrant of θ_K is determined from the sign of X_K and Y_K according to Fig. (3.4) . θ_K is based on the fundamental scale. On the harmonic scale, $\theta_K = K * \theta_K$. It is important to note that θ_K is always checked and adjusted to an angle between 0 and 360 degree.

<6> Part 6 chooses the angle of the fundamental component of Va as the reference. All angles of the harmonic components, which are sets of data, refer to it. If any angle is larger than 360 degree the microprocessor adjusts the angle to the range of 0 to 360 degree.

<7> Part 7 transfers amplitudes and angles of V_K and I_K from the fundamental up to the assigned harmonic order (maximum 25), to the GPIB bus. The interface address of this instrument is arbitrarily assigned as 9. Procedures "GPIB" and "GPIB1" are called three times in total to transfer three types and sets of data: (1) total number of data that needs to be transferred, (2) fundamental frequency and (3) amplitudes and angles , to the GPIB interface. The GPIB is one of the most complex interface systems. To describe its operation is beyond the scope of this thesis. To understand this routine one needs to consult the data sheet of MC68488 and IEEE_488 bus specification. The whole program will be repeated after the data has been transferred to the interface.

5-3. Software of the microcomputer.

A program called "H7" written in the Basic language runs on an HP85 microcomputer for scaling the raw data of harmonic components from the HPIB, expressing them in symmetrical components and calculating the rms values of output voltage and current of the 3 phases. Fig. 5.3 shows the flowchart of the program. The program listing is appended in Appendix D.

The program first polls the HPIB until it is ready for transferring data. The raw data is then received from the HPIB. The microcomputer then scales the data to obtain the resultant harmonic components of amplitude and angle. After scaling, the resultant components will be printed. Thereafter, the resultant components are relocated in the memory to create the initial circumstances for calculation of symmtrical components ($\bar{U}0$, $\bar{U}+$ and $\bar{U}-$) of each harmonic voltage and current. According to Fortesque's theory [13], $\bar{U}0$, $\bar{U}+$ and $\bar{U}-$ can be calculated as follows :

$$\bar{U}0 = (\bar{U}a + \bar{U}b + \bar{U}c) / 3$$

$$\bar{U}+ = (\bar{U}a + a \bar{U}b + a^2 \bar{U}c) / 3$$

$$\bar{U}- = (\bar{U}a + a^2 \bar{U}b + a \bar{U}c) / 3$$

or,

$$\bar{U}0 = \{ [Ua \cos \theta a + Ub \cos (\theta b) + Uc \cos (\theta c)] + j [Ua \sin \theta a + Ub \sin (\theta b) + Uc \sin (\theta c)] \} / 3$$

$$\bar{U}+ = \{ [Ua \cos \theta a + Ub \cos (120+\theta b) + Uc \cos (240+\theta c)] + j [Ua \sin \theta a + Ub \sin (120+\theta b) + Uc \sin (240+\theta c)] \} / 3$$

$$\bar{U}- = \{ [Ua \cos \theta a + Ub \cos (240+\theta b) + Uc \cos (120+\theta c)] + j [Ua \sin \theta a + Ub \sin (240+\theta b) + Uc \sin (120+\theta c)] \} / 3$$

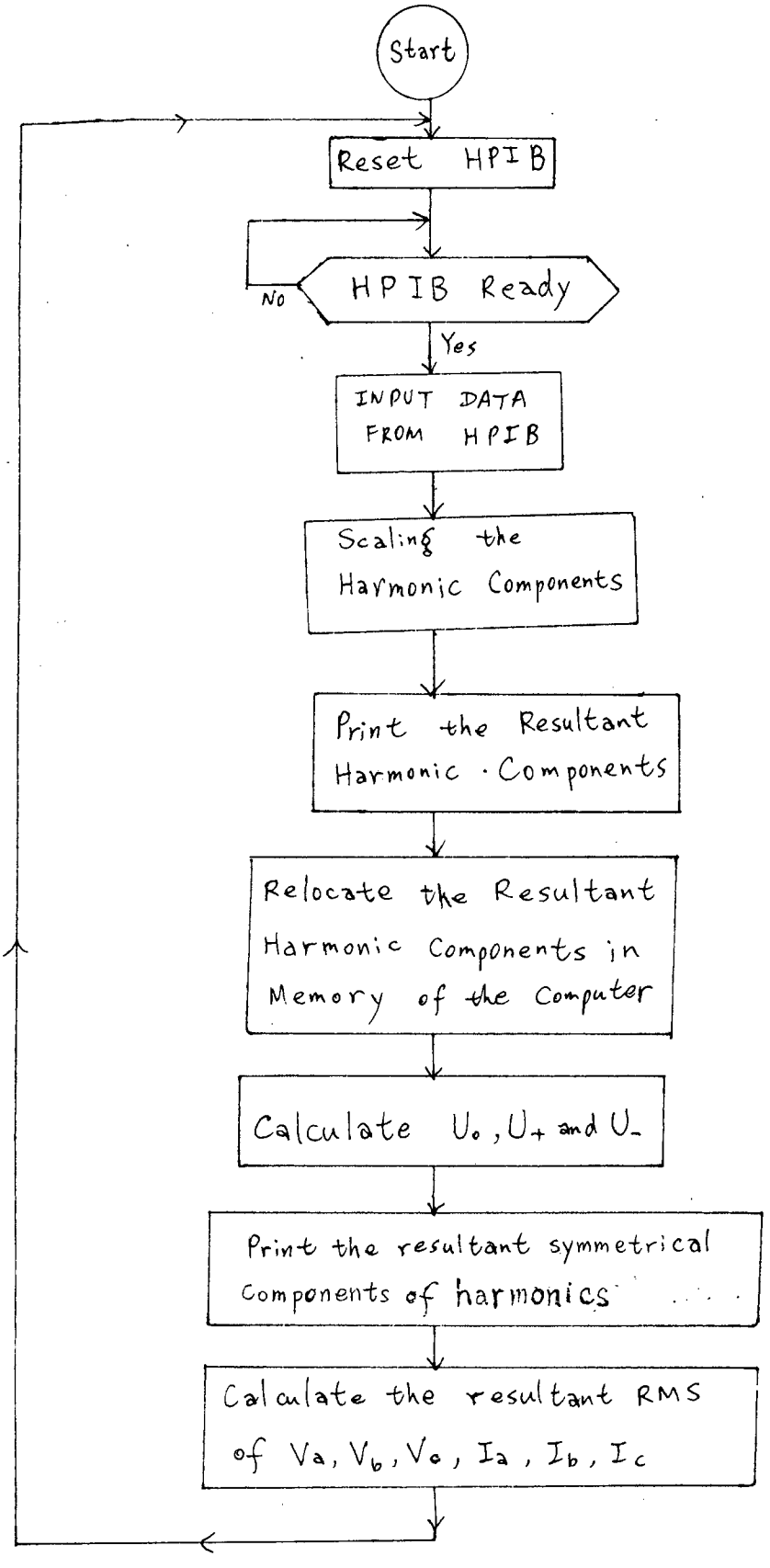


Fig. 5.3 Flowchart of Program "H7".

Referring to the above formula, $\bar{U}a$, $\bar{U}b$ and $\bar{U}c$ are to be considered as sinusoidal steady state and are expressed in notation of the phase voltage or current of three phase systems. Define $\bar{U}i = Ui \angle \theta i$, where i can be a, b or c. $\bar{U}0$, $\bar{U}+$ and $\bar{U}-$ are zero, positive and negative sequence components respectively. The last step of the program is to calculate and print the resultant rms values of Va, Vb, Vc, Ia, Ib and Ic in order to compare them to readings from the analogue meters.

CHAPTER SIX

Nothing ever becomes real till it is experienced _____ even a proverb is no proverb to you till your life has illustrated it.

John Keats

6 RESULTS

The success of a new instrument depends on its ability to measure a given value more accurately, more simply, more cheaply and with more versatility than is allowed by existing equipments. Thus the testing and evaluation is as important as the design and construction of a new instrument.

6-1. Testing Apparatus.

The apparatus employed to evaluate the performance of the harmonic analyser are as follows :

(1) A set-up of three phase synchronous rotating harmonic generators manufactured by the Mawdsley's Ltd., England.

(2) Three sets of CTs (JIS C1731, Type 2243, Rated Accuracy 0.1%) manufactured by the Yokogawa Electric Works Ltd., Japan.

(3) Three sets of Voltmeters and Ammeters (Type 2013, Class 0.5) manufactured by the same company as the CTs.

(4) One Digital Storage Oscilloscope.

(5) One X-Y Plotter.

(6) Three sets of adjustable Resistive Loads.

(7) One Current Probe.

Further details about the characteristics of the above apparatus can be obtained by consulting the specification sheets of their manufacturers.

6-2. Preparation of Testing Apparatus.

The following matters have to prepare for the testing :

(1) Firstly all the meters used in test were calibrated and a range on them has been selected to give a maximum deflection in order to obtain a more accurate and reliable reference for measurement.

(2) The connecting leads between the analyser and the CT were made as short as possible so as to avoid excessive unwanted pickup.

(3) One of the input channels of a digital storage oscilloscope was utilized to monitor the output voltage waveform of phase A.

(4) A current probe was connected to the other channel of the oscilloscope to show the current waveform of phase A.

(5) The stored voltage and current waveforms were then plotted using an X-Y plotter.

(6) The readings from the analogue meters were the root mean square values of the tested waveforms. Each reading represents the summation of all the measured harmonics of each phase. This can be illustrated in the following equation :

$$Urms = \sqrt{\frac{1}{T}\int_0^T [\sum H_k(t)]^2 \, dt}$$

where Urms is the resultant root mean square (RMS) value of the voltage or current.

A software approach was adopted to calculate the resultant RMS values of Va, Vb, Vc, Ia, Ib and Ic of all the harmonics from the memory of the microcomputer. These resultant values are used to compare the readings obtained from the analogue meters.

(7) The expression given by $[\ \sum \hat{U}_k \sin (KW_s t + \theta_k/K)\ ]$ represents the tested waveform. Substituting the peak amplitudes ($\hat{U}_k$) and phase angles (θ_k) of harmonic components obtained from the analyser to the expression, the waveform could be reconstructed. This was accomplished using a programming technique to take the summation of the most significant harmonics of phase A, i.e. the fundamental, 3rd, 5th and 7th. The reconstructed individual and resultant waveforms of phase A were then utilized to compare the one recorded by the X-Y plotter.

6-3. Procedure of operating the harmonic analyser.

Procedure of operating the harmonic analyser is as follows :

(1) Connect the voltages and currents inputs properly as in Fig. 6.1. Resistive loads A, B and C must be adjusted to match each other precisely to minimize unbalance amongst phases.

(2) Using the manual switch inside the analyser to assign the maximum order (from 1 to 25) of the harmonic needed to be measured (in this measurement the switch is set to 7) and then turn on the analyser.

(3) Switch on the HP85 and load the "H7" program from the tape.

(4) Press the reset button on the front panel of the analyser.

(5) Wait for 1 minute time and then press the RUN button on the keyboard of HP85.

(6) The results will be shown in the screen or printer of HP85 automatically and continuously.

(7) The operation can be stopped by pressing the reset key of HP85 together with the reset button of the analyser.

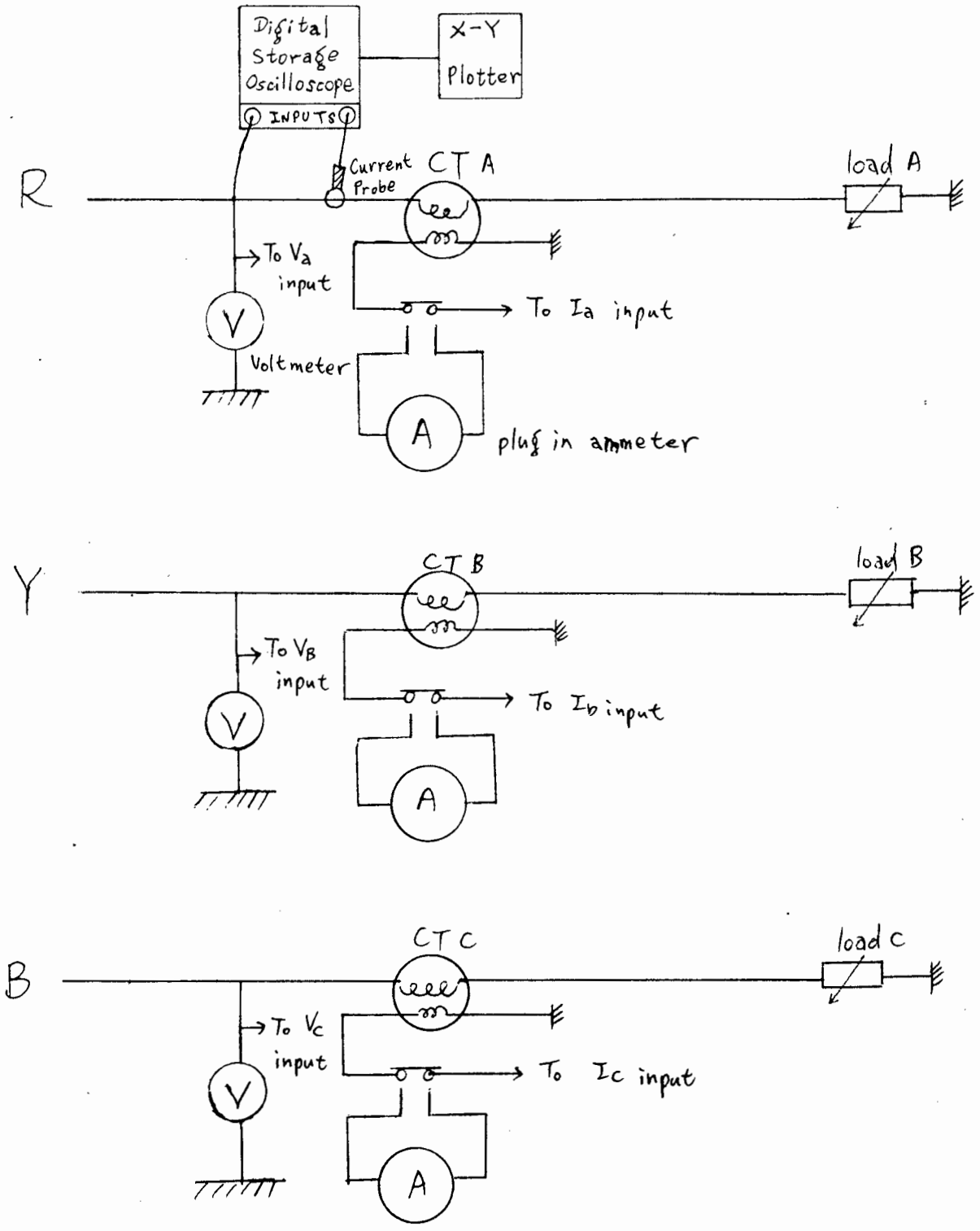


Fig. 6.1 Interface between the analyser and the supply.

6-4. Results of the tests.

Two sets of results each were recorded at different electrical angles for the following combinations of harmonics, which were generated by the harmonic generators.

(1) 1st and 3rd (Test 1 and 2).

(2) 1st and 5th (Test 3 and 4).

(3) 1st and 7th (Test 5 and 6).

(4) 1st, 3rd, 5th and 7th (Test 7 and 8).

An additional test (Test 9) was done to examine non-distorted waveforms with fundamental frequency in an unbalanced three phase power supply by decreasing the resistances of Load A, B and C in turn.

The results of the tests are appended in Appendix E to demonstrate the capability of the analyser.

6-5. Conclusion of the tests.

The various tests performed on the analyser show that the analyser does measure harmonic components in amplitude and angle correctly for voltage and current. Unfortunately the goals of high degree of precision and real time speed were not consummately achieved with this model, but some alterations could be made to enhance both accuracy and speed conciderably.

Firstly with regard to the real time speed, this can be improved by adding more hardware into the measuring system. One analyser per channel would be ideal if the economic factor is not of concern.

Secondly with regard to accuracy, an attempt to explain the difference of readings between the analyser and the analogue meters has to be consider first :

(1) The readings taken from the reference meters are at a time later or earlier than that obtained from the analyser. This is because of the unavailability of the sophisticated controlling excitation circuitry to stabilize the generators. Hence, there must be some difference between the two readings.

(2) The analogue multiplexer in the input circuit of the analyser generates noise. This is caused by channel switching. It also has an inherent voltage and current offset error.

(3) The readings were taken by the analyser on each channel at least one fundamental period after the previous one, instead of taken simultaneously. This also causes error owing to frequency fluctuations of the signal from the generators at various measuring times.

(4) The performance of ADC is not as reliable as a commercial equivalent. The former device is more probably susceptible to error.

(5) The analogue meters and current transformers have nonlinear characteristics such as stray inductance, capacitance of windings and the frequency dependent core loss, which way also cause error.

(6) The harmonic generators have no scale to show the change of the electrical angle. This makes the measurement very inconvenient.

The way to eliminate the experimental errors is as follows :

(a) The errors owing to the instability of the rotating harmonic generators and the nonlinearity of analogue meters as in (1), (5) and (6) above can be eliminated by the employment of the electronic harmonic generators instead of the one used in the measurement as explained in section 1-7. The construction and design the electronic generators is beyond the scope of this thesis.

(b) The error owing to the switching noise, voltage and current offset of the multiplexer and the time interval between the measurements of successive channels as in (2) and (3) above can be overcome by using 12 ADCs, two for each channel at 0 and 90 deg. phase shift modulating clock, instead of employment of the noisy analogue multiplexer.

(c) The error owing to the performance of ADC in (4) above can be overcome by replacement of the homemade ADC with a more reliable commercial equivalent.

{d} A more careful layout of the circuit on a printed circuit board would also reduce the noise, i.e. reduce the degree of error.

CHAPTER SEVEN

To make an end is to make a beginning.

The end is where we start from.

T. S. Eliot

If a jade travels thousand miles, it is only through perseverance.

K. L. Shum

7 CONCLUSIONS AND RECOMMENDATIONS

This thesis has covered the subject of harmonics existing in a three phase power system and the measurement thereof. It is hoped that its application will be of some use in solving some of the problems caused by harmonics in three phase systems.

In view of the contents of this thesis the following conclusions can be drawn.

(1) The main contribution of this project was the development of a general purpose instrument for measuring amplitudes and phase angles of harmonics of the three phase power systems and express them in symmetrical components.

(2) The final configuration of the instrument is relatively unimportant. Important is the measurement technique employed by the instrument.

(3) The project showed that an innovative "+1 and -1" modulation technique can be successfully applied to measure the amplitudes and phase angles of harmonics.

(4) The various tests performed on the instrument show that it functions properly, but the goals of high degree of precision and real time speed were not consummately achieved with this first model.

(5) The overall impression of the thesis is that the expressing of the amplitudes and phase angles of harmonic components in symmetrical components seems irrelevant. The reason of expressing the testing results in symmetrical components will be explained in Recommendation (3).

In the view of the author of this thesis the following recommendations are proposed.

<1> A thorough analysis and software simulation tests to evaluate the performance of the "+1 and -1" technique should be internationally disclosed by the author of this thesis in order to raise a challenge to the current signal processing methods. These jobs are obviously beyond the scope of this thesis.

<2> Both measuring speed and accuracy will be considerably improved if some alterations are made according to the suggestions in section 6-5.

<3> "Symmetrical components" is the elementary vehicle of unbalance and load flow analyses for three phase power systems. With a little additional software, this instrument can be extended to analyse unbalance and load flow, etc. i.e. increasing the versatility of the instrument.

<4> An instrument like this is useful for harmonic, unbalance, load flow analyses, etc. in areas with dense electrical distribution networks, for example the USA, Europe and North-east Asia.

<5> The merits and advantages of this instrument over that of the mini- and/or mainframe computer include the following :

Inexpensive and easy installation, maintenance and supervision of performance in terms of

(a) harmonic analyais,

(b) unbalance analysis,

(c) load flow analysis,

(d) the ability of communication with host computer and/or

parallel operation with other instruments such as controllers, etc.

is ensured if an entire distribution network is served by this instrument.

<6> The deployment of hundreds of this instrument in a whole distribution network will prove more effective than a few mini- and/or mainframe computers.

<7> The versatility of the instrument makes it extremely powerful and it is hoped that circumstances will permit the further development and application of the instrument.

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APPENDICES

The world is surely large enough for you and me.

Toby

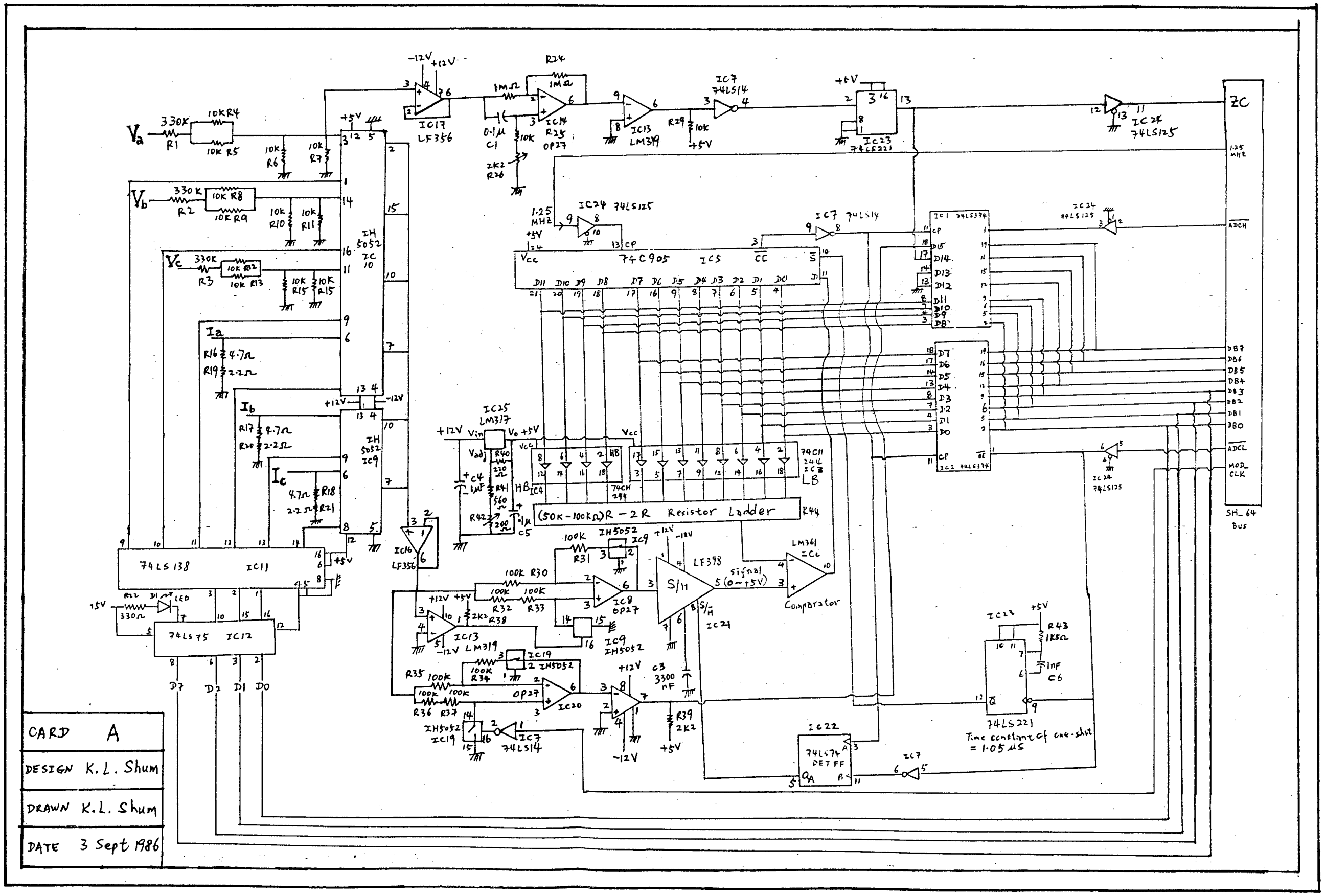
Appendix A. Assignment of SH-64 Bus

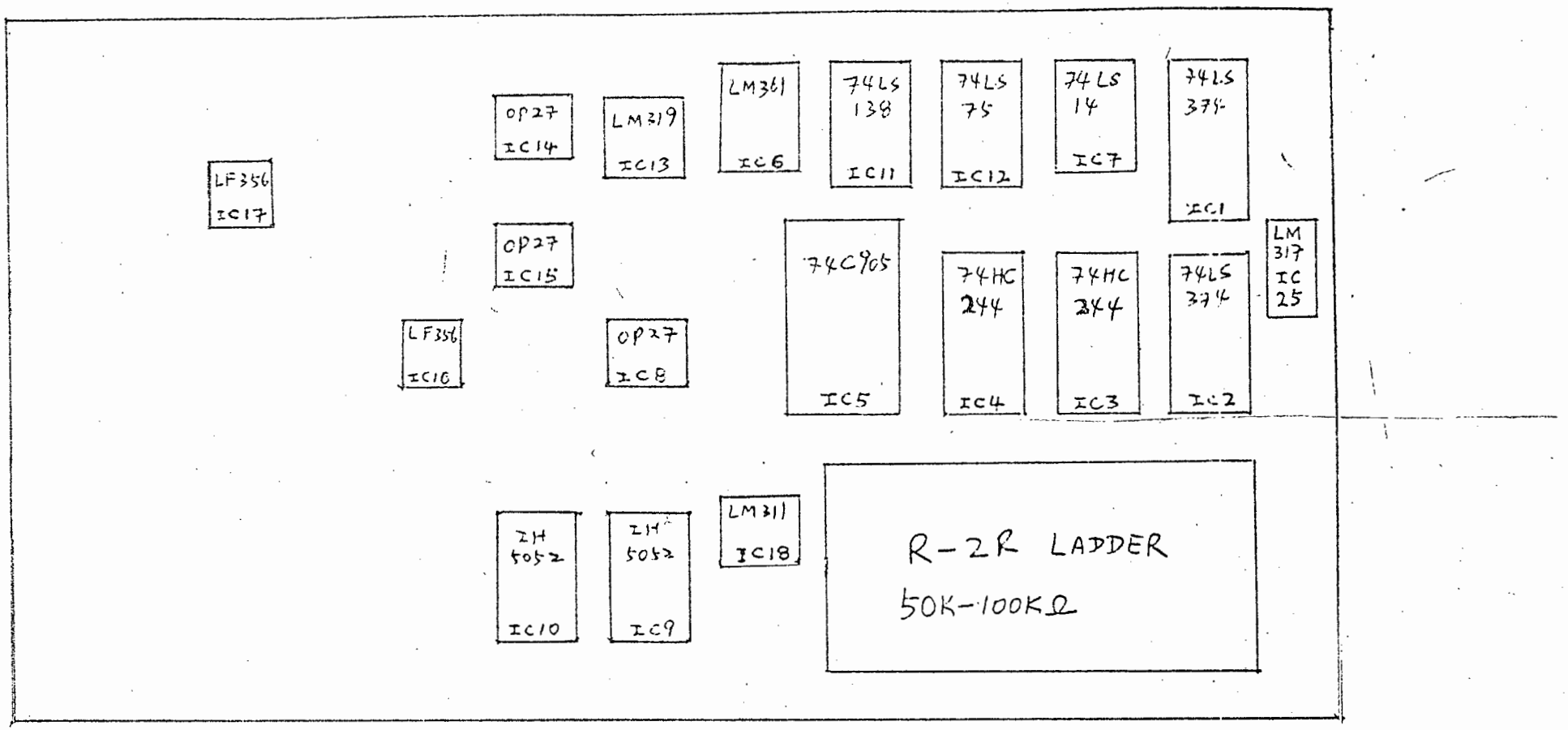
(C)	(Pin)	(A)
+ 5 V	1	+ 5 V
DB1	2	DB0
DB3	3	DB2
DB5	4	DB4
DB7	5	DB6
ZC	6	1.25 MHz
R/$\overline{W}$	7	E
LEDP	8	
$\overline{ADCH}$	9	$\overline{ADCL}$
AB1	10	AB0
	11	AB2
	12	
	13	
	14	
	15	
	16	
	17	
	18	
	19	
	20	
	21	$\overline{RESET}$
	22	
	23	
	24	
	25	
	26	
OUT 0	27	$\overline{CS}$ OF 68488
	28	
	29	
	30	MOD_CLK
- 12 V	31	PHASE PORT
+ 12 V	32	GND

Notice : DB and AB stand for Data and Address Bus respectively.

A P P E N D I X B

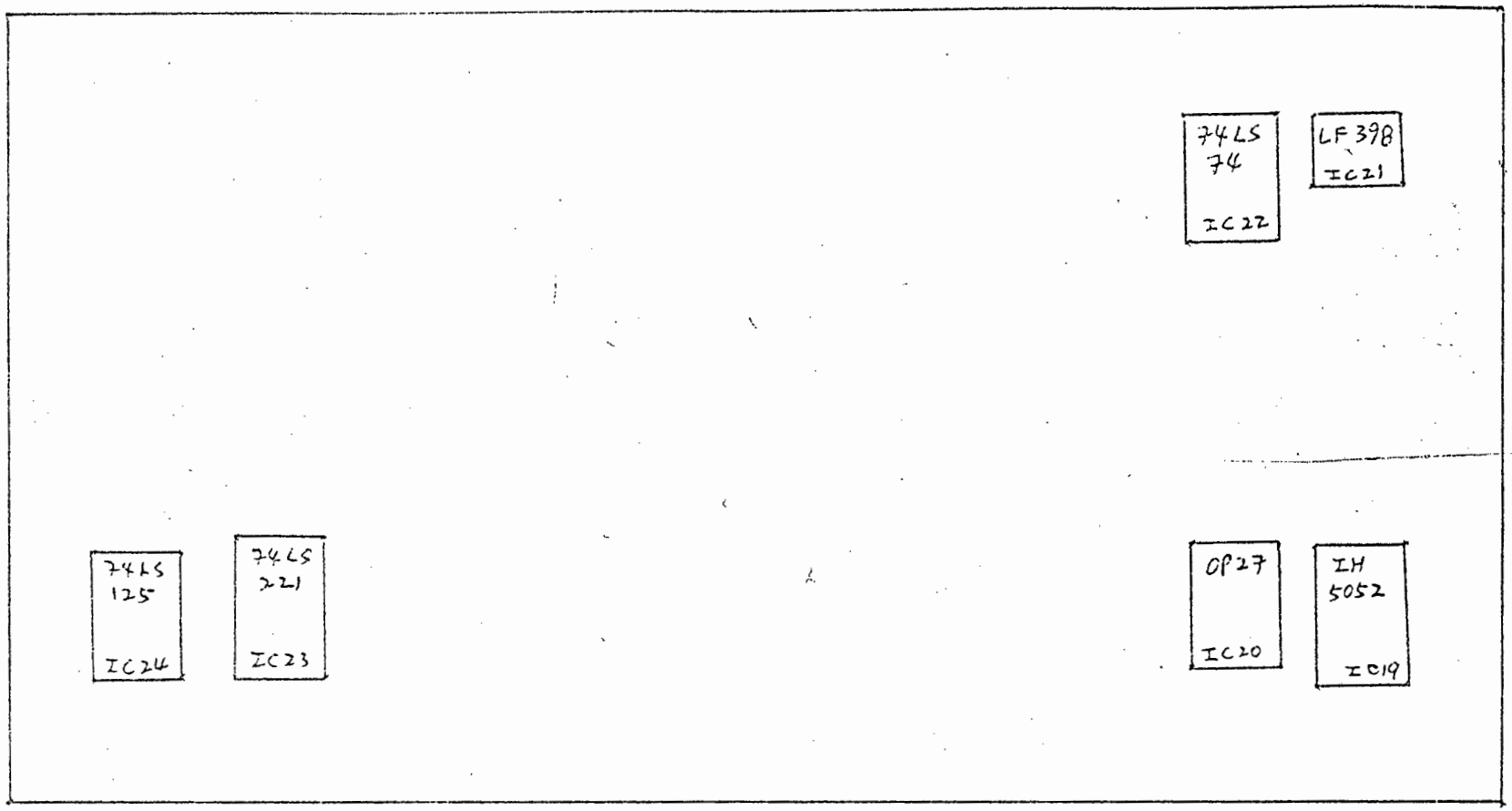
Individual Circuit Diagrams of Card A, B and C.


Va
Vb
Vc
330K
10K R4
10K R5
R1
10K R6
10K R7
330K
10K R8
10K R9
R2
10K R10
10K R11
330K
10K R12
10K R13
R3
10K R14
10K R15
Ia
R16 4.7Ω
R19 2.2Ω
Ib
R17 4.7Ω
R20 2.2Ω
Ic
4.7Ω R18
2.2Ω R21
IH 5052 IC10
IH 5052 IC9
74LS138 IC11
74LS75 IC12
LED
330Ω
D7 D2 D1 D0
-12V +12V
IC17 LF356
1MΩ
0.1μ C1
10K
2K2 R26
R24 1MΩ
IC14 R25 OP27
IC13 LM349
R29 10K
+5V
IC7 74LS14
IC23 74LS221
IC24 74LS125
1.25 MHz
ZC
ADCH
ADCL
MOD_CLK
SH_64 Bus
IC24 74LS125
IC7 74LS14
IC1 74LS374
IC2 74LS374
DB7 DB6 DB5 DB4 DB3 DB2 DB1 DB0
IC5 74C905
Vcc CC S
D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0
IC25 LM317
Vin Vo +5V
Vadj
R40 220Ω
C4 1μF
R41 560Ω
R42 200Ω
C5 1μF
74CH 244 IC3 LB
74CH 244 IC4 HB
(50K-100KΩ)R-2R Resistor Ladder
R44
100K R31
IC9 IH5052
100K R30
100K R32
100K R33
R38 2K2
IC8 OP27
IC13 LM319
IC19 IH5052
R35 100K
R34 100K
R36 100K
R37 100K
OP27 IC20
IC7 74LS14
LF398 S/H
signal 5 (0~+5V)
S/H IC21
LM361 IC6
Comparator
C3 3300 nF
R39 2K2
IC22 74LS74 DET FF
IC23 +5V
R43 1K5Ω
C6 1nF
74LS221
Time constant of one-shot = 1.05 μs
CARD A
DESIGN K.L. Shum
DRAWN K.L. Shum
DATE 3 Sept 1986



Layout of CARD A (Top View)

(Top View)



Layout of CARD A (Bottom View)

(Bottom View)

IC Listing of CARD A :

1) 74LS374
2) 74LS374
3) 74HC244
4) 74HC244
5) 74C905
6) LM361
7) 74LS14
8) OP27
9) IH5052
10) IH5052
11) 74LS138
12) 74LS75
13) LM319
14) OP27
15) OP27
16) LF356
17) LF356
18) LM311
19) IH5052
20) OP27
21) LF398
22) 74LS74
23) 74LS221
24) 74LS125A
25) LM317

Components Listing of Card A :

Capacitor

C1,C2 -----0.1μ

C3 -------3300n polyethylene

C4 --------1μ tant

C5 ------- 0.1μ tant

C6 ------ 1n

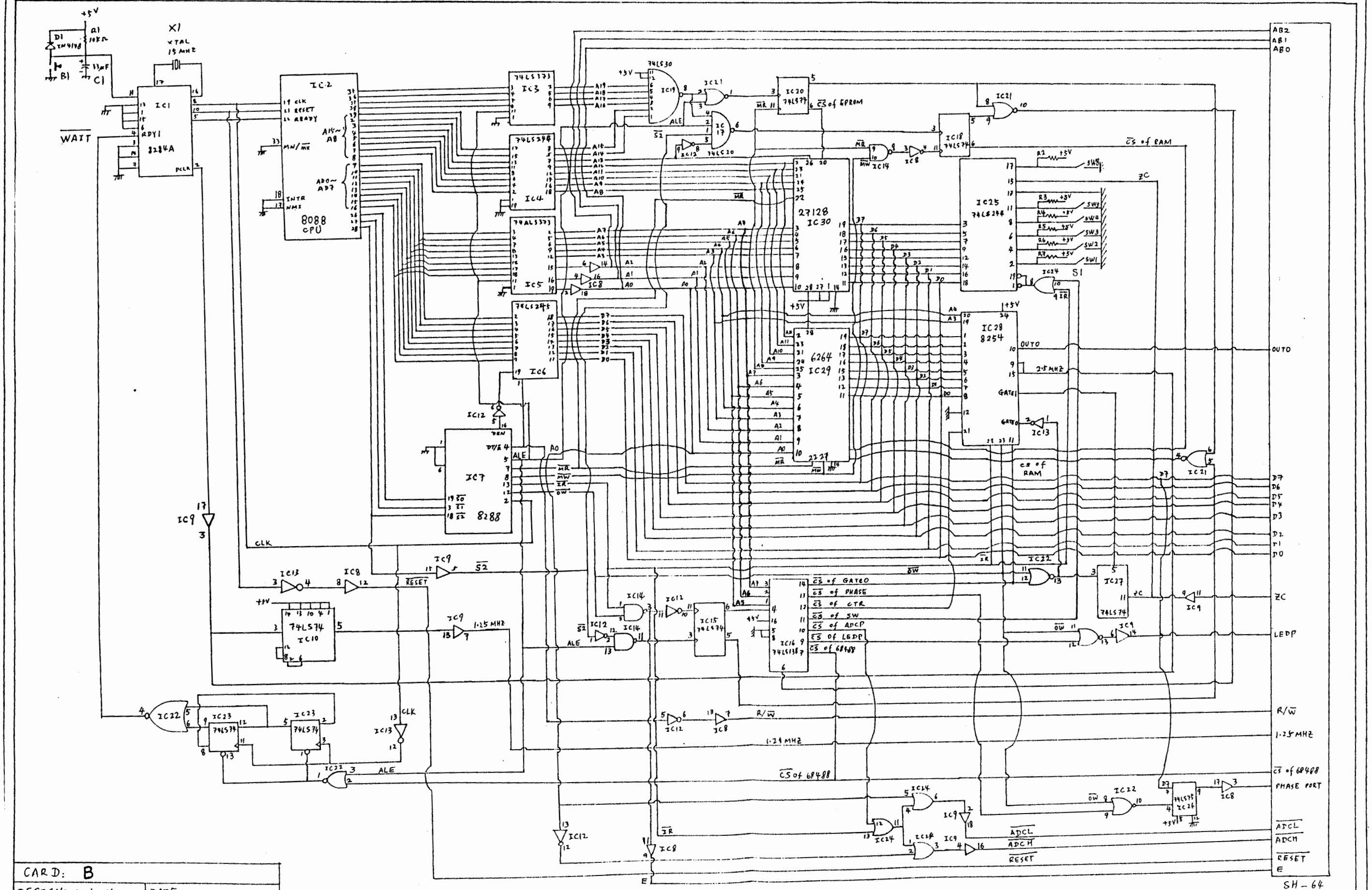
C7 ------- 1μ

Others

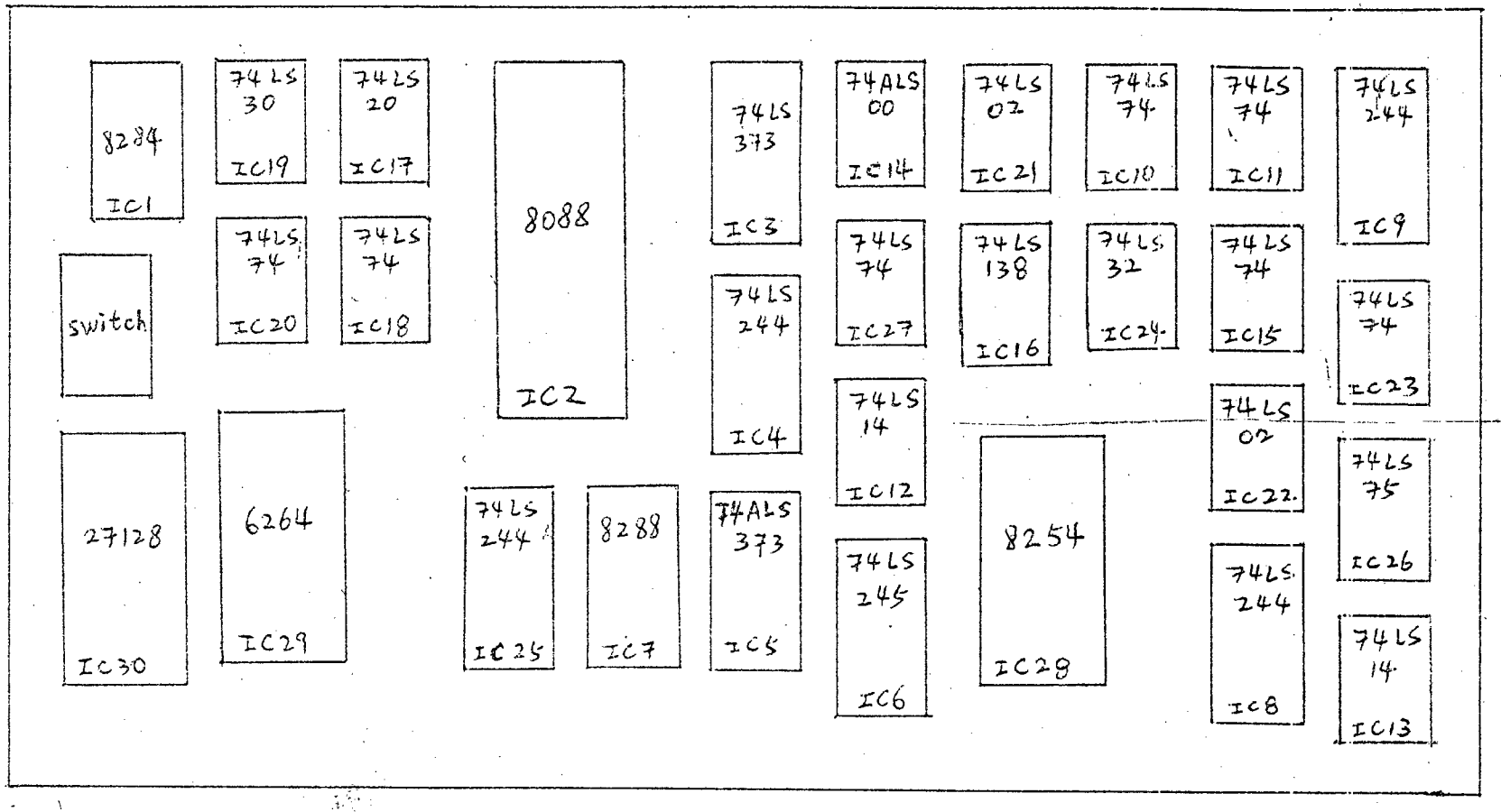
D1 -------LED

Resistor :

R1,R2,R3 330K ohm 1/2W
R4,R5,R6,R7,R8,R9,R10,R11,R12,R13,R14,R15 10K ohm 1/2W
R16,R17,R18 4.7 ohm 10W
R19,R20,R21 2.2 ohm 10W
R22 330 ohm 1/2W
R23,R24 1Mohm 1%
R25 10K ohm
R26 2K2 trimmed pot
R27,R28 15K ohm 1%
R30,R31,R32,R33,R34,R35,R36,R37 100K ohm 1%
R38,R39 2K2 ohm
R40 220 ohm
R41 560 ohm
R42 200 ohm trimmed pot
R43 1K5 ohm
R44 50K-100K ohm (12-bit) Resistor Ladder



CARD: B	
DESIGN: K.L. Shum	DATE: 3 SEPT 1986
DRAWN: K.L. Shum	



(Top View)

Lay out of CARD B

IC Listing of CARD B :

1)	8284	16)	74LS138
2)	8088	17)	74LS20
3)	74LS373	18)	74LS74
4)	74LS244	19)	74LS30
5)	74ALS373	20)	74LS74
6)	74LS245	21)	74LS02
7)	8288	22)	74LS02
8)	74LS244	23)	74LS74
9)	74LS244	24)	74LS32
10)	74LS74	25)	74LS244
11)	xxxxxx	26)	74LS75
12)	74LS14	27)	74LS74
13)	74LS14	28)	8254
14)	74ALS00	29)	6264
15)	74LS74	30)	27128

Component Listing of Card B :

X1 ---------- 15MHZ Crystal

D1 ---------- IN4148 Diode

B1 ---------- Press-button switch

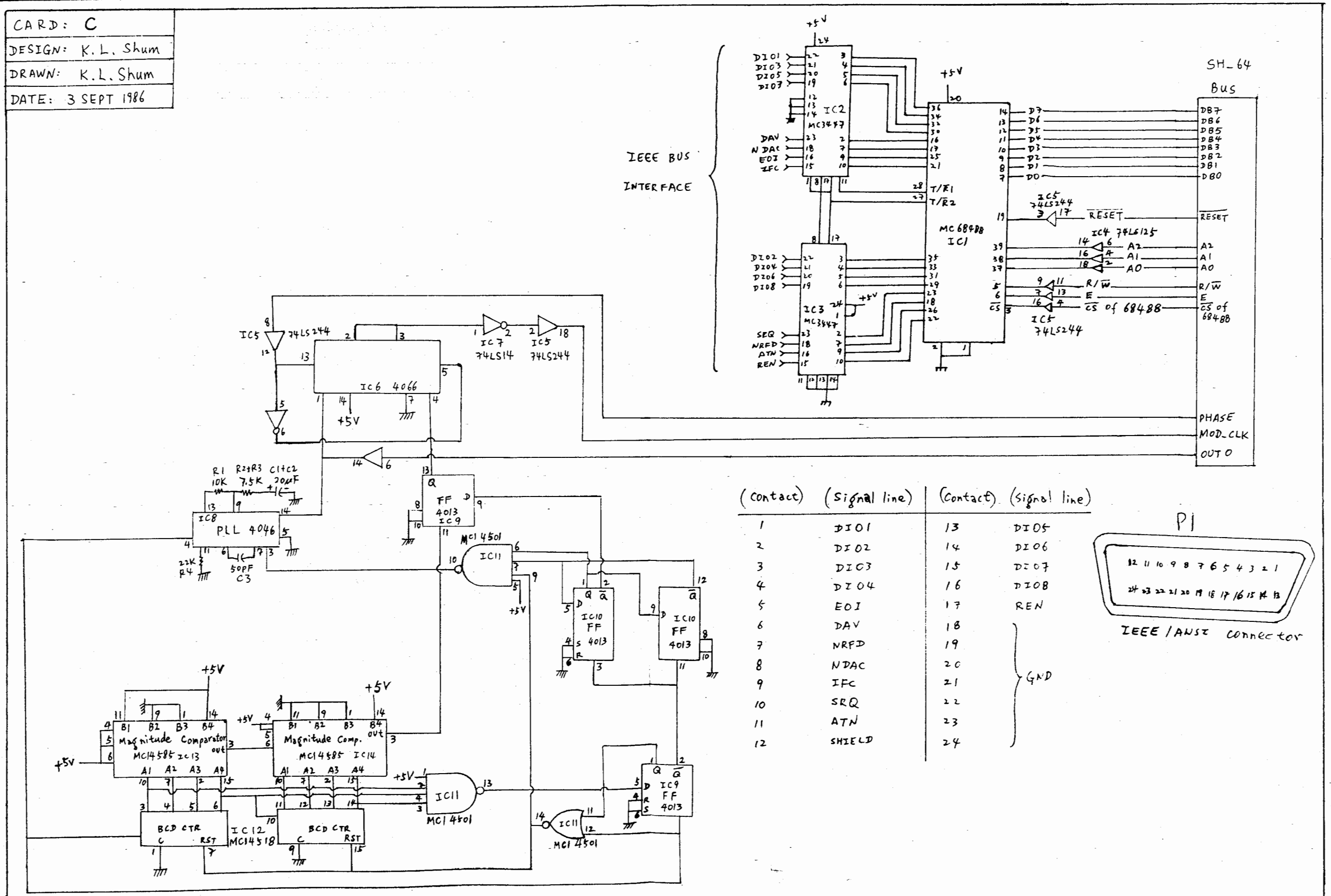
C1 ---------- 33µF tant

R1 ---------- 10K ohm

R2,R3,R4,R5,R6,R7 ---------- 2K2 ohm

S1 ---------- 8 position switch

CARD:	C
DESIGN:	K.L. Shum
DRAWN:	K.L. Shum
DATE:	3 SEPT 1986



(Contact)	(Signal line)	(Contact)	(Signal line)
1	DIO1	13	DIO5
2	DIO2	14	DIO6
3	DIO3	15	DIO7
4	DIO4	16	DIO8
5	EOI	17	REN
6	DAV	18	GND
7	NRFD	19	
8	NDAC	20	
9	IFC	21	
10	SRQ	22	
11	ATN	23	
12	SHIELD	24	

IEEE/ANSI connector

(Top View)

Layout of CARD C

IC Listing of Card C :

1) MC68488
2) MC3447
3) MC3447
4) 74LS125A
5) 74LS244
6) 4066
7) 74LS14
8) 4046
9) 4013
10) 4013
11) 4051
12) 4518
13) 4585
14) 4585

Component Listing of Card C :

P1 IEEE/ANSI Connector

C1,C2 10 u ohm tant

C3 50pF

R1 10 K ohm

R2,R3 15 K ohm

R4 22K ohm

A P P E N D I X C

Program Listing of Operating System.

ES-III 8086/87/88/186 MACRO ASSEMBLER V2.0 ASSEMBLY OF MODULE SHUM
CT MODULE PLACED IN :F3:A2.OBJ
MBLER INVOKED BY: ASM86.86 :F3:A2.SRC SYMBOLS

```
OBJ                     LINE     SOURCE

                           1
                           2
                           3
                           4     ;       ALL PRAISE BE TO GOD
                           5     ;
                           6     ;       THE LORD OF THE WORLDS
                           7     ;
                           8     ;       MOST BENEFICIENT AND MOST MERCIFUL
                           9     ;
                          10     ;       THE MASTER OF THE DAY OF JUDGEMENT
                          11     ;
                          12     ;       TO THEE ALONE DO WE WORSHIP
                          13     ;
                          14     ;       THINE AID WE SEEK
                          15     ;
                          16     ;       SHOW US THE STRAIGHT PATH
                          17     ;
                          18     ;       THE PATH OF THOSE ON WHOM THOU HAST BESTOWED THY GRACE
                          19     ;
                          20     ;       NOT OF THOSE WHOSE PORTION IS WRATH NOR OF THOSE WHO GO ASTRAY
                          21     ;
                          22     ;       AMEN
                          23
                          24
                          25             NAME    SHUM
                          26
                          27
                          28     ;###############################################################
                          29     ;
                          30     ;ABBREVIATION :
                          31     ;
                          32     ;ABS.    STANDS FOR ABSOLUTE VALUE
                          33     ;
                          34     ;ADC     STANDS FOR ANALOGUE TO DIGITAL CONVERTOR
                          35     ;
                          36     ;AMP.    STANDS FOR AMPLITUDE
                          37     ;
                          38     ;ANG.    STANDS FOR ANGLE
                          39     ;
                          40     ;CLK     STANDS FOR CLOCK
                          41     ;
                          42     ;MAX.    STANDS FOR MAXIMUM
                          43     ;
                          44     ;MIN.    STANDS FOR MINIMUM
                          45     ;
                          46     ;XY      STANDS FOR D.C. TERM
                          47     ;
                          48     ;ZC.     STANDS FOR FUNDAMENTAL FILTERED ZERO_CROSSING
                          49     ;
                          50     ;
```

```
OBJ                     LINE     SOURCE

                          51
                          52     ;#########################################################################
                          53
                          54
                          55
                          56     ;$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
                          57     ;
                          58     ;PROCEDURES ORDER :
                          59     ;
                          60     ;(1)   BEGIN
                          61     ;(2)   ZC_ADC
                          62     ;(3)   AVERAGING
                          63     ;(4)   MOD_CLK_UPDATE_1
                          64     ;(5)   MOD_CLK_UPDATE
                          65     ;(6)   MOD_CLK_SYN
                          66     ;(7)   DEHA
                          67     ;(8)   DIV_32
                          68     ;(9)   SROOT
                          69     ;(10)  QUE
                          70     ;(11)  LED
                          71     ;(12)  FANG
                          72     ;(13)  GPIB
                          73     ;(14)  GPIB1
                          74     ;(15)  DUMMY_READ
                          75     ;(16)  THREE_7_8
                          76     ;(17)  THREE_7_7
                          77     ;(18)  THREE_7_6
                          78     ;(19)  THREE_7_5
                          79     ;(20)  THREE_7_4
                          80     ;(21)  THREE_7_3
                          81     ;(22)  THREE_7_2
                          82     ;(23)  THREE_7_1
                          83     ;
                          84     ;$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
                          85
                          86
                          87
                          88     ;#########################################################################
                          89     ;
                          90     ;PART :0
                          91     ;
                          92     ;SET UP STORAGE AREA AND LOOK_UP TABLE FOR ARC_COS .
                          93     ;
                          94     ;#########################################################################
                          95
                          96
                          97
                          98     SAMP    SEGMENT WORD AT 45H
                          99
(2000                    100     SAM     DW      2000D   DUP(?)      ;NO. OF SAM FROM ADC
????
)
(150                     101     AMP     DW      150D    DUP(?)      ;6*25_  NO. OF V AND I
????
)
```

```
OBJ                     LINE    SOURCE
(150                     102    ANG     DW      150D    DUP(?)      ;6*25_  NO. OF ANG OF V AND I
????
)
(300                     103    XY      DW      300D    DUP(?)      ;12*25_ NO. OF X OR Y PER CHANNEL
????
)
????                     104    PAP     DW      ?
(3                       105    PA      DW      3       DUP(?)
????
)
????                     106    ASH     DW      ?
????                     107    ASL     DW      ?
????                     108    FREQ    DW      ?                   ;AVERAGE FREQUENCY OF INPUT SIGNAL
????                     109    ZCCP    DW      ?                   ;ZCC POINTER
(12                      110    ZCC     DW      12D     DUP(?)      ;ZCC STORES 1ST 12 VALUE OF COUNTER 1
????
)
                         111
                         112    ;R0 TO R16 ARE SCRATCH PADS TO STORE TEMPORARY DATA :
????                     113    R0      DW      ?
????                     114    R1      DW      ?
????                     115    R2      DW      ?
????                     116    R3      DW      ?
????                     117    R4      DW      ?
????                     118    R5      DW      ?
????                     119    R6      DW      ?
????                     120    R7      DW      ?
????                     121    R8      DW      ?
????                     122    R9      DW      ?
????                     123    R10     DW      ?
????                     124    R11     DW      ?
????                     125    R12     DW      ?
                         126
??                       127    R13     DB      ?
??                       128    R14     DB      ?
??                       129    R15     DB      ?
??                       130    R16     DB      ?
                         131
                         132    SAMP ENDS
                         133
                         134
                         135
                         136
                         137    ATCS    SEGMENT WORD AT 0FC00H
                         138
FFFF                     139    ACOS    DW      0FFFFH              ;SI=0
FEFF                     140            DW      0FFFEH              ;SI=2
FDFF                     141            DW      0FFFDH              ;SI=4
FBFF                     142            DW      0FFFBH
F8FF                     143            DW      0FFF8H
F5FF                     144            DW      0FFF5H
F0FF                     145            DW      0FFF0H
EBFF                     146            DW      0FFEBH
E5FF                     147            DW      0FFE5H
DEFF                     148            DW      0FFDEH
```

```
OBJ                 LINE    SOURCE

D7FF                 149            DW      0FFD7H          ;SI=20 (10)
CEFF                 150            DW      0FFCEH
C5FF                 151            DW      0FFC5H
BBFF                 152            DW      0FFBBH
B0FF                 153            DW      0FFB0H
A5FF                 154            DW      0FFA5H
98FF                 155            DW      0FF98H
88FF                 156            DW      0FF88H
70FF                 157            DW      0FF70H
6EFF                 158            DW      0FF6EH
5FFF                 159            DW      0FF5FH          ;SI=40 (20)
4FFF                 160            DW      0FF4FH
3DFF                 161            DW      0FF3DH
2BFF                 162            DW      0FF2BH
19FF                 163            DW      0FF19H
05FF                 164            DW      0FF05H
F1FE                 165            DW      0FEF1H
DCFE                 166            DW      0FEDCH
C6FE                 167            DW      0FEC6H
AFFE                 168            DW      0FEAFH
97FE                 169            DW      0FE97H          ;SI=60 (120)
7FFE                 170            DW      0FE7FH
66FE                 171            DW      0FE66H
4CFE                 172            DW      0FE4CH
31FE                 173            DW      0FE31H
16FE                 174            DW      0FE16H
FAFD                 175            DW      0FDFAH          ;SI=72 (#36)
DDFD                 176            DW      0FDDDH
BFFD                 177            DW      0FDBFH
A0FD                 178            DW      0FDA0H
81FD                 179            DW      0FD81H          ;SI=80 (40)
60FD                 180            DW      0FD60H
3FFD                 181            DW      0FD3FH
1EFD                 182            DW      0FD1EH
FBFC                 183            DW      0FCFBH
D8FC                 184            DW      0FCD8H
B3FC                 185            DW      0FCB3H
8FFC                 186            DW      0FC8FH
69FC                 187            DW      0FC69H
42FC                 188            DW      0FC42H
1BFC                 189            DW      0FC1BH          ;SI=100 (50)
F3FB                 190            DW      0FBF3H
CAFB                 191            DW      0FBCAH
A0FB                 192            DW      0FBA0H
76FB                 193            DW      0FB76H
4AFB                 194            DW      0FB4AH
1EFB                 195            DW      0FB1EH
F2FA                 196            DW      0FAF2H
C4FA                 197            DW      0FAC4H
96FA                 198            DW      0FA96H
66FA                 199            DW      0FA66H          ;SI=120 (60)
36FA                 200            DW      0FA36H
06FA                 201            DW      0FA06H
D4F9                 202            DW      0F9D4H
A2F9                 203            DW      0F9A2H
```

```
OBJ                     LINE     SOURCE

6FF9                     204              DW      0F96FH
3BF9                     205              DW      0F93BH
06F9                     206              DW      0F906H
D1F8                     207              DW      0F8D1H
9BF8                     208              DW      0F89BH
64F8                     209              DW      0F864H          ;SI=140 (70)
2CF8                     210              DW      0F82CH
F4F7                     211              DW      0F7F4H          ;SI=144 (#72)
BAF7                     212              DW      0F7BAH
80F7                     213              DW      0F780H
45F7                     214              DW      0F745H
0AF7                     215              DW      0F70AH
CDF6                     216              DW      0F6CDH
90F6                     217              DW      0F690H
52F6                     218              DW      0F652H
14F6                     219              DW      0F614H          ;SI=160 (80)
D4F5                     220              DW      0F5D4H
94F5                     221              DW      0F594H
53F5                     222              DW      0F553H
11F5                     223              DW      0F511H
CFF4                     224              DW      0F4CFH
8CF4                     225              DW      0F48CH
48F4                     226              DW      0F448H
03F4                     227              DW      0F403H
BDF3                     228              DW      0F3BDH
77F3                     229              DW      0F377H          ;SI=180 (90)
30F3                     230              DW      0F330H
E8F2                     231              DW      0F2E8H
A0F2                     232              DW      0F2A0H
56F2                     233              DW      0F256H
0CF2                     234              DW      0F20CH
C1F1                     235              DW      0F1C1H
76F1                     236              DW      0F176H
29F1                     237              DW      0F129H
DCF0                     238              DW      0F0DCH
8EF0                     239              DW      0F08EH          ;SI=200 (100)
40F0                     240              DW      0F040H
F0EF                     241              DW      0EFF0H          ;SI=204 (#102)
A0EF                     242              DW      0EFA0H
4FEF                     243              DW      0EF4FH
FEEE                     244              DW      0EEFEH
ABEE                     245              DW      0EEABH
58EE                     246              DW      0EE58H
04EE                     247              DW      0EE04H
B0ED                     248              DW      0EDB0H
5AED                     249              DW      0ED5AH          ;SI=220 (110)
04ED                     250              DW      0ED04H
AEEC                     251              DW      0ECAEH
56EC                     252              DW      0EC56H
FEEB                     253              DW      0EBFEH
A5EB                     254              DW      0EBA5H
4BEB                     255              DW      0EB4BH
F1EA                     256              DW      0EAF1H
95EA                     257              DW      0EA95H
39EA                     258              DW      0EA39H
```

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OBJ                     LINE     SOURCE

DDE9                     259              DW      0E9DDH          ;SI=240 (120)
7FE9                     260              DW      0E97FH
21E9                     261              DW      0E921H
C2E8                     262              DW      0E8C2H          ;SI=246 (#123)
63E8                     263              DW      0E863H
02E8                     264              DW      0E802H
A1E7                     265              DW      0E7A1H
40E7                     266              DW      0E740H
DDE6                     267              DW      0E6DDH
7AE6                     268              DW      0E67AH
16E6                     269              DW      0E616H          ;SI=260 (130)
B1E5                     270              DW      0E5B1H
4CE5                     271              DW      0E54CH
E6E4                     272              DW      0E4E6H
7FE4                     273              DW      0E47FH
18E4                     274              DW      0E418H
AFE3                     275              DW      0E3AFH
46E3                     276              DW      0E346H
DDE2                     277              DW      0E2DDH
73E2                     278              DW      0E273H
07E2                     279              DW      0E207H          ;SI=280 (140)
9CE1                     280              DW      0E19CH
2FE1                     281              DW      0E12FH
C2E0                     282              DW      0E0C2H
54E0                     283              DW      0E054H
E6DF                     284              DW      0DFE6H          ;SI=290 (#145)
76DF                     285              DW      0DF76H
06DF                     286              DW      0DF06H
96DE                     287              DW      0DE96H
25DE                     288              DW      0DE25H
B2DD                     289              DW      0DDB2H          ;SI=300 (150)
40DD                     290              DW      0DD40H
CCD2                     291              DW      0D2CCH
58DC                     292              DW      0DC58H
E3DB                     293              DW      0DBE3H
6EDB                     294              DW      0DB6EH
F8DA                     295              DW      0DAF8H
81DA                     296              DW      0DA81H
09DA                     297              DW      0DA09H
91D9                     298              DW      0D991H
18D9                     299              DW      0D918H          ;SI=320 (160)
9FD8                     300              DW      0D89FH          ;SI=322 (#161)
25D8                     301              DW      0D825H
AAD7                     302              DW      0D7AAH
2ED7                     303              DW      0D72EH
B2D6                     304              DW      0D6B2H
35D6                     305              DW      0D635H
B7D5                     306              DW      0D5B7H
39D5                     307              DW      0D539H
BAD4                     308              DW      0D4BAH
3AD4                     309              DW      0D43AH          ;SI=340 (170)
BAD3                     310              DW      0D3BAH
39D3                     311              DW      0D339H
B8D2                     312              DW      0D2B8H
36D2                     313              DW      0D236H
```

```
OBJ                     LINE    SOURCE

B3D1                     314            DW      0D1B3H
2FD1                     315            DW      0D12FH
ABD0                     316            DW      0D0ABH
26D0                     317            DW      0D026H
A1CF                     318            DW      0CFA1H          ;SI=358 (#179)
1ACF                     319            DW      0CF1AH          ;SI=360 (180)
94CE                     320            DW      0CE94H
0CCE                     321            DW      0CE0CH
84CD                     322            DW      0CD84H
FBCC                     323            DW      0CCFBH
72CC                     324            DW      0CC72H
E8CB                     325            DW      0CBE8H
5DCB                     326            DW      0CB5DH
D2CA                     327            DW      0CAD2H
46CA                     328            DW      0CA46H
BAC9                     329            DW      0C9BAH          ;SI=380 (190)
2DC9                     330            DW      0C92DH
9FC8                     331            DW      0C89FH
10C8                     332            DW      0C810H
81C7                     333            DW      0C781H
F2C6                     334            DW      0C6F2H
61C6                     335            DW      0C661H
D1C5                     336            DW      0C5D1H
3FC5                     337            DW      0C53FH
ADC4                     338            DW      0C4ADH
1AC4                     339            DW      0C41AH          ;SI=400 (200)
87C3                     340            DW      0C387H
F3C2                     341            DW      0C2F3H
5EC2                     342            DW      0C25EH
C9C1                     343            DW      0C1C9H
33C1                     344            DW      0C133H
9DC0                     345            DW      0C09DH
06C0                     346            DW      0C006H
6EBF                     347            DW      0BF6EH          ;SI=416 (#208)
D6BE                     348            DW      0BED6H
3DBE                     349            DW      0BE3DH          ;SI=420 (210)
A4BD                     350            DW      0BDA4H
0ABD                     351            DW      0BD0AH
70BC                     352            DW      0BC70H
D4B8                     353            DW      0BBD4H
39BB                     354            DW      0BB39H
9CBA                     355            DW      0BA9CH
00BA                     356            DW      0BA00H
62B9                     357            DW      0B962H
C4B8                     358            DW      0B8C4H
25B8                     359            DW      0B825H          ;SI=440 (220)
86B7                     360            DW      0B786H
E6B6                     361            DW      0B6E6H
46B6                     362            DW      0B646H
A5B5                     363            DW      0B5A5H
04B5                     364            DW      0B504H
62B4                     365            DW      0B462H
BFB3                     366            DW      0B3BFH
1CB3                     367            DW      0B31CH
78B2                     368            DW      0B278H
```

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OBJ                LINE     SOURCE

D4B1                369             DW      0B1D4H          ;SI=460 (230)
2FB1                370             DW      0B12FH
8AB0                371             DW      0B08AH
E4AF                372             DW      0AFE4H          ;SI=466 (#233)
3DAF                373             DW      0AF3DH
96AE                374             DW      0AE96H
EFAD                375             DW      0ADEFH
47AD                376             DW      0AD47H
9EAC                377             DW      0AC9EH
F5AB                378             DW      0ABF5H
4BAB                379             DW      0AB4BH          ;SI=480 (240)
A1AA                380             DW      0AAA1H
F6A9                381             DW      0A9F6H
4BA9                382             DW      0A94BH
9FA8                383             DW      0A89FH
F2A7                384             DW      0A7F2H
45A7                385             DW      0A745H
98A6                386             DW      0A698H
EAA5                387             DW      0A5EAH
3CA5                388             DW      0A53CH
8DA4                389             DW      0A48DH          ;SI=500 (250)
DDA3                390             DW      0A3DDH
2DA3                391             DW      0A32DH
7DA2                392             DW      0A27DH
CCA1                393             DW      0A1CCH
1AA1                394             DW      0A11AH
68A0                395             DW      0A068H
B59F                396             DW      09FB5H          ;SI=514 (#257)
029F                397             DW      09F02H
4F9E                398             DW      09E4FH
9B9D                399             DW      09D9BH          ;SI=520 (260)
E69C                400             DW      09CE6H
319C                401             DW      09C31H
7C9B                402             DW      09B7CH
C69A                403             DW      09AC6H
0F9A                404             DW      09A0FH
5999                405             DW      09959H
A198                406             DW      098A1H
E997                407             DW      097E9H
3197                408             DW      09731H
7896                409             DW      09678H          ;SI=540 (270)
BF95                410             DW      095BFH
0595                411             DW      09505H
4B94                412             DW      0944BH
9093                413             DW      09390H
D592                414             DW      092D5H
1992                415             DW      09219H
5D91                416             DW      0915DH
A190                417             DW      090A1H
E48F                418             DW      08FE4H          ;SI=558 (#279)
268F                419             DW      08F26H          ;SI=560 (280)
688E                420             DW      08E68H
AA8D                421             DW      08DAAH
EB8C                422             DW      08CEBH
2C8C                423             DW      08C2CH
```

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OBJ                     LINE    SOURCE

6C8B                     424            DW      08B6CH
AC8A                     425            DW      08AACH
EC89                     426            DW      089ECH
2B89                     427            DW      0892BH
6A88                     428            DW      0886AH
A887                     429            DW      087A8H          ;SI=580 (290)
E686                     430            DW      086E6H
2386                     431            DW      08623H
6085                     432            DW      08560H
9C84                     433            DW      0849CH
D983                     434            DW      083D9H
1483                     435            DW      08314H
5082                     436            DW      08250H
8A81                     437            DW      0818AH
C580                     438            DW      080C5H
FF7F                     439            DW      07FFFH          ;SI=600 (#300)
397F                     440            DW      07F39H
727E                     441            DW      07E72H
AB7D                     442            DW      07DABH
E37C                     443            DW      07CE3H
1B7C                     444            DW      07C1BH
537B                     445            DW      07B53H
8B7A                     446            DW      07A8BH
C279                     447            DW      079C2H
F878                     448            DW      078F8H
2E78                     449            DW      0782EH          ;SI=620 (310)
6477                     450            DW      07764H
9A76                     451            DW      0769AH
CF75                     452            DW      075CFH
0375                     453            DW      07503H
3874                     454            DW      07438H
6C73                     455            DW      0736CH
9F72                     456            DW      0729FH
D371                     457            DW      071D3H
0671                     458            DW      07106H
3870                     459            DW      07038H          ;SI=640 (320)
6A6F                     460            DW      06F6AH          ;SI=642 (#321)
9C6E                     461            DW      06E9CH
CE6D                     462            DW      06DCEH
FF6C                     463            DW      06CFFH
306C                     464            DW      06C30H
606B                     465            DW      06B60H
906A                     466            DW      06A90H
C069                     467            DW      069C0H
F068                     468            DW      068F0H
1F68                     469            DW      0681FH          ;SI=660 (330)
4E67                     470            DW      0674EH
7C66                     471            DW      0667CH
AB65                     472            DW      065ABH
D864                     473            DW      064D8H
0664                     474            DW      06406H
3363                     475            DW      06333H
6062                     476            DW      06260H
8D61                     477            DW      0618DH
B960                     478            DW      060B9H
```

```
OBJ                     LINE      SOURCE

E55F                     479                DW        05FE5H                ;SI=680 (#340)
115F                     480                DW        05F11H
3D5E                     481                DW        05E3DH
685D                     482                DW        05D68H
935C                     483                DW        05C93H
BD5B                     484                DW        05BBDH
E75A                     485                DW        05AE7H
115A                     486                DW        05A11H
3B59                     487                DW        0593BH
6558                     488                DW        05865H
8E57                     489                DW        0578EH                ;SI=700 (350)
B756                     490                DW        056B7H
DF55                     491                DW        055DFH
0855                     492                DW        05508H
3054                     493                DW        05430H
5853                     494                DW        05358H
7F52                     495                DW        0527FH
A651                     496                DW        051A6H
CE50                     497                DW        050CEH
F44F                     498                DW        04FF4H                ;SI=718 (#359)
1B4F                     499                DW        04F1BH                ;SI=720 (360)
414E                     500                DW        04E41H
674D                     501                DW        04D67H
8D4C                     502                DW        04C8DH
B34B                     503                DW        04BB3H
D84A                     504                DW        04AD8H
FD49                     505                DW        049FDH
2249                     506                DW        04922H
4748                     507                DW        04847H
6B47                     508                DW        0476BH
8F46                     509                DW        0468FH                ;SI=740 (370)
B345                     510                DW        045B3H
D744                     511                DW        044D7H
FB43                     512                DW        043FBH
1E43                     513                DW        0431EH
4142                     514                DW        04241H
6441                     515                DW        04164H
8740                     516                DW        04087H
A93F                     517                DW        03FA9H                ;SI=756 (#378)
CC3E                     518                DW        03ECCH
EE3D                     519                DW        03DEEH                ;SI=760 (380)
103D                     520                DW        03D10H
323C                     521                DW        03C32H
533B                     522                DW        03B53H
743A                     523                DW        03A74H
9639                     524                DW        03996H
B738                     525                DW        038B7H
D837                     526                DW        037D8H
F836                     527                DW        036F8H
1936                     528                DW        03619H
3935                     529                DW        03539H                ;SI=780 (390)
5934                     530                DW        03459H
7933                     531                DW        03379H
9932                     532                DW        03299H
B931                     533                DW        031B9H
```

```
  OBJ                    LINE     SOURCE

  D830                    534              DW      030D8H
  F82F                    535              DW      02FF8H          ;SI=792 (#396)
  172F                    536              DW      02F17H
  362E                    537              DW      02E36H
  552D                    538              DW      02D55H
  742C                    539              DW      02C74H          ;SI=800 (400)
  922B                    540              DW      02B92H
  B12A                    541              DW      02AB1H
  CF29                    542              DW      029CFH
  ED28                    543              DW      028EDH
  0B28                    544              DW      0280BH
  2927                    545              DW      02729H
  4726                    546              DW      02647H
  6525                    547              DW      02565H
  8324                    548              DW      02483H
  A023                    549              DW      023A0H          ;SI=820 (410)
  BE22                    550              DW      022BEH
  DB21                    551              DW      021DBH
  F820                    552              DW      020F8H
  1520                    553              DW      02015H
  321F                    554              DW      01F32H          ;SI=830 (#415)
  4F1E                    555              DW      01E4FH
  6C1D                    556              DW      01D6CH
  891C                    557              DW      01C89H
  A51B                    558              DW      01BA5H
  C21A                    559              DW      01AC2H          ;SI=840 (420)
  DE19                    560              DW      019DEH
  FB18                    561              DW      018FBH
  1718                    562              DW      01817H
  3317                    563              DW      01733H
  4F16                    564              DW      0164FH
  6B15                    565              DW      0156BH
  8714                    566              DW      01487H
  A313                    567              DW      013A3H
  BF12                    568              DW      012BFH
  DB11                    569              DW      011DBH          ;SI=860 (430)
  F710                    570              DW      010F7H
  1210                    571              DW      01012H
  2E0F                    572              DW      00F2EH          ;SI=866 (#433)
  4A0E                    573              DW      00E4AH
  650D                    574              DW      00D65H
  810C                    575              DW      00C81H
  9C0B                    576              DW      00B9CH
  B80A                    577              DW      00AB8H
  D309                    578              DW      009D3H
  EF08                    579              DW      008EFH          ;SI=880 (440)
  0A08                    580              DW      0080AH
  2507                    581              DW      00725H
  4106                    582              DW      00641H
  5C05                    583              DW      0055CH
  7704                    584              DW      00477H
  9303                    585              DW      00393H
  AE02                    586              DW      002AEH
  C901                    587              DW      001C9H
  E400                    588              DW      000E4H
```

```
OBJ                     LINE    SOURCE
0000                     589            DW      00000H              ;SI=900 (450)
                         590
                         591    ATCS    ENDS
                         592
                         593
                         594
                         595    STACK_SEG       SEGMENT WORD AT 40H
(25                      596            DW      25      DUP(?)
????
)
                         597    STACK_TOP LABEL WORD
                         598    STACK_SEG       ENDS
                         599
                         600
                         601
                         602    ;################################################################
                         603    ;
                         604    ;PART : 1
                         605    ;
                         606    ;STARTS THE CODE SEGMENT AND INITIALIZES ALL THE SEGMENT REGISTERS
                         607    ;
                         608    ;AND STACKS, AND DEFINES ADDRESSES OF ALL THE I/O PORTS.
                         609    ;
                         610    ;################################################################
                         611
                         612
                         613
                         614    CODE_SEG        SEGMENT WORD AT 0FC50H
                         615
                         616    ASSUME CS:CODE_SEG,DS:SAMP,SS:STACK_SEG,ES:ATCS
                         617
                         618    ;----------------------------------------------------------------
:0                       619    LEDP    EQU     0C0H                ;LEDP CONTAINS 8_ BIT D0 TO D7,
                         620                                        ;D7 IS FOR LED.
30                       621    LED_ON  EQU     80H
10                       622    LED_OFF EQU     00H                 ;D0 TO D2 ARE FOR DECODER TO CHOOSE
                         623                                        ;ONE OF SIX ANALOGUE INPUT CHANNALS.
16                       624    CHAN_Va EQU     06H                 ;SELECT CHANNAL Va, D3 TO D6 ARE UNUSED.
                         625
                         626    ;----------------------------------------------------------------
A0                       627    ADCP    EQU     0A0H                ;INPUT AND STARTING PORT OF ADC,
                         628                                        ;D15 IS  SIGN_ BIT AND D14 IS ZC SIGNAL,
                         629                                        ;D0 TO D11 IS SAMPLE FROM 12_BIT_ADC.
40                       630    ZC_MASK_OF_ADC  EQU     40H
80                       631    SIGN_BIT_MASK   EQU     8000H
FF                       632    SAMPLE_MASK     EQU     0FFFH
                         633
                         634    ;----------------------------------------------------------------
80                       635    SWP     EQU     80H                 ;SWP CONTAINS 8_ BIT D0 TO D7,
80                       636    FORM_MASK       EQU     80H         ;D6 IS ZERO- CROSSING SIGNAL.
40                       637    ZC_MASK_OF_SWP  EQU     40H         ;D5 AND D7 ARE UNUSED, D0 TO D4 ARE
                         638                                        ;FOR MANUAL SET SWITCHES TO DECIDE
                         639                                        ;THE MAX ORDER OF HARMONICS THAT NEEDS
                         640                                        ;TO BE MEASURED.
1F                       641    HA_ORDER_MASK   EQU     1FH
```

```
OBJ                     LINE     SOURCE

                          642
                          643     ;-------------------------------------------------------------------
78                        644     CTRC     EQU      78H                ;CONTRAL WORD OF COUNTER.
36                        645     CTR0_CNTL_WORD  EQU      36H         ;INITIALIZES COUNTER0 AS SQUARE WAVE,
                          646                                         ;BINARY, MODE 3.
74                        647     CTR1_CNTL_WORD  EQU      74H         ;INITIALIZES COUNTER1 AS RATE GENERATOR,
                          648                                         ;BINARY, MODE 2.
                          649
                          650     ;-------------------------------------------------------------------
68                        651     CTR1     EQU      68H                ;COUNTER1 PORT.
60                        652     CTR0     EQU      60H                ;COUNTER0 PORT.
                          653
                          654     ;-------------------------------------------------------------------
40                        655     PHASE    EQU      40H                ;0 OR 90 DEG MODULATING CLK SELECT PORT,
                          656                                         ;ONLY D7 IS EMPLOYED IN THE PORT.
80                        657     MOD_CLK_0        EQU      80H
                          658
00                        659     MOD_CLK_90       EQU      00H
                          660
                          661     ;-------------------------------------------------------------------
20                        662     GATE     EQU      20H                ;MODULATING CLK SYNCHRONIZED PORT.
                          663
                          664     ;-------------------------------------------------------------------
                          665
                          666
                          667
                          668     BEGIN    PROC     FAR
                          669
                          670
                          671
FA                        672              CLI                         ;DISABLE INTERRUPT.
B84500                    673              MOV AX,SAMP
8ED8                      674              MOV DS,AX                   ;INITIALIZES DATA SEG.
B84000                    675              MOV AX,STACK_SEG
8ED0                      676              MOV SS,AX                   ;INITIALIZES STACK SEG.
B800FC                    677              MOV AX,ATCS
8EC0                      678              MOV ES,AX                   ;INITIALIZES EXTRA SEG.
BC3200                    679              MOV SP,OFFSET STACK_TOP     ;INITIALIZES STACK.
                          680
                          681     ;#################################################################
                          682     ;
                          683     ;PART : 2
                          684     ;
                          685     ;THIS ROUTINE INITIALIZES MOST I/O PORTS AND TEMPORARY REGISTERS.
                          686     ;
                          687     ;IT ALSO MODULATES SIX CHANNELS CYCLICALLY  AT  EITHER 0_ DEG.
                          688     ;
                          689     ;OR 90_ DEG. PHASE_ SHIFT MODULATING CLK.   THIS MODULATING CLOCK CAN
                          690     ;
                          691     ;HAVE DIFFERENT HARMONIC FREQUENCIES WHICH WOULD BE ASSIGNED BY THE
                          692     ;
                          693     ;EXTERNAL SWITCH.   IT ALSO DIRECTS ADC TO OPERATE IN SYNCHRONIZATION
                          694     ;
                          695     ;WITH THE FUNDAMENTAL FILTERED ZERO_ CROSSING SIGNAL.   THE MODULATED
                          696     ;
```

```
OBJ                     LINE    SOURCE

                         697    ;SAMPLES HAVE TO BE SUMMED UP AND AVERAGED TO GET THE RESULTANT D.C.
                         698    ;
                         699    ;TERMS AS EXPRESSED IN EQUATION SET (3.7) .
                         700    ;
                         701    ;THE INPUT FUNDAMENTAL FREQUENCY OF THE SIGNAL MUST NOT BE LESS THAN
                         702    ;
                         703    ;45 HZ AND NOT GREATER THAN 65 HZ.
                         704    ;
                         705    ;THE CPU CLK FREQUENCY IS 5 MHZ, THE OPERATIONAL CLOCK FREQUENCY OF
                         706    ;
                         707    ;COUNTER0 AND COUNTER1 IS 2.5 MHZ AND THE ADC CLK FREQUENCY IS 1.25 MHZ.
                         708    ;
                         709    ;THE DATA SAMPLING TIME IS 13.2 MICRO SEC.
                         710    ;
                         711    ;
                         712    ;
                         713    ;PROCEDURES INVOLVED :
                         714    ;
                         715    ;MOD_CLK_SYN,
                         716    ;MOD_CLK_UPDATE,
                         717    ;DUMMY_READ(ZC_ADC,MOD_CLK_UPDATE_1),
                         718    ;ZC_ADC,
                         719    ;MOD_UPDATE_1,
                         720    ;AVERAGING(CED),
                         721    ;ZC_ADC,
                         722    ;MOD_UPDATE_1,
                         723    ;AVERAGING(CED),
                         724    ;MOD_CLK_UPDATE_1.
                         725    ;
                         726    ;
                         727    ;
                         728    ;SCATCH PAD REGISTERS :
                         729    ;
                         730    ;R6_    CHANNEL POINTER.
                         731    ;R7_    NUMBER OF NET +VE OR -VE SAMPLES.
                         732    ;R8_    RESULTANT VALUE OF THE COUNT_ DOWN COUNTER, COUNTER1.
                         733    ;R11_   XYP (Xk OR Yk POINTER) .
                         734    ;R14_   HARMONIC ORDER THAT IS GOING TO BE EXECUTED.
                         735    ;R15_   MAX. ORDER OF HARMONIC THAT NEEDS TO BE MEASURED,
                         736    ;       SELECTED BY EXTERNAL SWITCH.
                         737    ;ZCC    THE VALUE OF COUNTER1.
                         738    ;ZCCP_  POINTER OF ZCC.
                         739    ;
                         740    ;###############################################################
                         741
                         742
                         743
B000                     744    LBEGIN: MOV AL,LED_OFF
E6C0                     745            OUT LEDP,AL             ;TURN OFF LED.
B006                     746            MOV AL,CHAN_Va
E6C0                     747            OUT LEDP,AL             ;AT THE BEGINNING OF MEASUREMENT CPU SELECTS
                         748                                    ;CHANNEL 6 WHICH ACCESSES Va AS THE FIRST
                         749                                    ;CHANNEL TO BE PROCESSED.
                         750
B90900                   751            MOV CX,9                ;WAIT 10 MICRO. SEC. FOR MULTIPLEXER SETTLE
```

```
OBJ                     LINE    SOURCE

                         752                                    ;DOWN.
50                       753    LA217:  PUSH AX
58                       754            POP AX
E2FC                     755            LOOP LA217
                         756
B036                     757            MOV AL,CTR0_CNTL_WORD
                         758                                    ;INITIALIZES COUNTER0 AS SQUARE WAVE, BINARY,
                         759                                    ;MODE 3 .
E678                     760            OUT CTRC,AL
                         761
B074                     762            MOV AL,CTR1_CNTL_WORD
                         763                                    ;INITIALIZES COUNTER1 AS RATE GENERATOR,
                         764                                    ;BINARY, MODE 2.
E678                     765            OUT CTRC,AL
                         766
B8FFFF                   767            MOV AX,0FFFFH           ;INITIALIZES COUNTER1 WITH 0FFFFH.
E768                     768            OUT CTR1,AX
                         769
B080                     770            MOV AL,MOD_CLK_0
E640                     771            OUT PHASE,AL            ;CHOOSE PHASE 0 DEG MODULATING CLK AT THE
                         772                                    ;BEGINNING, TO MODULATE THE INPUT SIGNAL.
                         773
E480                     774            IN AL,SWP               ;INPUT FROM EXTERNAL SWITCH PORT TO SEE
                         775                                    ;MAX. ORDER OF HARMONIC THAT NEEDS TO BE
                         776                                    ;MEASURED.
241F                     777            AND AL,HA_ORDER_MASK
BB9414                   778            MOV BX,OFFSET R15
8807                     779            MOV [BX],AL
                         780
B850C3                   781            MOV AX,50000D           ;INITIALIZES THE MODULATING CLK IMPLEMENTED
                         782                                    ;BY COUNTER0 OF 8254 AS 50 HZ WHICH IS
                         783                                    ;EQUIVALENT TO 2.5 MHZ/50 HZ=50 000.
E760                     784            OUT CTR0,AX
                         785
E81F04                   786            CALL MOD_CLK_SYN        ;SYNCHRONIZE MODULATING CLK.
                         787
E8F703                   788            CALL MOD_CLK_UPDATE     ;UPDATE MODULATING CLK.
                         789
E8E206                   790            CALL DUMMY_READ         ;GUIDE THE ADC INTO NORMAL OPERATION.
                         791
33F6                     792            XOR SI,SI               ;NULL SI .
                         793
BB8E14                   794            MOV BX,OFFSET R11
8937                     795            MOV [BX],SI             ;INITIALIZES XYP .
                         796
BB5E14                   797            MOV BX,OFFSET ZCCP
8937                     798            MOV [BX],SI             ;INITIALIZES ZCCP .
                         799
B001                     800            MOV AL,1
BB9314                   801            MOV BX,OFFSET R14
                         802
8807                     803            MOV [BX],AL             ;R14 INITIALIZED WITH FUNDAMENTAL .
                         804
B90600                   805    LAC:    MOV CX,6                ;CX  6 CHANNELS .
BB8414                   806            MOV BX,OFFSET R6        ;INITIALIZES CHANNEL POINTER WITH CHANNEL
```

```
OBJ                     LINE    SOURCE

                         807                             ;Va AT THE BEGINNING.
                         808
890F                     809    LA11:    MOV [BX],CX     ;CHANNEL STARTS FROM 6 DOWN TO 1 .
                         810
E86002                   811             CALL ZC_ADC     ;POLL ZC PORT AND OPERATE ADC AT
                         812                             ;ZERO PHASE SHIFT MOD_ CLK .
                         813
E8B803                   814             CALL MOD_CLK_UPDATE_1
                         815
B000                     816             MOV AL,MOD_CLK_90
E640                     817             OUT PHASE,AL
                         818
E8F802                   819             CALL AVERAGING
                         820
E85302                   821             CALL ZC_ADC     ;POLL ZC AND OPERATE ADC AT
                         822                             ;90_DEG PHASE SHIFT MOD_ CLK .
                         823
E8AB03                   824             CALL MOD_CLK_UPDATE_1
                         825
BB8414                   826             MOV BX,OFFSET R6
8B07                     827             MOV AX,[BX]
48                       828             DEC AX          ;NEXT CHANNEL.
3D0000                   829             CMP AX,0        ;CHECK TO SEE WHETHER ALL 6 CHANNEL SERVED ?
7502                     830             JNE L3211       ;NO .
                         831
B006                     832             MOV AL,CHAN_Va  ;YES, INITIALIZES CHANNEL Va AGAIN.
                         833
E6C0                     834    L3211:   OUT LEDP,AL     ;SELECT NEXT CHANNEL.
                         835
B080                     836             MOV AL,MOD_CLK_0
E640                     837             OUT PHASE,AL
                         838
E8DC02                   839             CALL AVERAGING
                         840
BB8414                   841             MOV BX,OFFSET R6
8B0F                     842             MOV CX,[BX]
E2CE                     843             LOOP LA11       ;CX_ NEXT CHANNEL.
                         844
BB9414                   845             MOV BX,OFFSET R15
8A17                     846             MOV DL,[BX]     ;DL_ MAX ORDER OF HARMONIC THAT NEEDS TO BE
                         847                             ;MEASURED.
                         848
BB9314                   849             MOV BX,OFFSET R14
8A07                     850             MOV AL,[BX]     ;AL_ ORDER OF HARMONIC THAT JUST EXECUTED.
3AC2                     851             CMP AL,DL       ;CHECK WHETHER EXECUTED ASSIGNED ORDERS ?
7409                     852             JZ LK21         ;IF FINISH JUMP TO PART 3.
                         853
FEC0                     854             INC AL          ;NO .
8807                     855             MOV [BX],AL     ;NEXT ORDER OF HARMONIC THAT NEEDS TO BE
                         856                             ;MEASURED.
                         857
E87903                   858             CALL MOD_CLK_UPDATE_1
                         859
EBB1                     860             JMP LAC         ;REPEAT EXECUTE INPUT ROUTINE.
                         861
```

```
OBJ                     LINE    SOURCE

                         862
                         863
                         864    ;#################################################################
                         865    ;
                         866    ;PART : 3
                         867    ;
                         868    ;THIS ROUTINE PROCESSES EQUATION SET (3.7) AND IS PROGRAMMED TO CALCULATE
                         869    ;
                         870    ;D.C. TERMS OF  2Uk(COS θk)/PI*(p+1)k  AND  2Uk(SIN θ )/PI*(p+1)k  IN THE
                         871    ;
                         872    ;EQUATION SET (3.7) BASED ON THE METHOD DESCRIBED IN THE SECTION (3_2_3).
                         873    ;
                         874    ;EQUATIONS (3.7.6) TO (3.7.8) EACH HAVE TWO D.C. TERMS.     THE 2ND TERM
                         875    ;
                         876    ;ARISING FROM THE HIGHER HARMONICS COULD BE ELIMINATED BY DIVIDING EQUATIONS
                         877    ;
                         878    ;(3.7.18), (3.7.21) AND (3.7.24) BY A FACTOR OF 3 AND THEN SUBTRACTING THEM
                         879    ;
                         880    ;FROM EQUATIONS (3.7.6) TO (3.7.8) RESPECTIVELY.     BY REPEATING THE SAME
                         881    ;
                         882    ;PROCEDURE, THOSE D.C. TERMS WHICH EXIST IN EQUATIONS (3.7.1) TO (3.7.5)
                         883    ;
                         884    ;CAN BE ELIMINATED.
                         885    ;
                         886    ;THE D.C. TERMS ARE STORED IN MEMORY IN THE FOLLOWING ORDER :
                         887    ;
                         888    ;     [ 0Vak  90Vak   0Vbk  90Vbk   0Vck  90Vck
                         889    ;
                         890    ;       0Iak  90Iak   0Ibk  90Ibk   0Ick  90Ick ]
                         891    ;
                         892    ;WHERE SUBSCRIPT k IS THE ORDER OF THE HARMONIC.
                         893    ;
                         894    ;ACCORDING TO THE ABOVE DATA STRUCTURE, EACH SET OF THE VALUES RELATED
                         895    ;
                         896    ;TO A PARTICULAR HARMONIC OCCUPIES 2*2*6 BYTES OF MEMORY IN ADDRESS XY.
                         897    ;
                         898    ;THIS MEANS THAT THE STARTING ADDRESS OFFSET OF EACH SET OF DATA
                         899    ;
                         900    ;RELATED TO A PARTICULAR HARMONIC IS A MULTIPLE OF 24.     ALL DATA ARE
                         901    ;
                         902    ;EXPRESSED IN 2'S COMPLEMENT FORM.
                         903    ;
                         904    ;EIGHT PROCEDURES ARE NEEDED TO BE PROCESSED IN THIS PART, NAMELY
                         905    ;
                         906    ;PROCEDURE "THREE_7_8" DOWN TO "THREE_7_1" .
                         907    ;
                         908    ;
                         909    ;
                         910    ;PROCEDURES INVOLVED :
                         911    ;
                         912    ;THREE_7_8(DEHA),
                         913    ;THREE_7_7(DEHA),
                         914    ;THREE_7_6(DEHA),
                         915    ;THREE_7_5(DEHA),
                         916    ;THREE_7_4(DEHA),
```

```
OBJ                     LINE    SOURCE

                         917    ;THREE_7_3(DEHA),
                         918    ;THREE_7_2(DEHA),
                         919    ;THREE_7_1(DEHA).
                         920    ;
                         921    ;
                         922    ;
                         923    ;SCATCH PAD REGISTERS :
                         924    ;
                         925    ;R0_ POINTER FOR CHANNEL.
                         926    ;R1_ LAST D.C. TERM ADDRESS POINTER.
                         927    ;R2_ DIVISOR.
                         928    ;R3_ NEXT D.C. TERM ADDRESS OFFSET.
                         929    ;R5_ POINTER FOR 0 AND 90 DEG.
                         930    ;R6_ GREATEST DIVISOR.
                         931    ;
                         932    ;#################################################################
                         933    ;
                         934    ;
E89706                   935    LK21:   CALL THREE_7_8
E8D406                   936            CALL THREE_7_7
E81107                   937            CALL THREE_7_6
E84E07                   938            CALL THREE_7_5
E89807                   939            CALL THREE_7_4
E8E207                   940            CALL THREE_7_3
E83908                   941            CALL THREE_7_2
E8AA08                   942            CALL THREE_7_1
                         943    ;
                         944    ;
                         945    ;#################################################################
                         946    ;
                         947    ;PART : 4
                         948    ;
                         949    ;CALCULATE THE AVERAGE INPUT FUNDAMENTAL FREQUENCY OF 6 CHANNELS
                         950    ;
                         951    ;BASED ON THE FIRST 12 INPUT VALUES FROM COUNTER1 USING THE FOLLOWING
                         952    ;
                         953    ;FREQ*10 = ( 10*12*2.5E6 ) / (SUM[ ZCC ]) ,
                         954    ;
                         955    ;WHERE OPERATING FREQUENCY OF COUNTER1 IS 2.5 MHZ, 10 IS A SCALING
                         956    ;
                         957    ;FACTOR AND SUM[ZCC] IS THE SUMMATION OF THE 12 INPUT VALUES.
                         958    ;
                         959    ;
                         960    ;
                         961    ;PROCEDURES INVOLVED :
                         962    ;
                         963    ;DIV_32 .
                         964    ;
                         965    ;#################################################################
                         966    ;
                         967    ;
                         968    ;
BB6014                   969    LQ9:    MOV BX,OFFSET ZCC
33F6                     970            XOR SI,SI               ;NULL SI.
B90C00                   971            MOV CX,12D              ;CX_ NUMBER OF EXECUTING TIMES OF LOOP.
```

```
OBJ                     LINE    SOURCE
                        1027    ;R8_ NUMBER OF X_K AND Y_K  THAT NEEDS TO BE MANAGED.
                        1028    ;
                        1029    ;#################################################################
                        1030
                        1031
                        1032
33F6                    1033            XOR SI,SI               ;NULL SI.
BB8214                  1034            MOV BX,OFFSET R5
8937                    1035            MOV [BX],SI             ;INITIALIZES AMP AND ANG ADDRESS POINTER.
                        1036
BB7814                  1037            MOV BX,OFFSET R0
8937                    1038            MOV [BX],SI             ;INITIALIZES XY ADDRESS POINTER.
                        1039
33C0                    1040            XOR AX,AX               ;NULL AX.
                        1041
E480                    1042            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE THE MAX ORDER
                        1043                                    ;OF HARMONIC THAT NEEDS TO BE MEASURED.
241F                    1044            AND AL,HA_ORDER_MASK
                        1045
BA0600                  1046            MOV DX,6                ;6 CHANNALS.
F7E2                    1047            MUL DX                  ;NUMBER OF X_K & Y_K THAT NEEDS TO BE MANAGED.
                        1048
BB8814                  1049            MOV BX,OFFSET R8        ;R8_ NUMBER OF EXECUTING TIMES OF THE LOOP
                        1050                                    ;WHICH IS EQUAL TO THE PRODUCT OF NUMBER OF
                        1051                                    ;CHANNELS AND MAX ORDER OF HARMONIC THAT
                        1052                                    ;NEEDS TO BE MEASURED.
8907                    1053    L00:    MOV [BX],AX
                        1054
BB7814                  1055            MOV BX,OFFSET R0
8B37                    1056            MOV SI,[BX]             ;SI_ POINTER OF ADDRESS XY.
                        1057
BBF811                  1058            MOV BX,OFFSET XY
8B00                    1059            MOV AX,[BX+SI]          ;AX_ X_K .
                        1060
BB7A14                  1061            MOV BX,OFFSET R1
8907                    1062            MOV [BX],AX
                        1063
BBF811                  1064            MOV BX,OFFSET XY
83C602                  1065            ADD SI,2
8B38                    1066            MOV DI,[BX+SI]          ;DI_ Y_K .
                        1067
8BD0                    1068            MOV DX,AX               ;CHECK SIGN BIT OF X_K FOR PREPARATION OF
                        1069                                    ;MULTIPLICATION.
F6C680                  1070            TEST DH,80H
7402                    1071            JZ LM11
                        1072
F7D8                    1073            NEG AX
                        1074
8BD0                    1075    LM11:   MOV DX,AX
F7E2                    1076            MUL DX                  ;Xk ^2 .
                        1077
BB7E14                  1078            MOV BX,OFFSET R3        ;MSW_  Xk ^2 .
8917                    1079            MOV [BX],DX
                        1080
BB8014                  1081            MOV BX,OFFSET R4        ;LSW_  Xk ^2 .
```

```
OBJ                     LINE    SOURCE

8907                    1082            MOV [BX],AX
                        1083
8BD7                    1084            MOV DX,DI               ;CHECK SIGN BIT OF Yk FOR PREPARATION OF
                        1085                                    ;MULTIPLICATION.
F6C680                  1086            TEST DH,80H
7402                    1087            JZ LM12
                        1088
F7DA                    1089            NEG DX
                        1090
8BC2                    1091    LM12:   MOV AX,DX
F7E2                    1092            MUL DX                  ;Yk ^2 .
                        1093
8B3F                    1094            MOV DI,[BX]             ;DI_ Xk ^2 _ LSBY .
                        1095
BB7E14                  1096            MOV BX,OFFSET R3
8B2F                    1097            MOV BP,[BX]             ;BP_ Xk ^2 _ MSBY .
                        1098
03C7                    1099            ADD AX,DI
13D5                    1100            ADC DX,BP               ;Xk ^2 + Yk ^2  .
                        1101
E8BD03                  1102            CALL SROOT              ;SRQ ( Xk ^2 + Yk ^2 ) .
                        1103
BB8214                  1104            MOV BX,OFFSET R5
8B37                    1105            MOV SI,[BX]
                        1106
BBA00F                  1107            MOV BX,OFFSET AMP
8908                    1108            MOV [BX+SI],CX          ;STORE ROOT .
                        1109
BB7A14                  1110            MOV BX,OFFSET R1
8B07                    1111            MOV AX,[BX]             ;AX_ Xk WITH SIGN_ BIT .
                        1112
8BD0                    1113            MOV DX,AX
81E20080                1114            AND DX,8000H            ;TEST SIGN .
7402                    1115            JZ LQ91                 ;+VE Xk .
                        1116
F7D8                    1117            NEG AX                  ;-VE Xk  NEEDS TO BE CHANGED TO +VE VALUE .
                        1118
BD0000                  1119    LQ91:   MOV BP,0                ;BP_ MSW OF DIVISOR.
BAFFFF                  1120            MOV DX,0FFFFH           ;0FFFFH IS SCALING FACTOR OF DIVIDEND .
F7E2                    1121            MUL DX                  ;SCALING .
8BF8                    1122            MOV DI,AX
                        1123
E86203                  1124            CALL DIV_32             ;Xk/Ak .
                        1125
E82004                  1126            CALL FANG               ;FIND ADS[ANG] .
                        1127
                        1128    ;θk IS BASED ON THE FUNDAMENTAL SCALE.    ON HARMONIC SCALE, θk=K*θ .
                        1129    ;θk IS CHECKED AND ADJECTED TO ANGLE TO THE RANGE OF 0 AND 360 DEG.
                        1130
33C0                    1131            XOR AX,AX
E480                    1132            IN AL,SWP
241F                    1133            AND AL,HA_ORDER_MASK
97                      1134            XCHG DI,AX
F7E7                    1135            MUL DI
3D100E                  1136            CMP AX,3600D
```

```
OBJ                     LINE    SOURCE

7303                    1137            JNB LQ95
2D100E                  1138            SUB AX,3600D
8BF8                    1139    LQ95:   MOV DI,AX
                        1140
BB7814                  1141            MOV BX,OFFSET R0
8B37                    1142            MOV SI,[BX]             ;SI_ XY ADDRESS INDEX .
                        1143
BBF811                  1144            MOV BX,OFFSET XY
                        1145
8B00                    1146            MOV AX,[BX+SI]          ;Xk SIGN .
250080                  1147            AND AX,8000H            ;MASK OFF OTHER BITS EXCEPT SIGN_ BIT.
83C602                  1148            ADD SI,2
                        1149
8B10                    1150            MOV DX,[BX+SI]          ;Yk SIGN.
81E20080                1151            AND DX,8000H            ;MASK OFF OTHER BITS EXCEPT SIGN_ BIT.
83C602                  1152            ADD SI,2                ;SI_ NEXT XY POINTER.
                        1153
BB7814                  1154            MOV BX,OFFSET R0
8937                    1155            MOV [BX],SI
                        1156
                        1157
                        1158
                        1159    ;DETERMINE ONE OF FOUR QUADRANTS THE ANGLE BELONGS ACCORDING TO
                        1160    ;FIG.(3.4)    :
                        1161
D1C0                    1162            ROL AX,1                ;AX_ BIT 1 CONTAINS THE SIGN OF Xk .
D1C0                    1163            ROL AX,1                ;DX_ BIT 0 CONTAINS THE SIGN OF Xk .
250200                  1164            AND AX,2
                        1165
D1C2                    1166            ROL DX,1                ;DX_ BIT 1 (Xk SIGN) AND BIT 0 (Yk SIGN) .
81E20100                1167            AND DX,1
03D0                    1168            ADD DX,AX
                        1169
83FA00                  1170            CMP DX,0
7503                    1171            JNE LQ2K
EB2390                  1172            JMP LQ0K                ;[+,+]      1_ QUAD.
                        1173
83FA02                  1174    LQ2K:   CMP DX,2
750A                    1175            JNE LQ3K
BD0807                  1176            MOV BP,1800D
87FD                    1177            XCHG DI,BP              ;[-,+]      2_ QUAD.
2BFD                    1178            SUB DI,BP
EB1490                  1179            JMP LQ0K
                        1180
83FA03                  1181    LQ3K:   CMP DX,3                ;[-,-]      3_ QUAD.
7507                    1182            JNE LQ4K
81C70807                1183            ADD DI,1800D
EB0890                  1184            JMP LQ0K
                        1185
BD100E                  1186    LQ4K:   MOV  BP,3600D           ;[+,-]      4_ QUAD.
87EF                    1187            XCHG BP,DI
2BFD                    1188            SUB DI,BP
                        1189
BB8214                  1190    LQ0K:   MOV BX,OFFSET R5
8B37                    1191            MOV SI,[BX]             ;INDEX OF ANG ADDRESS.
```

```
  OBJ                   LINE     SOURCE

                        1192
3 BBCC10                1193             MOV BX,OFFSET ANG
E 8938                  1194             MOV [BX+SI],DI          ;STORE ANG.
0 83C602                1195             ADD SI,2                ;NEXT ADDRESS INDEX.
                        1196
3 BB8214                1197             MOV BX,OFFSET R5
6 8937                  1198             MOV [BX],SI
                        1199
3 BB8814                1200             MOV BX,OFFSET R8        ;TEST NUMBER OF EXECUTING TIMES OF LOOP.
3 8B07                  1201             MOV AX,[BX]
) 48                    1202             DEC AX
E 7403                  1203             JZ LQR
                        1204
0 E905FF                1205             JMP LQQ
                        1206
                        1207
                        1208
                        1209     ;#################################################################
                        1210     ;
                        1211     ;PART :  6
                        1212     ;
                        1213     ;CHOOSE THE ANGLE OF THE FUNDAMENTAL COMPONENT OF Va AS THE REFERENCE.
                        1214     ;
                        1215     ;ALL ANGLES OF HARMONIC COMPONENTS REFER TO IT.      IF ANY ANGLGE IS
                        1216     ;
                        1217     ;LARGE THAN 360 DEGREE, THE CPU ADJUSTS THE ANGLE TO THE RANGE OF
                        1218     ;
                        1219     ;0 TO 360 DEG.
                        1220     ;
                        1221     ;#################################################################
                        1222
                        1223
                        1224
3 33C0                  1225     LQR:    XOR AX,AX               ;NULL AX .
                        1226
5 E480                  1227             IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE THE MAX ORDER
                        1228                                     ;OF HARMONIC THAT NEEDS TO BE MEASURED.
7 241F                  1229             AND AL,HA_ORDER_MASK
9 D1E0                  1230             SHL AX,1                ;2*AX .
B 8BE8                  1231             MOV BP,AX               ;BP_ 2*AX .
                        1232
) BA0300                1233             MOV DX,3                ;DX_ 3*AX .
0 F7E2                  1234             MUL DX
                        1235
2 33F6                  1236             XOR SI,SI               ;NULL SI .
4 BBCC10                1237             MOV BX,OFFSET ANG
7 8B10                  1238             MOV DX,[BX+SI]          ;GET ANG. OF Va OF FUNDAMENTAL .
9 F7DA                  1239             NEG DX                  ;NEGATIVE IT .
                        1240
3 8BC8                  1241             MOV CX,AX               ;CX_ 2*3*AX .
) 8B00                  1242     LT31:   MOV AX,[BX+SI]          ;GET ANG(I) .
  03C2                  1243             ADD AX,DX               ;ANG(I) - REFERENCE ANG .
1 8900                  1244             MOV [BX+SI],AX          ;STORE NEW VALUE OF ANG(I) .
3 83C602                1245             ADD SI,2                ;NEXT ANG ADDRESS INDEX .
6 E2F5                  1246             LOOP LT31               ;TEST EXECUTING TIMES OF THE LOOP.
```

```
   OBJ                      LINE     SOURCE

                            1247
8 8BCD                      1248             MOV CX,BP
A BE0000                    1249             MOV SI,0
                            1250
0 8B00                      1251     LTB4:   MOV AX,[BX+SI]
F 50                        1252             PUSH AX
2 056009                    1253             ADD AX,2400D
                            1254
3 3D100E                    1255             CMP AX,3600D
6 720B                      1256             JB LTB5
                            1257
8 2D100E                    1258             SUB AX,3600D
8 3D100E                    1259             CMP AX,3600D
E 7203                      1260             JB LTB5
                            1261
0 2D100E                    1262             SUB AX,3600D
3 83C602                    1263     LTB5:   ADD SI,2
5 8900                      1264             MOV [BX+SI],AX
                            1265
8 58                        1266             POP AX
9 05B004                    1267             ADD AX,1200D
C 3D100E                    1268             CMP AX,3600D
F 720B                      1269             JB LTB6
                            1270
1 2D100E                    1271             SUB AX,3600D
4 3D100E                    1272             CMP AX,3600D
7 7203                      1273             JB LTB6
                            1274
9 2D100E                    1275             SUB AX,3600D
C 83C602                    1276     LTB6:   ADD SI,2
F 8900                      1277             MOV [BX+SI],AX
1 83C602                    1278             ADD SI,2
                            1279
4 E2C7                      1280             LOOP LTB4
                            1281
                            1282
                            1283
                            1284     ;#################################################################
                            1285
                            1286     ;PART : 7
                            1287
                            1288     ;TRANSFER : (1) THE TOTAL NUMBER OF DATA THAT NEEDS TO BE TRANSFERRED,
                            1289
                            1290     ;[2] AMPLITUDES AND ANGLES OF V  & I  FROM FUNDAMENTAL TO THE ASSIGNED
                            1291
                            1292     ;HARMONICS ORDER [MAX 25] AND  (3) THE AVERAGE INPUT FREQUENCY TO GPIB
                            1293
                            1294     ;BUS.      THE WHOLE PROGRAM WILL BE REPEATED AFTER THE DATA HAS BEEN
                            1295
                            1296     ;TRANSFERRED TO THE INTERFACE.
                            1297
                            1298
                            1299
                            1300     ;PROCEDURES INVOLVED :
                            1301     ;
```

```
OBJ                     LINE     SOURCE

                        13302    ;GPIB,
                        13303    ;GPIG,
                        13304    ;GPIG1.
                        13305    ;
                        13306    ;
                        13307    ;
                        13308    ;SCATCH PAD REGISTERS :
                        13309    ;
                        13310    ;
                        13311    ;
                        13312    ;R4_ THE TOTAL NUMBER OF AMPLITUDES OR ANGLES THAT NEEDS TO BE TRANSFERED
                        13313    ;    TO GPIB.
                        13314    ;    INITIALLY THE CONTENT OF R4 =
                        13315    ;    6*(MAX ORDER OF HARMONIC THAT NEEDS TO BE MEASURED)
                        13316    ;    AND WILL EVENTUALLY DECREASE TO ZERO.
                        13317    ;
                        13318    ;R5_ THE TOTAL NUMBER OF DATA THAT NEEDS TO BE TRANSFERED TO GPIB.
                        13319    ;    INITIALLY THE CONTENT OF R5 =
                        13320    ;    6*2*(MAX ORDER OF HARMONIC THAT NEEDS TO BE MEASURED) + 1
                        13321    ;    AND WILL EVENTUALLY DECREASE TO ZERO.
                        13322    ;
                        13323    ;
                        13324    ;
                        13325    ;NOTES :
                        13326    ;
                        13327    ;TO UNDERSTAND THIS ROUTINE ONE NEEDS TO CONSULT THE DATA SHEET OF
                        13328    ;
                        13329    ;MC68488 AND IEEE_ 488 BUS SPECIFICATION.
                        13330    ;
                        13331    ;################################################################
                        13332    ;
                        13333    ;
                        13334    ;
6 33C0                  13335            XOR AX,AX               ;NULL AX .
                        13336    ;
8 E480                  13337            IN AL,SWP
A 241F                  13338            AND AL,HA_ORDER_MASK    ;AL_ MAX ORDER OF HARMONIC THAT NEEDS
                        13339                                    ;TO BE MEASURED.
                        13340    ;
E0 BA0600               13341            MOV DX,6                ;6*AX .
E3 F7E2                 13342            MUL DX
                        13343    ;
1 BB8014                13344            MOV BX,OFFSET R4
4 8907                  13345            MOV [BX],AX
                        13346    ;
6 D1E0                  13347            SHL AX,1                ;2*6*AX .
8 40                    13348            INC AX                  ;2*6*AX +1 .
                        13349    ;
9 BB8214                13350            MOV BX,OFFSET R5
C 8907                  13351            MOV [BX],AX
                        13352    ;
E B009                  13353            MOV AL,9
0 E6E4                  13354            OUT 0E4H,AL             ;INITIALIZES INTERFACE ADDRESS AS 9 .
                        13355    ;
2 B080                  13356            MOV AL,80H              ;RESET GPIB .
```

```
  OBJ                   LINE      SOURCE
4 E6E3                  1357              OUT 0E3H,AL
                        1358
6 32C0                  1359              XOR AL,AL
8 E6E3                  1360              OUT 0E3H,AL           ;CLEAR RESET.
                        1361
A E6E0                  1362              OUT 0E0H,AL           ;NO INTERRUPTS .
                        1363
C E6E2                  1364              OUT 0E2H,AL           ;NO OPTION .
                        1365
E B041                  1366              MOV AL,41H
0 E6E5                  1367              OUT 0E5H,AL           ;SERIAL POLL AND SQR .
                        1368
2 E4E1                  1369    LHT:      IN AL,0E1H            ;SPE OCCURED ?
4 2404                  1370              AND AL,4
6 74FA                  1371              JZ LHT                ;NO .
                        1372
                        1373                                    ;YES .
8 E4E1                  1374    LJT:      IN AL,0E1H            ;SERIAL POLL END ?
A 2404                  1375              AND AL,4
C 75FA                  1376              JNZ LJT               ;NO .
                        1377
                        1378                                    ;YES .
E 32C0                  1379              XOR AL,AL
0 E6E5                  1380              OUT 0E5H,AL           ;CLEAR RSV .
                        1381
                        1382
                        1383
                        1384    ;-------------------------------------------------------------------
                        1385    ;TRANSFER TOTAL NUMBER OF DATA THAT NEEDS TO BE TRANSFERRED :
                        1386
2 BB8214                1387              MOV BX,OFFSET R5
5 B90100                1388              MOV CX,1
8 BE0000                1389              MOV SI,0
  E8E903                1390              CALL GPIB
                        1391
                        1392
                        1393
                        1394    ;-------------------------------------------------------------------
                        1395    ;TRANSFER FUNDAMENTAL FREQUENCY :
                        1396
  BB5C14                1397              MOV BX,OFFSET FREQ
  B90100                1398              MOV CX,1
  BE0000                1399              MOV SI,0
  E8DD03                1400              CALL GPIB
                        1401
                        1402
                        1403
                        1404    ;-------------------------------------------------------------------
                        1405    ;TRANSFER AMP. AND ANG. :
                        1406
  BB8014                1407              MOV BX,OFFSET R4
  8B0F                  1408              MOV CX,[BX]
  BE0000                1409              MOV SI,0
  E80404                1410              CALL GPIB1
                        1411
```

```
OBJ                SOURCE

5 E94BFD                   JMP LBEGIN          ;GO BACK TO THE BEGINNING.


                   BEGIN   ENDP


                   ;~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~


3                  ZC_ADC  PROC    NEAR


                   ;####################################################################
                   ;
                   ;THIS PROCEDURE LETS THE CPU FIRST POLL THE ZC PORT UNTIL ZC SWITCHES
                   ;
                   ;FROM THE "0" TO THE "1" STATE, THEN THE ADC STARTS OPERATING .
                   ;
                   ;ADC GETS THE SAMPLES FOR ONE PERIOD OF ZC SIGNAL, AND THEN CHECKS EACH
                   ;
                   ;SAMPLE TO SEE WHETHER ITS VALUE IS OUT OF THE 0 TO 5 V RANGE.    IF IT
                   ;
                   ;IS, CPU LIGHTS THE LED TO SHOW OVERFLOW STATUS OF INPUT SIGNAL.
                   ;
                   ;WHILE CHECKING OVERFLOW OPERATION, CPU ALSO MODULATES EACH SAMPLE BY
                   ;
                   ;GAIN +1 OR -1 ACCORDING TO ITS SIGN- BIT, D15, WHICH COMES FROM THE
                   ;
                   ;SIGN-BIT MODULATOR.     IF THE D15 CONTAINS "1", THE CPU WILL CONVERT THE
                   ;
                   ;SAMPLE INTO 2'S COMPLEMENT FORM, WHICH MEANS THE SAMPLE IS MULTIPLIED BY
                   ;
                   ;NEGATIVE ONE.       IF THE D15 CONTAINS "0", THE CPU WILL NOT CHANGE THE
                   ;
                   ;SAMPLE, WHICH MEANS THE SAMPLE IS MULTIPLIED BY ONE.     AFTER MODULATING
                   ;
                   ;THE SAMPLES, CPU SUMS THEM UP AND THEN AVERAGES THEM BY DIVIDING THE
                   ;
                   ;SUMMATION VALUE WITH THE TOTAL NUMBER OF SAMPLES INVOLVED IN SUMMATION.
                   ;
                   ;AFTER AVERAGING, THE MEAN LEVEL VALUES OF OUTPUT, 0Uk AND 90Uk, ARE
                   ;
                   ;OBTAINED.      0Uk COMES FROM MODULATION AT 0_DEG. PHASE SHIFT REFERENCE
                   ;
                   ;CLOCK AND 90Uk COMES FROM MODULATION AT 90_DEG. CLOCK      0Uk AND 90Uk
                   ;
                   ;ARE THEN STORED AT XY ADDRESS OF MEMORY.
                   ;
                   ;THE ADC DOES HAVE OFFSET ERROR WHICH MUST BE ELIMINATED BY SOFTWARE
```

```
OBJ                     LINE    SOURCE

                        1467
                        1468    ;APPROACH.      THE PROCEDURE OF ELIMINATING OFFSET ERROR IS AS FOLLOWS :
                        1469
                        1470    ;LET Pi BE THE ABSOLUTE VALUE OF SAMPLE WITH +VE SIGN_ BIT
                        1471
                        1472    ;LET Qj BE THE ABSOLUTE VALUE OF SAMPLE WITH -VE SIGN_ BIT
                        1473
                        1474    ;LET Ri AND Rj  BE THE ABSOLUTE VALUES OF OFFSET ERROR OF ADC ,
                        1475
                        1476    ;WHERE i = 1,2,.....,M
                        1477
                        1478    ;      j = 1,2,.....,N
                        1479
                        1480    ;      k = i + j
                        1481
                        1482    ;WHERE k IS THE TOTAL NUMBER OF INPUT SAMPLES IN ONE FUNDAMENTAL PERIOD.
                        1483
                        1484    ;TAKE APPROXIMATION, Ri OR Rj = R  WHISH WILL BE EQUAL TO THE MIN. ABS.
                        1485
                        1486    ;VALUE OF SAMPLES, THAT IS,  R = MIN ( Pi OR Qj ) .
                        1487
                        1488    ;SUM OF SAMPLES = SUMMATION [(+Pi + Ri)] + SUMMATION [(-Qj - Rj)]
                        1489
                        1490    ;                 = SUMMATION [Pi] - SUMMATION [Qj] + (M-N)*R
                        1491
                        1492    ;THEREFORE,
                        1493
                        1494    ;SUMMATION [Pi] + SUMMATION [Qj] = SUM OF SAMPLES - (M-N)*R
                        1495
                        1496    ;WHERE (M-N) IS THE DIFFERENCE OF THE NUMBER OF SAMPLES WITH +VE SIGN BIT
                        1497
                        1498    ;AND -VE SIGN BIT.
                        1499
                        1500    ;IN SUMMARY, THE TRUE VALUE OF THE SUM OF THE SAMPLES IS EQUAL TO THE SUM
                        1501
                        1502    ;OF THE SAMPLES MINUS THE PRODUCT OF THE DIFFERENCE OF THE NUMBER OF SAMPLES
                        1503
                        1504    ;WITH +VE SIGN BIT & -VE SIGN BIT AND THE SAMPLE WITH MINIMUM ABSOLUTE VALUE.
                        1505
                        1506    ;###############################################################
                        1507
                        1508
BF0080                  1510    LA10:   MOV DI,32768D           ;DI  THE DIFFERENCE OF THE NUMBER OF SAMPLES
                        1511                                    ;WITH +VE SIGN BIT AND -VE SIGN_ BIT STARTING
                        1512                                    ;WITH OFFSET 32768 .
BB8614                  1513            MOV BX,OFFSET R7
893F                    1514            MOV [BX],DI
                        1515
33F6                    1516            XOR SI,SI               ;NULL SI .
BB0000                  1517            MOV BX,OFFSET SAM       ;SAMPLE ADDRESS.
BD0200                  1518            MOV BP,2                ;INCREMENT OF ADDRESS AND +VE SIGN INDEXES.
B140                    1519            MOV CL,ZC_MASK_OF_SWP
                        1520
BA8000                  1521            MOV DX,SWP              ;DX_ ZC ADDRESS .
```

```
:  OBJ                  LINE     SOURCE

0D EC                   1522     LA1:    IN AL,DX                ;POLL ZC .
0E 22C1                 1523             AND AL,CL
10 75FB                 1524             JNZ LA1                 ;ZC_ HIGH .
                        1525
12 B80900               1526             MOV AX,9
15 50                   1527     LA3:    PUSH AX                 ;WAIT 10 MICRO SEC FOR ZC SETTLE DOWN.
16 58                   1528             POP AX
17 48                   1529             DEC AX
18 75FB                 1530             JNZ LA3
                        1531
1A EC                   1532     LA2:    IN AL,DX
1B 22C1                 1533             AND AL,CL
1D 74FB                 1534             JZ LA2                  ;ZC_ LOW .
                        1535
                        1536                                     ;ZC_ HIGH
1F E620                 1537             OUT GATE,AL             ;SYNCHRONIZE MODULATING CLK AND START COUNTER1
                        1538                                     ;COUNTING.
                        1539
                        1540                                     ;WHEN ZC SWITCHES FROM "0" TO "1" STATE,
                        1541                                     ;ADC STARTS ITS OPERATION.
21 BAA000               1542             MOV DX,ADCP             ;DX_ ADC ADDRESS .
24 ED                   1543             IN AX,DX                ;INITIALIZES ADC OPERATION.
25 8900                 1544             MOV [BX+SI],AX          ;FIRST SAMPLE IS INVALID.
                        1545
27 B10A                 1546             MOV CL,10D
29 FEC9                 1547             DEC CL                  ;CL_ NUMBER OF EXECUTING TIMES OF THIS LOOP.
                        1548                                     ;ADC TAKES 9 SAMPLES WITHOUT POLL ZC IN ORDER
                        1549                                     ;TO GIVE ZC 120 MICRO SEC TO SETTLE DOWN.
2B 7501                 1550             JNZ L3H
2D 90                   1551             NOP
                        1552
2E ED                   1553     L3H:    IN AX,DX
2F 8900                 1554             MOV [BX+SI],AX
31 03F5                 1555             ADD SI,BP
33 FEC9                 1556             DEC CL
35 75F7                 1557             JNZ L3H
37 90                   1558             NOP
38 90                   1559             NOP
39 B140                 1560             MOV CL,ZC_MASK_OF_ADC
                        1561
3B ED                   1562     L3A:    IN AX,DX
3C 8900                 1563             MOV [BX+SI],AX
3E 03F5                 1564             ADD SI,BP
40 84E1                 1565             TEST AH,CL              ;TEST ZC .
42 75F7                 1566             JNZ L3A                 ;ZC_ HIGH .
44 90                   1567             NOP                     ;ZC_ LOW .
45 90                   1568             NOP
                        1569
46 B109                 1570             MOV CL,9                ;CL_ NUMBER OF EXECUTING TIMES OF THIS LOOP.
                        1571                                     ;ADC TAKES 9 SAMPLES WITHOUT POLL ZC IN ORDER
                        1572                                     ;TO GIVE ZC 120 MICRO SEC TO SETTLE DOWN.
48 ED                   1573     L3F:    IN AX,DX
49 8900                 1574             MOV [BX+SI],AX
4B 03F5                 1575             ADD SI,BP
4D FEC9                 1576             DEC CL
```

```
   OBJ                  LINE     SOURCE

F  75F7                 1577             JNZ L3F
1  90                   1578             NOP
2  90                   1579             NOP
3  B140                 1580             MOV CL,ZC_MASK_OF_ADC
                        1581
5  ED                   1582     L3C:    IN AX,DX
6  8900                 1583             MOV [BX+SI],AX
8  03F5                 1584             ADD SI,BP
A  84E1                 1585             TEST AH,CL              ;TEST ZC.
C  74F7                 1586             JZ L3C                  ;ZC_ LOW.
                        1587
                        1588                                     ;ZC_ HIGH.
E  E568                 1589             IN AX,CTR1              ;GETS THE LASTEST VALUE FROM COUNTER1.
0  D1EE                 1590             SHR SI,1                ;SI=SI/2, SI_ TOTAL NUMBER OF SAMPLES.
                        1591
2  BBA406               1592             MOV BX,1700D
5  3BF3                 1593             CMP SI,BX
7  7202                 1594             JB L395
9  EB8D                 1595             JMP LA10
                        1596                                     ;CHECK TO SEE WHETHER THE FREQUENCY OF ZC
                        1597                                     ;SIGNAL, THAT IS, THE FREQUENCY OF FUNDAMENTAL
                        1598                                     ;IS ABOVE 45 HZ WHICH IS EQUIVALENT TO THE
                        1599                                     ;NUMBER OF INPUT SAMPLES, 1700 (5 MHZ/66*45 HZ),
                        1600                                     ;IN WHICH 66 IS THE NUMBER OF CPU CYCLES NEEDED
                        1601                                     ;TO EXECUTE THE INPUT ROUTINE OF ADC.      THE
                        1602                                     ;FREQUENCY OF ZC IS BELOW 45 HZ, REPEAT THE
                        1603                                     ;OPERATION UNTIL IT MATCHES THE REQUIREMENT .
                        1604
B  BB4C04               1605     L395:   MOV BX,1100D
D  3BF3                 1606             CMP SI,BX
F  7702                 1607             JA L396
1  EB84                 1608             JMP LA10
                        1609                                     ;CHECK TO SEE WHETHER THE FREQUENCY OF ZC
                        1610                                     ;SIGNAL, THAT IS, THE FREQUENCY OF FUNDAMENTAL
                        1611                                     ;IS BELOW 65 HZ WHICH IS EQUIVALENT TO THE
                        1612                                     ;NUMBER OF INPUT SAMPLES, 1100 (5 MHZ/66*65 HZ),
                        1613                                     ;IN WHICH 66 IS THE NUMBER OF CPU CYCLES NEEDED
                        1614                                     ;TO EXECUTE THE INPUT ROUTINE OF ADC.      THE
                        1615                                     ;FREQUENCY OF ZC IS ABOVE 65 HZ, REPEAT THE
                        1616                                     ;OPERATION UNTIL IT MATCHES THE REQUIREMENT .
                        1617
4  8BD0                 1618     L396:   MOV DX,AX
6  B8FFFF               1619             MOV AX,0FFFFH           ;START VALUE OF COUNTER1 = 0FFFFH .
9  2BC2                 1620             SUB AX,DX               ;AX_ RESULTANT VALUE OF COUNTER1.
                        1621
B  BB8814               1622             MOV BX,OFFSET R8
D  8907                 1623             MOV [BX],AX             ;R8_ RESULTANT VALUE OF COUNTER1.
                        1624
F  56                   1625             PUSH SI
                        1626
0  BB5E14               1627             MOV BX,OFFSET ZCCP      ;STORE FIRST 12 COUNTS OR COUNTER1.
3  8B37                 1628             MOV SI,[BX]
5  83FE18               1629             CMP SI,24D
8  740D                 1630             JE L321
                        1631
```

```
OBJ                 LINE    SOURCE

BB6014              1632            MOV BX,OFFSET ZCC
8900                1633            MOV [BX+SI],AX
83C602              1634            ADD SI,2                ;NEXT ADDRESS POINTER.
                    1635
BB5E14              1636            MOV BX,OFFSET ZCCP
8937                1637            MOV [BX],SI
                    1638
5E                  1639    L321:   POP SI
                    1640
C3                  1641            RET
                    1642
                    1643
                    1644
                    1645    ZC_ADC  ENDP
                    1646
                    1647
                    1648
                    1649    ;=================================================================
                    1650
                    1651
                    1652    ;#################################################################
                    1653    ;
                    1654    ;THIS PROCEDURE CHECKS FOR OVERFLOW OF THE INPUT SIGNAL AND MODULATES
                    1655    ;
                    1656    ;SAMPLES WITH GAIN +1 AND -1 ACCORDING TO SIGN-BIT.          IT ALSO
                    1657    ;
                    1658    ;ELIMINATES THE OFFSET ERROR ACCORDING TO THE METHOD USED IN "ZC_ADC" .
                    1659    ;
                    1660    ;#################################################################
                    1661
                    1662
                    1663    AVERAGING       PROC    NEAR
                    1664
                    1665
BFFF0F              1666            MOV DI,0FFFH            ;DI  MINIMUM OFFSET ERROR, THE 1ST SEED IS
                    1667                                    ;0FFFH .
                    1668
8BC6                1669            MOV AX,SI               ;THE CONTENT OF SI IS FROM ZC_ADC PROC .
50                  1670            PUSH AX                 ;SAVE TOTAL NUMBER OF SAMPLES IN STACK.
                    1671
33C9                1672            XOR CX,CX               ;CX  NULL LSBY OF SUM OF SUMMATION OF ALL
                    1673                                    ;MODULATED SAMPLES.
                    1674
33ED                1675            XOR BP,BP               ;BP  NULL MSBY OF SUM OF SUMMATION OF ALL
                    1676                                    ;MODULATED SAMPLES.
                    1677
BB0000              1678            MOV BX,OFFSET SAM
33F6                1679            XOR SI,SI               ;NULL SI.
EB0490              1680            JMP L4C
                    1681
E81802              1682    LLED:   CALL LED                ;OVERFLOW.
                    1683
50                  1684    L4C:    PUSH AX                 ;SAVE NUMBER OF EXECUTING TIMES OF THIS LOOP.
                    1685
8B00                1686            MOV AX,[BX+SI]          ;AX  ORIGINAL SAMPLE.
```

```
OBJ                 LINE    SOURCE

83C602              1687            ADD SI,2                ;NEXT ADDRESS INDEX OF SAMPLES.
8BD8                1688            MOV BX,AX
81E3FF0F            1689            AND BX,SAMPLE_MASK      ;BX_ ABS [SAM] .
56                  1690            PUSH SI                 ;SAVE ADDRESS INDEX OF SAMPLES IN STACK.
8BF3                1691            MOV SI,BX               ;SI_ ABS [ SAM ] .
81FBFF0F            1692            CMP BX,SAMPLE_MASK      ;CHECK OVERFLOW.
74E8                1693            JE LLED                 ;OVERFLOW.
                    1694
                    1695                                    ;LOOK FOR MIN. ABS [SAM] AS OFFSET ERROR.
3BDF                1696            CMP BX,DI               ;DI_ MINIMUM OFFSET ERROR.
7302                1697            JNB L4A
87DF                1698            XCHG BX,DI
                    1699
96                  1700    L4A:    XCHG AX,SI              ;SI_ ORIGINAL SAMPLES, AX_ ABS [SAM] .
                    1701
57                  1702            PUSH DI
                    1703
BB8614              1704            MOV BX,OFFSET R7
8B3F                1705            MOV DI,[BX]             ;DI_ NUMBER OF NET +VE OR -VE SAMPLES WITH
                    1706                                    ;OFFSET 32768 .
                    1707
81E60080            1708            AND SI,SIGN_BIT_MASK    ;MODULATE SAMPLES WITH GAIN +1 OR -1 ACCORDING
                    1709                                    ;TO SIGN_ BIT .
                    1710
7409                1711            JZ L4B                  ;+VE SIGN_ BIT, D15_ ZERO .
                    1712
4F                  1713            DEC DI                  ;-VE SAMPLE, DI-1 .
                    1714
                    1715                                    ; -VE SIGN_ BIT, D15_ ZERO, NEGATE THE SAMPLE
                    1716                                    ;INTO 2'S COMP. FORM.
BAFFFF              1717            MOV DX,0FFFFH
F7D8                1718            NEG AX
EB0490              1719            JMP L4BB
                    1720
47                  1721    L4B:    INC DI                  ;+VE SAMPLE, DI+1 .
33D2                1722            XOR DX,DX               ;MSBY OF +VE MODULATED SAMPLE.
                    1723
893F                1724    L4BB:   MOV [BX],DI             ;SAVE NUMBER OF NET +VE OR -VE SAMPLES WITH
                    1725                                    ;OFFSET 32768 IN R7.
                    1726
5F                  1727            POP DI                  ;DI_ MINIMUM OFFSET ERROR.
                    1728
03C8                1729            ADD CX,AX               ;SUM THE SAMPLES_ LSBY .
13EA                1730            ADC BP,DX               ;SUM THE SAMPLES_ MSBY .
                    1731
5E                  1732            POP SI                  ;SI_ ADDRESS INDEX OF SAMPLES.
                    1733
BB0000              1734            MOV BX,OFFSET SAM
                    1735
58                  1736            POP AX                  ;AX_ NUMBER OF EXECUTING TIMES OF THIS LOOP.
48                  1737            DEC AX                  ;DECREASE LOOP TIMES.
75BD                1738            JNZ L4C
                    1739
BB8614              1740            MOV BX,OFFSET R7
8B07                1741            MOV AX,[BX]             ;AX_ NUMBER OF NET +VE OR -VE SAMPLES WITH
```

```
OBJ                     LINE    SOURCE
                        1742                            ;OFFSET 32768 .
                        1743
BA0080                  1744            MOV DX,32768D
3BC2                    1745            CMP AX,DX
7211                    1746            JB L4           ;32768 > AX .
                        1747
                        1748                            ;32768 < AX .
2BC2                    1749            SUB AX,DX       ;AX_ NUMBER OF NET +VE SAMPLES.
                        1750
F7E7                    1751            MUL DI          ;DX+AX
                        1752                            ;(MINIMUM OFFSET ERROR)*
                        1753                            ;(NUMBER OF NET +VE SAMPLES) .
F7D0                    1754            NOT AX
F7D2                    1755            NOT DX
050100                  1756            ADD AX,1
83D200                  1757            ADC DX,0        ;(SUM OF SAMPLES)-
                        1758                            ;(MINIMUM OFFSET ERROR)*
                        1759                            ;(NUMBER OF NET +VE SAMPLES) .
EB0690                  1760            JMP L5
                        1761
92                      1762    L4:     XCHG DX,AX      ;32768 > AX .
2BC2                    1763            SUB AX,DX
F7E7                    1764            MUL DI          ;DX+AX
                        1765                            ;(MINIMUM OFFSET ERROR)*
                        1766                            ;(NUMBER OF NET -VE SAMPLES) .
                        1767
                        1768    ;SUM OF SAMPLES + (MINIMUM OFFSET ERROR)*(NUMBER OF NET -VE SAMPLES)
03C8                    1769    L5:     ADD CX,AX
13EA                    1770            ADC BP,DX
                        1771
8BD5                    1772            MOV DX,BP       ;DX_ MSBY OF TRUE SUM.
8BF9                    1773            MOV DI,CX       ;DI_ LSBY OF TRUE SUM.
8BC2                    1774            MOV AX,DX       ;CHECK SIGN.
250080                  1775            AND AX,8000H
740E                    1776            JZ L41          ;+VE .
                        1777
                        1778                            ;EXPRESS THE TRUE SUM IN [ SIGN_ FORM ]
                        1779                            ;INSTEAD  OF 2'S COMP .
83EF01                  1780            SUB DI,1
83DA00                  1781            SBB DX,0
F7D7                    1782            NOT DI
F7D2                    1783            NOT DX
81C20080                1784            ADD DX,8000H
                        1785
                        1786                            ;AVERAGING THE SUM OF SAMPLES TO GET THE MEAN
                        1787                            ;LEVEL OF MODULATED OUTPUT.
59                      1788     L41:   POP CX          ;CX_ TOTAL NUMBER OF SAMPLES
BD0000                  1789            MOV BP,0
                        1790
E8D300                  1791            CALL DIV_32     ;SUM OF SAMPLES/NUMBER OF SAMPLES.
                        1792
81E20080                1793            AND DX,8000H    ;CHECK SIGN OF THE MEAN.
7402                    1794            JZ L42          ;+VE MEAN.
                        1795
F7DF                    1796            NEG DI          ;-VE MEAN , EXPRESS IT IN 2'S COMP .
```

```
OBJ                     LINE    SOURCE

                        1797
BB8E14                  1798    L42:    MOV BX,OFFSET R11
8B37                    1799            MOV SI,[BX]
                        1800
BBF811                  1801            MOV BX,OFFSET XY
8938                    1802            MOV [BX+SI],DI          ;SAVE MEAN VALUE OF MODULATED OUTPUT.
83C602                  1803            ADD SI,2
                        1804
BB8E14                  1805            MOV BX,OFFSET R11
8937                    1806            MOV [BX],SI             ;NEXT XY ADDRESS INDEX.
                        1807
C3                      1808            RET
                        1809
                        1810
                        1811
                        1812    AVERAGING       ENDP
                        1813
                        1814
                        1815
                        1816    ;=================================================================
                        1817
                        1818
                        1819    MOD_CLK_UPDATE_1        PROC    NEAR
                        1820
                        1821
                        1822    ;#################################################################
                        1823    ;
                        1824    ;THIS PROCEDURE NOTIFIES COUNTER 0 TO GENERATE A MODULATING CLK WITH
                        1825    ;
                        1826    ;ASSIGNED HARMONIC FREQUENCY.
                        1827    ;
                        1828    ;#################################################################
                        1829
                        1830
50                      1831            PUSH AX
53                      1832            PUSH BX
51                      1833            PUSH CX
52                      1834            PUSH DX
                        1835
BB8814                  1836            MOV BX,OFFSET R8
8B07                    1837            MOV AX,[BX]
                        1838
33C9                    1839            XOR CX,CX
                        1840
BB9314                  1841            MOV BX,OFFSET R14
8A0F                    1842            MOV CL,[BX]             ;CX_ ORDER OF HARMONIC.
                        1843
33D2                    1844            XOR DX,DX
F7F1                    1845            DIV CX
                        1846
E760                    1847            OUT CTR0,AX             ;GENERATE MODULATING CLK.
                        1848
5A                      1849            POP DX
59                      1850            POP CX
5B                      1851            POP BX
```

```
OBJ                     LINE     SOURCE
58                      1852             POP AX
                        1853
C3                      1854             RET
                        1855
                        1856
                        1857
                        1858     MOD_CLK_UPDATE_1        ENDP
                        1859
                        1860
                        1861
                        1862     ;=================================================================
                        1863
                        1864
                        1865
                        1866     ;#################################################################
                        1867     ;
                        1868     ;THIS PROCEDURE POLLS THE ZC PORT UNTIL ZC SIGNAL SWITCHES FROM THE LOW
                        1869     ;
                        1870     ;STATE TO THE HIGH STATE.       THEN IT SYNCHRONIZES THE MODULATING CLOCK
                        1871     ;
                        1872     ;IMMEDIATELY AND UPDATES THE VALUE OF COUNTER0.
                        1873     ;
                        1874     ;#################################################################
                        1875
                        1876
                        1877
                        1878     MOD_CLK_UPDATE  PROC    NEAR
                        1879
                        1880
                        1881
BDFFFF                  1882             MOV BP,0FFFFH          ;COUNTER1 IS COUNT_DOWN COUNTER, START AT
                        1883                                    ;0FFFFH .
B140                    1884             MOV CL,ZC_MASK_OF_SWP
BA8000                  1885             MOV DX,SWP             ;DX_ ZC PORT.
                        1886
EC                      1887     LA215:  IN AL,DX               ;POLL ZC .
22C1                    1888             AND AL,CL
75FB                    1889             JNZ LA215              ;ZC_ HIGH .
                        1890
B80900                  1891             MOV AX,9               ;ZC_ LOW.
50                      1892     LA216:  PUSH AX                ;WAIT 10 MICRO SEC FOR ZC SETTLE DOWN.
58                      1893             POP AX
48                      1894             DEC AX
75FB                    1895             JNZ LA216
                        1896
EC                      1897     LA214:  IN AL,DX               ;POLL ZC .
22C1                    1898             AND AL,CL
74FB                    1899             JZ LA214               ;ZC_ LOW.
                        1900
                        1901                                    ;ZC_ HIGH.
E568                    1902             IN AX,CTR1             ;INPUT VALUE FROM COUNTER1.
2BE8                    1903             SUB BP,AX              ;WORK OUT THE VALUE.
8BC5                    1904             MOV AX,BP
                        1905
E760                    1906             OUT CTR0,AX            ;UPDATE COUNTER0 .
```

```
 OBJ                    LINE     SOURCE
 E620                   1907             OUT GATE,AL            ;SYNCHRONIZE THE MODULATING CLK .
                        1908
 C3                     1909             RET
                        1910
                        1911
                        1912
                        1913     MOD_CLK_UPDATE  ENDP
                        1914
                        1915
                        1916
                        1917     ;=================================================================
                        1918
                        1919
                        1920
                        1921     ;#################################################################
                        1922     ;
                        1923     ;THIS PROCEDURE POLLS THE ZC PORT UNTIL ZC SIGNAL SWITCHES FROM THE LOW TO
                        1924     ;
                        1925     ;THE HIGH STATE.    THEN IT SYNCHRONIZES THE MODULATING CLK IMMEDIATELY.
                        1926     ;
                        1927     ;#################################################################
                        1928
                        1929
                        1930
                        1931     MOD_CLK_SYN     PROC    NEAR
                        1932
                        1933
                        1934
 B140                   1935             MOV CL,ZC_MASK_OF_SWP
 BA8000                 1936             MOV DX,SWP             ;DX_ ZC PORT.
                        1937
 EC                     1938     LA17:   IN AL,DX               ;POLL ZC .
 22C1                   1939             AND AL,CL
 75FB                   1940             JNZ LA17               ;ZC_ HIGH.
                        1941
 B80900                 1942             MOV AX,9               ;ZC_ LOW.
 50                     1943     LA171:  PUSH AX                ;WAIT 10 MICRO SEC FOR ZC SETTLE DOWN.
 58                     1944             POP AX
 48                     1945             DEC AX
 75FB                   1946             JNZ LA171
                        1947
 EC                     1948     LA27:   IN AL,DX               ;POLL ZC .
 22C1                   1949             AND AL,CL
 74FB                   1950             JZ LA27                ;ZC_ LOW.
                        1951
 E620                   1952             OUT GATE,AL            ;ZC_ HIGH , SYNCHRONIZE MODULATING CLK.
                        1953
 C3                     1954             RET
                        1955
                        1956
                        1957
                        1958     MOD_CLK_SYN     ENDP
                        1959
                        1960
                        1961
```

```
OBJ                     LINE    SOURCE

                        1962    ;=================================================================
                        1963
                        1964
                        1965    ;#################################################################
                        1966    ;
                        1967    ;THIS PROCEDURE ELIMINATES D.C. TERMS DERIVED FROM THE HIGH HARMONICS
                        1968    ;
                        1969    ;WHICH EXISTS IN THE MEAN LEVEL OUTPUT GENERATED BY MODULATING THE LOW
                        1970    ;
                        1971    ;HARMONICS SIGNAL.
                        1972    ;
                        1973    ;#################################################################
                        1974
                        1975
                        1976    DEHA    PROC NEAR
                        1977
                        1978
BB8414                  1979            MOV BX,OFFSET R6
8B07                    1980            MOV AX,[BX]             ;AX_ DIVISOR.
                        1981
BB7C14                  1982            MOV BX,OFFSET R2
8907                    1983            MOV [BX],AX             ;R2_ DIVISOR.
                        1984
33FF                    1985            XOR DI,DI               ;DI_ SUM, INITIALIZED WITH ZERO.
                        1986
BBF811                  1987    LQA:    MOV BX,OFFSET XY
8B00                    1988            MOV AX,[BX+SI]          ;AX_ X_K OR Y_K .
                        1989
BB7E14                  1990            MOV BX,OFFSET R3
8B17                    1991            MOV DX,[BX]             ;DX_ NEXT ADDRESS OFFSET.
2BF2                    1992            SUB SI,DX               ;SI_ NEXT ADDRESS INDEX.
                        1993
BB7C14                  1994            MOV BX,OFFSET R2
8B0F                    1995            MOV CX,[BX]             ;CX_ DIVISOR LSBY .
8BD1                    1996            MOV DX,CX               ;DX_ DIVISOR.
83EA02                  1997            SUB DX,2                ;DX_ NEXT DIVIDER.
8917                    1998            MOV [BX],DX
                        1999
                        2000                                    ;CHECK SIGN BIT OF X_K OR Y_K FOR PREPARATION
                        2001                                    ;OF DIVISION.
8BD0                    2002            MOV DX,AX
80E680                  2003            AND DH,80H
7402                    2004            JZ LAQM
                        2005
F7D8                    2006            NEG AX
                        2007
52                      2008    LAQM:   PUSH DX
33D2                    2009            XOR DX,DX
F7F1                    2010            DIV CX
59                      2011            POP CX
F6C680                  2012            TEST DH,80H
7402                    2013            JZ LAQN
                        2014
F7D8                    2015            NEG AX
                        2016
```

```
OBJ                     LINE    SOURCE

                        1962    ;=============================================================================
                        1963
                        1964
                        1965    ;#############################################################
                        1966    ;
                        1967    ;THIS PROCEDURE ELIMINATES D.C. TERMS DERIVED FROM THE HIGH HARMONICS
                        1968    ;
                        1969    ;WHICH EXISTS IN THE MEAN LEVEL OUTPUT GENERATED BY MODULATING THE LOW
                        1970    ;
                        1971    ;HARMONICS SIGNAL.
                        1972    ;
                        1973    ;#############################################################
                        1974
                        1975
                        1976    DEHA    PROC NEAR
                        1977
                        1978
BB8414                  1979            MOV BX,OFFSET R6
8B07                    1980            MOV AX,[BX]             ;AX_ DIVISOR.
                        1981
BB7C14                  1982            MOV BX,OFFSET R2
8907                    1983            MOV [BX],AX             ;R2_ DIVISOR.
                        1984
33FF                    1985            XOR DI,DI               ;DI_ SUM, INITIALIZED WITH ZERO.
                        1986
BBF811                  1987    LQA:    MOV BX,OFFSET XY
8B00                    1988            MOV AX,[BX+SI]          ;AX_ X_K OR Y_K .
                        1989
BB7E14                  1990            MOV BX,OFFSET R3
8B17                    1991            MOV DX,[BX]             ;DX_ NEXT ADDRESS OFFSET.
2BF2                    1992            SUB SI,DX               ;SI_ NEXT ADDRESS INDEX.
                        1993
BB7C14                  1994            MOV BX,OFFSET R2
8B0F                    1995            MOV CX,[BX]             ;CX_ DIVISOR LSBY .
8BD1                    1996            MOV DX,CX               ;DX_ DIVISOR.
83EA02                  1997            SUB DX,2                ;DX_ NEXT DIVIDER.
8917                    1998            MOV [BX],DX
                        1999
                        2000                                    ;CHECK SIGN BIT OF X_K OR Y_K FOR PREPARATION
                        2001                                    ;OF DIVISION.
8BD0                    2002            MOV DX,AX
80E680                  2003            AND DH,80H
7402                    2004            JZ LAQM
                        2005
F7D8                    2006            NEG AX
                        2007
52                      2008    LAQM:   PUSH DX
33D2                    2009            XOR DX,DX
F7F1                    2010            DIV CX
59                      2011            POP CX
F6C680                  2012            TEST DH,80H
7402                    2013            JZ LAQN
                        2014
F7D8                    2015            NEG AX
                        2016
```

```
OBJ                     LINE    SOURCE

03F8                    2017    LAQN:   ADD DI,AX              ;DI_ SUM.
                        2018
8B07                    2019            MOV AX,[BX]             ;CHECK TO SEE WHETHER THE 1ST D.C. OF
                        2020                                    ;EQUATION ARISES ?
3D0100                  2021            CMP AX,1
75C9                    2022            JNE LQA                 ;NO.
                        2023
F7DF                    2024            NEG DI                  ;YES, NEGATIVE THE SUM IN 2'S COMP. FORM.
                        2025
BBF811                  2026            MOV BX,OFFSET XY
8B00                    2027            MOV AX,[BX+SI]          ;ROOT OF 1ST D.C. TERM.
03C7                    2028            ADD AX,DI               ;SUBTRACT THE SUM OF ALL D.C. TERMS ARISING
                        2029                                    ;FROM HIGHER HARMONICS FROM THE LOWEST D.C.
                        2030                                    ;TERM.
8900                    2031            MOV [BX+SI],AX
                        2032
BB7A14                  2033            MOV BX,OFFSET R1        ;R1_ XYP_.
8B37                    2034            MOV SI,[BX]             ;SI_ LAST D.C. TERM ADDRESS POINTER.
83C602                  2035            ADD SI,2
8937                    2036            MOV [BX],SI             ;STORE NEXTD.C. TERM ADDRESS POINTER.
                        2037
BB8214                  2038            MOV BX,OFFSET R5        ;R5_ POINTER OF 2_.
8B0F                    2039            MOV CX,[BX]             ;TEST LOOP TIMES EXECUTED.
                        2040
C3                      2041            RET                     ;THE DATA STORE IN ADDRESS XY ARE IN 2'S
                        2042                                    ;COMP. FORM.
                        2043
                        2044
                        2045
                        2046    DEHA    ENDP
                        2047
                        2048
                        2049
                        2050    ;===============================================================
                        2051
                        2052
                        2053
                        2054    ;###############################################################
                        2055
                        2056    ;32_ BIT BY 32_ BIT DIVISION PROCEDURE USING THE SUBTRACT_ AND_ TEST
                        2057
                        2058    ;METHOD.
                        2059
                        2060    ;THIS PROCEDURE DIVIDES THE 32_BIT QUANTITY IN REGISTER PAIR DX AND DI BY
                        2061
                        2062    ;THE 32_BIT QUANTITY IN REGISTER PAIR BP AND CX .       THE RESULT WILL BE
                        2063
                        2064    ;STORED IN REGISTER PAIR DX AND DI AND THE REMAINDER IN REGISTER PAIR
                        2065
                        2066    ;BP AND CX  WHEN THE 8088 RETURNS FROM THE PROCEDURE.
                        2067
                        2068    ;THE SUBTRACT_ AND_ TEST METHOD WAS DESCRIBED IN TWO BOOKS, [ 36,37 ] .
                        2069
                        2070
                        2071    ;SUBTRACT_AND_TEST METHOD :
```

```
OBJ                     LINE    SOURCE

                        2072
                        2073    ;IN BINARY DIVISION, THE DIVISOR WAS SUBTRACTED FROM THE FIRST BIT OF
                        2074
                        2075    ;THE DIVIDEND.      IF A BORROW OCCURRED AS A RESULT OF THE SUBTRACTION,
                        2076
                        2077    ;WHICH IT DID, A "0" IS ENTER IN THE QUOTIENT, AND THE DIVISOR IS ADDED TO
                        2078
                        2079    ;THE RESULT OF THE SUBTRACTION SO THAT THE ORIGINAL VALUE OF THE DIVIDEND
                        2080
                        2081    ;IS RESTORED.       IF NO BORROW OCCURS DURING THE SUBTRACTION, A "1" IS
                        2082
                        2083    ;ENTERED INTO THE QUOTIENT, AND THE RESULT OF THE SUBTRACTION IS USED FOR
                        2084
                        2085    ;THE NEXT SUBTRACT_AND_TEST PROCESS.
                        2086
                        2087    ;FOR EXAMPLE, DIVIDES 1101 0010 BY 101  :
                        2088
                        2089    ;        00 1101 0010   DIVIDEND
                        2090    ;       -10 1000 0000   DIVISOR
                        2091    ;       ---------------------------
                        2092    ;        10 0101 0010   BORROW OCCURS, QUOTIENT BIT = 0 ,
                        2093    ;       +10 1000 0000   SO ADD DIVISOR TO RESULT.
                        2094    ;       ---------------------------
                        2095    ;        00 1101 0010
                        2096    ;       - 1 0100 0000   SHIFT DIVISOR , TRY AGAIN.
                        2097    ;       ---------------------------
                        2098    ;        11 1001 0010   BORROW OCCURS, QUOTIENT BIT = 0 ,
                        2099    ;       + 1 0100 0000   SO ADD DIVISOR TO RESULT.
                        2100    ;       ---------------------------
                        2101    ;        00 1101 0010
                        2102    ;       -   1010 0000   SHIFT DIVISOR , TRY AGAIN.
                        2103    ;       ---------------------------
                        2104    ;        00 0011 0010   NO BORROW , QUOTIENT BIT = 1.
                        2105    ;       -    101 0000   NO ADDITION , SHIFT DIVISOR ,TRY AGAIN .
                        2106    ;       ---------------------------
                        2107    ;        11 1110 0010   BORROW OCCURS, QUOTIENT BIT = 0 ,
                        2108    ;       +    101 0000   SO ADD DIVISOR TO RESULT.
                        2109    ;       ---------------------------
                        2110    ;        00 0011 0010
                        2111    ;       -     10 1000   SHIFT DIVISOR , TRY AGAIN.
                        2112    ;       ---------------------------
                        2113    ;        00 0000 1010   NO BORROW , QUOTIENT BIT = 1.
                        2114    ;       -      1 0100   NO ADDITION , SHIFT DIVISOR ,TRY AGAIN .
                        2115    ;       ---------------------------
                        2116    ;        11 1111 0110   BORROW OCCURS, QUOTIENT BIT = 0 ,
                        2117    ;       +      1 0100   SO ADD DIVISOR TO RESULT.
                        2118    ;       ---------------------------
                        2119    ;        00 0000 1010
                        2120    ;       -        1010   SHIFT DIVISOR , TRY AGAIN.
                        2121    ;       ---------------------------
                        2122    ;        00 0000 0000   NO BORROW , QUOTIENT BIT = 1.
                        2123    ;       -         101   NO ADDITION , SHIFT DIVISOR ,TRY AGAIN .
                        2124    ;       ---------------------------
                        2125    ;        11 1111 1011   BORROW OCCURS, QUOTIENT BIT = 0 ,
                        2126    ;       +         101   SO ADD DIVISOR TO RESULT.
```

```
OBJ                     LINE    SOURCE

                        2127    ;          ------------------------
                        2128    ;           00 0000 0000
                        2129    ;
                        2130    ;EIGHT SHIFTS AND SUBTRACTIONS HAVE BEEN PERFORM, SO THE DIVIDEND
                        2131    ;
                        2132    ;HAS BEEN DIVIDED BY THE QUOTIENT.      THE RESULT IS (0010 1010) .
                        2133    ;
                        2134    ;
                        2135    ;################################################################
                        2136
                        2137
                        2138
                        2139    DIV_32  PROC    NEAR
                        2140
                        2141
                        2142
56                      2143            PUSH SI
B80080                  2144            MOV AX,8000H            ;MASK OF SIGN_ BIT.
23C2                    2145            AND AX,DX
50                      2146            PUSH AX                 ;SAVE SIGN_ BIT
53                      2147            PUSH BX
8BF1                    2148            MOV SI,CX               ;SI_ LSBY OF THE DIVISOR.
8BC5                    2149            MOV AX,BP               ;AX_ MSBY OF THE DIVISOR.
BB2100                  2150            MOV BX,33D              ;BX_ DIVISOR'S BIT VALUE ,START VALUE,33 .
33ED                    2151            XOR BP,BP               ;NULL PAIR BP AND CX THEY WILL USED TO STORE
                        2152                                    ;THE PARTIAL DIVIDEND.
33C9                    2153            XOR CX,CX
81E2FF7F                2154            AND DX,7FFFH
                        2155
D1D7                    2156    NXTBIT: RCL DI,1                ;ROTATE THE LSB OF DIVIDEND INTO THE CARRY.
D1D2                    2157            RCL DX,1                ;ROTATE THE MSB OF DIVIDEND INTO THE CARRY.
                        2158
4B                      2159            DEC BX                  ;BX_ DECREMENT THE BIT COUNT.
7411                    2160            JZ L112                 ;RETURN IF VALUE IS 0 .
                        2161
D1D1                    2162            RCL CX,1                ;OTHERWISE , ROTATE THE MSB OF THE DIVISOR
                        2163                                    ;INTO THE PARTIAL DIVISOR STORED IN REGISTERS
                        2164                                    ;BP AND CX .
D1D5                    2165            RCL BP,1
2BCE                    2166            SUB CX,SI               ;SUBTRACT THE LSB OF DIVISOR FROM LSBY OF
                        2167                                    ;PARTIAL DIVIDEND.
                        2168
1BE8                    2169            SBB BP,AX               ;SUBTRACT WITH BORROW THE DIVISOR FROM MSBY
                        2170                                    ;OF PARTIAL DIVIDEND.
                        2171
7304                    2172            JNC NOADD               ;IF THE CARRY IS 0, DO NOT ADD THE DIVISOR TO.
                        2173
03CE                    2174            ADD CX,SI
13E8                    2175            ADC BP,AX
                        2176                                    ;THE RESULT OF THE PREVIOUS SUBTRACTION THE
                        2177                                    ;DIVISOR MUST BE ADDED TO THE RESULT OF THE
                        2178                                    ;SUBTRACTION SO THAT THE PREVIOUS VALUE OF
                        2179                                    ;PARTIAL DIVIDENDIS RE-ESTABLISHED .
                        2180
F5                      2181    NOADD:  CMC                     ;COMPLEMENT THE CARRY.
```

```
OBJ             LINE    SOURCE
EBE8            2182            JMP NXTBIT              ;THEN TEST ANOTHER BIT IN THE DIVISOR.
                2183
5B              2184    L112:   POP BX
58              2185            POP AX                  ;AX_ SIGN_ BIT.
13D0            2186            ADD DX,AX               ;RECOVER SIGN_ BIT OF DIVIDEND.
5E              2187            POP SI
                2188
C3              2189            RET
                2190
                2191
                2192
                2193    DIV_32  ENDP
                2194
                2195
                2196
                2197    ;-----------------------------------------------------------------
                2198    ;
                2199    ;WHEN PROCEDURE DIV_32 IS CALLED, THE DIVIDEND MUST BE CONTAINED IN THE
                2200    ;REGISTER PAIR DX AND DI AND THE DIVISOR MUST BE IN REGISTER PAIR BP AND
                2201    ;CX.      THE BIT COUNT IS 33 BECAUSE THERE ARE 32 BITS IN THE DIVIDEND ,
                2202    ;AND THE ROTATE LOOP WITHIN THE PROCEDURE MUST BE EXECUTED AN ADDITIONAL
                2203    ;TIME SO THAT THE LAST BIT OF THE QUOTIENT IS SAVED IN THE APPROPRIATE
                2204    ;REGISTER PAIR.         REGISTER BP AND CX IS THEN CLEARED BECAUSE THIS IS
                2205    ;THE REGISTER PAIR THAT IS USED TO HOLD THE PARTIAL DIVIDEND.      THE 32_
                2206    ;BIT DIVIDEND CONTAINED IN REGISTER PAIR DX AND DI IS THEN ROTATED ONCE TO
                2207    ;THE LEFT.      THE CARRY IS EITHER A LOGIC 1 OR A LOGIC 0 AS A RESULT OF
                2208    ;THIS ROTATION.      THIS SEQUENCE OF TWO INSTRUCTIONS NOT ONLY ROTATES THE
                2209    ;MSB OF THE DIVIDEND INTO THE CARRY, BUT IT ALSO CAUSES THE CARRY TO BE
                2210    ;ROTATED INTO THE LSB OF REGISTER PAIR DX AND DI.     THIS TECHNIQUE IS USED
                2211    ;TO ROTATE THE QUOTIENT, BIT-BY-BIT, INTO REGISTER PAIR DX AND DI.     AFTER
                2212    ;THE DIVIDEND HAS BEEN ROTATED, THE BIT COUNT STORED IS DECREMENTED .
                2213    ;WHEN THE COUNT REACHES ZERO, THE PROCEDURE IS COMPLETED.       IF THE COUNT
                2214    ;IS NONZERO AFTER THE DEC BX INSTRUCTION IS EXECUTED, THE JZ INSTRUCTION IS
                2215    ;NOT EXECUTED.       THE MSB OF THE DIVIDEND, WHICH IS NOW IN THE CARRY, IS
                2216    ;ROTATED INTO THE LSB OF THE PARTIAL DIVIDEND THAT IS STORED IN REGISTER PAIR
                2217    ;BP AND CX , ONCE THE PARTIAL DIVIDEND IS FORMED , THE DIVISOR HAS TO BE
                2218
                2219
                2220
                2221
                2222
                2223
                2224
                2225
                2226
                2227
                2228
                2229
                2230
                2231
                2232
                2233
                2234
                2235
                2236
```

```
OBJ                     LINE    SOURCE

                        2237    ;SUBTRACTED FROM IT.     THE CONTENT OF SI IS SUBTRACTED FROM THE CONTENT OF
                        2238    ;
                        2239    ;THE CX REGISTER (THE LSBY OF THE PARTIAL DIVIDEND), SUB CX,SI .     THE
                        2240    ;
                        2241    ;RESULT OF THE SUBTRACTION IS SAVED IN THE CX REGISTER.     THE MSBY OF THE
                        2242    ;
                        2243    ;PARTIAL DIVIDEND, STORED IN THE BP REGISTER AND THE CONTENT OF AX IS
                        2244    ;
                        2245    ;SUBTRACTED-WITH-BORROW FROM BP (SBB BP,AX) .     THE SBB INSTRUCTION IS
                        2246    ;
                        2247    ;USED BECAUSE THERE MAY HAVE BEEN A BORROW GENERATED WHEN THE LSBY OF THE
                        2248    ;
                        2249    ;DIVISOR WAS SUBTRACTED FROM THE LSBY OF THE PARTIAL DIVIDEND.     THE SBB
                        2250    ;
                        2251    ;INSTRUCTION NOT ONLY SUBTRACTS THE CONTENT OF MEMORY FROM THE BP REGISTER.
                        2252    ;
                        2253    ;OF COURSE, THE CARRY CONTAINS ANY BORROW .   IF NO BORROW OCCURS FROM THIS
                        2254    ;
                        2255    ;ENTIRE 32_ BIT SUBTRACTION, THEN THE PARTIAL DIVIDEND IS EQUAL TO OR LARGER
                        2256    ;
                        2257    ;THAN THE DIVISOR.       IF THERE IS A BORROW AS A RESULT OF THE 32_ BIT
                        2258    ;
                        2259    ;SUBTRACION, THEN THE PARTIAL DIVIDEND IS SMALLER THAN THE DIVISOR MUST BE
                        2260    ;
                        2261    ;ADDED TO THE RESULT OF THE 32_BIT SUBTRACTION TO RESTORE THE PARTIAL
                        2262    ;
                        2263    ;DIVIDEND TO ITS ORIGINAL VALUE .     TO DO THIS, BOTH ADD AND ADC
                        2264    ;
                        2265    ;INSTRUCTIONS ARE EXECUTED.     IF THERE IS NO BORROW AS A RESULT OF THE
                        2266    ;
                        2267    ;32_BIT SUBTRACTION, THE 8088 JUMPS TO NOADD.     AT NOADD , THE CARRY IS
                        2268    ;
                        2269    ;COMPLEMENTED TO REFLECT WHETHER OR NOT A BORROW OCCURED AS A RESULT OF THE
                        2270    ;
                        2271    ;32_BIT SUBTRACTION.       THIS CARRY BIT IS THEN ROTATED INTO THE LSB OF
                        2272    ;
                        2273    ;REGISTER PAIR DX AND DI AT THE TIME THAT THE NEXT MSB OF THE DIVIDEND
                        2274    ;
                        2275    ;CONTAINED IN REGISTER PAIR DX AND DI IS ROTATED LEFT INTO THE CARRY.
                        2276    ;
                        2277    ;THE QUOTIENT IS STORED IN REGISTER PAIR DX AND DI .       THE 32_BIT
                        2278    ;
                        2279    ;REMAINDER IS SAVED IN THE REGISTER PAIR BP AND CX .
                        2280    ;
                        2281    ;-----------------------------------------------------------------


                        2282
                        2283
                        2284
                        2285    ;=================================================================


                        2286
                        2287
                        2288
                        2289    ;#################################################################
                        2290    ;
                        2291    ;32- BIT SQUARE ROOT PROCEDURE :
```

OBJ LINE SOURCE

```
2292
2293    ;THIS PROCEDURE CALCULATES THE SQUARE ROOT OF DATA STORED IN REGISTER
2294    ;PAIR DX AND AX (32_BIT) WHERE DX CONTAINS MSW, AX CONTAINS LSW, THE
2295    ;RESULT WILL BE STORED IN CX REGISTER (16_BIT).      THE ALGORITHM OF
2296    ;CALCULATING SQUARE ROOTS FOR BINARY NUMBERS IS MODIFIED FROM AN OLD
2297    ;CHINESE RHYMED PITHY FORMULA FOR DECIMAL NUMBERS.      THE PROCEDURE
2298    ;IS AS FOLLOWS :
2299    ;(1) SEPARATE THE BITS OF THE RADICAND INTO GROUPS OF TWO BITS
2300    ;    EACH , STARTING FROM THE MSB.
2301    ;(2) BEGIN THE ACTUAL EXTRACTION OPERATION AT THE FIRST GROUP OF BITS
2302    ;    FROM THE LEFT THAT DOES NOT CONTAIN TWO ZEROES.      ALIGN A 1 WITH
2303    ;    THE RIGHT-HAND BIT OF THIS GROUP AND SUBTRACT.      THE REMAINDER WILL
2304    ;    BE NONNEGATIVE AND A 1 IS ENTERED IN THE ROOT FOR THIS GROUP.      FOR
2305    ;    EACH DOUBLE 0 GROUP TO THE LEFT OF THIS GROUP,  A 0 IS ENTERED IN THE
2306    ;    ROOT .
2307    ;(3) FOR ALL SUCCEEDING GROUPS, THE TRIAL FACTOR TO BE SUBTRACTED FROM THE
2308    ;    REMAINDER IS THE EXPRESSION [ 4*2^N+1 ] , THE RIGHT HAND DIGIT OF THE
2309    ;    TRIAL DIVISOR IS ALIGNED WITH THE RIGHT HAND DIGIT OF THE GROUP FOR
2310    ;    WHICH IT IS USED, AND SUBTRACTED.      IF THE REMAINDER IS NONNEGATIVE,
2311    ;    A 1 IS ENTERED AS THE ROOT FOR THAT GROUP.      IF THE REMAINDER IS
2312    ;    NEGATIVE, THE ROOT IS 0 AND THE SUBTRACTION IS RESTORED.      SEE THE
2313    ;    FOLLOWING EXAMPLES IN WHICH THE SQUARE ROOT OF (01 01 00 01) IS
2314    ;    EXTRACTED .
2315    ;
2316    ;     1  0  0  1    ROOT
2317    ;   ---------------
2318    ;  / 01 01 00 01
2319    ;    01
2320    ;  ---------------
2321    ;     0 01
2322    ;     1 01          (4*1)+1
2323    ;  ---------------
2324    ;     RESTORE
2325    ;       01 00
2326
```

```
OBJ                     LINE    SOURCE

                        2347    ;       10 01         (4*2)+1
                        2348    ; --------------------
                        2349    ;     RESTORE
                        2350    ;        1 00 01
                        2351    ;        1 00 01      (4*4)+1
                        2352    ; --------------------
                        2353    ;           0 00     REMAINDER
                        2354    ;
                        2355    ;#################################################################
                        2356
                        2357
                        2358
                        2359    SROOT   PROC    NEAR
                        2360
                        2361
                        2362
BB5814                  2363            MOV BX,OFFSET ASH       ;STORE MS WORD OF DATA.
8917                    2364            MOV [BX],DX
                        2365
BB5A14                  2366            MOV BX,OFFSET ASL       ;STORE LS WORD OF DATA.
8907                    2367            MOV [BX],AX
                        2368
BD0000                  2369            MOV BP,0                ;INITIALIZES ROOT.
                        2370
8BCA                    2371            MOV CX,DX               ;CX_ MS WORD OF DATA.
                        2372
D1C2                    2373            ROL DX,1                ;SHIFT BIT 15 AND 14 TO BIT 9 AND 8 POSITION.
D1C2                    2374            ROL DX,1
                        2375
BB8414                  2376            MOV BX,OFFSET R6        ;STORE IT.
8917                    2377            MOV [BX],DX
                        2378
81E100C0                2379            AND CX,0C000H           ;MASK OFF ALL BITS EXCEPT BIT 15 AND 14.
D1C1                    2380            ROL CX,1                ;SHIFT THESE TWO BITS TO RIGHT END POSITION.
D1C1                    2381            ROL CX,1
                        2382
E82300                  2383            CALL QUE                ;FIRST WORK OUT THE MS WORD OF DATA.
                        2384
BB5A14                  2385            MOV BX,OFFSET ASL
8B07                    2386            MOV AX,[BX]             ;AX_ LS WORD OF DATA.
8BD0                    2387            MOV DX,AX               ;DX_ LS WORD OF DATA.
D1C2                    2388            ROL DX,1                ;SHIFT BIT 7 AND 6 TO BIT 21 AND 0 POSITION.
D1C2                    2389            ROL DX,1
                        2390
BB8414                  2391            MOV BX,OFFSET R6        ;STORE IT.
8917                    2392            MOV [BX],DX
                        2393
2500C0                  2394            AND AX,0C000H
D1C0                    2395            ROL AX,1                ;SHIFT THESE TWO BITS TO RIGHT END POSITION.
D1C0                    2396            ROL AX,1
                        2397
81E1FCFF                2398            AND CX,0FFFCH           ;MASK OFF LAST 2 BITS OF MS WORD OF LAST
                        2399                                    ;REMAINDER.
0BC8                    2400            OR CX,AX                ;CX- NEW DIVIDEND.
                        2401
```

```
OBJ                     LINE    SOURCE

E80300                  2402            CALL QUE                ;WORK OUT THE LS WORD OF DATA.
                        2403
8BCD                    2404            MOV CX,BP               ;CX_ STORE THE RESULT.
                        2405
C3                      2406            RET
                        2407
                        2408
                        2409
                        2410    SROOT   ENDP
                        2411
                        2412
                        2413
                        2414    ;=================================================================
                        2415
                        2416
                        2417    ;#################################################################
                        2418    ;
                        2419    ;THIS PROCEDURE CALCULATES BOTH THE MOST OR THE LEAST SIGNIFICANT
                        2420    ;
                        2421    ;(MS OR LS) WORD OF THE SQUARE ROOT.
                        2422    ;
                        2423    ;#################################################################
                        2424
                        2425
                        2426    QUE     PROC NEAR
                        2427
                        2428
                        2429
BF0800                  2430            MOV DI,8                ;DI_ NUMBER OF EXECUTING TIMES DOES THE
                        2431                                    ;FOCLOWING LOOP, TOTAL IS 8 FOR 8 BITS.
8BC5                    2432     LSR3:  MOV AX,BP
03C0                    2433            ADD AX,AX
03C0                    2434            ADD AX,AX
40                      2435            INC AX                  ;4*2^N+1 .
                        2436
8BD1                    2437            MOV DX,CX               ;DX_ PSUEDO REMAINDER.
2BC8                    2438            SUB CX,AX               ;CX_ REMAINDER .
7308                    2439            JNB LSR1                ;IF REMAINDER > TRIAL FACTOR.
                        2440
8BCA                    2441            MOV CX,DX
B80000                  2442            MOV AX,0                ;ASSIGN ROOT FOR THAT TWO BITS IS 0.
EB0490                  2443            JMP LSR2
                        2444
B80100                  2445    LSR1:   MOV AX,1                ;ASSIGN ROOT FOR THAT TWO BITS IS 1.
                        2446
D1C5                    2447    LSR2:   ROL BP,1                ;BP_ ROOT.
0BE8                    2448            OR BP,AX
                        2449
8B8414                  2450            MOV BX,OFFSET R6        ;PREPARE NEXT TWO BITS WHICH ARE TO BE
                        2451                                    ;DEALT WITH.
8B17                    2452            MOV DX,[BX]
8BC2                    2453            MOV AX,DX
D1C0                    2454            ROL AX,1
D1C0                    2455            ROL AX,1
                        2456
```

```
OBJ                     LINE    SOURCE

8B8414                  2457            MOV BX,OFFSET R6
8907                    2458            MOV [BX],AX
                        2459
81E200C0                2460            AND DX,0C000H
D1C2                    2461            ROL DX,1                ;REMAINDER LS WORD.
D1C2                    2462            ROL DX,1
                        2463
D1C1                    2464            ROL CX,1                ;REMAINDER MS WORD.
D1C1                    2465            ROL CX,1
                        2466
0BCA                    2467            OR CX,DX                ;CX_ NEW DIVIDEND.
                        2468
4F                      2469            DEC DI                  ;TEST EXECUTING TIME.
75C3                    2470            JNZ LSR3
                        2471
C3                      2472            RET
                        2473
                        2474
                        2475
                        2476    QUE     ENDP
                        2477
                        2478
                        2479
                        2480    ;=======================================================================
                        2481
                        2482
                        2483
                        2484    ;-----------------------------------------------------------------------
                        2485    ;
                        2486    ;FUNCTION OF THIS PROCEDURE IS :
                        2487    ;
                        2488    ;LIGHT THE LED TO SHOW OVERFLOW STATUS OF ADC AND HALT THE CPU.
                        2489    ;
                        2490    ;THE SYSTEM CAN ONLY RESTART AGAIN BY PRESSING THE RESET BUTTON
                        2491    ;
                        2492    ;ON THE FRONT_ PANEL .
                        2493    ;
                        2494    ;-----------------------------------------------------------------------
                        2495
                        2496
                        2497
                        2498    LED     PROC    NEAR
                        2499
                        2500
                        2501
8080                    2502            MOV AL,LED_ON
E6C0                    2503            OUT LEDP,AL
                        2504
F4                      2505            HLT                     ;HALT THE CPU.
                        2506
                        2507
                        2508
                        2509    LED     ENDP
                        2510
                        2511
```

```
OBJ             LINE    SOURCE

                2512
                2513    ;=================================================================
                2514
                2515
                2516
                2517    FANG    PROC    NEAR
                2518
                2519
                2520    ;-----------------------------------------------------------------
                2521    ;
                2522    ;THIS PROCEDURE CAN CALCULATE ARC_ COSINE IN BINARY FORM THE ARC_ COSINE
                2523    ;
                2524    ;VALUE IS CONTAINED IN THE DI REGISTER.      THE ANGLE FOUND IS ONLY IN
                2525    ;
                2526    ;THE RANGE 0 TO 90 DEG WITH SCALING FACTOR 10, THAT IS, 0 TO 900.    ITS
                2527    ;
                2528    ;QUADRANT HAS TO BE DETERMINED BY OTHER PROCEDURES.
                2529    ;
                2530    ;THIS PROCEDURE USES FAST SEARCHING METHOD TO FIND OUT THE ANGLE FROM
                2531    ;
                2532    ;THE LOOK_ UP TABLE DEFINED IN THE "ATCS" SEGMENT OF THE PROGRAM.
                2533    ;
                2534    ;FOR EXAMPLES :
                2535    ;
                2536    ;WHEN THE ARC_ COS VALUE IS 0FFFFH CORRESPONDING TO
                2537    ;INDEX SI= 0 MEANS 0 DEG.
                2538    ;
                2539    ;WHEN THE ARC_ COS VALUE IS 0FFD7H CORRESPONDING TO
                2540    ;INDEX SI= 20 MEANS 0.2 DEG.
                2541    ;
                2542    ;WHEN THE ARC_ COS VALUE IS 9FB5H CORRESPONDING TO
                2543    ;INDEX SI= 514 MEANS 51.4 DEG.
                2544    ;
                2545    ;WHEN THE ARC_ COS VALUE IS 0000H CORRESPONDING TO
                2546    ;INDEX SI= 900 MEANS 90.0 DEG.
                2547    ;
                2548    ;THE ACCURACY OF THIS LOOK_ UP TABLE IS 0.2 DEG RESOLUTION.
                2549    ;
                2550    ;EVERY ITEM IN ACOS TABLE HAS 4 DIGITS EXPRESSED IN HEX FORM.
                2551    ;
                2552    ;PROCEDURE "FANG" FIRST CHECKS THE MOST SIGNIFICANT DIGIT TO SEE WHICH
                2553    ;
                2554    ;ONE (FROM 0 TO F) IT IS.     IT THEN JUMPS TO THE STARTING ADDRESS OF
                2555    ;
                2556    ;ONE OF THOSE ITEMS WITH SAME MOST SIGNIFICANT DIGIT, SO THAT IT STARTS
                2557    ;
                2558    ;SEARCHING THERE UNTIL THE RIGHT ANGLE IS FOUND, INSTEAD OF SEACHING
                2559    ;
                2560    ;VERY SLOWLY FROM THE BEGINNING ( SI = 0 ) TO THE END ( SI = 900 ) OF
                2561    ;
                2562    ;THE TABLE.     FOR EXAMPLE 0FXXXH STARTS AT SI = 0, 0EXXXH START AT
                2563    ;
                2564    ;SI= 204 AND 7XXXH STARTS AT SI = 600.      BECAUSE THOSE ITEMS UNDER
                2565    ;
                2566    ;THE HEADING OF F, E AND D ARE TOO MANY, THE SECOND MOST SIGNIFICANT
```

```
OBJ                     LINE    SOURCE

                        2567
                        2568    ;DIGIT OF THEM ALSO NEEDS TO BE CHECKED IN ORDER TO SPEED UP THE SEARCH
                        2569
                        2570    ;PROCEDURE .
                        2571
                        2572    ;SIMILARLY, THE ANGLE OF ARC_ SINE CAN ALSO BE FOUND OUT BY REVERSING
                        2573
                        2574    ;THE ORDER OF THE SI INDEX IN THE INVERTED ARC_ COS TABLE, THAT IS,
                        2575
                        2576    ;SI = 900 MEANS 0 DEG AND SI = 0 MEANS 90 DEG.
                        2577
                        2578    ;THE SPEED OF THIS PROCEDURE USING A LOOK_UP TABLE INCOOPERATED WITH A
                        2579
                        2580    ;SEARCHING TECHNIQUE IS MUCH FASTER THAN NUMERICAL PROCESSORS.
                        2581
                        2582    ;-----------------------------------------------------------------
                        2583
                        2584
3BC7                    2585            MOV AX,DI
3BD0                    2586            MOV DX,AX
                        2587
)1C0                    2588            ROL AX,1
)1C0                    2589            ROL AX,1
)1C0                    2590            ROL AX,1
)1C0                    2591            ROL AX,1
                        2592
3BF8                    2593            MOV DI,AX
                        2594
)1C7                    2595            ROL DI,1
)1C7                    2596            ROL DI,1
)1C7                    2597            ROL DI,1
)1C7                    2598            ROL DI,1
                        2599
81E70F00                2600            AND DI,000FH            ;AX_ MOST SIGNIFICANT DIGIT (HEX).
250F00                  2601            AND AX,000FH            ;DI_ 2ND MOST SIGNIFICANT DIGIT (HEX).
                        2602
)BC0                    2603            OR AX,AX
'412                    2604            JZ LT09
                        2605
-8                      2606            DEC AX
'412                    2607            JZ LT19
                        2608
 8                      2609            DEC AX
 412                    2610            JZ LT29
                        2611
 8                      2612            DEC AX
 412                    2613            JZ LT39
                        2614
 8                      2615            DEC AX
 412                    2616            JZ LT49
                        2617
 8                      2618            DEC AX
 412                    2619            JZ LT59
                        2620
 B1390                  2621            JMP LCN9
```

```
OBJ                     LINE      SOURCE

                        2622
E9B000                  2623      LT09:   JMP LT0
                        2624
E9A700                  2625      LT19:   JMP LT1
                        2626
E99E00                  2627      LT29:   JMP LT2
                        2628
E99500                  2629      LT39:   JMP LT3
                        2630
E98C00                  2631      LT49:   JMP LT4
                        2632
E98300                  2633      LT59:   JMP LT5
                        2634
48                      2635      LCN9:   DEC AX
747A                    2636              JZ LT6
                        2637
48                      2638              DEC AX
7471                    2639              JZ LT7
                        2640
48                      2641              DEC AX
7468                    2642              JZ LT8
                        2643
48                      2644              DEC AX
745F                    2645              JZ LT9
                        2646
48                      2647              DEC AX
7456                    2648              JZ LT10
                        2649
48                      2650              DEC AX
744D                    2651              JZ LT11
                        2652
48                      2653              DEC AX
7444                    2654              JZ LT12
                        2655
48                      2656              DEC AX
7430                    2657              JZ LT13
                        2658
48                      2659              DEC AX
741C                    2660              JZ LT14
                        2661
83FF0E                  2662              CMP DI,000EH
7206                    2663              JB LT151
                        2664
BE0000                  2665              MOV SI,0
EB7F90                  2666              JMP LTE
                        2667
83FF07                  2668      LT151:  CMP DI,0007H
7606                    2669              JNA LT152
BE2400                  2670              MOV SI,36D
EB7490                  2671              JMP LTE
                        2672
BE4800                  2673      LT152:  MOV SI,72D
EB6E90                  2674              JMP LTE
                        2675
83FF08                  2676      LT14:   CMP DI,0008H
```

```
OBJ                     LINE     SOURCE

7206                    2677             JB LT141
                        2678
BE6600                  2679             MOV SI,102D
EB6390                  2680             JMP LTE
                        2681
BE7B00                  2682     LT141:  MOV SI,123D
EB5D90                  2683             JMP LTE
                        2684
83FF09                  2685     LT13:   CMP DI,0009D
7206                    2686             JB LT131
                        2687
BE9100                  2688             MOV SI,145D
EB5290                  2689             JMP LTE
                        2690
BEA100                  2691     LT131:  MOV SI,161D
EB4C90                  2692             JMP LTE
                        2693
BEB300                  2694     LT12:   MOV SI,179D
EB4690                  2695             JMP LTE
                        2696
BED000                  2697     LT11:   MOV SI,208D
EB4090                  2698             JMP LTE
                        2699
BEE900                  2700     LT10:   MOV SI,233D
EB3A90                  2701             JMP LTE
                        2702
BE0101                  2703     LT9:    MOV SI,257D
EB3490                  2704             JMP LTE
                        2705
BE1701                  2706     LT8:    MOV SI,279D
EB2E90                  2707             JMP LTE
                        2708
BE2C01                  2709     LT7:    MOV SI,300D
EB2890                  2710             JMP LTE
                        2711
BE4101                  2712     LT6:    MOV SI,321D
EB2290                  2713             JMP LTE
                        2714
BE5401                  2715     LT5:    MOV SI,340D
EB1C90                  2716             JMP LTE
                        2717
BE6701                  2718     LT4:    MOV SI,359D
EB1690                  2719             JMP LTE
                        2720
BE7A01                  2721     LT3:    MOV SI,378D
EB1090                  2722             JMP LTE
                        2723
BE8C01                  2724     LT2:    MOV SI,396D
EB0A90                  2725             JMP LTE
                        2726
BE9F01                  2727     LT1:    MOV SI,415D
EB0490                  2728             JMP LTE
                        2729
BEB101                  2730     LT0:    MOV SI,433D
                        2731
```

```
OBJ                 LINE    SOURCE
03F6                2732    LTE:    ADD SI,SI               ;WORK OUT THE TRUE ADDRESS INDEX.
                    2733
3B0000              2734            MOV BX,OFFSET ACOS
                    2735
263B10              2736    LTE1:   CMP DX,ES:[BX+SI]
7305                2737            JNB LT20
                    2738
83C602              2739            ADD SI,2                ;SEARCH UNTIL THE INPUT VALUE IN DI MATCHES
                    2740                                    ;WITH THE ONE IN LOOK_UP TABLE .
EBF6                2741            JMP LTE1
                    2742
8BFE                2743    LT20:   MOV DI,SI               ;DI_ ANG .
                    2744
C3                  2745            RET
                    2746
                    2747
                    2748
                    2749    FANG    ENDP
                    2750
                    2751
                    2752
                    2753    ;=================================================================
                    2754
                    2755
                    2756    ;#################################################################
                    2757    ;
                    2758    ;THIS PROCEDURE POLLS THE READINESS OF HPIB AND TRANSFERS THE DATA
                    2759    ;
                    2760    ;OF TOTAL NUMBER OF DATA NEEDS TO BE TRANSFERRED AND THE FUNDAMENTAL
                    2761    ;
                    2762    ;FREQUENCY TO THE HPIB.
                    2763    ;
                    2764    ;=================================================================
                    2765
                    2766
                    2767
                    2768    GPIB    PROC    NEAR
                    2769
                    2770
                    2771
8B10                2772    LBL:    MOV DX,[BX+SI]          ;DX_ DATA TO SEND.
                    2773
E4E2                2774    LBL1:   IN AL,0E2H              ;PRIMARY TKR OK TO GO OCCURED ?
2488                2775            AND AL,88H
3C88                2776            CMP AL,88H
75F8                2777            JNZ LBL1                ;NO .
                    2778
E4E0                2779    LBL3:   IN AL,0E0H              ;YES .
A840                2780            TEST AL,40H             ;B0 SET ?
74FA                2781            JZ LBL3                 ;NO .
                    2782
8AC6                2783            MOV AL,DH               ;YES, LOAD DATA TO SEND (MSBY) .
E6E7                2784            OUT 0E7H,AL
                    2785
E4E2                2786    LBLA:   IN AL,0E2H              ;PRIMARY TKR OK TO GO OCCURED ?
```

```
OBJ                 LINE    SOURCE

2488                2787            AND AL,88H
3C88                2788            CMP AL,88H
75F8                2789            JNZ LBLA                ;NO .
                    2790
E4E0                2791    LBLC:   IN AL,0E0H              ;YES
                    2792
A840                2793            TEST AL,40H             ;B0 SET ?
74FA                2794            JZ LBLC                 ;NO .
                    2795
8AC2                2796            MOV AL,DL               ;YES, LOAD DATA TO SEND (LSBY).
E6E7                2797            OUT 0E7H,AL
                    2798
83C602              2799            ADD SI,2                ;INCREASE ADDRESS POINTER.
E2D5                2800            LOOP LBL
                    2801
E4E0                2802    LBL4:   IN AL,0E0H
A840                2803            TEST AL,40H             ;B0 SET ?
74FA                2804            JZ LBL4                 ;NO .
                    2805
C3                  2806            RET                     ;YES .
                    2807
                    2808
                    2809
                    2810    GPIB    ENDP
                    2811
                    2812
                    2813
                    2814    ;=================================================================
                    2815
                    2816
                    2817    ;#################################################################
                    2818    ;
                    2819    ;THIS PROCEDURE POLLS THE READINESS OF HPIB AND TRANSFERS THE DATA
                    2820    ;
                    2821    ;OF AMP. AND ANG. TO THE HPIB.
                    2822    ;
                    2823    ;=================================================================
                    2824
                    2825
                    2826
                    2827    GPIB1   PROC    NEAR
                    2828
                    2829
                    2830
BA00F               2831    TLBT:   MOV BX,OFFSET AMP
8B10                2832            MOV DX,[BX+SI]          ;DX_ DATA TO SEND
                    2833
E4E2                2834    TLBT1:  IN AL,0E2H              ;PRIMARY TKR OK TO GO OCCURED ?
2488                2835            AND AL,88H
3C88                2836            CMP AL,88H
75F8                2837            JNZ TLBT1               ;NO .
                    2838
E4E0                2839    TLBT3:  IN AL,0E0H              ;YES .
A840                2840            TEST AL,40H             ;B0 SET ?
74FA                2841            JZ TLBT3                ;NO .
```

```
OBJ                     LINE    SOURCE

                        2842
3AC6                    2843            MOV AL,DH               ;YES, LOAD DATA TO SEND (MSBY).
E6E7                    2844            OUT 0E7H,AL
                        2845
E4E2                    2846    TLBTA:  IN AL,0E2H              ;PRIMARY TKR OK TO GO OCCURED ?
2488                    2847            AND AL,88H
3C88                    2848            CMP AL,88H
75F8                    2849            JNZ TLBTA               ;NO .
                        2850
E4E0                    2851    TLBTC:  IN AL,0E0H              ;YES .
A840                    2852            TEST AL,40H             ;B0 SET ?
74FA                    2853            JZ TLBTC                ;NO .
                        2854
3AC2                    2855            MOV AL,DL               ;YES, LOAD DATA TO SEND (LSBY).
E6E7                    2856            OUT 0E7H,AL
                        2857
BCC10                   2858    PLBL:   MOV BX,OFFSET ANG
8B10                    2859            MOV DX,[BX+SI]          ;DX_ DATA TO SEND..
                        2860
                        2861
E4E2                    2862    PLBL1:  IN AL,0E2H              ;PRIMARY TKR OK TO GO OCCURED ?
2488                    2863            AND AL,88H
3C88                    2864            CMP AL,88H
75F8                    2865            JNZ PLBL1               ;NO .
                        2866
E4E0                    2867    PLBL3:  IN AL,0E0H              ;YES .
A840                    2868            TEST AL,40H             ;B0 SET ?
74FA                    2869            JZ PLBL3                ;NO .
                        2870
3AC6                    2871            MOV AL,DH               ;YES, LOAD DATA TO SEND (MSBY).
E6E7                    2872            OUT 0E7H,AL
                        2873
E4E2                    2874    PLBLA:  IN AL,0E2H              ;PRIMARY TKR OK TO GO OCCURED ?
2488                    2875            AND AL,88H
3C88                    2876            CMP AL,88H
75F8                    2877            JNZ PLBLA               ;NO .
                        2878
E4E0                    2879    PLBLC:  IN AL,0E0H              ;YES .
A840                    2880            TEST AL,40H             ;B0 SET ?
74FA                    2881            JZ PLBLC                ;NO .
                        2882
3AC2                    2883            MOV AL,DL               ;YES, LOAD DATA TO SEND (LSBY).
E6E7                    2884            OUT 0E7H,AL
                        2885
83C602                  2886            ADD SI,2                ;INCREASE ADDRESS POINTER.
E203                    2887            LOOP TLBX
                        2888
EB0390                  2889            JMP TLBL4
                        2890
EBA4                    2891    TLBX:   JMP TLBT
                        2892
E4E0                    2893    TLBL4:  IN AL,0E0H
A840                    2894            TEST AL,40H             ;B0 SET ?
74FA                    2895            JZ TLBL4                ;NO .
                        2896
```

```
OBJ                     LINE    SOURCE
C3                      2897            RET                     ;YES .
                        2898
                        2899
                        2900
                        2901    GPIB1   ENDP
                        2902
                        2903
                        2904
                        2905    ;=======================================================================
                        2906
                        2907
                        2908
                        2909    DUMMY_READ      PROC    NEAR
                        2910
                        2911
B001                    2912            MOV AL,1
BB9314                  2913            MOV BX,OFFSET R14
8807                    2914            MOV [BX],AL
33F6                    2915            XOR SI,SI               ;NULL SI .
                        2916
BB8E14                  2917            MOV BX,OFFSET R11
8937                    2918            MOV [BX],SI             ;INITIALIZES XYP .
                        2919
BB5E14                  2920            MOV BX,OFFSET ZCCP
8937                    2921            MOV [BX],SI             ;INITIALIZES ZCCP.
                        2922
E886FB                  2923            CALL ZC_ADC
                        2924
E8DEFC                  2925            CALL MOD_CLK_UPDATE_1
                        2926
C3                      2927            RET
                        2928
                        2929
                        2930    DUMMY_READ      ENDP
                        2931
                        2932
                        2933    ;=======================================================================
                        2934
                        2935
                        2936    THREE_7_8       PROC    NEAR
                        2937
                        2938    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION (3.7.8).
                        2939
E480                    2940            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER OF
                        2941                                    ;HARMONIC THAT NEEDS TO BE MEASURED.
241F                    2942            AND AL,HA_ORDER_MASK
3C17                    2943            CMP AL,23D
                        2944
7703                    2945            JA LQ9H                 ;ORDER :  > 23 .
EB3590                  2946            JMP LQ98L               ;ORDER : =< 23 .
                        2947
BE2802                  2948    LQ9H:   MOV SI,552D             ;(24-1)*2*2*6 .
                        2949
BB8414                  2950            MOV BX,OFFSET R6
B80300                  2951            MOV AX,3
```

```
OBJ                     LINE    SOURCE

8907                    2952            MOV [BX],AX
                        2953
                        2954
                        2955
                        2956    ;CALCULATE EQUATION (3.7.8) :
                        2957
BB7E14                  2958            MOV BX,OFFSET R3
B88001                  2959            MOV AX,384D             ;2*2*6*(16), WHERE THE CONTENT INSIDE THE
                        2960                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        2961                                    ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN THE
                        2962                                    ;EQUATION .
8907                    2963            MOV [BX],AX
                        2964
BB7A14                  2965            MOV BX,OFFSET R1
8937                    2966            MOV [BX],SI             ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        2967
B90600                  2968            MOV CX,6
BB7814                  2969            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
890F                    2970    LQ88:   MOV [BX],CX
                        2971
B90200                  2972            MOV CX,2
BB8214                  2973            MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    2974    LQ8:    MOV [BX],CX
                        2975
E801FD                  2976            CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        2977
E2F9                    2978            LOOP LQ8
                        2979
BB7814                  2980            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
8B0F                    2981            MOV CX,[BX]
                        2982
E2EA                    2983            LOOP LQ88
                        2984
C3                      2985    LQ98L:  RET
                        2986
                        2987
                        2988    THREE_7_8       ENDP
                        2989
                        2990
                        2991    ;===============================================================
                        2992
                        2993
                        2994    THREE_7_7       PROC    NEAR
                        2995
                        2996    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.7).
                        2997
E480                    2998            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER
                        2999                                    ;OF HARMONIC THAT NEEDS TO BE MEASURED.
241F                    3000            AND AL,HA_ORDER_MASK
3C14                    3001            CMP AL,20D
                        3002
7703                    3003            JA LQ9G                 ;ORDER :  > 20 .
EB3590                  3004            JMP LQ97L                ;ORDER : =< 20 .
                        3005
                        3006
```

```
OBJ                     LINE    SOURCE

                        3007
                        3008    ;FOR INSTRUCTIONS BELOW :
                        3009
                        3010    ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3011    ;AX_ GREATEST DIVISOR.
                        3012
BEE001                  3013    LQ96:   MOV SI,480D             ;(21-1)*2*2*6 .
                        3014
BB8414                  3015            MOV BX,OFFSET R6
B80300                  3016            MOV AX,3
8907                    3017            MOV [BX],AX
                        3018
                        3019
                        3020
                        3021    ;CALCULATE EQUATION (3.7.7) :
                        3022
BB7E14                  3023            MOV BX,OFFSET R3
B85001                  3024            MOV AX,336D             ;2*2*6*(14), WHERE THE CONTENT INSIDE THE
                        3025                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        3026                                    ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN THE
                        3027                                    ;EQUATION .
8907                    3028            MOV [BX],AX
                        3029
BB7A14                  3030            MOV BX,OFFSET R1
8937                    3031            MOV [BX],SI             ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3032
B90600                  3033            MOV CX,6
BB7814                  3034            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
890F                    3035    LQ77:   MOV [BX],CX
                        3036
B90200                  3037            MOV CX,2
BB8214                  3038            MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    3039    LQ7:    MOV [BX],CX
                        3040
E8C1FC                  3041            CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        3042
E2F9                    3043            LOOP LQ7
                        3044
BB7814                  3045            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
8B0F                    3046            MOV CX,[BX]
                        3047
E2EA                    3048            LOOP LQ77
                        3049
C3                      3050    LQ97L:  RET
                        3051
                        3052
                        3053    THREE_7_7       ENDP
                        3054
                        3055
                        3056    ;=======================================================================
                        3057
                        3058
                        3059
                        3060    THREE_7_6       PROC    NEAR
                        3061
```

```
OBJ                     LINE    SOURCE

                        3062    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.6).
                        3063
E480                    3064            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER
                        3065                                    ;OF HARMONIC THAT NEEDS TO BE MEASURED.
241F                    3066            AND AL,HA_ORDER_MASK
3C11                    3067            CMP AL,17D
                        3068
7703                    3069            JA LQ9F                 ;ORDER :  > 17 .
EB3590                  3070            JMP LQ96L                ;ORDER : =< 17 .
                        3071
                        3072
                        3073
                        3074    ;INSTRUCTIONS BELOW :
                        3075
                        3076    ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3077    ;AX_ GREATEST DIVISOR.
                        3078
BE9801                  3079    LQ9F:   MOV SI,408D             ;(18-1)*2*2*6 .
                        3080
BB8414                  3081            MOV BX,OFFSET R6
B80300                  3082            MOV AX,3
8907                    3083            MOV [BX],AX
                        3084
                        3085
                        3086
                        3087    ;CALCULATE EQUATION (2.4.6) :
                        3088
BB7E14                  3089            MOV BX,OFFSET R3
B8E400                  3090            MOV AX,228D             ;2*2*6*(12), WHERE THE CONTENT INSIDE THE
                        3091                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        3092                                    ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN THE
                        3093                                    ;EQUATION .
8907                    3094            MOV [BX],AX
                        3095
BB7A14                  3096            MOV BX,OFFSET R1
8937                    3097            MOV [BX],SI             ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3098
B90600                  3099            MOV CX,6
BB7814                  3100            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
890F                    3101    LQ66:   MOV [BX],CX
                        3102
B90200                  3103            MOV CX,2
BB8214                  3104            MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    3105    LQ6:    MOV [BX],CX
                        3106
E881FC                  3107            CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        3108
E2F9                    3109            LOOP LQ6
                        3110
BB7814                  3111            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
8B0F                    3112            MOV CX,[BX]
                        3113
E2EA                    3114            LOOP LQ66
                        3115
C3                      3116    LQ96L:  RET
```

```
OBJ                     LINE    SOURCE

                        3117
                        3118
                        3119    THREE_7_6       ENDP
                        3120
                        3121
                        3122    ;===============================================================
                        3123
                        3124
                        3125    THREE_7_5       PROC    NEAR
                        3126
                        3127    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.5).
                        3128
E480                    3129            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER OF
                        3130                                    ;HARMONIC THAT NEEDS TO BE MEASURED.
241F                    3131            AND AL,HA_ORDER_MASK
3C0E                    3132            CMP AL,14D
                        3133
7703                    3134            JA LQ9E                 ;ORDER :  > 14 .
EB4290                  3135            JMP LQ95L               ;ORDER : =< 14 .
                        3136
                        3137
                        3138
                        3139    ;FOR INSTRUCTIONS BELOW :
                        3140    ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3141    ;AX_ GREATEST DIVISOR.
                        3142
3C19                    3143    LQ9E:   CMP AL,25D
7209                    3144            JB Q551                 ;ORDER <  25 .
                        3145
                        3146                                    ;ORDER >= 25 .
BE4002                  3147            MOV SI,576D             ;(25-1)*2*2*6 .
B80500                  3148            MOV AX,5
EB0790                  3149            JMP Q559
                        3150
BE5001                  3151    Q551:   MOV SI,336D             ;(15-1)*2*2*6 .
B80300                  3152            MOV AX,3
                        3153
BB8414                  3154    Q559:   MOV BX,OFFSET R6
8907                    3155            MOV [BX],AX
                        3156
                        3157
                        3158
                        3159    ;CALCULATE EQUATION (3.7.5) :
                        3160
BB7E14                  3161            MOV BX,OFFSET R3
B8F000                  3162            MOV AX,240D             ;2*2*6*(10), WHERE THE CONTENT INSIDE THE
                        3163                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        3164                                    ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN
                        3165                                    ;THE EQUATION .
8907                    3166            MOV [BX],AX
                        3167
BB7A14                  3168            MOV BX,OFFSET R1
8937                    3169            MOV [BX],SI             ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3170
B90600                  3171            MOV CX,6
```

```
OBJ                     LINE    SOURCE

BB7814                  3172            MOV BX,OFFSET R0
890F                    3173    LQ55:   MOV [BX],CX
                        3174
B90200                  3175            MOV CX,2
BB8214                  3176            MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    3177    LQ5:    MOV [BX],CX
                        3178
E834FC                  3179            CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        3180
E2F9                    3181            LOOP LQ5
                        3182
BB7814                  3183            MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
8B0F                    3184            MOV CX,[BX]
                        3185
E2EA                    3186            LOOP LQ55
                        3187
C3                      3188    LQ95L:  RET
                        3189
                        3190
                        3191    THREE_7_5       ENDP
                        3192
                        3193
                        3194    ;=================================================================
                        3195
                        3196
                        3197    THREE_7_4       PROC
                        3198
                        3199    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.4).
                        3200
E480                    3201            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER
                        3202                                    ;OF HARMONIC THAT NEEDS TO BE MEASURED.
241F                    3203            AND AL,HA_ORDER_MASK
3C0B                    3204            CMP AL,11D
                        3205
7703                    3206            JA LQ9D                 ;ORDER : >  11 .
EB4290                  3207            JMP LQ94L               ;ORDER : =< 11 .
                        3208
                        3209
                        3210
                        3211    ;FOR INSTRUCTIONS BELOW :
                        3212    ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3213    ;AX_ GREATEST DIVISOR.
                        3214
3C14                    3215    LQ9D:   CMP AL,20D
7209                    3216            JB Q441                 ;ORDER <  20 .
                        3217
                        3218                                    ;ORDER >= 20 .
BEC801                  3219            MOV SI,456D             ;(20-1)*2*2*6 .
B80500                  3220            MOV AX,5
EB0790                  3221            JMP Q449
                        3222
BE0801                  3223    Q441:   MOV SI,264D             ;(12-1)*2*2*6 .
B80300                  3224            MOV AX,3
                        3225
BB8414                  3226    Q449:   MOV BX,OFFSET R6
```

```
OBJ                     LINE    SOURCE

8907                    03227           MOV [BX],AX
                        03228
                        03229
                        03230
                        03231   ;CALCULATE EQUATION (3.7.4) :
                        03232
BB7E14                  03233           MOV BX,OFFSET R3
B8C000                  03234           MOV AX,192D             ;2*2*6*(8), WHERE THE CONTENT INSIDE THE
                        03235                                   ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        03236                                   ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN
                        03237                                   ;THE EQUATION.
8907                    03238           MOV [BX],AX
                        03239
BB7A14                  03240           MOV BX,OFFSET R1
8937                    03241           MOV [BX],SI             ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        03242
B90600                  03243           MOV CX,6
BB7814                  03244           MOV BX,OFFSET R0
890F                    03245   LQ44:   MOV [BX],CX
                        03246
B90200                  03247           MOV CX,2
BB8214                  03248           MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    03249   LQ4:    MOV [BX],CX
                        03250
E8E7FB                  03251           CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        03252
E2F9                    03253           LOOP LQ4
                        03254
BB7814                  03255           MOV BX,OFFSET R0        ;CX_ POINTER FOR CHANNEL.
8B0F                    03256           MOV CX,[BX]
                        03257
E2EA                    03258           LOOP LQ44
                        03259
C3                      03260   LQ94L:  RET
                        03261
                        03262
                        03263   THREE_7_4       ENDP
                        03264
                        03265
                        03266   ;===============================================================
                        03267
                        03268
                        03269   THREE_7_3       PROC    NEAR
                        03270
                        03271   ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.3).
                        03272
E480                    03273           IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER
                        03274                                   ;OF HARMONIC THAT NEEDS TO BE MEASURED.
241F                    03275           AND AL,HA_ORDER_MASK
3C08                    03276           CMP AL,8
                        03277
7703                    03278           JA LQ9C                 ;ORDER :  > 8 .
EB4F90                  03279           JMP LQ93L               ;ORDER : =< 8 .
                        03280
                        03281
```

```
OBJ                     LINE    SOURCE

                        3282
                        3283    ;FOR INSTRUCTIONS BELOW :
                        3284    ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3285    ;AX_ GREATEST DIVISOR.
                        3286
3C15                    3287    LQ9C:   CMP AL,21D
7209                    3288            JB Q331                 ;ORDER <  21 .
                        3289
                        3290                                    ;ORDER >= 21 .
BEE001                  3291            MOV SI,480D             ;(21-1)*2*2*6 .
B80700                  3292            MOV AX,7
EB1490                  3293            JMP Q339
                        3294
3C0F                    3295    Q331:   CMP AL,15D
7209                    3296            JB Q332                 ;ORDER <  15.
                        3297
                        3298                                    ;ORDER >= 15 .
BE5001                  3299            MOV SI,336D             ;(15-1)*2*2*6 .
B80500                  3300            MOV AX,5
EB0790                  3301            JMP Q339
                        3302
BEC000                  3303    Q332:   MOV SI,192D             ;(9-1)*2*2*6 .
B80300                  3304            MOV AX,3
                        3305
BB8414                  3306    Q339:   MOV BX,OFFSET R6
8907                    3307            MOV [BX],AX
                        3308
                        3309
                        3310
                        3311    ;CALCULATE EQUATION (3.7.3) :
                        3312
8B7E14                  3313            MOV BX,OFFSET R3
B89000                  3314            MOV AX,144D             ;2*2*6*(6), WHERE THE CONTENT INSIDE THE
                        3315                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        3316                                    ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN THE
                        3317                                    ;EQUATION.
8907                    3318            MOV [BX],AX
                        3319
8B7A14                  3320            MOV BX,OFFSET R1
8937                    3321            MOV [BX],SI             ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3322
B90600                  3323            MOV CX,6
8B7814                  3324            MOV BX,OFFSET R0
890F                    3325    LQ33:   MOV [BX],CX
                        3326
B90200                  3327            MOV CX,2
8B8214                  3328            MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    3329    LQ3:    MOV [BX],CX
                        3330
E88DFB                  3331            CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        3332
E2F9                    3333            LOOP LQ3
                        3334
8B7814                  3335            MOV BX,OFFSET R0
8B0F                    3336            MOV CX,[BX]
```

```
OBJ                     LINE     SOURCE

                        03337
E2EA                    03338            LOOP LQ33
                        03339
C3                      03340    LQ93L:  RET
                        03341
                        03342
                        03343    THREE_7_3       ENDP
                        03344
                        03345
                        03346    ;=================================================================
                        03347
                        03348
                        03349    THREE_7_2       PROC    NEAR
                        03350
                        03351    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.2) .
                        03352
E480                    03353            IN AL,SWP              ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER
                        03354                                   ;OF HARMONIC THAT NEEDS TO BE MEASURED.
241F                    03355            AND AL,HA_ORDER_MASK
3C05                    03356            CMP AL,5
                        03357
7703                    03358            JA LQ9B                ;ORDER : >  5 .
EB6990                  03359            JMP LQ92L              ;ORDER : =< 5 .
                        03360
                        03361
                        03362
                        03363    ;FOR THE INSTRUCTIONS BELOW :
                        03364    ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        03365    ;AX_ GREATEST DIVISOR.
                        03366
3C16                    03367    LQ9B:   CMP AL,22D
7209                    03368            JB Q221                ;ORDER <  22 .
                        03369
                        03370                                   ;ORDER >= 22 .
BEF801                  03371            MOV SI,504D            ;(22-1)*2*2*6 .
B80B00                  03372            MOV AX,11D
EB2E90                  03373            JMP Q229
                        03374
3C12                    03375    Q221:   CMP AL,18D
7209                    03376            JB Q222                ;ORDER <  18 .
                        03377
                        03378                                   ;ORDER >= 18 .
BE9801                  03379            MOV SI,408D            ;(18-1)*2*2*6 .
B80900                  03380            MOV AX,9
EB2190                  03381            JMP Q229
                        03382
3C0E                    03383    Q222:   CMP AL,14D
7209                    03384            JB Q223                ;ORDER <  14 .
                        03385
                        03386                                   ;ORDER >= 14 .
BE3801                  03387            MOV SI,312D            ;(14-1)*2*2*6 .
B80700                  03388            MOV AX,7
EB1490                  03389            JMP Q229
                        03390
3C0A                    03391    Q223:   CMP AL,10D
```

```
OBJ                     LINE     SOURCE

7209                    3392             JB Q224                ;ORDER < 10.
                        3393
                        3394                                    ;ORDER >= 10 .
BED800                  3395             MOV SI,216D            ;(10-1)*2*2*6 .
B80500                  3396             MOV AX,5
EB0790                  3397             JMP Q229
                        3398
                        3399
BE7800                  3400     Q224:   MOV SI,120D            ;(6-1)*2*2*6 .
B80300                  3401             MOV AX,3
                        3402
BB8414                  3403     Q229:   MOV BX,OFFSET R6
8907                    3404             MOV [BX],AX
                        3405
                        3406
                        3407
                        3408     ;CALCULATE EQUATION (3.7.2) :
                        3409
B7E14                   3410             MOV BX,OFFSET R3
B86000                  3411             MOV AX,96D             ;2*2*6*(4), WHERE THE CONTENT INSIDE THE
                        3412                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN
                        3413                                    ;TWO SUCCESSIVE NEIGHBOUR D.C. TERMS IN THE
                        3414                                    ;EQUATION.
8907                    3415             MOV [BX],AX
B7A14                   3416             MOV BX,OFFSET R1
8937                    3417             MOV [BX],SI            ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3418
890600                  3419             MOV CX,6
B7814                   3420             MOV BX,OFFSET R0       ;CX_ POINTER FOR CHANNEL.
890F                    3421     LQ22:   MOV [BX],CX
                        3422
890200                  3423             MOV CX,2
B8214                   3424             MOV BX,OFFSET R5       ;CX_ POINTER FOR 0 AND 90 DEG.
890F                    3425     LQ2:    MOV [BX],CX
                        3426
E819FB                  3427             CALL DEHA              ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        3428
E2F9                    3429             LOOP LQ2
                        3430
B7814                   3431             MOV BX,OFFSET R0       ;CX_ POINTER FOR CHANNEL.
8B0F                    3432             MOV CX,[BX]
                        3433
E2EA                    3434             LOOP LQ22
                        3435
C3                      3436     LQ92L:  RET
                        3437
                        3438
                        3439     THREE_7_2       ENDP
                        3440
                        3441
                        3442     ;=======================================================================
                        3443
                        3444
                        3445
                        3446     THREE_7_1       PROC    NEAR
```

```
OBJ                     LINE    SOURCE

                        3447
                        3448    ;INITIALIZES THE STARTING ENVIRONMENT FOR CALCULATING EQUATION(3.7.1) .
                        3449
E480                    3450            IN AL,SWP               ;INPUT FROM SWITCH PORT TO SEE MAX. ORDER OF
                        3451                                    ;HARMONIC THAT NEEDS TO BE MEASURED.
                        3452
241F                    3453            AND AL,HA_ORDER_MASK
3C02                    3454            CMP AL,2                ;CHECK 2ND ORDER.
                        3455
7703                    3456            JA LQ9A                 ;ORDER : > 2 .
EB4190                  3457            JMP LQ91L               ;ORDER : =< 2 .
                        3458
                        3459
                        3460
                        3461    ;CALCULATE EQUATION (3.7.1) :
                        3462
BB7E14                  3463    LQ9A:   MOV BX,OFFSET R3
BA3000                  3464            MOV DX,48D              ;2*2*6*(2), WHERE THE CONTENT INSIDE THE
                        3465                                    ;( ) IS THE DIFFERERCE OF ORDER BETWEEN TWO
                        3466                                    ;SUCCESSIVE NEIGHBOUR D.C. TERMS IN THE
                        3467                                    ;EQUATION .
8917                    3468            MOV [BX],DX
                        3469
8AE0                    3470            MOV AH,AL               ;AH_ MAX ORDER OF HARMONIC THAT NEEDS TO BE
                        3471                                    ;MANAGED.
D0DC                    3472            RCR AH,1                ;USE CARRY BIT TO TEST ODD OR EVEN NUMBER ?
7202                    3473            JC LQ1E                 ;ODD NUMBER.
                        3474
FEC8                    3475            DEC AL                  ;EVEN NUMBER, MAKE IT ODD.
                        3476
32E4                    3477    LQ1E:   XOR AH,AH               ;NULL AH.
                        3478
BB8414                  3479            MOV BX,OFFSET R6
8907                    3480            MOV [BX],AX
48                      3481            DEC AX
                        3482
BA1800                  3483            MOV DX,24D              ;2*2*6 .
F7E2                    3484            MUL DX
                        3485
BB7A14                  3486            MOV BX,OFFSET R1
8907                    3487            MOV [BX],AX
8BF0                    3488            MOV SI,AX               ;SI_ LAST D.C. TERM ADDRESS POINTER.
                        3489
B90600                  3490            MOV CX,6
BB7814                  3491            MOV BX,OFFSET R0
890F                    3492    LQ11:   MOV [BX],CX             ;CX_ POINTER FOR CHANNEL.
                        3493
B90200                  3494            MOV CX,2
BB8214                  3495            MOV BX,OFFSET R5        ;CX_ POINTER FOR 0 AND 90 DEG.
                        3496
890F                    3497    LQ1:    MOV [BX],CX
                        3498
E8CDFA                  3499            CALL DEHA               ;ELIMINATE D.C. TERMS DUE TO HIGHER HARMONICS.
                        3500
E2F9                    3501            LOOP LQ1
```

```
OBJ                     LINE      SOURCE

                        03502
8B7814                  03503             MOV BX,OFFSET R0      ;CX_ POINTER FOR CHANNEL.
8B0F                    03504             MOV CX,[BX]
                        03505
E2EA                    03506             LOOP LQ11
                        03507
C3                      03508     LQ91L:  RET
                        03509
                        03510
                        03511     THREE_7_1         ENDP
                        03512
                        03513
                        03514     ;=================================================================================
                        03515
                        03516
                        03517
                        03518     CODE_SEG          ENDS
                        03519
                        03520
                        03521     ;~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
                        03522
                        03523
                        03524
                        03525     RES       SEGMENT AT 0FFFFH
                        03526
A000050FC               03527             JMP BEGIN
                        03528
                        03529     RES       ENDS
                        03530
                        03531
                        03532
                        03533     ;=================================================================================
                        03534
                        03535
                        03536
                        03537             END       BEGIN
```

SYMBOL TABLE LISTING

NAME	TYPE	VALUE	ATTRIBUTES
??SEG	SEGMENT		SIZE=0000H PARA PUBLIC
ACOS	V WORD	0000H	ATCS
ADCF	NUMBER	00A0H	
AMP	V WORD	0FA0H	(150) SAMP
ANG	V WORD	10CCH	(150) SAMP
ASH	V WORD	1458H	SAMP
ASL	V WORD	145AH	SAMP
ATCS	SEGMENT		SIZE=0386H WORD ABS
AVERAGING	P NEAR	036AH	SIZE=00B9H CODE_SEG
BEGIN	P FAR	0000H	SIZE=02C8H CODE_SEG
CHAN_VA	NUMBER	0006H	
CODE_SEG	SEGMENT		SIZE=09BAH WORD ABS
CTR0	NUMBER	0060H	
CTR0_CNTL_WORD	NUMBER	0036H	
CTR1	NUMBER	0068H	
CTR1_CNTL_WORD	NUMBER	0074H	
CTRC	NUMBER	0078H	
DEHA	P NEAR	047DH	SIZE=005EH CODE_SEG
DIV_32	P NEAR	04DBH	SIZE=0035H CODE_SEG
DUMMY_READ	P NEAR	072CH	SIZE=001AH CODE_SEG
FANG	P NEAR	059CH	SIZE=00FBH CODE_SEG
FORM_MASK	NUMBER	0080H	
FREQ	V WORD	145CH	SAMP
GATE	NUMBER	0020H	
GPIB	P NEAR	0697H	SIZE=0032H CODE_SEG
GPIB1	P NEAR	06C9H	SIZE=0063H CODE_SEG
HA_ORDER_MASK	NUMBER	001FH	
L1I2	L NEAR	050AH	CODE_SEG
L321	L NEAR	0368H	CODE_SEG
L3211	L NEAR	0085H	CODE_SEG
L395	L NEAR	033BH	CODE_SEG
L396	L NEAR	0344H	CODE_SEG
L3A	L NEAR	030BH	CODE_SEG
L3C	L NEAR	0325H	CODE_SEG
L3F	L NEAR	0318H	CODE_SEG
L3H	L NEAR	02FEH	CODE_SEG
L4	L NEAR	03DFH	CODE_SEG
L41	L NEAR	0401H	CODE_SEG
L42	L NEAR	0410H	CODE_SEG
L4A	L NEAR	039AH	CODE_SEG
L4B	L NEAR	03B0H	CODE_SEG
L4BB	L NEAR	03B3H	CODE_SEG
L4C	L NEAR	037FH	CODE_SEG
L5	L NEAR	03E4H	CODE_SEG
L999	L NEAR	00D0H	CODE_SEG
LA1	L NEAR	02DDH	CODE_SEG
LA10	L NEAR	02C8H	CODE_SEG
LA11	L NEAR	0063H	CODE_SEG
LA17	L NEAR	0468H	CODE_SEG
LA171	L NEAR	0470H	CODE_SEG
LA2	L NEAR	02EAH	CODE_SEG

NAME	TYPE	VALUE	ATTRIBUTES
LA214	L NEAR	0453H	CODE_SEG
LA215	L NEAR	0446H	CODE_SEG
LA216	L NEAR	044EH	CODE_SEG
LA217	L NEAR	001EH	CODE_SEG
LA27.	L NEAR	0475H	CODE_SEG
LA3	L NEAR	02E5H	CODE_SEG
LAC	L NEAR	005DH	CODE_SEG
LAQM.	L NEAR	04AAH	CODE_SEG
LAQN.	L NEAR	04B7H	CODE_SEG
LBEGIN.	L NEAR	0013H	CODE_SEG
LBL	L NEAR	0697H	CODE_SEG
LBL1.	L NEAR	0699H	CODE_SEG
LBL3.	L NEAR	06A1H	CODE_SEG
LBL4.	L NEAR	06C2H	CODE_SEG
LBLA.	L NEAR	06ABH	CODE_SEG
LBLC.	L NEAR	06B3H	CODE_SEG
LCN9.	L NEAR	05E1H	CODE_SEG
LED	P NEAR	0597H	SIZE=0005H CODE_SEG
LED_OFF	NUMBER	0000H	
LED_ON.	NUMBER	0080H	
LEDP.	NUMBER	00C0H	
LHT	L NEAR	0292H	CODE_SEG
LJT	L NEAR	0298H	CODE_SEG
LK21.	L NEAR	00ACH	CODE_SEG
LLED.	L NEAR	037CH	CODE_SEG
LM11.	L NEAR	012AH	CODE_SEG
LM12.	L NEAR	0141H	CODE_SEG
LQ0K.	L NEAR	01E6H	CODE_SEG
LQ1	L NEAR	09ABH	CODE_SEG
LQ11.	L NEAR	09A3H	CODE_SEG
LQ1E.	L NEAR	0989H	CODE_SEG
LQ2	L NEAR	095FH	CODE_SEG
LQ22.	L NEAR	0957H	CODE_SEG
LQ2K.	L NEAR	01C4H	CODE_SEG
LQ3	L NEAR	08EBH	CODE_SEG
LQ33.	L NEAR	08E3H	CODE_SEG
LQ3K.	L NEAR	01D3H	CODE_SEG
LQ4	L NEAR	0891H	CODE_SEG
LQ44.	L NEAR	0889H	CODE_SEG
LQ4K.	L NEAR	01DFH	CODE_SEG
LQ5	L NEAR	0844H	CODE_SEG
LQ55.	L NEAR	083CH	CODE_SEG
LQ6	L NEAR	07F7H	CODE_SEG
LQ66.	L NEAR	07EFH	CODE_SEG
LQ7	L NEAR	07B7H	CODE_SEG
LQ77.	L NEAR	07AFH	CODE_SEG
LQ8	L NEAR	0777H	CODE_SEG
LQ88.	L NEAR	076FH	CODE_SEG
LQ9	L NEAR	00C4H	CODE_SEG
LQ91.	L NEAR	016CH	CODE_SEG
LQ91L	L NEAR	09B9H	CODE_SEG
LQ92L	L NEAR	096DH	CODE_SEG
LQ93L	L NEAR	08F9H	CODE_SEG
LQ94L	L NEAR	089FH	CODE_SEG
LQ95.	L NEAR	018DH	CODE_SEG

NAME	TYPE	VALUE	ATTRIBUTES
LQ95L	L NEAR	0852H	CODE_SEG
LQ96L	L NEAR	0805H	CODE_SEG
LQ97L	L NEAR	07C5H	CODE_SEG
LQ98L	L NEAR	0785H	CODE_SEG
LQ9A	L NEAR	0979H	CODE_SEG
LQ9B	L NEAR	0905H	CODE_SEG
LQ9C	L NEAR	08ABH	CODE_SEG
LQ9D	L NEAR	085EH	CODE_SEG
LQ9E	L NEAR	0811H	CODE_SEG
LQ9F	L NEAR	07D1H	CODE_SEG
LQ9G	L NEAR	0791H	CODE_SEG
LQ9H	L NEAR	0751H	CODE_SEG
LQA	L NEAR	0489H	CODE_SEG
LQQ	L NEAR	0108H	CODE_SEG
LQR	L NEAR	0203H	CODE_SEG
LSR1	L NEAR	056EH	CODE_SEG
LSR2	L NEAR	0571H	CODE_SEG
LSR3	L NEAR	0559H	CODE_SEG
LT0	L NEAR	0682H	CODE_SEG
LT09	L NEAR	05CFH	CODE_SEG
LT1	L NEAR	067CH	CODE_SEG
LT10	L NEAR	0646H	CODE_SEG
LT11	L NEAR	0640H	CODE_SEG
LT12	L NEAR	063AH	CODE_SEG
LT13	L NEAR	0629H	CODE_SEG
LT131	L NEAR	0634H	CODE_SEG
LT14	L NEAR	0618H	CODE_SEG
LT141	L NEAR	0623H	CODE_SEG
LT151	L NEAR	0607H	CODE_SEG
LT152	L NEAR	0612H	CODE_SEG
LT19	L NEAR	05D2H	CODE_SEG
LT2	L NEAR	0676H	CODE_SEG
LT20	L NEAR	0694H	CODE_SEG
LT29	L NEAR	05D5H	CODE_SEG
LT3	L NEAR	0670H	CODE_SEG
LT31	L NEAR	021DH	CODE_SEG
LT39	L NEAR	05D8H	CODE_SEG
LT4	L NEAR	066AH	CODE_SEG
LT49	L NEAR	05DBH	CODE_SEG
LT5	L NEAR	0664H	CODE_SEG
LT59	L NEAR	05DEH	CODE_SEG
LT6	L NEAR	065EH	CODE_SEG
LT7	L NEAR	0658H	CODE_SEG
LT8	L NEAR	0652H	CODE_SEG
LT9	L NEAR	064CH	CODE_SEG
LTB4	L NEAR	022DH	CODE_SEG
LTB5	L NEAR	0243H	CODE_SEG
LTB6	L NEAR	025CH	CODE_SEG
LTE	L NEAR	0685H	CODE_SEG
LTE1	L NEAR	068AH	CODE_SEG
MOD_CLK_0	NUMBER	0080H	
MOD_CLK_90	NUMBER	0000H	
MOD_CLK_SYN	P NEAR	0463H	SIZE=001AH CODE_SEG
MOD_CLK_UPDATE	P NEAR	043EH	SIZE=0025H CODE_SEG
MOD_CLK_UPDATE_1	P NEAR	0423H	SIZE=001BH CODE_SEG

NAME	TYPE	VALUE	ATTRIBUTES
NOADD	L NEAR	0507H	CODE_SEG
NXTBIT	L NEAR	04F2H	CODE_SEG
PA	V WORD	1452H	(3) SAMP
PAP	V WORD	1450H	SAMP
PHASE	NUMBER	0040H	
PLBL	L NEAR	06F2H	CODE_SEG
PLBL1	L NEAR	06F7H	CODE_SEG
PLBL3	L NEAR	06FFH	CODE_SEG
PLBLA	L NEAR	0709H	CODE_SEG
PLBLC	L NEAR	0711H	CODE_SEG
Q221	L NEAR	0912H	CODE_SEG
Q222	L NEAR	091FH	CODE_SEG
Q223	L NEAR	092CH	CODE_SEG
Q224	L NEAR	0939H	CODE_SEG
Q229	L NEAR	093FH	CODE_SEG
Q331	L NEAR	08B8H	CODE_SEG
Q332	L NEAR	08C5H	CODE_SEG
Q339	L NEAR	08CBH	CODE_SEG
Q441	L NEAR	086BH	CODE_SEG
Q449	L NEAR	0871H	CODE_SEG
Q551	L NEAR	081EH	CODE_SEG
Q559	L NEAR	0824H	CODE_SEG
QUE	P NEAR	0556H	SIZE=0041H CODE_SEG
R0	V WORD	1478H	SAMP
R1	V WORD	147AH	SAMP
R10	V WORD	148CH	SAMP
R11	V WORD	148EH	SAMP
R12	V WORD	1490H	SAMP
R13	V BYTE	1492H	SAMP
R14	V BYTE	1493H	SAMP
R15	V BYTE	1494H	SAMP
R16	V BYTE	1495H	SAMP
R2	V WORD	147CH	SAMP
R3	V WORD	147EH	SAMP
R4	V WORD	1480H	SAMP
R5	V WORD	1482H	SAMP
R6	V WORD	1484H	SAMP
R7	V WORD	1486H	SAMP
R8	V WORD	1488H	SAMP
R9	V WORD	148AH	SAMP
RES	SEGMENT		SIZE=0005H PARA ABS
SAM	V WORD	0000H	(2000) SAMP
SAMP	SEGMENT		SIZE=1496H WORD ABS
SAMPLE_MASK	NUMBER	0FFFH	
SIGN_BIT_MASK	NUMBER	8000H	
SROOT	P NEAR	0510H	SIZE=0046H CODE_SEG
STACK_SEG	SEGMENT		SIZE=0032H WORD ABS
STACK_TOP	V WORD	0032H	STACK_SEG
SWP	NUMBER	0080H	
THREE_7_1	P NEAR	096EH	SIZE=004CH CODE_SEG
THREE_7_2	P NEAR	08FAH	SIZE=0074H CODE_SEG
THREE_7_3	P NEAR	08A0H	SIZE=005AH CODE_SEG
THREE_7_4	P NEAR	0853H	SIZE=004DH CODE_SEG
THREE_7_5	P NEAR	0806H	SIZE=004DH CODE_SEG
THREE_7_6	P NEAR	07C6H	SIZE=0040H CODE_SEG

```
NAME                    TYPE     VALUE   ATTRIBUTES

THREE_7_7 . . . . .     P NEAR   0786H   SIZE=0040H CODE_SEG
THREE_7_8 . . . . .     P NEAR   0746H   SIZE=0040H CODE_SEG
TLBL4 . . . . . .       L NEAR   0725H   CODE_SEG
TLBT. . . . . .         L NEAR   06C9H   CODE_SEG
TLBT1 . . . . . .       L NEAR   06CEH   CODE_SEG
TLBT3 . . . . . .       L NEAR   06D6H   CODE_SEG
TLBTA . . . . . .       L NEAR   06E0H   CODE_SEG
TLBTC . . . . . .       L NEAR   06E8H   CODE_SEG
TLBX. . . . . .         L NEAR   0723H   CODE_SEG
XY. . . . . .           V WORD   11F8H   (300) SAMP
ZC_ADC. . . . . .       P NEAR   02C8H   SIZE=00A2H CODE_SEG
ZC_MASK_OF_ADC. . .     NUMBER   0040H
ZC_MASK_OF_SWP. . .     NUMBER   0040H
ZCC . . . . . .         V WORD   1460H   (12) SAMP
ZCCP. . . . . .         V WORD   145EH   SAMP

END OF SYMBOL TABLE LISTING

ASSEMBLY COMPLETE, NO ERRORS FOUND
```

```
SERIES-III 8086 LOCATER, V2.0

INPUT FILE: :F3:A2.LNK
OUTPUT FILE: :F3:A2
CONTROLS SPECIFIED IN INVOCATION COMMAND:


DATE:  14/07/86  TIME:
WARNING 63:  SS AND SP REGISTERS NOT INITIALIZED
WARNING 64:  DS REGISTER NOT INITIALIZED


MEMORY MAP OF MODULE SHUM

MODULE START ADDRESS  PARAGRAPH = FC50H  OFFSET = 0000H
SEGMENT MAP

START     STOP      LENGTH ALIGN NAME            CLASS           OVERLAY

00200H    00200H     0000H   G   ??SEG
00400H    00431H     0032H   A   STACK_SEG
00450H    018E5H     1496H   A   SAMP
FC000H    FC385H     0386H   A   ATCS
FC500H    FCEB9H     09BAH   A   CODE_SEG
FFFF0H    FFFF4H     0005H   A   RES
```

A P P E N D I X D

Program Listing of the Software of Microcomputer.

```
 10 REM PROG H7
 20 DIM A(20) ! Va
 30 DIM B(20) ! ANG Va
 40 DIM C(20) ! Vb
 50 DIM D(20) ! ANG Vb
 60 DIM E(20) ! Vc
 70 DIM F(20) ! ANG Vc
 80 DIM Z(500) ! RAW DATA
 90 DEG
100 RESET 7 ! RESET HPIB
110 ! ########################
120 ! POLL FOR HPIB READINESS
130 ! ########################
140 S=SPOLL(709) ! SERIAL POLL
150 DISP S ! STATUS OF HPIB
160 IF NOT BIT(S,6) THEN 140
170 DISP "SQR OK ?"
180 REM SERVICE REQUEST
190 DISP "S = ";S
200 IF NOT BIT(S,0) THEN 140
210 REM TEST READINESS OF HPIB
220 DISP "BIT 0 SET  OK"
230 ENTER 709 USING "#,W" ; B
240 REM B IS TOTAL NUMBER OF
250 REM INPUT SAMPLES AND EACH
260 REM CONSISTS OF ONE WORD IN
270 REM MEMORY.
280 DISP " B=";B
290 ! ####################
300 ! INPUT DATA FROM HPIB
310 ! ####################
320 FOR I=0 TO B-1
330 ENTER 709 USING "#,W" ; Z(I)
340 REM Z(I) IS AMP. OR ANG.
350 NEXT I
360 ! ##########################
370 ! SCALE HARMONIC COMPONENTS
380 ! ##########################
390 F=Z(0)/10
400 REM RECOVER THE FUND. FREQ.
410 PRINT "FUND. FREQ.=";F;" HZ"
420 PRINT
430 C=B-1
440 REM C IS TOTAL NUMBER OF RAW
    DATA OF AMP. AND ANG.
450 M=C DIV 12
460 REM M IS ORDER OF HARMONICS
    NEEDED TO BE HANDLED.
470 J=1
480 REM J=1 IS INDEX TO ADDRESS
    THE FIRST DATA,Va,IN MEMORY.

490 L=7
500 REM L=7 IS INDEX TO ADDRESS
    THE FIRST CURRENT AMPLITUDE,
    Ia.
510 FOR K=1 TO M
520 FOR I=J TO J+5 STEP 2
530 Z(I)=.0922*Z(I)
540 REM .0922 IS SCALING FACTOR
    OF VOLTAGE = (340/5)(5/2^12)
    *(PI/2)(1/SQR 2)
550 REM (340/5) FROM INPUT
    SCALING CIRCUIT.
560 REM (5/2^12) FROM ADC.
570 REM (PI/2) FROM COEF. OF
    EQN SET (3),(1/SQR 2) IS RMS

580 NEXT I
590 J=J+12
600 NEXT K
610 FOR K=1 TO M
620 FOR I=L TO L+5 STEP 2
630 Z(I)=.001965*Z(I)
640 REM .001965 IS INPUT CURRENT
    SCALING FACTOR = (1/SQR 2)*
    (1/6.9)(5/2^12)(PI/2)

650 REM (1/6.9)_ SCALING FACTOR.
660 NEXT I
670 L=L+12
680 NEXT K
690 FOR I=2 TO C STEP 2
700 Z(I)=Z(I)/10
710 REM SCALING FACTOR OF ANG.
720 NEXT I
730 ! ####################
740 ! PRINT RESULTANT
750 ! HARMONIC COMPONENTS
760 ! ####################
770 H=1 ! H IS HARMONIC ORDER
780 FOR I=1 TO C STEP 12
790 PRINT "HA. ORDER= ";H
800 PRINT
810 PRINT "VA= ";Z(I)
820 PRINT "ANG VA= ";Z(I+1)
830 PRINT "VB= ";Z(I+2)
840 PRINT "ANG VB= ";Z(I+3)
850 PRINT "VC= ";Z(I+4)
860 PRINT "ANG VC=";Z(I+5)
870 PRINT
880 PRINT "IA= ";Z(I+6)
890 PRINT "ANG IA= ";Z(I+7)
900 PRINT "IB= ";Z(I+8)
910 PRINT "ANG IB= ";Z(I+9)
920 PRINT "IC= ";Z(I+10)
930 PRINT "ANG IC= ";Z(I+11)
940 PRINT
950 PRINT
960 H=H+1
970 NEXT I
980 H=H-1
990 ! ####################
1000 ! RELOCATE RESULTANT
1010 ! HARMONIC COMPONENTS
1020 ! IN MEMORY
1030 ! ####################
1040 REM STORE Va,Ia
1050 T=0
1060 J=0
1070 FOR I=T TO 12*6+6+T STEP 6
1080 A(J)=Z(I)
```

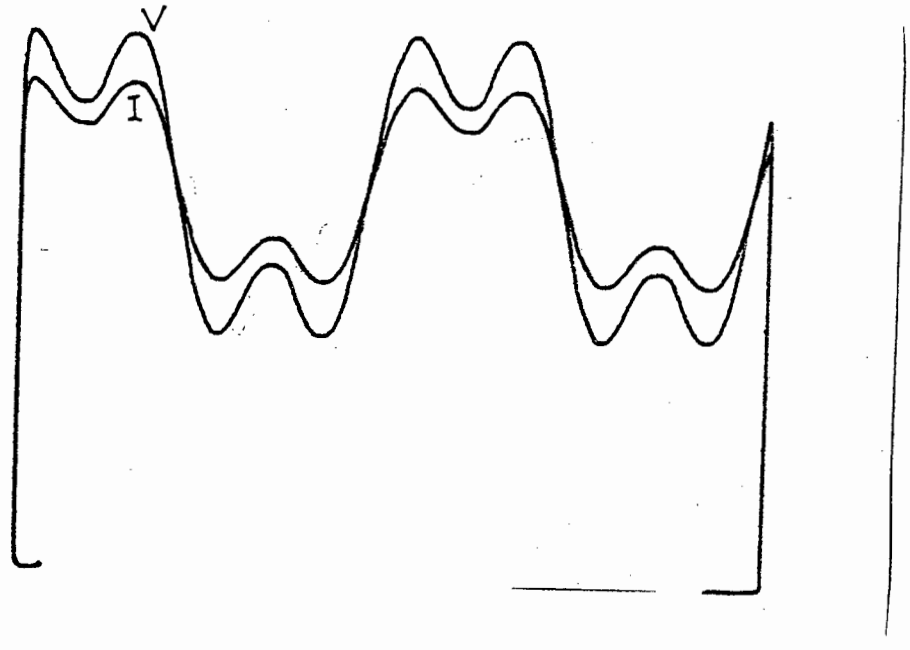
```
1090 J=J+1
1100 NEXT I
1110 REM STORE ANG OF Va AND Ia
1120 T=T+1
1130 J=0
1140 FOR I=T TO 12*6+6+T STEP 6
1150 B(J)=Z(I)
1160 J=J+1
1170 NEXT I
1180 REM STORE Vb,Ib
1190 T=T+1
1200 J=0
1210 FOR I=T TO 12*6+6+T STEP 6
1220 C(J)=Z(I)
1230 J=J+1
1240 NEXT I
1250 REM STORE ANG OF Vb AND Ib
1260 T=T+1
1270 J=0
1280 FOR I=T TO 12*6+6+T STEP 6
1290 D(J)=Z(I)
1300 J=J+1
1310 NEXT I
1320 REM STORE Vc,Ic
1330 T=T+1
1340 J=0
1350 FOR I=T TO 12*6+6+T STEP 6
1360 E(J)=Z(I)
1370 J=J+1
1380 NEXT I
1390 REM STORE ANG OF Vc AND Ic
1400 T=T+1
1410 J=0
1420 FOR I=T TO 12*6+6+T STEP 6
1430 F(J)=Z(I)
1440 J=J+1
1450 NEXT I
1460 ! ########################
1470 ! CALCULATE U0,U+ AND U-
1480 ! ########################
1490 N=0
1500 FOR I=1 TO H
1510 Q=0
1520 FOR P=1 TO 2
1530 G=A(N)*COS(B(N))
1540 W=A(N)*SIN(B(N))
1550 X=G+C(N)*COS(D(N))+E(N)*COS
     (F(N))
1560 Y=W+C(N)*SIN(D(N))+E(N)*SIN
     (F(N))
1570 K=SQR(X^2+Y^2)/3
1580 L=ATN2(Y,X)
1590 X=G+C(N)*COS(120+D(N))+E(N)
     *COS(240+F(N))
1600 Y=W+C(N)*SIN(120+D(N))+E(N)
     *SIN(240+F(N))
1610 M=SQR(X^2+Y^2)/3
1620 R=ATN2(Y,X)
1630 X=G+C(N)*COS(240+D(N))+E(N)
     *COS(120+F(N))
1640 Y=W+C(N)*SIN(240+D(N))+E(N)
     *SIN(120+F(N))
1650 U=SQR(X^2+Y^2)/3
1660 V=ATN2(Y,X)
1670 N=N+1
1680 IF Q=1 THEN GOTO 1850
1690 ! ########################
1700 ! PRINT RESULTANT
1710 ! SYMMETRICAL COMPONENTS
1720 ! OF HARMONICS.
1730 ! ########################
1740 PRINT "HA. ORDER= ";I
1750 PRINT
1760 PRINT "V0= ";K
1770 PRINT "ANG V0= ";L
1780 PRINT "V+= ";M
1790 PRINT "ANG V+= ";R
1800 PRINT "V-= ";U
1810 PRINT "ANG V-= ";V
1820 PRINT
1830 Q=1
1840 GOTO 1940
1850 PRINT "I0= ";K
1860 PRINT "ANG I0= ";L
1870 PRINT "I+= ";M
1880 PRINT "ANG I+= ";R
1890 PRINT "I-= ";U
1900 PRINT "ANG I-= ";V
1910 PRINT
1920 PRINT
1930 Q=0
1940 NEXT P
1950 NEXT I
1960 ! ####################
1970 ! CALCULATE RESULTANT
1980 ! PHASE VOLTAGES
1990 ! AND CURRENTS.
2000 ! ####################
2010 K=SQR(2)
2020 L=0
2030 M=0
2040 N=0
2050 Q=0
2060 R=0
2070 Z=0
2080 FOR P=0 TO 360
2090 U=0
2100 V=0
2110 W=0
2120 X=0
2130 Y=0
2140 O=0
2150 FOR G=1 TO H
2160 T=2*(G-1)
2170 U=U+A(T)*SIN(G*(P-B(T)/G))*
     K
2180 V=V+C(T)*SIN(G*(P-D(T)/G))*
     K
2190 W=W+E(T)*SIN(G*(P-F(T)/G))*
     K
```

```
2200 S=T+1
2210 X=X+A(S)*SIN(G*(P-B(S)/G))*
     K
2220 Y=Y+C(S)*SIN(G*(P-D(S)/G))*
     K
2230 O=O+E(S)*SIN(G*(P-F(S)/G))*
     K
2240 NEXT G
2250 L=L+U^2
2260 M=M+V^2
2270 N=N+W^2
2280 Q=Q+X^2
2290 R=R+Y^2
2300 Z=Z+O^2
2310 NEXT P
2320 A=L/360
2330 B=SQR(A)
2340 C=M/360
2350 D=SQR(C)
2360 E=N/360
2370 F=SQR(E)
2380 G=Q/360
2390 H=SQR(G)
2400 I=R/360
2410 J=SQR(I)
2420 K=Z/360
2430 L=SQR(K)
2440 ! ######################
2450 ! PRINT RESULTANT RMS
2460 ! OF Va,Vb,Vc,Ia,Ib,Ic.
2470 ! ######################
2480 PRINT
2490 PRINT
2500 PRINT "VA= ";B
2510 PRINT "VB= ";D
2520 PRINT "VC= ";F
2530 PRINT "IA= ";H
2540 PRINT "IB= ";J
2550 PRINT "IC= ";L
2560 END
```

A P P E N D I X E

Note : The units of voltage and current used in this appendix are V and A respectively.

T E S T 1



Resultant Waveform of Harmonics : 1st + 3rd

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	67.0529388831	68.8	-2.61
VB=	67.8032042389	68.8	-1.48
VC=	69.6338462756	68.7	+1.34
IA=	4.55966540441	4.48	+1.75
IB=	4.32040754068	4.51	-4.40
IC=	4.48314959128	4.50	-0.45

```
FUND. FREQ = 50 HZ

HA. ORDER=  1

VA=   60.8876
ANG VA=   0
VB=   61.7244
ANG VB=   240
VC=   63.6252
ANG VC=   120

IA=   4.22432
ANG IA=   4.6
IB=   3.953365
ANG IB=   244.6
IC=   4.148115
ANG IC=   124.6


HA. ORDER=  2

VA=   .3688
ANG VA=   79.7
VB=   .3603
ANG VB=   319.7
VC=   .3466
ANG VC=   199.7

IA=   .013755
ANG IA=   87.5
IB=   .01179
ANG IB=   327.5
IC=   .01179
ANG IC=   207.5


HA. ORDER=  3

VA=   28.0054
ANG VA=   26.9
VB=   27.3522
ANG VB=   266.9
VC=   27.7146
ANG VC=   146.9

IA=   1.711515
ANG IA=   48.3
IB=   1.69776
ANG IB=   288.3
IC=   1.676145
ANG IC=   168.3


HA. ORDER=  4

VA=   .0922
ANG VA=   87.9
VB=   .0921
ANG VB=   327.9
VC=   .0896
ANG VC=   207.9

IA=   .00986
ANG IA=   77.9
IB=   .009257
ANG IB=   317.9
IC=   .008579
ANG IC=   197.9


HA. ORDER=  5

VA=   1.5362
ANG VA=   270.5
VB=   1.46596
ANG VB=   150.5
VC=   1.61064
ANG VC=   30.5

IA=   .036055
ANG IA=   267.9
IB=   .038545
ANG IB=   147.9
IC=   .03169
ANG IC=   27.9


HA. ORDER=  6

VA=   .0922
ANG VA=   347.9
VB=   .0936
ANG VB=   227.9
VC=   .09657
ANG VC=   107.9

IA=   .02075
ANG IA=   -2.1
IB=   .02358
ANG IB=   237.9
IC=   .021615
ANG IC=   117.9


HA. ORDER=  7

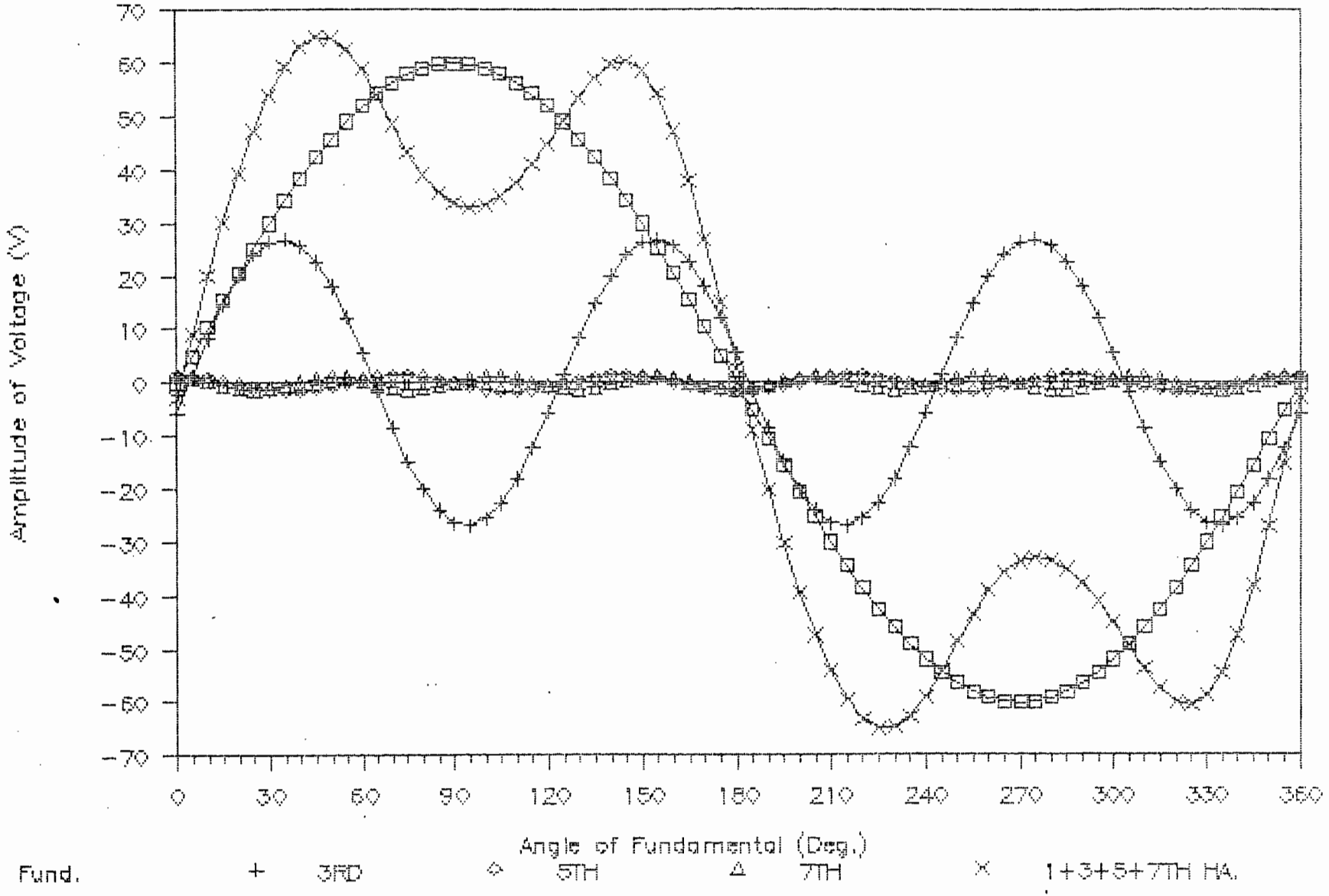
VA=   1.1752
ANG VA=   268.9
VB=   1.2576
ANG VB=   147.9
VC=   1.1986
ANG VC=   27.9

IA=   .021615
ANG IA=   277.9
IB=   .01972
ANG IB=   157.9
IC=   .024545
ANG IC=   37.9
```

Amplitudes and phase angles of harmonic components.

Reconstructed waveforms

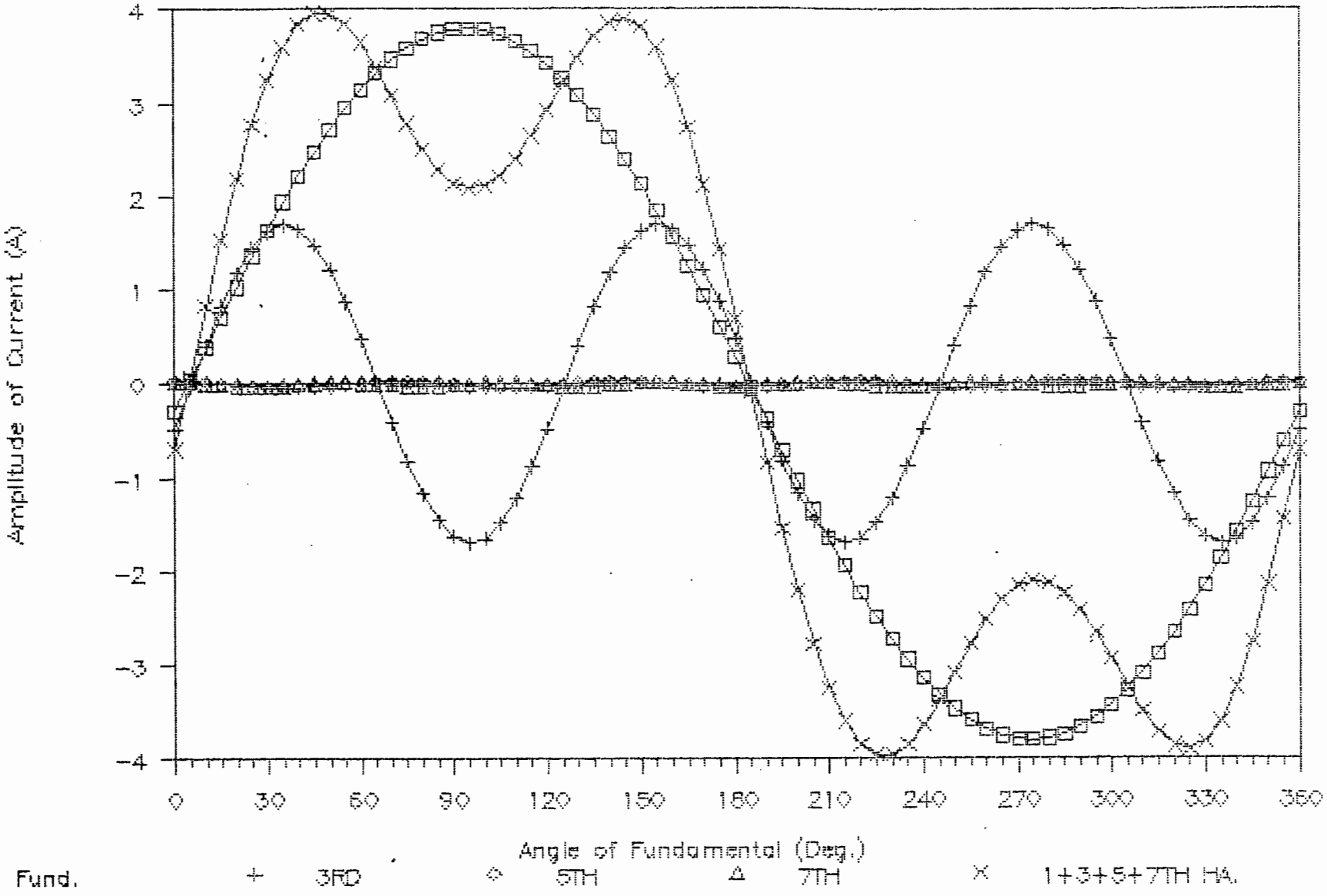
TEST_1



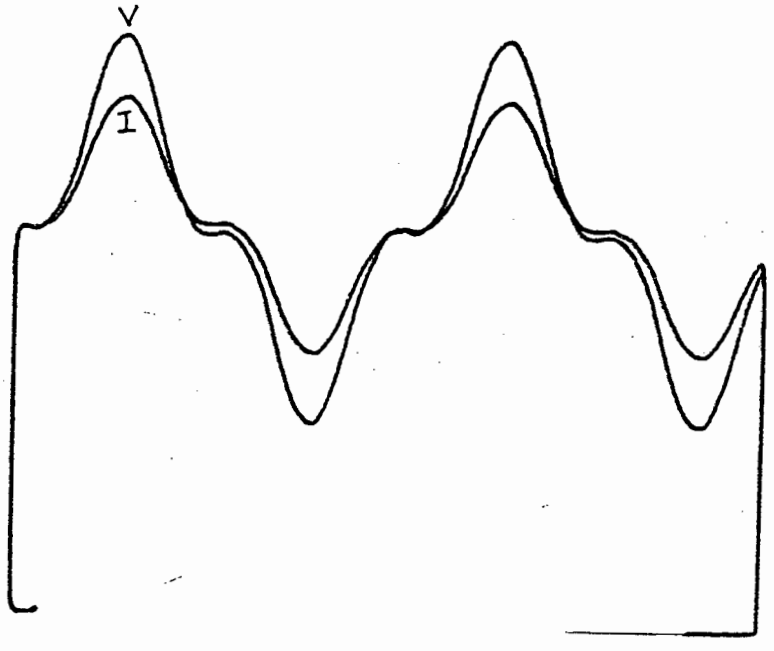
E4

Reconstructed waveforms

TEST_1



T E S T 2



Resultant Waveform of Harmonics : 1st + 3rd

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	63.5193948132	66·5	−0·82
VB=	64.3324605928	66·4	−2·06
VC=	64.4957617223	66·6	−4·35
IA=	3.28211639887	3·35	−2·13
IB=	3.2624909387	3·31	−1·53
IC=	3.38656677526	3·36	+0·88

```
FUND. FREQ.= 50.1  HZ

HA. ORDER=  1

VA=  61.544
ANG VA=  0
VB=  62.2706
ANG VB=  240
VC=  62.5828
ANG VC=  120

IA=  3.110595
ANG IA=  .6
IB=  3.08505
ANG IB=  240.6
IC=  3.232425
ANG IC=  120.6


HA. ORDER=  2

VA=  .1944
ANG VA=  95.8
VB=  .23572
ANG VB=  335.8
VC=  .2272
ANG VC=  215.8

IA=  .053055
ANG IA=  110.3
IB=  .053051
ANG IB=  350.3
IC=  .055548
ANG IC=  230.3


HA. ORDER=  3

VA=  15.674
ANG VA=  186.6
VB=  15.8584
ANG VB=  66.6
VC=  15.235
ANG VC=  306.6

IA=  1.043415
ANG IA=  190.4
IB=  1.051275
ANG IB=  70.4
IC=  .99499
ANG IC=  310.4


HA. ORDER=  4

VA=  .2844
ANG VA=  253.2
VB=  .2305
ANG VB=  133.2
VC=  .2858
ANG VC=  13.2

IA=  .01104
ANG IA=  270.6
IB=  .01198
ANG IB=  150.6
IC=  .010021
ANG IC=  30.6


HA. ORDER=  5

VA=  .6192
ANG VA=  234.4
VB=  .6305
ANG VB=  114.4
VC=  .5956
ANG VC=  354.4

IA=  .06681
ANG IA=  247.2
IB=  .067705
ANG IB=  127.2
IC=  .068775
ANG IC=  367.2


HA. ORDER=  6

VA=  .5532
ANG VA=  73.2
VB=  .5206
ANG VB=  313.2
VC=  .5298
ANG VC=  193.2

IA=  .010025
ANG IA=  87.6
IB=  .01061
ANG IB=  327.6
IC=  .01139
ANG IC=  207.6


HA. ORDER=  7

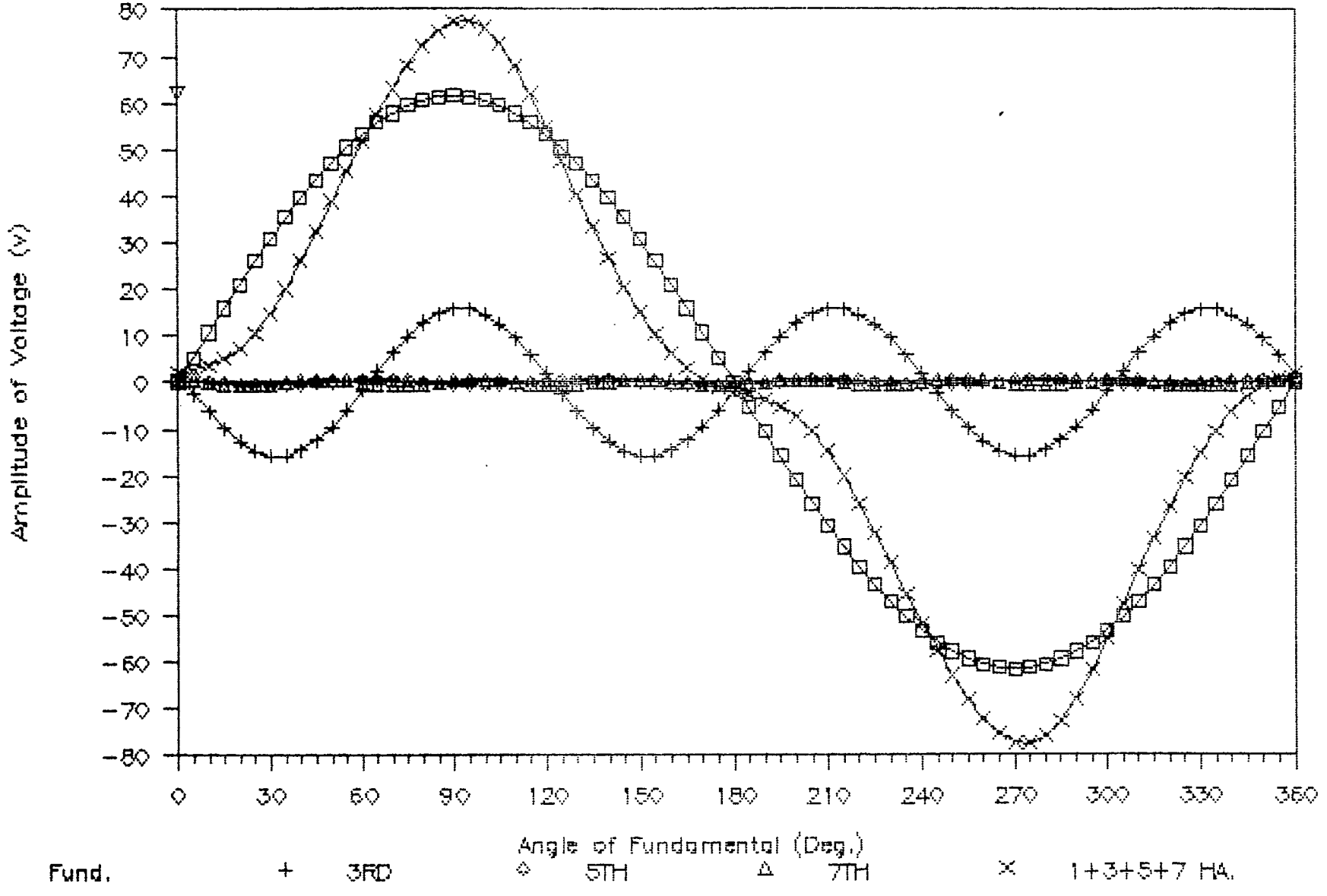
VA=  .7298
ANG VA=  241.4
VB=  .7397
ANG VB=  121.4
VC=  .7376
ANG VC=  1.4

IA=  .010565
ANG IA=  248.8
IB=  .00978
ANG IB=  128.8
IC=  .012755
ANG IC=  8.8
```

Amplitudes and phase angles of harmonic components.

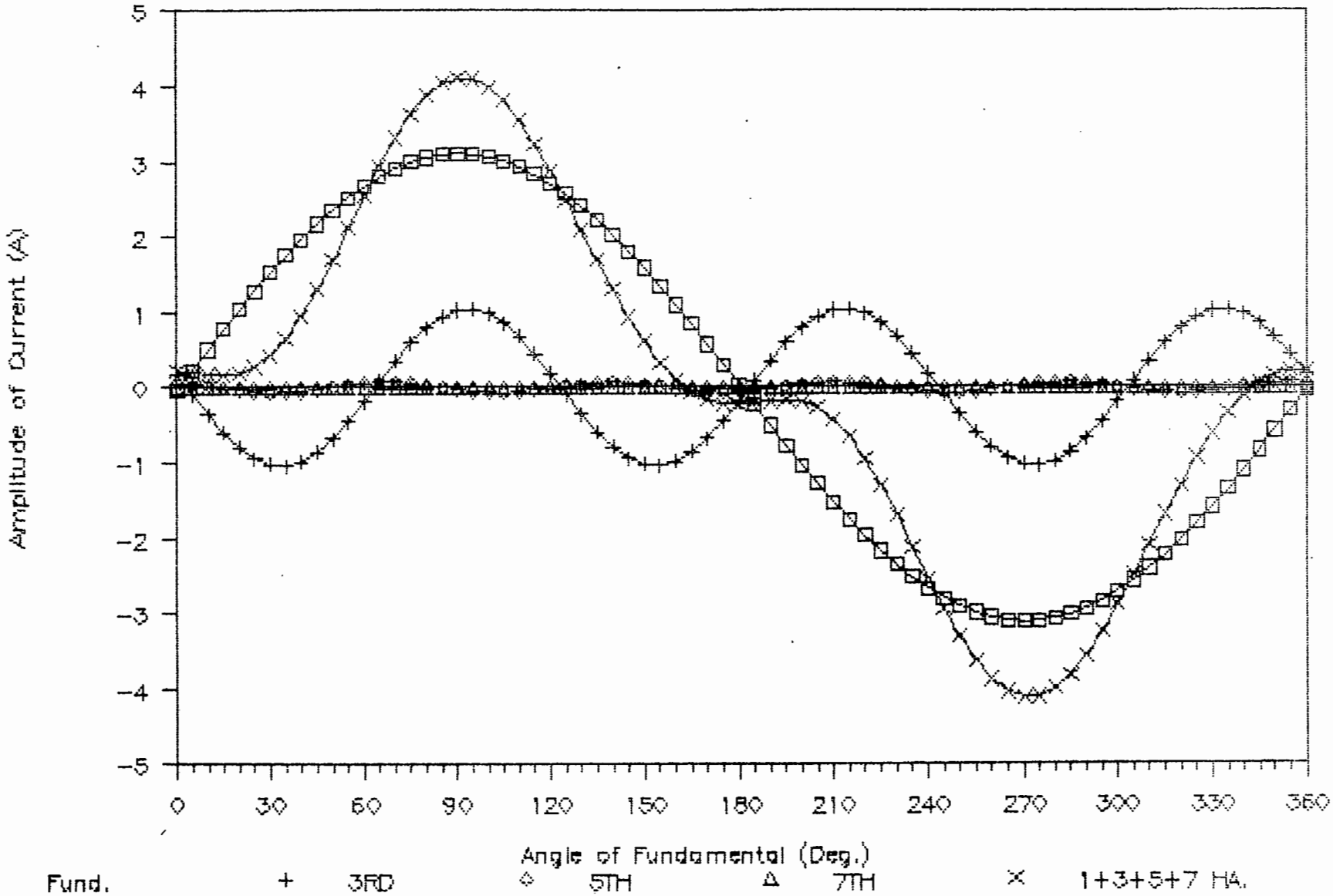
Reconstructed waveforms

TEST_2



Reconstructed waveforms

TEST_2



```
HA. ORDER=  1

V0=   .307726595819
ANG V0=  162.970047695
V+=   62.1324666667
ANG V+=  0
V-=   .307726595819
ANG V-= -162.970047695

I0=   4.54694565057E-2
ANG I0=  111.266584568
I+=   3.14269
ANG I+=   .599999999997
I-=   4.54694565073E-2
ANG I-= -110.066584566


HA. ORDER=  2

V0=   1.25957947128E-2
ANG V0= -72.9398219061
V+=   .219106666666
ANG V+=  95.8
V-=   1.25957947128E-2
ANG V-= -95.4601780928

I0=   6.45706363433E-3
ANG I0=  176.699152836
I+=   4.78846666667E-2
ANG I+=  110.3
I-=   6.4570636343E-3
ANG I-=  43.9008471639


HA. ORDER=  3

V0=   .184895153474
ANG V0=  109.867603214
V+=   15.5891333333
ANG V+= -173.4
V-=   .184895153472
ANG V-= -96.6676032156

I0=   1.75985502087E-2
ANG I0=  122.992216517
I+=   1.02989333333
ANG I+= -169.6
I-=   1.75985502088E-2
ANG I-= -102.192216517


HA. ORDER=  4

V0=   1.82044866262E-2
ANG V0= -45.5279116091
V+=   .2669
ANG V+= -106.8
V-=   1.82044866267E-2
ANG V-= -168.072088392

I0=   5.65667845223E-4
ANG I0= -178.066244557
I+=   1.10136666667E-2
ANG I+= -89.4
I-=   5.656678452E-4
ANG I-= -.733755442334


HA. ORDER=  5

V0=   1.02812126394E-2
ANG V0=  155.901455161
V+=   .6151
ANG V+= -125.6
V-=   1.02812126392E-2
ANG V-= -47.1014551595

I0=   6.0453434789E-4
ANG I0=  36.4733590374
I+=   6.77203333333E-2
ANG I+= -112.8
I-=   6.04534347847E-4
ANG I-=  97.9266409574


HA. ORDER=  6

V0=   9.70383658393E-3
ANG V0=  89.0837667315
V+=   .534533333333
ANG V+=  73.2
V-=   9.70383658353E-3
ANG V-=  57.3162332697

I0=   3.95379564473E-4
ANG I0= -127.115003951
I+=   .010675
ANG I+=  87.6
I-=   3.9537956448E-4
ANG I-= -57.684996047

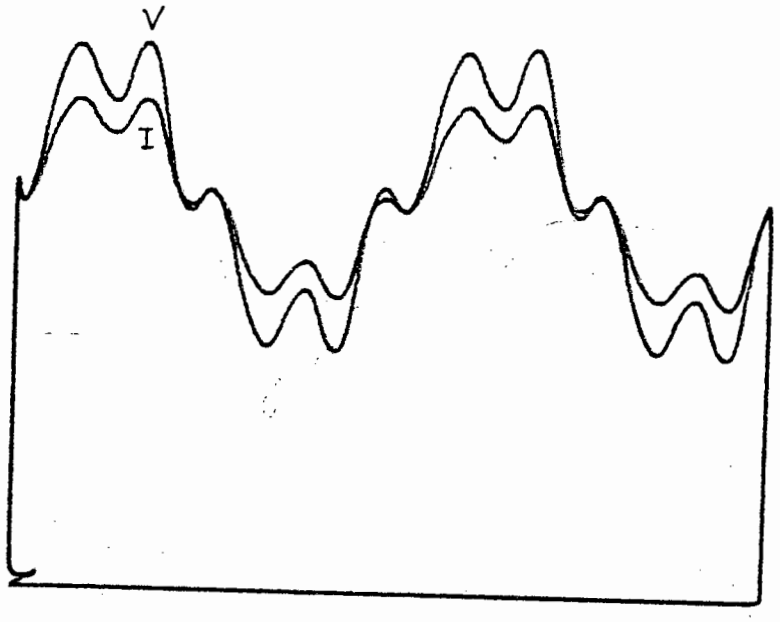

HA. ORDER=  7

V0=   3.0116440691E-3
ANG V0=  73.0124815438
V+=   .7357
ANG V+= -118.6
V-=   3.01164406931E-3
ANG V-=  49.7875184668

I0=   8.90160722083E-4
ANG I0= -5.94822465143
I+=   1.10333333333E-2
ANG I+= -111.2
I-=   8.90160722063E-4
ANG I-=  143.548224652
```

Symmetrical components of harmonics.

T E S T 3



Resultant Waveform of Harmonics : 1st + 5th

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	65.9948721091	65·6	+0·59
VB=	64.3132509633	65·2	−1·38
VC=	68.5060398004	65·8	+4·0
IA=	3.59300894235	3·60	−0·29
IB=	3.53322204009	3·61	−2·27
IC=	3.71060885465	3·58	+3·50

```
FUND. FREQ.= 49.9  HZ

HA. ORDER=  1

VA=   62.0506
ANG VA=   0
VB=   60.086
ANG VB=   240
VC=   64.54
ANG VC=   120

IA=   3.267795
ANG IA=   5.1
IB=   3.20295
ANG IB=   245.1
IC=   3.42696
ANG IC=   125.1


HA. ORDER=  2

VA=   .35178
ANG VA=   268.1
VB=   .34894
ANG VB=   148.1
VC=   .33192
ANG VC=   28.1

IA=   .03144
ANG IA=   270.7
IB=   .033406
ANG IB=   150.7
IC=   .031965
ANG IC=   30.7


HA. ORDER=  3

VA=   1.6596
ANG VA=   177.1
VB=   1.5674
ANG VB=   57.1
VC=   1.844
ANG VC=   297.1

IA=   .03537
ANG IA=   180.9
IB=   .03375
ANG IB=   60.9
IC=   .039651
ANG IC=   300.9


HA. ORDER=  4

VA=   .0505
ANG VA=   273.7
VB=   .04752
ANG VB=   153.7
VC=   .05674
ANG VC=   33.7

IA=   .008405
ANG IA=   264.5
IB=   .00786
ANG IB=   144.5
IC=   .008825
ANG IC=   24.5


HA. ORDER=  5

VA=   21.7592
ANG VA=   175.7
VB=   22.3124
ANG VB=   55.7
VC=   22.3124
ANG VC=   295.7

IA=   1.440345
ANG IA=   180.1
IB=   1.44624
ANG IB=   60.1
IC=   1.36764
ANG IC=   300.1


HA. ORDER=  6

VA=   .0553
ANG VA=   87.1
VB=   .0614
ANG VB=   327.1
VC=   .0698
ANG VC=   207.1

IA=   .080565
ANG IA=   79.7
IB=   .060915
ANG IB=   319.7
IC=   .07323
ANG IC=   199.7


HA. ORDER=  7

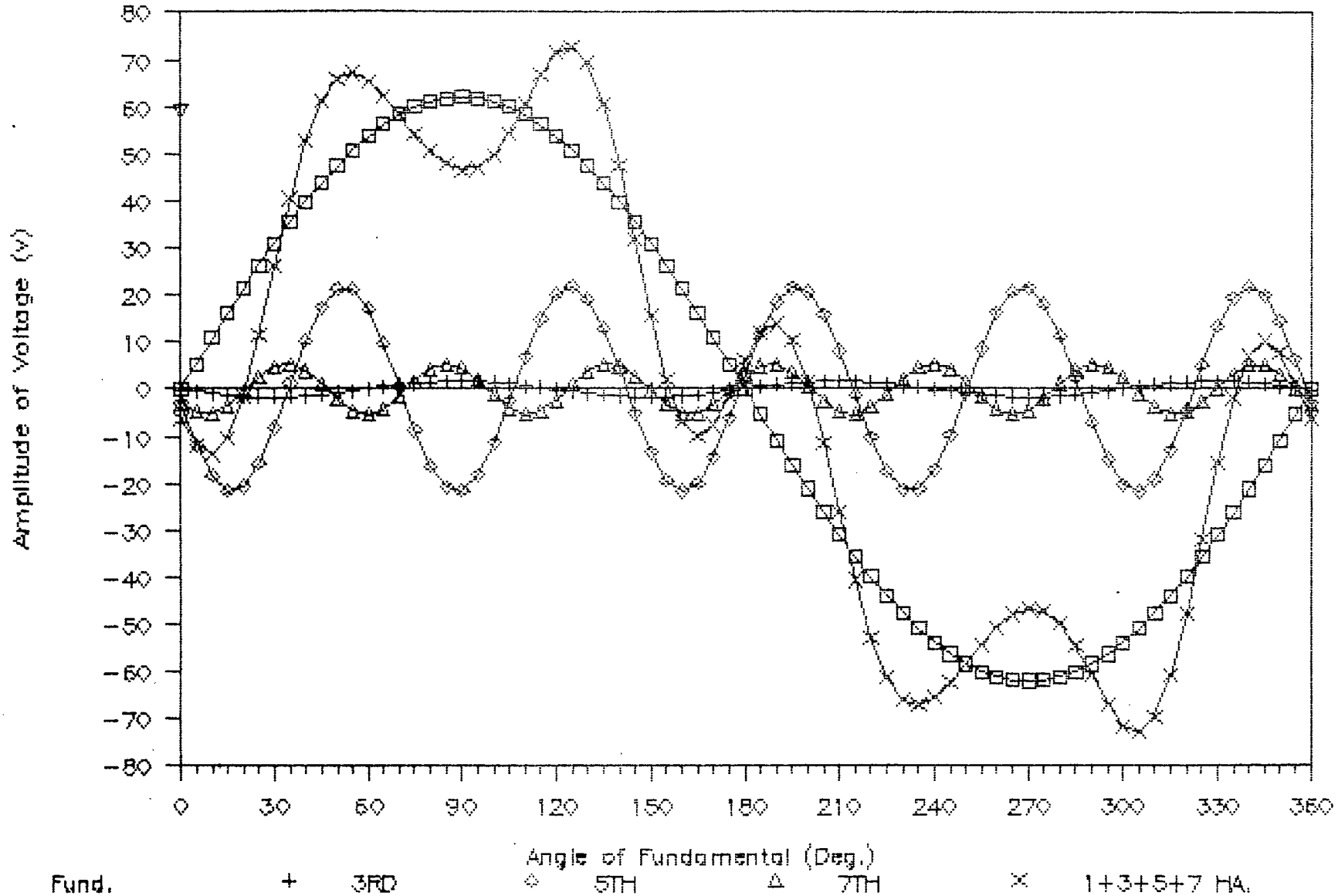
VA=   5.3476
ANG VA=   146.7
VB=   4.5178
ANG VB=   26.7
VC=   4.627
ANG VC=   266.7

IA=   .382785
ANG IA=   155.5
IB=   .339945
ANG IB=   35.5
IC=   .371385
ANG IC=   275.5
```

Amplitudes and phase angles of harmonic components.

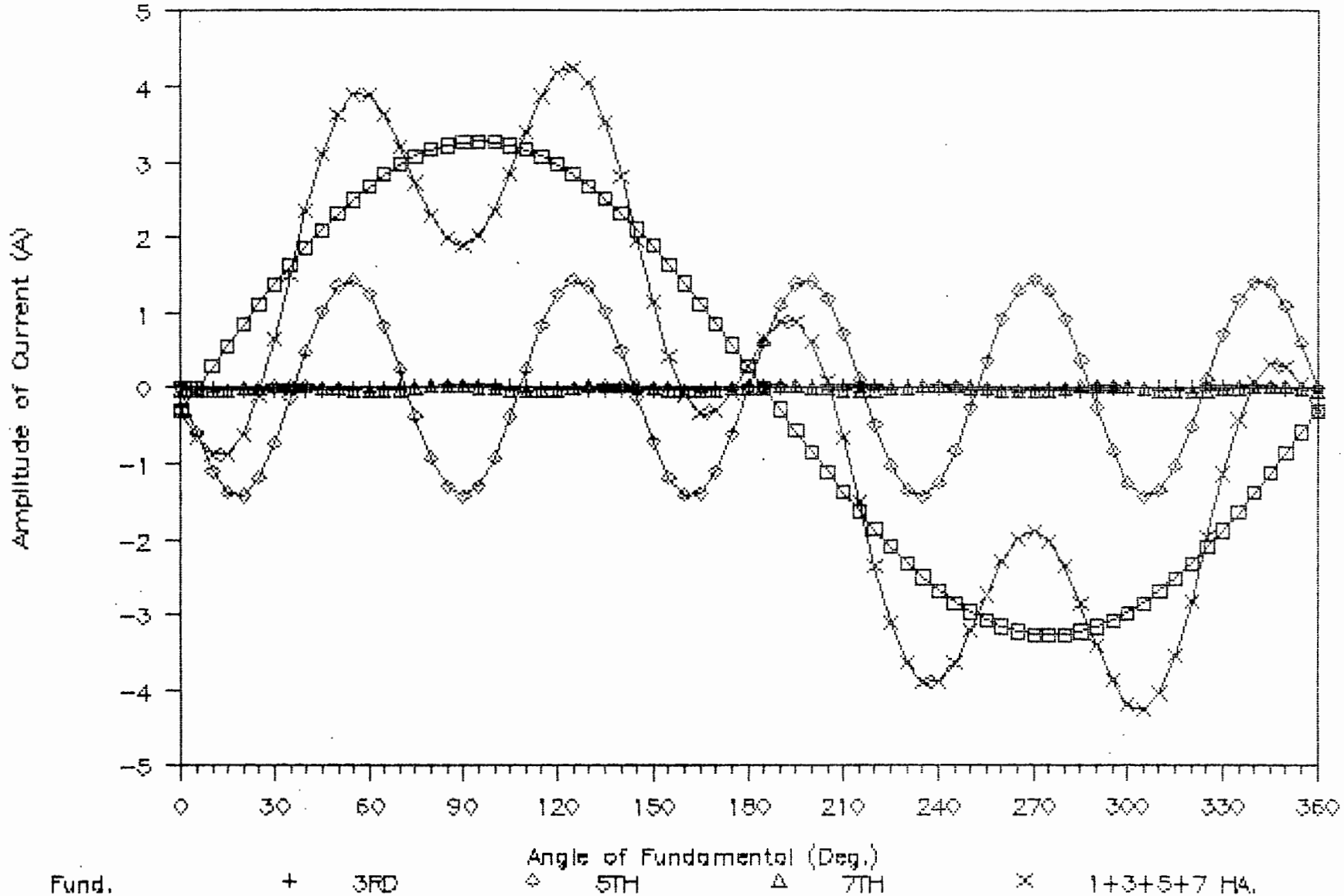
Reconstructed waveforms

TEST_3



Reconstructed waveforms

TEST_3



```
HA. ORDER=  1

V0=  1.28873067437
ANG V0=  93.8916791623
V+=  62.2255333333
ANG V+=  0
V-=  1.28873067437
ANG V-= -93.8916791623

I0=  6.65494182947E-2
ANG I0=  108.763279517
I+=  3.299235
ANG I+=  5.1
I-=  6.65494182887E-2
ANG I-= -98.5632795202


HA. ORDER=  2

V0=  6.2011002608E-3
ANG V0= -144.302775502
V+=  .344213333333
ANG V+= -91.9
V-=  6.2011002608E-3
ANG V-= -39.4972244955

I0=  5.87710340607E-4
ANG I0=  135.756127626
I+=  3.22703333333E-2
ANG I+= -89.3
I-=  5.8771034064E-4
ANG I-=  45.6438723732


HA. ORDER=  3

V0=  .08131275696
ANG V0= -82.00660535
V+=  1.69033333333
ANG V+=  177.1
V-=  8.13127569587E-2
ANG V-=  76.2066053494

I0=  1.76025821972E-3
ANG I0= -74.5069678687
I+=  .036257
ANG I+= -179.1
I-=  1.7602582197E-3
ANG I-=  76.3069678683


HA. ORDER=  4

V0=  2.71647647599E-3
ANG V0=  15.2377778769
V+=  5.15866666667E-2
ANG V+= -86.3
V-=  2.71647647595E-3
ANG V-=  172.162222123

I0=  2.79349442656E-4
ANG I0= -9.77697775913
I+=  8.36333333333E-3
ANG I+= -95.5
I-=  2.79349442652E-4
ANG I-=  178.776977759


HA. ORDER=  5

V0=  .184399999996
ANG V0= -4.29999999175
V+=  22.128
ANG V+=  175.7
V-=  .184400000009
ANG V-= -4.29999999144

I0=  2.52748536077E-2
ANG I0=  116.23939078
I+=  1.418075
ANG I+= -179.9
I-=  2.52748536143E-2
ANG I-= -116.039390773


HA. ORDER=  6

V0=  4.2033055775E-3
ANG V0= -128.132534604
V+=  6.21666666663E-2
ANG V+=  87.1
V-=  4.20330557753E-3
ANG V-= -57.6674653958

I0=  5.73286795593E-3
ANG I0=  118.024492995
I+=  .07157
ANG I+=  79.7
I-=  5.73286795593E-3
ANG I-=  41.3755070053

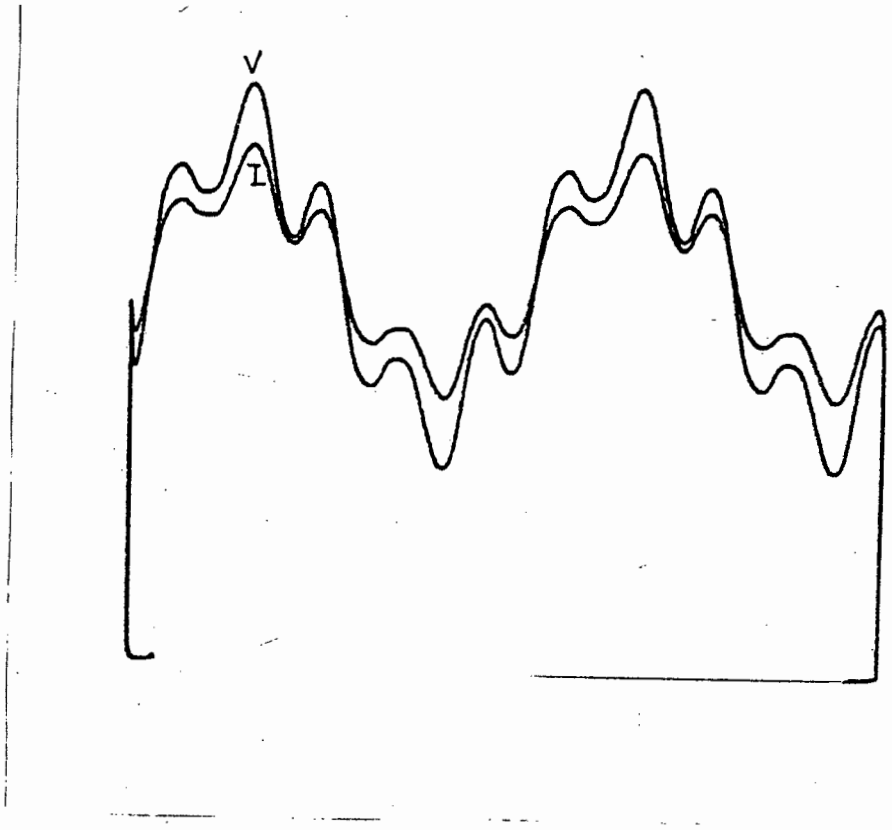

HA. ORDER=  7

V0=  .260315731372
ANG V0=  153.655389084
V+=  4.8308
ANG V+=  146.7
V-=  .260315731374
ANG V-=  139.744610915

I0=  1.28099336455E-2
ANG I0= -159.386312056
I+=  .364705
ANG I+=  155.5
I-=  1.28099336455E-2
ANG I-=  110.386312058
```

Symmetrical components of harmonics.

T E S T 4



Resultant Waveform of Harmonics : 1st + 5th

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	69.7298610701	68·7	+1·48
VB=	70.4163674201	68·8	+2·3
VC=	68.8809356176	68·9	−0·03
IA=	3.63730758947	3·59	+1·29
IB=	3.65189706206	3·60	+1·42
IC=	3.78473008016	3·60	−5·14

```
FUND. FREQ.= 50.1  HZ

HA. ORDER=  1

VA=  67.49004
ANG VA=  0
VB=  68.0202
ANG VB=  240
VC=  66.0932
ANG VC=  120

IA=  3.456435
ANG IA=  .6
IB=  3.46626
ANG IB=  240.6
IC=  3.60708
ANG IC=  120.6


HA. ORDER=  2

VA=  .3688
ANG VA=  87.8
VB=  .3688
ANG VB=  327.8
VC=  .3844
ANG VC=  207.8

IA=  .00393
ANG IA=  95.7
IB=  .003405
ANG IB=  335.7
IC=  .005895
ANG IC=  215.7


HA. ORDER=  3

VA=  .461
ANG VA=  338.8
VB=  .4688
ANG VB=  218.8
VC=  .4532
ANG VC=  98.8

IA=  .112005
ANG IA=  342.6
IB=  .12327
ANG IB=  222.6
IC=  .113755
ANG IC=  102.6


HA. ORDER=  4

VA=  .0922
ANG VA=  81.8
VB=  .0844
ANG VB=  321.8
VC=  .0795
ANG VC=  201.8

IA=  .00786
ANG IA=  94.5
IB=  .006895
ANG IB=  334.5
IC=  .00786
ANG IC=  214.5


HA. ORDER=  5

VA=  16.8726
ANG VA=  32.6
VB=  16.7024
ANG VB=  272.6
VC=  18.2414
ANG VC=  152.6

IA=  1.098435
ANG IA=  40
IB=  1.07289
ANG IB=  280
IC=  1.081625
ANG IC=  160


HA. ORDER=  6

VA=  .0922
ANG VA=  -2.2
VB=  .1044
ANG VB=  237.8
VC=  .0811
ANG VC=  117.8

IA=  .00786
ANG IA=  10.4
IB=  .00786
ANG IB=  250.4
IC=  .005895
ANG IC=  130.4


HA. ORDER=  7

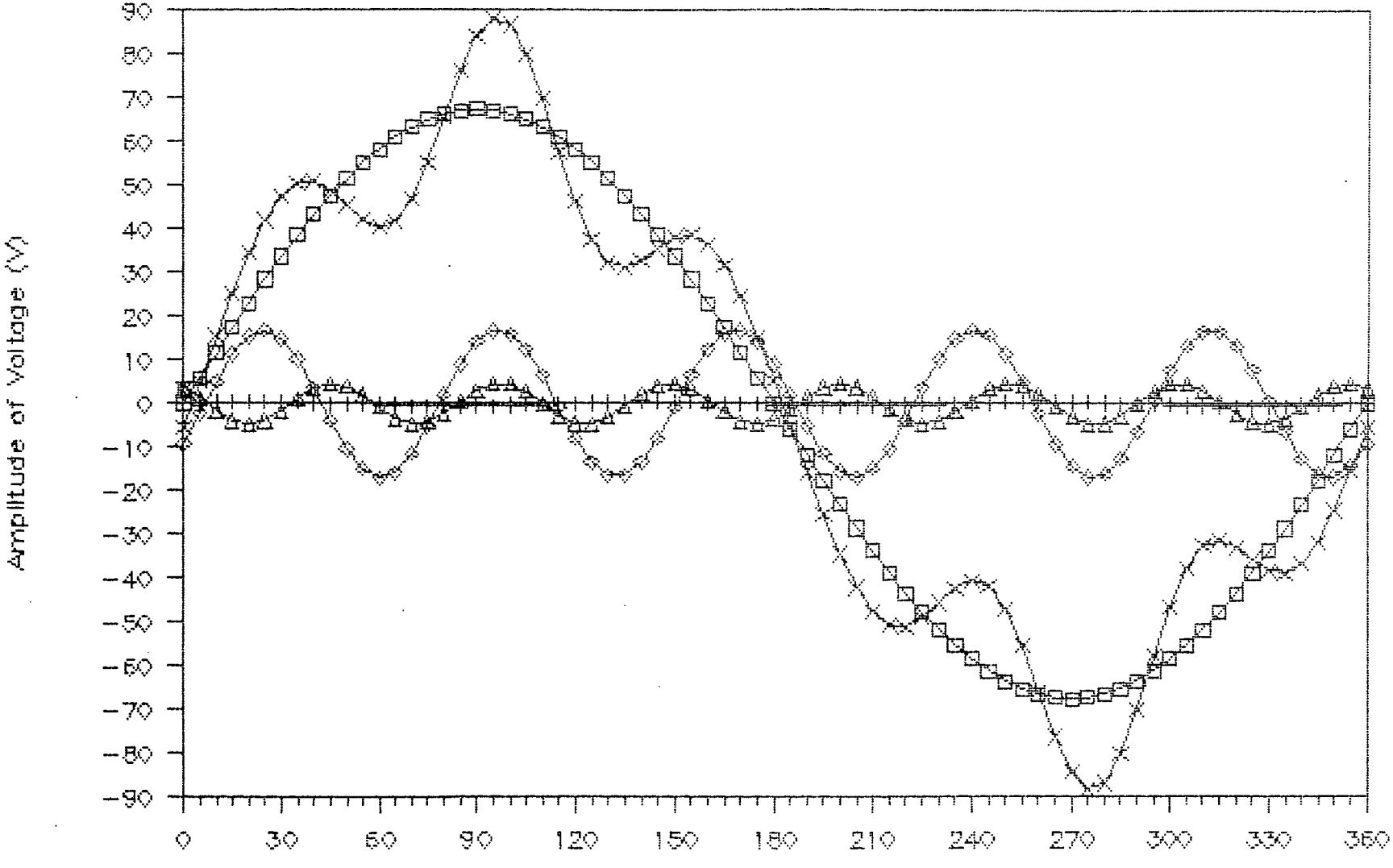
VA=  4.7022
ANG VA=  229.5
VB=  4.8866
ANG VB=  109.5
VC=  4.4256
ANG VC=  349.5

IA=  .249555
ANG IA=  231.4
IB=  .26331
ANG IB=  111.4
IC=  .245625
ANG IC=  351.4
```

Amplitudes and phase angles of harmonic components.

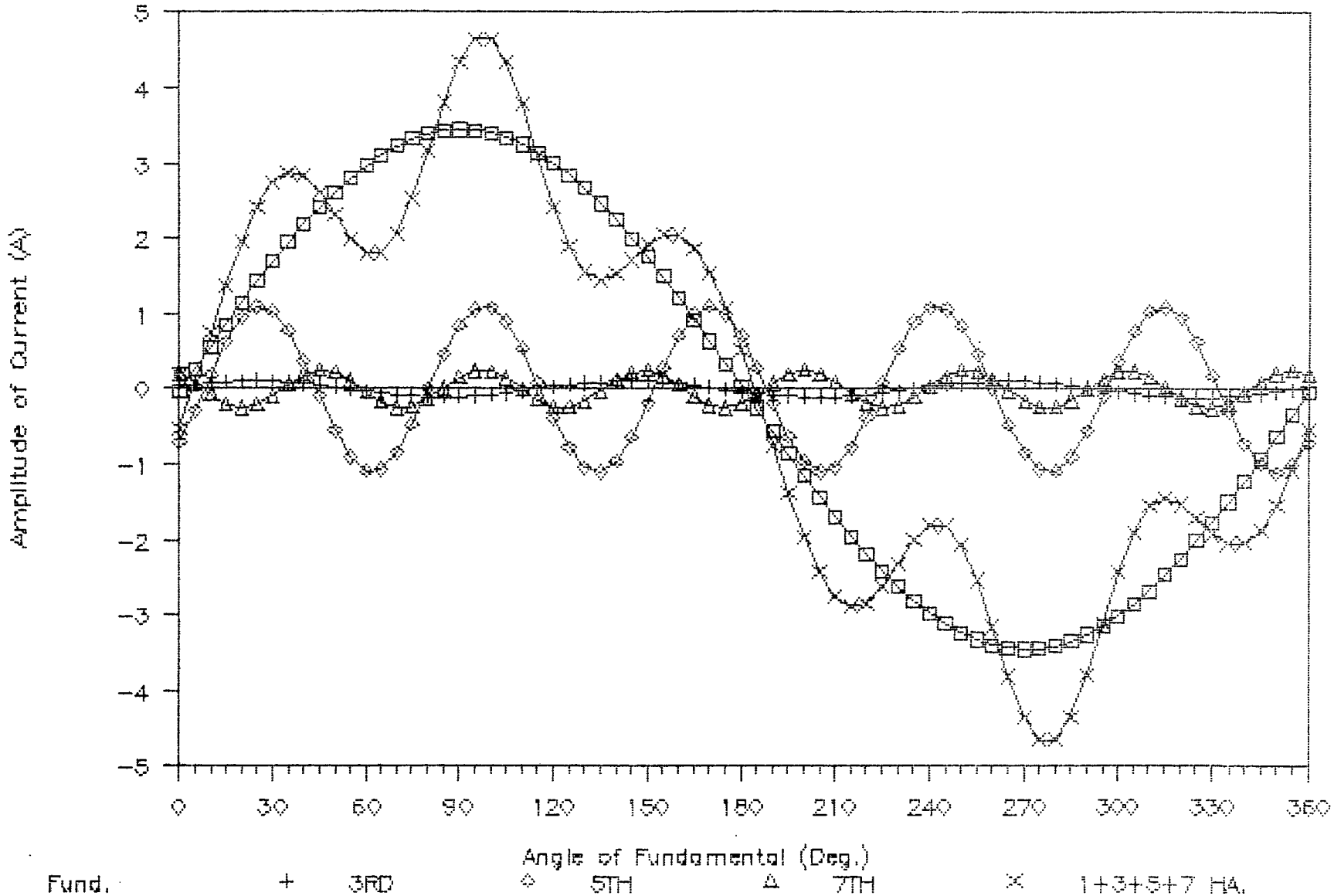
Reconstructed waveforms

TEST_4



Reconstructed waveforms

TEST_4



```
HA. ORDER=  1

V0=   .57472508458
ANG V0= -75.4436671604
V+=   67.2011466667
ANG V+=  0
V-=   .57472508458
ANG V-=  75.4436671604

I0=   .048660227343
ANG I0=  123.941462927
I+=   3.509925
ANG I+=   .599999999994
I-=   4.86602273413E-2
ANG I-= -122.741462929


HA. ORDER=  2

V0=   .0052
ANG V0= -152.199999997
V+=   .374
ANG V+=  87.8
V-=   5.20000000017E-3
ANG V-= -32.2000000001

I0=   7.57809342777E-4
ANG I0= -155.836386237
I+=   .00441
ANG I+=  95.7
I-=   7.57809342773E-4
ANG I-= -12.7636137631


HA. ORDER=  3

V0=   4.50333209933E-3
ANG V0= -111.199999999
V+=   .461
ANG V+= -21.2
V-=   4.50333209977E-3
ANG V-=  68.7999999979

I0=   3.49998373027E-3
ANG I0= -145.69895992
I+=   .116343333333
ANG I+= -17.4
I-=   3.49998373013E-3
ANG I-=  110.898959921


HA. ORDER=  4

V0=   3.69789730043E-3
ANG V0=  59.3103282475
V+=   8.53666666667E-2
ANG V+=  81.8
V-=   3.6978973004E-3
ANG V-=  104.289671752

I0=   3.21666666667E-4
ANG I0=  154.5
I+=   7.5383333333E-3
ANG I+=  94.5
I-=   3.21666666666E-4
ANG I-=  34.4999999999


HA. ORDER=  5

V0=   .48711751264
ANG V0=  146.81108775
V+=   17.2721333333
ANG V+=  32.6
V-=   .487117512627
ANG V-= -81.6110877495

I0=   7.4960113458E-3
ANG I0=  59.6570369813
I+=   1.08431666667
ANG I+=  39.9999999999
I-=   7.49601134547E-3
ANG I-=  20.3429630469


HA. ORDER=  6

V0=   6.72862871953E-3
ANG V0= -93.7613175901
V+=   9.25666666667E-2
ANG V+= -2.2
V-=   6.72862871943E-3
ANG V-=  89.3613175902

I0=   6.54999999997E-4
ANG I0= -49.6000000002
I+=   .007205
ANG I+=  10.4
I-=   .000655
ANG I-=  70.4000000003

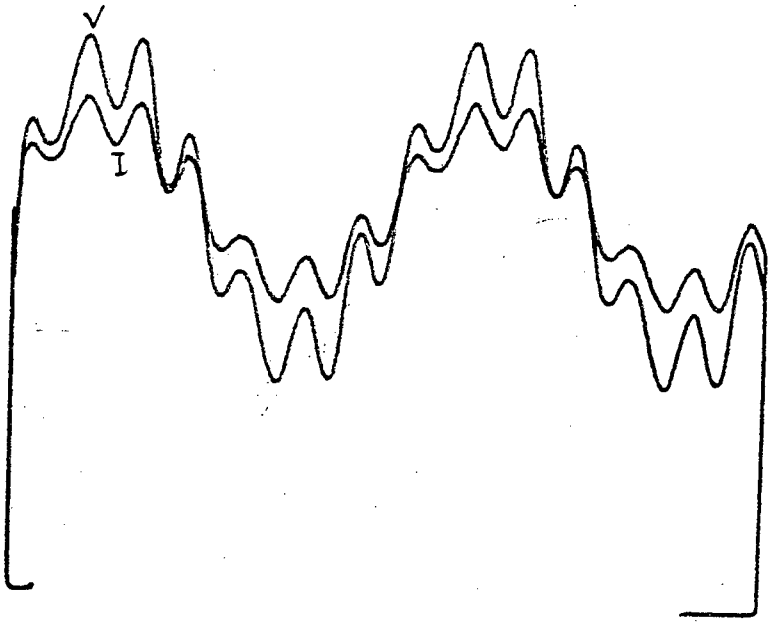

HA. ORDER=  7

V0=   .133963494198
ANG V0=  146.086775553
V+=   4.67146666667
ANG V+= -130.5
V-=   .133963494194
ANG V-= -47.0867755539

I0=   5.36140606547E-3
ANG I0=  123.61634884
I+=   .25283
ANG I+= -128.6
I-=   5.3614060654E-3
ANG I-= -20.8163488426
```

Symmetrical components of harmonics.

T E S T 5



Resultant Waveform of Harmonics : 1st + 7th

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	68.4758053145	68·3	+ 0·26
VB=	66.2619574706	68·3	- 3·08
VC=	69.0493238655	68·2	+ 1·23
IA=	3.86254413218	3·79	+ 1·81
IB=	3.88116442695	3·81	+ 1·80
IC=	3.89538410965	3·80	+ 2·30

```
FUND. FREQ.= 49.9  HZ

HA. ORDER=  1

VA=  65.923
ANG VA=  0
VB=  63.5116
ANG VB=  240
VC=  66.4266
ANG VC=  120

IA=  3.680445
ANG IA=  357.8
IB=  3.688305
ANG IB=  233.8
IC=  3.696165
ANG IC=  117.8


HA. ORDER=  2

VA=  .0016
ANG VA=  -2.2
VB=  .0025
ANG VB=  237.8
VC=  .0022
ANG VC=  117.8

IA=  .02716
ANG IA=  12.2
IB=  .029125
ANG IB=  252.2
IC=  .027335
ANG IC=  132.2


HA. ORDER=  3

VA=  1.6596
ANG VA=  195.6
VB=  1.4114
ANG VB=  75.6
VC=  1.5674
ANG VC=  315.6

IA=  .09253
ANG IA=  187.8
IB=  .09432
ANG IB=  67.8
IC=  .103795
ANG IC=  307.8


HA. ORDER=  4

VA=  .1844
ANG VA=  297.8
VB=  .1844
ANG VB=  177.8
VC=  .1992
ANG VC=  57.8

IA=  .013755
ANG IA=  320.8
IB=  .01965
ANG IB=  200.8
IC=  .01358
ANG IC=  80.8


HA. ORDER=  5

VA=  .2331
ANG VA=  267.8
VB=  .2662
ANG VB=  147.8
VC=  .1948
ANG VC=  27.8

IA=  .03716
ANG IA=  270
IB=  .03405
ANG IB=  150
IC=  .0393
ANG IC=  30


HA. ORDER=  6

VA=  .1688
ANG VA=  267.8
VB=  .1844
ANG VB=  147.8
VC=  .1922
ANG VC=  27.8

IA=  .013755
ANG IA=  257.8
IB=  .015895
ANG IB=  137.8
IC=  .019125
ANG IC=  17.8


HA. ORDER=  7

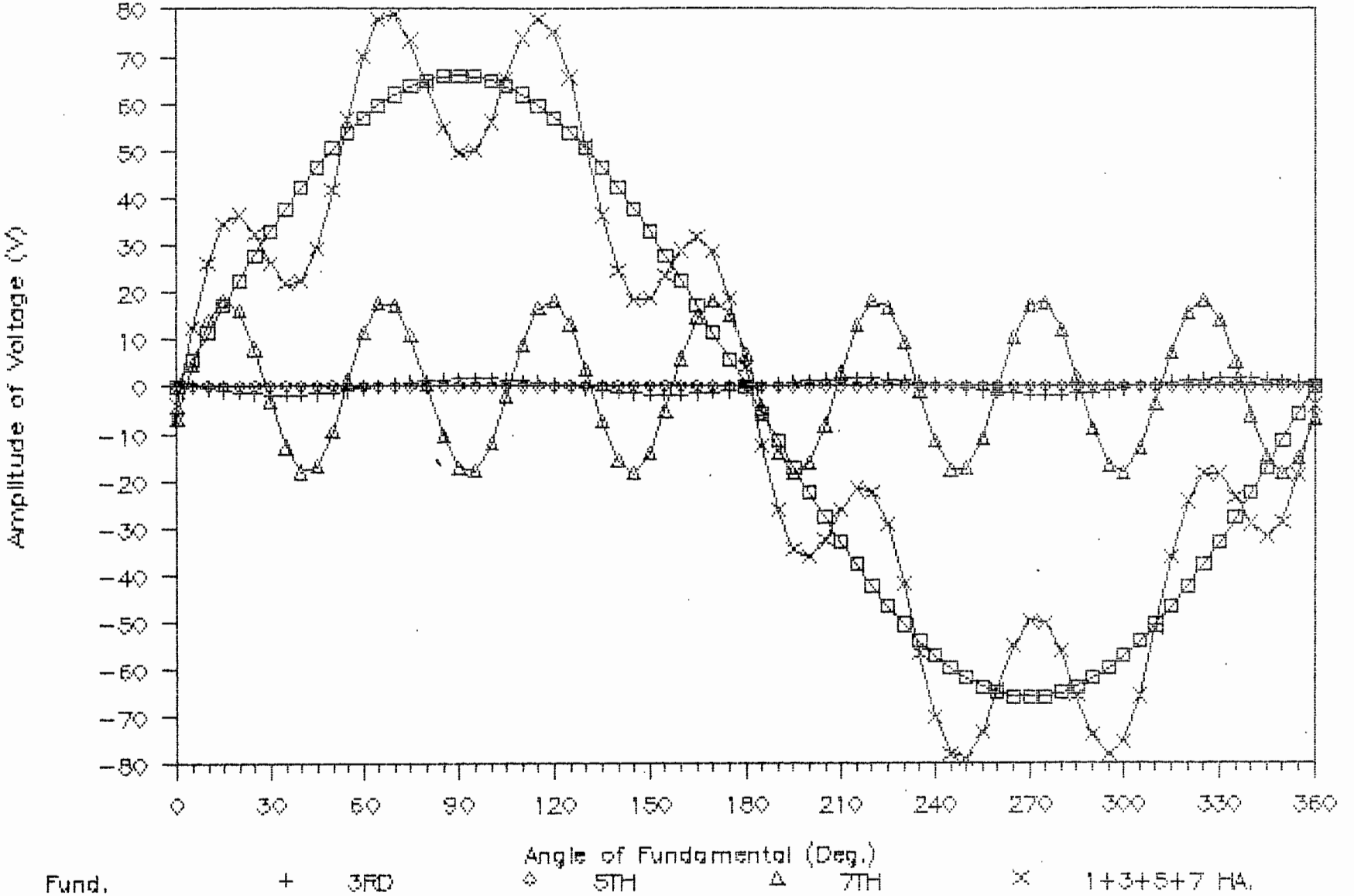
VA=  18.44
ANG VA=  21.8
VB=  18.0712
ANG VB=  261.8
VC=  18.0854
ANG VC=  141.8

IA=  1.16721
ANG IA=  18.1
IB=  1.165245
ANG IB=  258.1
IC=  1.18686
ANG IC=  138.1
```

Amplitudes and phase angles of harmonic components.

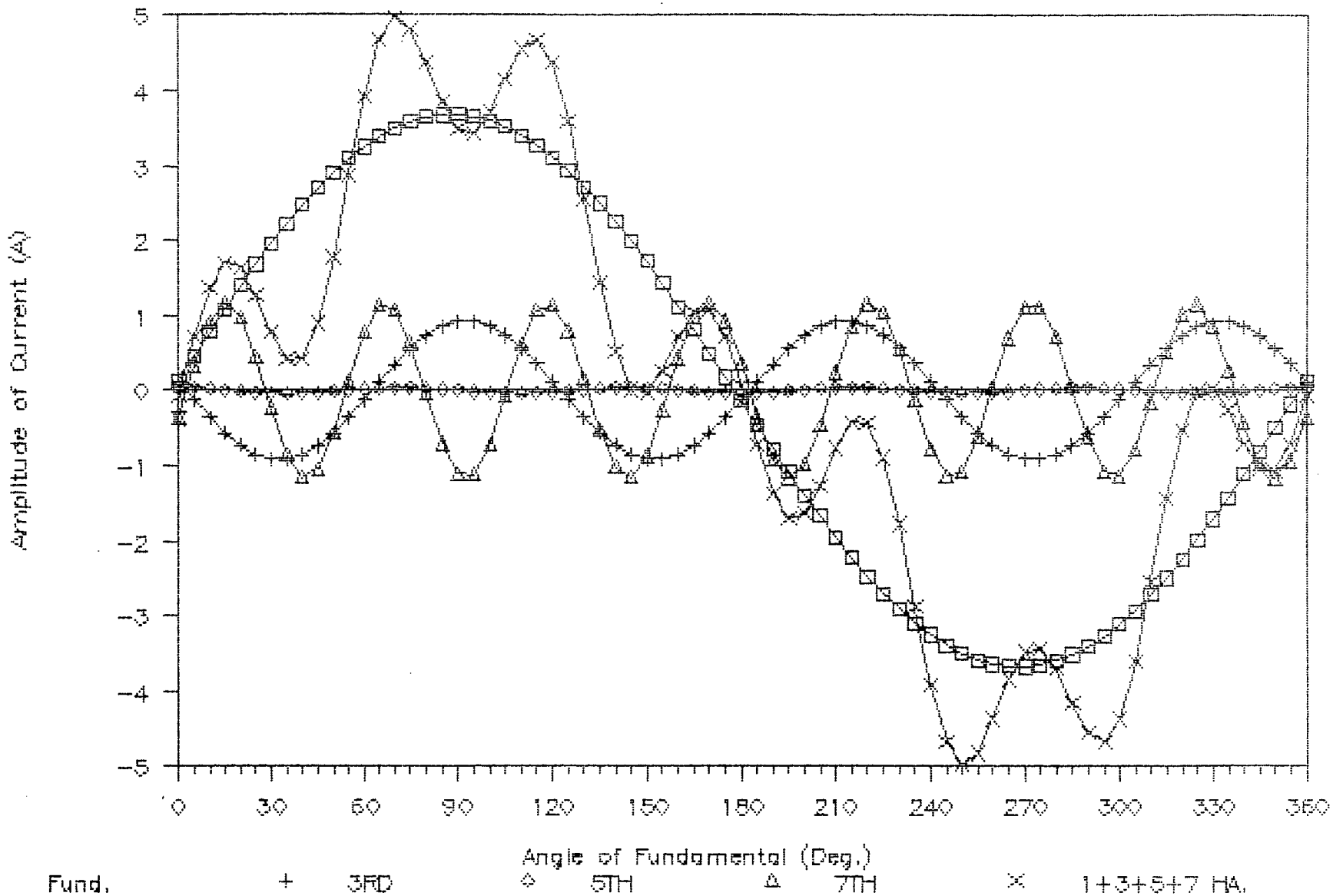
Reconstructed waveforms

TEST_5



Reconstructed waveforms

TEST_5



```
HA. ORDER=  1

V0=   .89955816067
ANG V0=  69.3003073284
V+=  65.2870666667
ANG V+=  0
V-=   .89955816067
ANG V-= -69.3003073284

I0=  9.03486729683E-2
ANG I0=  145.900434323
I+=  3.68630789807
ANG I+= -3.53309255017
I-=  8.12782710507E-2
ANG I-=  25.688357504


HA. ORDER=  2

V0=  2.64575131108E-4
ANG V0= -163.093394649
V+=   .0021
ANG V+= -2.2
V-=  2.64575131108E-4
ANG V-=  158.693394649

I0=  6.27868970753E-4
ANG I0= -112.414989741
I+=  2.78733333333E-2
ANG I+=  12.2
I-=  6.2786897076E-4
ANG I-=  136.814989742


HA. ORDER=  3

V0=  7.24339085723E-2
ANG V0= -125.958444441
V+=  1.54613333333
ANG V+= -164.4
V-=  7.24339085747E-2
ANG V-=  157.15844444

I0=  3.49507550387E-3
ANG I0= -43.697953952
I+=  9.68816666667E-2
ANG I+= -172.2
I-=  3.4950755039E-3
ANG I-=  59.297953952


HA. ORDER=  4

V0=  4.9333333334E-3
ANG V0=  57.8000000011
V+=   .189333333334
ANG V+= -62.2
V-=  4.93333333337E-3
ANG V-=  177.800000001

I0=  4.9699527674E-3
ANG I0= -67.3773691619
I+=  1.32069436776E-2
ANG I+= -58.3036964963
I-=  7.3568006987E-3
ANG I-=  75.7695297575


HA. ORDER=  5

V0=  2.06296173281E-2
ANG V0= -179.792250039
V+=   .231366666667
ANG V+= -92.2
V-=  2.06296173281E-2
ANG V-= -4.60774996041

I0=  1.52414274631E-3
ANG I0= -6.08884929744
I+=  3.68366666667E-2
ANG I+= -90
I-=  1.52414274631E-3
ANG I-= -173.911150703


HA. ORDER=  6

V0=  6.87895340877E-3
ANG V0=  68.6933946504
V+=   .1818
ANG V+= -92.2
V-=  6.87895340887E-3
ANG V-=  106.906605351

I0=  1.56079395751E-3
ANG I0=  41.1159788746
I+=  1.62583333333E-2
ANG I+= -102.2
I-=  1.56079395751E-3
ANG I-=  114.484021125

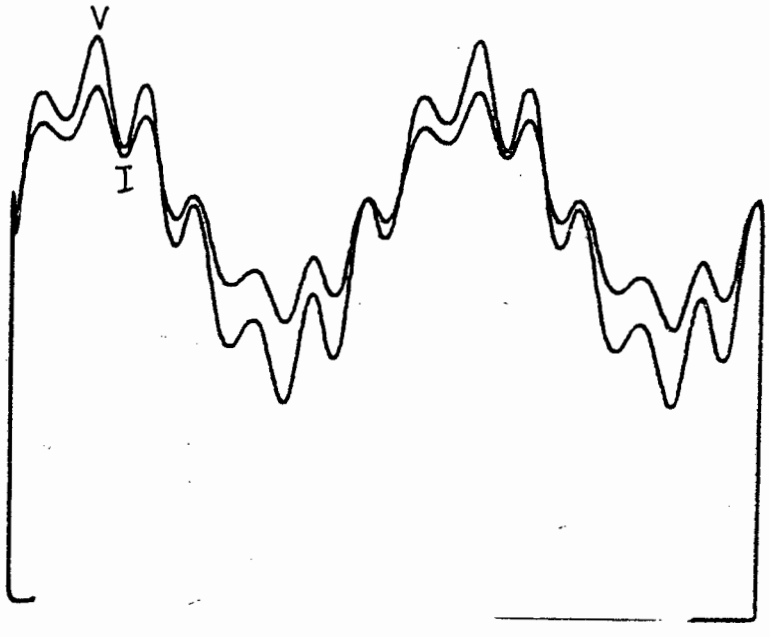

HA. ORDER=  7

V0=   .120636331362
ANG V0=  23.7472685036
V+=  18.1988666667
ANG V+=  21.8
V-=   .120636331371
ANG V-=  19.8527314714

I0=  6.90085320787E-3
ANG I0=  133.384996063
I+=  1.173105
ANG I+=  18.1000000001
I-=  6.90085320867E-3
ANG I-= -97.1849960547
```

Symmetrical components of harmonics.

T E S T 6



Resultant Waveform of Harmonics : 1st + 7th

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	67.9139168173	67·5	+ 0·60
VB=	68.3451306581	67·6	+ 1·11
VC=	70.3145667161	67·5	+ 4·00
IA=	4.07056726523	3·86	+ 5·16
IB=	3.90141061957	3·88	+ 0·51
IC=	4.06407707808	3·87	+ 4·77

```
FUND. FREQ.= 50.1  HZ

HA. ORDER=  1

VA=   65.7102
ANG VA=   0
VB=   66.1144
ANG VB=   240
VC=   68.0436
ANG VC=   120

IA=   3.90292
ANG IA=   3.8
IB=   3.723675
ANG IB=   243.8
IC=   3.896595
ANG IC=   123.8

HA. ORDER=  2

VA=   .2766
ANG VA=   87.8
VB=   .261
ANG VB=   327.8
VC=   .2922
ANG VC=   207.8

IA=   .02751
ANG IA=   95.6
IB=   .02358
ANG IB=   335.6
IC=   .02786
ANG IC=   215.6

HA. ORDER=  3

VA=   3.3972
ANG VA=   80.1
VB=   3.5816
ANG VB=   320.1
VC=   3.4894
ANG VC=   200.1

IA=   .09422
ANG IA=   76.3
IB=   .09482
ANG IB=   316.3
IC=   .084495
ANG IC=   196.3

HA. ORDER=  4

VA=   .4688
ANG VA=   237.7
VB=   .5376
ANG VB=   117.7
VC=   .4454
ANG VC=   357.7

IA=   .020545
ANG IA=   263.2
IB=   .025545
ANG IB=   143.2
IC=   .02393
ANG IC=   23.2

HA. ORDER=  5

VA=   1.2
ANG VA=   269.6
VB=   1.1986
ANG VB=   149.6
VC=   1.2376
ANG VC=   29.6

IA=   .019475
ANG IA=   254.2
IB=   .019825
ANG IB=   134.2
IC=   .01786
ANG IC=   14.2

HA. ORDER=  6

VA=   .0922
ANG VA=   177.8
VB=   .0832
ANG VB=   57.8
VC=   .0844
ANG VC=   297.8

IA=   .005895
ANG IA=   188.4
IB=   .00537
ANG IB=   68.4
IC=   .00786
ANG IC=   308.4

HA. ORDER=  7

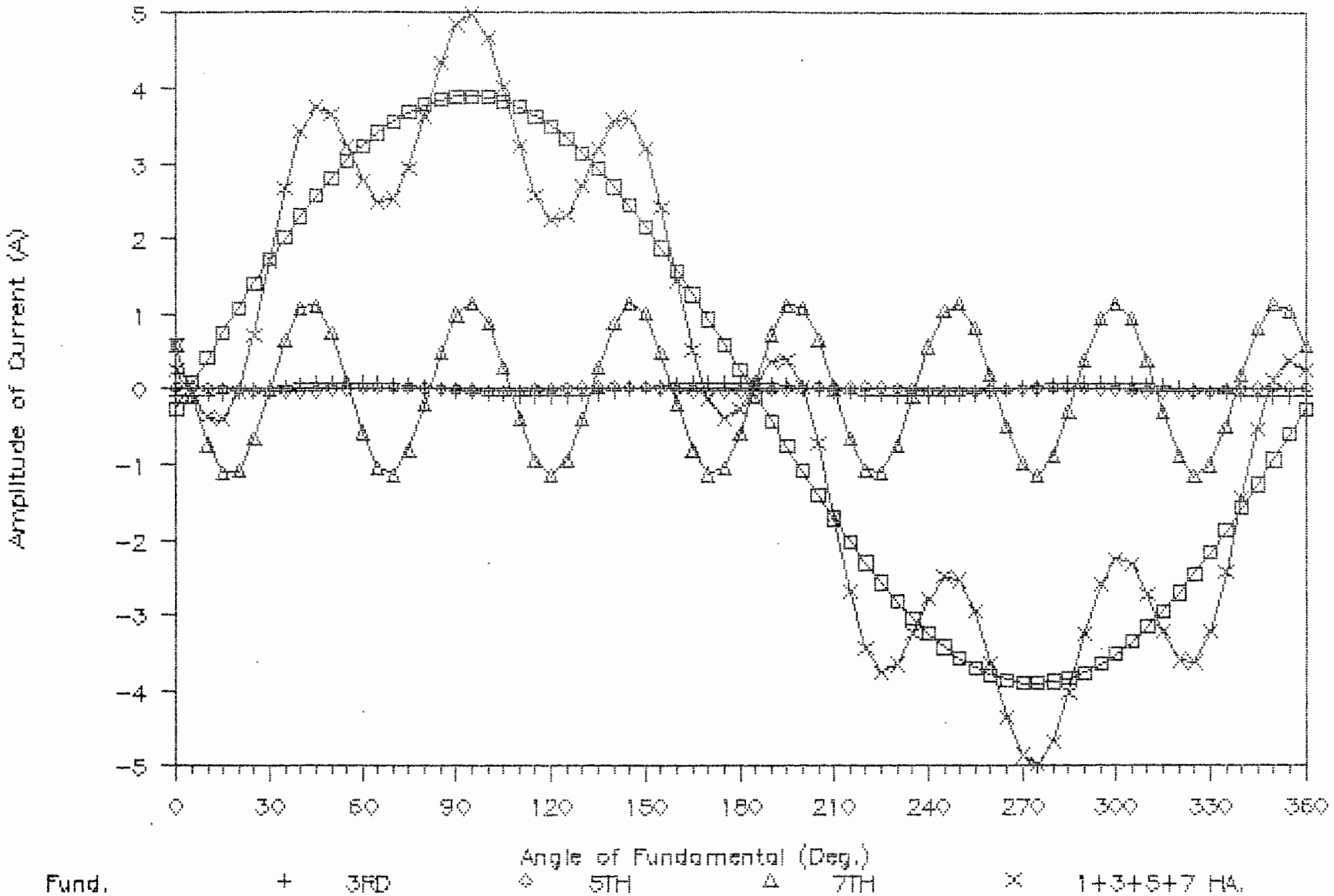
VA=   16.7662
ANG VA=   200.2
VB=   16.596
ANG VB=   80.2
VC=   16.9648
ANG VC=   320.2

IA=   1.15149
ANG IA=   210.4
IB=   1.14756
ANG IB=   90.4
IC=   1.133805
ANG IC=   330.4
```

Amplitudes and phase angles of harmonic components.

Reconstructed waveforms

TEST_6



E30

```
HA. ORDER=  1

V0=   .719951612577
ANG V0=  129.327061372
V+=   66.6227333333
ANG V+=  0
V-=   .719951612577
ANG V-= -129.327061372

I0=   5.87225595713E-2
ANG I0=  62.0182057005
I+=   3.84106333333
ANG I+=  3.8
I-=   5.87225595737E-2
ANG I-= -54.4182057011


HA. ORDER=  2

V0=   9.00666419937E-3
ANG V0=  177.800000001
V+=   .2766
ANG V+=  87.8
V-=   9.0066641997E-3
ANG V-= -2.20000000118

I0=   1.37205846977E-3
ANG I0=  159.822996488
I+=   2.63166666667E-2
ANG I+=  95.6
I-=   1.37205846977E-3
ANG I-=  31.3770035133


HA. ORDER=  3

V0=   5.32316948213E-2
ANG V0= -69.9000000015
V+=   3.4894
ANG V+=  80.1000000001
V-=   5.32316948213E-2
ANG V-= -129.899999999

I0=   3.34615243397E-3
ANG I0=  13.3329035276
I+=   .091178333333
ANG I+=  76.3
I-=   3.3461524339E-3
ANG I-=  139.267096472


HA. ORDER=  4

V0=   2.76705218198E-2
ANG V0=  131.829984681
V+=   .483933333333
ANG V+= -122.3
V-=   2.76705218195E-2
ANG V-= -16.4299846807

I0=   1.4732136075E-3
ANG I0=  101.648858913
I+=   .02334
ANG I+= -96.8
I-=   1.47321360749E-3
ANG I-=  64.7511410874


HA. ORDER=  5

V0=   1.27730619321E-2
ANG V0=  27.7868341984
V+=   1.21206666667
ANG V+= -90.4
V-=   .012773061933
ANG V-=  151.413165802

I0=   6.05160676557E-4
ANG I0= -175.410986162
I+=   1.90533333333E-2
ANG I+= -105.8
I-=   6.0516067658E-4
ANG I-= -36.189013841


HA. ORDER=  6

V0=   2.82134719594E-3
ANG V0= -175.147322973
V+=   8.66000000003E-2
ANG V+=  177.8
V-=   2.82134719593E-3
ANG V-=  170.747322972

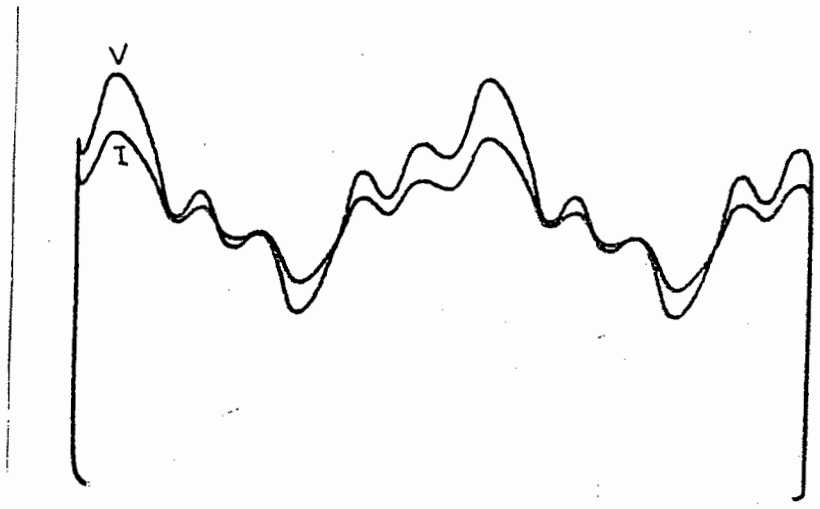
I0=   7.57809342777E-4
ANG I0= -63.1363862369
I+=   .006375
ANG I+= -171.6
I-=   7.57809342777E-4
ANG I-=  79.9363862373


HA. ORDER=  7

V0=   .106568559077
ANG V0= -67.2543216625
V+=   16.7756666667
ANG V+= -159.8
V-=   .106568559017
ANG V-=  107.65432167

I0=   5.36140606463E-3
ANG I0=  162.616348844
I+=   1.144285
ANG I+= -149.6
I-=   5.36140606773E-3
ANG I-= -101.816348833
```

T E S T 7



Resultant Waveform of Harmonics : 1st + 3rd + 5th + 7th

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	44.3830492041	45.1	-1.62
VB=	44.3373683613	45.1	-1.71
VC=	44.9042010583	45.2	-0.67
IA=	2.67576605228	2.70	-0.75
IB=	2.64710039713	2.72	-2.64
IC=	2.65348301378	2.73	-2.90

```
FUND. FREQ.= 50.1  HZ

HA. ORDER=  1

VA=   38.695
ANG VA=   0
VB=   38.452
ANG VB=   240
VC=   39.132
ANG VC=   120

IA=   2.240235
ANG IA=   3.1
IB=   2.19678
ANG IB=   243.1
IC=   2.20874
ANG IC=   123.1


HA. ORDER=  2

VA=   .1742
ANG VA=   289.5
VB=   .1764
ANG VB=   169.5
VC=   .1821
ANG VC=   49.5

IA=   .044126
ANG IA=   296.3
IB=   .042216
ANG IB=   176.3
IC=   .040112
ANG IC=   56.3


HA. ORDER=  3

VA=   13.6245
ANG VA=   222.4
VB=   14.1321
ANG VB=   102.4
VC=   13.9279
ANG VC=   342.4

IA=   .97825
ANG IA=   214.7
IB=   .98216
ANG IB=   94.7
IC=   .96862
ANG IC=   334.7


HA. ORDER=  4

VA=   .09126
ANG VA=   -5.6
VB=   .07652
ANG VB=   244.4
VC=   .09864
ANG VC=   124.4

IA=   .01872
ANG IA=   -1.3
IB=   .01537
ANG IB=   238.7
IC=   .01924
ANG IC=   118.7


HA. ORDER=  5

VA=   13.1262
ANG VA=   124.9
VB=   12.80188
ANG VB=   4.9
VC=   12.5637
ANG VC=   244.9

IA=   .836127
ANG IA=   127.5
IB=   .870212
ANG IB=   7.5
IC=   .85429
ANG IC=   247.5


HA. ORDER=  6

VA=   .2041
ANG VA=   281.2
VB=   .2171
ANG VB=   161.2
VC=   .1976
ANG VC=   41.2

IA=   .018054
ANG IA=   272.5
IB=   .021106
ANG IB=   152.5
IC=   .017452
ANG IC=   32.5


HA. ORDER=  7

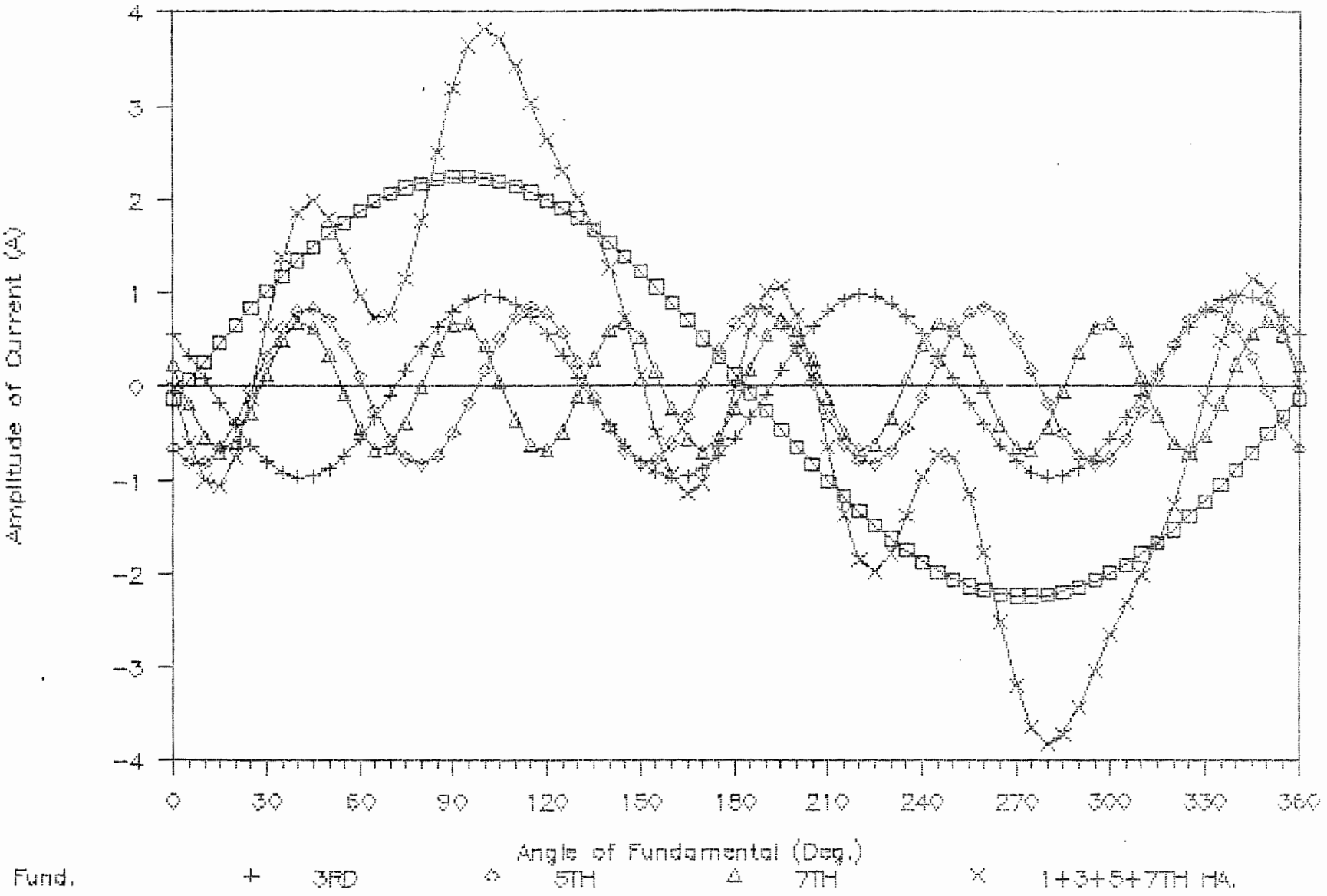
VA=   10.7013
ANG VA=   199.2
VB=   11.1017
ANG VB=   79.2
VC=   11.5102
ANG VC=   319.2

IA=   .6945
ANG IA=   201.1
IB=   .6758
ANG IB=   81.1
IC=   .7012
ANG IC=   321.1
```

Amplitudes and phase angles of harmonic components.

Reconstructed waveforms

TEST_7



```
HA. ORDER=  1

V0=   .198944157444
ANG V0=   99.3534675283
V+=   38.7596666667
ANG V+=   0
V-=   .198944157444
ANG V-= -99.3534675283

I0=   1.29591733926E-2
ANG I0=   18.564458455
I+=   2.215255
ANG I+=   3.1
I-=   1.29591733912E-2
ANG I-= -12.3644584646


HA. ORDER=  2

V0=   2.35395648062E-3
ANG V0=   65.1520586001
V+=   .177566666667
ANG V+= -70.4999999999
V-=   2.35395648022E-3
ANG V-=   153.847941392

I0=   1.15919301432E-3
ANG I0= -95.298356633
I+=   4.21513333333E-2
ANG I+= -63.7000000001
I-=   1.15919301432E-3
ANG I-= -32.1016433684


HA. ORDER=  3

V0=   .147442693172
ANG V0=   66.0268292783
V+=   13.8946666667
ANG V+= -137.6
V-=   .147442693183
ANG V-=   18.773170739

I0=   4.02324219727E-3
ANG I0=   138.406979038
I+=   .976343333333
ANG I+= -145.3
I-=   4.02324219693E-3
ANG I-= -69.0069790391


HA. ORDER=  4

V0=   1.34214543809E-3
ANG V0=   59.6759761878
V+=   8.85023020273E-2
ANG V+=   .978191492941
V-=   1.16928916388E-2
ANG V-= -81.8511450922

I0=   1.21266006963E-3
ANG I0=   65.8106890118
I+=   1.77766666667E-2
ANG I+= -1.3
I-=   1.21266006962E-3
ANG I-= -68.4106890117


HA. ORDER=  5

V0=   .163013193899
ANG V0=   99.952618703
V+=   12.8305933333
ANG V+=   124.9
V-=   .163013193868
ANG V-=   149.847381296

I0=   .009846578306
ANG I0= -24.6738626511
I+=   .853543
ANG I+=   127.5
I-=   9.84657830573E-3
ANG I-= -80.3261373501


HA. ORDER=  6

V0=   5.73246117387E-3
ANG V0= -179.693394652
V+=   .206266666667
ANG V+= -78.8
V-=   5.73246117387E-3
ANG V-=   22.0933946498

I0=   1.13109641992E-3
ANG I0=   161.337969067
I+=   1.88706666666E-2
ANG I+= -87.5
I-=   1.13109641991E-3
ANG I-=   23.6620309336

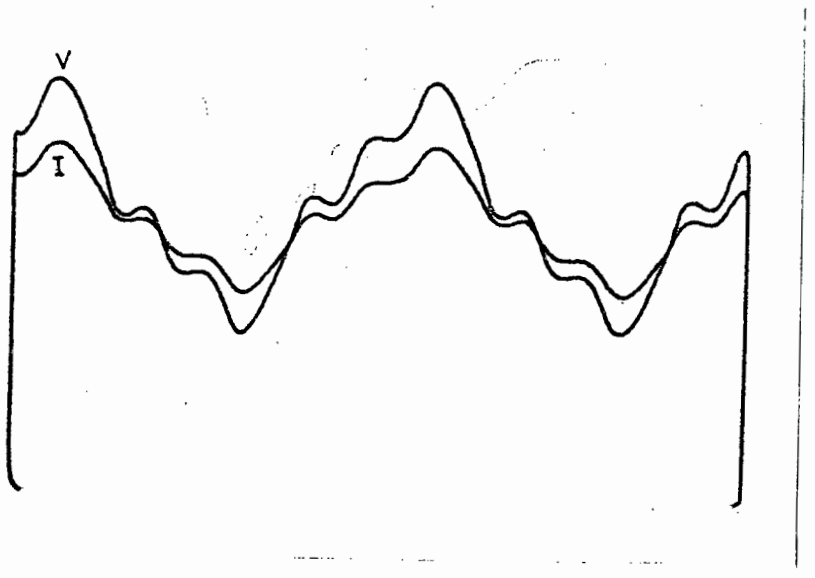

HA. ORDER=  7

V0=   .233513218767
ANG V0= -11.1312434901
V+=   11.1044
ANG V+= -160.8
V-=   .233513218742
ANG V-=   49.5312434828

I0=   7.6002192947E-3
ANG I0= -84.1570723442
I+=   .6905
ANG I+= -158.9
I-=   7.60021929513E-3
ANG I-=   126.357072343
```

Symmetrical components of harmonics.

TEST 8



Resultant Waveform of Harmonics : 1st + 3rd + 5th + 7th

Resultant RMS Values of 3 phase components		Analogue Meters readings of 3 phase power supply	DEVIATION (%)
VA=	57.7644336395	55.2	+4.45
VB=	54.7388799311	55.3	-1.02
VC=	56.9422137505	55.4	+2.70
IA=	3.16394054622	3.00	+5.18
IB=	3.26697949845	3.05	+6.64
IC=	3.17080819827	2.95	+6.97

```
FUND. FREQ.= 49.9  HZ

HA. ORDER=  1

VA=   55.712
ANG VA=   0
VB=   52.4588
ANG VB=   240
VC=   54.8245
ANG VC=   120

IA=   3.00124
ANG IA=   1.1
IB=   3.10876
ANG IB=   241.1
IC=   3.00674
ANG IC=   121.1


HA. ORDER=  2

VA=   .08342
ANG VA=   113.1
VB=   .08267
ANG VB=   353.1
VC=   .08198
ANG VC=   233.1

IA=   .01988
ANG IA=   120.3
IB=   .02076
ANG IB=   3
IC=   .02104
ANG IC=   240.3


HA. ORDER=  3

VA=   10.2138
ANG VA=   216.9
VB=   10.3426
ANG VB=   96.9
VC=   10.0987
ANG VC=   336.9

IA=   .691035
ANG IA=   220.1
IB=   .686752
ANG IB=   100.1
IC=   .693421
ANG IC=   340.1


HA. ORDER=  4

VA=   .1085
ANG VA=   307.2
VB=   .0982
ANG VB=   187.2
VC=   .1124
ANG VC=   67.2

IA=   .01685
ANG IA=   322.7
IB=   .01724
ANG IB=   202.7
IC=   .01421
ANG IC=   82.7


HA. ORDER=  5

VA=   8.6517
ANG VA=   147.1
VB=   8.8431
ANG VB=   27.1
VC=   8.5462
ANG VC=   267.1

IA=   .59223
ANG IA=   140.5
IB=   .57374
ANG IB=   20.5
IC=   .58247
ANG IC=   260.5


HA. ORDER=  6

VA=   .0847
ANG VA=   291.6
VB=   .0768
ANG VB=   171.6
VC=   .0882
ANG VC=   51.6

IA=   .02434
ANG IA=   280.1
IB=   .02248
ANG IB=   160.1
IC=   .027625
ANG IC=   40.1


HA. ORDER=  7

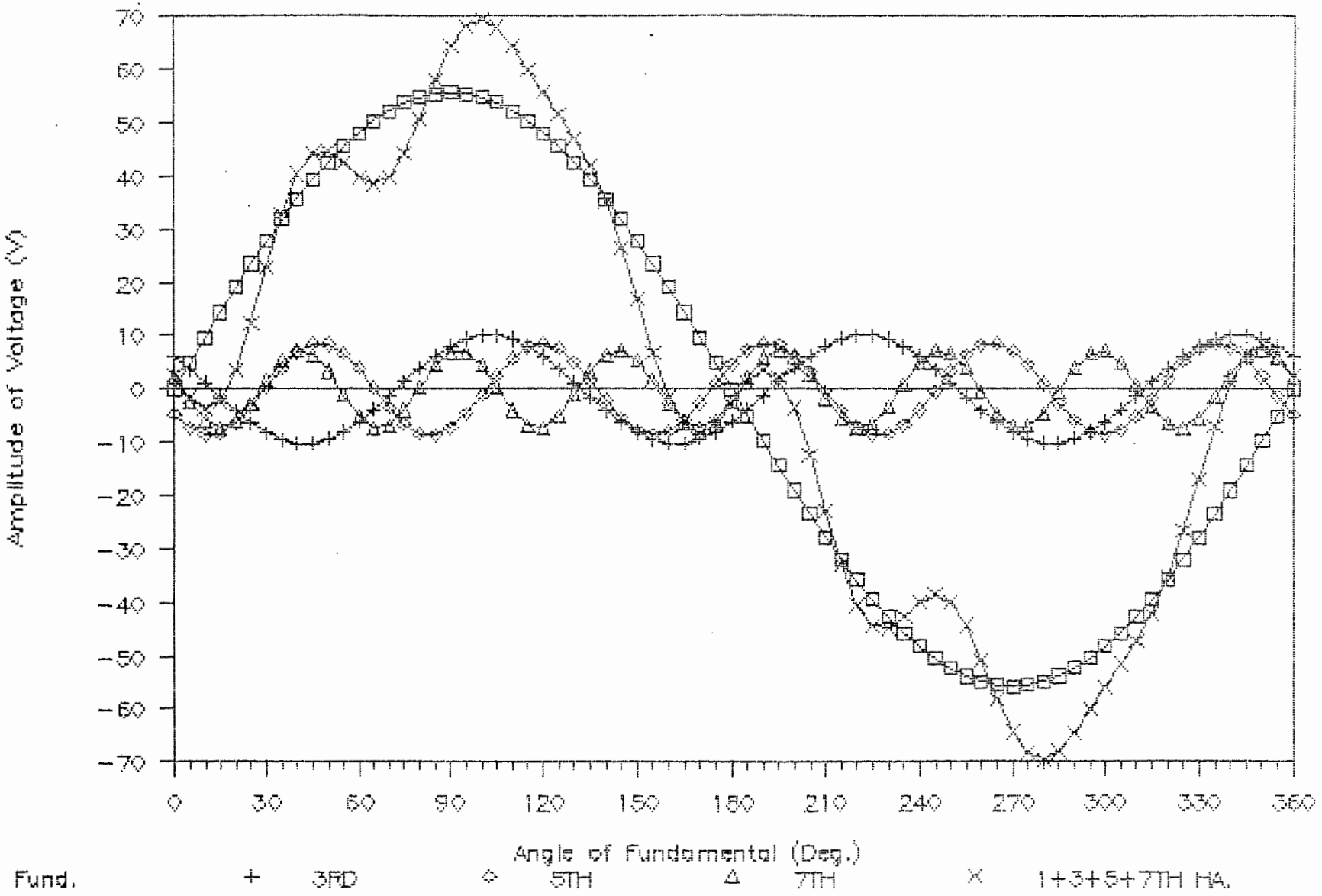
VA=   7.3231
ANG VA=   197.2
VB=   7.4879
ANG VB=   77.2
VC=   7.5266
ANG VC=   317.2

IA=   .416367
ANG IA=   201.4
IB=   .44243
ANG IB=   81.4
IC=   .42344
ANG IC=   321.4
```

Amplitudes and phase angles of harmonic components.

Reconstructed waveforms

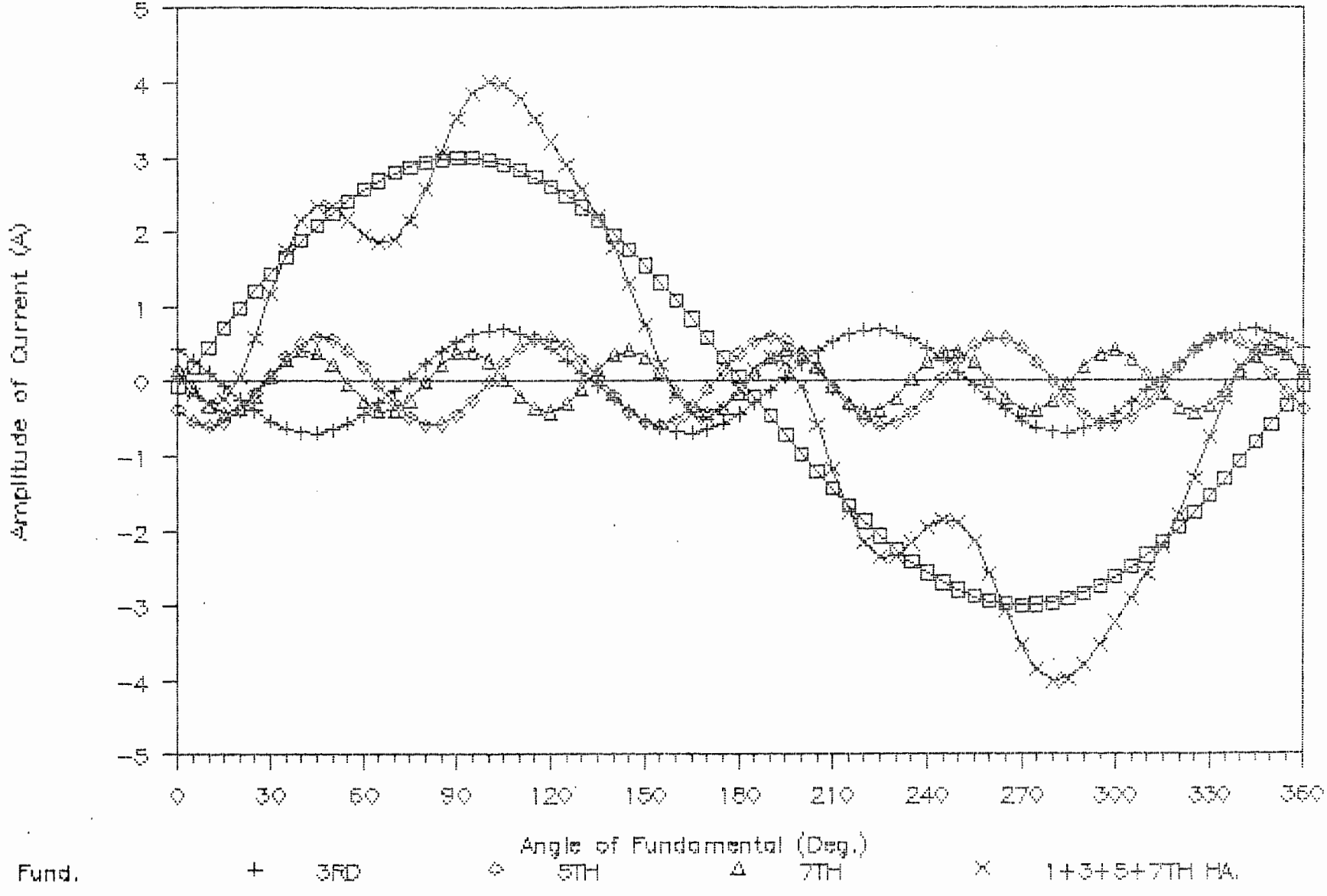
TEST_8



E39

Reconstructed waveforms

TEST_8



```
HA. ORDER=  1

V0=   .970896006003
ANG V0=   44.699639539
V+=   54.3317666667
ANG V+=   0
V-=   .970896006003
ANG V-= -44.699639539

I0=   3.49594056663E-2
ANG I0= -121.50303536
I+=   3.03891333334
ANG I+=   1.1
I-=   .034959405666
ANG I-=   123.70303536


HA. ORDER=  2

V0=   4.1581245771E-4
ANG V0=   84.4780564516
V+=   .08269
ANG V+=   113.1
V-=   4.1581245776E-4
ANG V-=   141.721943552

I0=   3.4947579793E-4
ANG I0= -73.0728258083
I+=   .02056
ANG I+=   120.3
I-=   3.4947579793E-4
ANG I-= -46.3271741846


HA. ORDER=  3

V0=   7.04448799357E-2
ANG V0=   125.042543765
V+=   10.2183666667
ANG V+= -143.1
V-=   7.04448799573E-2
ANG V-= -51.2425437651

I0=   1.95096338009E-3
ANG I0= -59.2262940338
I+=   .69040266667
ANG I+= -139.9
I-=   1.95096338015E-3
ANG I-=   139.426294035


HA. ORDER=  4

V0=   4.23569487943E-3
ANG V0=   22.6142884408
V+=   .106366666667
ANG V+= -52.8
V-=   4.23569487943E-3
ANG V-= -128.21428844

I0=   9.51682720257E-4
ANG I0= -104.093954611
I+=   .0161
ANG I+= -37.3000000001
I-=   9.51682720237E-4
ANG I-=   29.4939546121


HA. ORDER=  5

V0=   8.68951539393E-2
ANG V0=   47.616826923
V+=   8.68033333337
ANG V+=   147.1
V-=   8.68951539337E-2
ANG V-= -113.416826923

I0=   5.3403630758E-3
ANG I0=   168.657902368
I+=   .582813333333
ANG I+=   140.5
I-=   5.34036307553E-3
ANG I-=   112.342097636


HA. ORDER=  6

V0=   3.37161352733E-3
ANG V0=   9.03763304827
V+=   8.32333333333E-2
ANG V+= -68.4
V-=   3.37161352733E-3
ANG V-= -145.837633047

I0=   1.50410272256E-3
ANG I0=   19.185109776
I+=   .024815
ANG I+= -79.9
I-=   1.50410272257E-3
ANG I-= -178.985109776

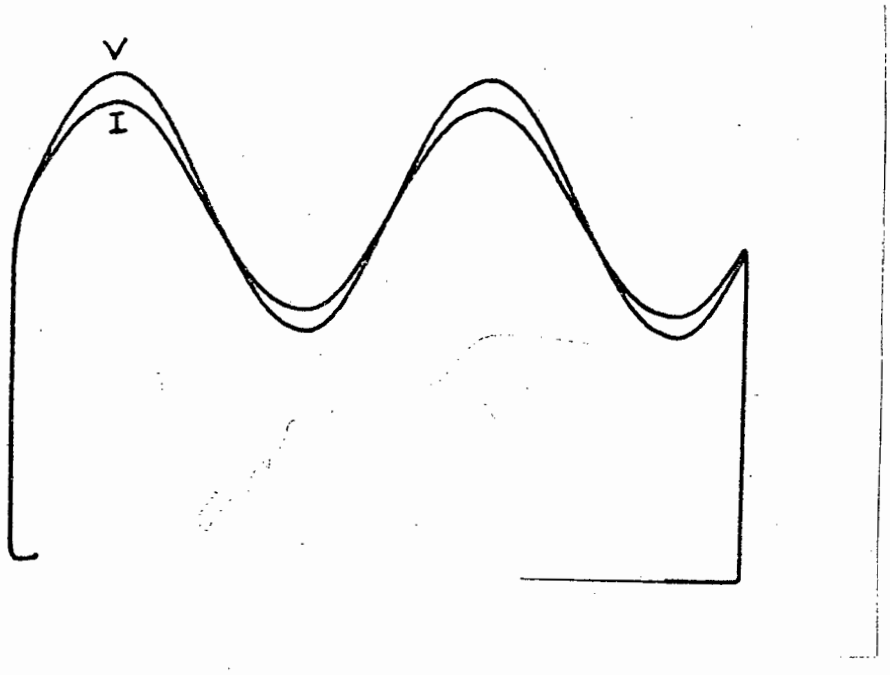

HA. ORDER=  7

V0=   .062391675013
ANG V0=   6.885104994
V+=   7.44586666667
ANG V+= -162.8
V-=   .062391675013
ANG V-=   27.5148950065

I0=   7.78148585543E-3
ANG I0=   66.1879606987
I+=   .427412333333
ANG I+= -158.6
I-=   7.78148585487E-3
ANG I-= -23.3879606963
```

Symmetrical components of harmonics.

T E S T 9



Waveform of Fundamental

	RMS Values of 3 phase components	Analogue Meters Readings of 3 phase power supply	DEVIATION (%)
[A]			
Va=	60.4282	59.9	+0.87
Vb=	61.766	61.5	+0.43
Vc=	62.4724	61.5	+1.56
Ia=	4.680723	4.70	-0.41
Ib=	3.643274	3.60	+1.19
Ic=	3.574456	3.61	-1.0
[B]			
Va=	61.6544	61.8	-0.24
Vb=	60.483	61.0	-0.85
Vc=	62.3241	61.7	+1.0
Ia=	3.54338	3.56	-0.47
Ib=	4.728361	4.74	-0.47
Ic=	3.4848	3.55	-1.87
[C]			
Va=	61.5734	61.9	-0.53
Vb=	62.3348	61.8	+0.86
Vc=	59.0723	60.2	-1.91
Ia=	3.6762	3.58	+2.62
Ib=	3.5437	3.58	-1.02
Ic=	4.773264	4.75	+0.49

(A)

```
FUND. FREQ.= 50.1  HZ

HA. ORDER=  1

VA=  60.4282
ANG VA=  0
VB=  61.766
ANG VB=  240
VC=  62.4724
ANG VC=  120

IA=  4.680723
ANG IA=  3.8
IB=  3.643274
ANG IB=  243.8
IC=  3.574456
ANG IC=  123.8
```

```
HA. ORDER=  1

V0=  .599482013453
ANG V0=  160.113345716
V+=  61.5554666667
ANG V+=  0
V-=  .599482013453
ANG V-= -160.113345716

I0=  .357836749417
ANG I0=  .617840670755
I+=  3.96615
ANG I+=  3.8
I-=  .357836749417
ANG I-=  6.98215932943
```

(B)

```
FUND. FREQ.= 49.9  HZ

HA. ORDER=  1

VA=  61.6544
ANG VA=  0
VB=  60.483
ANG VB=  240
VC=  62.3241
ANG VC=  120

IA=  3.54338
ANG IA=  5.4
IB=  4.728361
ANG IB=  245.4
IC=  3.4848
ANG IC=  125.4
```

```
HA. ORDER=  1

V0=  .5379965004
ANG V0=  81.0730836803
V+=  61.4870333333
ANG V+=  0
V-=  .5379965004
ANG V-= -81.0730836803

I0=  .42351108377
ANG I0= -112.311599324
I+=  3.93726333333
ANG I+=  5.39999999998
I-=  .423511083773
ANG I-=  123.111599324
```

(C)

```
FUND. FREQ.= 49.9  HZ

HA. ORDER=  1

VA=  61.5734
ANG VA=  0
VB=  62.3348
ANG VB=  240
VC=  59.0723
ANG VC=  120

IA=  3.6762
ANG IA=  8.3
IB=  3.5437
ANG IB=  248.3
IC=  4.773264
ANG IC=  128.3
```

```
HA. ORDER=  1

V0=  .985431540573
ANG V0= -72.8983743999
V+=  60.9934333333
ANG V+=  0
V-=  .985431540573
ANG V-=  72.8983743999

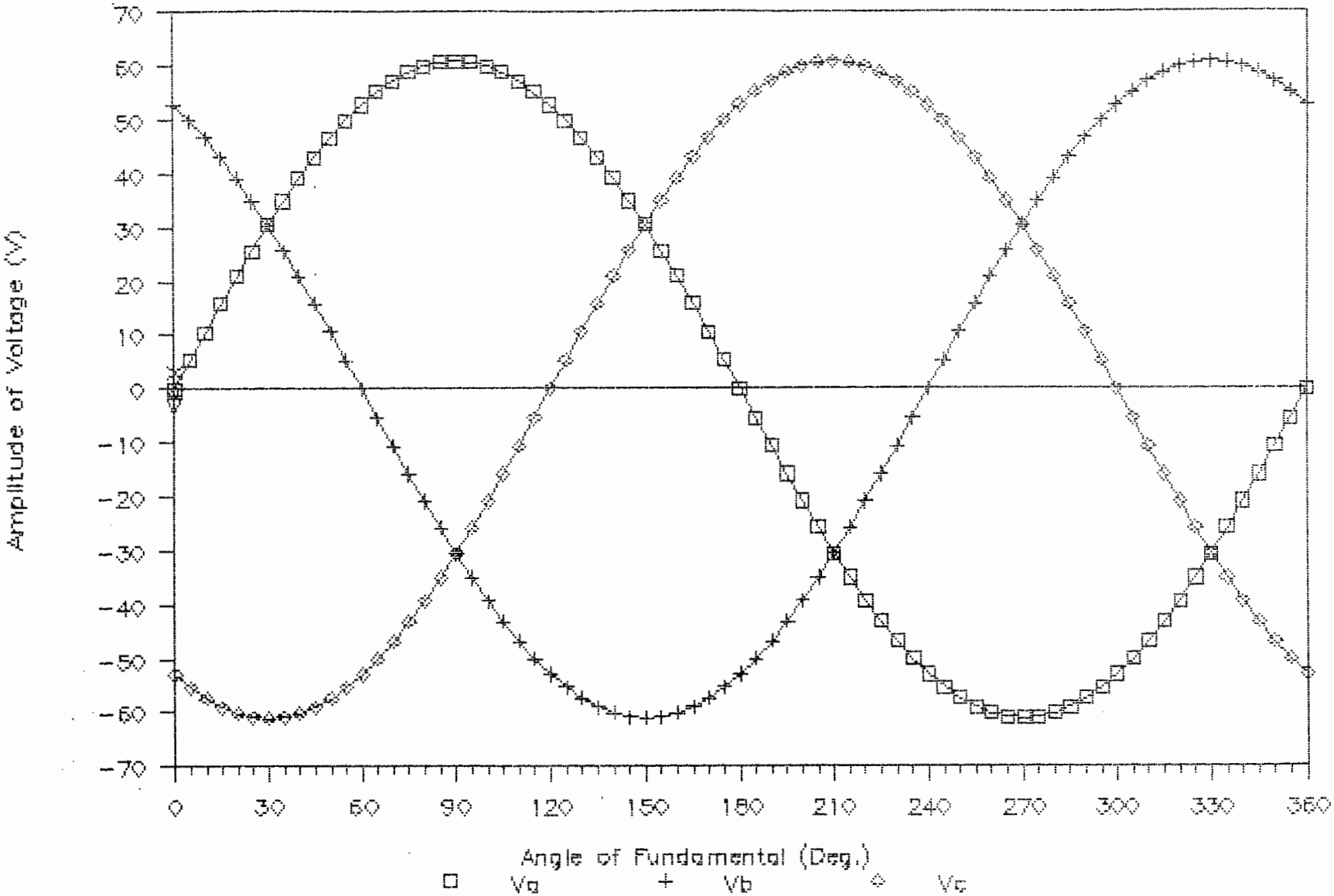
I0=  .389665156827
ANG I0=  122.666786378
I+=  3.99773333333
ANG I+=  8.3
I-=  .389665156823
ANG I-= -106.066786378
```

Amplitudes and Angles of Fundamental

Symmetrical Components of Fundamental

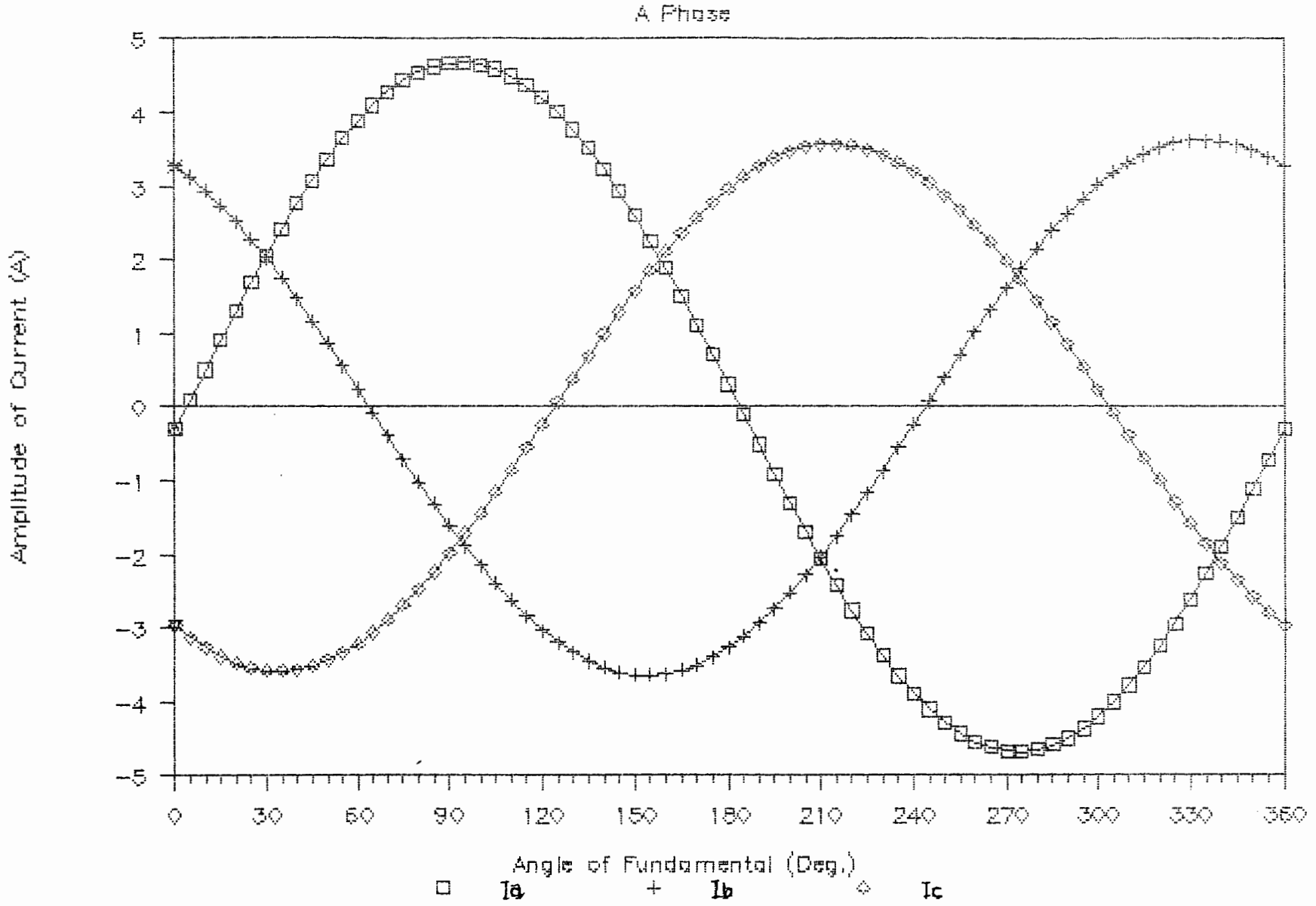
Reconstructed waveforms

TEST_9



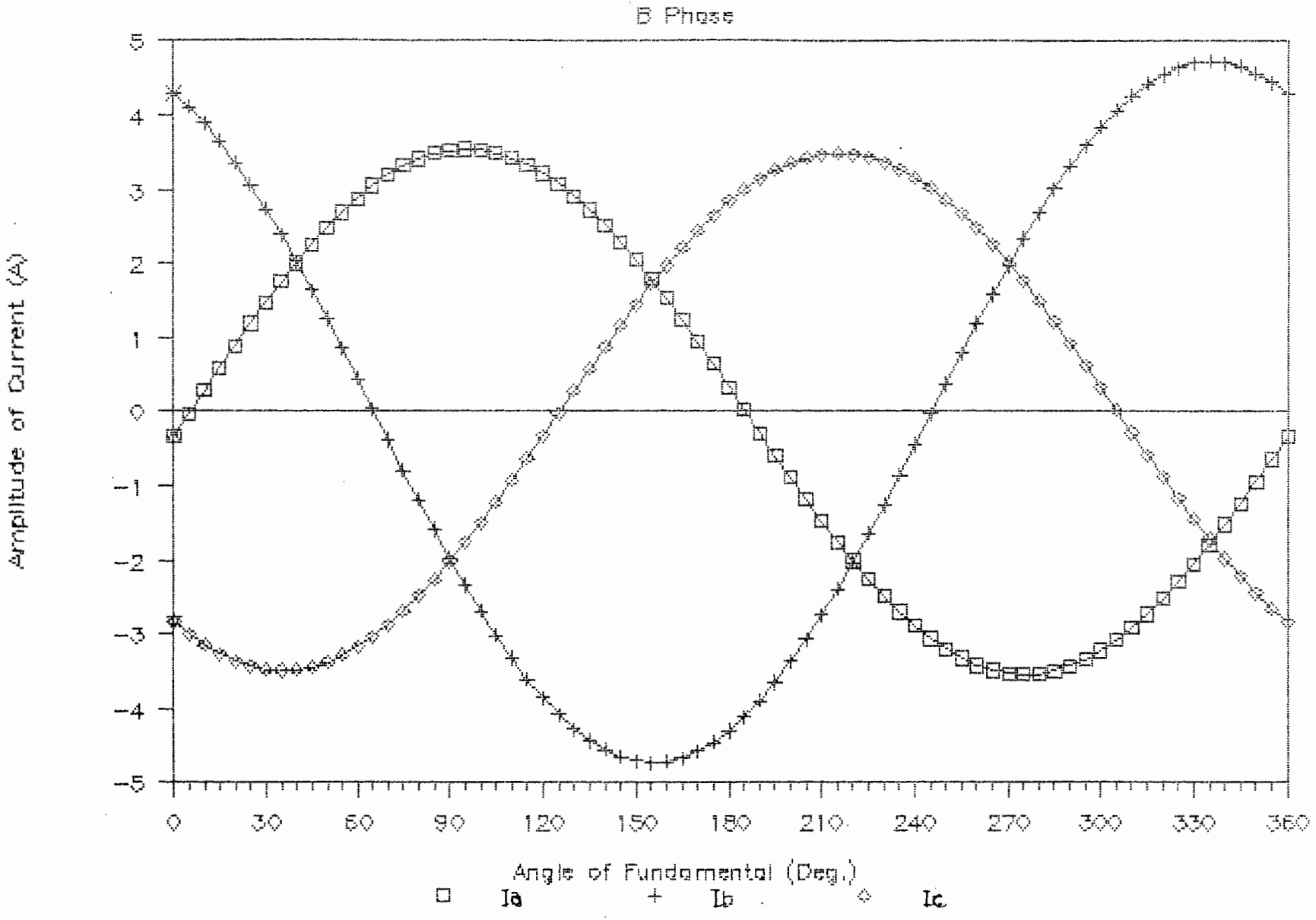
Reconstructed waveforms

TEST_9



Reconstructed waveforms

TEST_9



Reconstructed waveforms

TEST_9

C Phase

Amplitude of Current (A)

5
4
3
2
1
0
-1
-2
-3
-4
-5

0 30 60 90 120 150 180 210 240 270 300 330 360

Angle of Fundamental (Deg.)

□ Ia + Ib ◇ Ic

E47

17 DEC 1986