MICROPROCESSOR BASED DEAD RECKONING TABLE

by

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I would like to thank my wife for her careful typing and patience.

ABSTRACT

The application areas of microprocessors have been growing recently. In addition to various areas, efficient and reliable results have been obtained in military applications.

The object of this thesis is to apply microprocessor control on a device used in the Navy and the realization of the necessary hardware and software and the observation of the results.

In this study, the Dead Reckoning Table used on the ships of the Navy was controlled and operated by microprocessor. The Dead Reckoning Table is used for recording the movements of our ship and the others in the same operation area. Many tactical and manoeuvre problems are solved on this table. The preparing speed and the reliability of the records are increased and the operator mistakes are prevented with the aid of microprocessor.

ÖZET

Son yıllarda mikrobilgisayarların uygulama sahaları hızla artmaktadır. Çeşitli kullanım yerlerine ek olarak askeri uygulamalardada verimli ve güvenilir neticeler elde edilmektedir.

Bu tezin amacı mikroişlemcinin Deniz Kuvvetlerinin savaş gemilerinde kullanılmakta olan bir aygıta uygulanabilirliğine karar vermek ve gerekli donanım ve yazılımı gerçekleştirerek sonuçları incelemektir.

Yapılan çalışmada Deniz Kuvvetlerine ait gemilerin Savaş Harekat Merkezlerinde bulunan iz masalarının mikroişlemci ile kontrolu ve çalışması gerçekleştirilmiştir. İz masasının görevi kendi gemimiz ile birlikte harekat sahasında bulunan diğer gemilerin bütün hareketlerini kağıt üzerine işaretlemek, taktik ve manevra ile ilgili problemlerin çözülmesine yardımcı olmaktır. Mikroişlemci kullanılması ile kayıtların tutulmasında sürat ve güvenilirlik sağlanarak operatör hataları önlenmiştir.

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CHAPTER I
INTRODUCTION

The Dead Reckoning Table (DRT) is used at the combat Information Centers (CIC) of the Naval ships. Most of the operation records in an exercise are prepared on this table.

The DRT is a projection device with a transparent plastic top. A ship's position pointer which is driven by gears is projected through the plastic. A sheet of translucent paper, placed over the top and temporarily taped down at the corners, is marked by the operators with the position of the ship at regular intervals. This paper may be considered to be a map. The other ships in the same operation area can also be plotted. The geographical positions and movements are displayed on the paper. When the ship's track runs out of the edge of the paper the pointer is placed to another location and a new piece of paper is put on the table.

Many operation problems are solved on this paper. This paper is the summary of an operation at the sea.

The course and the speed of the ship are the inputs to DRT. These signals are transmitted from the gyro compass and the log as synchro signals. The ship's position pointer moves with these input signals and shows the position of the ship.

In order to plot one or more target ships on the same paper the operator finds out the bearing and the distance of them from his ship. Then he draws the bearing line in the length of the distance and plots the target's position. The operator also records the time at which the plotting is done. The time intervals between the marks is adjusted by the operator.

The purpose of this thesis is to design and build a microprocessor based DRT. Many improvements will be achived by using the microprocessor control on the DRT. Primarily, these are:

- No personnel will be required for plotting.
- The ship's position pen will automatically shift to the opposite edge when running out of the paper.
- Scale changes can be made by push button.
- Remote read outs can be made available to the other parts of the ship.
- Modifications or improvements via softvare changes.

- Entry and display of one or more targets.
- Plotter can print the time on the plot.
- Automatic printing of the data.
- Automatic changing of the paper.
- Solutions of the manoeuvre and operation problems.

The small Fast Patrol Boats (FPB's) which have a limited number of seaman onboard move with a very high speed in the operation area. A microprocessor controlled DRT will be very useful for FPB's.

In this study most of the items above were realized, but some of them were considered as a further work.

In addition to the plotting of the ships', the input data and the calculated values such as ship's course and target speed are transmitted to a teletype-writer which displays the situation. This information can be delivered to the other departments to inform the personnel about the operation.

CHAPTER 2
M6800 MICROCOMPUTER SYSTEM

System Components

The microcomputer system consists of:

1. Microprocessing Unit (MPU)
2. Clock Generator
3. Read Only Memory (ROM)
4. Random Access Memory (RAM)
5. Parallel Input/Output Interface
6. Asynchronous Serial Input/Output Interface

Fig. 2-1 shows the block diagram of the microcomputer system.

This block diagram represents all of the hardware required for a fully operational microcomputer system.[2] The data bus is shared fully between all devices in the system. The control bus is shared by all devices which get their own required signal from the bus. Different combinations of signals may be received from the address bus to define where each device is located. The address bus selects one byte or location from 64 K bytes or locations.

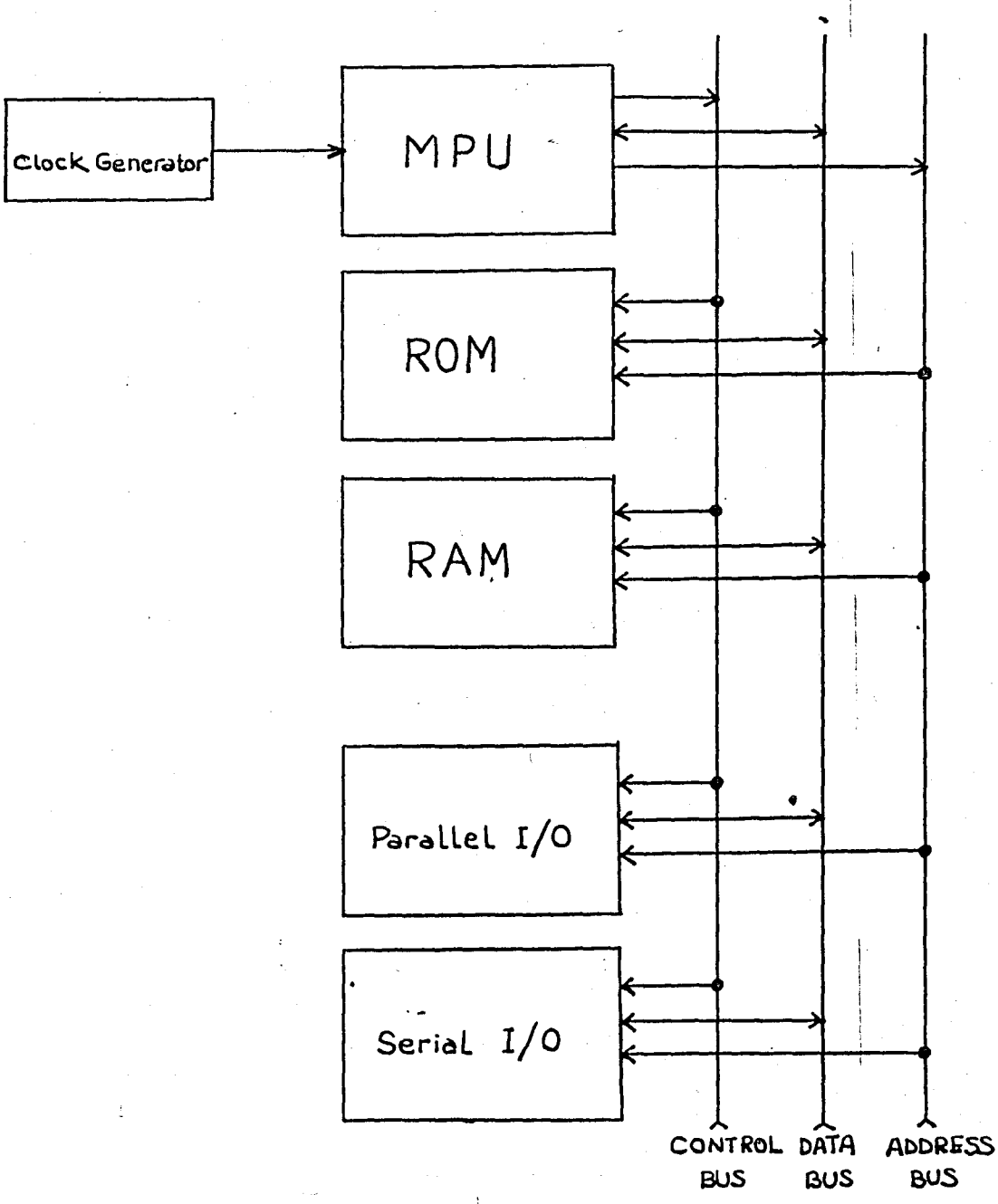


Fig.2-1 Block Diagram of the Microcomputer System.

Microprocessing Unit

MC6800 MPU is the heart of the system. It is a monolithic 8-bit microprocessor performing the central control function for the system. The MPU can execute 72 different instructions including arithmetic, logical, shift, rotate, load, store, conditional or unconditional branch, jump, interrupt and stack manipulation instructions.[4] The MPU has three 16-bit registers and three 8-bit regiters available for use by the programmer. These are shown in Fig.2-2. The program counter points to the current program address.

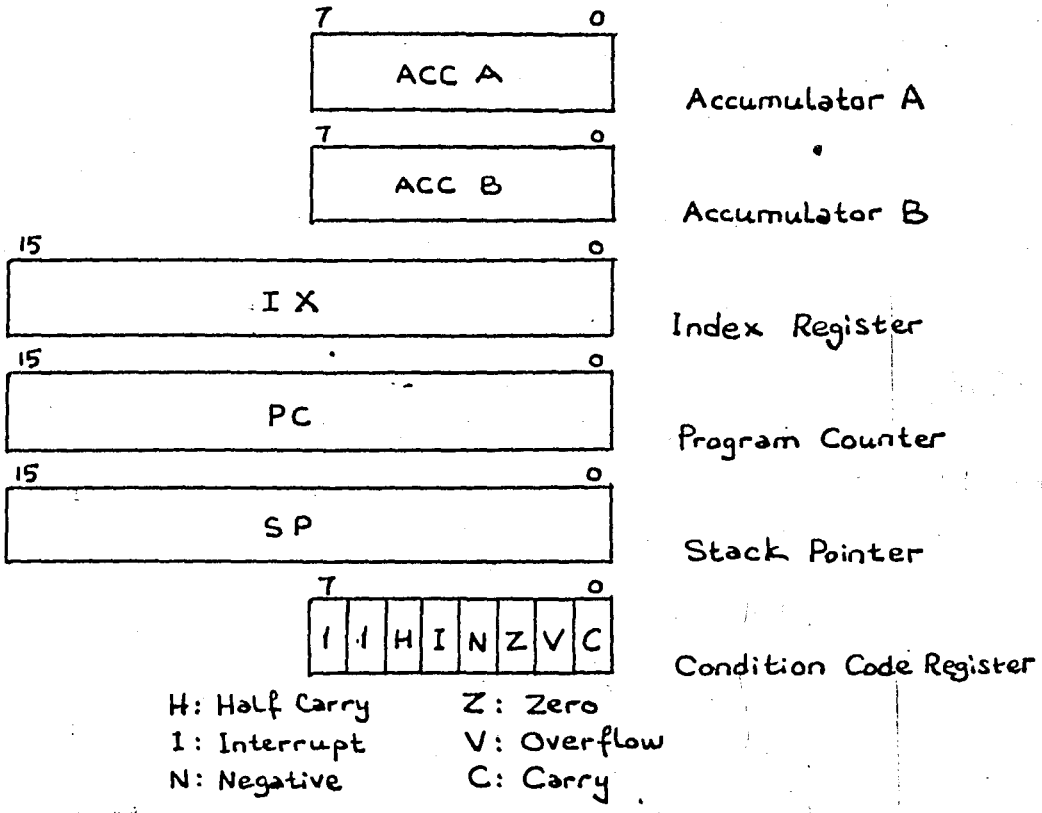


Fig.2-2 The Registers of MC 6800

The stack pointer contains the address of the next available location in the stack which is a RAM. Index register is used to store data or a sixteen bit memory address for the indexed mode of addressing. The two accumulators are used to hold operands and results from the arithmetic logic unit (ALU). The condition code register indicates the results of an ALU operation. The bits of this register are used as testable conditions for the conditional branch instructions. Bit 4 is the interrupt mask bit. The unused bits of the condition code register are ones.

A general block diagram of the MC 6800 is shown in Fig.2-3. The control and timing signals regulate the system operation.

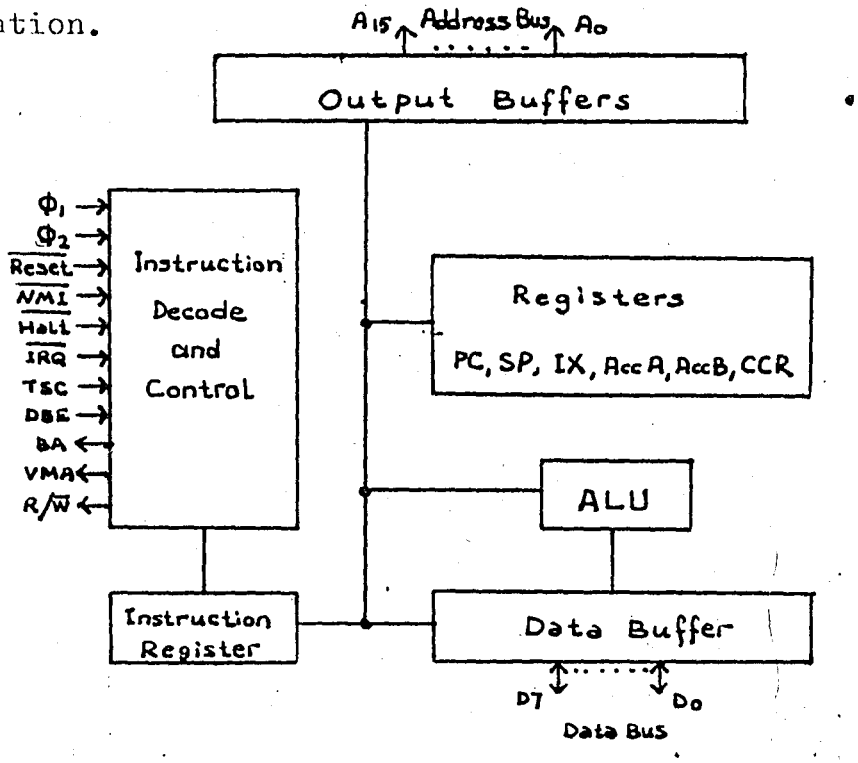


Fig.2-3 The Block Diagram of the MC 6800.

ϕ_1 and ϕ_2 are two-phase non-overlapping clock signals. The $\overline{\text{Halt}}$ input is used to stop the MPU. In the Halt mode all three-state lines will be in three-state mode. Three State Control (TSC) input causes all of the address lines and the R/$\overline{W}$ line to go into the high impedence state. R/$\overline{W}$ line signals the peripherals and memory devices whether the MPU is in Read or Write state.

Valid Memory Address (VMA) output indicates to peripheral devices that there is a valid address on the address bus. This signal is applied to the enable or chip select inputs of each family device in order to disable data transfer when VMA is low. Data Bus Enable (DBE) input is the three state control signal for the MPU data bus. Normally, this signal will be ϕ_2, derived from the clock. Bus Available (BA) signal will normally be in the low state; when activated, it will go to the high state indicating that the MPU has stopped. The interrupt reguest ($\overline{\text{IRQ}}$) is a level sensitive input which requests that an interrupt sequence be generated with in the machine. If the interrupt mask bit in the CCR is not set, the machine will begin an interrupt sequence. A low-going edge on the Non-Maskable Interrupt ($\overline{\text{NMI}}$)input requests that a non-maskable interrupt sequence be generated within the processor. The interrupt mask bit in the CCR has no effect on $\overline{\text{NMI}}$. Reset input is used to reset and start

the MPU from a power down condition.

The MC 6800 has seven addressing modes that can be used by the programmer, with the addressing mode a function of both the type of the instruction and the coding within the instruction. In Accumulator Addresing mode, either accumulator A or accumulator B is specified. In Immediate Addressing, the operand is contained in the second byte of instruction except LDS and LDX instructions which have the operand in the second and third bytes of the instruction. In Direct Addressing mode, the address of the operand is contained in the second byte of the instruction. In Extended Addressing, the address contained in the second byte of the instruction is used as the higher eight bits of the address of the operand. The third byte of the instruction is used as the lower eight bits of the address for the operand. In Indexed Addresing, the operand of the instruction is added to the index register to provide the address. In Implied Addressing mode, the mnemonic operator specifies one or more registers which contain operands or in which results are saved. In Relative Addressing, the address contained in the second byte of the instruction is added to the program counter's lowest eight bits plus two. The carry or borrow is then added to the higher eight bits.

Memory

The ROM section is permanent data storage. The ROM keeps the data whether the power is on or not. The RAM section will keep its stored data as long as power is supplied to it and can be written into or read out of as desired. The ROM is used in order to storage the system start up instructions, monitor programming and all the necessary software. The RAM will be used for temporary data and program storage.

To read an information stored in the memory; the R/$\overline{W}$ line is placed in a read state, the address of the memory cell to be read is loaded onto the address lines, the memory is enabled by applying the proper signals to the chip enable lines, after a lenght of time required to propagate the information to the output, the data is read from the data out lines.

To write an information to the memory; the address at which the data to be stored is applied to the address bus, the memory is enabled, R/$\overline{W}$ line is placed in write state and the data to be written is applied to the data in lines.[1]

Input / Output Interface

The MC 6821 Peripheral Interface Adapter (PIA) is used as parallel I/O interface. This device is capable of interfacing the MPU to peripherals through two 8-bit bidirectional peripheral data buses and four control lines. The simplified block diagram of the PIA is shown in Fig.2-4.

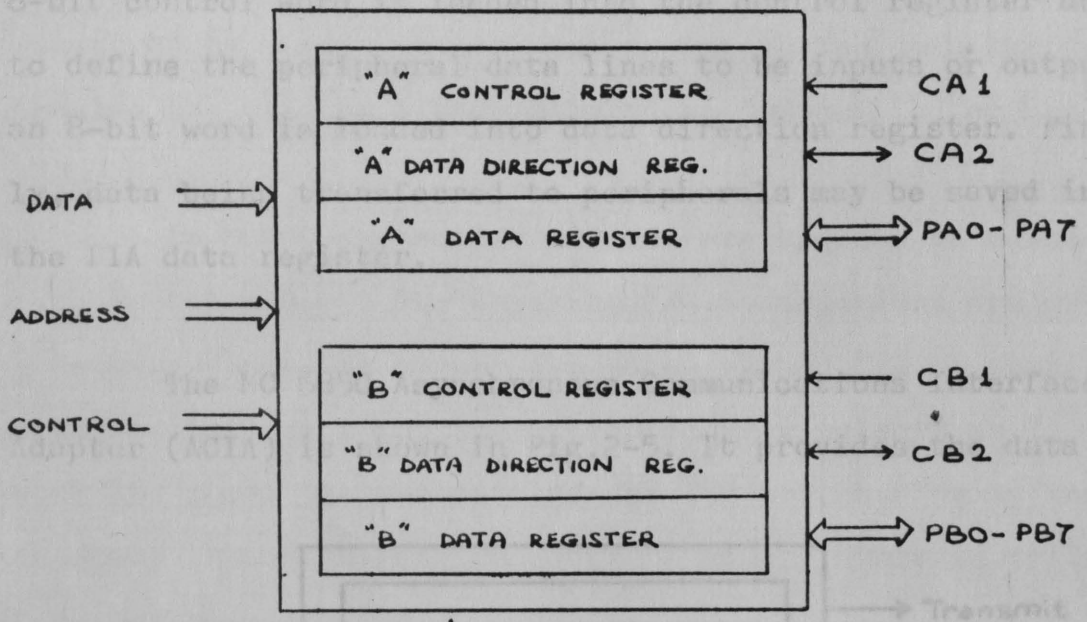


Fig. 2-4 The Simplified Block Diagram of the PIA.

The PIA is programmed by the MPU during system initialization. Each of the peripheral data lines can be programmed to act as an input or output and each of the four control

or interrupt lines may be programmed for one of the several control modes. The PIA is programmable in the sense that the MPU can read and/or write into its internal registers. There are six 8-bit registersin the PIA. They are seperated into an A and B side, each side containing a Control Register, Data Direction Register and a Data Register. To define the operation of the PIA control lines, an 8-bit control word is loaded into the control register and to define the peripheral data lines to be inputs or outputs, an 8-bit word is loaded into data direction register. Finally, data being transferred to peripherals may be saved in the PIA data register.

The MC 6850 Asynchronous Communications Interface Adapter (ACIA) is shown in Fig.2-5. It provides the data

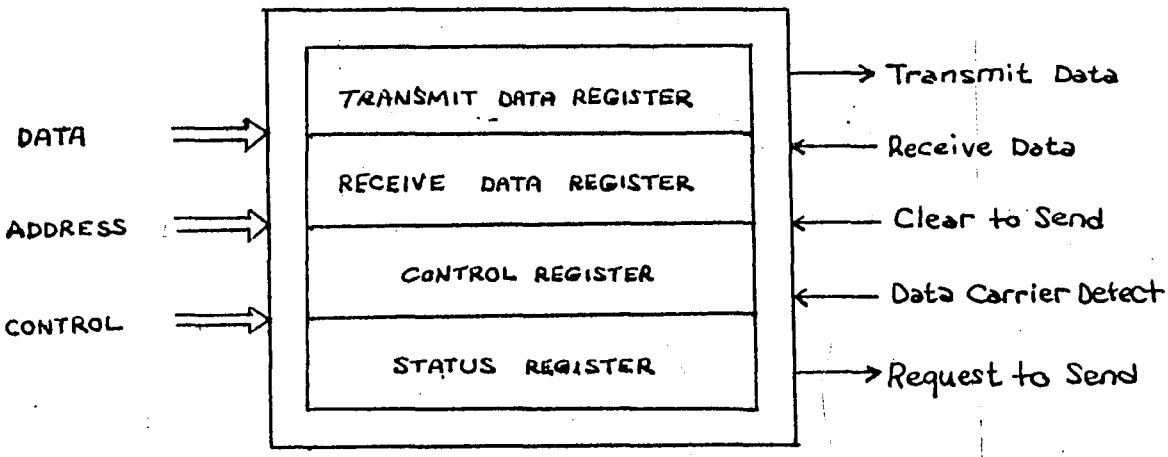


Fig. 2-5 The ACIA Registers.

formatting and control to interface serial asynchronous data communications information to bus organized systems. The parallel data of the bus is serially transmitted or received by the ACIA. The ACIA has four registers: Control, Status, Transmit Data and Receive Data.

The ACIA is programmed by loading an 8-bit word into the control register. The status and error conditions are monitored by reading the status register. The data buffers provide the storage of the data to be transmitted or received.

In M6800 system I/O devices are treated as a location in the memory. The separate I/O instructions are unnecessary since the memory can house either I/O or memory data in its locations. The microprocessor selects an I/O port and reads the contents of the I/O port buffer in the same way that data gets read out of memory.[9] This is called " Memory Mapped I/O ".

CHAPTER 3
DESCRIPTION OF THE MICROPROCESSOR BASED DRT

Microprocessor Based System Design

The development of a microprocessor based system contains some important steps. During development, the designer performs the following steps to satisfy the system requirements:

1. System design criteria: This step includes the consideration of the cost of hardware, software, designing effort, flexibility, compatibility, reliability, speed and availability.

2. The efficiency of the microprocessor than hardware logic.

3. Microprocessor selection criteria: In this step the designer takes the viability, the system and the software support and the upgrading potential of the microprocessor into account.

4. Designing the auxilary hardware.

5. Software development.

6. Integrating the hardware and the software.

7. Debugging and testing.

8. Developing the maintenance facilities.

System Layout

The general block diagram of the system is shown in Fig. 3-1. The system is built around the M6800 Based Microcomputer because it is extensively supported in the university. All the necessary data inputs are simulated by developed cicuits. The input and the output signals are received or transmitted by the 6821 PIA's.

The own course and the target bearing inputs are allowed to be eight-bit Gray code. The own ship speed and the target distance inputs are implemented as eight-bit binary signals. The binary word at the own speed input port corresponds the velocity of the ship in miles per hour (knots). The eight-bit binary number at the target distance input port is multiplied by 100 in order to find the real distance in yards.

For the reset input, two eight-bit ports are required. One each for the two bytes representing desired x and y position to the full plotter range of eight bits. The reset position is considered as a reference position for

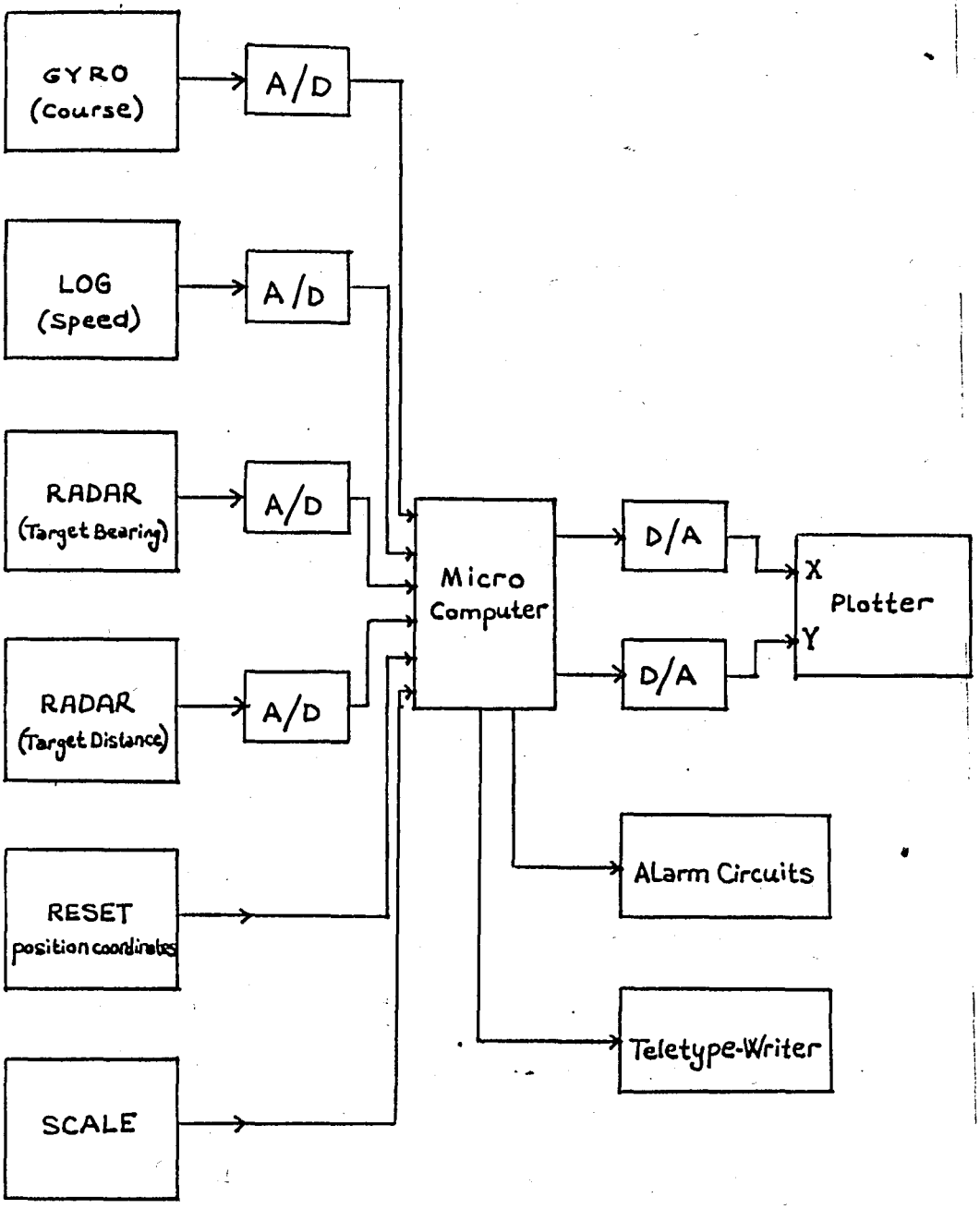


Fig. 3-1 Block Diagram of the Microprocessor Based DRT.

the plotting. This position should be chosen in according to the route of our ship. For example, the reference position should be at any desired place at north for a ship going southwards.

The sixteen-bit scale factor is required for the trigonometric calculations. The different scales can be used for various operations. Two additional ports are required to output the eight-bit x and eight-bit y coordinates to the plotter. The digital outputs are converted to analog by eight-bit digital to analog converters.

The positions of the target and own ship are marked with different figures on the plotter surface. If the positions mentioned above are outside of the plotting area, alarm circuits inform us about the situation. The data about the ships can be printed and displayed by sending the course and the speed information signals to the teletype-writer.

CHAPTER 4
INTERFACE CIRCUITS

Input Circuits

Own ship's course and the bearing of the target are transmitted from the gyro and the radar, respectively. They are synchro signals. In order to get the digital representation of the angle, the shaft encoder may be used.

The Gray code is useful for shaft encoders because the change of only 1 bit for each increment eliminates false intermediate codes that could occur in natural binary conversion. Gray code is closely related to binary in which the bit-position does not signify a numerical weighting. Gray code is a unit distance code. The unit distance property means that in going from the coding for any integer I to the coding for I+1 only one bit changes, regardless of the value of I. This property is usefully employed in transferring a coded variable reliably between a transducer and an instrument input.

The general structure of an n-bit Gray code can be described by the following scheme:

1. Except for beginning and ending of the code the least significant bit (LSB) g_o alternates two zeros, two ones, two zeros etc., g_1 alternates four zeros, four ones, four zeros etc. and g_k alternates 2^{k+1} zeros, 2^{k+1} ones, 2^{k+1} zeros etc.

2. The first transition from 0 to 1 for bit g_{k+1} occurs right in the middle of the first string of ones for bit g_k.

The results of Gray code and natural binary code for optical shaft encoders with 4-bit resolution are illustrated in Fig.4-1. Note that, with the Gray code converter, there is only a 1-bit change at each transition. If the edge of a shaded area is slightly out of line, the coding will be in error by a small fraction of an LSB. In binary converter, however, all 4 bits change at once at the 180-degree and 360-degree transitions. If bit 2's shaded area were to end a little before from the 180-degree transition, the code, in a small region, would be 0011, indicating the 67.5 degree range. If the other shaded areas are out of line, there will be a total of 15 combinations of wrong range indication.

In this thesis an 8-bit shaft encoder was developed.

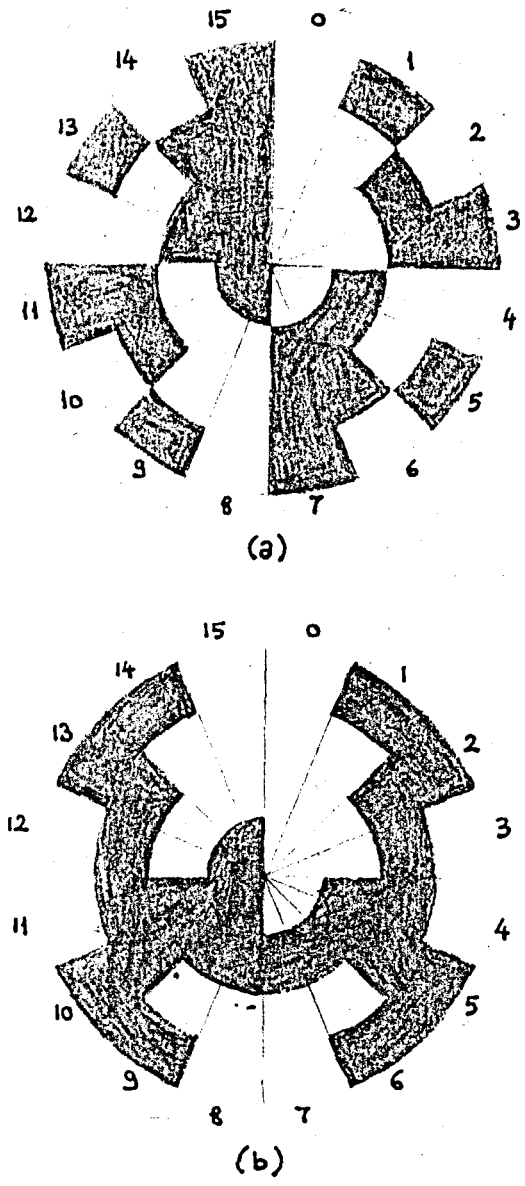


Fig.4-1. The results of Gray versus binary encoding. a) Binary encoding, b) Gray code encoding.

This encoder divides one revolution of its shaft into 256 parts. The angle of each part is 45/32 degree as shown in Fig. 4-2.

In order to perform the calculations in the MPU, the Gray code is converted to the conventional binary code by software. The conversion from the Gray code to the binary code can be simply formulated as follows.[6] Let

$b=b_n b_{n-1}\cdots b_2 b_1 b_0$ conventional binary number and

$g=g_n g_{n-1}\cdots g_2 g_1 g_0$ Gray code equivalent

Then

$$b_n=g_n$$

$$b_{n-j}=\oplus\sum_{k=n}^{k=n-j} g_k=g_n \oplus g_{n-1} \oplus\cdots\oplus g_{n-j}$$

where the operator $\oplus$ signifies binary addition without carry, i.e., exclusive or operation. The binary MSB will be the same as the Gray code MSB. Then, continuing to read from MSB to LSB, if the next bit is 1, the next binary bit is the complement of the previous binary bit. For example, Gray code 0111000111 becomes 0101111010 in binary as shown below:

Gray code 0 1 1 1 0 0 0 1 1 1

Binary 0→1→0→1→1→1→1→0→1→0

The coding wheel in Fig. 4-2 is used in an instrument as shown in Fig. 4-3. The output signal of this device is own ship course input to the system.

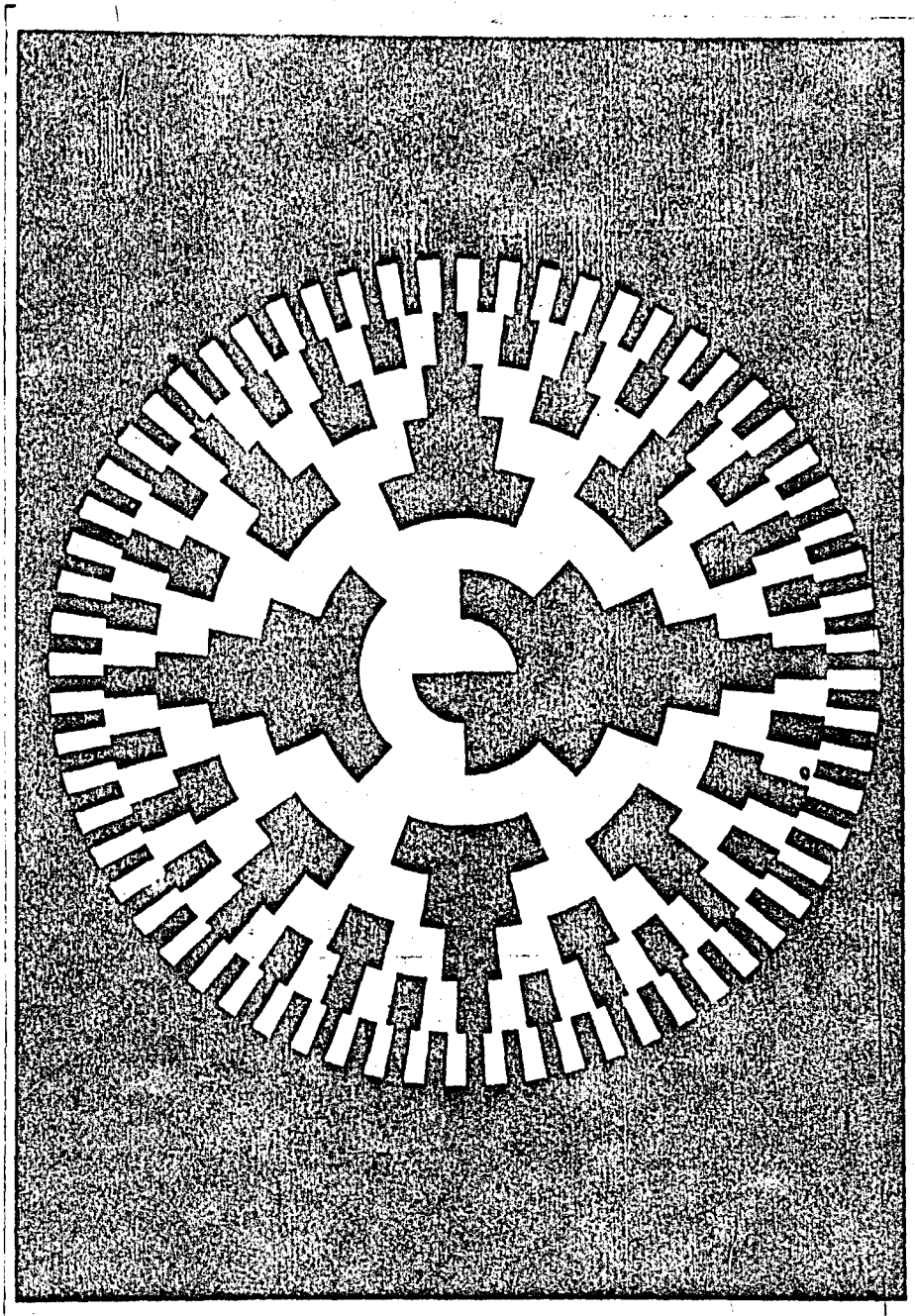


Fig.4-2. Eight-bit Optical Shaft Encoder.

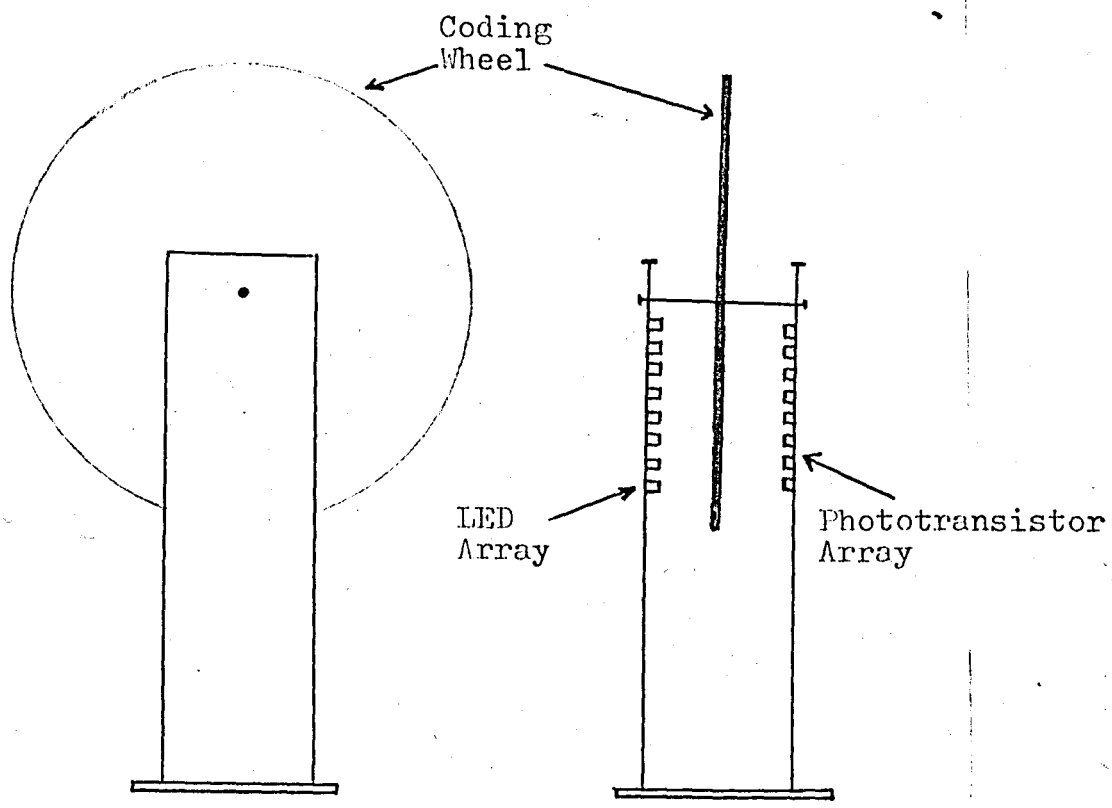


Fig. 4-3. Shaft Encoder Instrument.

The position of the wheel is detected by the photo-transistors with the circuit in Fig.4-4.

Some current flows through the illuminated photo-transistor. The voltage across the emitter resistor is compared with a reference level by the LM 339. The TTL level output of the comparator IC is fed to the PIA port programmed as input. The adjusment of the shaft encoder can be made by the 47 K potentiometers.

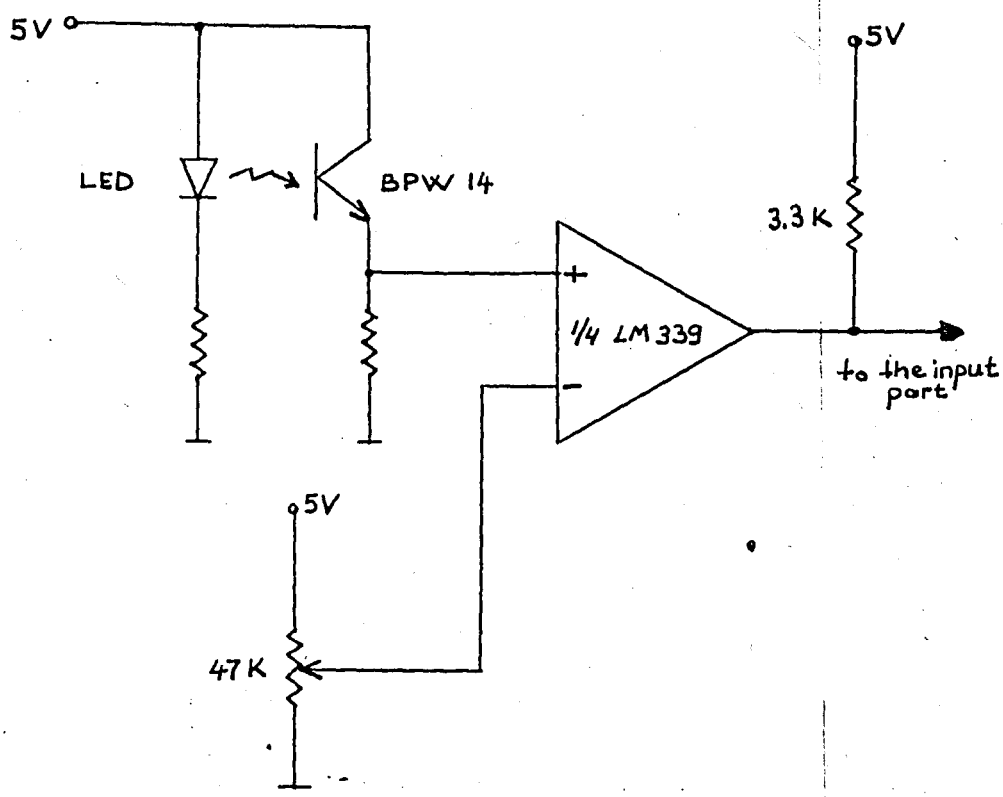


Fig. 4-4 A LED-Phototransistor Pair from the Array.

The other inputs to the system are; own ship's speed, target bearing, target distance, reference coordinates and the scale factor. These input signals are realized by switches except the scale factor. The scale factor is placed in a memory location because there is not one more port in the

system. Each of the signals above occupies an 8-bit port of the PIA's. The target bearing signal is accepted as Gray coded. It is converted to the binary code by software.

Output Circuits

The position coordinates calculated by the microcomputer are transmitted via the 6821 PIA are in 8-bit digital form. A and B ports of the PIA hold the X and Y coordinates respectively. The 8-bit digital data are converted to analog form by MC 1408L8 digital-to-analog converter. The output current of the MC 1408L8 is a linear product of an 8-bit digital word and an analog reference voltage. The 741 operational amplifier is used to obtain the voltage level in proportion to the analog current of the output of the D-to-A converter. Fig.4-5 shows the D-to-A converter circuit.

There are two digital to analog converter circuits, one for the horizantal axis and the other for the vertical axis. The output voltages of the operational amplifiers are applied to the inputs of the XY Plotter.

The voltage level at the output of the D to A converter is chosen as 1 volt when the digital word is FF in

hexadecimal notation.

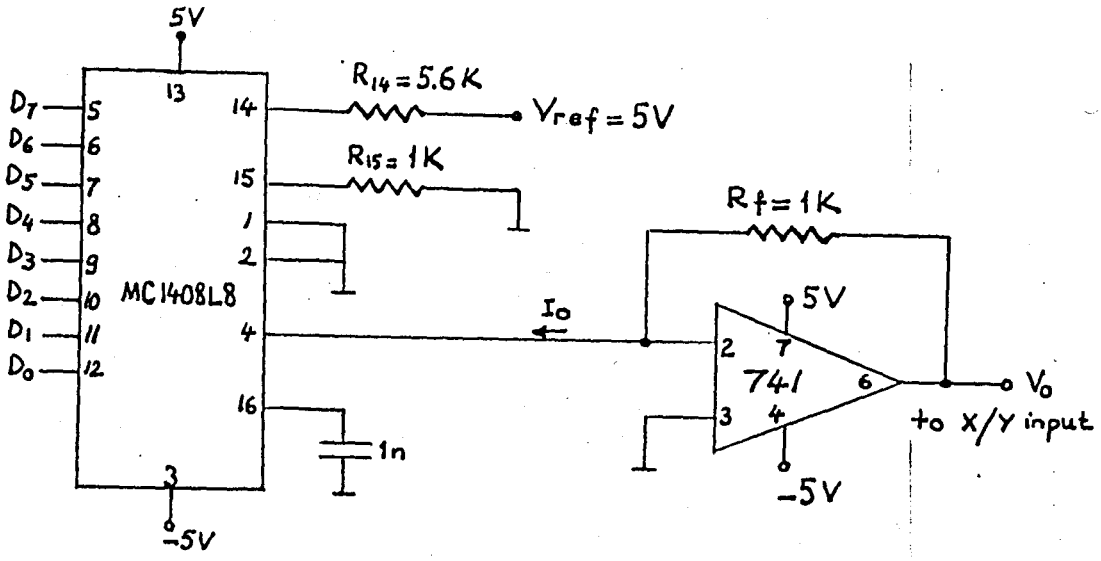


Fig. 4-5 Digital to Analog Converter Circuit.

In order to calculate the component values the following equations should be used:

The output current of the MC 1408L8 is:

$$I_o = K \cdot \left[\frac{D_7}{2} + \frac{D_6}{4} + \frac{D_5}{8} + \frac{D_4}{16} + \frac{D_3}{32} + \frac{D_2}{64} + \frac{D_1}{128} + \frac{D_0}{256} \right]$$

where $$K = \frac{V_{ref}}{R_{14}}$$

When all the bits of the word are logic ones:

$$I_o = K \frac{255}{256}$$

The output voltage of the op-amp is:

$$V_o = I_o \cdot R_f$$

If R_f is taken as 1 K, then

$$I_o = \frac{V_o}{R_L} = \frac{1}{1 \cdot 10^3} = 1 \text{ mA.}$$

$$K = \frac{256}{255} \cdot 1 \cdot 10^{-3} = 1.0039 \text{ mA.}$$

$$R_{14} = \frac{V_{ref}}{K} = \frac{5}{1.0039} = 4.98 \text{ K.}$$

A 5.6 K resistor is used as R_{14} to get a lower voltage than 1 volt at the output.

$$V_o = \frac{V_{ref}}{R_{14}} \cdot R_f \cdot \frac{255}{256} = \frac{5}{5.6} \cdot 1 \cdot \frac{255}{256} = 0.89 \text{ V.}$$

The pen drop/raise circuit is shown in Fig. 4-6. The CA2 pin of the MC 6821 PIA is connected to the base of the transistor Q_1. Q_1 and Q_2 are used as an electronic switch. The microcomputer can drop or raise the pen of the XY plotter. At the beginning the pen is lifted up. When the pen holder goes to the appropriate X and Y coordinates a high level voltage is applied to the base of Q_1 by CA2 and the pen drops down. CA2 goes low and the pen is raised when the drawing is finished.

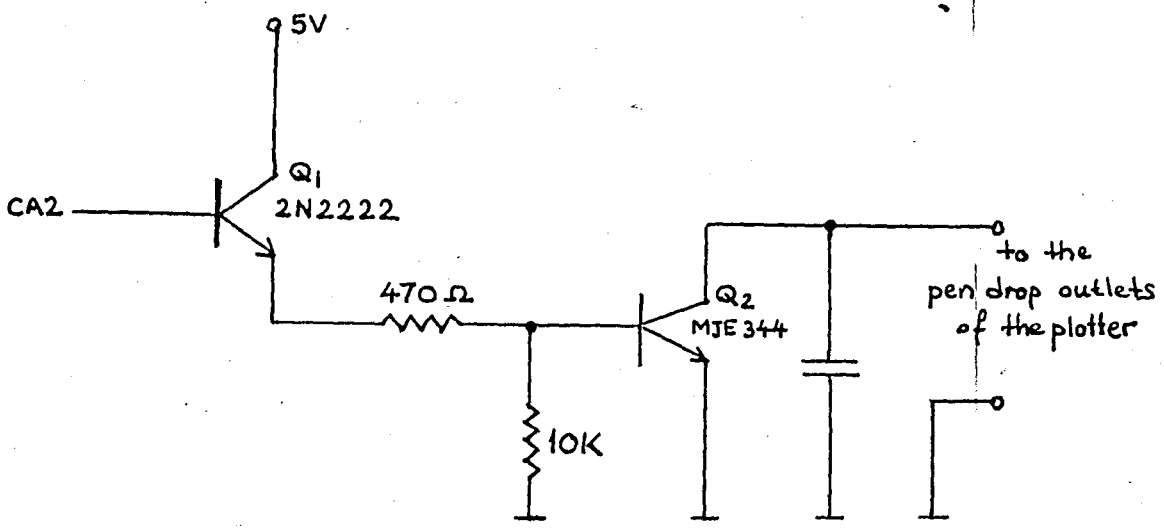


Fig.4-6 Pen Drop/Raise Circuit.

The alarm circuits are used to generate the appropriate signals when the position of the marker pen is outside of the map. One of the two alarm signals indicates that the position of the target is outside and the other warns us for our ship. These signals can be used for automatic changing of the paper in further developments. Fig.4-7 shows the alarm circuit..

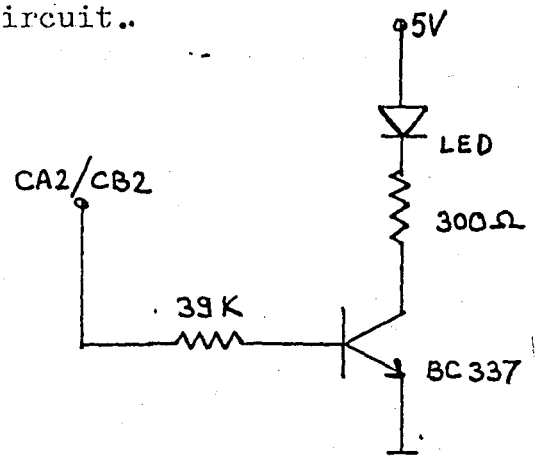


Fig.4-7 Alarm Circuit.

Timing Circuit

The positions of the ship are marked at regular intervals. Timing circuit generates an interrupt signal to the CPU when the plotting time es reached. The processor executes the interrupt service routine and the position of the ship is marked on the paper.

In Fig.4-8 the 555 timer is connected for astable operation.

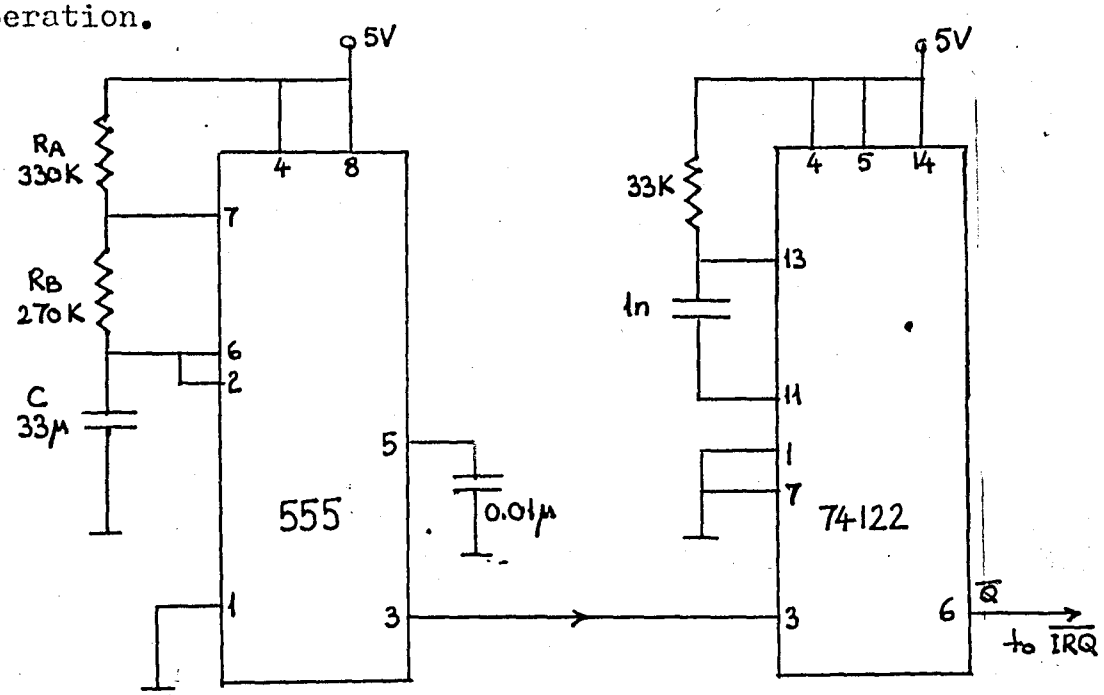


Fig.4-8 Timing Circuit

The period of the output signal is

$$T = 0.693\ (R_A + 2R_B) \cdot C$$

$T = 0.693\ (330 \cdot 10^3 + 2 \cdot 270 \cdot 10^3) \cdot 33 \cdot 10^{-6}$

$T = 19.9$ s.

The output of the 555 is fed to the 74122 Monostable Multivibrator to get the 10 μs. length interrupt request pulses. The waveforms are shown in Fig.4-9

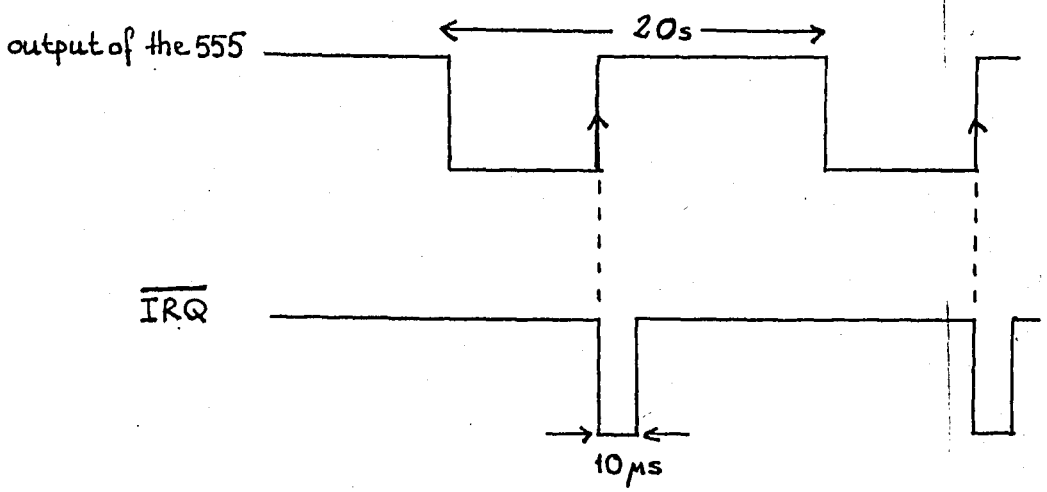


Fig.4-9 Waveforms

The time intervals between the position markings may be changed by using different resistors and capacitors in the timing circuit. Variable plotting frequencies are useful to mark the positions of the ships having rapid variations in their courses. If a 500 K potentiometer is used instead of 270 K resistor the plotting interval may be adjusted in the range of 7-30 s. The scale number should be calculated after the adjustment of the time interval.

CHAPTER 5
SOFTWARE DEVELOPMENT

The program of the system includes two parts: Main Program and Interrupt Service Routine. In this chapter the two parts of the program will be described completely.

Main Program

The processor will begin to execute the Main Program when the system is turned on. The program initializes the PIA's as shown in Fig.5-1. The situations of the PIA's are as follows:

DF00	P1ORA	X output to the plotter.
DF01	P1CRA	Pen drop signal (CA2)
DF02	P1ORB	Y output to the plotter.
DF03	P1CRB	Own ship alarm indicator (CB2)
DF04	P2ORA	Own course input
DF05	P2CRA	Target alarm indicator (CA2)
DF06	P2ORB	Own speed input
DF07	P2CRB	Spare alarm (CB2)
DF08	P3ORA	Reset x input

DF09	P3CRA	
DF0A	P3ORB	Reset y input
DF0B	P3CRB	
DF0C	P4ORA	Target Bearing input
DF0D	P4CRA	
DF0E	P4ORB	Target Distance input
DF0F	P4CRB	

After initialization, data present on peripheral lines programmed as inputs are transferred to the memory. These are, own course, own speed, target bearing, target distance and reset or reference position inputs. One another input to the system is the Scale. It would be desirable to have selectable scales. The scale to be used is determined by a combination of the size of the plotting surface, 10" by 10", and the fact that an 8-bit D to A converter is selected. Using a scale of 500 yards per inch and a sample time of 20 seconds results in a scale factor 0.56666 which, when multiplied by the speed of the ship, gives the number of bits to output for ship travel in a 20 second period of time. The following equation shows this calculation:

$$S \frac{\text{Miles}}{\text{Hour}} \times 2000 \frac{\text{Yards}}{\text{Mile}} \times \frac{1}{3600} \frac{\text{Hours}}{\text{Second}} \times \frac{1}{500} \frac{\text{Inches}}{\text{Yard}}$$

$$\times 20 \text{ Seconds} \times 25.5 \frac{\text{bits}}{\text{inch}} = 0.56666 \times S \text{ Bits}$$

where S is the speed of the ship. Because an eight-bit converter is used, 1 inch corresponds $\frac{255}{10}=25.5$ bits on the plotting surface.

The calculations for the target needs another scale. Target Scale is calculated by a multiplication subroutine as follows:

$$100 \times D \text{ yards} \times \frac{1}{500} \frac{\text{Inches}}{\text{Yard}} \times 25.5 \frac{\text{bits}}{\text{inches}} = D \times 5.1 \text{ Bits}$$

In this example 1 inch corresponds 500 yards, but in different operations the various scales can be used i.e. for a man-overboard operation 1 inch→200 yards, for a gunnery operation 1 inch→694 yards.

The own course and target bearing are in Gray code and must be converted to binary. The resulted binary number is between 0-255. In order to find the real course between 0-359, the binary number is multiplied by $\frac{360}{256}=1.4265$. The program clears the target flag (TARGET) and starts to the calculations for own ship. The first duty is to find the quadrant of the course. After determining the quadrant, the course will be an angle between $0\text{-}90^{\circ}$.

Since the object of these calculations is taking polar coordinates in and outputing cartesian coordinates,

it is necessary to do some trigonometric operations. Because the inputs are converted in whole degrees it is possible to write a program which makes all necessary operations with only a table of sines from 0^{o} to 90^{o}. The use of a look-up table increases the speed and provides reduction in instructions.

After reducing the angle to less than 90^{o} the table is accessed to get the sine, then the angle is subtracted from 90^{o} and the sine table again accessed, but this time to get the cosine of the original angle.

Because a 16 bit binary number is used to represent the sine accurately, it is necessary to utilize a 16 bit by 16 bit multiplication routine. The scale factor, as a 16 bit binary number, is first multiplied by sine. The scaled sine is multiplied by the speed in order to get the y component of the departure of own ship. The same algorithm is repeated for x axis. Therefore, x and y components of the movement in unit time, is ready for further calculations. The flow charts of the algorithms above as shown in Fig.5-12.

The program returns back to "AGAIN" point and repeats same algorithm by loading the target bearing and distance to the working registers. During this part of the program Target

Scale is used as the scale factor in calculations. At the end of this routine the x and y components of the distance between own ship and the target are determined and stored.

The algorithm of the main program is completed by clearing the interrupt mask bit. The processor returns to the "BEGIN" point and reads all the inputs again. Since the execution time of the main program is very short, the variations at the all inputs are detected immediately. The calculated values are corrected with the new data at the inputs. When there is no interrupt request signal the system executes the main program repeatedly. The x and the y components of the departure of both own ship and the target are renewed by the latest input values.

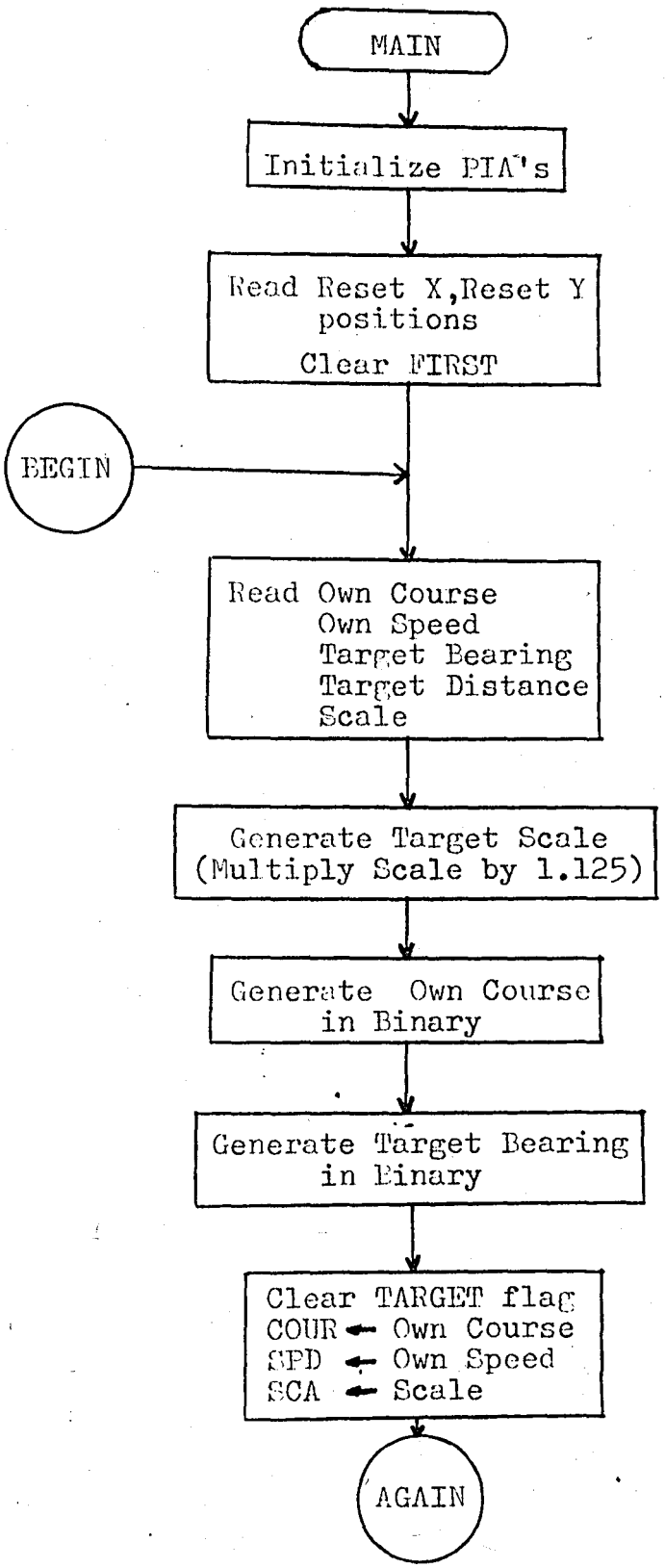

MAIN
Initialize PIA's
Read Reset X,Reset Y positions
Clear FIRST
BEGIN
Read Own Course
Own Speed
Target Bearing
Target Distance
Scale
Generate Target Scale (Multiply Scale by 1.125)
Generate Own Course in Binary
Generate Target Bearing in Binary
Clear TARGET flag
COUR ← Own Course
SPD ← Own Speed
SCA ← Scale
AGAIN

Fig. 5-1

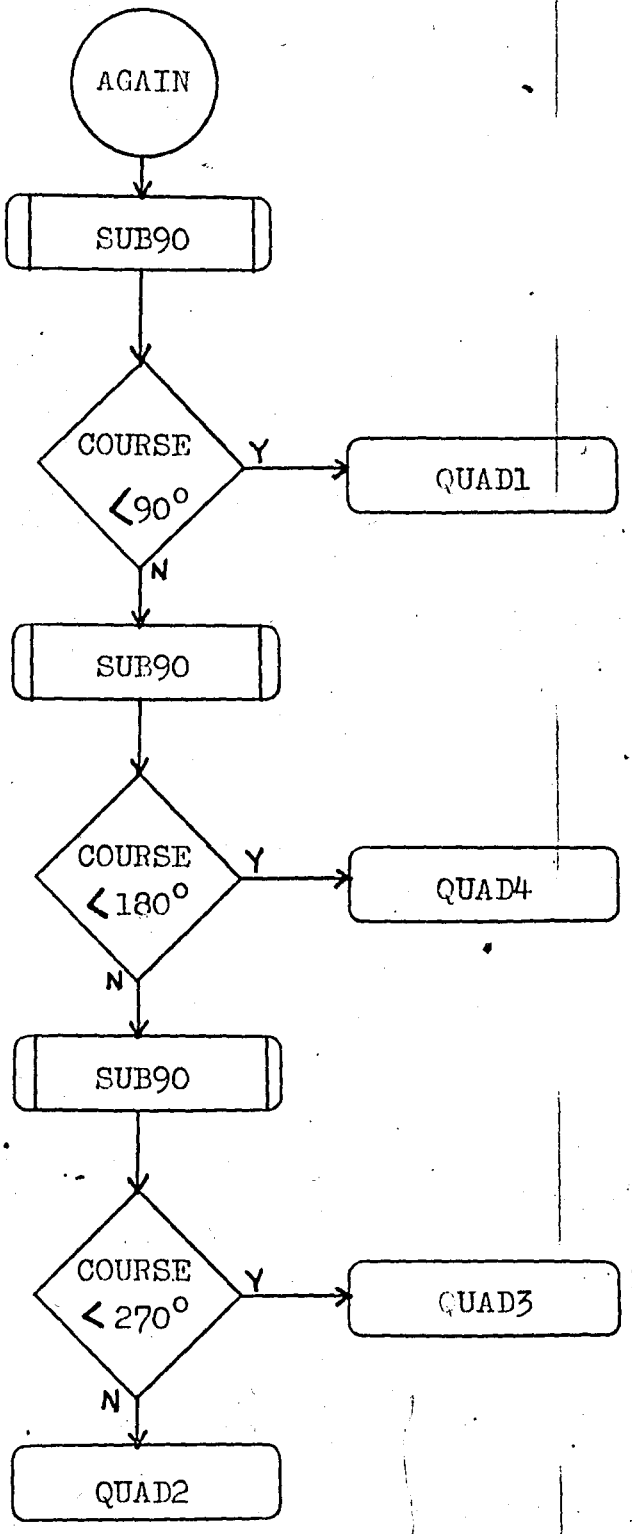
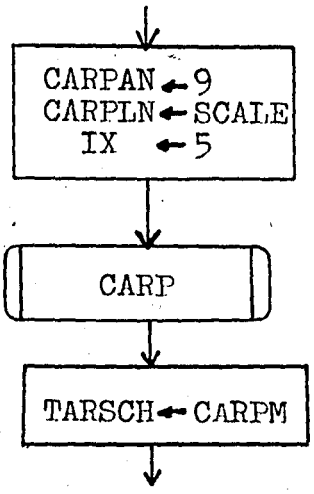

AGAIN
SUB90
COURSE
<90°
Y
QUAD1
N
SUB90
COURSE
<180°
Y
QUAD4
N
SUB90
COURSE
<270°
Y
QUAD3
N
QUAD2

Fig. 5-2

Generation of target scale:



Generation of own course/target bearing:

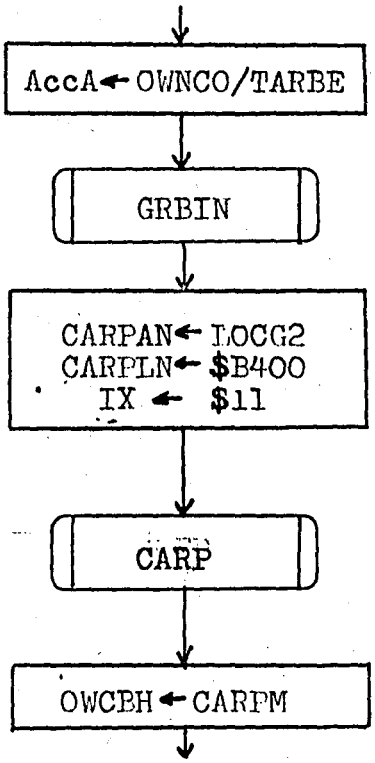


Fig. 5-3

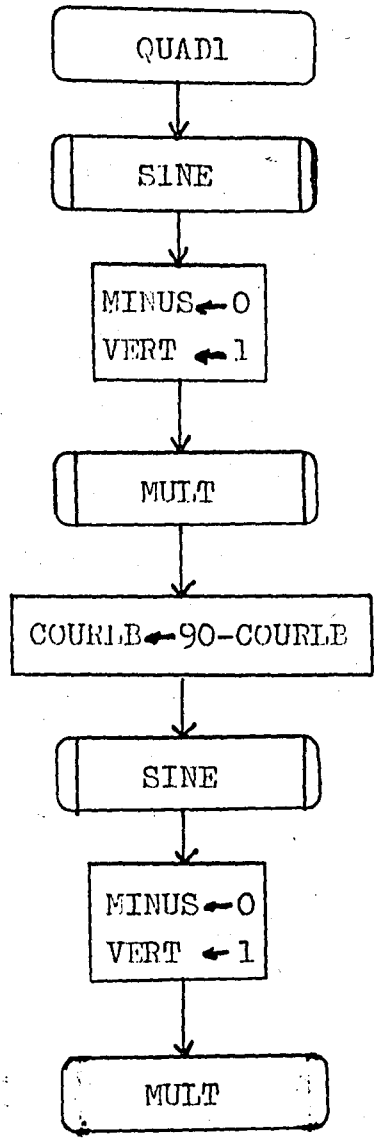

QUAD1
SINE
MINUS←0
VERT ←1
MULT
COURLB←90-COURLB
SINE
MINUS←0
VERT ←1
MULT

Fig. 5-4

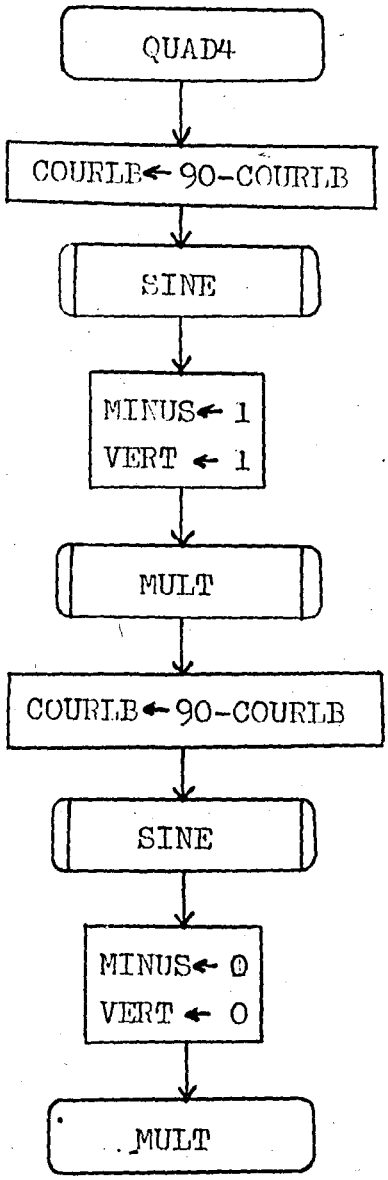

QUAD4
COURLB ← 90-COURLB
SINE
MINUS ← 1
VERT ← 1
MULT
COURLB ← 90-COURLB
SINE
MINUS ← 0
VERT ← 0
MULT

Fig. 5-5

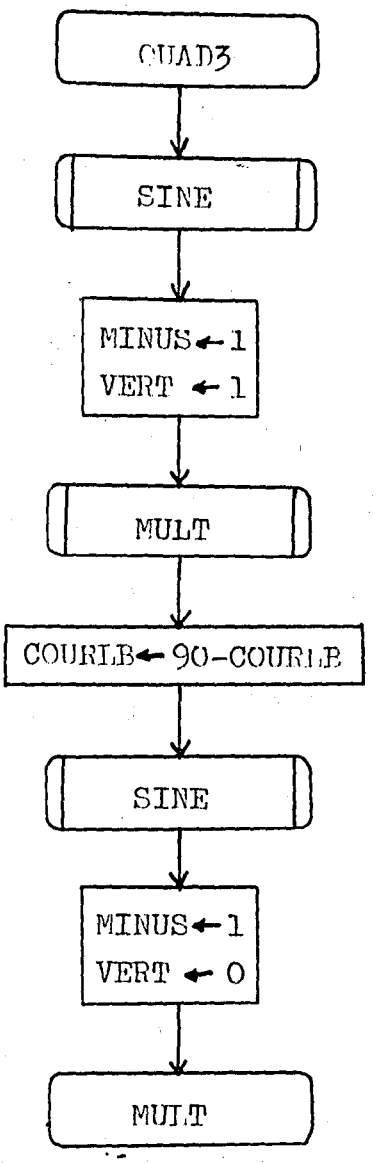

QUAD3
SINE
MINUS ← 1
VERT ← 1
MULT
COURLB ← 90-COURLB
SINE
MINUS ← 1
VERT ← 0
MULT

Fig. 5-6

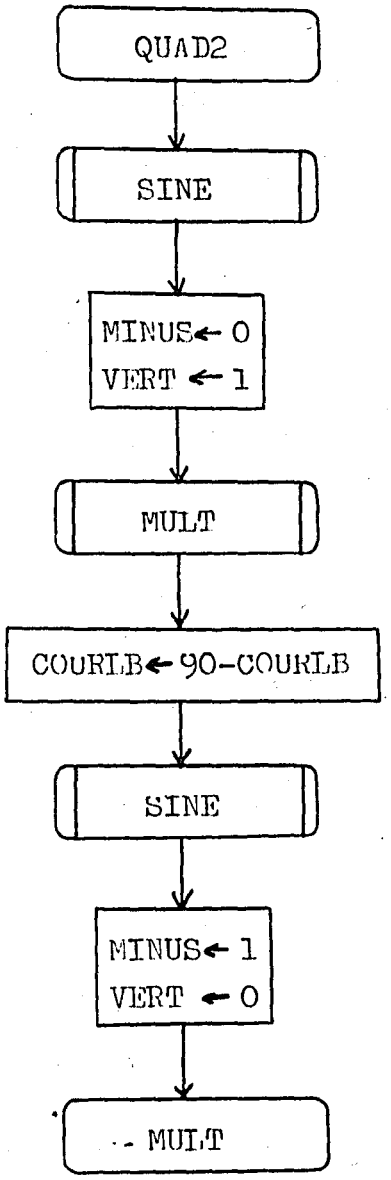
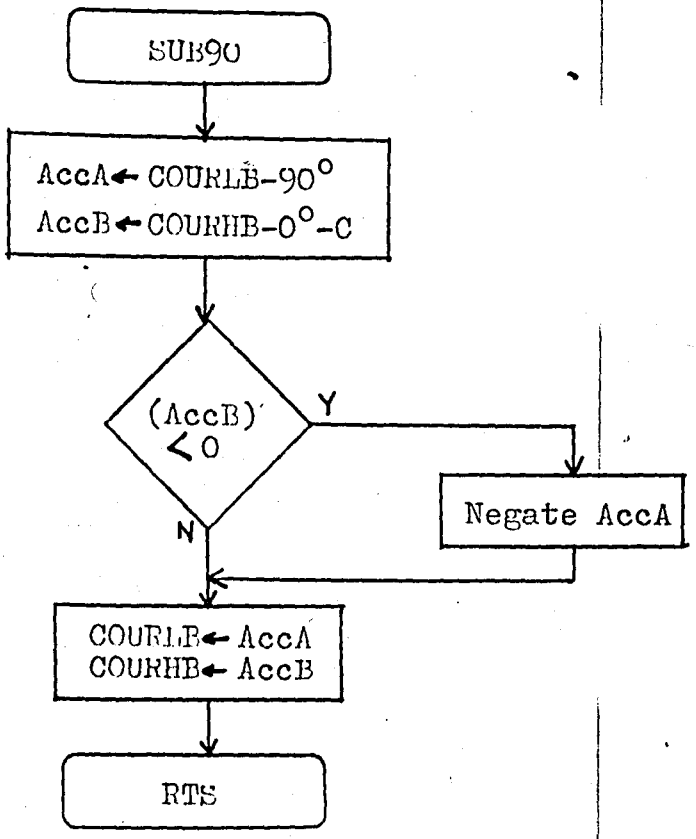

QUAD2
SINE
MINUS← 0
VERT ← 1
MULT
COURLB← 90-COURLB
SINE
MINUS← 1
VERT ← 0
MULT

Fig. 5-7


SUB90
AccA← COURLB-90°
AccB← COURHB-0°-C
(AccB) < 0
Y
N
Negate AccA
COURLB← AccA
COURHB← AccB
RTS

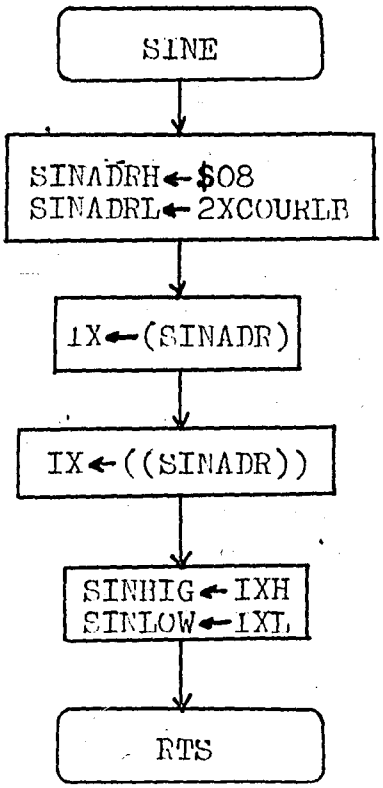

SINE
SINADRH← $08
SINADRL← 2XCOURLB
IX← (SINADR)
IX← ((SINADR))
SINHIG← IXH
SINLOW← IXL
RTS

Fig. 5-8

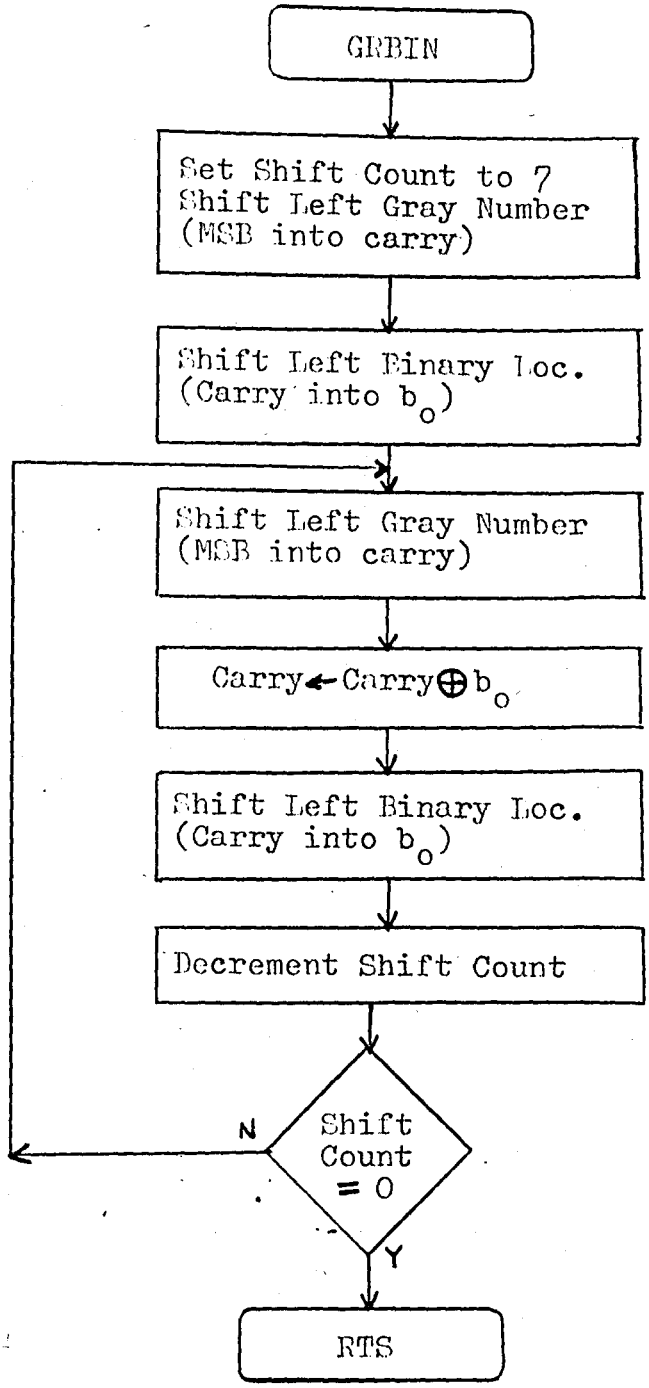

GRBIN
Set Shift Count to 7
Shift Left Gray Number
(MSB into carry)
Shift Left Binary Loc.
(Carry into b_o)
Shift Left Gray Number
(MSB into carry)
Carry←Carry⊕b_o
Shift Left Binary Loc.
(Carry into b_o)
Decrement Shift Count
Shift
Count
= 0
N
Y
RTS

Fig. 5-9

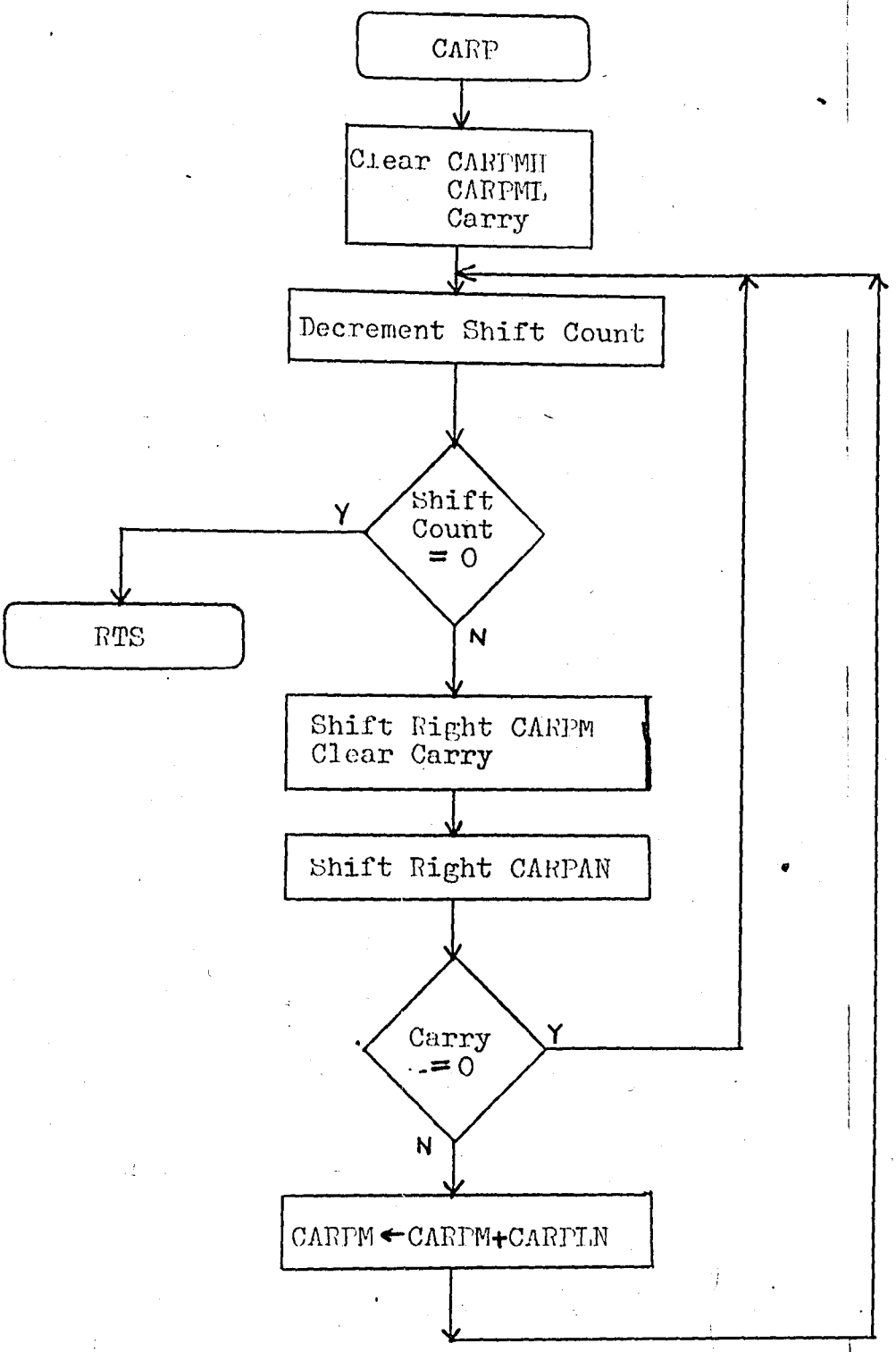

CARP
Clear CARPMH
CARPML
Carry
Decrement Shift Count
Shift
Count
= 0
Y
N
RTS
Shift Right CARPM
Clear Carry
Shift Right CARPAN
Carry
= 0
Y
N
CARPM ← CARPM+CARPLN

Fig. 5-10

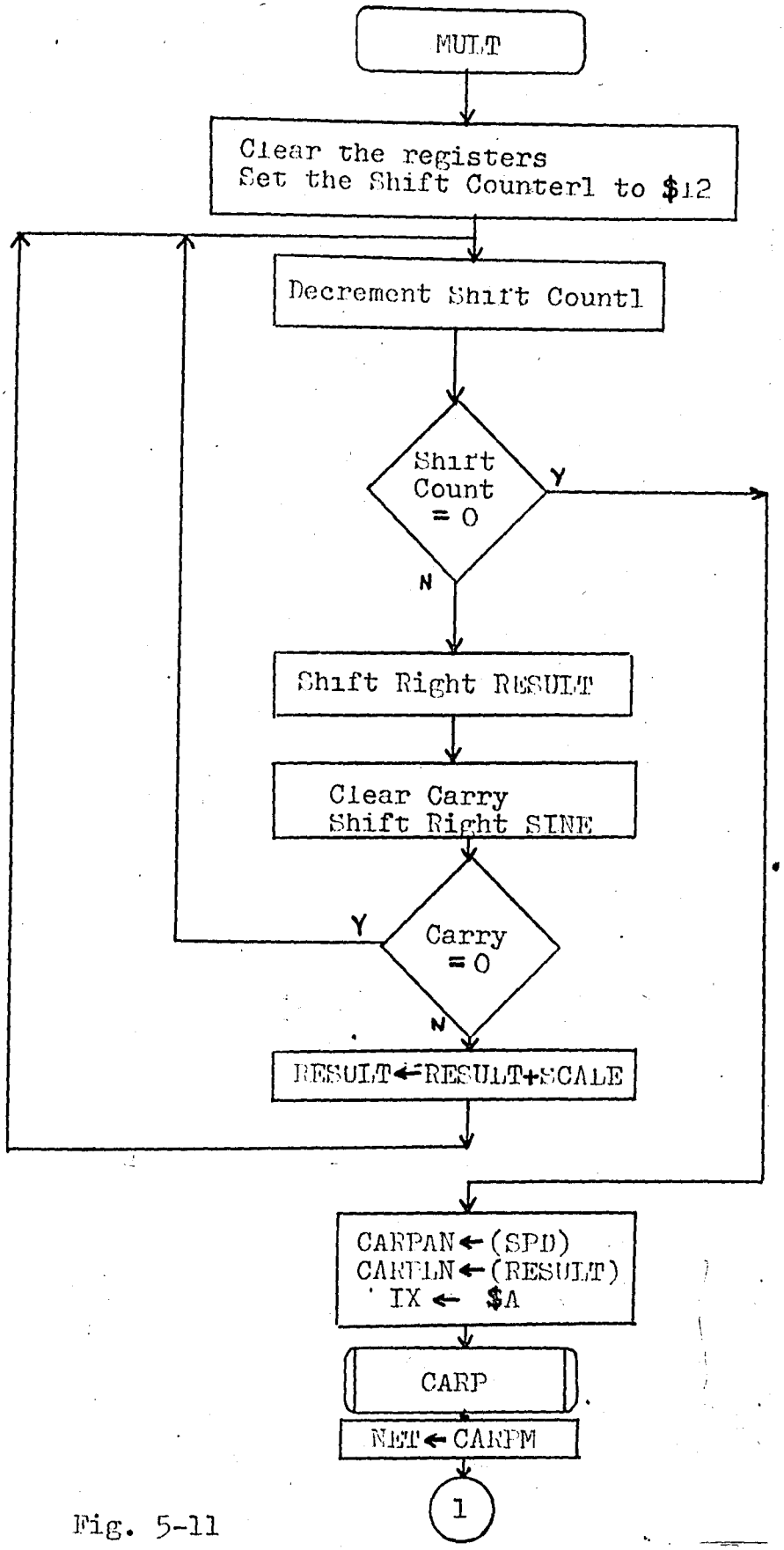

MULT
Clear the registers
Set the Shift Counterl to $12
Decrement Shift Countl
Shift Count = 0
Y
N
Shift Right RESULT
Clear Carry
Shift Right SINE
Carry = 0
Y
N
RESULT←RESULT+SCALE
CARPAN←(SPD)
CARPLN←(RESULT)
IX ← $A
CARP
NET←CARPM
1

Fig. 5-11

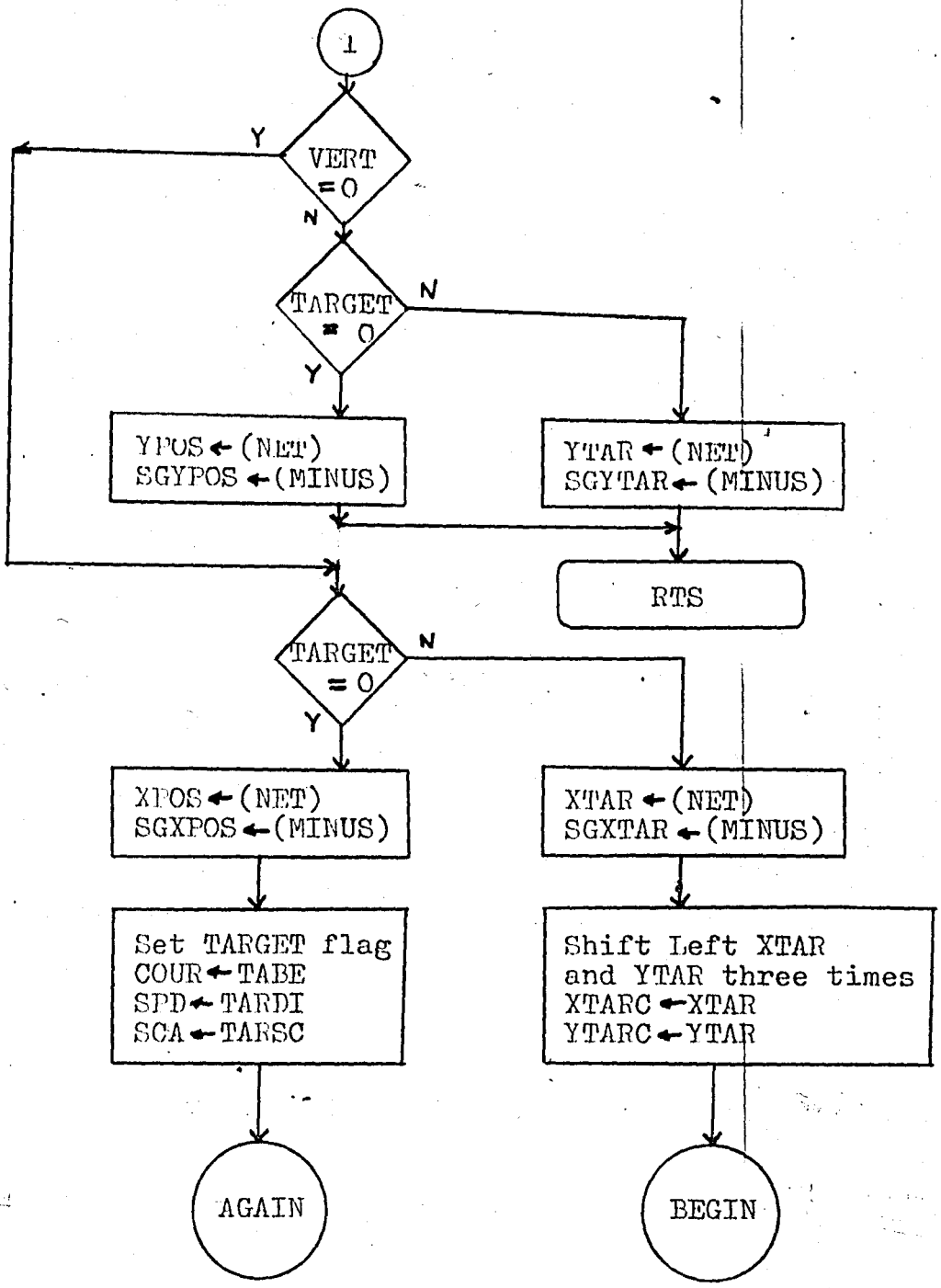

1
VERT = 0
Y
N
TARGET = 0
N
Y
YPOS ← (NET)
SGYPOS ← (MINUS)
YTAR ← (NET)
SGYTAR ← (MINUS)
RTS
TARGET = 0
N
Y
XPOS ← (NET)
SGXPOS ← (MINUS)
XTAR ← (NET)
SGXTAR ← (MINUS)
Set TARGET flag
COUR ← TABE
SPD ← TARDI
SCA ← TARSC
Shift Left XTAR
and YTAR three times
XTARC ← XTAR
YTARC ← YTAR
AGAIN
BEGIN

Fig. 5-12

Interrupt Service Routine

When the interrupt request signal is detected, the processor jumps to the service routine. The binary coded information about the course and the speed of our ship are converted to Binary Coded Decimal (BCD) digits. The data about own ship are transmitted to the teletype in the following form:

OWN COURSE : 356

OWN SPEED : 015

where the unit of the course is degree and the unit of the speed is mile per hour (knot).

The coordinates of the position of our ship are determined by the addition of the departure component to the reference coordinate if the movement is in positive direction, otherwise the departure is subtracted from the reference coordinate. The position of the ship is examined in order to learn whether it is inside of the plotter boundaries. If the position is outside of the plotter, CB2 output of the PIA 1 is set to inform the alarm circuit and the processor returns from interrupt service routine. If the position is plottable, a square figure is drown by PLOTME subroutine.

The reference for the target position is the position of our ship. The coordinates of the target position are calculated with the x and y components of the distance. These components are added to the coordinates of our ship or subtracted from them. If the distance between the target and our ship is zero, the system thinks that there is not any target ship in the area and returns from the interrupt routine.

After calculating the target position, it is checked if the position is inside of the plotter surface. If it is outside, CA2 pin of the PIA 2 is set in order to transmit an alarm signal.

During the first pass through this routine, the course and the speed of the target can not be determined since there is not any knowledge about the previous position. In order to understand whether this is the first pass or not, the "FIRST" flag is checked. The situation of this flag is complemented during the first pass. During the second or any other passes, the difference between the present and the former position stored before is calculated. After some trigonometric operations the course and the speed of the target are ready to be printed on the teletype paper in the following form:

TARGET BEARING : 073

TARGET DISTANCE : 01500

TARGET COURSE : 187

TARGET SPEED : 021

where the unit of the distance is yard. This routine is finished by drawing a diamond shape on the position of the target. The interrupt service routine flowcharts are shown in Fig.5-13 to 5-25.

During the target course and speed calculations, Newton-Raphson method is used for computing the square-roots. The general formula of this method is[8]:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \qquad n = 0,1...$$

Let $x = c^{1/2}$, hence $f(x) = x^2 - c = 0$

$$f'(x) = 2x$$

and

$$x_{n+1} = x_n - \frac{x_n^2 - c}{2x_n} = 0.5(x_n - \frac{c}{x_n})$$

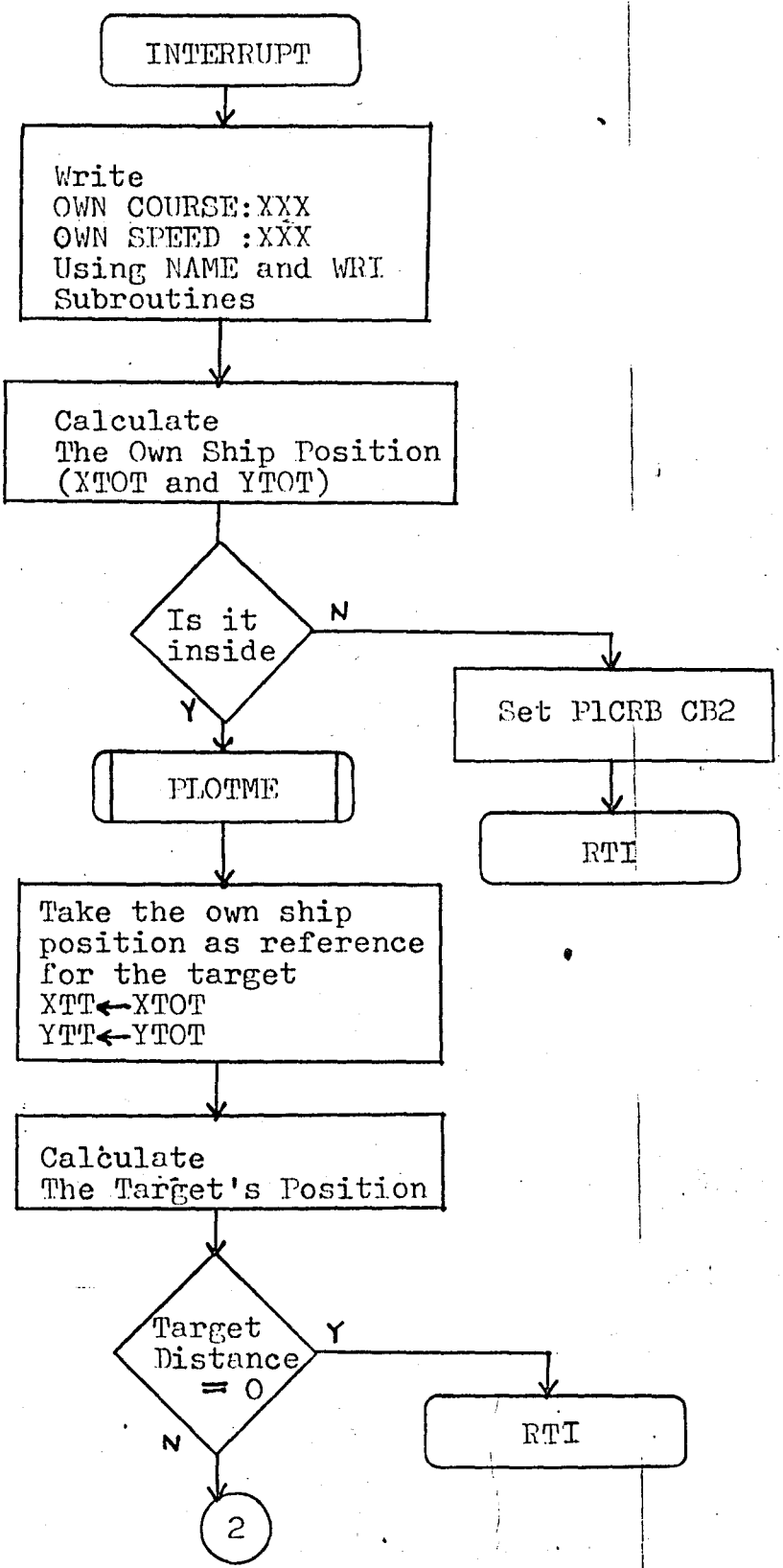

INTERRUPT
Write
OWN COURSE:XXX
OWN SPEED :XXX
Using NAME and WRI
Subroutines
Calculate
The Own Ship Position
(XTOT and YTOT)
Is it
inside
N
Y
Set P1CRB CB2
RTI
PLOTME
Take the own ship
position as reference
for the target
XTT←XTOT
YTT←YTOT
Calculate
The Target's Position
Target
Distance
= 0
Y
N
RTI
2

Fig.5-13

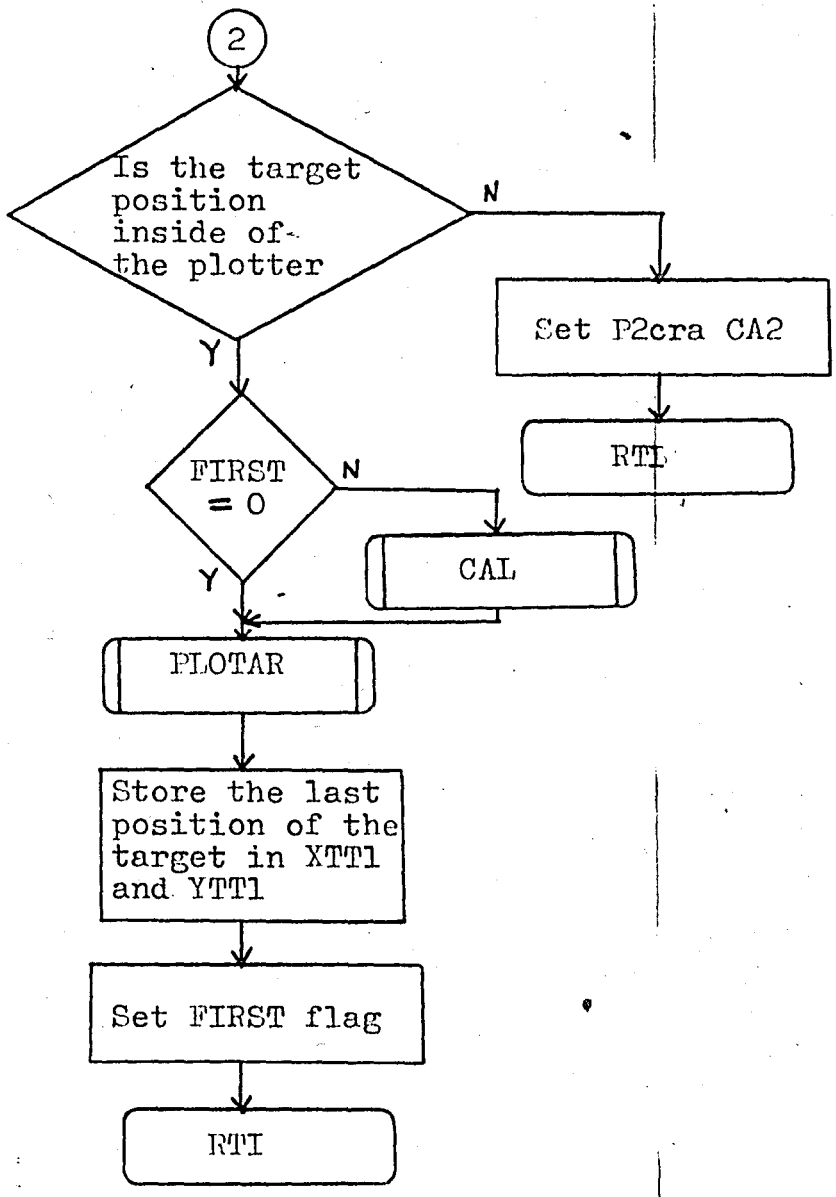

2
Is the target position inside of the plotter
N
Y
Set P2cra CA2
RTI
FIRST = 0
N
Y
CAL
PLOTAR
Store the last position of the target in XTT1 and YTT1
Set FIRST flag
RTI

Fig.5-14

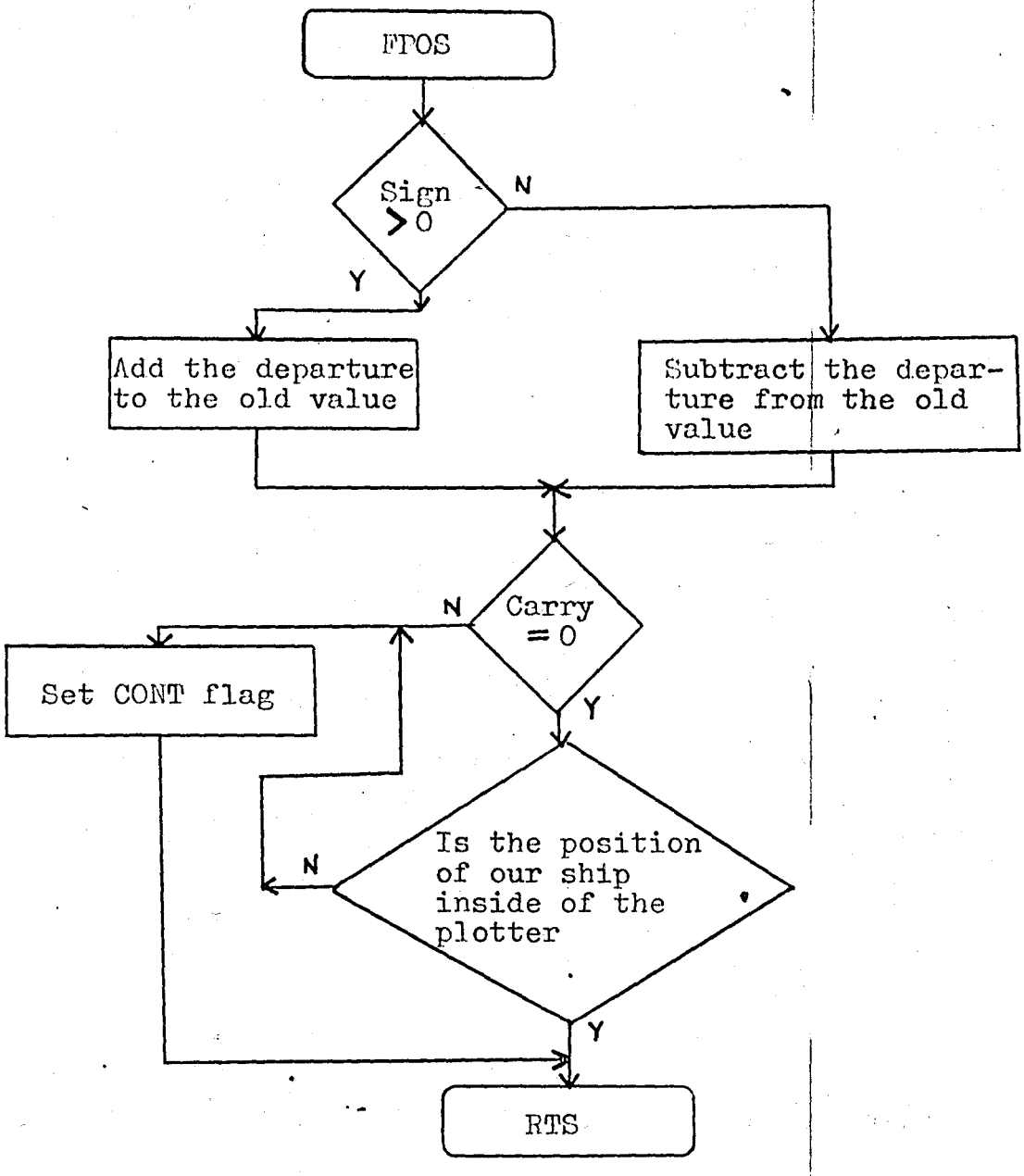

FPOS
Sign > 0
N
Y
Add the departure to the old value
Subtract the departure from the old value
Carry = 0
N
Y
Set CONT flag
Is the position of our ship inside of the plotter
N
Y
RTS

Fig.5-15

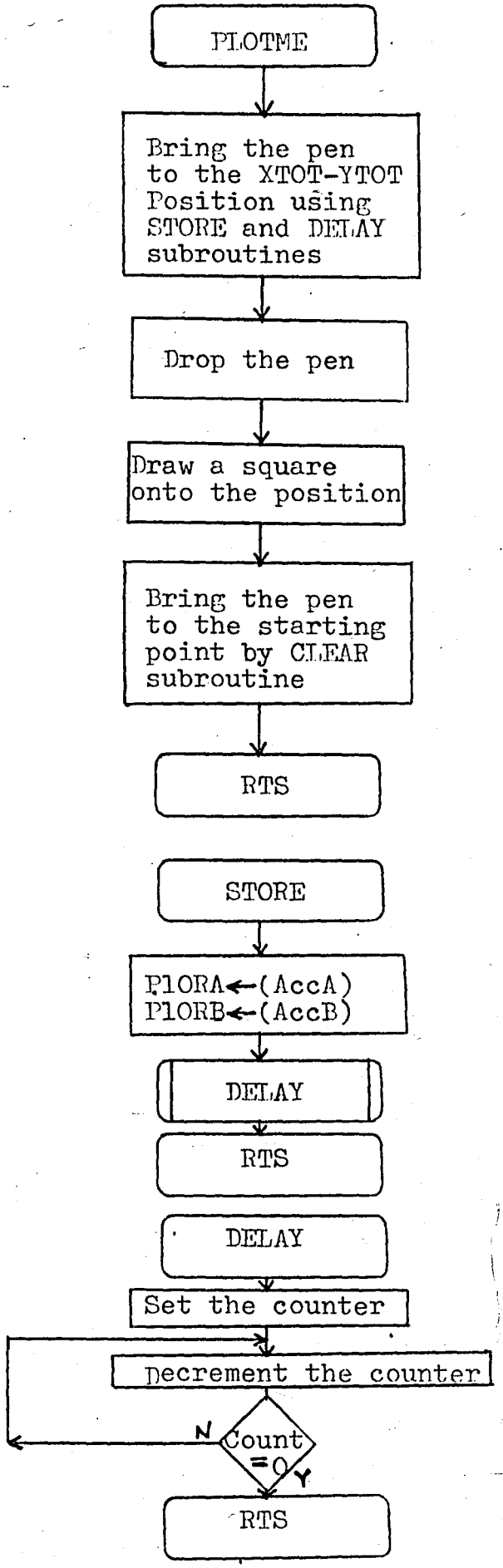

PLOTME
Bring the pen to the XTOT-YTOT Position using STORE and DELAY subroutines
Drop the pen
Draw a square onto the position
Bring the pen to the starting point by CLEAR subroutine
RTS
STORE
P1ORA←(AccA)
P1ORB←(AccB)
DELAY
RTS
DELAY
Set the counter
Decrement the counter
N
Count =0
Y
RTS

Fig.5-16

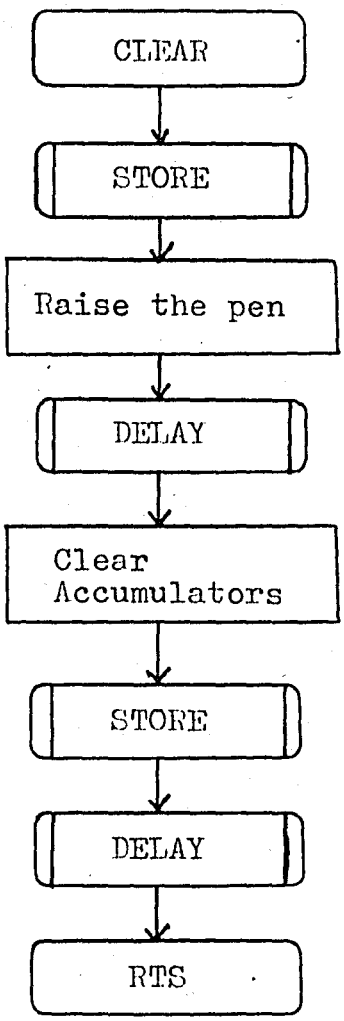

CLEAR
STORE
Raise the pen
DELAY
Clear
Accumulators
STORE
DELAY
RTS

Fig.5-17

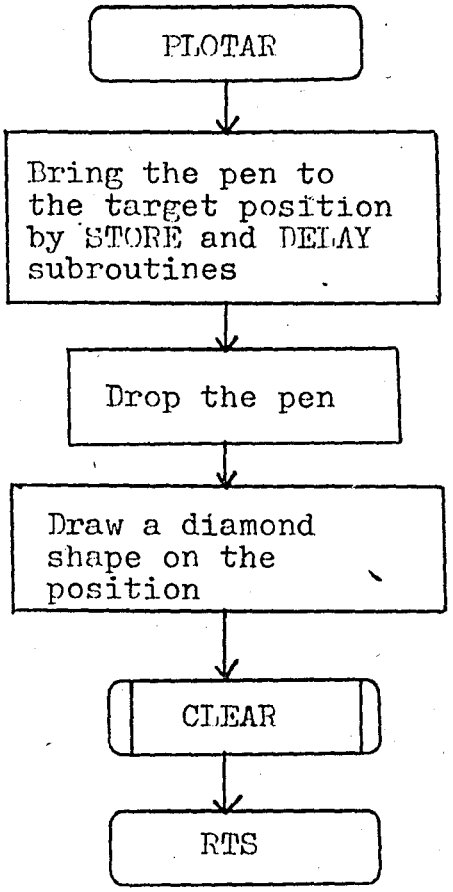

PLOTAR
Bring the pen to the target position by STORE and DELAY subroutines
Drop the pen
Draw a diamond shape on the position
CLEAR
RTS

Fig.5-18

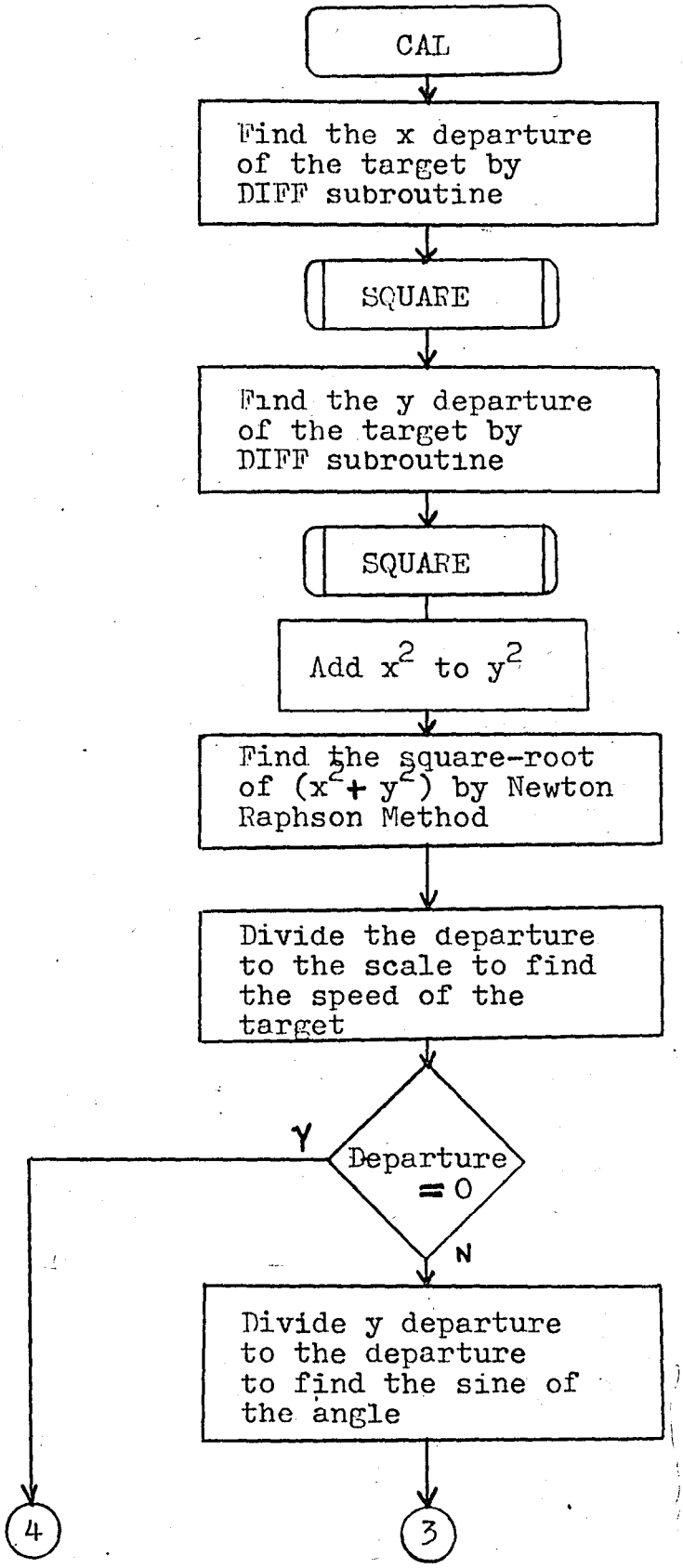
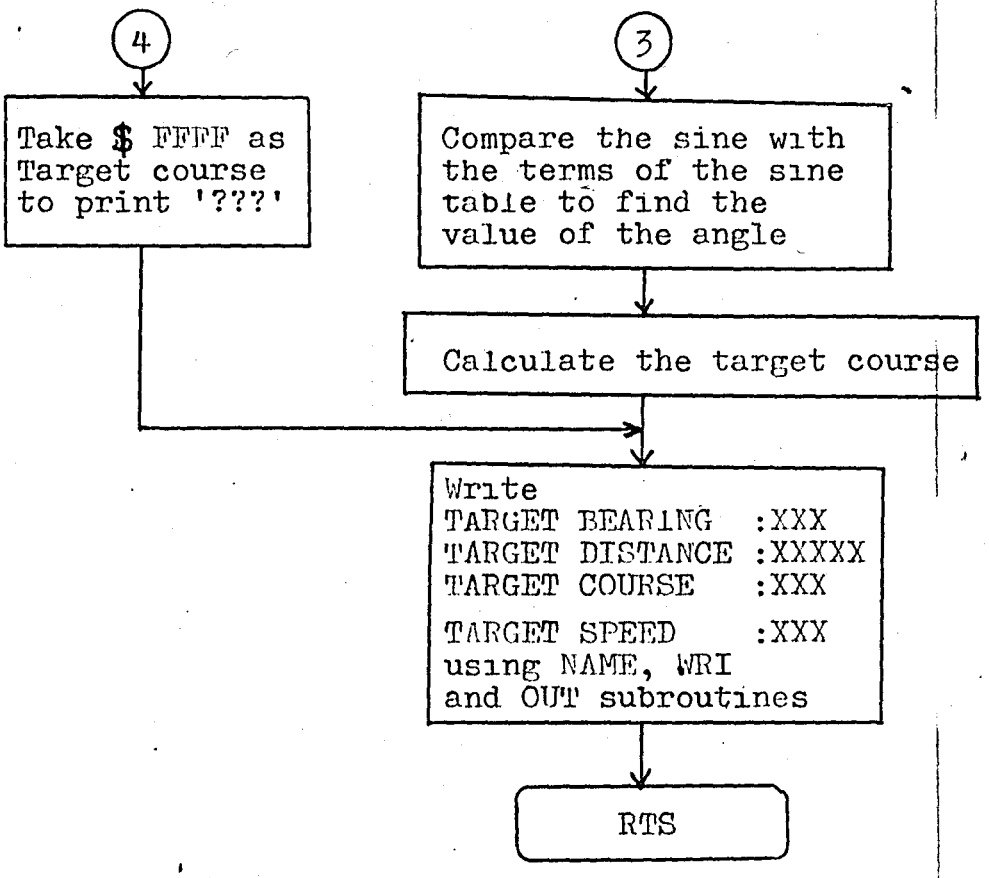

CAL
Find the x departure of the target by DIFF subroutine
SQUARE
Find the y departure of the target by DIFF subroutine
SQUARE
Add x^2 to y^2
Find the square-root of $(x^2 + y^2)$ by Newton Raphson Method
Divide the departure to the scale to find the speed of the target
Departure = 0
Y
N
Divide y departure to the departure to find the sine of the angle
4
3

Fig.5-19


4
Take $ FFFF as Target course to print '???'
3
Compare the sine with the terms of the sine table to find the value of the angle
Calculate the target course
Write
TARGET BEARING :XXX
TARGET DISTANCE :XXXXX
TARGET COURSE :XXX
TARGET SPEED :XXX
using NAME, WRI and OUT subroutines
RTS

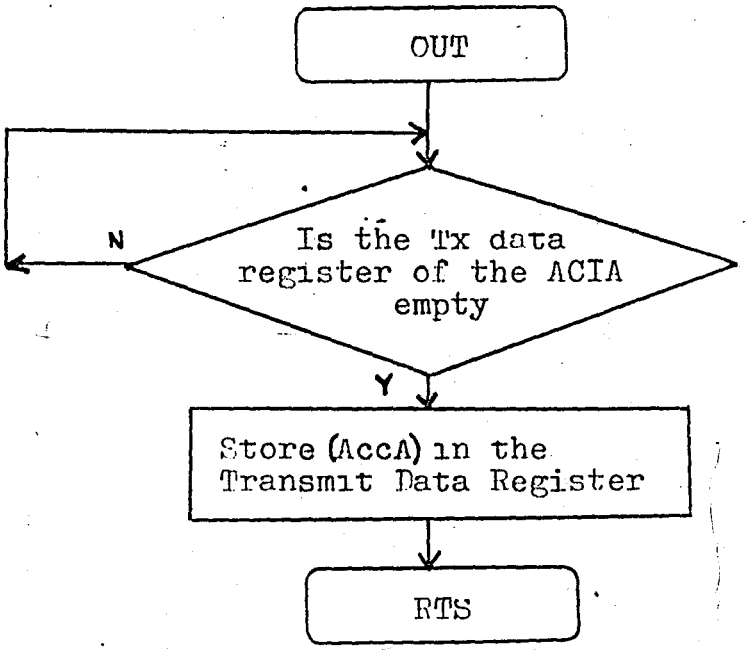

OUT
N
Is the Tx data register of the ACIA empty
Y
Store (AccA) in the Transmit Data Register
RTS

Fig.5-20

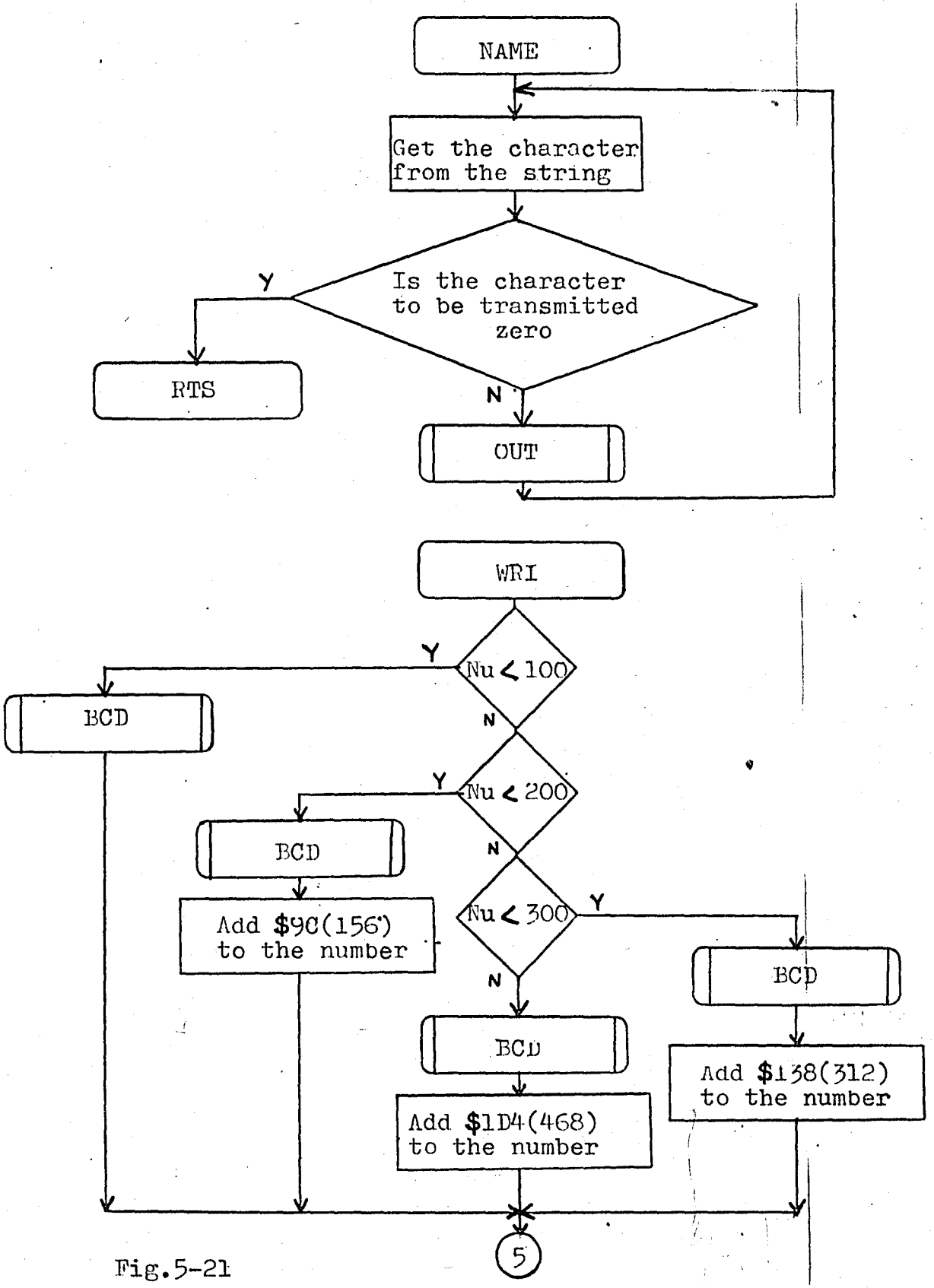

NAME
Get the character from the string
Is the character to be transmitted zero
Y
N
RTS
OUT
WRI
Nu < 100
Y
N
BCD
Nu < 200
Y
N
BCD
Add $90(156) to the number
Nu < 300
Y
N
BCD
Add $138(312) to the number
BCD
Add $1D4(468) to the number
5

Fig.5-21

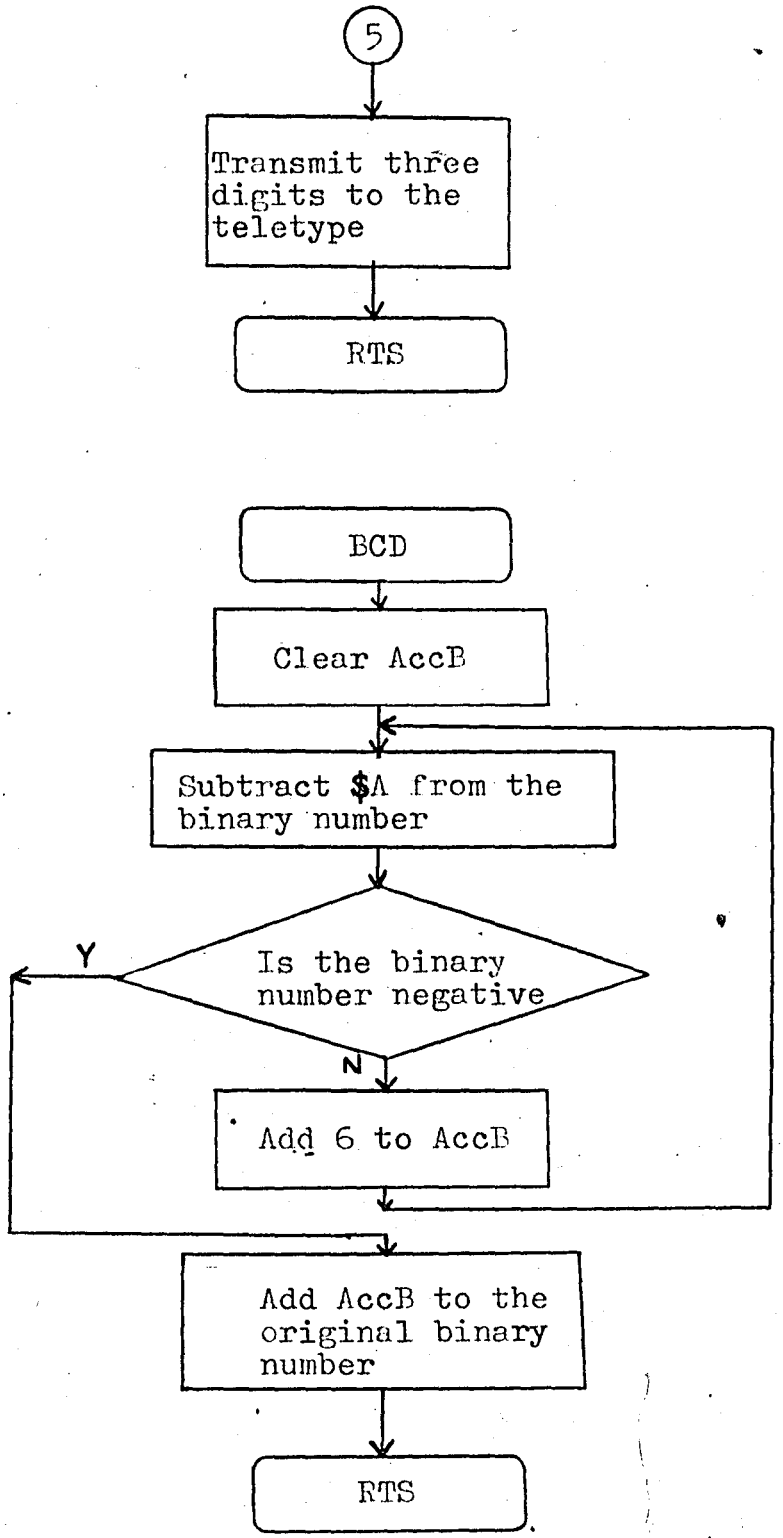

5
Transmit three digits to the teletype
RTS
BCD
Clear AccB
Subtract $A from the binary number
Is the binary number negative
Y
N
Add 6 to AccB
Add AccB to the original binary number
RTS

Fig.5-22

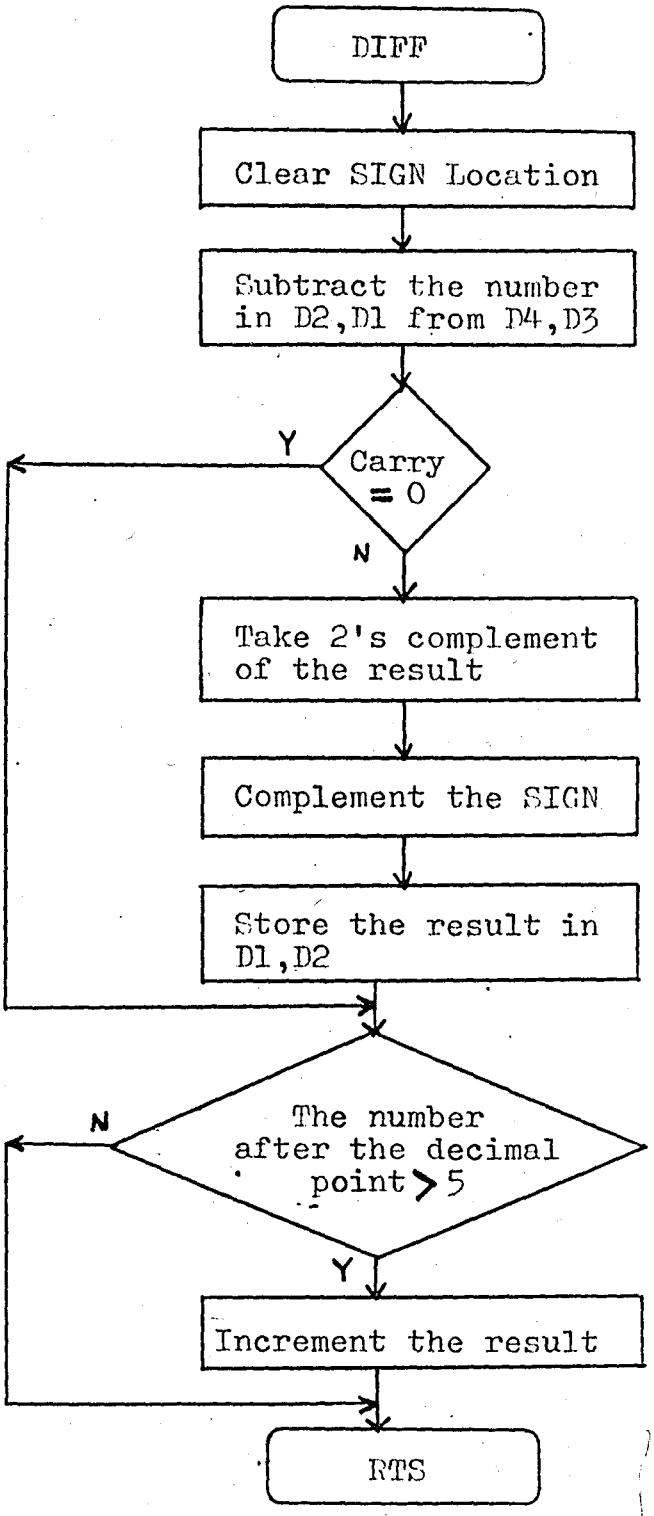

DIFF
Clear SIGN Location
Subtract the number in D2,D1 from D4,D3
Carry = 0
Y
N
Take 2's complement of the result
Complement the SIGN
Store the result in D1,D2
The number after the decimal point > 5
N
Y
Increment the result
RTS

Fig.5-23

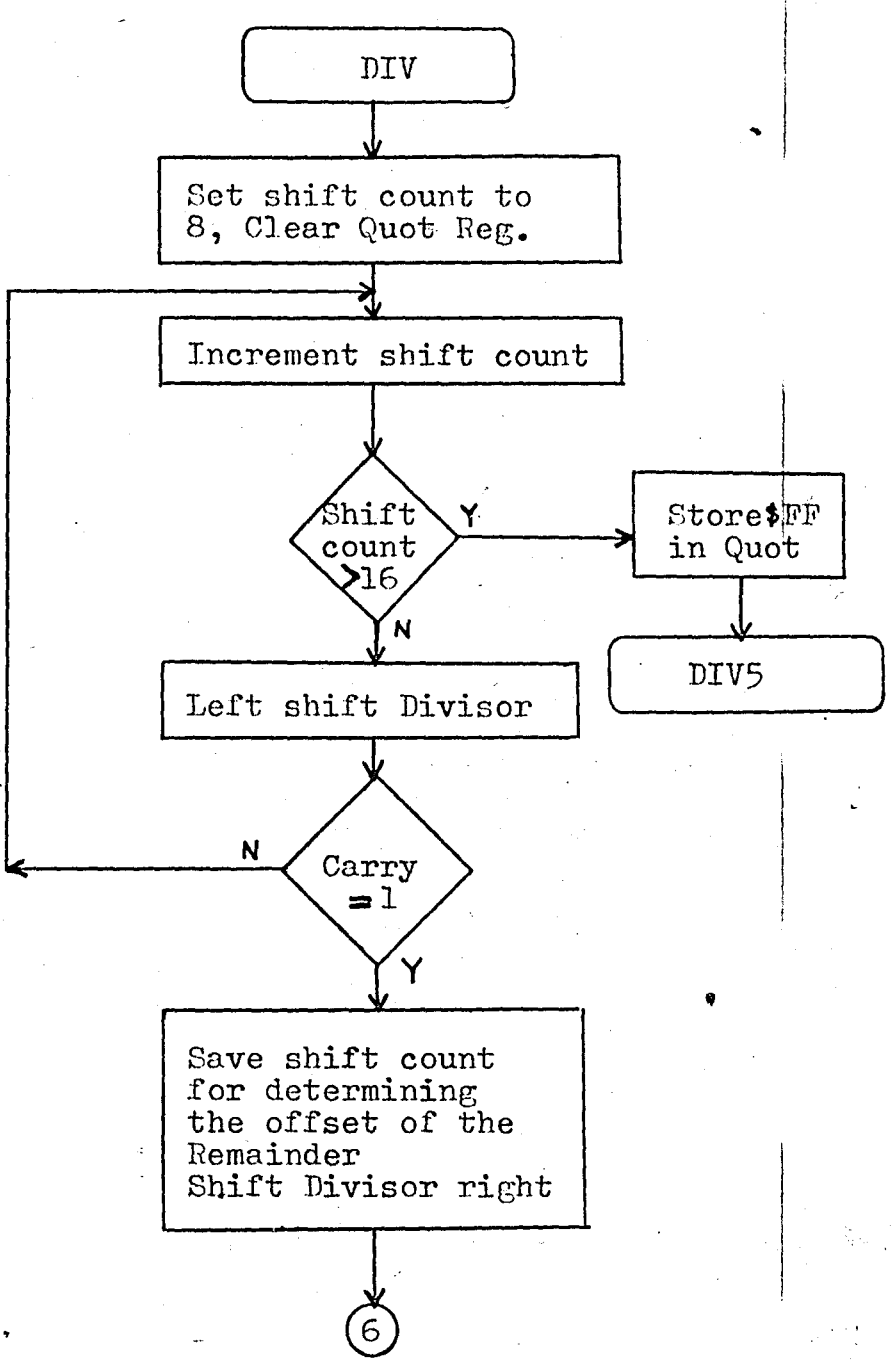

DIV
Set shift count to 8, Clear Quot Reg.
Increment shift count
Shift count >16
Y
Store $FF in Quot
DIV5
N
Left shift Divisor
Carry = 1
N
Y
Save shift count for determining the offset of the Remainder Shift Divisor right
6

Fig.5-24(a)

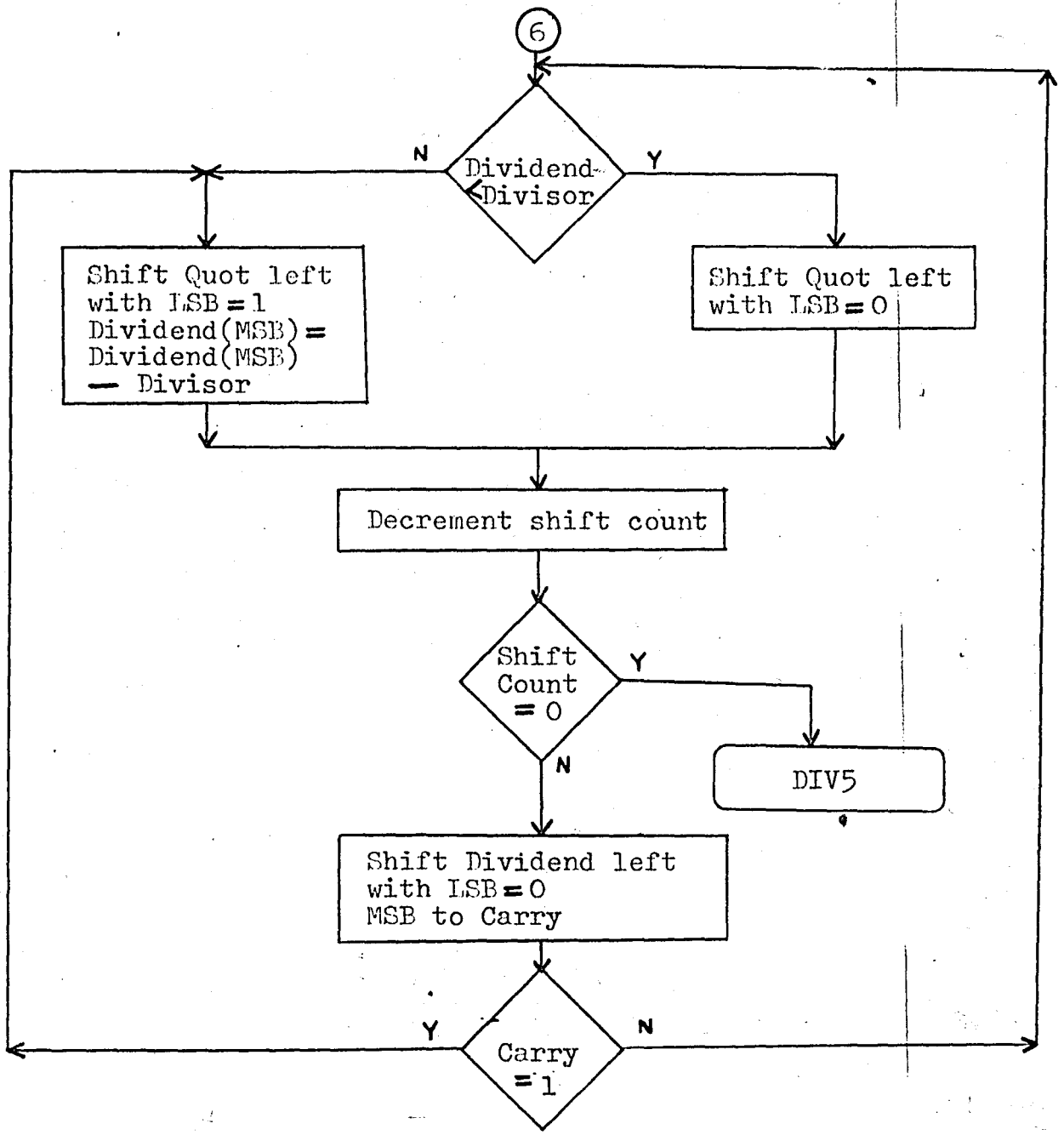
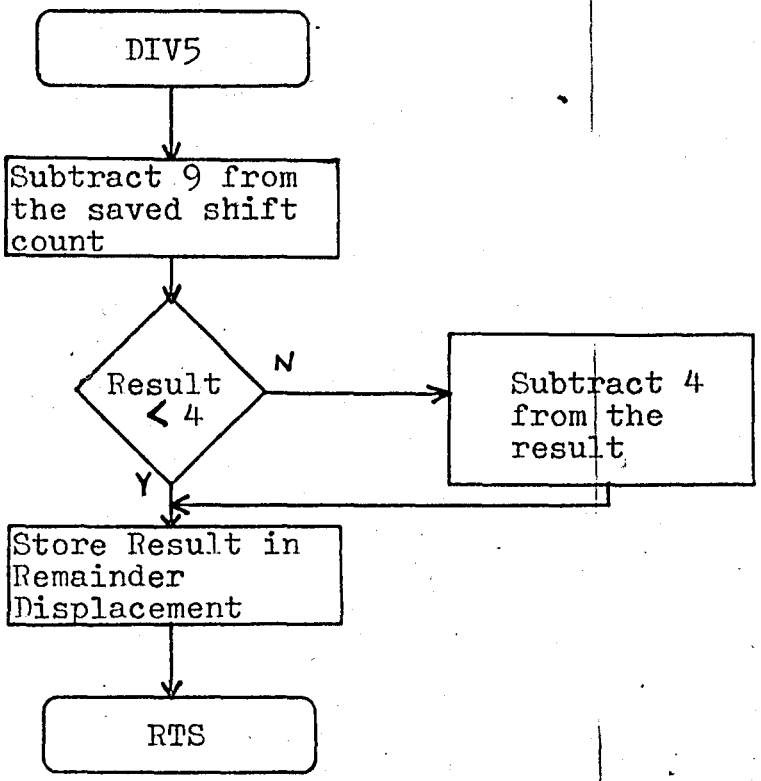

6
Dividend
Divisor
N
Y
Shift Quot left
with LSB = 1
Dividend(MSB) =
Dividend(MSB)
— Divisor
Shift Quot left
with LSB = 0
Decrement shift count
Shift
Count
= 0
Y
N
DIV5
Shift Dividend left
with LSB = 0
MSB to Carry
Y
Carry
= 1
N

Fig.5-24(b)


DIV5
Subtract 9 from the saved shift count
Result < 4
N
Subtract 4 from the result
Y
Store Result in Remainder Displacement
RTS

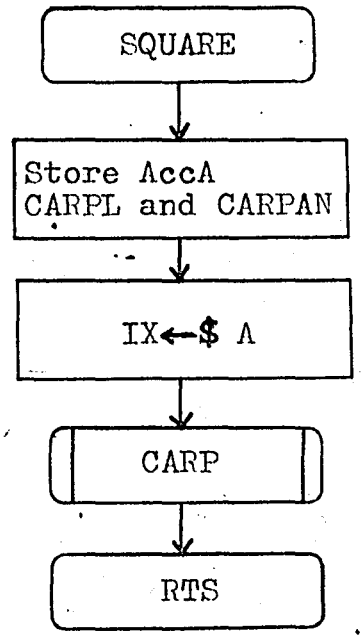

SQUARE
Store AccA CARPL and CARPAN
IX←$ A
CARP
RTS

Fig.5-25

CHAPTER 6
DISCUSSION

A sixteen-bit microprocessor will be very useful for this system. There are many subroutines with 16 bit operations in the program. A 16-bit microprocessor will decrease the execution time and provide reduction in instructions.

The use of an eight-bit digital to analog converter results some difficulties. The range of the plotter is 255 bits with this converter. A ship having a departure of 10 bits in a sampling period, reaches to the edge of the paper at the 25^{th} mark. This number may be increased using a sixteen bit D/A converter.

CHAPTER 7
CONCLUSION

The application of microprocessor control on the Dead Reckoning Table was realized at the end of this study.

The errors produced by the operators were prevented and the correct results for the operation problems were obtained with the aid of microprocessor.

In future development, this plotting system can be connected to a central computer on the ship. Therefore, the other weapon control systems can be operated with the data from the DRT.

The most important advantage of this system is the potential for future developments.

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APPENDIX A PROGRAM LISTING

MAIN PROGRAM

```
00FD    LDS #0D00     8E 0D 00   INITIALIZE STACK
0100    LDX #DF00     CE DF 00   POINTER,INITIALIZE
0103    LDAA #FF      86 FF      PIA'S
0105    LDAB #$34     C6 34
0107    CLR 1,X       6F 01
0109    STAA 0,X      A7 00      P1ORA OUTPUT PORT
010B    CLR 3,X       6F 03
010D    STAA 2,X      A7 02      P1ORB OUTPUT PORT
010F    STAB 1,X      E7 01      P1CRA2 CA2 RESET
0111    STAB 3,X      E7 03      P1CRB2 CB2 RESET
0113    CLR 5,X       6F 05
0115    CLR 4,X       6F 04      P2ORA INPUT PORT
0117    CLR 7,X       6F 07
0119    CLR 6,X       6F 06      P2ORB INPUT PORT
011B    STAB 5,X      E7 05      P2CRA CA2 RESET
011D    STAB 7,X      E7 07      P2CRB CB2 RESET
011F    CLR 9,X       6F 09
0121    CLR 8,X       6F 08      P3ORA INPUT PORT
0123    CLR B,X       6F 0B
0125    CLR A,X       6F 0A      P3ORB INPUT PORT
0127    STAB 9,X      E7 09      P3CRA CA2 RESET
0129    STAB B,X      E7 0B      P3CRB CB2 RESET
012B    CLR D,X       6F 0D
012D    CLR C,X       6F 0C      P4ORA INPUT PORT
012F    CLR F,X       6F 0F
0131    CLR E,X       6F 0E      P4ORB INPUT PORT
0133    STAB D,X      E7 0D      P4CRA CA2 RESET
0135    STAB F,X      E7 0F      P4CRB CB2 RESET

0137    LDAA P3ORA    B6 DF 08   READRESET X REF
013A    STAA XTOTH    97 D7
013C    LDAA P3ORB    B6 DF 0A   READ RESET Y REF
013F    STAA YTOTH    97 DF
0141    CLR XTOTL     7F 00 D8
0144    CLR YTOTL     7F 00 E0
0147    CLR FIRST     7F 00 C0
```

```
014A    BEGIN   LDAA P2ORA      B6 DF 04    READ OWN COURSE
014D            STAA OWNCO      97 B0
014F            LDAA P2ORB      B6 DF 06    READ OWN SPEED
0152            STAA OWNSP      97 B1
0154            LDAA P4ORA      B6 DF 0C    READ TARGET BEARING
0157            STAA TARBE      97 B2
0159            LDAA P4ORB      B6 DF 0E    READ TARGET DISTANCE
015C            STAA TARDI      97 E4
015E            LDX INSCAH      FE 00 C2    READ SCALE
0161            STX SCAHIG      DF C4
0163            LDAA #9         86 09       MULTIPLY SCALE BY
0165            STAA CARPAN     97 B8       1.125 AND GENERATE
0167            LDX SCAHIG      DE C4       TARGET SCALE
0169            STX CARPLH      DF B9
016B            LDX #5          CE 00 05
016E            JSR CARP        BD 02 7E
0171            LDX CARPMH      DE B6
0173            STX TARSCH      DF DA

0175            LDAA OWNCO      96 B0       CONVERT GRAY CODED
0177            JSR GRBIN       BD 02 65    OWN COURSE INTO
017A            LDAA LOCG2      96 B4       BINARY
017C            STAA CARPAN     97 B8
017E            LDX #B4 00      CE B4 00
0181            STX CARPLH      DF B9
0183            LDX #11         CE 00 11
0186            JSR CARP        BD 02 7E
0189            LDX CARPMH      DE B6
018B            STX COURHB      DF C8
018D            STX OWCBH       DF BB

018F            LDAA OWNSP      96 B1
0191            STAA SPD        97 C1
0193            LDAA TARBE      96 B2       CONVERT GRAY CODED
0195            JSR GRBIN       BD 02 65    TARGET BEARING INTO
0198            LDAA LOCG2      96 B4       BINARY
019A            STAA CARPAN     97 B8
019C            LDX #B400       CE B4 00
019F            STX CARPLH      DF B9
01A1            LDX #11         CE 00 11
01A4            JSRCARP         BD 02 7E
01A7            LDX CARPMH      DE B6
01A9            STX TABEH       DF E5

01AB            CLR TARGET      7F 00 E2
01AE    AGAIN   JSR SUB90       BD 02 45
01B1            LDAB COURHB     D6 C8       BRANCH TO FIRST
01B3            BMI QUAD1       2B 2E       QUADRANT CALCULATION
```

```
01B5            JSR SUB90       BD 02 45    IF THE COURSE < 90°
01B8            LDAB COURHB     D6 C8       BRANCH TO FOURTH
01BA            BMI QUAD4       2B 46       QUADRANT CALCULATION
01BC            JSR SUB90       BD 02 45    IF THE COURSE < 180°
01BF            LDAB COURHB     D6 C8       BRANCH TO THIRD
01C1            BMI QUAD3       2B 63       QUADRANT CALCULATION
                                            IF THE COURSE < 270°
01C3            JSR SINE        BD 02 55    THE COURSE > 270°
01C6            CLR MINUS       7F 00 CE    SECOND QUADRANT
01C9            LDAA #1         86 01       CALCULATION
01CB            STAA VERT       97 CF
01CD            JSR MULT        BD 02 A3
01D0            LDAA #5A        86 5A
01D2            SUBA COURLB     90 C9
01D4            STAA COURLB     97 C9
01D6            JSR SINE        BD 02 55
01D9            LDAA #1         86 01
01DB            STAA MINUS      97 CE
01DD            CLR VERT        7F 00 CF
01E0            JMP MULT        7E 02 A3

01E3    QUAD1   JSR SINE        BD 02 55    FIND SINE
01E6            CLR MINUS       7F 00 CE
01E9            LDAA #1         86 01
01EB            STAA VERT       97 CF
01ED            JSR MULT        BD 02 A3
01F0            LDAA #5A        86 5A
01F2            SUBA COURLB     90 C9
01F4            STAA COURLB     97 C9
01F6            JSR SINE        BD 02 55    FIND COSINE
01F9            CLR MINUS       7F 00 CE
01FC            CLR VERT        7F 00 CF
01FF            JMP MULT        7E 02 A3

0202    QUAD4   LDAA #5A        86 5A
0204            SUBA COURLB     90 C9
0206            STAA COURLB     97 C9
0208            JSR SINE        BD 02 55    FIND SINE
020B            LDAA #1         86 01
020D            STAA MINUS      97 CE
020F            STAA VERT       97 CF
0211            JSR MULT        BD 02 A3
0214            LDAA #5A        86 5A
0216            SUBA COURLB     90 C9
0218            STAA COURLB     97 C9
021A            JSR SINE        BD 02 55    FIND COSINE
021D            CLR MINUS       7F 00 CE
0220            CLR VERT        7F 00 CF
```

```
0223                JMP MULT        7E 02 A3

0226    QUAD3       JSR SINE        BD 02 55    FIND SINE
0229                LDAA #1         86 01
022B                STAA MINUS      97 CE
022D                STAA VERT       97 CF
022F                JSR MULT        BD 02 A3
0232                LDAA #5A        86 5A
0234                SUBA COURLB     90 C9
0236                STAA COURLB     97 C9
0238                JSR SINE        BD 02 55    FIND COSINE
023B                LDAA #1         86 01
023D                STAA MINUS      97 CE
023F                CLR VERT        7F 00 CF
0242                JMP MULT        7E 02 A3

0245    SUB90       LDAA COURLB     96 C9       SUBTRACT 90°FROM
0247                LDAB COURHB     D6 C8       THE COURSE
0249                SUBA #5A        80 5A
024B                SBCB #00        C2 00
024D                BPL POS         2A 01       IF THE COURSE<90°
024F                NEG A           40          NEGATE IT
0250    POS         STAA COURLB     97 C9
0252                STAB COURHB     D7 C8
0254                RTS             39

0255    SINE        LDAA #08        86 08       USING THE SINE TABLE
0257                STAA SINADH     97 CA       GET THE SINE OF
0259                LDAA COURLB     96 C9       THE ANGLE
0258                ASLA            48
025C                STAA SINADL     97 CB
025E                LDX SINADH      DE CA
0260                LDX 0,X         EE 00
0262                STX SINHIG      DF CC
0264                RTS             39

0265    GRBIN       LDX #7          CE 00 07    CONVERT THE GRAY
0268                ASLA            48          CODED NUMBER INTO
0269                ROL LOCG2       79 00 B4    BINARY. STORE THE
026C    G1          ASLA            48          RESULT IN LOCG2
026D                ROL LOCG1       79 00 B5
0270                LDAB LOCG1      F6 00 B5
0273                EORB LOCG2      F8 00 B4
0276                ASRB            57
0277                ROL LOCG2       79 00 B4
027A                DEX             09
027B                BNE G1          26 EF
027D                RTS             39
```

```
027E    CARP    CLR CARPMH      7F 00 B6    MULTIPLY THE NUMBER
0281            CLR CARPML      7F 00 B7    IN CARPM BY CARPLN
0284            CLC             0C          AND STORE THE RESULT
0285    CA1     DEX             09          IN CARPM
0286            BEQ CIK         27 1A
0288            ROR CARPMH      76 00 B6
028B            ROR CARPML      76 00 B7
028E            CLC             0C
028F            ROR CARPAN      76 00 B8
0292            BCC CA1         24 F1
0294            LDAA CARPML     96 B7
0296            LDAB CARPMH     D6 B6
0298            ADDA CARPLL     9B BA
029A            ADCB CARPLH     D9 B9
029C            STAA CARPML     97 B7
029E            STAB CARPMH     D7 B6
02A0            BRA CA1         20 E3
02A2    CIK     RTS             39

02A3    MULT    CLRA            4F          CLEAR THE REGISTERS
02A4            STAA RESH       97 D0       FOR MULTIPLYING
02A6            STAA RESL       97 D1       SINE BY SCALE.
02A8            LDX#0012        CE 00 12    SET THE SHIFT COUNT
02AB            CLC             0C          TO $ 12
02AC    NEW     DEX             09          DECREMENT SHIFT COUNT
02AD            BEQ THEN        27 1D       IF THE SHIFT COUNT IS
02AF            ROR RESH        76 00 D0    EQUAL TO ZERO GOTO THEN
02B2            ROR RESL        76 00 D1    SHIFT RIGHT RESULT
02B5            CLC             0C
02B6            ROR SINHIG      76 00 CC    SHIFT RIGHT SINE
02B9            ROR SINLOW      76 00 CD
02BC            BCC NEW         24 EE       IF CARRY CLEAR GOTO NEW
02BE            LDAA RESL       96 D1       ADD SCALE TO RESULT
02C0            LDAB RESH       D6 D0
02C2            ADDA SCALOW     9B C5
02C4            ADCB SCAHIG     D9 C4
02C6            STAA RESL       97 D1
02C8            STAB RESH       D7 D0
02CA            BRA NEW         20 E0

02CC    THEN    LDAA SPD        96 C1       MULTIPLY SPEED
02CE            STAA CARPAN     97 B8       BY RESULT WHICH
02D0            LDX RESH        DE D0       IS SCALED SINE
02D2            STX CARPLH      DF B9
02D4            LDX #0A         CE 00 0A
02D7            JSR CARP        BD 02 7E
02DA            LDX CARPMH      DE B6
```

```
02DC            STX NETH        DF D2       STORE THE RESULT
                                            IN NET
02DE            LDAA MINUS      96 CE       GET SIGN AND RESULT
02E0            LDX NETH        DE D2
02E2            LDAB VERT       D6 CF
02E4            BEQ BC          27 0F
02E6            LDAB TARGET     D6 E2
02E8            BNE BA          26 06
02EA            STX YPOSH       DF DC       STORE THEM FOR OWN
02EC            STAA SGYPOS     97 DE       SHIP Y AXIS
02EE            BRA BB          20 04
02F0  BA        STX YTARH       DF A8       STORE THEM FOR TARGET
02F2            STAA SGYTAR     97 EE       Y AXIS
02F4  BB        RTS             39          RETURN FOR CALCULATION
02F5  BC        LDAB TARGET     D6 E2       ON X AXIS
02F7            BNE CA          26 06
02F9            STX XPOSH       DF D4       STORE RESULTS FOR OWN
02FB            STAA SGXPOS     97 D6       SHIP X AXIS
02FD            BRA CC          20 06
02FF  CA        STX XTARH       DF A6       STORE RESULTS FOR
0301            STAA SGXTAR     97 E9       TARGET X AXIS
0303            BRA CD          20 13
0305  CC        LDAA TARDI      96 E4       GET THE TARGET
0307            STAA SPD        97 C1       INFORMATION
0309            LDX TARSCH      DE DA
030B            STX SCAHIG      DF C4
030D            LDX TABEH       DE E5
030F            STX COURHB      DF C8
0311            LDAA #FF        86 FF
0313            STAA TARGET     97 E2       SET TARGET FLAG
0315            JMP AGAIN       7E 01 AE    JUMP TO AGAIN FOR
0318  CD        LDAA #3         86 03       TARGET CALCULATION
031A  LOOP      ASL XTARL       78 00 A7    SHIFT LEFT TARGET
031D            ROL XTARH       79 00 A6    COMPONENTS THREE
0320            ASL YTARL       78 00 A9    TIMES
0323            ROL YTARH       79 00 A8
0326            DEC A           4A
0327            BNE LOOP        26 F1
0329            LDX XTARH       DE A6
032B            STX XTARHC      DF E7
032D            LDX YTARH       DE A8
032F            STX YTARHC      DF EC
0331            CLI             0E          CLEAR INT MASK
0332            JMP BEGIN       7E 01 4A    JUMP TO THE BEGINNING
```

INTERRUPT SERVICE ROUTINE

```
0400    LDX # 08B6      CE 08 B6
0403    JSR NAME        BD 06 75    PRINT "OWN"
0406    LDX # 08C7      CE 08 C7
0409    JSR NAME        BD 06 75    PRINT "COURSE"
040C    LDX OWCBH       DE BB
040E    STX HB          DF BD
0410    JSR WRI         BD 06 80    PRINT OWN COURSE
0413    LDX # 08B6      CE 08 B6
0416    JSR NAME        BD 06 75    PRINT "OWN"
0419    LDX # 08CF      CE 08 CF
041C    JSR NAME        BD 06 75    PRINT "SPEED"
041F    LDAA OWNSP      96 B1
0421    STAA LB         97 BE
0423    CLR HB          7F 00 BD
0426    JSR WRI         BD 06 80    PRINT OWN SPEED

0429    LDAA # 34       86 34       RESET THE FLAG
042B    STAA CONT       97 BF
042D    LDX # 00D4      CE 00 D4
0430    JSR FPOS        BD 04 7E    FIND OWNSHIP X
0433    LDX # 00DC      CE 00 DC    DEPARTURE
0436    JSR FPOS        BD 04 7E    FIND OWNSHIP Y
0439    LDAA CONT       96 BF       DEPARTURE
043B    STAA P1CRB      B7 DF 03
043E    BITA # 08       85 08       IF THE POSITION
0440    BNE CHANGE      26 3B       OUTSIDE GOTO CHANGE
0442    JSR PLOTME      BD 04 A7    PLOT OWN SHIP
0445    LDX XTOTH       DE D7       GET THE OWN SHIP
0447    STX XTTH        DF EA       POSITION AS REFERENCE
0449    LDX YTOTH       DE DF       FOR TARGET
044B    STX YTTH        DF EF
044D    LDX # 00E7      CE 00 E7
0450    JSR FPOS        BD 04 7E    FIND THE TARGET
0453    LDX # 00EC      CE 00 EC    DISTANCE ON X AXIS
0456    JSR FPOS        BD 04 7E    FIND THE TARGET
0459    TST TARDI       7D 00 E4    DISTANCE ON Y AXIS
045C    BEQ CHANGE      27 1F       IF THE TARGET DISTANCE
045E    LDAA CONT       96 BF       IS ZERO GOTO CHANGE
0460    STAA P2CRA      B7 DF 05
0463    BITA # 08       85 08       IF THE TARGET POSITION
0465    BNE CHANGE      26 16       IS NOT PLOTTABLE GOTO
                                    CHANGE
0467    LDAA FIRST      96 C0       IF THIS IS NOT THE
0469    BEQ 1 1         27 03       FIRST PASS DO NOT
046B    JSR CAL         BD 05 28    CALCULATE TARGET
```

```
046E    I1        JSR PLOTAR    BD 04 F7    PLOT THE TARGET
0471              LDX XTTH      DE EA
0473              STX XTTH1     DF 94       STORE THE TARGET
0475              LDX YTTH      DE EF       POSITION FOR SECOND
0477              STX YTTH1     DF 96       PASS CALCULATIONS
0479              LDAA #FF      86 FF       SET FIRST FLAG
047B              STAA FIRST    97 C0
047D    CHANGE    RTI           3B          SERVICE ROUTINE IS
                                            FINISHED
047E    FPOS      LDAA 4,X      A6 04       FIND THE LAST POSITION
0480              LDAB 3,X      E6 03
0482              TST 2,X       6D 02
0484              BNE F1        26 08       IF THE MOTION IS
0486              ADDA 1,X      AB 01       POSITIVE ADD THE
0488              ADCB 0,X      E9 00       DEPARTURE TO THE
048A              BCS F3        25 15       LAST POSITION
048C              BRA F2        20 06
048E    F1        SUBA 1,X      A0 01       IF THE MOTION IS
0490              SBCB 0,X      E2 00       NEGATIVE SUBTRACT
0492              BCS F3        25 0D       THE DEPARTURE FROM
0494    F2        STAA 4,X      A7 04       LAST LOCATION
0496              STAB 3,X      E7 03
0498              ADDB #05      CB 05       TEST IF THE POSITION
049A              BCS F3        25 05       IS PLOTTABLE
049C              SUBB #0A      C0 0A
049E              BCS F3        25 01
04A0              RTS           39
04A1    F3        LDAA  3C      86 3C       IF NOT, SET THE FLAG
04A3              STAA CONT     B7 00 BF
04A6              RTS           39

04A7    PLOTME    LDAA XTOTH    96 D7
04A9              LDAB YTOTH    D6 DF
04AB              JSR STORE     BD 04 D0    BRING THE PEN TO THE
04AE              JSR DELAY     BD 04 DA    OWN SHIP POSITION
04B1              LDAA #3C      86 3C
04B3              STAA P1CRA    B7 DF 01    DROP THE PEN
04B6              JSR DELAY     BD 04 DA
04B9              LDAA XTOTH    96 D7
04BB              ADDA #5       8B 05       DRAW A SQUARE
04BD              JSR STORE     BD 04 D0    ONTO THE POSITION
04C0              ADDB #5       CB 05
04C2              JSR STORE     BD 04 D0
04C5              LDAA XTOTH    96 D7
04C7              JSR STORE     BD 04 D0
04CA              LDAB YTOTH    D6 DF
04CC              JSR CLEAR     BD 04 E3    BRING THE PEN TO THE
04CF              RTS           39          STARTING POINT
```

```
04D0    STORE   STAA P1ORA     B7 DF 00    OUTPUT THE CONTENTS
04D3            STAB P1ORB     F7 DF 02    OF ACCUMULATORS
04D6            JSR DELAY      BD 04 DA    WAIT FOR THE RESPONSE
04D9            RTS            39          OF THE PEN

04DA    DELAY   LDX #8000      CE 80 00    DELAY SUBROUTINE
04DD    L1      PSHA           36
04DE            PULA           32
04DF            DEX            09
04E0            BNE L1         26 FB
04E2            RTS            39

04E3    CLEAR   JSR STORE      BD 04 D0    CLEAR THE OUTPUT
04E6            LDAA #34       86 34       REGISTERS
04E8            STAA P1CRA     B7 DF 01
04EB            JSR DELAY      BD 04 DA
04EE            CLRA           4F
04EF            CLRB           5F
04F0            JSR STORE      BD 04 D0
04F3            JSR DELAY      BD 04 DA
04F6            RTS            39

04F7    PLOTAR  LDAA XTTH      96 EA
04F9            LDAB YTTH      D6 EF
04FB            JSR STORE      BD 04 D0    BRING THE PEN TO
04FE            JSR DELAY      BD 04 DA    THE TARGET POSITION
0501            LDAA #3C       86 3C
0503            STAA P1CRA     B7 DF 01    DROP THE PEN
0506            JSR DELAY      BD 04 DA
0509            LDAA XTTH      96 EA
050B            ADDA #3        8B 03       DRAW A DIAMOND SHAPE
050D            ADDB #3        CB 03       ONTO THE TARGET
050F            JSR STORE      BD 04 D0     POSITION
0512            LDAA XTTH      96 EA
0514            ADDB #3        CB 03
0516            JSR STORE      BD 04 D0
0519            SUBA #3        80 03
051B            SUBB #3        C0 03
051D            JSR STORE      BD 04 D0
0520            LDAA XTTH      96 EA
0522            LDAB YTTH      D6 EF
0524            JSR CLEAR      BD 04 E3    BRING THE PEN
0527            RTS            39          TO THE STARTING POINT

0528    CAL     LDX XTTH       DE EA       FIND THE X DEPARTURE
052A            STX LOCD3      DF 9D       OF THE TARGET
052C            LDX XTTH1      DE 94
052E            STX LOCD1      DF 9B
```

```
0530            JSR DIFF        BD 06 E9
0533            LDAA LOCNEG     96 9F
0535            STAA XSIGN      97 9A
0537            LDAA LOCD1      96 9B
0539            STAA XTADEP     97 A3
053B            JSR SQUARE      BD 07 5C    SQUARE X DEP
053E            LDX CARPMH      DE B6
0540            STX SQUH        DF 98
0542            LDX YTTH        DE EF
0544            STX LOCD3       DF 9D
0546            LDX YTTH1       DE 96
0548            STX LOCD1       DF 9B
054A            JSR DIFF        BD 06 E9    FIND Y DEPARTURE
054D            LDAA LOCNEG     96 9F
054F            STAA YSIGN      97 A5
0551            LDAA LOCD1      96 9B
0553            STAA YTADEP     97 A4
0555            JSR SQUARE      BD 07 5C    SQUARE IT
0558            LDAA CARPML     96 B7
055A            LDAB CARPMH     D6 B6
055C            ADDA SQUL       9B 99       ADD X^2 TO Y^2
055E            ADCB SQUH       D9 98
0560            STAA SQUL       97 99
0562            STAB SQUH       D7 98

0564            LDAA #1         86 01       FIND THE SQUARE ROOT
0566            CMPB #64        C1 40       OF(X^2+Y^2) BY
0568            BCC KAR1        24 0A       NEWTON-RAPHSON METHOD
056A            CMPB #16        C1 10       IN ORDER TO FIND
056C            BCC KAR2        24 08       THE DEPARTURE
056E            CMPB #1         C1 01
0570            BCC KAR3        24 06
0572            BRA KAR4        20 06
0574  KAR1      ADDA #40        8B 40
0576  KAR2      ADDA #30        8B 30
0578  KAR3      ADDA #0F        8B 0F
057A  KAR4      LOAB #0A        C6 0A
057C  KAR5      STAA TEMPL      97 C7
057E            STAA DVSR       97 AA
0580            LDX SQUH        DE 98
0582            BEQ KAR6        27 16
0584            STX DVDNH       DF AB
0586            PSHB            37
0587            JSR DIV         BD 07 09
058A            LDAB QUOTH      D6 AD
058C            LDAA QUOTL      96 AE
058E            ADDA TEMPL      9B C7
0590            ADCB #00        C9 00
```

```
0592            LSR B           54
0593            ROR A           46
0594            PUL B           33
0595            DEC B           5A
0596            BNE KAR5        26 E4
0598            BRA KAR7        20 01
059A    KAR6    CLRA            4F
059B    KAR7    STAA DEP        97 B3
059D            STAA DVDNH      97 AB
059F            CLR DVDNL       7F 00 AC
05A2            LDAA INSCAH     96 C2
05A4            STAA DVSR       97 AA
05A6            JSR DIV         BD 07 09    DIVIDE THE DEPARTURE
05A9            LDAA QUOTL      96 AE       TO THE SCALE TO
05AB            STAA TARSPD     97 A2       FIND THE SPEED OF
05AD            LDAA DEP        96 B3       THE TARGET
05AF            BEQ NOCO        27 43       IF THE DEPARTURE IS
05B1            STAA DVSR       97 AA       ZERO THE TARGET HAS
05B3            LDAA YTADEP     96 A4       NO SPEED AND COURSE
05B5            STAA DVDNH      97 AB
05B7            CLR DVDNL       7F 00 AC
05BA            JSR DIV         BD 07 09    IF NOT DIVIDE Y
05BD            LDAA QUOTH      96 AD       DEPARTURE TO THE
05BF            BEQ RO1         27 04       DEPARTURE TO FIND
05C1            LDAA #5A        86 5A       THE SINE OF THE
05C3            BRA NIN         20 10       ANGLE (COURSE)
05C5    RO1     LDAA QUOTL      96 AE
05C7            LDX #07FE       CE 07 FE
05CA    RO2     INX             08
05CB            INX             08
05CC            CMPA 0,X        A1 00       COMPARE THE SINE
05CE            BHI RO2         22 FA       WITH THE TERMS ON THE
05D0            STX TEMPH       DF C6       LOOK UP TABLE
05D2            LDAA TEMPL      96 C7
05D4            LSRA            44
05D5    NIN     STAA TEMPL      97 C7
05D7            LDAB #5A        C6 5A
05D9            LDAA XSIGN      96 9A       CALCULATE THE TARGET
05DB            EORA YSIGN      98 A5       COURSE
05DD            BEQ RO3         27 04
05DF            ADDB TEMPL      DB C7
05E1            BRA RO4         20 02
05E3    RO3     SUBB TEMPL      D0 C7
05E5    RO4     LDAA XSIGN      96 9A
05E7            BEQ RO5         27 05
05E9            CLRA            4F
05EA            ADDB #B4        CB B4
05EC            ADCA #00        89 00
```

```
05EE    R05     STAA TARCOH     97 A0
05F0            STAB TARCOL     D7 A1
05F2            BRA YAZ         20 05
05F4    NOCO    LDX #FFFF       CE FF FF    TAKE $ FFFF AS TARGET
05F7            STX TARCOH      DF A0       COURSE FOR PRINTING
                                            "???"
05F9    YAZ     LDX #08BD       CE 08 BD
05FC            JSR NAME        BD 06 75    PRINT "TARGET"
05FF            LDX #08D6       CE 08 D6
0602            JSR NAME        BD 06 75    PRINT "BEARING"
0605            LDX TABEH       DE E5       PRINT TARGET
0607            STX HB          DF BD       BEARING
0609            JSR WRI         BD 06 80
060C            LDX #08BD       CE 08 BD
060F            JSR NAME        BD 06 75    PRINT "TARGET"
0612            LDX #08DF       CE 08 DF
0615            JSR NAME        BD 06 75    PRINT "DISTANCE"
0618            LDAA TARDI      96 E4
061A            STAA LB         97 BE
061C            CLR HB          7F 00 BD
061F            JSR WRI         BD 06 80    PRINT TARGET DIS-
0622            LDAA #30        86 30       TANCE
0624            JSR OUT         BD 06 6A
0627            JSR OUT         BD 06 6A

062A            LDX #08BD       CE 08 BD
062D            JSR NAME        BD 06 75    PRINT "TARGET"
0630            LDX #08C7       CE 08 C7
0633            JSR NAME        BD 06 75    PRINT "COURSE"
0636            LDX TARCOH      DE A0
0638            STX HB          DF BD
063A            BPL YA1         2A 07
063C            LDAA HB         96 BD
063E            JSR THEX        BD 06 BC
0641            BRA YA2         20 03
0643    YA1     JSR WRI         BD 06 80    PRINT TARGET COURSE
0646    YA2     LDX #08BD       CE 08 BD
0649            JSR NAME        BD 06 75    PRINT "TARGET"
064C            LDX #08CF       CE 08 CF
064F            JSR NAME        BD 06 75    PRINT "SPEED"
0652            LDAA TARSPD     96 A2
0654            STAA LB         97 BE
0656            CLR HB          7F 00 BD
0659            JSR WRI         BD 06 80    PRINT TARGET SPEED
065C            LDAA #0D        86 0D       TRANSMIT CR AND
065E            JSR OUT         BD 06 6A    TWO LF
0661            LDAA #0A        86 0A
0663            JSR OUT         BD 06 6A
```

```
0666            JSR OUT         BD 06 6A
0669            RTS             39

066A    OUT     LDAB ACIACR     F6 DF 10
066D            ASRB            57
066E            ASRB            57
066F            BCC OUT         24 F9       IF TX DATA REG IS
0671            STAA ACIADR     B7 DF 11    EMPTY, OUTPUT THE
0674            RTS             39          CHARACTER

0675    NAME    LDAA 0,X        A6 00       GET THE CHARACTER
0677            BEQ NA1         27 06       FROM THE STRING
0679            JSR OUT         BD 06 6A    IF IT IS NOT ZERO
067C            INX             08          TRANSMIT IT
067D            BRA NAME        20 F6       GET NEW CHARACTER
067F    NA1     RTS             39          IF IT IS ZERO RETURN
                                            FROM SUBROUTINE
0680    WRI     LDAA LB         96 BE       CONVERT THE BINARY
0682            LDAB HB         D6 BD       NUMBER BETWEEN 0-359
0684            SUBA #64        80 64       TO BCD
0686            SBCB #00        C2 00
0688            BPL WR1         2A 07
068A            ADDA #64        8B 64
068C            JSR BCD         BD 06 DA
068F            BRA WR4         20 29
0691    WR1     SUBA #64        80 64
0693            SBCB #00        C2 00
0695            BPL WR2         2A 0B
0697            ADDA #64        8B 64
0699            JSR BCD         BD 06 DA
069C            ADDB #9C        CB 9C
069E            ADCA #00        89 00
06A0            BRA WR4         20 18
06A2    WR2     SUBA #64        80 64
06A4            SBCB #00        C2 00
06A6            BPL WR3         2A 0B
06A8            ADDA #64        8B 64
06AA            JSR BCD         BD 06 DA
06AD            ADDB #38        CB 38
06AF            ADCA #01        89 01
06B1            BRA WR4         20 07
06B3    WR3     JSR BCD         BD 06 DA
06B6            ADDB #D4        CB D4
06B8            ADCA #01        89 01
06BA    WR4     STAB LB         D7 BE

06BC    THEX    ANDA #0F        84 0F       TRANSMIT THREE DIGITS
06BE            ADDA #30        8B 30
06C0            JSR OUT         BD 06 DA
06C3            LDAA LB         96 BE
06C5            ANDA #F0        84 F0
```

```
06C7            LSRA        44
06C8            LSRA        44
06C9            LSRA        44
06CA            LSRA        44
06CB            ADDA #30    8B 30
06CD            JSR OUT     BD 06 6A
06D0            LDAA LB     96 BE
06D2            ANDA #0F    84 0F
06D4            ADDA #30    8B 30
06D6            JSR OUT     BD 06 6A
06D9            RTS         39

06DA  BCD       CLR B       5F          CONVERT THE BINARY
06DB  DEV       SUBA #0A    80 0A       NUMBER BETWEEN 0-100
06DD            BMI SON     2B 04       INTO BCD
06DF            ADDB #06    CB 06
06E1            BRA DEV     20 F8
06E3  SON       CLR A       4F
06E4            ADDB LB     DB BE
06E6            ADCA HB     99 BD
06E8            RTS         39

06E9  DIFF      CLR LOCNEG  7F 00 9F    DOUBLE PRECISION
06EC            LDAA LOCD4  96 9E       SUBTRACTION
06EE            LDAB LOCD3  D6 9D
06F0            SUBA LOCD2  90 9C
06F2            SBCB LOCD1  D2 9B
06F4            BCC DA1     24 09
06F6            COM A       43
06F7            COM B       53
06F8            ADDA #01    8B 01
06FA            ADCB #00    C9 00
06FC            COM LOCNEG  73 00 9F
06FF  DA1       STAB LOCD1  D7 9B
0701            STAA LOCD2  97 9C
0703            BPL DA2     2A 03
0705            INC LOCD1   7C 00 9B
0708  DA2       RTS         39

0709  DIV       LDAB #08    C6 08       DIVIDE THE NUMBER
070B            CLR QUOTH   7F 00 AD    IN DVDNH,DVDNL BY
070E            CLR QUOTL   7F 00 AE    DVSR AND STORE THE
0711  DIV2      INCB        5C          RESULT IN QUOTH,
0712            CMPB #16    C1 10       QUOTL
0714            BGT DIV1    2E 34
0716            ASL DVSR    78 00 AA
0719            BCC DIV2    24 F6
071B            STAB SHCO   D7 AF
```

```
071D            ROR DVSR        76 00 AA
0720            LDAA DVDNH      96 AB
0722    DIV7    CMPA DVSR       91 AA
0724            BCS DIV3        25 0D
0726    DIV6    SEC             0D
0727            ROL QUOTL       79 00 AE
072A            ROL QUOTH       79 00 AD
072D            SUBA DVSR       90 AA
072F            STAA DVDNH      97 AB
0731            BRA DIV4        20 07
0733    DIV3    CLC             0C
0734            ROL QUOTL       79 00 AE
3737            ROL QUOTH       79 00 AD
073A    DIV4    DECB            5A
073B            BEQ DIV5        27 12
073D            CLC             0C
073E            ROL DVDNL       79 00 AC
0741            ROL DVDNH       79 00 AB
0744            LDAA DVDNH      96 AB
0746            BCS DIV6        25 DE
0748            BRA DIV7        20 D8
074A    DIV1    LDX #FFFF       CE FF FF
074D            STX QUOTH       DF AD
074F    DIV5    LDAB SHCO       D6 AF
0751            SUBB#9          C0 09
0753            CMPB #4         C1 04
0755            BCS DIV8        25 02
0757            SUBB#4          C0 04
0759    DIV8    STAB SHCO       D7 AF
075B            RTS             39

075C    SQUARE  STAA CARPLH     97 B9       CALCULATE THE
075E            STAA CARPAN     97 B8       SQUARE OF THE
0760            CLR CARPLL      7F 00 BA    NUMBER IN ACC A
0763            LDX #0A         CE 00 0A
0766            JSR CARP        BD 02 7E
0769            RTS             39
```

SINE TABLE

0800	00	00	04	78	08	EF	0D	66	11	DB	16	50	1A	C2	1F	33	0°- 7°
0810	23	A1	28	0C	2C	74	30	D9	35	3A	39	96	3D	EE	42	42	8°-15°
0820	46	90	4A	D9	4F	1B	53	58	57	8E	5B	BE	5F	E6	64	07	16°-23°
0830	68	20	6C	30	70	39	74	38	78	2F	7C	1C	80	01	83	D9	24°-31°
0840	87	A8	8B	6D	8F	27	92	D5	96	78	9A	10	9D	9B	A1	1A	32°-39°
0850	A4	8D	A7	F3	AB	4C	AE	97	B1	D4	B5	04	B8	26	BB	39	40°-47°
0860	BE	3E	C1	34	C4	1A	C6	F2	C9	BA	CC	73	CF	1B	D1	B3	48°-55°
0870	D4	3B	D6	B2	D9	18	DB	6E	DD	B3	DF	E6	E2	08	E4	18	56°-63°
0880	E6	16	E8	03	E9	DD	EB	A5	ED	5B	EE	FE	F0	8F	F2	0D	64°-71°
0890	F3	78	F4	CF	F6	14	F7	46	F8	64	F9	6F	FA	67	FB	4B	72°-79°
08A0	FC	1B	FC	D8	FD	81	FE	16	FE	98	FF	06	FF	5F	FF	A5	80°-87°
08B0	FF	D7	FF	F5	FF	FF											88°-90°

CHARACTER TABLE

08B6	0D	0A	4F	57	4E	20	00			CR LF OWN SP NUL
08BD	0D	0A	54	41	52	47	45	54	20	00 CR LF TARGET SP NUL
08C7	43	4F	55	52	53	45	3A	00		COURSE : NUL
08CF	53	50	45	45	44	3A	00			SPEED : NUL
08D6	42	45	41	52	49	4E	47	3A	00	BEARING : NUL
08DF	44	49	53	54	41	4E	43	45	3A	00 DISTANCE : NUL

APPENDIX B
MPU INSTRUCTIONS

Accumulator and Memory Instructions

OPERATIONS	MNEMONIC	IMMED OP	IMMED ~	IMMED #	DIRECT OP	DIRECT ~	DIRECT #	INDEX OP	INDEX ~	INDEX #	EXTND OP	EXTND ~	EXTND #	IMPLIED OP	IMPLIED ~	IMPLIED #	BOOLEAN/ARITHMETIC OPERATION (All register labels refer to contents)	5 H	4 I	3 N	2 Z	1 V	0 C
Add	ADDA	8B	2	2	9B	3	2	AB	5	2	BB	4	3				A + M → A	↕	•	↕	↕	↕	↕
	ADDB	CB	2	2	DB	3	2	EB	5	2	FB	4	3				B + M → B	↕	•	↕	↕	↕	↕
Add Acmltrs	ABA													1B	2	1	A + B → A	↕	•	↕	↕	↕	↕
Add with Carry	ADCA	89	2	2	99	3	2	A9	5	2	B9	4	3				A + M + C → A	↕	•	↕	↕	↕	↕
	ADCB	C9	2	2	D9	3	2	E9	5	2	F9	4	3				B + M + C → B	↕	•	↕	↕	↕	↕
And	ANDA	84	2	2	94	3	2	A4	5	2	B4	4	3				A · M → A	•	•	↕	↕	R	•
	ANDB	C4	2	2	D4	3	2	E4	5	2	F4	4	3				B · M → B	•	•	↕	↕	R	•
Bit Test	BITA	85	2	2	95	3	2	A5	5	2	B5	4	3				A · M	•	•	↕	↕	R	•
	BITB	C5	2	2	D5	3	2	E5	5	2	F5	4	3				B · M	•	•	↕	↕	R	•
Clear	CLR							6F	7	2	7F	6	3				00 → M	•	•	R	S	R	R
	CLRA													4F	2	1	00 → A	•	•	R	S	R	R
	CLRB													5F	2	1	00 → B	•	•	R	S	R	R
Compare	CMPA	81	2	2	91	3	2	A1	5	2	B1	4	3				A − M	•	•	↕	↕	↕	↕
	CMPB	C1	2	2	D1	3	2	E1	5	2	F1	4	3				B − M						
Compare Acmltrs	CBA													11	2	1	A − B	•	•	↕	↕	↕	↕
Complement, 1's	COM							63	7	2	73	6	3				M̄ → M	•	•	↕	↕	R	S
	COMA													43	2	1	Ā → A	•	•	↕	↕	R	S
	COMB													53	2	1	B̄ → B	•	•	↕	↕	R	S
Complement, 2's (Negate)	NEG							60	7	2	70	6	3				00 − M → M	•	•	↕	↕	①	②
	NEGA													40	2	1	00 − A → A	•	•	↕	↕	①	②
	NEGB													50	2	1	00 − B → B	•	•	↕	↕	①	②
Decimal Adjust, A	DAA													19	2	1	Converts Binary Add. of BCD Characters into BCD Format	•	•	↕	↕	↕	③
Decrement	DEC							6A	7	2	7A	6	3				M − 1 → M	•	•	↕	↕	4	•
	DECA													4A	2	1	A − 1 → A	•	•	↕	↕	4	•
	DECB													5A	2	1	B − 1 → B	•	•	↕	↕	4	•
Exclusive OR	EORA	88	2	2	98	3	2	A8	5	2	B8	4	3				A⊕M → A	•	•	↕	↕	R	•
	EORB	C8	2	2	D8	3	2	E8	5	2	F8	4	3				B⊕M → B	•	•	↕	↕	R	•
Increment	INC							6C	7	2	7C	6	3				M + 1 → M	•	•	↕	↕	⑤	•
	INCA													4C	2	1	A + 1 → A	•	•	↕	↕	⑤	•
	INCB													5C	2	1	B + 1 → B	•	•	↕	↕	⑤	•
Load Acmltr	LDAA	86	2	2	96	3	2	A6	5	2	B6	4	3				M → A	•	•	↕	↕	R	•
	LDAB	C6	2	2	D6	3	2	E6	5	2	F6	4	3				M → B	•	•	↕	↕	R	•
Or, Inclusive	ORAA	8A	2	2	9A	3	2	AA	5	2	BA	4	3				A + M → A	•	•	↕	↕	R	•
	ORAB	CA	2	2	DA	3	2	EA	5	2	FA	4	3				B + M → B	•	•	↕	↕	R	•
Push Data	PSHA													36	4	1	A → M_{SP}, SP − 1 → SP	•	•	•	•	•	•
	PSHB													37	4	1	B → M_{SP}, SP − 1 → SP	•	•	•	•	•	•
Pull Data	PULA													32	4	1	SP + 1 → SP, M_{SP} → A	•	•	•	•	•	•
	PULB													33	4	1	SP + 1 → SP, M_{SP} → B	•	•	•	•	•	•
Rotate Left	ROL							69	7	2	79	6	3				M	•	•	↕	↕	⑥	↕
	ROLA													49	2	1	A	•	•	↕	↕	⑥	↕
	ROLB													59	2	1	B	•	•	↕	↕	⑥	↕
Rotate Right	ROR							66	7	2	76	6	3				M	•	•	↕	↕	⑥	↕
	RORA													46	2	1	A	•	•	↕	↕	⑥	↕
	RORB													56	2	1	B	•	•	↕	↕	⑥	↕
Shift Left, Arithmetic	ASL							68	7	2	78	6	3				M	•	•	↕	↕	⑥	↕
	ASLA													48	2	1	A	•	•	↕	↕	⑥	↕
	ASLB													58	2	1	B	•	•	↕	↕	⑥	↕
Shift Right, Arithmetic	ASR							67	7	2	77	6	3				M	•	•	↕	↕	⑥	↕
	ASRA													47	2	1	A	•	•	↕	↕	⑥	↕
	ASRB													57	2	1	B	•	•	↕	↕	⑥	↕
Shift Right, Logic	LSR							64	7	2	74	6	3				M	•	•	R	↕	⑥	↕
	LSRA													44	2	1	A	•	•	R	↕	⑥	↕
	LSRB													54	2	1	B	•	•	R	↕	⑥	↕
Store Acmltr.	STAA				97	4	2	A7	6	2	B7	5	3				A → M	•	•	↕	↕	R	•
	STAB				D7	4	2	E7	6	2	F7	5	3				B → M	•	•	↕	↕	R	•
Subtract	SUBA	80	2	2	90	3	2	A0	5	2	B0	4	3				A − M → A	•	•	↕	↕	↕	↕
	SUBB	C0	2	2	D0	3	2	E0	5	2	F0	4	3				B − M → B	•	•	↕	↕	↕	↕
Subtract Acmltrs.	SBA													10	2	1	A − B → A	•	•	↕	↕	↕	↕
Subtr. with Carry	SBCA	82	2	2	92	3	2	A2	5	2	B2	4	3				A − M − C → A	•	•	↕	↕	↕	↕
	SBCB	C2	2	2	D2	3	2	E2	5	2	F2	4	3				B − M − C → B	•	•	↕	↕	↕	↕
Transfer Acmltrs	TAB													16	2	1	A → B	•	•	↕	↕	R	•
	TBA													17	2	1	B → A	•	•	↕	↕	R	•
Test, Zero or Minus	TST							6D	7	2	7D	6	3				M − 00	•	•	↕	↕	R	R
	TSTA													4D	2	1	A − 00	•	•	↕	↕	R	R
	TSTB													5D	2	1	B − 00	•	•	↕	↕	R	R
																		H	I	N	Z	V	C

LEGEND:

- OP Operation Code (Hexadecimal);
- ~ Number of MPU Cycles;
- # Number of Program Bytes;
- + Arithmetic Plus;
- − Arithmetic Minus;
- · Boolean AND;
- M_{SP} Contents of memory location pointed to be Stack Pointer;
- + Boolean Inclusive OR;
- ⊙ Boolean Exclusive OR;
- M̄ Complement of M;
- → Transfer Into;
- 0 Bit = Zero;
- 00 Byte = Zero;

Note – Accumulator addressing mode instructions are included in the column for IMPLIED addressing

CONDITION CODE SYMBOLS:

- H Half-carry from bit 3;
- I Interrupt mask
- N Negative (sign bit)
- Z Zero (byte)
- V Overflow, 2's complement
- C Carry from bit 7
- R Reset Always
- S Set Always
- ↕ Test and set if true, cleared otherwise
- • Not Affected

Index Register and Stack Manipulation Instructions

POINTER OPERATIONS	MNEMONIC	IMMED OP	IMMED ~	IMMED #	DIRECT OP	DIRECT ~	DIRECT #	INDEX OP	INDEX ~	INDEX #	EXTND OP	EXTND ~	EXTND #	IMPLIED OP	IMPLIED ~	IMPLIED #	BOOLEAN/ARITHMETIC OPERATION	5 H	4 I	3 N	2 Z	1 V	0 C
Compare Index Reg	CPX	8C	3	3	9C	4	2	AC	6	2	BC	5	3				$X_H - M, X_L - (M+1)$	•	•	⑦	↕	⑦	•
Decrement Index Reg	DEX													09	4	1	$X - 1 \rightarrow X$	•	•	•	↕	•	•
Decrement Stack Pntr	DES													34	4	1	$SP - 1 \rightarrow SP$	•	•	•	•	•	•
Increment Index Reg	INX													08	4	1	$X + 1 \rightarrow X$	•	•	•	↕	•	•
Increment Stack Pntr	INS													31	4	1	$SP + 1 \rightarrow SP$	•	•	•	•	•	•
Load Index Reg	LDX	CE	3	3	DE	4	2	EE	6	2	FE	5	3				$M \rightarrow X_H, (M+1) \rightarrow X_L$	•	•	⑨	↕	R	•
Load Stack Pntr	LDS	8E	3	3	9E	4	2	AE	6	2	BE	5	3				$M \rightarrow SP_H, (M+1) \rightarrow SP_L$	•	•	⑨	↕	R	•
Store Index Reg.	STX				DF	5	2	EF	7	2	FF	6	3				$X_H \rightarrow M, X_L \rightarrow (M+1)$	•	•	⑨	↕	R	•
Store Stack Pntr	STS				9F	5	2	AF	7	2	BF	6	3				$SP_H \rightarrow M, SP_L \rightarrow (M+1)$	•	•	⑨	↕	R	•
Indx Reg → Stack Pntr	TXS													35	4	1	$X - 1 \rightarrow SP$	•	•	•	•	•	•
Stack Pntr → Indx Reg	TSX													30	4	1	$SP + 1 \rightarrow X$	•	•	•	•	•	•

Jump and Branch Instructions

OPERATIONS	MNEMONIC	RELATIVE OP	RELATIVE ~	RELATIVE #	INDEX OP	INDEX ~	INDEX #	EXTND OP	EXTND ~	EXTND #	IMPLIED OP	IMPLIED ~	IMPLIED #	BRANCH TEST	5 H	4 I	3 N	2 Z	1 V	0 C
Branch Always	BRA	20	4	2										None	•	•	•	•	•	•
Branch If Carry Clear	BCC	24	4	2										C = 0	•	•	•	•	•	•
Branch If Carry Set	BCS	25	4	2										C = 1	•	•	•	•	•	•
Branch If = Zero	BEQ	27	4	2										Z = 1	•	•	•	•	•	•
Branch If ≥ Zero	BGE	2C	4	2										$N \oplus V = 0$	•	•	•	•	•	•
Branch If > Zero	BGT	2E	4	2										$Z + (N \oplus V) = 0$	•	•	•	•	•	•
Branch If Higher	BHI	22	4	2										C + Z = 0	•	•	•	•	•	•
Branch If ≤ Zero	BLE	2F	4	2										$Z + (N \oplus V) = 1$	•	•	•	•	•	•
Branch If Lower Or Same	BLS	23	4	2										C + Z = 1	•	•	•	•	•	•
Branch If < Zero	BLT	2D	4	2										$N \oplus V = 1$	•	•	•	•	•	•
Branch If Minus	BMI	2B	4	2										N = 1	•	•	•	•	•	•
Branch If Not Equal Zero	BNE	26	4	2										Z = 0	•	•	•	•	•	•
Branch If Overflow Clear	BVC	28	4	2										V = 0	•	•	•	•	•	•
Branch If Overflow Set	BVS	29	4	2										V = 1	•	•	•	•	•	•
Branch If Plus	BPL	2A	4	2										N = 0	•	•	•	•	•	•
Branch To Subroutine	BSR	8D	8	2											•	•	•	•	•	•
Jump	JMP				6E	4	2	7E	3	3				See Special Operations	•	•	•	•	•	•
Jump To Subroutine	JSR				AD	8	2	BD	9	3					•	•	•	•	•	•
No Operation	NOP										02	2	1	Advances Prog. Cntr. Only	•	•	•	•	•	•
Return From Interrupt	RTI										3B	10	1		———		⑩		———	
Return From Subroutine	RTS										39	5	1		•	•	•	•	•	•
Software Interrupt	SWI										3F	12	1	See Special Operations	•	•	•	•	•	•
Wait for Interrupt	WAI										3E	9	1		•	⑪	•	•	•	•

Condition Code Register Manipulation Instructions

OPERATIONS	MNEMONIC	IMPLIED OP	IMPLIED ~	IMPLIED #	BOOLEAN OPERATION	5 H	4 I	3 N	2 Z	1 V	0 C
Clear Carry	CLC	0C	2	1	$0 \rightarrow C$	•	•	•	•	•	R
Clear Interrupt Mask	CLI	0E	2	1	$0 \rightarrow I$	•	R	•	•	•	•
Clear Overflow	CLV	0A	2	1	$0 \rightarrow V$	•	•	•	•	R	•
Set Carry	SEC	0D	2	1	$1 \rightarrow C$	•	•	•	•	•	S
Set Interrupt Mask	SEI	0F	2	1	$1 \rightarrow I$	•	S	•	•	•	•
Set Overflow	SEV	0B	2	1	$1 \rightarrow V$	•	•	•	•	S	•
Acmltr A → CCR	TAP	06	2	1	$A \rightarrow CCR$	———			⑫		———
CCR → Acmltr A	TPA	07	2	1	$CCR \rightarrow A$	•	•	•	•	•	•

CONDITION CODE REGISTER NOTES:

(Bit set if test is true and cleared otherwise)

1 (Bit V) Test: Result = 10000000β?
2 (Bit C) Test: Result = 00000000?
3 (Bit C) Test: Decimal value of most significant BCD Character greater than nine? (Not cleared if previously set.)
4 (Bit V) Test: Operand = 10000000 prior to execution?
5 (Bit V) Test: Operand = 01111111 prior to execution?
6 (Bit V) Test: Set equal to result of N⊕C after shift has occurred.
7 (Bit N) Test: Sign bit of most significant (MS) byte = 1?
8 (Bit V) Test: 2's complement overflow from subtraction of MS bytes?
9 (Bit N) Test: Result less than zero? (Bit 15 = 1)
10 (All) Load Condition Code Register from Stack. (See Special Operations)
11 (Bit I) Set when interrupt occurs. If previously set, a Non-Maskable Interrupt is required to exit the wait state.
12 (All) Set according to the contents of Accumulator A.

APPENDIX C COST

a. Microcomputer Minimum System

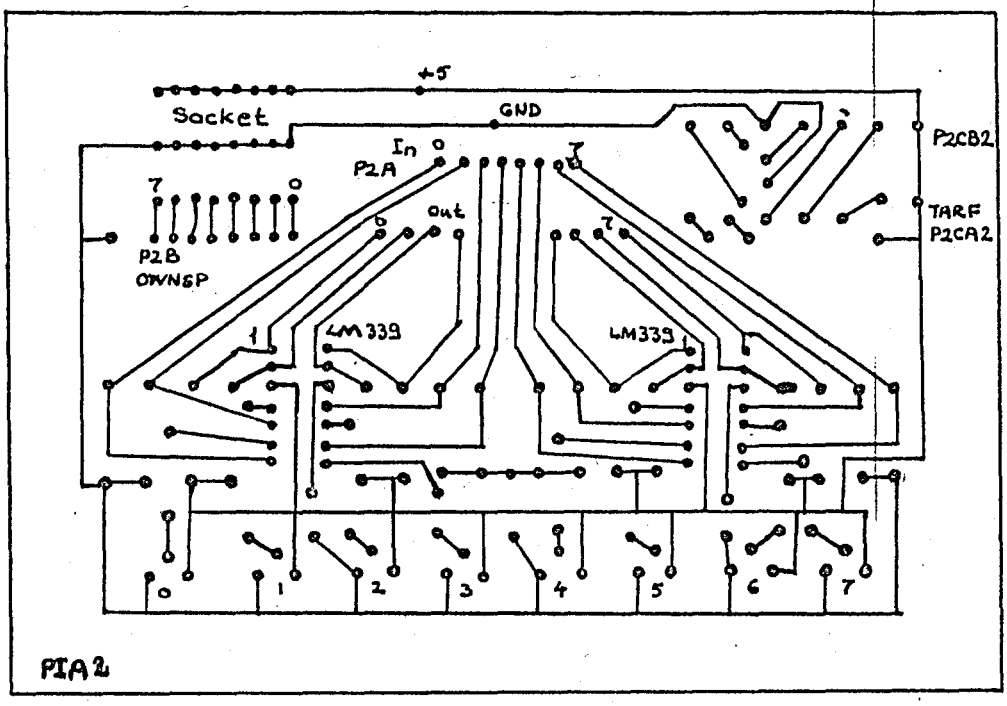
MPU	3000 TL	
EPROM	2000 TL	
RAM	2000 TL	
PIA's	3000 TL	
ACIA	750 TL	
Miscellaneous	10000 TL	
		20750 TL

b. Interface Circuits

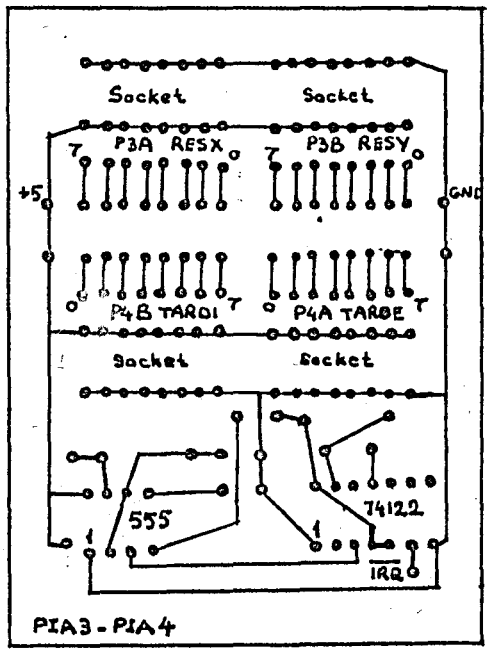
Semiconductor Components	5000 TL	
Miscellaneous	3000 TL	
		8000 TL

c. Engineering Cost 50000 TL

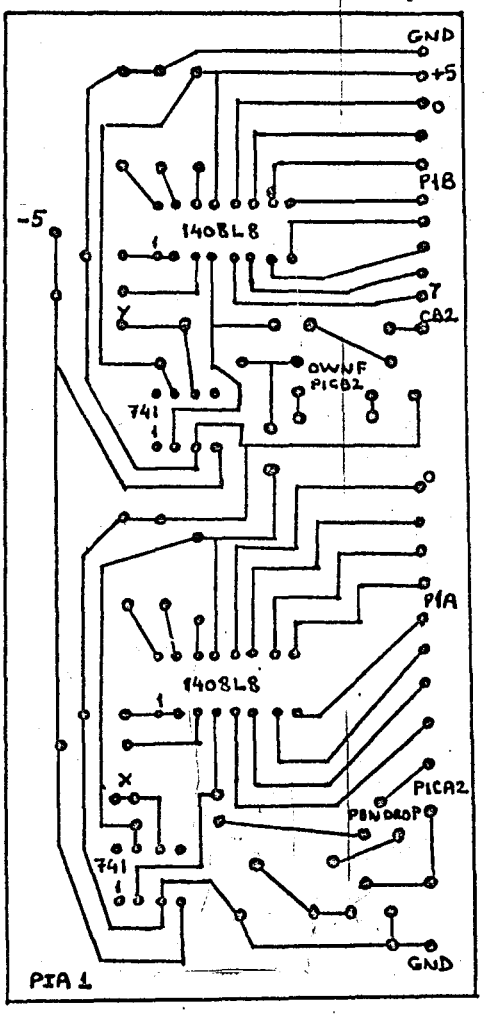
APPENDIX D PRINTED CIRCUIT BOARDS



Shaft encoder and Own Speed Input Board



Timer and
Reset Coordinates,
Target Information
Input Board



D/A Converter Board