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A Digital Processor for Beacon-aided Distance Measuring Systems

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ABSTRACT

Synchronized beacons and transponders are widely used in distance measuring systems for navigation and surveying purposes. As to the synchronized beacons, the LORAN-C and DECCA systems are typical examples and are used in hyperbolic navigation systems. The transponder type systems are found with avionics DME (Distance measuring equipment) and TACAN systems. For surveying applications, Tellurometers are synchronized frequency-locked systems allowing distance measurements. In all these systems, distance (or distance difference) are measured on the basis of finding the phase difference or the time delay between a reference signal and a "slaved" signal carrying the required distance information.

The present work introduces a microprocessor (or microcontroller)-based digital processor implementation for extraction and display of distance information. This implementation is conceived to be too versatile to be used (with minor modification in signal conditioning aspects) in all of the above systems and for similar applications requiring phase difference measurements. Actually it has been tested as a whole for Tellurometers and in parts for other navigation systems.

KEY WORDS : Distance measurement, Tellurometer, surveying, beacon navigation, microprocessor.

I. Introduction

Distance is one of the important measurands of radio location and navigation systems to allow position-fixing through intersection of at least two position lines for the plane navigation. Three of the four known combinations of lines for position fixing : (ρ, ϑ) , $(\Delta\rho - \Delta\rho)$, $(\rho - \rho)$ and $(\vartheta - \vartheta)$ systems [1-4] involve distance measurements. These systems entail generally synchronized beacons or transponders for their operation. In aviation, synchronized beacons are preferred to transponders as transmission of radio signals are confined to ground stations and saturation problems inherent in two-way transmissions required for direct distance measurement are avoided. $(\Delta\rho - \Delta\rho)$ systems are known as hyperbolic systems are known to offer a very good combination of accuracy and range [5]. In essence, the distance difference is also measured through time interval or phase difference measurement.

As to the implementation of measurement, two methods are used : time interval in pulsed system as LORAN-C and phase difference in CW case as DECCA and OMEGA systems. In both cases a beacon synchronization is a must and is solved either by configuring a chain around a master and secondary stations (as in LORAN-C and DECCA) or by subjecting transmitting stations to synchronization using frequency /time standards based on atomic clock (as in OMEGA system). This latter concept is also applied to GPS systems.

As to surveying equipments , Tellurometers are operated on the basis of transponder or secondary radar principle allowing for a Line-of-Sight distance upto 50 Km to be measured and is limited by the intervisibility distance, ground conditions and meteorological conditions. In these systems , distance measurement is based upon successively modulating the carrier frequency by several *pattern* frequencies generated by switching corresponding crystals or frequency dividers (at the MASTER side) in "synchronism" with corresponding *pattern* frequencies (at the REMOTE side of the link) and measuring the phase difference of a derived low frequency at the master side. Required frequency locking is secured by automatic frequency control (AFC) of the both link equipments.

As the problem in the above systems boils down to either phase difference or time difference measurement , the present work is heavily concerned with the solution of this problem. Fig.1 introduces the proposed digital processing system. It comprises the signal conditioning section , the time interval measuring section , the microcomputer board along with a keypad and display, Moreover , a dual port random access memory (RAM). This RAM is conceived for temporary data storage before being polled by the microcomputer section . Section II introduce the various solution issues for the phase difference measurement while section III considers the adopted counter-based phase measurement and data formatting scheme. Section IV is devoted to the user interface : keypad and display . As to the microcomputer , section V outlines some hardware as well as software details. Finally conclusions and future work are given.

II. Principles of Phase/Time difference measurement

Phase or time difference measurement is generally achieved through :

- conversion of phase difference to voltage by using correlators or their approximators : phase detectors. The voltage is the measured by a digital voltmeter scaled to the require phase , time interval or distance

- conversion of phase difference to time interval that is subsequently measured with counters, for instance, or any duration measuring method. This reduces to a linear phase detector implementation .

- nulling method with application of phase shifters. This reduces somehow to a form of closed loop implementation.

The question of accurate phase measurements always arises especially in open loop configuration. Accurate phase

measurement is attainable by various methods. When nulling or phase-to-voltage conversion is applied, frequency multiplication may help phase magnification but this multiplication may induce ambiguity. When phase measurement is done through time measurement then either use of high frequency counters or vernier technique ought to be applied. Vernier technique is based upon measuring the time interval using a coarse clock and the remainder is measured after its magnification (expansion of duration). Counter overflow or periodic resetting induce ambiguity. The problem of ambiguity is formulated as follows : It is required to find the constant K associated with the measurement since the measured phase Δ is unknown to be really Δ or $\Delta + K(2\pi)$ with K integer .

This ambiguity problem appears in the previously mentioned systems and appears also when phase discretization is involved to achieve accurate measurement. Solution of ambiguity problem will be done through use of a family of phase detector characteristics (Diversity Operation) ; i.e to use a multiple phase detector characteristic and solve results concurrently. This approach is easier to implement and it solves together equations of the type :

$$\begin{aligned}x &= \Delta_1 \bmod T_1 + k_1 T_1 \\x &= \Delta_2 \bmod T_2 + k_2 T_2\end{aligned}$$

where Δ_1 and Δ_2 are measured time delays reduced modulo signal periods T_1 and T_2 respectively . k_1 and k_2 are integers .

The chinese remainder theorem offer a convenient means for finding the true solution. This entails the appearance of Δ_i and T_i as integer numbers . This is easily secured through use of digital phase detectors that transform the phase difference into time interval to be measured and is considered hereafter. Phase "quantification" in such a case is to be admitted within the tolerable accuracy in the system. In practice , systems adopting such "diversity" approach are exemplified by the use of multiple frequencies in CW systems as DECCA system and multiple modulating frequency as in Tellurometers. In pulse systems as doppler radars, multiple Pulse Repetition Frequencies (PRF) are used to implement the diversity principle.

III. Counter-Based Phase Measurement and Display

In the following , we assume phase difference-to-time interval conversion . This is usually done at frequency of a few kHz and even less according to the considered system . We are now confronting a counter-type phase measurement whose result is to be digitally displayed.

In such a discrete counter type , the two signals having Frequencies ν kHz that are subjected to phase difference measurement have to be conditioned . A typical signal shaping scheme is shown in Fig. 2. Moreover , a "Clock" signal are generated using an independent crystal oscillator.

3.1. The Phase Measurement Scheme

A scheme based on the counting method is described below in Fig.3. In this scheme a linear phase detector is built around the D-Flip/flop 7474. It is sufficient for our purposes here to have a gating signal at the 7474 output whose duration is equal to the time delay between the reference signal (A) and the "delayed" signal (B). Therefore, the remainder (the integrator) of the linear phase detector is skipped.

As to the clock frequency relation to the input frequency ν , their ratio controls the accuracy with which the phase difference or the time interval is measured. We have chosen the clock to be 1000ν . Averaging of several measurements would yield better accuracy than 10^{-3} and reduce the random error that may occur in practical conditions of measurement.

Such discrete (74590) and integrated (as 7226, 7216 and 8253) counters suffer quantization error specially at low clock rate leading to an accuracy problem. This would be improved by adopting some sort of vernier or an averaging procedure over a large number of measurements. This latter approach was adopted here where the processor commands several hundreds of measurements and takes their average value as the required result *with the inherent improvement*. The flowchart of the averaging stage is given in Fig. 4. It is noteworthy that a hardware averaging is realized though accumulating 64 readings in the 2-stage counter (74590) before being accessed by the processor. This is controlled by a specific timing loop in the processor software. The data for 2048 readings are averaged for each measurement. This means that each reading takes about 2 seconds. The smoothing effect of averaging has proven very effective in reducing the measurement errors. Further computation such as determination of the measured time delay (or equivalently the distance) so as to combine several measurements in multifrequency type systems (e.g. Tellurometers). These algorithms form an essential part of the built-in function of the developed operating system for the μP 6802 chosen for the application.

3.2. Data Formatting for Display

For display purposes, some sort of data formatting is required. This is attained mainly through *Binary-to-BCD conversion*. Other code conversions depend upon the adopted display and its display drivers.

As to the Binary-to-BCD conversion a software solution was adopted. The relevant pseudocode for the algorithm is given in Fig.5.

As to the *Display*, a multiplexed 8-digit 7-segment display is used for both numeric as well as some alphanumeric-type data. Adding some simple messages under microprocessor control is essential. The choice of display multiplexing is generally a decision taken power-consumption-wise.

To control the display so as to present some Alphanumeric messages, the encoding of the english alphabets and numerals is to be implemented. This will be realized through programming an EPROM for driving the 7-segment display as shown in Fig. 6.

IV. User interface : Keypad and Display

A keypad is conceived as a set of function keys for operating the system. The Keyboard-and-display functions are built around the keyboard encoder of INTEL 8279 with built-in scanned (multiplexed) display controller. The display scanning requires an external demultiplexer. The underlying operating principle of the Keyboard-Display module is shown in Fig.7.

V. The Microcomputer Attachment

A microcomputer board is built around the Motorola μ P 6802 and is shown in Fig.8. Detailed schematic circuits and layout are available. Data of the processor 6802 and ACIA 6850 are taken out of the Motorola data book [8].

This board is designed to control the measurement process in polling mode of input-output (I / O). The keypad is designed to interrupt the processor. The measured data is partially processed in the RAM ; this could be with minor modification become a *Dual port RAM* for connection to avionics computers that can't tolerate the polling mode of I/O [6].

5.1. The Memory Map

The addressing zone (64 K) of the Motorola μ P-6802 has been partitioned as follows :

0000 - 07FF	:RAM (and Stack)
4000 - 5000	:Peripherals
8000 - FFFF	:ROM (Operating System)
Reset Address	:8000 (at FFFE+FFFF)
SWI Address	:FC00 (at FFFA + FFFB)
IRQ Address	:FA00 (at FFF8 + FFF9)

As to the peripheral zone , the following partition is used :

4000-40FF	:8279 Keyboard-Display.
4100-41FF	:74245 Status bus driver
4200-42FF	:74474 Latch
4300-43FF	:Reserved for an A/D converter
4400-44FF	:74590 counter-1
4500-45FF	:74590 counter-2

5.2. The System Software (Operating system)

It written in the code of Motorola 6802 and dumped in an EPROM 27256 (32 kbyte). A part of this software (widely known as the Operating system) is concerned with interpretation of :

A. Interrupt modes :

RESET
IRQ for Keyboard operation.
SWI for serial communication (ACIA operation).

B. Commands : S (Status : A present / B present , Overflow)
 a (Freq. A), b (Freq. B) , A (phase A-B) , P (phase B-A) .

C. Test Display.

D. Data Entry : Numeric data for averaging or computation.

E. Measure.

F. Display readings and messages.

Other functions such as initialization ,computation ..etc are included

-Initialization

This concerns the :Stack range,Reset Address ,SWI Address and IRQ Address as well as the keyboard/display Modes (8279) being set to : KBD(12),CLK(2A),Dsp.RAM(70),ERR.(E0), CLR and Blank Display (A3).These values are selected and programmed after the data sheet [9].

-Messages

The following messages are used in the system :

A-Prompt Messages

B. Error Messages corresponding to each operational function in both test and measurement.

C. Numeric information

D. Entered Data and commands

-Computation Algorithm

The computation algorithm is developed to perform the reading determination and correction functions. This may be considered as application software and may include algorithms for position fixing as those developed in [5,6].

Conclusions and Future Work

A built-and-proven phase difference or time delay measuring unit is presented in this work .This unit has been field tested for upgrading a Tellurometer . Although the specific system is built around the Motorola microprocessor 6802 ,the system could be built around other microprocessors and microcontrollers.Dual port RAM is considered as a sort of direct memory access (DMA) mode that is heavily used in avionic systems.This would free the processor from frequent polling or monitoring the measuring unit on the one hand.On the other hand,it allows further processing of the stored data so as to implement smoothing and prediction required for a transponder type system like DME needing "delay locking "to distinguish its own signal from other interferers. Detailed schematic circuits and programs are available at the author department if needed.

References

- [1] M.Kayton and W.R.Fried," Avionics Navigation Systems ", John Wiley and sons,New York,1969 ,Chap.5.
- [2] J.Powell," Aircraft Radio Systems ",Chap 6.Pitman, London,1981,
- [3] A.Helfric," Modern Aviation Electronics ",Chap 4 .., Printice-Hall,N.J.,2-nd Edition,1994.
- [4]B.Forssell,"Radio Navigation Systems ",Chap 4,6,12. Prentice Hall ,1991.
- [5] A.M.Hamad and M.A.Matar ," Operability Improvement of Hyperbolic Position fixing Systems" Proc.of 8-th URSI conf.19-21 Feb.1991.,Cairo ,Egypt.

- [6] A.A.Mohamed ,A.M.Hamad and M.A.Matar " Towards Better Position Fix with Hyperbolic Navigation Systems "Proc. of the 4-th ASAT Conf., 14-16 May 1991, Cairo,Egypt.
- [7] M.A.Matar, "Discretization-Induced Ambiguity Problem in Phase Handling Systems" Proc.of 9-th URSI conf.18-20 Feb. 1992.,Cairo ,Egypt.
- [8] Motorola :Microprocessors,Microcontrollers and Peripheral Data Books ,1988
- [9] Intel :Microsystem Component Handbook ,1985.
- [10] Texas Instruments : The TTL Data Book ,1987.
- [11] Microprocessors Data Handbook ,Micro-Tech Publications, 1991.

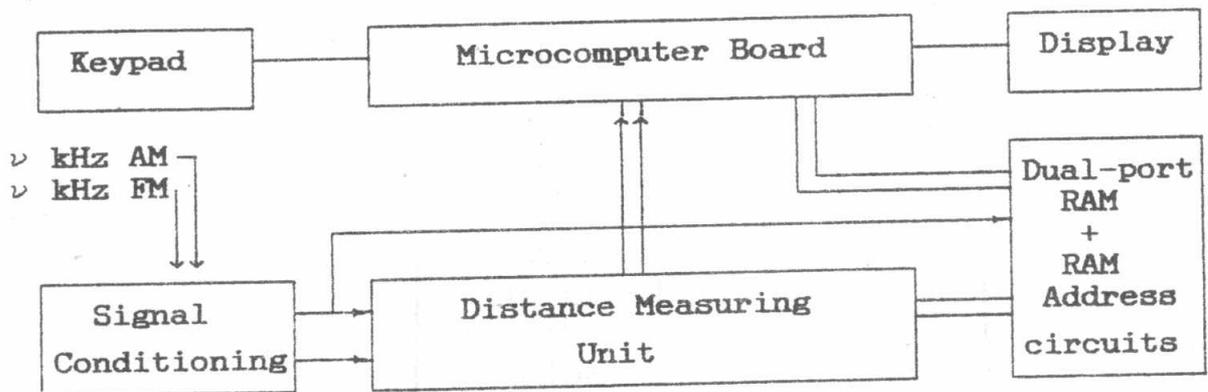


Fig.1.The Digital Processor Functional Diagram

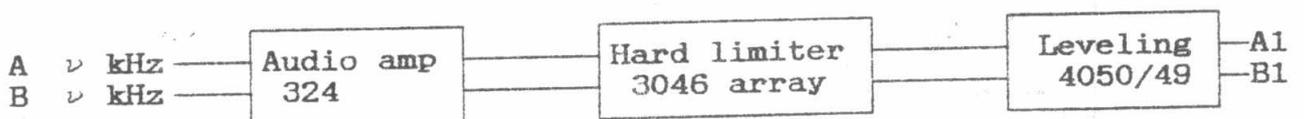


Fig.2.The kHz A and B Signal Conditioning section

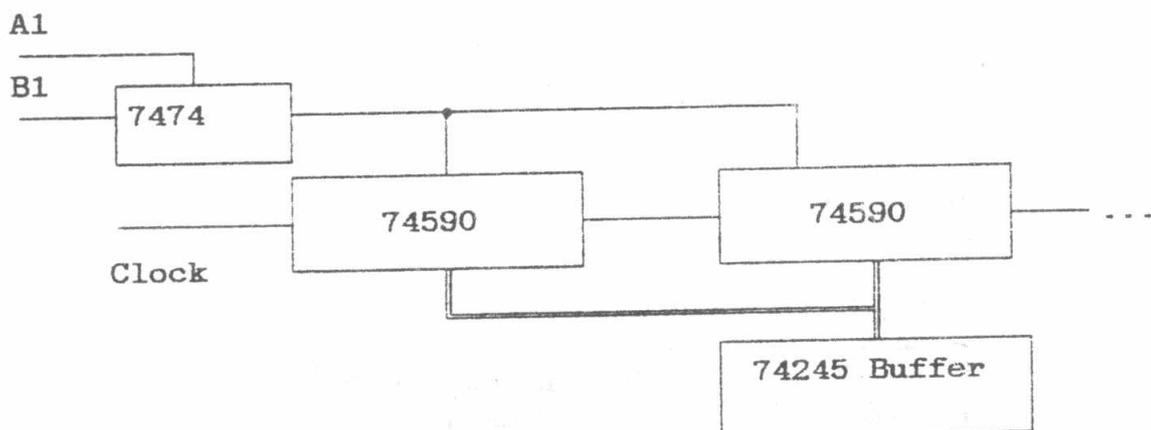


Fig.3. Counter type phase measurement

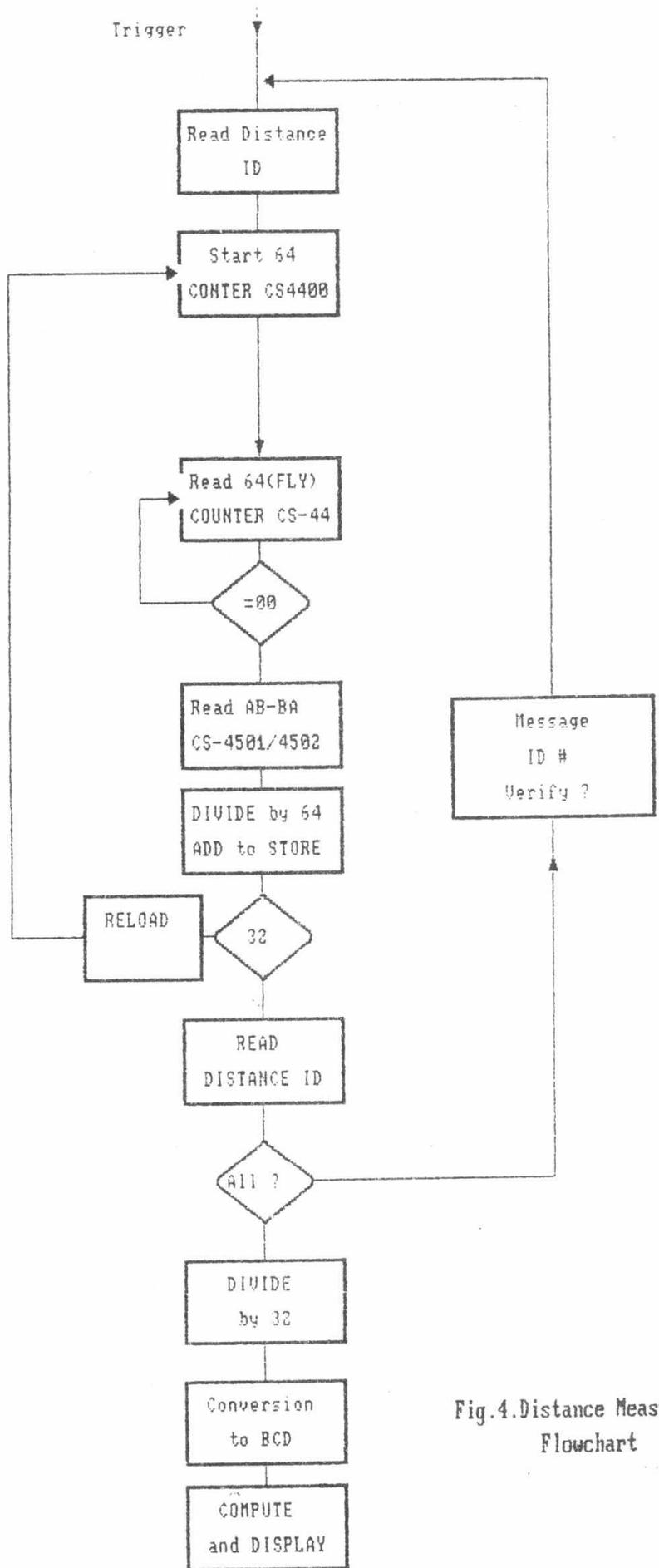


Fig.4.Distance Measurement Flowchart

1. Clear locations for Thousands, Hundreds, Tens and Units digits
2. Load the binary number.
3. Do
 - Subtract $(1000)_{10}$ from the number
 - In-place store the remainder
 - increment Thousands digit
 - While + ve sign of the remainder .
4. Load the binary number
5. Do
 - Subtract $(100)_{10}$ from the number
 - In-place store the remainder
 - increment Hundreds digit
 - While + ve sign of the remainder .
6. Load the binary number
7. Do
 - Subtract $(10)_{10}$ from the number
 - In-place store the remainder
 - increment tens digit
 - While + ve sign of the remainder .
8. Load the binary number
9. Store the remainder in the units digit

Fig.5.Pseudocode for (4-digit) Binary-to-BCD Conversion Algorithm

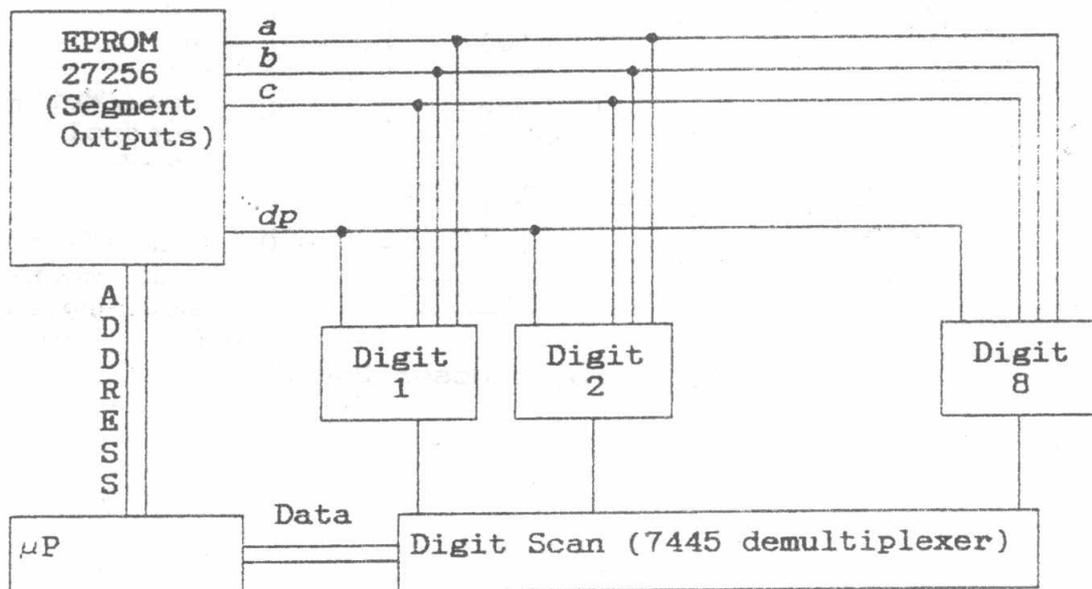


Fig.6.Alphanumeric Display based on Common 7-segment displays

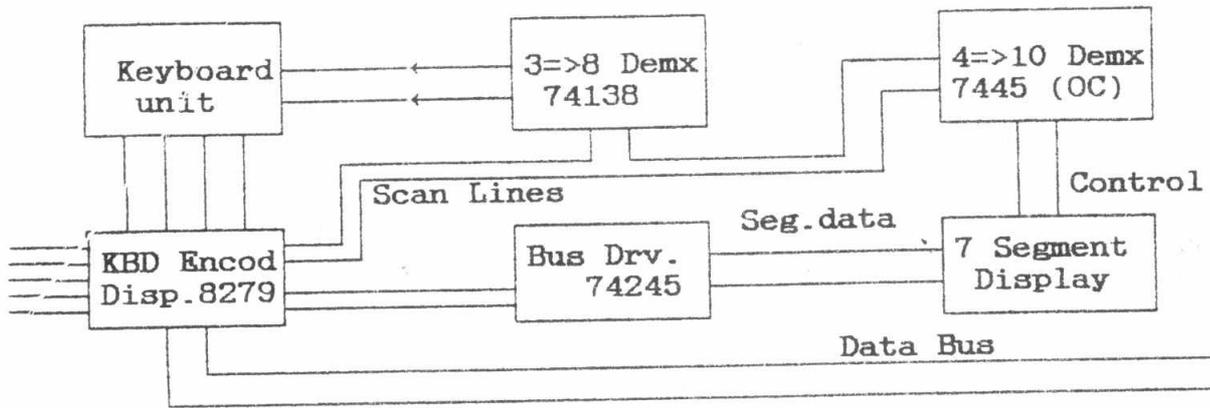


Fig.7. Keyboard / Display

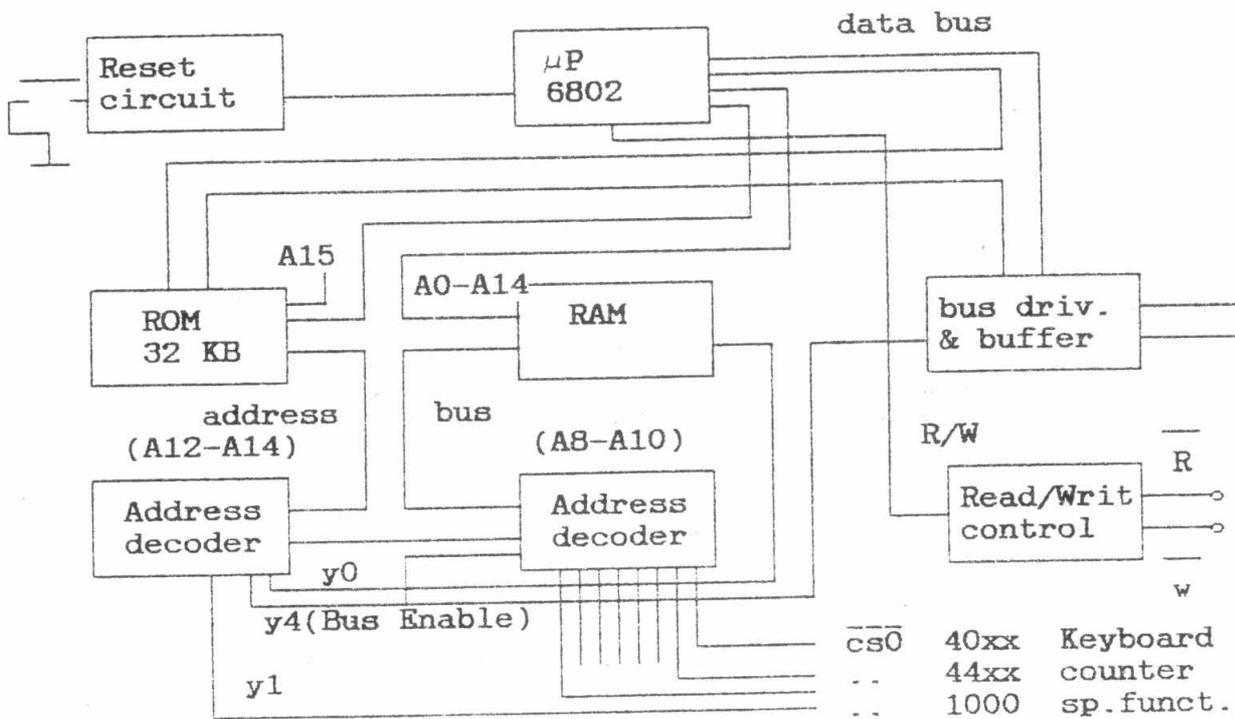


Fig.8. Microprocessor Board