

## A microprocessor-based tide measuring system

A Joseph and E S Desa

Instrumentation Division, National Institute of Oceanography,  
Dona Paula, Goa 403 004, India

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**Abstract.** The design and performance of an oceanographic tide measuring instrument is described. Tidal data converted to read directly in engineering units is stored on EPROMs (erasable programmable read only memories). The storage capacity is about 80 days of data which is sampled every 15 minutes. The instrument has built-in interfaces to a seven segment display, a printer and a chart recorder so that the user can inspect data in the field. Data collected over a week of unattended operation at the Mandovi river, Goa is presented.

### 1. Introduction

Tide measuring instruments (or tide gauges in brief) belong to that class of oceanographic instruments that sample and record data unattended. For several weeks in remote locations. Under such conditions, it is clear that this type of instrument should consume a minimum of power, be rugged in mechanical design, and also possess a reliable method of storing or displaying collected data.

In the older forms of tide gauges i.e. the mechanical Pattern Gauges, personnel on site are needed to monitor data recording, check mechanical parts, and change the paper on the recording drum at regular intervals. Later tide gauges developed in this laboratory (Peshwe *et al* 1980) incorporated strain gauge pressure transducers, and analogue signal processing circuits to trace the tidal signal as a function of time on strip chart recorders. Close attendance was needed if data was to be collected on a routine basis.

In order to avoid the above shortcomings of tide gauges in general, we report here the design and development of a fully automatic self-recording tide gauge which uses an Intel 8085 microprocessor in a single board computer developed in-house, and erasable programmable read only memories (EPROMs) for data storage. A single 12 V lead acid battery provides power to all circuits in the shore unit. As a departure from previous design, user friendly features built into the instrument permit the user to inspect or obtain hardcopy outputs of data at the recording site or in the laboratory in linearised engineering units.

In the next section, a mechanical description is given of the sea unit which houses a Digiquartz pressure sensor. The shore electronics which connects to the sea unit via a 3-core underwater cable is described in § 3. Simplified software flow diagrams are discussed in § 4. Tidal data obtained in the field with our instrument are presented in § 5. Finally, the work is summarised in § 6, together with future improvements to be incorporated in the existing design.

### 2. Sea unit

A photograph of the complete system is shown in figures 1 and 2. The sea unit (figure 1) consists of a cylindrical brass bottle containing only a Digiquartz pressure transducer. The unit sits on a stainless steel framework with a 10 kg annular lead weight

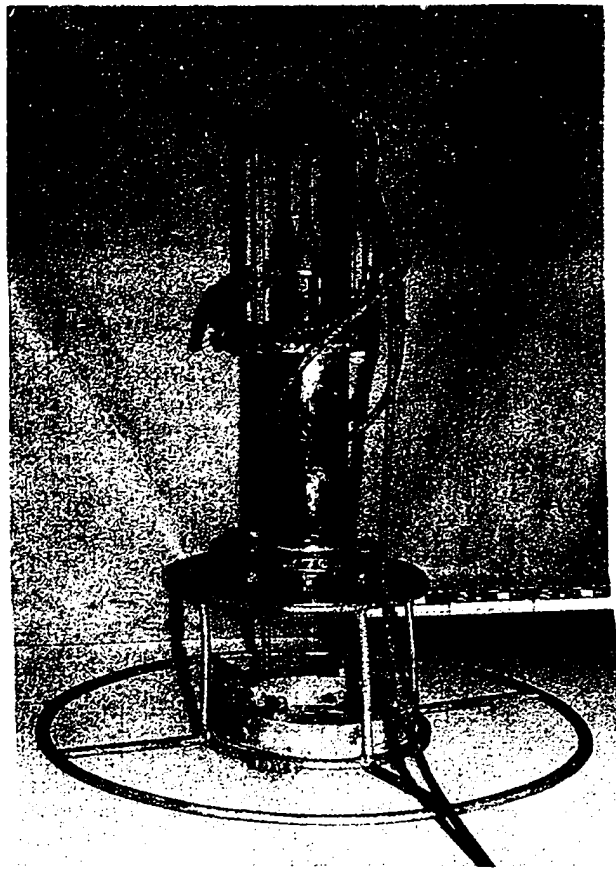


Figure 1. Sea unit.

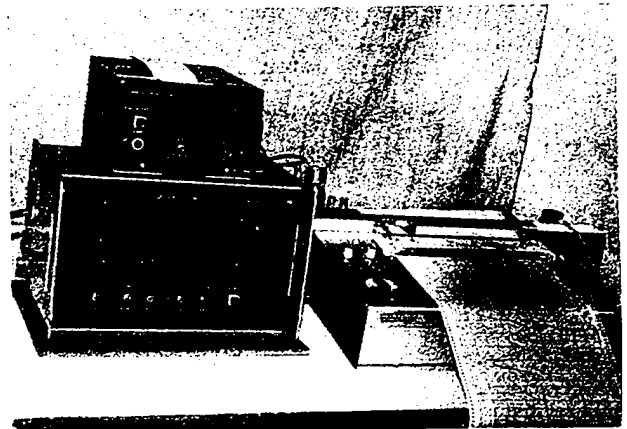


Figure 2. Shore unit electronics

secured on the base of the framework. A 500 m cable with a male flying lead at one end can be plugged on to an underwater connector mounted on a fixed top plate of the brass bottle. The other end plate of the bottle is removable and is secured with nuts and bolts and an O ring seal to the bottle, and to the framework. The sensor is fixed inside the bottle to the removable end plate with its pressure port aligned with a through hole on this plate. All potential entry points have O ring seals to prevent seawater entering the bottle.

2.1. Sensor

The transducer used in measuring tidal height is the Model 8060 D S Digiquartz sensor (from Paroscientific Inc., USA) which has a range of 600 kPa and a calibration accuracy of 0.015% below 300 kPa and 0.025% above.

The choice of this sensor was made due to several excellent design features incorporated in its construction; the important features being:

- (i) Its long term drift and stability characteristics are a factor of 10 better than the best existing strain gauge transducers (Wearn and Larson 1982).
- (ii) High reliability and accuracy.
- (iii) The output is frequency based, and hence is easily incorporated in microprocessor designs.
- (iv) Low power requirements +6 V, 1 mA.
- (v) Wide operational temperature range -54 °C to 106 °C (Paros 1976).

The frequency output of the transducer varies nominally from 40 kHz at zero pressure to 36 kHz at full scale absolute pressure, and this change is described by the equation:

$$P = A(1 - T_0/T) - B(1 - T_0/T)^2 \quad (1)$$

where  $P$  = absolute pressure in kPa

$$A = 6.705 \text{ MPa}$$

$$B = 3.410 \text{ MPa}$$

$$T_0 = 25.83683 \text{ } \mu\text{s.}$$

The pressure  $P$  is the absolute pressure measured by the transducer i.e. the pressure exerted by the column of seawater above the sea unit, and the atmospheric pressure exerted on the water surface. Under normal atmospheric conditions, atmospheric fluctuations of the order of 50 mm change in water level are expected, and this is well within the 100 mm accuracy margin demanded by most tide gauge users. Thus we have chosen to neglect the atmospheric contribution, and to assume that it is essentially a constant giving rise to an offset equivalent to 10 m water level for standard seawater. Moreover, in harmonic analysis of tide data, what is important is not the absolute tidal height but the tidal amplitude. In storm surge measurements, atmospheric pressure changes must be taken into account as fluctuations corresponding to 300 mm change in water level can be expected. In such cases, a differential type pressure transducer with the negative port vented to the atmosphere via a separate outlet will effectively annul the atmospheric component presenting only the tidal variation.

In equation (1),  $A$  and  $B$  are the calibration coefficients supplied by the manufacturer,  $T_0$  is the period of the transducer output at zero pressure, and  $T$  is the measured period of the signal output. The temperature dependence of  $A$ ,  $B$  and  $T_0$  is small and negligible (Busse 1978), and may be assumed constant. The calculated value of the pressure  $P$  is easily converted to read in metres of water height by the multiplying factor  $1.0197 \times 10^{-4}$  valid for standard seawater at 35 000 PPM salinity and 4 °C.

3. Hardware description of the shore unit electronics

A simplified block diagram of the shore unit electronics is shown in figure 3. The electronics is built around an 8085A single board computer (SBC) running at 4 MHz. The SBC contains 6 k EPROM space for program code, 1 k random access memory (RAM) for scratchpad calculations, and on-board decoding logic for up to four parallel I/O ports (Intel 8255) giving a total of 96 programmable I/O lines.

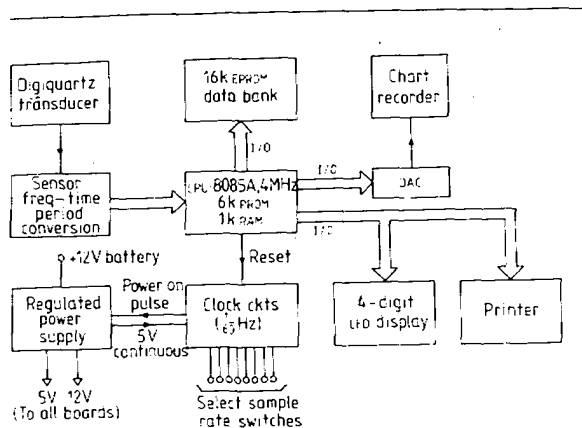


Figure 3. Block diagram of shore unit electronics.

An EPROM card containing 16 kbytes of memory for data storage, a 4-digit LED display, a chart recorder, and an 18-column impact printer are interfaced to the SBC card via I/O ports. The remaining I/O lines are used for control functions such as status checks on front panel switches, generating set and reset pulses to flip-flops, and energising a bleeper mounted on the front panel of the unit.

A separate card is used for converting the frequency output of the transducer into 16-bit time period data for software processing by the CPU (central processing unit). The technique involves the measurement of the number  $N$  of 1 MHz clock pulses over the time interval occupied by 1000 output cycles of the transducer signal. Thus:

$$N = 1 \text{ MHz} \times (\text{average period } T) \times 1000 \quad (2)$$

$$N = 1000 T \text{ counts.}$$

For example if  $T = 26.245 \text{ } \mu\text{s}$  (38.09 kHz) then  $N = 26245$  counts.

With this method a pressure resolution of 0.04% due to the uncertainty of one clock count out of the total number of measured counts is obtainable. In other words, a depth resolution of 25 mm over a full scale range of 60 m is realisable. A higher pressure resolution of 0.0004% is possible by using a 10 MHz clock and counting to 10 000 sensor cycles.

The CMOS (complementary metal oxide semiconductor) clock circuits which are continuously powered, reside on a card which provides the user with programmable DIL (dual in line) switches for the selection of the data sampling rate. Sampling rates from 1 minute to a maximum of 255 minutes are obtainable. The clock oscillator on this card provides a basic 1/60 Hz clock signal to binary counters in cascade. When the counter outputs match the selected sampling interval code on the comparators, a high pulse from the comparator sets a flip flop energising a switched driver which provides power to the remaining cards. After completion of the program, the CPU resets the flip-flop and turns off power to the SBC card, EPROM card, and the sensor frequency conversion card.

4. Software description

The software developed for this instrument was written in 8085 Assembly language on an Intel Microprocessor Development System (MDS) and essentially consists of three independent modules, namely the main data acquisition module, the display/print module for inspecting data on a 4-digit seven segment display or obtaining hardcopy outputs, and the chart module for tracing the tidal oscillation onto a chart recorder.

4.1. Data acquisition

The simplified flow diagram of this module is shown in figure 4. The module performs the following essential functions:

(i) The time period  $T$  from the binary counters on the sensor board is accessed by the CPU and stored temporarily as a binary word in RAM.

(ii) A novel method of using the Intel Floating-Point Arithmetic Library (FPAL) routines evaluates the sensor polynomial (equation (1)), and stores the computed pressure data in RAM.

(iii) The tidal signal is sampled 512 times over a time span of 30 s and the final result is the averaged tidal height (without the atmospheric offset) in centimetres. This is also stored in RAM in 16-bit binary integer format.

(iv) The final tidal height data is written into the first empty 2-byte area of the 16 k EPROM memory bank. The routine written for this purpose generates the appropriate address and chip enable signals to the selected EPROM, and issues the 50 ms write pulse to ensure that data is burned into the desired EPROM address location.

(v) On completion of the above, the CPU generates an audible bleep to indicate the end of data acquisition, and resets the flip-flop on the clock board, thus switching off power to itself and the remaining electronics except the clock board.

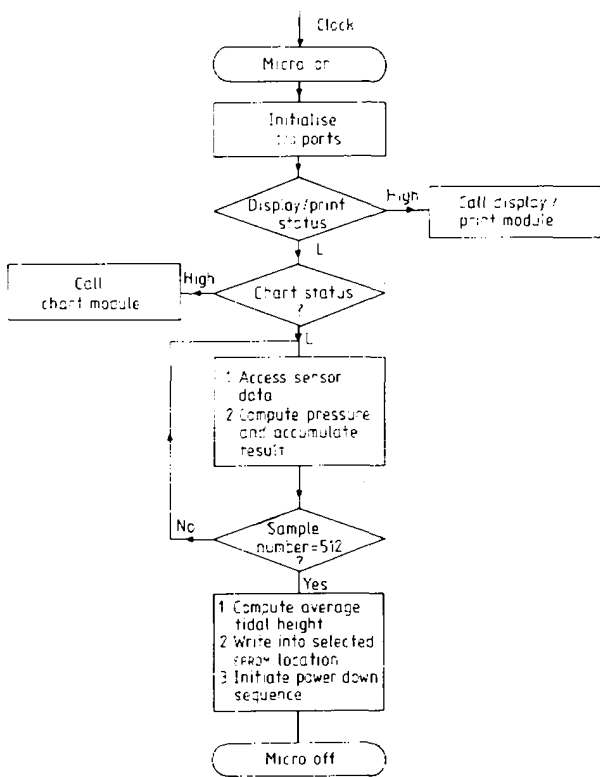


Figure 4. Flow diagram of main module.

4.2. Display/print module

The data acquisition module 'sees' this module as its subroutine and calls it when the status of the display/print switch on the front panel is high. The module begins by displaying the last ten data values in descending order starting with the most recent sample (this is useful when trouble shooting the instrument). After each data value is displayed, a bleep is sounded and the

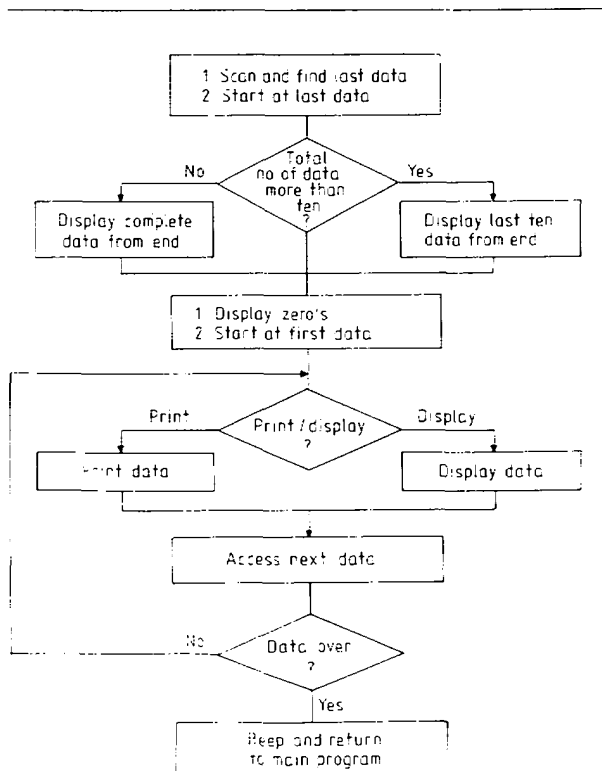


Figure 5. Flow diagram of display/print module.

display blanked out simultaneously. The end of display of ten data is indicated, by displaying zeros on the display panel.

The second and third stages in the program flow in figure 5, provide the user with the options of visual output, or a printout of all collected data starting with the first sampled data. Selection of either of these choices is decided by the status of a switch on the front panel of the shore unit. During printing, the CPU issues a blanking signal to the seven segment display so as to conserve power. The end of data display is signalled by audible bleeps.

4.3. Chart module

As before, the high status of the chart switch selects this module. In the design of this module, an offsetting feature allows only tidal variations to be traced on the largest scale selection of the chart recorder, independent of the datum at which the pressure sensor has been placed during its operation. In addition, time marker pips are generated on the tidal trace. This is useful in dividing the time axis of the recorded trace into known intervals.

The flow diagram in figure 6 begins by scanning the complete data set in memory, and locating the minimum value from the set. This minimum is subtracted from each data sample, and produces the desired tidal change via a 12-bit digital to analogue converger (DAC) whose buffered output is fed to a chart recorder.

In reading each data sample, the CPU performs a binary division by 99 of the address of the high order byte of that sample. A marker pip is generated when the remainder of the division operation is zero. The pip appears on the tidal trace by adding a constant  $K$  (proportional to the height of the pip) to the offsetted data. The first marker pip on the record is generated after  $(N + 1)/2$  samples where  $N = 99$ . The end of the data plot is signalled by audible bleeps, so that the user knows that all data has been plotted.

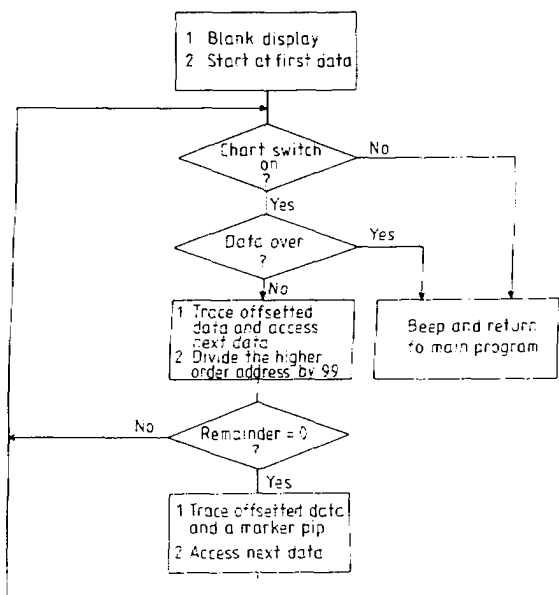


Figure 6. Flow diagram of chart module.

### 5. Field performance

The sea unit was checked for no leaks, and then deployed at the lowest tide to a depth of 1 m water height. This was necessary so that the sensor was never exposed to the atmosphere. The location for the experiment was a sheltered cove in the Mandovi River estuary in Goa, where no extreme wave or wind effects were present. A length of 500 m of underwater cable was secured to the river bed with cast iron weights, and provided the necessary link between the sea unit and the shore electronics.

The electronics was switched on, and left unattended for more than a week. Initial problems due to humidity were cured by varnishing all printed circuit boards.

The chart recorder output with time marker pips every 24 h 45 min is typical of tidal changes and is shown in figure 7. The maximum tidal amplitude is about 2 m.

### 6. Conclusions

In the foregoing sections, a description has been given of a new type of tide gauge using a single board computer to automate and simplify the task of data acquisition. The important outputs emerging from this development include:

- (a) The on-site calculation of the tidal height directly in metres using the Intel floating point arithmetic routines† to evaluate the sensor polynomial (equation (1)).
- (b) The use of EPROMs to store data is ideally suited to tide measurements as the tidal signal is a slowly changing variable, and hence memory requirements are not critical. Ottonello and Papa (1980) have also used EPROMs as a data storage medium.
- (c) User friendly interfaces have been built into the instrument so that data can be inspected on site either on a seven segment display, printer, or chart recorder. No separate playback unit is required to process or examine data.
- (d) The use of CMOS circuitry, and the automatic power on/power off features conserve power and satisfy the requirements of long term self recording instruments.

† Intel 8080/8085 Floating Point Arithmetic Library user's manual No 9800452-03 1979 Intel Corporation.

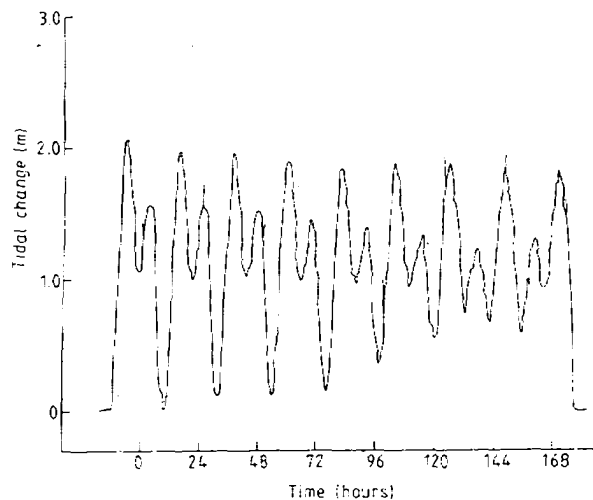


Figure 7. Tidal changes as a function of time (in hours) shown with marker pips every 25 hours approximately.

One serious drawback to the present set up is the absence of a real time clock to log tidal height with time, as would be necessary for any serious tidal computations. The existing method used here is to use the basic crystal oscillator to power the electronics at precisely set time intervals e.g. every 15 min without reference to a time standard e.g. GMT.

Improvements to the existing design will include a real time clock chip (MM 58167A) to be incorporated in the existing circuitry, and necessary software additions so that real time is logged with tidal height. With the advent of satellite technology this tide gauge can be made to transmit data on a near real time basis. Data can then be received for analysis in the laboratory on a conventional telex facility.

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### References

Busse D W 1978 Digital quartz pressure transducers for air data applications  
*Air Data Symposium, US Air Force Academy, Colorado Springs*

Ottonello P and Papa L 1980 All solid state data logger for recording slow sea oscillations  
*J. Phys. E: Sci. Instrum.* **13** 287-8

Paros J M 1976 Digital pressure transducer  
*Measurements and Data* **10** No 2, issue 56

Peshwe V B, Diwan S G, Joseph A and Desa E 1980 Wave and tide gauge  
*Indian J. Marine Sciences* **9** 73-6

Wearn R B and Larson N G 1982 Measurements of drift on digiquartz pressure transducers  
*Deep Sea Research* **29** No 1A, 111-34