Kodaikanal Obs. Bull. (1993) **12**, 1-14

Telescope drive requirements and design of a Microcontroller based drive and display system

V.CHINNAPPAN

Received 9 November 1992, accepted 5 January 1993

Abstract

Optical telescope is a precision instrument which gives images of stars and galaxies when the telescope is pointed towards them. To design a good telescope drive, the requirements of a good telescope is to be well defined. This article gives an overview of the requirements and the actual design of the drive and display system for the 76 cm telescope at VBO, Kavalur.

Key words : microcontroller, telescope drives, telescope position displays, software

1. Introduction

The present 76 cm telescope was fabricated in house, in the Institute's workshop. The optical workshop ground, polished and aluminized the mirror. The dome, telescope tube and other accessories were made in the mechanical workshop at Kavalur. Till 1983, the polar axis had a friction wheel drive. There was no star position display system hence it was very inconvenient to point the telescope to the required object. In order to effectively use the telescope, a telescope position display system was added later. This system used a 10 bit absolute encoder to measure the angle by which the telescope shaft moved. As the resolution of the encoder was very poor, a thumbwheel switch was added to extend the range of the encoder. An INTEL 8039 single chip computer based display system was fabricated and installed. Programs were written in machine code of 8039 chip as there was no development support available (Chinnappan 1982). It was found that the friction drive failed to transmit the motion properly creating error in tracking. Hence it was changed by worm gear set, manufactured to Institute's specifications by a local firm in Bangalore. The performance of the telescope has considerably improved after this change. To improve the display accuracy, a microcontroller based system was designed and fabricated. The 16 bit, binary, multiturn, optical encoders were installed for position information. The stepper motor drive which had only limited speed range was modified to have speeds like set, guide, fine guide along with the track were provided like the 1 meter telescope. Light emitting diode (LED) displays were provided in the console which enabled the read out of position even from a distance. Independent sidereal time and universal time were provided by a separate clock which was provided by Raman Research Institute, Bangalore. The system was installed in 1988 and the operation of this low cost system was found suitable for this class of telescopes.

It is to be emphasized that before a telescope drive is made, all the requirements are to be thoroughly understood. It is now possible to have different alternatives for drive and display system. This will enable one to design an optimum system for a given size of the telescope. The next section deals with the requirements of the optical telescope and different drive schemes possible.

2. Basic requirements of a Telescope

The basic requirements of a medium sized telescope is already well known. The main requirements are good mirror without errors, accurate position display system to acquire objects with ease, ability to focus the object on detector, suitable operating speeds to acquire the object at a short time, good tracking accuracy and ability to guide on the star for longer observation time. A good dome design which does not create temperature difference between outside and inside the dome is also required. Modern telescopes need efficient and easy to use detectors. Ability for on-line data reduction atleast partially is necessary, so that the quality of data collected is assured. Even though unattended guiding system like autoguiders will help to improve the observing quality, it is not an essential requirement for all telescopes.

3. Telescope drive requirements

Telescope drive in polar and declination axes require varying speeds for acquisition of the object. When the star to be acquired is more than 10 degrees, then the speeds in the range of one to two degrees per second is required. For small and medium sized telescopes, the slew speed can be even as high as 5 degrees per second. Speed ranges of 100 arcseconds and 10 arcseconds per second are useful to position the star image at the centre of the detector, while one arcsecond per second is required to correct any drift in the star position across the detector during observation. Hence, the normal drive speed range required is more than 7200 : 1. This wide range is normally high for a single motor to produce. Only special motors like the servo motors used in 2.34 meter Vainu Bappu Telescope (VBT) can give this much range with matching gear box. Smaller telescopes can use stepper motor for low speeds and AC induction motor for slew speeds.

Normally DC servo motor cannot be used in open loop configuration because it may have unacceptable speed regulation with varying load conditions. Hence closed loop control with speed feedback is required to achieve good tracking speeds. Even current feedback is required for better performance. The drive motor power rating for telescope drive is not more than 400 watts. VBT uses a DC servo motor with 300 watts capacity. As linear DC amplifiers are available up to 1500 watts, linear amplifiers can be used for power control. Ordinary DC motors like shunt motors may not be suitable for telescope control because of their inertia, electrical and mechanical time constants. Speed loop alone gives a speed accuracy of about only 1%. Telescope drives need more accuracy than this. Only Phase Lock Loop (PLL) control with incremental encoder can reach this accuracy. At present servo motors are locally available hence it is highly recommended for drives of large telescopes.

Stepper motors are attractive for medium and smal size telescopes. It requires minimal system to control varying speeds. A four phase DC stepper motor has good position accuracy. The stepper motor controller which generates the sequence of voltage levels required at different phases are not very complex and can be fabricated in house. Stepper motors can be used in open loop configuration. Very high accuracy systems can use stepper motors in closed loop configuration with position feedback from encoders and other similar devices. Stepper motor does not cover the speed range that is required for telescope control. Normal motors have speed range in the order of 600:1. Unlike other motors, stepper motor cannot start and run at high speeds. It has to be slowly accelerated to high speeds. This requires additional programmable controls. Usual step size of stepper motor is 1.8 degrees per pulse input. It is possible to run in half step mode with 0.9 degrees per step. Micro-stepping which gives 100 or more positions in one step size of 1.8 degrees may be used to have low speeds and high positional accuracy without the help of reduction gears. Micro-stepping needs additional hardware with its own complexity but the system cost may be less than the DC servo motor drive and is free from stability problems.

Three phase AC synchronous motors were used in older designs. As the AC motor speed is normally constant, to cover the varying speed ranges, separate motors with associated reduction gear for each speed is required. As the normal motor speeds are 1500 or 3000 RPM, it requires matching gear trains to achieve the required speed ranges. In the 1 metre Carl Zeiss telescope at Vainu Bappu Observatory (VBO), 5 different motors are used for slew, set, guide, fine guide and track speeds, with its own associated gear box. The output of all the motors end in a single shaft. This requires machanisms like differential gears. As the speed of the motor and accuracy of speed depends on the frequency of AC supply, it is possible to generate accurate input frequency using temperature compensated crystal controlled oscillators. A very small speed variation at selected speed is possible with adjustment of frequency. As the motors are less than 400 watts, it is possible to drive them with DC linear amplifiers and such a system is installed at 1 meter telescope recently (Srinivasan 1989).

Recent advances in AC motor speed control makes them a competing candidate against the DC torque (servo) motors. The industry's workhorse AC induction motor can be electronically controlled using vector control techniques to have variable speed. Such systems are coming to the market in recent times. Induction motor is the rugged one of all the motor types and is easily manufactured and repaired. But the electronic control needs high speed processors like Digital signal processors (DSP).

To summarize, a DC servo motor control gives very simple mechanical gear system and can have a very wide speed range. A single motor may be enough for each axis of the telescope. The complexity is only in the closed loop feedback for the DC motor. A stepper motor in open loop configuration can be simple and additional motor for slew speed is required. This can be rugged AC 3 phase induction motors. The additional complexity is in the gear system; differential gear is required to couple the two motor shafts to the telescope shaft. Microstepping scheme with feed back can give accurate speeds and high speed operation requires closed loop control. This may eliminate the need for the gear box. The AC motor control is electrically simple, but the mechanical complexity is very high. Large number of gears and differential stages are required. The recent electronic speed control techniques using DSPs may see the AC motor as a rival to the torque motor applications with smooth speed control systems.

4. The 76 cm telescope drive

From the previous discussion on the telescope drives, it is seen that a stepper motor system operated in open loop configuration is the most cost effective solution for small telescope drives. The 76 cm telescope drive consists of a stepper motor drive system which controls the set, guide, fine guide and track speeds. A 3 phase AC induction motor is used for slew speed. Both the shafts of the motor is coupled to the telescope drive shaft through a differential gear implemented with harmonic drive. The different speeds available are:

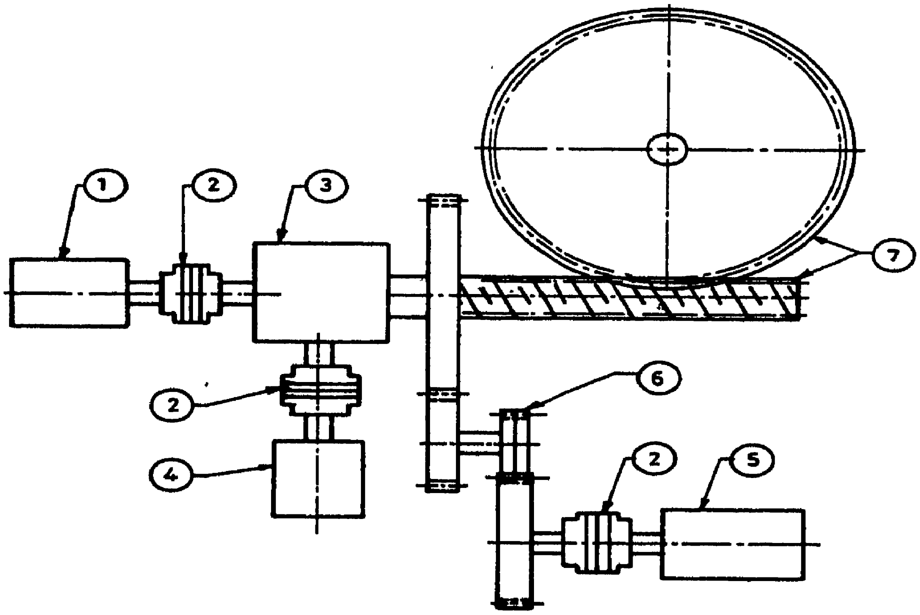
Slew	: 2 degrees per second
Set	: 120 arcsecond per second
Guide	: 10 arcsecond per second
Fine Guide	: 1 arcsecond per second
Track speed	: 15 arcsecond per second

The declination axis drive is identical to polar axis drive except for the fact that declination axis need not have track speed. Normally step motor moves by 1.8 degrees per step. In order to move the telescope in the increments of about 0.2 arcsecond per second, the gear ratio between step motor and telescope shaft is 32,400:1. This can be achieved only through multiple stage gear box. The polar axis drive with gear box details is shown in fig.1.

In order to achieve compactness, harmonics drive which gives higher gear reduction ratio of 80:1 is used in the present 76 cm telescope. The worm wheel gear reduction in polar axis is 440:1 and in the declination axis, it is 372:1. One step of stepper motor moves the telescope by 0.18 arcsecond in polar axis and 0.217 arcseconds in declination. To achieve a speed of 2 degree per second in polar axis, the stepper motor needs 38,380 pulses per second. As normal motors respond to about 600 pulses per second, only low speeds can be controlled by stepper motor. The slew speed is achieved by using a 3 phase AC induction motor.

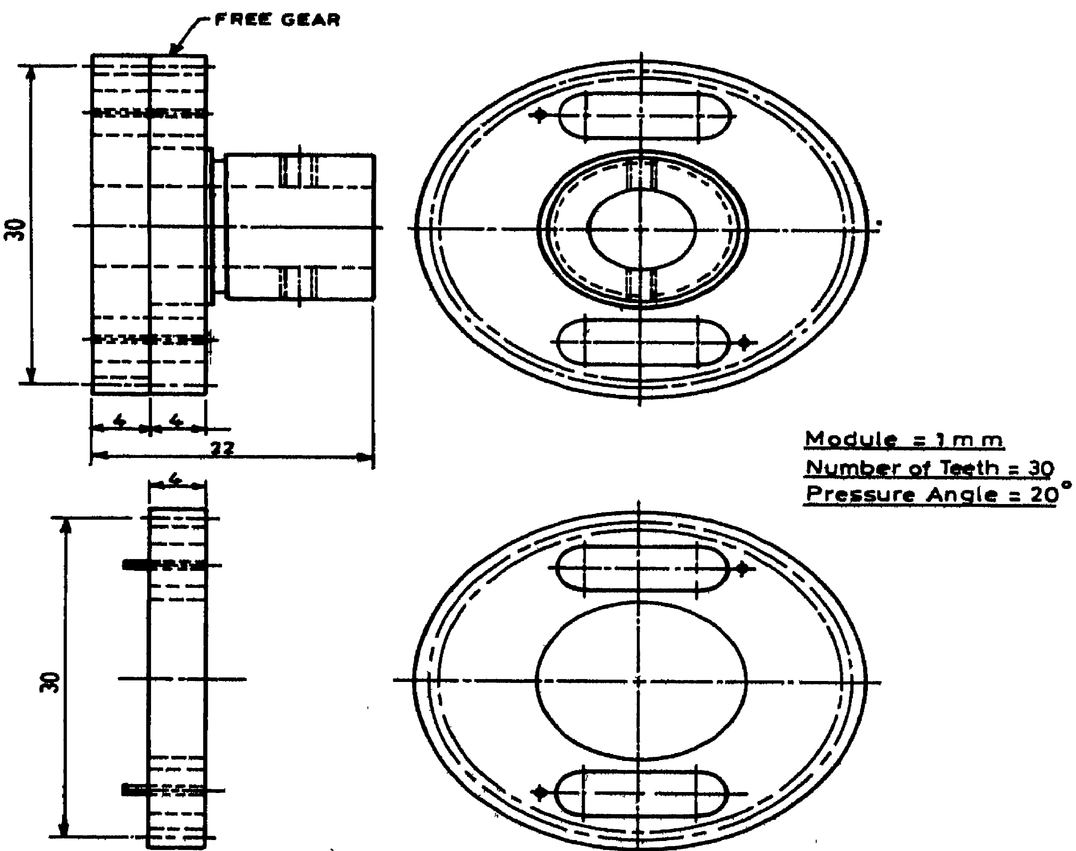
5. Requirements of telescope display system

In order to point to the faint stars in the sky, an accurate position display system is a must. Position information from the polar and declination axes must have high resolution. As the star diameter seen in the telescope is in the order of 1 arcsecond, the display should have resolution of that order. Absolute encoders which give electrical output that can be read by computers are the standard ones used in big telescopes. To achieve best accuracy, the encoder must be mounted on the telescope shaft directly, without any intermediate gears. Good flexible coupling needs to be used. A single turn, 20 bit absolute encoder costs aboout Rs.5,00,000 and prohibitively high to be used in small and medium size telescopes. The resolution of this encoder is 1.24 arcseconds. The other alternative is multiturn encoders. This type of encoders are to be coupled through appropriate gear set. Gear errors like backlash error, tooth to tooth pitch error should be negligibly small. This can, to a large extent, be achieved through grinding the gear to high precision and designing an anti-backlash gear train. Multiturn absolute encoders are not



① — STEPPER MOTOR
② — FLEXIBLE COUPLINGS
③ — DIFFERENTIAL GEAR BOX
④ — 3 ϕ A C INDUCTION MOTOR
⑤ — 16 BIT 128 TURN ABSOLUTE ENCODER
⑥ — ANTI BACKLASH GEAR
⑦ — WORM & WHEEL DRIVE

Figure 1.
DRIVE DETAILS & ENCODER MOUNTING IN POLAR AXIS



FREE GEAR

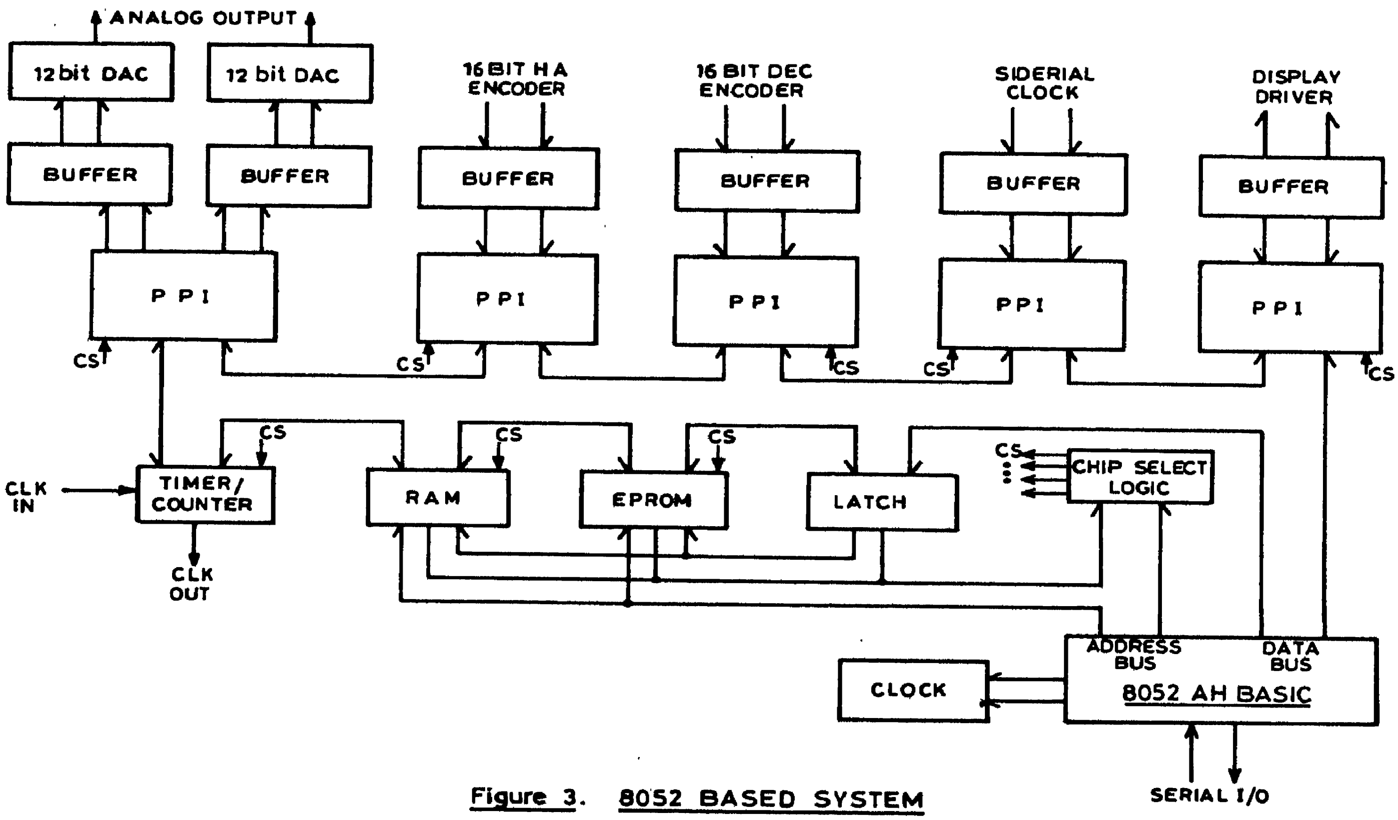


Figure 3. 8052 BASED SYSTEM

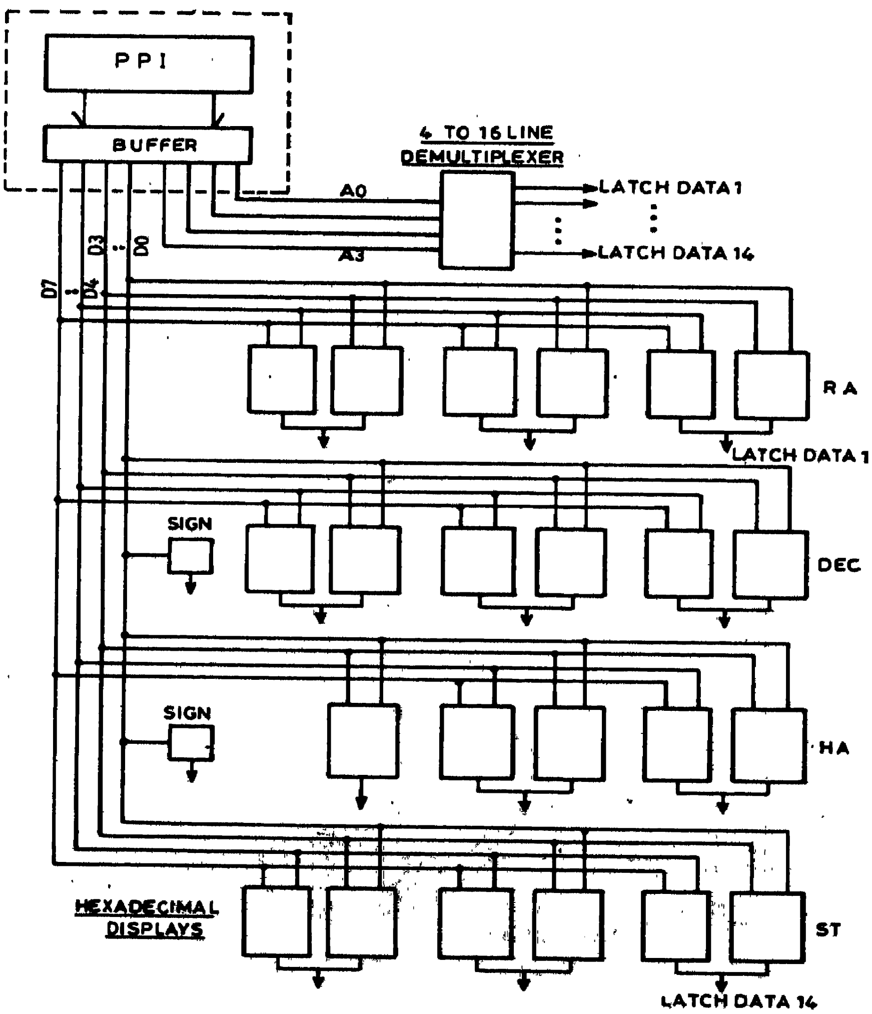


Figure 4. DISPLAY OF CO-ORDINATES

as costly as single turn encoders. 18 bit, 256 turn absolute encoder costs about Rs.60,000. Line drivers are required to drive the parallel output from the encoders. Encoders also have built-in line driver. 16 bit encoder gives an accuracy of 19.8 arcsecond. As the field of view of telescope is normally a few arc-minutes, this resolution may be adequate for manually putting the star in the exact centre of the detector.

In 76 cm telescope 16 bit, 128 turn absolute encoders are mounted in both axes. The encoders have natural binary, line driven outputs. It is coupled to the drive shaft through a gear train which is treated and ground to 5 micron accuracy. The last stage of the gear train contains a backlash elimination mechanism using two split gears which is coupled with a spring. The details of the gear is shown in Fig.2.

As the data coming out of the encoder is binary and only hour angle value is coming from the polar axis encoder, a computational unit like Personal Computer (PC) or a microcontroller is necessary for obtaining RA information.

6. The microcontroller

The microcontroller chosen to do this function is INTEL 8052-AH-BASIC. This is an eight bit microcontroller with built-in BASIC. Other microcontrollers without BASIC is hard to use if proper development facility is not available and it is difficult to invest in the development facility if only one or two systems are to be built (Chinnappan 1982). 8052 is a single chip computer with 40 pins. With only a 1K RAM externally coupled to the chip through a latch and powered-up, the system starts working. It has RS232C serial communication, power on reset and input and output (I/O) ports. Portion of I/O port is used to interface to the external memory. Program can reside in external RAM. 8052 can execute the program in an external ROM on power-on reset, if the ROM is stored with 8052 BASIC program. The internal timer/counters can be used to generate waveforms or divide the incoming frequency. The system can be expanded to have memory upto 96K with the combination of ROMs and RAMs. Schematic of the system built around 8052-AH-BASIC is shown in Fig.3.

There are three tasks the 8052 is supposed to do. First is to generate pulses to drive the stepper motor in polar and declination axes. The second task is to read the encoders and sidereal time (ST) to compute Right Ascension (RA), Declination (DEC) and hour Angle (HA) of the telescope. The third task is to drive the hexadecimal displays mounted in the console with the values of RA, DEC, HA and ST.

Slew speed in RA and DEC axis is obtained by AC induction motor which is independently controlled by the console switches. Speeds other than slew are delivered by a stepper motor in each axis. When the console switches are pressed, first it is passed through a debounce logic and then microcontroller reads the switch pressed. There are six switches in each axis for the control of stepper motor; ie set north, set south, guide north, guide south, fine guide north and fine guide south in DEC axis. Similarly six switches are there for polar axis. When no switch is pressed and when the power is on, microcontroller generates square wave required for tracking in polar axis. When any switch is pressed, microcontroller reads the switch and generates corresponding frequency. The frequency generation is through an 8254 timer/counter. 5 MHz input signal is given to counter and the counter zero control register is loaded with the dividing factor required. Output of the counter is given to counters 1 and 2. Counter 1 controls polar axis and counter 2 controls the declination axis. Then the pulses are given to the stepper motor drive unit. In polar axis the speeds are to be superimposed on track speed, which means that to move towards east at 10 arcseconds per second, rate required for 25 arcsecond is to be loaded.

In the declination axis, there is no difference in pulse rate in either north or south direction. Only the pulses have to be suitably gated to the clock-wise or anticlock-wise input at the stepper motor drive unit. A logic circuit derives this information from the console switch inputs.

The focus motor also is a stepper motor. The declination stepper motor drive is used for the focus motor also. It is possible to operate the focus motor at different speeds. Hence to focus the star, one has a coarse motion and a fine motion as available at VBT (Chinnappan, 1992).

For telescope position display, encoders and sidereal time are to be read. Five numbers of Programmable Peripheral Interfaces (PPI) are connected in the system. Each PPI gives 24 input/output lines. One PPI is used to read hour angle encoder, second one reads the declination encoder. Third one is used to read sideral time from the sidereal clock. Fourth PPI controls console displays and the fifth one is connected to 12 bit bipolar Digital to Analog Converters (DAC). Latches are provided in the input side of PPI and buffers are put in the output side.

The 16 bit binary hour angle information from the encoder is read into microcontroller and is converted into +/− six hour format, +6 hour being towards west and −6 hour being towards east. The declination encoder is read and converted to +/− 90 degree format, +90 being towards north. The sidereal time is read from the sidereal clock. RA is computed from sidereal time from the equation RA = ST-HA. The computed values of RA, DEC, HA and ST are arranged in a table in RAM for display.

The display used is hexadecimal displays from M/S Hewlett Packard. These displays have built-in latch, decoder and driver. All the displays are connected in the 8 bit line from the PPI. Data is sent as two nibbles in BCD format over 8 data lines. The latches in the displays are selected in position dependent manner, to accept the data from the 8 bit common path. This scheme of multiplexing is simple and saves lot of hardware. The schematic of display card is shown in Fig.4.

The entire program is written in the format of built-in BASIC of the chip. Flow chart for the program is shown in Fig. 5. The complete program is included in the appendix. Debugged program is programmed in EPROM. The EPROM contents are such that the command executes the first program in EPROM on power on reset. This way the microcontroller is initialized and executes the program without any operator intervention. In the 76 cm telescope, when the console switch is turned on, the microcontroller automatically starts the polar axis motor in the tracking rate and displays RA, DEC, HA, and ST without any further action.

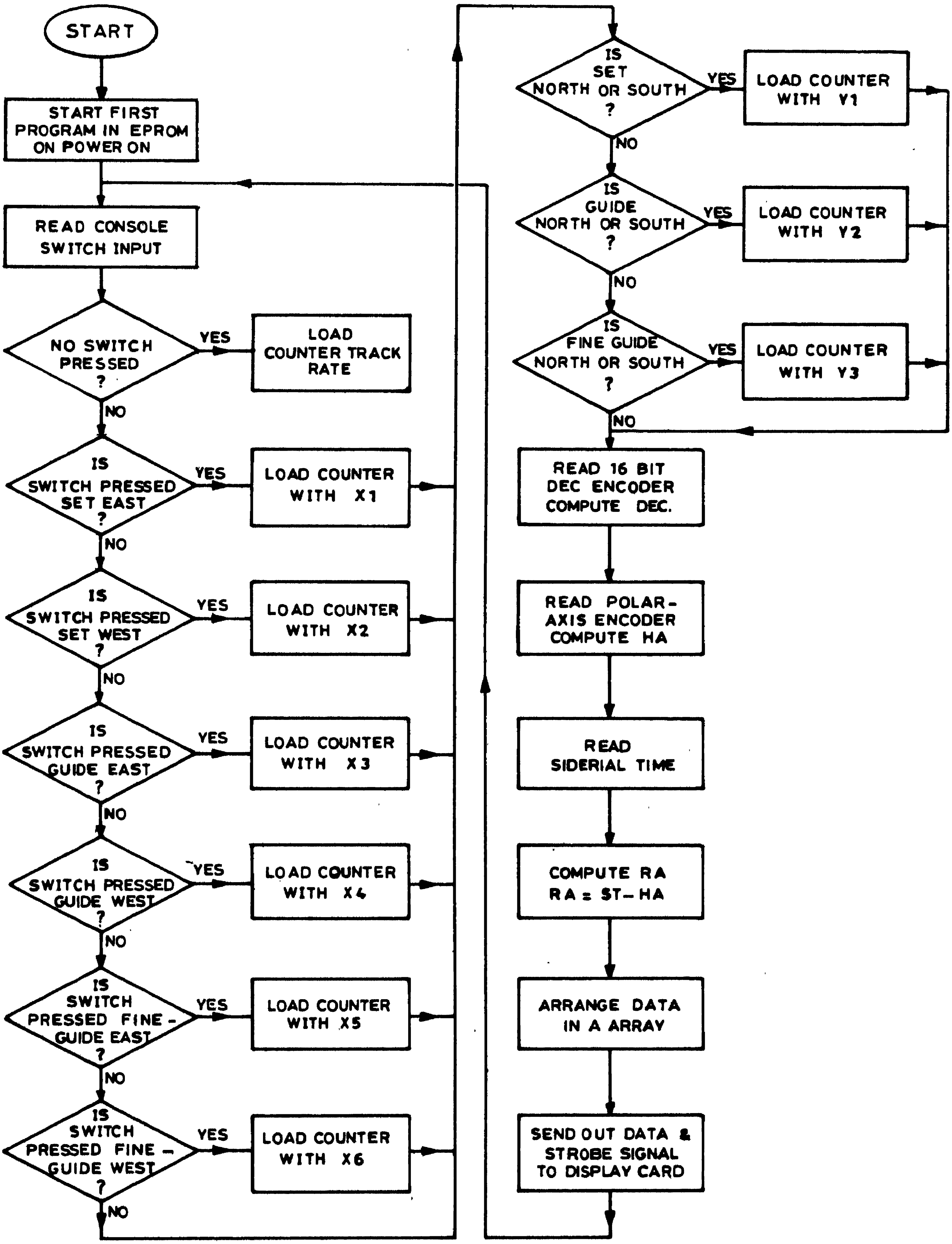


Fig 5. FLOW CHART OF DRIVE AND DISPLAY PROGRAM

7. The PC and microcontroller link

During the program development cycle, it is always necessary to have auxiliary storages like floppy drive or disk to store the program being developed. For this purpose, the serial port in PC is connected with the serial port in 8052. When the baud rate and other communication parameters are matching, data can be sent or received by 8052. The PC is connected as an emulated terminal to 8052. The terminal emulation software like Cross Talk, for example, can be used to establish communication between the two. Special features in Cross Talk like waiting for a particular character after carriage return and line feed is very useful to synchronize the data sent. Program sent out through serial port can be captured in PC and can be stored in a file. It can be downloaded to 8052 as and when required. As the program resides in RAM area during this phase, any modification can be done in RAM and thus easing the task of debugging.

8. Conclusion

The drive and display system for 76 cm telescope was designed and fabricated at our laboratory using the INTEL 8052-AH-BASIC microncontroller. The microcontroller system is a single card design measuring 25 × 18 cms. The system was installed during 1988 and is found to work satisfactorily. This gives a minimal system for this application. As the system executes program at power on, the system is transparent to the user.

Acknowledgement

I thank the Electronics Laboratory personal at Bangalore and at Kavalur for their help during this work. M.R.Somsekhar and C.V. Sri Harsha did the PCB layout. K.Ravi and S.Ramachandran did the wiring at 76 cm telescope and A.S.Babu checked the switching circuits. N.Jayavel designed and supervised the fabrication of the gears and installation of anti-backslash gear train assembly. The workshop group fabricated mounting plates and helped in the installation of the encoders and the gears. V.K.Subramanian made all the drawings and has drawn all the schematics used in the project.

Appendix

Program Listing

```
1       XBY(0FFD7H)=36H : XBY(0FFD4H)=72H : XBY(0FFD4H)=0
2       XBY(0FFD7H)=76H
3       XBY(0FFD7H)=0B6H
4       XBY(0FFC7H)=9BH : XBY(0FFC3H)=9BH
6       INC2=XBY(0FFC2H) : INC1=XBY(0FFC6H)
7        IF INC1=96 THEN XBY(0FFD6H)=0CAH : XBY(0FFD6H)=0
8        IF INC1=80 THEN XBY(0FFD6H)=81H : XBY(0FFD6H)=0
9        IF INC1=72 THEN XBY(0FFD6H)=25H : XBY(0FFD6H)=0
10       IF INC1=68 THEN XBY(0FFD6H)=0E7H : XBY(0FFD6H)=0
11       IF INC1=66 THEN XBY(0FFD6H)=87H : XBY(0FFD6H)=02H
12       IF INC1=129 THEN XBY(0FFD6H)=23H : XBY(0FFD6H)=0
13       IF INC2=136.OR.INC2=65 THEN XBY(0FFD5H)=25H : XBY(0FFD5H)=0
14       IF INC2=144.OR.INC2=66 THEN XBY(0FFD5H)=7DH : XBY(0FFD5H)=01H
15       IF INC2=160.OR.INC2=68 THEN XBY(0FFD5H)=0B5H : XBY(0FFD5H)=0DH
16       IF INC1=0 THEN XBY(0FFD6H)=0B1H : XBY(0FFD6H)=0
18      XBY(0FFC3H)=09BH
19      ENINL=XBY(0FFC0H)
20      ENINH=XBY(0FFC1H)
21      ENINE=ENINH*256+ENINL
22      ERRORD=01H
23      ENIN=ENINE-ERRORD
24      DIRECT=ENIN-32768
25       IF DIRECT<0 THEN DIBIT0=0 ELSE DIBIT0=1
26       IF DIBIT0=1 THEN ENIN=0FFFFH-ENIN
27      LSBIT=27.217742
30      DDEG1=ENIN*LSBIT/3600
40      DDEG=INT(DDEG1)
50      DMIN1=(DDEG1-DDEG)*60
60      DMIN=INT(DMIN1)
65      DSEC=INT((DMIN1-DMIN)*60) /
70      XBY(0FFC7H)=09BH
71      ENINL=XBY(0FFC4H)
```

```
72   ENINH=XBY(0FFC5H)
73   ENINE=ENINH*256+ENINL
74   ERRORD=01H
75   ENIN=ENINE-ERRORD
77   DIRECT=ENIN-32768
78    IF DIRECT<0 THEN DIBIT=0 ELSE DIBIT=1
79    IF DIBIT=1 THEN ENIN=0FFFFH-ENIN
80   LSBIT=1.5340909
90   HHR1=ENIN*LSBIT/3600
100  HHR=INT(HHR1)
110  HMIN1=(HHR1-HHR)*60
120  HMIN=INT(HMIN1)
125  HSEC=INT((HMIN1-HMIN)*60)
130  XBY(0FFCBH)=9BH
132  THR=XBY(0FFCAH)
134  THRH=THR.AND.0F0H : THRL=THR.AND.0FH
136  THR=10*(THRH/16)+THRL
138  TMIN=XBY(0FFC9H)
140  TMINH=TMIN.AND.0F0H : TMINL=TMIN.AND.0FH
142  TMIN=10*(TMINH/16)+TMINL
144  TSEC=XBY(0FFC8H)
146  SECH=TSEC.AND.0F0H : SECL=TSEC.AND.0FH
148  TSEC=10*(SECH/16)+SECL
150  SIDS=TSEC+0 : SIDM=TMIN+0 : SIDH=THR+0
160   IF DIBIT=0 THEN  GOSUB 600 ELSE  GOSUB 720
175   GOSUB 780
180   GOTO 6
600  ASEC=TSEC+HSEC
610  AMIN=TMIN+HMIN
622  AHR=THR+HHR
630   IF ASEC>59 THEN 640 ELSE 660
640  ASEC=(ASEC-60)
650  AMIN=AMIN+1
660   IF AMIN>59 THEN 670 ELSE 690
670  AMIN=AMIN-60
```

```
680 AHR=AHR+1
690  IF AHR>23 THEN 700 ELSE 710
700 AHR=AHR-23
710  RETURN
720 ASEC=TSEC-HSEC
722  IF ASEC<0 THEN 724 ELSE 732
724 TSEC=TSEC+60
726 ASEC=TSEC-HSEC
730 TMIN=TMIN-1
732 AMIN=TMIN-HMIN
734  IF AMIN<0 THEN 736 ELSE 750
736 TMIN=TMIN+60
738 AMIN=TMIN-HMIN
745 THR=THR-1
750 AHR=THR-HHR
755  IF AHR<0 THEN 760 ELSE 775
760 THR=THR+24
765 AHR=THR-HHR
775  RETURN
780  FOR I=7911 TO 8192 STEP 8
785 DIGIT=XBY(I+5)-80H
790  IF DIGIT=1 THEN XBY(I)=XBY(I)/16
795  NEXT I
800 XBY(0FFCFH)=80H
802 XBY(0FFCCH)=XBY(7935)
804 XBY(0FFCEH)=0H
805 XBY(0FFCEH)=0FFH
806 XBY(0FFCCH)=XBY(7927)
808 XBY(0FFCEH)=1H
809 XBY(0FFCEH)=0FFH
810 XBY(0FFCCH)=XBY(07919)
812 XBY(0FFCEH)=2H
813 XBY(0FFCEH)=0FFH
814 XBY(0FFCCH)=XBY(8079)
816 XBY(0FFCEH)=3H
```

```
817 XBY(OFFCEH)=OFFH
818 XBY(OFFCCH)=XBY(8087)
820 XBY(OFFCEH)=4H
821 XBY(OFFCEH)=OFFH
822 XBY(OFFCCH)=XBY(8095)
824 XBY(OFFCEH)=5H
825 XBY(OFFCEH)=OFFH
826 XBY(OFFCCH)=XBY(8031)
828 XBY(OFFCEH)=6H
829 XBY(OFFCEH)=OFFH
830 XBY(OFFCCH)=XBY(8039)
832 XBY(OFFCEH)=7H
833 XBY(OFFCEH)=OFFH
834 XBY(OFFCCH)=XBY(8055)
836 XBY(OFFCEH)=8H
837 XBY(OFFCEH)=OFFH
838 XBY(OFFCCH)=XBY(7951)
840 XBY(OFFCEH)=9H
841 XBY(OFFCEH)=OFFH
842 XBY(OFFCCH)=XBY(7943)
844 XBY(OFFCEH)=OAH
845 XBY(OFFCEH)=OFFH
846 XBY(OFFCCH)=XBY(7967)
848 XBY(OFFCEH)=OBH
849 XBY(OFFCEH)=OFFH
850  RETURN
READY
```

References

Chinnappan, V., 1982, *Jour. Instrument Soc. India*, **12**, 3, 64

Chinnappan, V., Bhattacharyya, J.C., 1985, *Bull. Astro. Sco. India*, **13**, 153.

Srinivasan, R., Jagdev Singh, Ramamoorthy, K.S., 1989, IIA-Technical Report - No.3.

Chinnappan, V. 1992, *Bull. Astro. Soc. India*, (in press).