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# TAC-2

# TAC-2 Operations Manual

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## Contents

# QUICKSTART GUIDE
# to the
# TOTALLY ACCURATE CLOCK

Tom Clark • January 29, 1996

This document is a set of setup hints for new users of the my Totally Accurate Clock ("TAC") hardware and software. If you follow these steps, you should achieve 30-50 nsec timing accuracy without any problems.

## 1. THE HARDWARE YOU NEED

When you open the TAC box you should find the following hardware items:
- The TAC itself.

and also these items:
- A 3.5" floppy disk with all the support software you should need.
- Documentation on my SHOWTIME control/display software.
- Documentation on the "TAC" hardware.

You will need to provide these items:
- A standard PC clone computer running MSDOS or PCDOS. I will assume it has a 3.5" floppy drive, a small hard drive, and a COM1 or COM2 serial port.

- An RS232 cable to connect the computer's COM port to the TAC box.
- A standard IEC-type AC power cord suitable for your national standards.
- An outdoor mounting for the antenna at a location that can see the sky.
- Coax cable to run from the antenna to the TAC GPS receiver and appropriate connectors.

## 2. THE ANTENNA AND ITS INSTALLATION

You need to select an appropriate location at your station. If the antenna is magnetic and will "stick" to an ferrous roof. You may want to fabricate a small bracket to mount the antenna on a pole. The antenna will work better if it is placed on a metal ground-plane which should be at least one wavelength (20 cm) in size (and preferably larger). If you make a metal sheet, you will probably want to drill a couple of holes in it and make use of the threaded holes in the back of the antenna rather than relying on the magnet (especially if the ground plane is aluminum!).

Make certain that the location you choose has good visibility of the sky down to an elevation of 10 degrees. If you have to tolerate some blockage because of local obstructions, try to place the blockage in the north (if you are in the northern hemisphere, or in the south if you are in the southern hemisphere) in the area where no GPS satellites appear (they are in orbits inclined 55 degrees).

You will need to run a piece of 50 ohm coaxial cable from the antenna to the TAC, which you now need to prepare. The antenna has an L-band amplifier with about 30 dB of gain in it, so you need to select coax that will have less than 20-25 dB of loss at 1575 MHz (+5v DC power to run the preamplifier is supplied thru the coax by the TAC, so you will need to insure that you have a DC path as you install the cable). "Quarter-inch" (i.e. RG58) coax will be OK if the length is less than about 50' (15 meters). You should use "half-inch" (i.e. RG8 or RG214) if the length is up to about 150' (50 meters). If the run is longer, you may need to use an additional booster amplifier.

As you prepare the cable, make note of its length. We will need to make a pulse timing correction during the setup. If the cable does not have a solid dielectric also not that fact since the setup procedure assumes a cable with a velocity factor of 0.66.

The short cable from the antenna has a BNC connector, and this connector is NOT waterproof. So after you install it, apply suitable weatherproofing to the junction between the short antenna cable and your longer feed cable.

It may be that you have another precision (i.e. Geodetic) GPS receiver operating at your facility. If so, then you can "tap" the signals from that antenna in lieu of installing the antenna we provided. A 10-20 dB directional coupler installed in the feedline to your geodetic receiver should work fine to provide such a tap. Make sure that the directional coupler or power splitter provides DC continuity so that the existing antenna will still get power for its internal preamplifier. If you use this approach, open the TAC box and pull the small jumper connector near the internal SMA coax connector so that the TAC's +5v bias is disabled.

## 3. SETTING UP THE PC

The next step is to get the support software installed on the support PC. If your PC is fairly standard, this should be easy. I assume your 3.5" floppy is the A: drive and that you want to use your C: hard disk. Then the following should work

- Put the floppy disk into A:
- Type      A:      to change to the floppy.
- Type      DIR      to make sure that you can read the floppy disk
- Type      SETUP C:  to copy all the code to the hard disk
- There will be some "hit any key" prompts during installation

**Note:** It has been reported that some of the XCOPY commands in SETUP.BAT maY fail on earlier releases of MSDOS. I'm sure you are clever enough to work around such problems!

This should create a directory tree like

```
C:
 |
 +−\TAC
      | SHOWTIME.GPS   ****
      | SHOWTIME.TAC   ****
      | SHOWTIME.BAT   ****
      | several other .BAT files
      | some documentation files
      | some other miscellaneous files

   +−\BIN
         | SHOWTIME.EXE  ****
         | PKUNZIP.EXE
         | Motorola's "official"
            controller software
         | some other .EXE files

   +−\ZIP
         | the PKZIPped master files

   +−\EXC
         | the EXC shareware utility that
            is useful to run the Motorola
            controller software
   +−\DOC
         | the supporting documentation files
```

The critical files are flagged in this list like ****

## 4.SETTING UP THE SOFTWARE

The SHOWTIME.GPS file (or some other *.GPS file) must now be edited for your local system. Early in that file are 6 lines that look like:

```
> LAT:     +39.1883333333   ......
> LON:     -76.9350999832   ......
> HGT:         +110.000     ......
> COM2                      |COM1/2
> TZ:     UTC  0            |Time Zones: PC
> LTZ:    EST  5            | Local
```

The first 2 are your stations Lat/Lon in degrees. The numbers shown are for my home. You need to change these entries to put in your Lat/Lon accurate to the 1 degree (or better) level. The sign on LON is negative for West Longitudes (as usually used in the USA) or positive for east longitudes. The 3rd entry is your local height in meters.

These numbers need only be approximate for initial testing. SHOWTIME will update them to more accurate values later.

The 4th line defines which COM port on the PC you are using for the TAC.

The 5th and 6th lines are used to define the time zone your PC's clock is using and your local time zone. In this case, my PC runs in UTC with zero hours offset, and my local time zone is EST, 5 hours offset from UTC.

Verify that this line is correct, since we will want to run the TAC in 3- dimensional positioning mode for initial setup:

```
> NDim    3               |0/2/3-D
```

And while we are at it, we may need to edit another item in the line like:

```
> GEOID   0               |Corrections:
```

Look at the test sheet we sent with your receiver — you will find a 10-line screen dump showing the Motorola configuration information. In that listing are three lines reading something like:

```
> SOFTWARE VER # 6
> SOFTWARE REV # 0
> SOFTWARE DATE  20 APR 1994
```

Motorola made a change in the definition of heights reported in their NMEA message. If your TAC has SOFTWARE VER#5 or SOFTWARE VER#6 (and a date before January, 1995), then the line should read

```
> GEOID   0               |Corrections:
```

If you have a later software version, it should read

```
> GEOID   1               |Corrections:
```

Note:This annoying problem is discussed in some detail in FAQ's (in your     documentation booklet and in the SHOWTIME.FAQ file.

## 4. TRYING YOUR TAC

After making these changes to the file, we are ready to see if everything works. Apply power to the TAC, and the front-panel LED should start flashing. If it doesn't check to make sure power is connected!

On your PC, start in the C:\TAC directory and type SHOWTIME. After a brief signon message, you should see a "Checking 1PPS" message and an oscilloscope-like display. The computer should make 4 or 5 beeps while it verifies that the 1PPS signal is connected. You will then briefly see "INIT@4800" "@9600" and "@4800" messages while parameters are loaded into the GPS receiver. The screen should then change to display with big digits showing the HH:MM:SS time.

The lower right-hand quadrant of the screen should now be showing information on the GPS satellites that are visible — the PRN (Pseudo-Random code ID ##, which is in essence the satellite's serial number), azimuth and elevation. After the receiver locks onto a satellite, the SNR (Signal-to-noise ratio, in approximate dB) is shown both in numbers and in a bar-graph "S-meter" format. The SNRs are a good indication that your antenna installation is OK. Sat- ellites at high elevations should show SNRs of 25 or greater.

As you get lock on several satellites, the position panel in the lower left- hand quadrant should start reporting "Last" positions and you will start to form a more accurate average ("Avg") position. Your initial guess position is the "Ref" value and you see the differences (Greek delta) between the Ref, Avg and Last positions in meters. Don't be surprised or worried if your "Ref" initial position guess was wrong by kilometers (and perhaps the display has some overflows).

Now is a good time to see some of the other SHOWTIME characteristics. Hit the PC's space bar and you will see the positions replaced with a menu that tells you the single-key switches available to you. The detailed description of the menu functions is described in the SHOWTIME.DOC booklet.

At this point, let the receiver run for 15 minutes to an hour to "soak" up a better average position.

## 5. IMPROVING THE REFERENCE POSITION

Now that SHOWTIME has "soaked up" an average position, it is time to set a few parameters following this recipe:

- Hit [P] to get the [P]osition screen.
- Hit [L] to transfer the current AVG Lat/Lon to be the REFerence Lat/Lon
- Hit [H] to transfer the AVG height to the REFerence
- Hit [T] to go to the timing setup screen

Now we will account for the length of the coax cable between the receiver and the antenna using the cable length you made note of in step 2. Add to it the length of the 1PPS cable between the TAC and your station measurement system. The travel times in both the antenna and 1PPS cables make the pulse arrive at the end of the 1PPS cable LATE, and in this step we will insert an offset into the receiver to account for those delays. If both coax cables have ordinary polyethylene dielectric, they have a velocity factor of 0.66 and that is accounted for in this step:

- Hit [C] to enter the cable length
- Enter the cable length in a format like 37.2 feet or 28.7 meters
- hit [enter]

If the cables are have Teflon or Foam dielectric, then you will have to compute the appropriate time delay yourself, so for the second step you

- Enter the cable length in a format like 96.3 nsec
- hit [enter]

**Note:** This screen also shows a value of 8 nsec for the internal receiver delay. This is a provisional value subject to more detailed calibrations of the TAC and is based on the propagation delay thru two 74AC14 gates.

Now let us save these improved parameters to the SHOWTIME.GPS file:

- Hit [F] to go to the [F]iles screen
- Hit [R] and enter a descriptive text string of your choice
- Hit [U] to update the SHOWTIME.GPS file (or you can hit [F] and write the
  configuration information to a new file)
- Hit the <esc> key to resume operation.

## 6. GETTING A STILL BETTER REFERENCE POSITION

At this point, your reference position is probably accurate at the ~25 meter level. To do the best possible timing, we would like to improve it to the 5 meter or better level. To do this, we want to average the position for a much longer time — at least 6 hours, preferably one day. Hence we want to change the averaging parameters that SHOWTIME uses by doing the following:

- Hit [A] to bring up the [A]veraging parameter screen.
- Hit [P] (this must be the UPPER-CASE P) and enter a long averaging window like 24 hours by typing 24h (the screen will show this as 86400 sec). (These keyboard inputs are only read one character/sec, so they will seem very sluggish!)
- Hit <cr> (<enter>) to accept the value.
- Similarly, use [R] (UPPER CASE) and set the RMS window to be at least as    long.
- Hit [z] to start a fresh average
- Hit <esc> to restore the display

Now let the receiver "soak" while determining average positions for a day or so. Then repeat item 5 (except that you don't need to re-do the [T]iming [C]able step) to save these high-accuracy positions.

## 7. USING THE TAC FOR TIMING

During the preceding steps, the TAC's 1PPS signal was noisy and inaccurate at the ~200 nsec level. Now that we have determined a good position, we can set up for high accuracy timing. To see how dramatic the change will be, you might want to take a look at the graphical results in the oso-270.gif file. We are now at the middle of day 270 and we will now set up the TAC for high accuracy timing with the following steps:

- Hit [G] to bring up the [G]PS Mode Screen
- Hit [t] (lower-case t) to select timing mode defaults
- Hit <esc> to return to normal operation

At this point, the lower-left quadrant will have changed completely. The TAC GPS receiver has been setup to run in "zero-D" timing only mode and is no longer determining positions. A additional lines is in the upper right-hand corner report on the total epoch offset (not including the cable and internal calibration offsets) and give an estimate of the current one-sigma timing accuracy.

If you are happy, hit [F] to get the files menu, update the [R]eference ID text string, and [U]pdate the SHOWTIME.GPS file.

## 8. TIMING OFFSETS

It may be that you want the TAC 1PPS signal to be offset from the UTC second. You can move the pulse in 1 nsec steps anywhere in the second. You might want to do this to make certain that the GPS pulse follows the pulse from your station's atomic standard. To set in an offset you do this:

- Hit [T] to go to the timing screen
- You can enter a coarse offset using [E]
- Or you can enter a fine offset using [U]
- Or you can slew the epoch with [S]
- Or you can intentionally make the pulse be early with [I]

For all these commands, you will be prompted with default units, but you can over-ride the default when you enter the number. For example, if you wanted the pulse to be 2 usec late, you could use [U] and enter 2 (usec default) or enter 2000 nsec or enter .002 msec — all are equivalent. You can even enter timing offsets in feet or meters!

SHOWTIME will take care of all the arithmetic for you with the sign convention that "+" is late and "-" is early.

After you enter an offset and <esc> to normal operation, the display will look a bit different. The training digits (in medium-sized characters) following the HH:MM:SS display now show the nearest msec for the offset you entered. The lines in the top right-hand corner show the total epoch as well as the offset from the time displayed.

The screen update (and the fake WWV [N]oise ticks) are triggered by the 1PPS signal. If you entered a 500 msec offset, then the screen update (and the [N]oise ticks) occur half-way thru the second.

## 9. GETTING HELP

All the TAC documentation and the most current software is found on http://www.tapr.org

Support regarding the kit and software will be possible via the Internet mail list which TAPR has operational. This will allow everyone who has built or is building their unit to help you with your problem.

If you are not on the Internet, then you should try to locate someone who does have access.

To subscribe to the GPS mail group, do the following:

```
1. Send e-mail to 'listserv@tapr.org'
2. In the subject place 'Request'
3. In the message body place
      'subscribe gps FirstName LastName'
```

This will place you on the gps mail list. See the document files in the TAPR directory for more information on other lists and services.

# SHOWTIME.EXE
## Version 2.85

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Dec. 1, 1995

I have written the program SHOWTIME.EXE to provide a number of display functions for the MOTOROLA PVT-6 "ONCORE" receivers that are being used for high accuracy timing by both the Space Geodesy and Amateur Radio communi- ties in a project that I have dubbed the "Totally Accurate Clock" ("TAC", which I immodestly note happens to be my initials!).

SHOWTIME is a stand-alone program designed to run on an IBM-PC clone and is intended to provide a number of useful display and control functions. When you run it, you will see that the screen is divided into 3 general areas:

- The top half (the TIME screen) displays the current time and date information. The most striking feature is the HH:MM:SS field which has BIG characters that update once per second. You have the option of displaying either UTC or local time. The bottom part of the TIME screen is called the CALENDAR area where the current UTC date, day-of- year, day-of-week, GPS week, modified Julian Date (MJD) and both the Greenwich and Local mean sidereal times (GMST and LMST) are displayed. Also displayed (optionally) is information on the 1 pulse-per-second (1PPS) output timing (with a resolution of 1 nsec) and an estimate of the current accuracy of the 1 PPS signal.

- The bottom half of the screen is divided into two windows. The lower right- hand quadrant (the SAT screen) displays information on the satellites that are currently in view. For all satellites in view (defined by the current elevation mask, up to a maximum of 12), the current azimuth and elevation are shown, along with an arrow showing whether the satellite is rising or setting. For the satellites that are locked, the SNR is also displayed. The SNR (in approximate dB) is given both digitally and in a simple bar- graph "S-meter" format. The lower right-hand corner of the SAT window also shows a tally of the satellites in view, locked and in use.

- The lower left-hand quadrant half does double duty. In normal operation the display shows information on receiver status (tracking modes, xDOP, etc), and either position or timing data (the POS screen). In this screen you will see the fixed reference position, the long-term average position and the last position reported by the GPS receiver (at a 1/second rate).

- The lower left-hand quadrant also functions as a help screen and for parameter input for menu-driven commands. The basic menu is activated by hitting the SPACE key, and the POS screen is restored with the <esc> key. Hopefully the menu keys are fairly self-explanatory!

**Getting started:**

Two files (in addition to SHOWTIME.EXE) are required to make SHOWTIME work:

1. A *.GPS control file containing at least an approximate Lat/Lon/Height position (which should be accurate to 1 degree initially). The details of this file are described below. SHOWTIME can re-write the control file as you change parameters. The default file name is SHOWTIME.GPS

2. A read-only file named SHOWTIME.TAC which contains a legal disclaimer that I felt needed to be included.

These two files MUST be in the MSDOS subdirectory that you start SHOWTIME from. Don't try using a PATH or DOS ENVIRONMENT statement. I put the .EXE files in the \TAC\BIN directory and then have the files SHOWTIME.GPS, SHOWTIME.TAC and SHOWTIME.BAT file in my \TAC directory. The SHOWTIME distribution software disks set up this directory structure for you by running the SETUP file like      A:\>  SETUP C:

If you have already installed SHOWTIME with the SETUP.BAT file, then use the UPDATE.BAT file by typing      A:\>  UPDATE C:

The latest version of SHOWTIME can be obtained from http://www.tapr.org/tapt/html/tac-2.html

SHOWTIME assumes that you have a MOTOROLA PVT-6 "ONCORE" receiver connected to either the COM1 or COM2 port. You specify COM1/2 by either of 2 ways:
    a. Include it in the *.GPS set-up file described below
    b. Do nothing and you will get COM1 as a default

The PVT-6 "ONCORE" receiver MUST be equipped with the timing option, which MOTOROLA denotes as OPTION A (and which costs about $100 extra). The 1 PPS signal needs to be supplied to the PC on the COMx DCD handshaking line. As a part of our "TAC" project, I designed a piggyback board to mount on top of the receiver which supplies this function (along with a number of other "neat" things which I won't discuss here).
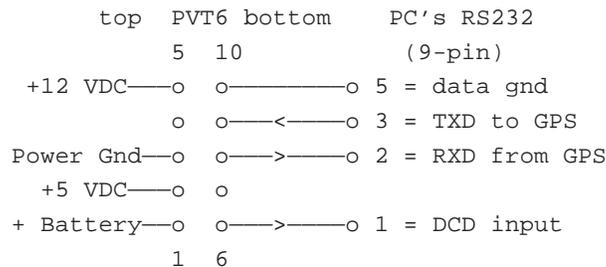
Nominally this signal should be at RS232 levels, but it will work on most PCs by connecting the receiver's CMOS-level (0/+5v) 1 PPS signal directly to the COM1/2 RS232 connector on most PC's; if your PC works OK with 0/+5 volt signals, then the following minimal configuration works for an IBM standard 9-pin RS232 connection. The battery (a 9V transistor radio batter works fine) is optional but highly recommended.

**CAVEAT EMPTOR #1: Use either the +5V  OR the +12V power input BUT NOT BOTH!!**

Also note that I have followed MOTOROLA's pin numbering scheme on the PVT-6 connector; this is different from the normal numbering sequence which has ODD pins on one side of the connector and EVEN pins on the other. MOTOROLA denotes their pin #7 as "1PPS Return" — however the Power Ground, 1 PPS Return and Data Return (pins #3, #7 and #10) are connected together on the receiver board.

**CAVEAT EMPTOR #2: DO NOT use these connections for the smaller Motorola "ONCORE**

VP" receiver board. While the pin numbers are similar to the PVT-6 "ONCORE BASIC", Motorola decided to use a different (and more conventional) way to number the pins (odd numbers on one side, even on the other) and you WILL burn up the receiver if you use the connections shown below !!!!

```
    top  PVT6 bottom      PC's RS232
          5  10             (9-pin)
  +12 VDC——o  o————————o 5 = data gnd
          o  o——<————o 3 = TXD to GPS
 Power Gnd—o  o——>————o 2 = RXD from GPS
   +5 VDC——o  o
 + Battery—o  o——>————o 1 = DCD input
          1  6
```

**To run SHOWTIME what to do, the command is SHOWTIME xxx.GPS   or   SHOWTIME ?**
[?] will display a brief sign-on message. If you include a [?], then SHOWTIME halts after displaying the message.

[xxx.GPS] denotes the name of a control file (default = SHOWTIME.GPS) which contains all normal operating parameters for the receiver. At a minimum, your startup file contain at least the three lines:

```
LON: ±dd.ddd  = your approximate longitude
               (-West, +East)
LAT: ±dd.ddd  = your approximate latitude
HGT: ±mmm     = your approximate height
```

which will be used to "seed" the receiver and get things started. Other parameters have reasonable defaults built-in to SHOWTIME. After SHOWTIME is running you can bring up the [F]iles menu and [U]pdate a complete list of operating parameters in whatever file you choose. If you want to be able to restart a particular operating configuration, you can choose from amongst any of the different files you have saved.

The xxx.GPS file contains a number of commands. If you enter the list manually, they can be in any order. When you tell SHOWTIME to write a file (with the [F] command), they are in a fixed order and the resulting file looks something like this — hopefully most of the entries are self explanatory!

```
   -=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-

#### Æ SHOWTIME v2.85 Ø  File
####  1 Dec. 1995 = #310 + 02:59:54.0
#### Posns:   Ref             Avg          Delta    RMS     #Sec
LAT:     +39.1883333333   +39.1883756070   +4.697   6.89    9065
LON:     -76.9350833333   -76.9351177120   -2.961   3.49    9065
HGT:         +100.000         +110.546    +10.546  17.06    9059  Geoid +34.0
REFID    Testing SHOWTIME v2.80
#### Control              ———+———
COM2                                   |COM1/2
TZ:      UTC  0                        |Time Zones: PC
LTZ:     EST 5                         |  Local
TimeSwap EST                           |  Initial
AUTOSET  0                             |AutoSet rate
XTIME    .85                           |Time Seq Slice
LOCKHYST 2                             |Alarm Hyst,s
PCRATE   1                             |PC Update,1-3s
#### Receiver             ———+———
NDim     3                             |0/2/3-D
ELEV     1                             |Min El
AIV                                    |All-in-View
PDOP                                   |xDOP Selection
HIGHest in Sky                         |not PDOP
APtype   4                             |=Fixd
IGNORE   ++++++++++++++++++Ì+++++++++++|Accept=+
; PRN=31^       21^       11^       1^| PRN31=>1
GEOID    0                             |Corrections:
IONO     1                             |   Geoid:N Ion:Y
#### Avg Window Length     ———+———
POS      43200                         |Pos
RMS      43200                         |RMS
SigmaT   43200                         |SigmaT
DOPWeight                              |DOP weighted positions
Tsigma: 100.5   58.6   64.2        9058 |max/min/avg Tsigma,#Sec
Locked: #309 + 23:50:36.0          1 |Since,#Unlock
#### Timing               ———+———
Epoch    0                             |Epoch Offset
Cable    92.4                          |Cables,ns
Inst     8                             |Rcvr Delay,ns
Early    0                             |Early offset,ns
#### Ticks                ———+———
Stone    1000                          |Sec tick,Hz
Mtone    1200                          |Min tone,Hz
SLong    0                             |Min tone@sec
#### Colors in order:      ———+———
##  BkGnd,BigUTC,Calndr,SatInfo,Epoch,Faint,Frame
##  Msec Offset,Posn,DOP/Stat,Help,Red Warning
Colors: 1  14  10  10  12  9  8  7  6  13  14  12
#### END OF FILE
  -=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-
```

If you have an incomplete *.GPS file, then SHOWTIME will supply suitable default values. When you re-write the file to disk (from the [F] menu), the new file will will contain all the parameters. The entries in the list can be in any order but will be re-written in fixed format. Lines starting with #'; or a blank character are ignored. The numeric data can be in any column providing a couple of blanks are between the command and the data (the file written by the machine has most data starting in column 10). Except for the longer lines (like LAT:/LON:/HGT:/Colors:), columns to the right of 40 are not parsed and are intended for text comments. Some commands are a single key-word with no numeric parameters. As an example, AIV/BEST4 are alter- natives for the receiver operating mode. Some parameters need additional explanation:

- [TZ: xxx #] and [LTZ: xxx #]: SHOWTIME includes several clock display options, and so it keeps three different times internally. The TZ parameters are used to set your PC's internal clock to high-accuracy GPS time. The numeric part of the TZ parameter specifies the offset of you PC's clock from UTC in hours earlier than UTC. The format is therefore like TZ: UTC 0  or  TZ: EST 5  or  TZ: MET 23 ( or MET -1), with a 3- or 4- character time-zone designation followed by the UTC offset in hours. (Personally, I keep my PC running in UTC, as you can see from the example above.)

- The LTZ parameter follows the same conventions for an alternate Local time display. At any time you can hit the [!] key and swap the main time display window between UTC and Local time. When you select Local time, then the Calendar window will display the time that your PC is keeping. The Calendar portion of the screen shows only the UTC date, day-of-year, day of the week, etc.

- The TimeSwap parameter lets you decide on whether the intialization routine starts in UTC time or your local time as defined by the LTZ parameter. When you [F]ile [U]pdate the current position of the [!] switch is saved as TimeSwap. If the TimeSwap line is missing from the file, or if the line reads "TimeSwap UTC", then the display clock initializes in UTC time. If the line reads "TimeSwap anythingelse", then the default is given by the LTZ parameter.

- [EXIT or EXIT BINARY]: When you exit SHOWTIME with the [X] command, the EXIT switch determines if the receiver is left running in 4800 baud ASCII NMEA mode or in 9600 baud Motorola Binary mode. (The Motorola controller software will run OK whichever position is used, but it takes longer to initialize if the receiver was left running in 4800 baud NMEA mode). The next time SHOWTIME is run, it doesn't care which mode the receiver was left in and timing functions set up by SHOWTIME continue to function after you exit. If the EXIT line is omitted from the file or just EXIT appears, then the default is 4800 baud NMEA format the message rates used in SHOWTIME. Prior to Version 2.50, and additional option "EXIT NMEA" allowed you to specify the rates of NMEA messages upon exit. This was dropped in Version 2.50.

- [STONE, MTONE and SLONG]: To make it easier to manually set the seconds on another clock (like the Mark-3 VLBI formatter or your wrist-watch) SHOWTIME can generate WWV-like audible time ticks, which are toggled with the [N]oise key. STONE (default 1000 Hz) is the frequency in Hz for the one-second ticks. You may need to change it if your PC has a really bad speaker! The [N]oise ticks can be turned on so that a longer tick with a different MTONE (default 1200 Hz) pitch on the SLONG second (default 0) of the minute. SLONG can be changed in the [T]iming menu, but you must set STONE and MTONE in the xxx.GPS configuration file.

- Most of my testing was done on a 486/66 machine. If you have a much slower machine, you may want to try tuning the XTIME parameter — XTIME is the fractional second after the last tick that the software quits looking for RS232 data and updates the screen (see next section). You can also insert a command PCRATE = 1,2 or 3 into the control file. If PCRATE > 1, then the NMEA GGA/GSA/GSV messages are sent by the receiver to once every 2 or 3 seconds. Because of vagaries of the PVT-6 ONCORE receiver, I have not been able to develop a foolproof algorithm that guarantees that this will work. Most of the time, if PCRATE=2 then the shorter GGA/GSA messages are in one second and the longer GSV messages are in another second, but the assignment

is not perfect. Similarly, if PCRATE=3 the 3 messages are supposed to be in different seconds. To see how the roll of the dice worked, hit the [&] key to see the time slicing in action. Two numbers are displayed — the first is the number of 10 msec "slices" that have elapsed, the second is the number of times passing thru the inner loop waiting for an NMEA "sentence" to arrive. Type [%] to re-roll the dice if not OK. PCRATE and XTIME can be set from either the xxx.GPS file or from the [G]PS screen. PCRATE is displayed and can be set from the [A]veraging Parameters screen.

- The parameter line like "IGNORE ++++++Ì+++" (and the comment line which follows it in the example above) are new in SHOWTIME Ver 2.50. This line (and the manual entry with [G]PS Ignore/Use in the [G]PS Mode screen) shows which satellites are to be used/ignored. The "+++Ì++++" field has 31 characters in it, corresponding to GPS PRNs 31 thru 01 (left- to-right) When SHOWTIME reads this line, it takes "+" to enable a satellite as good. Any other character (like "-" or "Ì" or a space) will disable the satellite. For the example shown above, PRNs 12, 22 and 27 have been turned off. {Note: The IGNORE switch does not work for PRN32 due to the fact  that a 32-bit un-signed number (1 bit/satellite) needs to be sent to  the Motorola receiver, but Microsoft only allows for 32-bit SIGNED  long integers and I didn't want to take the effort to kludge a full   32-bit solution! Perhaps this will happen when SHOWTIME is implemented  in a REAL computer language!}.

- [DCDmask #] — Note — this function deleted in V2.60. SHOWTIME now REQUIRES the RS232 1PPS to be on the DCD pin (pin #1 on a 9-pin RS232 connector) and DCDmask is hardwired to &80H in the SHOWTIME software.

## WHAT DOES SHOWTIME DO?

The software initially collects together all the parameters it needs and then starts running. The first thing is to make certain that it sees the 1PPS signal from the GPS receiver. It takes about 5 seconds to look for a pattern on the appropriate I/O pin (COM1/2 base address = &H3F8/&H2F8 +6 is the status port I/O address, and the port data is ANDed with DCDmask). Then SHOWTIME initializes communications with the GPS receiver. This involves sending receiver parameters at 9600 baud in Motorola binary frormat, and then listening for responses as 4800 baud ASCII NMEA0183 messages.

For various reasons (too mentionable to be numerous) I chose to have SHOWTIME get data from the GPS receiver using NMEA0183 ASCII strings (specifically, it uses the $GPZDA, $GPGGA, $GPGSA and $GPGSV NMEA "sentences") at 4800 baud.

However detailed control of the receiver's parameters and switches must be done at 9600 baud with MOTOROLA's proprietary binary protocol. Both at startup and whenever you want to make a fundamental change in the receiver config- uration, it is necessary to toggle between the two speeds — a nuisance, but not insurmountable! (Maybe someday this code will be re-written to only use the 9600 baud binary protocol, but for now we just accept the annoyance!)

A lot of work was done to accommodate the detailed timing of the PVT6 receiver outputs. The receiver's 1 PPS "tick" occurs on the UTC second (delayed by a user-defined offset to be discussed later) and lasts for 200 msec; the accuracy of the leading edge of the 1 PPS signal is what the "TAC" project is all about! About 50-100 msec after the start of the 1PPS tick, the receiver starts sending data (time, date, status, etc.) on its RS232 port. The time it sends lags the pulse and is akin to an announcement on WWV "At the tone, the time WAS xx:xx". The RS232 data continues for a large fraction of the second, with the sequencing order of the messages dependent on the details of how the receiver was initially set up (and hence the order is unpredictable).

The different NMEA messages sent each second are each terminated by a <cr><lf> sequence and range in length from about 40 and 80 bytes. In SHOWTIME, we use 4 different NMEA messages, each sent once per second:

```
$GPZDA:   HH,MM,SS,YEAR,MONTH and DAY data
$GPGGA:   position data and status information
$GPGSA:   PDOP, HDOP, VDOP and other status data
$GPGSV:   AZ, EL and SNR data for each satellite
          in view
```

Each $GPGSV message gives data on only 4 satellites, so there may be 1,2 or 3 such messages each second, depending on the number of satellites in view (i.e. above the Elevation mask limit), up to a maximum of 12.

Therefore each second we have at least 4 and sometimes as many as 7 NMEA messages to parse. The messages average 50-60 bytes long (about 500-550 bits, since each async byte has a start and stop bit) and hence take 100-120 msec each. Therefore when the maximum of 7 messages are occurring, nearly 800 msec are consumed in data transfer. The software doesn't care in what order the ZDA/GGA/GSA/GSV messages arrive; the important HH:MM:SS data is taken from the first valid ZDA or GGA message to be sent each second.

The inner loop of SHOWTIME is a big "chain" which is paced by the 1PPS GPS signal and the PC's 55 msec internal clock. About 10 msec after the "tick", the software starts looking for NMEA data terminated by the <lf> character — each NMEA sentence ends with a "* checksum <cr> <lf>" sequence. As a line is received, it is parsed for content and some brief computations are done if the data is valid; as the software has evolved, a number of validity tests have been added. The software then waits for another NMEA message terminated by <lf>.

At XTIME = 850 msec (default) since the last 1 PPS tick (measured using the PC's internal 55 msec clock) we stop looking for RS232 input. The time read from the GPS receiver in this second is incremented to the upcoming second, a number of "calendar" and status calculations are done, and the SAT and POS screens are updated.

{ Note — the best time for the mode change has been experimentally determined to be about 0.85 seconds after the 1 PPS tick. Your PC may be different. The parameter is called XTIME in the xxx.GPS setup file. It can be changed in SHOWTIME with the [^] (i.e. the up-arrow or carat)  command in the [G]PS menu. You can see a "stopwatch" that shows the timing of the incoming data by using the main-menu key [&] to show (in 10 msec units, on the top line of the screen) when RS232 data is being received.  The [&] "stopwatch" also displays the number of passages thru the inner timing loop waiting for NMEA "sentences" to arrive from the receiver. }

After XTIME, the PC then waits for the leading edge of the 1 PPS "tick" on the DCD pin of the RS232 connector to do time-critical tasks. These include posting the new time and calendar data to the screen, making a "WWV-like" tick sound (if requested), accurately setting the PC's internal clock, etc.

After doing these "on the second" tasks, SHOWTIME then looks to see if a keyboard entry is present. If a menu key has been struck, the appropriate action is taken. Finally, SHOWTIME loops back to look for the next second's NMEA data arriving from the GPS receiver. The input buffer on the COMx port is big enough so that if some data (especially GSV information) arrived after XTIME, it is processed at the start of the new second.

The various single-key menu requests set logical switches so that appropriate tasks are enabled in the once/second timing loop. Because the keyboard is only polled once/second, the response will seem sluggish. However you will quickly learn that you can hit several keys in succession and not lose manual input data. The most important single keys are the  SPACE BAR  (which activates the main Help menu) and  <esc>  (which deactivates the Help menu).

Some menu requests are for operations that will change the receiver config- uration and/or foul up the synchronization of the GPS => PC communications. These include changes to basic receiver parameters (timing, positions and operating modes) and disk file operations. For all these requests, you are asked to respond with a [Y]es in order to break the communications link. On completion of the "off-line" operations, the GPS => PC communications are re-established and the complete receiver parameter set is loaded.

The high-accuracy timing pulse from the receiver continues with no change during any of the parameter change operations. Only when you see the screen clear and "Init:" appears will the changes actually effect the receiver. At any time you can stop SHOWTIME (or unplug the PC from the "Totally Accurate Clock") and the timing pulse will be unaffected. The computer is NOT required for normal operation — its only function is to control the receiver and to display time and status information.

For various reasons, the SHOWTIME code is written in MicroSoft QuickBASIC and is therefore subject to some annoying limitations! The distribution version of SHOWTIME is compiled as a stand-alone .EXE file using the QuickBASIC (v4.5) compiler. As I was writing the code, I kept adding features until it was at the limit that QuickBasic's compiler could handle (˜65.5k of executable code, ˜65.5k of parameter storage, since I could never figure how to get QuickBasic to handle large code models!  Clearly the next version should be written in a real programming language!). The

distribution version is smaller (about 83 k) than the "real" 65.5k+65.5k since the distribution SHOWTIME.EXE file is squeezed with the PKLITE utility.

Initial SHOWTIME software development/testing was done on my personal 486 machine (486 DX2/66) under MSDOS 6.2 and PCDOS 7.0. It should not need a 486's CPU power, but I have done little testing on slower machines. I tried the code on an antique Toshiba T1000 (8088) laptop and it did not work at all. It runs OK on an old Toshiba 3100 (80286) laptop with the PCRATE=3 switch enabled. The code runs as a background task under DESQVIEW — I have even run two copies on different receivers at the same time. It has been reported that it runs OK in IBM OS/2 WARP. I have been able to make it run marginally as a DOS application in WINDOZE 3.1— you can play SOLITARE and see SHOWTIME at the same time!

Recent (SHOWTIME v2.60 onwards) software development has been in a W95 MSDOS window on my new Pentium box; the multi-tasking environment of W95 does work, but some RS232 inputs are clobbered depending on what else the machine is doing. This has been a blessing in disguise since it allowed me to find a number of places where the software needed "sanity" checks on data read from the GPS receiver. Extensive work (culminating in v2.70) has (hopefully) improved the ruggedness of the code when running on small PCs or in a Windows environment.

## USING SHOWTIME —
### THE MAIN "HELP" SCREEN:

Now let us discuss some of the operating commands in SHOWTIME. When you hit the SPACE key, you will see the POS window replaced with a "help" screen telling about the single-keystroke commands. You can use any of these commands from either the Help screen or while SHOWTIME is operating normally. The escape <esc> key removes the Help screen and restores the normal display.

### [C]OLORS:

You can customize the screen to your preference with the [C]olors menu key. SHOWTIME assumes only the most minimal IBM-PC video configuration which can be used on a monochrome or CGA monitor. Hence for the colors, you only have 16 choices. The [C]olor screen lets you assign any of the 16 colors to 10 different screen features. When you [U]pdate the xxx.GPS file in the [F]iles menu, the latest color choices are saved. I have provided you with default colors that look nice on my VGA CRT.

### [N]OISE (TICKS):

I have often found it useful to have some audible feedback when manually setting another clock (like the Mark-3 VLBI formatter or my wrist-watch). SHOWTIME can make "WWV-like" ticks. Hitting the [N]oise key toggles you through a 3-step sequence: Ticks off / Ticks ON / Ticks ON plus a long tick on some pre-defined second during the minute. You can select the second for the long tick in the [G]PS menu. You can also define the pitch of the tick tones in the *.GPS configuration file. The default tones are 1000 Hz for the seconds tick and 1200 Hz for the long minute tick.

Note that the time ticks and the screen update are triggered by the 1 PPS output from the receiver which is sent to SHOWTIME on the RS232 port. If you set a [T]iming [E]poch offset of 500 msec, the tick souds (and the screen update) will occur half-way through the second, out of phase with the ticks you would hear from a radio listening to WWV.

### [S, @, D, H, 0-9]:

SHOWTIME allows you to set your PC clock to the GPS rec- eiver either manually or automatically. At any time, hitting [S]et PC Clock will set the PC's clock with an offset specified in the *.GPS file. Hitting [@] will enable/disable an automatic PC clock updating at pre-determined intervals. The keys [1] [2] .... [9] set the automatic update period to be 1.2...9 updates/day. The [D] key sets it one update per day. The [H] key sets it one update/hour. The [@] key toggles the automatic updates on/off. The [0] key disables automatic updates (and therefore the [@] key toggle is disabled). The status of these switches is shown on the [SPACE] help screen. In case an automatic or manual setting operation wants to set the PC clock at the top of the minute (between seconds 58 and 02), the setting operation is deferred for a few seconds since the minute is a busy time for SHOWTIME.

The status of the AutoSet configuration is saved in the xxx.GPS configuration file in a line that reads "AUTOSET xxx" where xxx is the AutoSet period. If xxx=0 then the AutoSet operations are disabled until enabled interactively. All PC clock settings use the TZ: parameters read from the *.GPS file to determine the appropriate clock offset from UTC. The TZ: parameters do nothing else in the operation of SHOWTIME and the actual time on the PC's internal time clock is not used by SHOWTIME.

AutoSet does nothing to set the PC clock's date, so it is possible to set The PC's clock and lose/gain one day. Sorry, but the logic to set the PC date was beyond what I wanted to tackle at this time!

## THE SCREEN TOGGLE SWITCHES —
### [\], [/], [!], [=], [M], and [L]

In addition, there are some other single-key on/off toggle switches which can be used interactively to change some screen display parameters.

The [\] key turns the POS screen updating on/off and [/] turns the SAT screen on/off. These are useful if you want to copy down some numbers from the screen and freeze the display. Also, if you [R]efresh Screen with SAT and/or POS turned off, then those portions of the screen are blanked out. If the [\] and/or [/] switches are turned off (so that the sub-screens are not displayed), the switch positions are saved in the xxx.GPS file as lines with the words POSOFF and/or SATOFF so that the program can resume operation in the previously defined mode. If the lines POSOFF and/or SATOFF do not appear in the xxx.GPS file, SHOWTIME defaults to having the POS and SAT screens enabled. On the main help menu, a + or - appears following the [\] and [/] menu entries to show you if the appropriate screens are enabled.

The [!] key allows you to toggle the main time display between UTC and your Local time (as defined by the LTZ: parameters in the *.GPS file). The position of the [!] switch is saved in the *.GPS file in a line reading "TimeSwap UTC" or "TimeSwap anythingelse". If the TimeSwap line is omitted from the *.GPS file, the default is "TimeSwap UTC".

The [=] key toggles the display of the current timing offsets (in the top right-hand corner of the screen) on and off. The main reason for this switch is to reduce the screen "clutter". The [=] switch makes no changes in the operation of SHOWTIME and the current timing parameters continue even if they are not displayed. When you are operating in zero-D timing mode, the [=] key defaults to ON, and to OFF when operating in 2-D or 3-D positioning mode. The status of the [=] switch is not saved in the *.GPS configuration file.

The [M]aidenhead Grid Square/G[M]ST key toggles a "ham" feature — the GMST field is replaced by the "Maidenhead" grid locator for the current average Lat/Lon. A typical grid locator might be like FM19me. The first letter is the longitude modulo 20 degrees measured east from 180 degrees and the second letter corresponds to the latitude north from -90 degrees modulo 10 degrees. The next two digits are the Longitude modulo 2 degrees and the Lon/Lat with quantization of 5/2.5 arc minutes. I have augmented the conventional grid locator in SHOWTIME with two additional digits for Lon/Lat with 30/15 arcsec resolution. Thus the "augmented" field is shown with a format like

FM19me.75, corresponding to my home QTH at Long=76d56.098'W and Lat=39d11.292'N. The 7 means that you are 70% of the way in the F1m Longitude band and the 5 means 50% of the M9e Latitude band. The status of the [M]aidenhead/G[M]ST switch is not saved in the *.GPS configuration file and the program initializes with the switch in the G[M]ST position. (Just for information, Trimble has included Maidenhead Grid Square locator readout in their "Scout" handheld GPS receiver for the amateur's convenience, and I wouldn't allow SHOWTIME to have any lesser capabilities!)

The [L] key toggles on/off an audible alarm (revised in SHOWTIME V2.30) that beeps when the GPS receiver has lost lock on all satellites. The unlock condition is triggered when the receiver has been unlocked for more seconds than the Lock Hysteresis parameter (initialized by the *.GPS file, and which can be changed in the [G]PS Mode screen). When this happens, a large flashing "L" char- acter appears in each of the 6 digits of the time display and beeps once/second. In addition, the number of seconds during which the receiver has been unlocked and the "valid since" Date/Time (the last time the receiver achieved full lock) appear on the [A]veraging parameters screen. When operating in time-keeping 0-D mode, the "Valid since" date and # Unlocked counter are shown continuously in the lower left-hand quadrant of the screen. The visual "L" indicator is always activated and the [L] menu key can be used to toggle the noise on/off.

## GPS RECEIVER OPERATING MODE CHANGES — THE [G]PS SCREEN:

Many of the basic PVT-6 operating parameters are set in the [G]PS menu. Single- key commands optimize the receiver for [p]osition determination or [t]ime-keeping functions. [Note that the [p] and [t] commands are case sensitive; the uppercase [P] and [T] commands take you to the [P]osition and [T]iming setup screens.]

The PVT-6 has the ability to run in the [A]ll-in-view mode (all channels that are tracking satellites are used in a least-squares determination of time/ position), or in a mode where it makes use of only the [B]est-of-4 satellites ("Best" determined by the lowest possible xDOP value). Since both position and timing accuracy are improved by letting the receiver average over the maximum possible number of satellites, I can think of no logical reason to use the [B]est-4 mode, but it is included since Motorola allowed for it.

The PVT-6 can make its decision about which satellites to devote its 6 channels to on the basis of a DOP (dilution of precision) calculation. It can optimize based on General criteria (GDOP, based on 3-D position and timing accuracy), 3-D position (PDOP), Horizontal position (HDOP), Vertical position (VDOP) or Timing (TDOP). If you are doing position measurements, I suggest you use PDOP. You [S]elect the DOP type using the [S] key. Repeated pressing of [S] cycles thru the various options. If you select the [p]osition or [t]ime options, the selection is made for you automatically. If you select on the basis of xDOP, make sure that the [E]levation mask is reasonable since the xDOP criteria want to include some low-elevation satellites which might not be visible depending on you local elevation obscurations.

Alternatively, you can also allocate channel resources based on [H]ighest-in- Sky criteria with the 6 channels allocated to the 6 GPS satellites with the highest elevation — particularly suitable for accurate [t]imekeeping. If you select [H]ighest, SHOWTIME selects a 1⁻ [E]levation mask automatically, but this can be changed with [E]levation if you want to set a different limit.

The [%]APtype switch is included for experimentation. Motorola describes it in their documentation. I have found it of little use in a non-dynamic environment and suggest you use the default Aptype 4=Fixed position. Beginning with SHOWTIME V2.20, [%]APtype is a "rotary switch" — press the [%] key repeatedly until the desired value appears.

In SHOWTIME 2.50 a new switch, [G]PS Ignore/Use, has been added to allow you to selectively ignore any of the PRN01 thru PRN31 satellites. After hitting [G] you will be asked for a GPS PRN #, and that satellite will be toggled between on/off. Responding with a "0", or hitting <cr> will unconditionally enable all satellites. The screen shows PRN31 thru PRN01 (in clusters of eight with PRN31 on the left-hand end) with either a "+" or "Ì" to show on vs. off. The "Ì" symbol for disabled satellites also appears next to the PRN in the satellite status display in the lower right-hand quadrant of the screen. The Ignore feature only works for PRN's 01 thru 31 (i.e. NOT PRN32) because I was too lazy to solve a problem withe Microsoft's long integers.

## POSITIONS and AVERAGING — THE [P] and [A] SCREENS:

The POS window displays the fixed "REFerence" position, an average position and the most recent instantaneous position, all defined in the right-handed NEU (North/East/Up positive) WGS84 coordinate system. The differences (REF-AVG), (AVG-LAST) and (REF-LAST) and their RMS values are given in meters (where 1° of Lon = 111.111km * cos(Lat) and 1° Lat=111.111km). All SHOWTIME heights are referenced to the WGS-84 ellipsoid, and NOT to local mean sea-level (MSL). The WGS84 vs. MSL difference can be as much as about 50 meters. When running in the Zero-D (timing) mode, only the fixed reference position is displayed on the screen since the receiver is not determining any positions.

The avgerage positions computed in SHOWTIME are NOT weighted with the GPS xDOP (dilution of precision) for simplicity. Both the average positions and their RMS deviations are smoothed by a filter that works like like:  AVERAGE = [(Filter Length - 1)*oldvalue + newvalue] / (Filter Length)

Initially, the filter is set = 1, and then it is incremented by 1 per second. Simple algebra shows that the average thus computed is the running average. When WEIGHT hits the defined filter length "clamp" value, the incrementing is stopped. When the filter length reaches the "clamp" value, the Averages are then exponentially weighted with a time constant related to the "clamp" value. If you are running with PCRATE > 1, then the receiver sends position data at a lower rate, so the running filter length is incremented by 2 or 3. See FAQ #23 for some more details on this new capability.

With Version 2.85, a new capability to weight the average position/rms with the HDOP/VDOP (Horizontal/Vertical Dilution Of Precision) for the actual satellite geometry. The [A]veraging [D]OP Weighting switch toggles the DOP- weighted averaging on/off. The [D]OP Weighting switch can be set from and saved to the *.GPS configuration control file.

When SHOWTIME is running, hitting the [A]verage key will display a small menu that allows you to manipulate the averaging parameters. You can reset the [r]ms or [p]osition or [t]ime counters to start a "fresh" average and you can zero the [U]nlock counte, or you can zero all four with the [z] key. Note that the [p], [r] and [t] "zeroizer" keys are all lower case.

You can change the "clamp" time constant for the [P]osition, [R]MS or [T]ime averages. When you enter a new "clamp" time constant, you can simplify the entry by using the "hint" units shown in the menu — for example, 2H sets the averaging period to 2 hours = 7200 seconds. Note that the [P], [R] and [T] commands must be entered in UPPER CASE. When you [F]ile [U]pdate, the *.GPS configuration file in the [F]iles menu, all the current "clamp" filter time constants are saved and can be restored the next time you run SHOWTIME.

For really accurate time-keeping, the GPS receiver needs to be constrained to a fixed position, which should be accurate at the 10-15 meter level. The position that is used for this is called the REFerence position. Also, if you chose to operate in the 2-D (height fixed) mode, the receiver fixes the height to the REFerence height.

When you begin operation at a new location, you will probably not know your position accurately. The raw positions reported by the GPS receiver will wander by up to Ò100 meters horizontally and Ò250 meters vertically because of weak geometry of the satellites, errors in the broadcast ephemerides, atmospheric propagation errors and especially because the US Military degrades GPS by dithering the spacecraft clocks (known as SA = Selective Availability).

To overcome these errors, it is desirable to average position measurements for several hours to get an accurate position. When the receiver has been running in position mode for a while, you can use the [P]osition menu to transfer the average position into the REFerence position. The [P]osition menu also allows you to manually enter coordinates. You should also use the [R]eference ID command to enter a brief (36 character max) text description describing the setup conditions. The Reference ID appears on the bottom of the POS screen (unless an RTCM SC-104 DGPS beacon is being received, in which case the DGPS information is shown on the bottom line). If you make any Position changes, the Averaging filters are zeroed so that the position averages will be "fresh".

SHOWTIME assumes all position coordinates are in the GPS WGS84 reference frame (which is insignificantly different from the ITRF reference frame used by the geodetic science community). The main confusion about WGS84 comes in the defin- ition of heights. Conventional (old) topographic maps and civilian applications have historically referred heights to Mean Sea Level (MSL) which differ from the WGS84 global reference geoid by up to about 100 meters (in the Washington DC area, MSL heights are about 34 meters

greater than WGS84 heights — i.e. local MSL corresponds to a WGS84 altitude of about -34 meters on the USA east coast).

When running in 3D position determining mode, SHOWTIME gets its height inform- ation from the $GPGGA NMEA message which reports both the height and the Geoid reference offset. The NMEA messages are intended for maritime navigators and the $GPGGA height is (supposed to be) referenced to MSL. In May, 1995 I stumbled on the rude discovery that Motorola's ONCORE firmware releases 5.x/6.x (pre-1995 firmware) incorrectly reported the $GPGGA height in WGS84 coordinates; since the intital Totally Accurate Clock and SHOWTIME development was done with 5.x/6.x receivers, early versions of SHOWTIME simply ignored the geoid correction.

SHOWTIME was always intended to always run in WGS84 coordinates for time- keeping purposes. The position you enter as the REFerence position is loaded into the receiver in WGS84 Geoid units. The positions displayed were intended to be WGS84 positions. [Note: The AVGPOS.BAT utility I have provided uses Motorola's GPS53 controller software, not SHOWTIME and produces WGS84 coordinates.]

To my surprise, in mid-May '95 I received the first ONCORE receivers with their firmware release 8.0 (which shows a release date Jan.11, 1995 — use the VERSION.BAT utility to verify what version you have). In version 8.0, Motorola has corrected the earlier NMEA GEOID error. This caused me to revise SHOWTIME to accommodate the old vs. new firmware differences.

I have added a new switch called "GEOID" in the SHOWTIME V2.20 code. If the switch GEOID=0, then no geoid correction is applied, as appropriate for old Motorola 5.x and 6.x firmware releases. If the switch GEOID=1, then the geoid correction is applied to reported heights as required with new Motorola 8.x firmware. The switch appears as GEOID 0 or GEOID 1 (0=off, 1=on) in the *.GPS configuration file and it can be toggled on/off with the [W]GS84 GEOID key in either the [P]osition or [G]PS Receiver screens (which also show the words "old" and "new"). The current GEOID switch value is saved when you update the *.GPS control file on the [F]iles screen. If GEOID is not specified in the *.GPS file, the default is GEOID 0 for compatibility with earlier SHOWTIME versions. The position of the Geoid switch is also displayed as "Geoid:N" or "Geoid:Y" in the "Rcvr:" status line in the lower-left hand quadrant of the screen. Both the WGS84 and MSL heights (which differ by the value of the Geoid offset)

are shown in the [P]osition screen, with the sign of the correction depending on the current position of the GEOID on/off switch. [See also FAQ #7 for more detail]

## TIMING FUNCTIONS — THE [T] SCREEN:

Finally, we come to the real reason for doing the "Totally Accurate Clock" project — producing high accuracy timing data. Repeated tests of the "TAC" with respect to a Hydrogen Maser show that the 1PPS tick from the PVT-6 has a precision of 45 nsec or better when the receiver is running in a mode "[t]iming — best parameters" command (set in the [G]PS Mode menu) and with an accurate reference position).

Two early independent tests (one by MOTOROLA in cooperation with the US Naval Observatory, and one by me comparing the prototype "TAC" against a USNO traveling clock) showed that the PVT-6 has an intrinsic accuracy of ~20 nsec with respect to the USNO master clocks — providing that you account for all the instrumental effects! Subsequent tests I have run confirm the earlier traceability to the USNO master clocks with several "production" "Totally Accurate Clocks". [See FAQ#14 at the end of this document for details]

One of the instrumental biases that must be included is the propagation delay in the coax cables connecting the GPS antenna to the receiver and the cable connecting the receiver's 1PPS output to whatever is the "time sink". Both cables make the delivered pulse be LATE and so the receiver must be advanced by a corresponding amount.

Another instrumental bias that needs to be removed is any delay added in the receiver system. In the "TAC", we buffer the 1 PPS output through a pair of high-speed 74AC04 logic gates (my prototype used 74HC14's with a bit more delay) which further delay the pulse. For the 74AC04 gates used in the TAC package, the appropriate instrumental delay is ~8 nsec (SHOWTIME default).

In Motorola's GPS53 OEM controller software, these delays are compensated with the PPSDELAY command. In SHOWTIME there are [T]iming commands to account for [C]able and instrumental [D]elays separately. For both these SHOWTIME commands, you can enter the number followed by suitable units character(s).

For example, you can enter the [C]able delay as either 50 FT or 25 METERS and SHOWTIME will compute the appropriate number of nsec for a 50 foot or 25 meter cable length (assuming a velocity factor of 0.66 for typical coaxial cables).

On any of the [T]iming commands, you are told what are the default units, and you are given a "hint" of the alternative units you can use.

In many applications, you will want to offset the tick epoch from the UTC second. The ONCORE PVT-6 (with Option A) allows 3 ways to do this offset:
 - The basic measurement epoch of the receiver can be stepped in 1 msec steps. (In the MOTOROLA GPS53 controller software, this is done with the EPOCH command.)
 - The pulse can be moved LATE with respect to the receiver epoch in 1 nsec steps from 0 to 999999999 nsec. (MOTOROLA GPS53 command PPSOFF.)
 - The pulse can be moved up to 1 msec EARLY with respect to the epoch in 1 nsec steps (MOTOROLA GPS53 command PPSDELAY).

The bookkeeping on these 3 numbers can lead to much confusion, which I have attempted to remedy in SHOWTIME. Parameters for setting the time epoch are all handled in the [T]iming menu.

 - The [C]ABLE delay and INSTrumental [D]elay offsets can be entered separately. (These are used like MOTOROLA's PPSDELAY inputs.)

 - You enter separately a nominal msec coarse [E]poch offset and a de- sired fine [u]sec offset (the letter [u] is used since the Greek Ê is not easy to type on a PC). The fine Êsec offset can be either earlier or later than the msec [E]poch and the software will take care of the arithmetic signs for you (The computed values are used like MOTOROLA's PPSOFF and EPOCH parameters). You can also [S]lew the current values either earlier or later or [Z]ero both the [E] and [U] offsets.

 - You can offset the tick early by a small [I]ntentional offset which is not cleared by the [Z]ero command (This is applied like the [C]able and Instrumental [D]elay parameters equivalent to Motorola's parameter PPSDELAY). The purpose of this extra offset is to allow you to have the GPS tick occur earlier than the "house" time standard to facilitate unbiased time-interval measurements. While you are in the [T]ime setup screen, the display shows the total [E]+[U]+[I] offset from UTC.

- Back on the main CLOCK screen, the 3-digit msec field (shown in large digits at the end of the time field) is the nearest msec epoch to the tick time. The "1 PPS offset" field shows the TOTAL offset (+late, - early) of the tick from the UTC second.

In SHOWTIME I separated these various contributions and do all the arithmetic for you because in the VLBI world I have often seen time synchronization problems because of sign confusion when several contributions are combined.

Another parameter that is displayed on the main screen is my estimate of the current timing accuracy. The basic algorithm for estimate is

Timing sigma $= \sqrt{[\ \alpha^2 + (\ \beta^2/N\ )\ ]}$

where N is the number of "extra" satellites contributing to the timing:

N = (# Satellites being tracked) for the zero-D timing mode,

or N = (# Satellites being tracked - 2) for a 2-D position fix,

or N = (# Satellites being tracked - 3) for a 3-D position fix,

and where my experience shows $\alpha \approx 10$ nsec and $\beta \approx 100$ nsec seem appropriate.

In addition to the current Timing sigma in the upper-right hand part of the UTC time field, the maximum, minimum and average values of Timing sigma are shown at the bottom of the POS screen. The averaging parameters are set on the [A]verage screen.

**FILE UPDATES — the [F] COMMAND:**
At any time you can hit the [F]ILE command. In the [F]ILES screen, you are told if there have been any major changes to the screen colors, receiver operating parameters or epoch timing parameters. You can [U]PDATE the current receiver configuration data file so that you can resume operation later with the same setup. If you change the [F]ile name, then you Update to a different file. If you select a [F]ile name that already exists, you are given the option of over- writing the existing file. The old file name is changed from *.GPS to *.GP$ as a backup. The file you write with the [U]pdate or [F]ile command is a complete snapshot of the important receiver and software parameters.

You can [L]oad a different configuration file. All parameters that are defined in the file you [L]oad will override the existing values and the file name for the next [U]pdate is changed to the file you just [L]oaded.

In the file screen you can do a few DOS operations like [D]IR *.GP? to get a listing of the *.GPS and *.GP$ files in the active directory and [C]hange to a new directory. You can also [S]hell out of SHOWTIME to execute DOS commands. When you [S]hell to DOS, you lose about 140 kbytes of memory since the SHOWTIME code is still resident. If you change directories while in the DOS [S]hell, SHOWTIME will use the new directory for any subsequent file read or write operations. To return to SHOWTIME from the DOS [S]hell, type EXIT.

**EXITING SHOWTIME — THE [X] COMMAND:**
From the main menu (or from the [P]osition, [T]iming [F]ile and [G]PS screens) you can type [X] to exit SHOWTIME. You are told if there have been any parameter changes since the last update and you are asked TWICE to confirm that you want to exit. Responding with two "Y" answers will terminate the program. Responding with an "F" will take you to the [F]ile update screen. <esc> will abort the exit. If you abort the e[X]it with <esc>, the receiver will re-synchronize the RS-232 communications and resume normal operations.

If you have a glitch in the the receiver's power or the RS-232 communications, SHOWTIME may abort with an unrecoverable I/O error message and return to MSDOS. This is a Microsoft QB45 error message. I have tried to trap this error without having SHOWTIME abort, but I have been unsuccessful. Sorry, but this quirk has to be tolerated until SHOWTIME is ported to a "real" computer language.

## FAQ's — IS THE GPS RECEIVER LOCKED UP? IS IT WORKING?  HOW ACCURATE IS IT?

I have received number of questions (especially for the NASA/GSFC versions of the "Totally Accurate Clock") on receiver performance, so let me answer some FAQ (Frequently Asked Questions) here,  en masse:

_____

**(1) The SHOWTIME program seemed to start OK on my TAC. The initial signon messages appeared, and then the initial "AM I CONNECTED? test" sounded beeps and showed a pattern like .........#..#...............#..#.......  — but then nothing happened. What's wrong?**

In this case, the user had an old RS232 port on his computer, and it was   equipped with a 25-pin RS232 connector. The SHOWTIME initialization routine ONLY looks for the presence of a 1PPS signal on the DCD wire, but does not   check for other RS232 data signals. Their 9/25 pin adaptor widget had pins  2 and 3 swapped. The correct wiring for the cable is:

```
   TAC RS232          PC RS232 -or- PC RS232
    (9-pin)            (9 pin)        (25 pin)
  DATA gnd     5————————5—————————7
TXD to GPS     3————————3—————————2
RXD from GPS   2————————2—————————3
DCD input      1————————1—————————8
```

Note that only the 4 wires shown in this sketch are used in the production   TAC's and all other wires are ignored and un-needed.

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**(2) Occasionally I see excursions of several microseconds between the TAC output and a good frequency standard. Why?**

In ALL my testing I have never seen any spurious timing pulses generated   except when the receiver becomes disconnected from the antenna or when RFI is present and no GPS satellites are being tracked! Therefore I suspect your  antenna connection was faulty in some way. When you have no GPS signals being received, the 1PPS from the ONCORE is generated by crystal oscillator running   at the rate last steered by GPS. Its drift rate depends on your operating  conditions, but seems to be a few hundred nsec/minute typically.

In version 2.10 (logic revised in version 2.30) of SHOWTIME I have helped   this problem — I added a "loss of signal" unlock indicator that warns you   when the receiver has lost lock. When this happens, each digit of the UTC   time displayed on the PC is over-written

with a large flashing "L" (in the   color defined by the warning parameter ColorRED).  The total number of seconds that the fault has occurred appear on the screen when you are in   [G]PS [t]iming mode and also in the [A]veraging parameters menu screen.   The counter of the total seconds of data loss is reset by blipping the [A]veraging [t]ime or [A]veraging [z]ero all 4 controls. This obnoxious  alarm can be toggled ON/OFF with the [L] key but it defaults to being turned   ON whenever SHOWTIME is started. The flashing "L" on the screen and the   audible alarm are triggered whenever the receiver has been unlocked for  a time longer (in seconds) than defined by the [L]ock Hysteresis parameter  which is initialized in the *.GPS file and by the [G]PS Mode [L]ock Hyst   parameter. Note that LockHyst is set negative to silence the audible alarm.   The default is (positive=alarm noise on) but the audible alarm can be defeated by the main help menu [L] key.

If the fault is persistent, then I'd suggest you first check the TAC's   antenna connector and verify that it has the +5VDC bias voltage present.    If the cable developed a short, then it is likely that the fuse inside the TAC has blown and nothing will work including the front-panel LED.

Also, you should look for possible RFI (the old Rogue GPS receivers are   notorious RFI generators, and the newer TurboRogue receivers can also cause problems). Try relocating the antenna and/or receiver to clear the problem.

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**(3) The TAC displays a bogus date and/or time when I turn it on. After ˜10 minutes it finally starts working OK. Why?**

It is likely that the small 9 Volt battery inside the TAC is discharged.  This could be because you have not used the clock for several months. The  battery is a NiCd unit and its main purpose is to keep a low-accuracy wrist-watch crystal controlled clock on the Motorola ONCORE receiver  running.

In our TAC implementation, the battery is charged at a very low (˜1 mA)   rate thru a diode and a 3kohm resistor. The clock requires a few tens of   uA and will discharge the battery after a few weeks of non-use. Applying   power to the TAC will start the battery charging, but it will take several   days to become fully charged. If this slow charge rate causes you problems, you can increase the charging rate to ˜10 ma by putting a 470 ohm resistor   across the 3kohm resistor supplied with the TAC.

If the GPS receiver wakes up with a "dead clock", it will go into a   "sky search" mode and start looking blindly for GPS satellites. As soon   as it acquires the first satellite (which may take 5-15 minutes), it will  get

an approximate time synch that is good enough to continue operation.

The ONCORE receiver stores GPS "almanac" data (low-accuracy Keplerian elements) in non-volatile RAM, so as soon as it knows the current time and an approximate position, it can begin searching for satellites that it knows should be visible. Even if the receiver has lost this data, the complete set of almanac data for ALL the GPS satellites is broadcast by each GPS satellite every 12.5 minutes. Hence a completely "cold" ONCORE receiver should take no more than about 15 minutes to begin working.

Beginning with SHOWTIME V2.20, I have added a "Coldstart The Clock" option in case you have trouble with a receiver with a dead battery. Go to the [P]OSITION screen where you will find an entry [D]ate/ Time Coldstart. Simply enter the current UTC date and Time. The time should be accurate to about 10-15 minutes. If you miss the date by a day or two, don't worry. When the receiver locks up on the first satellite, it will correct the UTC time and date in a few seconds. If you use [D]ate/Time and the receiver already has a valid date/time, the receiver simply ignores the request.

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**(4) Occasionally the time display misses a second and then jumps ahead by 2 seconds. The WWV-like [N]oise ticks also skip a beat. It is most "ragged" when the satellite status display shows 9 or more satellites are visible above the elevation limit. Why?**

It takes 600-800 msec for the ONCORE receiver to send all its 4800 baud NMEA messages. The length of time depends on how many satellites are in view because each $GPGSV message reports on only 4 satellites — hence with 9 satellites, GSV messages are required in addition to the other 3 messages that the receiver sends ($GPZDA, $GPGSA, $GPGGA). The SHOWTIME software has an internal timer (called XTIME) that paces when it is listening for messages. The software then does some display updates and computes the next second's display, and then waits for the 1PPS tick to arrive on the DCD RS232 wire.

You can change the XTIME slice from the default value in the [G]PS screen with the [^] key. If this doesn't fix the problem, then slow down the NMEA message rate with the PCRATE parameter on the [G]PS screen. I find that an XTIME of 0.85 (850 msec) works fine for me on my personal 486/66.

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**(5) The bar-graph display shows the Signal-to-Noise Ratio (SNR). What are the units for the SNRs? What are "good" values? What range should I see?**

Motorola returns the SNR in the $GPGSV

messages in units that are nominally equal to dB. The maximum value the ONCORE reports is 36dB and the SHOWTIME bar-graph display can accommodate SNRs up to 38 dB.

If you are using an antenna with a really good noise figure which is in the open (no trees to attenuate the signal), you will probably see satellites at high elevations showing 33-36 dB SNR's. The small Trimble and Motorola patch antennas will probably show about 30 dB maximum SNR since they are more lossy and have poorer system temperatures.

Since the bar-graph "S-Meter" is sorted by satellite elevation, you can get a good feeling for the gain pattern of your antenna. The amplitudes should not bounce around more than Ò 1 dB from second to second unless you have high multipath or spotty obscuration by trees. Since the "S-Meter" display is easy to read and has a fast 1 second response, I have used SHOWTIME as a "GPS OHMMETER" to make certain that another GPS antenna/receiver is working OK!

Motorola provided little information about units it uses for SNRs, so let me give my speculations. The GPS signal structure uses a 1.023 MB/s pseudo-random CDMA (code-division multiple-access) spreading code. Each operational GPS satellite has a unique 1023 bit PRN (1 msec period) called the CA (Coarse Acquisition) code — in essence the satellite serial number. These CA codes ("Gold Codes") were selected to have maximum mutually orthogonality. The CA codes are made by convolving two different 10-bit shift-register sequence generators. Two different taps on one shift-register (with 10 choices for the position of the first tap and 9 choices for the 2nd, resulting in 45 unique codes) and the output of the second 10-stage generator are multiplied in a 3-way XOR gate to generate the 45 possible codes. GPS reserves 32 PRNs, several more are reserved for pseudolites, and the rest of the 45 are unused. [Note: If anybody wants to study these codes in more detail, I have included a small QUICKBASIC program called GPS_CODE.BAS in MISC.ZIP for your use.]

The GPS digital data has a bit rate of 50 bits/second, i.e. it takes 20 CA code repetitions to convey one bit and the matched-filter data bandwidth is hence 50 Hz. Therefore the signal "spreading gain" = $10*\log(1.023\text{Mb}/50\text{b})$ or 43 dB for each satellite. The downlink signal from the strongest GPS satellite is about half the noise in the 2 MHz (approx) passband of a simple CA code GPS receiver. Therefore the best SNR=S/(S+N) we can expect is about 38-39 dB. If there are several satellites in view, each receiver channel sees all other satellites as uncorrelated noise, so the 36 dB SNR "clamp" that Motorola set is a reasonable, practical upper limit to the SNR.

Since the 1023 bit CA codes are of finite length,

we expect some random correlation with a one-sigma dynamic range of about 10*log(1023) ~ 30 dB. The correlators in typical GPS receivers are one-bit devices (like those used in VLBI) so they suffer about 2 dB (the normal „/2 Van Vleck factor) in SNR loss, with the lost power appearing as code-to-code cross-modulation, further decreasing the dynamic range. The practical maximum (i.e. several sigma) dynamic range for GPS is in the 23-25 dB range. If the strongest GPS satellite has SNR = 33 dB, then the weakest detectable satellite will have an SNR of about 10 dB (assuming Motorola's numbers are really dB).

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(6) The time displayed in SHOWTIME "sticks" at a strange value, and this seems to repeat. The only way I can get it to work is to restart SHOWTIME.

"The best laid plans of mice and men aft gang agaly" — this problem arose because of a bizarre "feature" Motorola decided to implement which I had ignored. When running in zero-D "timekeeping" mode, the time field in the $GPGGA message does not get updated. The only valid time-of-day is in the $GPZDA message. Versions of SHOWTIME prior to 2.20 took the time from whichever GGA or ZDA arrived first, providing it was larger than the previous report. Hence the clock display could "stick" at the invalid time reported in the GGA message in zero-D mode if the GGA messages happened to arrive each second before the ZDA message. The bug is now fixed in 2.20 (I hope — if you see it happen, let me know!).

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**(7) A new switch GEOID is in the V2.20 code. What is it? Why have my reported heights changed? My newest (1995 production) ONCORE receiver seems to report different heights than my earlier receivers. Why?**

All these seemingly unrelated questions have to do with the WGS84 reference system for positions and a change Motorola seems to have made in their ONCORE firmware in early 1995 (Version 8.x). See the new discussion in the POSITIONS AND AVERAGING section earlier in this document. The bottom line is:

- If you have an older ONCORE receiver (Version 5.x or 6.x code dated prior to Jan.11, 1995), then set the SHOWTIME GEOID switch off (set GEOID 0 in the *.GPS file or use the [W]GS84 switch on the [G]PS/[P]osition screens).
- If you have a more recent ONCORE receiver (Version 8.x firmware dated Jan.11, 1995 or later), then set the GEOID switch on (set GEOID 1 in

SHOWTIME.GPS or use the [W]GS84 switch).

- If you want to verify your software release version/date, fire up the Motorola controller software (GPS53), hit [F8] to run a self-test, then type "id" to have the receiver dump its configuration information. When you finish, type "mode fix". Or you can run the utility I have provided called "VERSION.BAT" (which uses EXC.EXE to run the Motorola controller software and issue the necessary commands to determine the version with minimal intervention).

All this confusion applies ONLY to the units for the height when you are running the receiver in the positioning averaging mode in SHOWTIME. The only effect on the receiver's operations occurs if you let SHOWTIME average the positions and the GEOID switch is wrong, you will get a bad Reference height, which will introduce a timing bias error when you run in zero-D timing mode with the bogus reference height — see FAQ #14 below for a discussion of the magnitude of the error. The error (Geoid separation) is ~34 meters on the east-coast of the USA, corresponding to a timing bias of about (34 meters)/(c = 0.3 meters/nsec) * 63% ~ 70 nsec.

[Note: If you generate the REFerence coordinates using the AVGPOS.BAT utility I have provided, the positions in the POSITION.GPS file are are guaranteed to be in the correct WGS84 reference frame regardless of the setting of the GEOID switch.]

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**(8) I have an older PVT-6 equipped with "Option A", but SHOWTIME doesn't work with it. Why?**

Motorola made some significant code changes beginning with their 5.0 release. Their 4.x receivers (and presumably earlier ones also) did not implement the $GPZDA message (that reports the date & time in all modes) and $GPGSV (reporting on the visible satellites and their SNR). Also, their code versions prior to 5.0 had a ~560 nsec time bias error, so they are not recommended for precise timing use. Contact Motorola to arrange for a firmware update! Versions 5.0 and later all seem to work similarly.

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**(9) Will SHOWTIME run with other GPS receivers (i.e. not ONCORE with Option A)?**

Probably not. Many of the receivers do not generate all four of the NMEA messages that SHOWTIME uses. SHOWTIME requires that a ~200 msec 1 PPS pulse is sent by the GPS receiver to the computer on an RS232 status line. Someday I may write a similar, but more general GPS time display program.

**(10) The UNLOCK counter on the [A]veraging screen shows a few counts each day even though the "Totally Accurate Clock" seems to be working OK. Why?**

  The receiver can unlock for 1-2 seconds when it begins tracking a new GPS satellite after an old one sets. It can "glitch" briefly if there is local RFI. (See FAQ#2 above) Don't worry if you see a few counts.

  If you start seeing 100 counts or more, something is definitely wrong! You should look for possible problems in the coax cable feeding the GPS antenna (connectors are always a likely culprit). Perhaps your power supply is noisy or the DC power connector is loose. Wiggle everything to find the problem.

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**(11) Regarding the satellites reported as "Locked" and "Used (*)" — sometimes a satellite is Locked but not Used? Why?**

  When a satellite is added "fresh" to the receiver (it just came above the elevation limit, or now deserves to be in the "HIGHEST IN SKY" list, or it now needed to make the optimum xDOP), the satellite must be tracked long enough to decode a complete set of ephemeris data. A GPS satellite sends it own precise ephemeris every 30 seconds, and you have to wait for a complete block to be decoded. If a satellite is still weak, the carrier phase and CA code tracking loops may be locked, but some bit errors occur during the decoding of the ephemeris, so the receiver must wait for another 30 seconds to try again to decode a complete 1500 bit message.

  Or, you may have the receiver in the "Best-4" mode in which case only 4 satellites are used (not recommended but permitted!).

  Or, if you happen to be running with a DGPS beacon correcting the receiver and the beacon is not reporting corrections on a satellite your receiver is tracking, then it will not be used.

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**(12) I am running in the receiver in the "Highest-in-Sky" mode and a satellite that should be in the "tracking" list is not there. Why?**

  This could be for several reasons. First, you could have an obstruction in the part of the sky where the satellite is located, so it can't be detected.

  Or, the satellite in question may currently be flagged as "unhealthy" — the DoD people who control the satellites can instruct a satellite to report itself as unreliable. The DoD may do this if they are uploading new commands, or if they are maneuvering the satellite, or if there is a problem, or perhaps just because the feel grumpy.  C'est la vie!

  Or, perhaps you have added the sattelite to the "ignore" list ([G]PS [Y]es [G]PS ignore), in which case the satellite's PRN will be followed with a "Ì" character on the satellite status screen and will appear in the *.GPS file in a line reading like "IGNORE +++++++++++++++++++++Ì+++++++++++|"

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**(13) When SHOWTIME starts up, the little up-and down-arrows that show when the satellite is rising or setting don't appear for a while. Why?**

  The up/down arrows are generated in SHOWTIME by looking at the elevations reported by the receiver (quantized in 1 degree steps). When the elevation report changes, then SHOWTIME can make the rising/setting determination. SHOWTIME has to wait a few minutes to see the elevation change.

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**(14) What is the accuracy and precision of the "TAC" 1 PPS output signal?**

  First, about the precision: The 1 PPS output from the ONCORE receiver is derived from a ˜9.5 MHz crystal. There is no phase-resolver on it, and the individual tick pulses are derived from this oscillator. You can expect any single tick to be anywhere (uniformly distributed) in a 104 (i.e. Ò 52) nsec window centered on the correct epoch. The pulses will wander in a "sawtooth" pattern thru the Ò 52 nsec window at an indeterminate rate. Experience has shown that averaging the measurement over a 5-10 second period is needed to remove noise from this sawtooth. Since the peak-to-peak error is Ò 52 nsec, the per-pulse RMS error is about 30-35 nsec (˜ one-third of the p-p value). Averaging for 10 seconds then reduces this effect as $^{\circ}$N to ˜ 10 nsec RMS.

  The DoD "dithers" each GPS satellites Cesium clock in a process called Sel- ective Availability (SA). The SA modulation spectrum has an RMS amplitude of ˜100 nsec RMS (˜300 nsec peak-to-peak) with modulation time scales from 1 to 2000 seconds. The SA modulation is not coherent between the different GPS satellites, so that when you are running in zero-D "All-in-view" time-keeping mode tracking N=5 or 6 satellites, the SA effects are reduced as $^{\circ}$N. Thus the ˜100 nsec RMS errors are reduced to the 40-50 nsec RMS level (assuming 5-10 second averaging is used to remove the pulse-to-pulse "sawtooth" jitter). The RMS precision goes down to ˜30-35 nsec with 30-100 second averaging times, and the Allan Variance ÎT/T scales as ˜ 50 nsec/T, where ÎT is the uncertainty in measuring over an elapsed time interval T.

  Accuracy is affected by several factors, some of which (a, b, c and d in the following list) are beyond our control and must be tolerated, and some of which (e, f and g) we can some control:

(a) The timing effects of SA, plus the (in)accuracy of the satellite ephem- erides, satellite clock models, ionosphere corrections, etc. that the DoD chooses to provide us in each satellites's real-time data stream.

(b) The observing geometry — where are the GPS satellites in the sky?

(c) The "correctness" with which Motorola has implemented their internal receiver firmware.

(d) Propagation delays of the signals in the earth's atmosphere.

(e) The accuracy of the REFerence station positions that are used.

(f) The accuracy with which we account for all the cable and instrumental delays in our measurement setup.

(g) Errors caused by multipath at the GPS antenna.

To test the a+b+c+d+e+f+g "bottom line", we have done a number of tests at the Goddard Geophysical & Astronomical Observatory (GGAO) and AlliedSignal Technical Services Corp. (ATSC) which have yielded the following results:

- We routinely show a measurement repeatability of 40-45 nsec comparing a "TAC" against a Hydrogen Maser when we use 5-10 second time-interval averages, after a simple linear drift is fit to account for Maser frequency offsets.

- When these results are smoothed, systematic biases at the 10-20 nsec level are seen over times of hours to days. Assuming that the Hydrogen Maser is not at fault, these are likely due to (a) GPS ephemeris and clock model errors, although the (d) propagation delay errors are undoubtedly also present. (Robin Giffard at HP (Palo Alto) reports seeing similar long-term "wandering".)

- We compare a "TAC" against the USNO master clocks using a "TV line 10" time synchronization scheme (calibrated by traveling clocks which go between GGAO, ATSC and USNO monthly) and by direct comparisons when the traveling clocks visit us. The USNO-to-TAC offsets are rarely bigger than 20 nsec. (Mihran Miranian at USNO and I plan future tests using a TAC at the USNO master clock whenver we get around to it.)

- The most critical REFerence position parameter is the station height. To test the (e) dependence, I have intentionally corrupted the station height by Ò30 meters (equivalent to Ò100 nsec). With the height error of +30 meters (HIGH), the TAC pulse was observed to be LATE by 61Ò3 nsec (the results being obtained with 1000 second averaging times on an HP5328A counter with 10 nsec one-shot time-interval capability). When the height error was set -30 meters (LOW), the pulse was seen to be 64Ò2 nsec EARLY. From the average of these tests, we get the "63% rule": (Timing Error) ~ +63% * (Height Error) where a positive time error means LATE, and where the height error is expressed in nsec. The coefficient is not 100% because of geometric effects; each satellite contributes to the error as sin(Elevation) and the error is averaged over 5-6 satellites and the mean satellite elevation (at mid-latitudes) is typically ~40⁻ and sin(40⁻) = 0.64.

- As a partial test of the (c) Motorola contribution and on the repeat- ibility of our "TAC" hardware fabrication, I carefully compared three different TACs with three different Motorola firmware releases (versions 5.1, 6.0 and 8.0) running from the same GPS antenna thru an 8-port GPS power splitter and with identical length cables. Again I used 1000-sec averaging and the three TAC packages showed ZERO differences Ò2 nsec. As a test of other possible Motorola receiver "quirks", I have run tests where the "TAC" is powered down or the antenna is disconnected for several minutes. In all cases, the receiver recovers in a minute (after it shows that it has re-acquired the GPS satellites) with no loss in accuracy/precision and with no discontinuities at the few nsec level.

- Regarding (d) atmospheric biases, the troposphere contributes a zenith path delay of 1-3 meters (3-10 nsec) which maps thru the receiver as the equivalent of an error in the station height. Using the "63% rule" described above, this can induce systematic errors in the 2-6 nsec range. Motorola does not state if they make any attempt to correct for tropospheric delay in their documentation so I must presume that they do not. The ionosphere contributes up to 10 meters of delay at L-band. See the following FAQ (#15) for comments on [I]onospheric corrections.

- Multipath induced errors (g) are tricky and beyond the scope of this discussion! The main thing you can do is to make sure your antenna has a clear view of the sky and that there are few reflecting surfaces nearby. You can get a clue when you may be having multipath problems if you see the SNR "bar-graph" bouncing around by more than than 1

dB over time scales of a few seconds, especially at low elevation angles.

- A number of tests similar to those I have described here were done by Mike King and David Busch (Motorola) and Mihran Miranian (USNO) in 1993 and are described in the Institute of Navigation (ION) Jan.1994 Conference Proceedings. I have enclosed a reprint of this paper (with some additional notes on my measurements appended) with all the TACs we at GSFC are distributing. Their results are quite comparable to mine.

Assuming that you have determined your REFerence station positions to the 5-10 meter level by suitable averaging and that you account for all the cables in your setup, and that you average over the Ò 52 nsec "sawtooth", the "bottom line" is that the ONCORE/TAC clock performance is summarized: Precision ~ 40-50 nsec (with 5-10 sample time interval averages, improving to ~30 nsec with 100 second averaging times) Accuracy < 20 nsec (relative to USNO with multi-hour averages)

SHOWTIME's clock Tsigma error model (described earlier in this document) performs a real-time estimate of the performance based on my experience in parametrizing the performance.

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### (15) What does the Ionosphere correction do?

The GPS satellites send down an approximate global-average ionospheric parameter that the user may chose to use; the Motorola ONCORE receiver permits it to be used, and the [I]ono switch turns it on/off. I have done tests to check this correction. When the correction was turned OFF, the 1 PPS epoch time was observed to shift LATE by 18Ò2 nsec (using the same 1000-second averaging techniques described above in FAQ #14).

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### (16) PRN12 has been mis-behaving. How can I solve the problems it causes?

With Version 2.50, a new "Ignore the bad actors" switch has been added to the [G]PS Modes screen with the Ignore [G]PS Satellite command; this allows you to ignore any of the PRN01-31 satellites.

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### (17) My "TAC" seems to have locked up. The front-panel LED is on all the time and nothing seems to work. What do I do?

This glitch has been observed to happen occasionally (most recently to Joe Taylor at Princeton, who sent his TAC to me for checkout). I have no idea why it happens, but here is what I did to clear Joe's problem:

(a). I ran his receiver with the Motorola GPS53 controller. It came up running just fine. Apparently the Motorola software send some binary reset command I haven't identified in its initialization proceedure.

(b). I also did a "soft" reset on Joe's receiver by disconnecting the 9V battery. The easiest way to do this on MOST of the TAC's we made is to unplug the 10-pin ribbon cable from the top board for about a half-hour. This causes the receiver's BBRAM to get amnesia, and also resets the date/ time clock on the receiver. If you do this, follow the instructions in FAQ #3 when you start SHOWTIME to set an approximate time into the receiver.

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### (18) Sometimes (especially when a really bad set of Lat/Lon coordinates are in the receiver or when the antenna is in a bad location) SHOWTIME seems to reset itself a lot, and it then it bounces bad to MessDOS with a nasty, untelligible error message. Why?

SHOWTIME uses the stock QuickBASIC/DOS "Open COMx" RS232 I/O. It seems that the PVT-6 receiver can send some garbage characters occasionally and this caused a lot of problems. In Version 2.60 I spent a lot of effort trapping the most common of these error and changing the port reset philosophy. HOPEFULLY the new code cures most of these problems that seemed to occur only when operating under marginal conditions. Even more work has gone into solving this problem in the v2.70 release.

In addition to the RS232 I/O problems, there were cases when the NMEA string parsing routines glitched when satellies were dropping in and out rapidly. I hope I caught all these cases also.

### (19) Will SHOWTIME and the TAC operate under WINDOZE 3.11 and W95?

In September '95, I got a new 133 MHz Pentium at home, and it came loaded with WIN95. All the development of SHOWTIME after v2.60 was done in an MSDOS prompt screen in W95. A lot of the testing to try to force glitches was done by loading W95 with a lot of tasks (including running TASKMON,

NETSCAPE, and playing SOLITARE concurrently with SHOWTIME running in the background). When I started with the 2.51 code, it crashed all the time in W95. With v2.60, I seem to be able to run it OK with W95 programs, but it is unreliable with multiple MSDOS windows open — presumably because SHOWTIME has a hard-loop wait for the next 1PPS signal. With v2.70 a number of other timing-related problems were fixed.

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**(20) Occasionally the words "Timing Unreliable" flash on the position/timing screen. Should I be worried?**

The "Timing Unreliable" indicator is computed based on the estimated Timing sigma, which is based on the number of satellites being tracked. Occasionally (a) an NMEA message will have bad data or (b) a satellite is dropping in and out of lock or (c) a new satellite has just been added to the receiver's tracking list. When these rare events happen, the NMEA message may lag the event by a second or two, and the calculations get out of step. Don't worry about an occasional message that flashes briefly; it is only important if it persists.

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**(21) The [&] "speedometer" now (since v2.82) has two numbers. Why?**

To better access the internal timing of the program I added a second "stop-watch" display parameter on the top line (toggled on/off with [&]). The inner loop of SHOWTIME waits for a new <lf> terminated NMEA "sentence" until XTIME has elapsed. The first number is the time since the last 1 PPS tick in 10 msec units, and the second number is a counter of the number of times the software has passed thru the inner loop waiting for an <lf>.

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**(22) I see that I have an "Unlocked for 10 sec" indication, but the "Locked since" date/time hasn't changed. Why?**

The "Unlocked for" counts even brief 1 second dropouts, which may happen because the receiver re-sorts its satellite list or because there was a glitch in the RS232 communications. The "Locked Since" is triggered when the receiver has REALLY been unlocked (i.e. no satellites are detected for more than LockHyst seconds, the time display is over-written with "LLLLLL" characters, and then the receiver re-acquires lock). A few "Unlocked for" counts are not unusual and the counter can be reset to zero by hitting the [A]veraging [u]nlocked reset keys.

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**(23) SHOWTIME ignores the HDOP and VDOP quality flags when I'm running in 2-D or 3-D positioning mode. Can you put in DOP weighted averaging?**

I had resisted this request because for me, SHOWTIME and the TACs were intended to be used for TIMING tasks, not positioning! But in Ver 2.85 I relented and added the capability. You turn HDOP/VDOP weighting on/off with the [A]veraging [D]OP Weighting switch (or you can turn it on with a line that reads "DOPWEIGHT" in your *.GPS file. When turned on, the position and rms data is weighted proportional to $(1/HDOP)^2$ for Lat/Lon and to $(1/VDOP)^2$ for heights.

The filter length strategy is simiilar to that used before. The positions and rms differences are still exponentionally averaged as with a weight W:

$$\text{(new avg number)} = \frac{\text{(Filter Length-W)*(old avg) + W*(new value)}}{\text{Filter Length}}$$

with the Filter Length still increasing as PCRATE until it reaches a clamp value (which you set on the [A]veraging screen). This results in a simple average when Filter Length < Clamp and an exponential averaging after it reaches the clamp. What is new is the weight W. In the older SHOWTIME code, and in v2.85 when DOP weighting is turned off, W is set = 1.

In v2.85 when DOPWEIGHT is ON, W is computed as

$W = (1.5/HDOP)^2$ for Lat/Lon
and $W = (2.0/VDOP)^2$ for Heights

The 1.5 and 2.0 are chosen as typical "fairly good" HDOP/VDOP values, so the W coefficients are normally nearly = 1. Better values of HDOP/VDOP than these averages will "speed up" the averaging and poorer values will "slow it down". The filter algorithms are somewhat ad hoc, but I think they achieve the desired objectives.

# SHOWTIME 3.00 UPDATE NOTES

Dr. Thomas A. Clark
January 7, 1996

SHOWTIME 3.00 is a fairly major update from the earlier 2.xx versions of the "Totally Accurate Clock" ("TAC") support software. Sometime soon I need to make a major documentation update, but these notes, added to the earlier documentation, will have to suffice for now.

### The SHOWTIME 3.00 changes include:

a: Support for both the older 6-channel and the new 8-channel Motorola ONCORE receivers.

b: Inclusion of new debug diagnostics that display the incoming NMEA messages.

c: A revision of the Tsigma accuracy predictor algorithm when in position (not timing) mode, and the ability for the user to set the model coefficients.

d: A number of changes were made to improve the "smoothness" and reliability of the display updates. The PCrate philosophy was changed.

e: The ability for the user to make minor changes in the H/VDOP averaging parameters.

f: Menu and *.GPS file changes, mostly minor.

g: An attempt (not yet tested) to support some of the advertised Motorola RAIM options (some of which they haven't implemented yet!).

h: The ongoing, continuing saga fixing of minor buglets reported to me.

Let me discuss these in order:

## (a) 8-CHANNEL SUPPORT:

I had already put in most of the necessary hooks for the 8-channel ONCORE receiver, but I finally (thanks to Doug Hogarth of Microsoft & Lyle Johnson of Modular Mining) have had the chance to exercise one of the newer units. The satellite display window can display up to 8 satellites in lock (with SNRs showing) and an additional 4 satellites which are above the ELevation mask limit but which are not being tracked.

## (b) DEBUG DISPLAY:

In an attempt to sort out some timing problems, I wanted to be able to display the incoming NMEA messages.

the [&] key is now a 7-position switch, which increments each time the [&] key is depressed. The [R]efresh Screen key sets the [&] switch back to the no debug (a) position. The 7 switch positions are denoted a,b,c,d,e,f,g and do the following:

a: Normal Operation (use [R]efresh to get here immediately).

b: Display the incoming $GPZDA NMEA message on the top line. After the ZDA message are displayed X.## and W=##. As before, the X parameter is the time (in steps of 10 msec) showing the internal timer clocking the frac- tion of the second up to the XTIME time switch. The W parameter is a counter of the number of passes thru the internal loop waiting for data to arrive. At the right-hand end of the top line is a 5-character field like LLbXX where LL is the length of the NMEA message being displayed (normally =36 for the $GPZDA message which has no options), b shows that the [&] switch is in the "b" position, and XX is the time in 10 msec units (just like the X parameter in the middle of the line) when the ZDA message was received. The $GPZDA message format is:

$GPZDA,hhmmss.ss,dd,mm,yyyy,00,00*xx

where 'hhmmss.ss' is the UTC time (for the last tick), 'dd,mm,yyyy' are the UTC date. The '00,00' field is unused by Motorola, but is intended to be hh,mm for a local offset time. The '*' is the standard NMEA end-of-data flag, followed by the 'xx' hex check sum, and the message is terminated with a '<cr><lf>' sequence (not shown and not included in the LL length displayed at the end of the top line).

c: The next press of [&] displays the longer (and variable length) $GPGGA NMEA message. The X= and W= parameters are suppressed. At the right-hand end of the line is LLcXX where LL and XX are the NMEA string length and timing parameters as for case b. The $GPGGA message format is:

$GPGGA,hhmmss.ss,ddmm.mmm,N,dddmm.mmm, W,n,ss,d.d,hhh.h,M,gg.g,M,tt .t,ii*xx

where 'hhmmss.ss' is the UTC time of the last position fix (note — when in zero-D timing mode, this is

NOT the current UTC!!). The 'ddmm.mmm' field is the latitude, followed by a 'N/S' north/south sign. The 'dddmm.mmm' and 'W/E' fields are the longitude (SHOWTIME uses a right-handed coordinate system, with W negative and E positive). The single digit 'n' field is a quality indicator (0=no GPS, 1=normal, 2=DGPS active). The 'ss' field is the number of satellites currently being used. The 'd.d' field is the current HDOP. The 'hhh.h,M' fields are the current height (M=meters), and the 'gg.g,M' fields are the MSL-to- WGS84 geoid separation in meters [in SHOWTIME.DOC is a long discussion about these parameters. In software versions 5.x and earlier, 'hhh.h' was the height above the WGS84 reference geoid. In later software 'hhh.h' is the height above MSL (mean sea level). SHOWTIME internally uses the WGS84 height, and the geoid switch allows you to interchange the definitions.]. The 'tt.t' parameter is the age of the last DGPS correction and 'ii' is the 0-1023 serial number for your DGPS beacon if applicable; if there is no DGPS active, these fields have zero length. And like before, the field '*xx<cr><lf>' terminates the message.

d: Like c:, this displays the $GPGSA message and LLdXX at the end of line. The $GPGSA message format is:

$GPGSA,A,m,ss,ss,ss,ss,ss,ss,ss,ss,,,,,p.p,h.h,v.v*xx

where 'A' (or 'M') denotes Automatic vs. Manual (fixed positions) operation. The single digit 'm'=1 if a position fix is not available (either because lock is lost, or because the receiver is in zero-D timekeeping mode), or 'm'=2/3 for 2/3-D position fix. The string of 'ss' values (6 or 8 max length depending on 6 vs. 8 channel ONCORE receiver) indicate the GPS satellite PRN assigned to each of the 6/8 channels if the satellite is in lock. The total defined length of the 'ss' fields is 12, and unused slots or slots (where the satellite is not in lock) have zero length (i.e. ',,,,'). The 'p.p', 'h.h' and 'v.v' parameters are the current PDOP, HDOP and VDOP values. Again the message is terminated with a '*xx<cr><lf>' sequence.

e,f,g: The $GPGSV data arrives in multiple messages. The e: position of the [&] switch gets the first of these. The first digit of the GSV message gives the number of GSV messages to be sent (1,2 or 3) and the second digit is the number of this message. Each GSV message covers 4 satellites which are in view according to the current ELevation mask. The 3 switch positions (e,f,g) correspond to the 'm'=1,2,3 GSV messages as defined below. If n=2 and you use [&] to get to the g (m=3) display, then the f (m=2) message will be "frozen" on the screen. The $GSV message format is:

$GPGSV,n,m,pp,ee,aaa,ss,pp,ee,aaa,ss,pp,ee,aaa,ss,pp,ee,aaa,ss*xx

where 'n'=1-3 is the total number of GSV messages and 'm'=1-3 is the number for this message; only enough messages are sent to accommodate the satellites in view (n=1 for 1-4 satellites, n=2 for 5-8 or n=3 for 9-12). Each satellite in view has 'pp,ee,aaa,ss' data with 'pp'=PRN, 'ee'=el, 'aaa'=az and 'ss'=SNR (in approximate dB). If a satellite is in view but is not being tracked, the SNR field is a null (i.e. ',,'). If the full 4 slots in each message are not needed because of the number of satellites in view, the unused 'pp,ee,aaa,ss,' fields are nulls (i.e. ',,,,'). The GSV messages are each terminated with a '*xx<cr><lf>' sequence.

For all the (b-g) modes for which debug is turned on, the decimal point in the ss.sss display now flashes as the 1 second timing loop proceeds, to show that something is happening within the loop. It alternates between the "smiley face" and its inverse until XTIME elapses, and then shows the normal "o" character until the 1PPS tick arrives.

In addition, a new debug feature has been added. When the [_] (underscore) key is hit, a log of all NMEA messages sent by the ONCORE receiver is written. Another tap of the [_] key turns the log off. The log file name is hardcoded to be SHOWTIME.LOG. It was this log file that FINALLY let me trap the bogus and infrequent NMEA message that some recent ONCORE receivers generate (see the reliability section (d) following).

**(c) TIMING SIGMA ALGORITHM:**
As discussed in SHOWTIME.DOC, the basic algorithm for estimating the current accuracy/precision for the TAC/ONCORE receiver is:

$$SigmaT = sqrt [ (a^2) + (b^2)/N ]$$

where a and b are constants (typically I suggest a=10 nsec, b=100 nsec), and N is the equivalent number of

degrees of freedom available for averaging out timing errors due to instrumental effects, broadcast ephemerides, tropospheric path delays, ionosphere corrections, multipath, etc. and for averaging the DoD's diddling of the GPS satellite clocks (Selective Availability = SA). In earlier versions of SHOWTIME, we calculated N based on:

$$N = Nfree = Nsats - Nmin$$

where Nmin is the minimum number of satellites needed for the current mode:

Nmin = 1 for zero-D timekeeping,
or  Nmin = 3 for 2-D positioning,
or  Nmin = 4 for 3-D positioning,

and  Nsats = the number of satellites being tracked and Nfree is the number of "extra" degrees of freedom available.

When running in 2-D or 3-D positioning mode, the Tsigma algorithm used in earlier versions of SHOWTIME is overly optimistic about the Tsigma being achieved. While Nfree = the number of degrees of freedom is correct, not all this "strength" is used to improve timing; a part of the Nfree "strength" is applied to improving the positional accuracy.

It is beyond the scope of the realtime SHOWTIME calculations to figure the detailed covariance matrix necessary to apportion the Nfree degrees of freedom amongst the Nmin parameters being determined, so we might adopt an algorithm which equally apportions the degrees of freedom like:

$$N = Nfree/Nmin = (Nsats - Nmin)/Nmin$$

but this algorithm yields N=0 for Nfree=0 (i.e. Nsats=Nmin), which will cause the Tsigma algorithm to blow up with a "divide by zero" error; clearly this is to "harsh" since the timing solution is not degenerate when N=0. Hence in SHOWTIME 3.00 I have adopted the "softer" non-degenerate algorithm:

$$N = [Nsats - (Nmin-x)]/Nmin$$

where x=.5 seems to fit the measured parameters fairly well, yielding estimated 3-D Tsigma values of (283,164,127,107) nsec for Nsats=(4,5,6,7).

So that the user can adapt SHOWTIME to local measuring conditions, it is now possible to change the a and b Tsigma error model coefficients in the line in your SHOWTIME.GPS (or *.GPS) file:

```
MSigma   10.0 100.0
|Tsigma Model
```

In this case the default a=10 nsec and b=100 nsec values are shown which have proven to be about right for 1PPS averaging times of a few seconds. If you run with longer measurement averaging times, you may want to adjust the second (b) coefficient to a lower value.

### (d) PCRATE, RELIABILITY and "SMOOTHNESS" CHANGES:
A number of changes were made in SHOWTIME 3.00 to improve the "smoothness" and reliability of the display updates.

A major philosophy change involves the PCrate parameter. If your receiver is sending all 7 possible NMEA messages (ZDA, GGA, GSA and 3 GSV messages), the total time spent sending messages can be in the 800-900 msec range. For the proper update of the time display, the ZDA message is the most critical (we cannot use the time in the GGA message since it is invalid when the receiver is running in the Zero-D timekeeping mode). Motorola allows the various NMEA messages at different rates, and the PCrate parameter is included in SHOWTIME to try to prevent "overload" when the full 7 messages are being sent. Unfortunately, Motorola has hard-coded two annoying properties into the NMEA messages:

> The ZDA message is always the LAST message sent during each second.

> There seems to be no way to reliably assign a message to a particular second "slot" when the messages are sent at a rate slower than once per second. I have tried many slot assignment schemes, and I haven't found a reliable method (it was my futile attempts to try to invent a slot assignment algorithm that led to my inclusion of the NMEA debug display options described above.)

In terms of the 4 types of NMEA messages, we note that the different messages have different priorities:

> The ZDA message is most important since it conveys the correct time, and SHOWTIME is really a clock display program.

> The GGA message is important when determining position, since it conveys the Lat/Lon/Hgt data. It is also important because it reports the number of

satellites being tracked. It only conveys HDOP.

The GSA message is less important, but it conveys the PDOP, HDOP and VDOP and the number of satellites being tracked can be inferred. It also reports on 0/2/3-D position operation.

The GSV messages are the least important since they give only the satellite az/el/SNR data.

With this in mind, the PCrate algorithms have been changed thusly:

PCrate=1 has all 4 message types once per second just like before.

PCrate>1 yields variable rates according to the priorities in this table:

| PCrate | ZDA | GGA | GSA | GSV |
|--------|-----|-----|-----|-----|
| 1 | 1s | 1s | 1s | 1s |
| 2 | 1s | 1s | 2s | 4s |
| 3 | 1s | 1s | 3s | 6s |
| 4 | 1s | 2s | 4s | 8s |

with PCrate now has having values 1 thru 4 (formerly the limit was 3).

If you are having timing problems that can't be corrected with PCrate>1, the problems are probably occurring when 3 GSV messages are being sent because there are more than 8 satellites above the elevation limit. You can improve this case by raising the elevation mask so that fewer satellites are being reported. At mid-latitudes, there are seldom (if ever) more than 8 satellites above 10 degrees.

Other reliability/smoothness changes include:

The position averaging scheme has been changed. Formerly the position average was only updated when a new set of positions arrived with a GGA message. Now the last position received is averaged each second. This change made for smoother operation and made more sense with the HDOP/VDOP weighted averaging option that was added recently in SHOWTIME version 2.85.

A lot of work was done to improve the reliability, stimulated by a new bug found in Doug Hogarth's 8-channel ONCORE. Occasionally, but always at a time xx:00:24 (xx:00:23 before the Jan.1 Leap Second) a cryptic and hard to trace "divide by zero" error appeared. This particular time matches the time that the GPS satellites can do an ephemeris update. It turned out (caught by the new [_] data logging option) that the ONCORE was sending bogus NMEA messages at the magic time. The UTC hh:mm:ss repeated the previous

second's time, and the HDOP/VDOP/PDOP parameters in the GSA and GGA messages were all 0.0, which in turn was causing problems with the weighted position calculations. Since this error only happened once or twice per day, it was a BITCH to find!

To trap bogus NMEA data in earlier versions of SHOWTIME, I had used a lot of arithmetic tests for data validity. All these have been stripped out and replaced by a NMEA string validation test based on the NMEA hex check sum: the modulo 127 XOR of all the ASCII characters between (but not including) the "$" and "*". If the check sum fails the NMEA string is ignored. The ONLY arithmetic validity test surviving is the one found necessary to eradicate the bogus HDOP/VDOP/PDOP bug just described.

To help you keep track of setup changes, SHOWTIME now generates a (more or less) random checksum (4 hex characters) based on all the binary parameters sent to the Motorola ONCORE receiver. The current checksum is seen on the [F]iles screen and the old & new checksums are displayed during the "Init @4800 @9600..." sequence. The current checksum is also saved in the *.GPS file. Regard this as a configuration serial number — there is NO WAY to easily regenerate the parameters from the checksum!

**(e) USER CHANGES IN THE H/VDOP AVERAGING PARAMETERS:**
I added the ability to weight the position averages with HDOP (Lat/Lon) and VDOP (Hgt) in SHOWTIME 2.85. The exponential averaging algorithm (described in more detail in SHOWTIME.DOC) is still used:

$$Avg = [W*(new\ position) + (Length-W)*(old\ Avg)]/Length$$

The Length parameter defines the averaging window; it starts at a value of 1 and increments by 1 each second up to a "clamp" window length (set in the [A]veraging screen or the *.GPS file). Until Length reaches the clamp, we get uniform averaging, and after it hits the clamp the averaging becomes exponentially weighted with a time constant related to the clamp.

Before v2.85, the weight W was defined as 1. In 2.85 and later releases, the weight W can also be defined by the relevant xDOP parameter (x=H for Lat/Lon or x=V for Hgt) like

$$W = [xDOPnominal / xDOP]^2$$

In v2.85 I hard-coded HDOPnominal=1.5 and

VDOPnominal=2.0 as typical "good" values which would normally result with weights W close to 1.0; this allows the averaging window "time constants" to be similar for the weighted and unweighted cases. In SHOWTIME 3.00 I let you pick the nominal values in the *.GPS file in a line which reads like:

DOPWt    1    1.50    2.00              |Weight Posn Avg

The initial digit (1 or 0) turns xDOP weighting switch on/off (also available in the [A]veraging screen with the [D]OP Weight toggle). The next two numbers are the nominal "good" HDOP and VDOP parameters. You may want to revise these parameters for the 8-channel ONCORE (1.20 and 1.70 seem to work fairly well).

## (f) MENU AND *.GPS FILE CHANGES:
The main changes you will note on the screen are in the lower left-hand corner "positions" window. Some errors were discovered and hopefully fixed in the logic driving the top line in the  when satellite tracking was marginal. The window now updates just after the second, reflecting all information gathered during the previous second. The Tsigma now/max/min/avg line has been changed for esthetic reasons.

Occasionally when you make a [G]PS mode change from 0-D timekeeping to 2-D or 3-D positioning, the positions display may not "pop up" instantly. If this happens, just hit <esc>. Sometimes after making mode changes, the HH:MM time field may be blank. Just hit the [R]efresh Screen key.

The old switches [/] and [\] that allowed the position and satellite windows to be stopped have been deleted. I needed the code space for all the other features and nobody reported that the feature was useful.

The [=] timing summary in the upper right-hand corner was revised for esthetics reasons and to (hope-fully) make it more self-explanatory.

There are a few minor changes in the *.GPS file format with SHOWTIME 3.00, but your old files should still work OK. The SATOFF and POSOFF lines have been deleted, and new DOPWT and MSIGMA lines (discussed above) have been added. Running the new SHOWTIME 3.00 code with an old *.GPS file, and then doing a [F]ile [U]pdate will reformat the old file for you. The current *.GPS file looks like:

********

## (g) RAIM ADDITIONS:
Motorola has partially implemented RAIM integrity testing in the latest ONCORE firmware. According to their documentation, a future RAIM augmentation will allow the 1PPS pulse (and hence the front panel LED) only be present when satellites are in lock. I added the switches to enable this option per their documentation, but it is untested (and undelivered from Motorola, at least as of the Jan.95 date on the documentation). In particular, the *.GPS file (see the sample *.GPS file above) and the [T]iming screen now has a RAIM entry followed by an integer ## parameter. If ## = 0 then the RAIM testing is turned off. If the ## is in the range 3 to 32767, then than value is the 100s of nsec error that is tolerated before the RAIM algorithm triggers. Because Motorola has not fully documented their RAIM responses, I have no idea what will happen if the RAIM alarm triggers!

## (h) BUGLETS and GLITCHES:
A number of small tweaks (too mentionable to be numerous) have been made in an attempt to make the software be more reliable. Let me know if you find any new problems!

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## Ver 3.10  Updates — April 1, 1996

Corrected a leap-year error that made dates after Feb.29 be bad. Try as we may to test all the possible cases, we never seem to catch all the problems!

Added 4th digit to decimal portion of last Lat/Lon since some versions of the receivers now report an extra digit.

Restructured the NMEA parsing routines to make them more sanitary

Added minimal support for the Garmin GPS-20 "TAC Lite". To use a Garmin, set ApType=5 in your *.GPS file.

In anticipation of some future changes, the structure of the Rcvr: line in the lower-left hand quadrant has been revised.

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## SHOWTIME v3.2 Updates:

Version 3.2 contains several incremental enhancements to the earlier versions of SHOWTIME, hopefully all in the direction of improving things!

(1) Improved Error Handling: When running on slow PCs or in multitasking environments (especially Windoze 95), the RS232 serial input routine can have a buffer overflow and cause the program to die. I see this at my home when things get flaky during automatic time scheduled maintenance periods (SCANDISK, Disk Compression, etc) in the wee small hours of the morning.

I think I have found a better "fix" than trying to rely on Quick Basic's error handling and MAYBE 3.20 will improve things. I did the testing here by trying to get SHOWTIME to crash in W95 with 5 copies of "dir /s" plus SCANDISK running on top of SHOWTIME.

You will notice two minor changes associated with this fix. With the [&] debug running in position #1 (with ZDA messages) a 3rd counter shows a "sticky" version of the count of the number of characters in the RS232 input buffer. A few counts are not unusual. When it gets up to ~100, the computer is running behind. When it reaches 400 (representing about one second of unread data in the input buffer), the "fix" flushes the input buffer and resets the RS232 communications. Also, when the RS232 input is beginning to get "constipated", the decimal point in the time display changes to a "smiley face" as a warning.

(2) More W95 compatibility: When running in window mode, W95's DOS "box" allows you to use either a default character set or "True Type" characters. Unfortunately, several of the TT characters were incompatible with the character set I used in SHOWTIME. A few minor changes (like deleting Greek letters and making minor changes in the line drawing characters used) now make the display be legible with either type font.

(3) GEOID corrections revisited: In a much earlier version, I added a 2-position switch (GEOID) to accommodate two different Motorola Geoid conventions. Early PVT6 receivers sent WGS84 heights in their NMEA GGA messaage. But the NMEA "rules" specify that Mean Sea Level (MSL) heights should be reported and Motorola changed their ONCORE firmware. Unfortunately they got the sign of the Geoid height correction wrong, and the newest ONCORE receivers are (supposed to be — I haven't seen any yet) changed to fix that error. So there are THREE kinds of Motorola receivers out there, and the Geoid Switch has been changed to allow for all three receivers breeds (and for the Garmin GPS-20's which appear to be correct like the latest Motorola units). I went ahead and made the switch have 4 positions as shown in this table, with positions 0 & 1 preserving the definitions used in earlier versions of SHOWTIME, position 2 used for the new receivers and 3 to allow for some really pathalogical future case:

| GEOID SWITCH | MSL or WGS Height | Geoid Sign | Symbol |
|---|---|---|---|
| 0 (antique MOT PVT6) | WGS | OK | "." |
| 1 (old MOT ONCORE) | MSL | Wrong | "-" |
| 2 (new MOT+Garmin) | MSL | OK | "+" |
| 3 (pathological case) | WGS | Wrong | "x" |

The column headed "Symbol" shows the single character symbol I chose to use to display the Geoid correction in the Rcvr Status line. In the [G]PS Mode Screen, the [W]GS switch toggles thru these possibilities and the value is saved as GEOID in the *.GPS file.

(3) Height Displays: After I cleaned up the Geoid Sign problem in (2), I added another feature that had been requested by several people — the ability to work interchangably in WGS84 or MSL heights. The GEOID switch you find in the [G]PS Mode screen actually has 8 positions. The first 4 are as described above and correspond to the old SHOWTIME convention with heights converted from MSL (as reported by the receiver) to WGS84 Geoid heights (using the correction reported by the receiver, after the sign error is fixed) in accordance with conventional geodetic practice.

The next 4 positions change the displayed heights back to more "human" Mean Sea Level (MSL) units. In the [G]PS screen, you cycle thru the 8 possibilities with the [W] key.

When SHOWTIME is running, a new [W]GS/MSL switch appears on the help menu. This switch serves to toggle the height display function and can be used at any time. The height convention selected by either the [G]PS [W]GS switch or the real-time [W]GS/MSL toggle is saved when you write a *.GPS file.

Internally, SHOWTIME <<ALWAYS>> runs in WGS84 coordinates and toggling between WGS And MSL heights only effects the display and does nothing to any position averaging that is occurring.

(4) Improved GARMIN support: My "GARMINizing" of SHOWTIME is not yet complete. A Garmin (or similar) receiver lacks much of the configuration flexibility of the Motorola ONCOREs. You cannot operate in a Zero-D timing mode, or set elevation limits, or turn the Ionosphere corrections on/off, etcetera. My plans to accommodate the simpler receiver have begun. The main thing you will see is that much of the [G]PS Mode screen disappears when you select the Garmin=5 application type.

When ApType=5 is selected for the Garmin (or similar) receiver, the source of Date/Time information changes from the $GPZDA message to $GPRMC since most of the simpler receivers lack ZDA support. Note that the RMC date format is packed as a single DDMMYY value, while the ZDA format is like DD,MM,YYYY.

(5) Fixed a bug that crept in that prevented offsetting

the 1PPS timing epoch. Don't know when this happened but it's OK now.

More Garmin widgets will follow as time permits.

=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=
**SHOWTIME 3.3 Update Notes:**

The main changes between SHOWTIME 3.22 and 3.30 concern receiver specific items:

**MOTOROLA**: After finally sorting out the GEOID sign situation, I got tired of manually having to edit the *.GPS file to accommodate the different corrections, so I added an automatic detection feature. During the INIT@9600 phase, the receiver is queried to fetch the configuration. It looks for a 5.x or 6.x receiver and sets GEOID=0, or GEOID=1 for a 7.0 thru 8.6 receiver release or GEOID=2 for receivers 8.7 and later (which I still haven't seen). The user should no longer need to worry about this problem! The GEOID switch has been removed from the [G]PS mode screen.

After the INIT@9600 message, the receiver info is displayed on the screen briefly. If you want to get make note (like doing a screen print), hit any key after you see the INIT@4800 message and the program will commit suicide and stop after displaying the information.

The order of the lines in the *.GPS file format has changed slightly, and several lines have been reformatted. An old file should work fine.

In doing all these changes, I stripped out the code that kept the configuration checksum. After trying it, I decided it really wasn't very useful.

**GARMIN**: SHOWTIME now supports the limited list of GARMIN receiver options. You can manually select between 2D and automatic 3D operation. If you plug in a non-ONCORE receiver, the software will automatically select the proper APTYPE and GEOID switches.

The *.GPS file needed for the GARMIN is smaller than for the Motorola, so when you do a [F]ile [U]pdate the un-needed information is stripped out.

The timing sigma information now displays an estimate of the timing accuracy even for the GARMIN. I haven't "calibrated" it well enough to develop timing model parameters, and the software defaults to Motorola parameters. You can change these in your *.GPS file in

the MSIGMA line. An initial guess would say that the GARMIN case is something like

MSIGMA  500 500

i.e. an instrumental "noise" of about 500 nsec and sqrt(n) term of comparible size (the cannonical Motorola vales are 10 and 100 nsec respectively).

**BOTH**: SHOWTIME has limited ability to automatically detect MOTOROLA vs. GARMIN receivers, automatically setting the APTYPE parameter.

The detailed structure of the *.GPS files has changed, but old files should work OK. After getting the receiver to run, it is recommended that you do a [F]ile [U]pdate to re-write the new format *.GPS file. The *.GPS file for the GARMIN has fewer entries since many parameters are not applicable.

For the Motorola receiver, a typical *.GPS file now looks like:

```
#### . SHOWTIME v3.30 /  File   22 June 1996 =  #174  17:42:55.000
#### Posns:  Ref              Avg           Delta    RMS     #Sec
LAT:    +39.1883333365   +39.1883877673    +6.048  14.81    2748
LON:    -76.9349999746   -76.9350733235    -6.317  10.82    2748
HGT:        +108.000        +95.814       -12.186  41.38    2631
REFID  Testing SHOWTIME v3.30
GEOID    4      -34.00
#### Control                  ——————+——————
COM1                                       |COM1/2
TZ:      UTC  0                            |Time Zones: PC
LTZ:     EDT  4                            | Local
TimeSwap UTC                               | Initial
AUTOSET  240                               |AutoSet rate
XTIME    .9                                |Time Seq Slice
LOCKHYST 2                                 |Alarm Hyst,s
PCRATE   1                                 |PC Update,1-3s
#### Avg Windows & Statistics——————+——————
DOPWt    1    1.50    2.00                 |Weight Posn Avg
MSigma  10  100                            |Tsigma Model
POS     10000                              |Pos
RMS     10000                              |RMS
SigmaT  10000                              |SigmaT
Tsigma  283  127  149.0995  2810           |max/min/avg Tsigma,#Sec
Locked  #174  16:54:31.000 1               |Since,#Unlock
#### Receiver Modes           ——————+——————
APtype  4                                  |=Ap:Fixd
NDim    3                                  |0/2/3-D
ELEV    10                                 |Min El
AIV                                        |All-in-View
PDOP                                       |xDOP Selection
Select by xDOP                             |not Highest-in-Sky
IONO    1                                  |Ion+
RAIM    5                                  |RAIM 500ns
IGNORE  ++++++++++++++++++++++++++++|Accept=+
; PRN=31^       21^       11^        1^| PRN31=>1
Exit    Binary                             |@9600
#### Timing Info              ——————+——————
Epoch     +0.0000000000                    |Epoch Offset,sec
Cable    -92.400                           |Cable,ns
Inst      -8.000                           |Rcvr Delay,ns
Early     +0.000                           |Early offset,ns
#### Ticks                    ——————+——————
Stone   1000                               |Sec tick,Hz
Mtone   1200                               |Min tone,Hz
SLong   0                                  |Min tone@sec
#### Colors in order:         ——————+——————
##  BkGnd,BigUTC,Calndr,SatInfo,Epoch,Faint,Frame
##  Msec Offset,Posn,DOP/Stat,Help,Red Warning
Colors: 1  14  10  10  12  9  8  7  5  13  14  12

#### END OF FILE
```

and for a GARMIN GPS-20, it looks like:

```
#### . SHOWTIME v3.30 /  File   22 June 1996 =  #174  03:06:10.000
#### Posns:  Ref              Avg             Delta    RMS      #Sec
LAT:     +39.1883333365    +39.1882037753   -14.396  15.27       31
LON:     -76.9350000000    -76.9353430818   -29.546  28.87       31
HGT:          +108.000         +108.000     +0.000   0.00         0
REFID   Testing SHOWTIME v3.30
#### Control              ———+———
COM1                                      |COM1/2
TZ:      UTC   0                          |Time Zones: PC
LTZ:     EDT   4                          | Local
TimeSwap UTC                              | Initial
AUTOSET  240                              |AutoSet rate
XTIME    .9                               |Time Seq Slice
LOCKHYST 5                                |Alarm Hyst,s
PCRATE   3                                |PC Update,1-3s
GEOID    2       -34.00
#### Avg Windows & Statistics———+———
DOPWt    1   1.50    2.00                 |Weight Posn Avg
MSigma   500   500                        |Tsigma Model
POS      10000                            |Pos
RMS      10000                            |RMS
SigmaT   10000                            |SigmaT
Tsigma   742   742   741.6199   31        |max/min/avg Tsigma,#Sec
Locked   #173  21:27:21.000 0             |Since,#Unlock
#### Receiver Modes       ———+———
APtype   5                                |=   GARMIN
NDim     3                                |0/2/3-D
#### Ticks                ———+———
Stone    1000                             |Sec tick,Hz
Mtone    1200                             |Min tone,Hz
SLong    0                                |Min tone@sec
#### Colors in order:     ———+———
##   BkGnd,BigUTC,Calndr,SatInfo,Epoch,Faint,Frame
##   Msec Offset,Posn,DOP/Stat,Help,Red Warning
Colors: 1  14  10  10  12  9  8  7  5  13  14  12
#### END OF FILE
```

# SHOWTIME REVISION HISTORY

**Ver 1.x  — Developmental "Beta" releases. [Dec'94 to Apr'95]**

**Ver 2.0 — The first "public" releases of SHOWTIME.  [April 1, 1995]**

**Ver 2.10 — May 23, 1995**
- Added the alarm unlock indicator feature.
- Minor bug fixes & display enhancements.

**Ver 2.20 — June 1, 1995**
- Improved the unlock alarm functioning from 2.10.
- Added [L] toggle switch to turn the unlock alarm on/off.
- Fixed the "clock sticks in zero-D" bug (due to "feature" in Motorola's $GPGGA message that doesn't report time in Zero-D).
- Added the [W]GS84 GEOID correction on/off switch ([P]os & [G]PS screens and GEOID in the *.GPS file) to accommodate Motorola's new (Version 8.x) firmware changes in the way heights are reported.
- Added  [D]ate/Time Coldstart Clock initialization in [P]os screen.
- Stripped out a lot of spurious code and cleaned up a lot of the screens to make them more legible and to save code space.
- Improved wording on [SPACE BAR] main help screen menu.
- Deleted the [#] Channel number display (which nobody was using).
- Several menu inputs changed from manual "type a number" entry to "rotary switches" — for these, you press the key to cycle thru the legal values ( [%]ApType, [S]elect DOPtype, [I]on, [W]GS Geoid, [$]PCrate and [N]oise ticks all run this way now).
- Satellite Status "billboard" rearranged to make room for the new 8- channel ONCORE display (Untested - I haven't tried an 8-Ball yet!).

**Ver 2.21 — June 2, 1995**
- Corrected a minor bug in reported heights when running in positioning mode with old (pre-V8.0) ONCORE code. The [W]GS84 switch in the [P]osition screen now reads "new" vs. "old" to correspond with pre- and post- Version 8.0 receiver firmware.

- Entering a [M]anual position in the [P]osition screen now "seeds" the average position with the new reference position.
- In the [M]anual [H]eight entry, you can now enter either WGS84 or MSL heights and SHOWTIME will do the conversion for you, providing the [W]GS GEOID switch is in the correct position for your receiver's firmware. The correction is based on the WGS84 minus MSL Geoid separation computed in the Motorola receiver (the value of which is reported to you on the [P]osition screen).

**Ver 2.22 — June 4, 1995**
- Cleaned up & added some more logging info to the *.GPS file. The logging data in the file now includes the number of seconds included in the Lat/Lon/Hgt/ Tsigma averages, the "Valid Since" last locked time, and the number of times it was unlocked. Note that these parameters reflect the last time you write the *.GPS file with a [F]ile [U]pdate.
- The [P]osition screen now shows the RMS of (REF minus AVG)
- When you are in zero-D timing mode, the reported Average position is set to the 3-D REFerence position. In 2-D mode, the Hgt is set to the REFerence Hgt.
- Removed the [F]ile [K]ill *.GP$ command (not needed with [S]hell)

**Ver 2.23 — June 19, 1995**
- Made a few minor changes to make software recover from temporary data outage on RS232 cable better.
- Small change to screen that tells when PC clock has been [S]et.

**Ver 2.30 — August 1, 1995**
- The Lock Alarm logic that was added in Ver 2.10 had problems! A new, more robust logic was added in 2.30. The problem occurred because of the way that I counted the number of satellites that were in lock using the GSA message. The new logic uses the GGA report directly from the receiver. Showtime now has an added parameter (LOCKHYST in the *.GPS file, which can be set manually on the [G]PS Mode Screen) to act as a hysteresis "damper" to supress brief dropouts. A value ˜ 2-3 seconds for the hysteresis seems to work well.

## Ver 2.40 — Sept. 11, 1995

- Corrected minor bug in entering cable lengths — Meters units didn't work correctly, and the units code got confused if the units had an "S" in them (i.e. MSEC).
- The Time Offset screen was made a bit more explanatory. Several other cosmetic screen changes also were made.
- The Timing Offset "mini-screen" in the upper right-hand corner (toggled on/off with the [=] key) was streamlined and (hopefully) made more explantory. This screen is now framed in a box.
- The (ham) Maidenhead Grid Square computation was streamlined.
- Change to RS232 COM1/2 port initialization seems to improve glitch recovery reliability.

## Ver 2.50 — Sept. 16, 1995

- Added the ability to allow the user to disable & ignore multiple GPS satellites. In the [G]PS Screen, the [G]PS Use/Ignore key allows you to toggle any of the satellites PRN01-31. (You cannot toggle PRN32 on/off. This is because the ON/OFF status is sent to the Motorola as a 32-bit unsigned array, one bit/ satellite. Alas, QB45 does not have an unsigned long integer type, and it would have been a huge pain to add the 32nd bit to the field. Sorry!). This was added because the antique Block-1 PRN12 satellite has been unreliable. In the [G]PS modes screen, good satellites are shown as "+" and bad ones are flagged "Ì". The "Ì" character also is shown next to ignored satellite's PRN in the satellite status window in the lower right-hand quadrant of the screen.
- A new parameter "IGNORE" appears in the *.GPS control file to save the status of the new parameter as a 31-character string where a "+" means that the satellite is to be used an any other character (like a "-" or "Ì" or a blank) means that the PRN is to be ignored.
- To make room for the Ignore feature, the ability to exit SHOWTIME with any of the 7 "legal" NMEA messages being set to user-defined rates ("EXIT NMEA") has been discarded. "EXIT BINARY" still works.
- In general, a lot of cleanup was done on various screens to make the SHOWTIME code more compact. Also, several small, related subroutines were merged and/or put into inline code to make the program a bit smaller and faster.
- The display that shows the testing of the 1PPS RS232 tick at startup has been changed from ....#..#.... to something that looks more like an oscilloscope trace.
- The calculation of Local/Greenwich Mean Sidereal Time (LMST/GMST) was streamlined. Earlier versions included the quadratic (but not cubic) term to calculate the GMST at 00:00 UTC based on elapsed time from the J2000 epoch. For computational efficiency, the small quadratic term is now "locked" to 1996.0. The error for the next several years is < 1 msec.

## Ver 2.51 — Sept. 27, 1995

- In 2.40 & 2.50 I streamlined the RS232 configuration. Unfortunately, it didn't work on all machines. Some RS232 ports default to having the CTS and RTS lines low and some default to high. The 2.51 software has been modified to IGNORE the unused handshaking lines. (thanks to the folks at Onsala for giving me an opportunity to duplicate this problem).

## Ver 2.60 — Oct. 15, 1995

- A lot of work was expended to better trap RS232 I/O problems. The PC's 16450/16550 UART is now issued a hard reset each time the I/O is initialized. Error trapping has been improved. Several variables are now tested to make sure they don't go beyond reasonable bounds if the PVT-6 receiver send some garbage data.
- The DCDmask variable was hard-coded instead of being set in the *.GPS file, so users MUST input the 1PPS signal on the DCD line.

## Ver 2.61 — Oct. 17, 1995 (minor maintenance fixes)

- Still had to trap a couple of more bad data instances. Minor update from Ver. 2.60

## Ver 2.70 — Oct. 22, 1995

- Did a lot of testing to force errors that could cause SHOWTIME to die and implemented a LOT of new traps. All these involve possible bogus data returned in NMEA messages if the computer loses sync with the RS232 NMEA messages while running in W95.
- To make space for all the new traps, a number of separate subroutines were made into in-line code or subroutes in the MAIN module. This should also

speed execution a bit.
- A few minor cosmetic changes were made to the display,

**Ver 2.71 — Oct. 24, 1995 (minor maintenance fixes)**
- Found another sanity test that was needed.
- Cleaned up and slightly revised the [F]iles screen logic

**Ver 2.72 — Nov. 4, 1995 (never released publicly)**
- Fixed minor bug in the display of the nsec portion of the [U]+[I] total time offset in the [T]iming screen and the [=] display window. Calculations were done correctly — the display was wrong because an integer number was displayed in a floating point field.
- The PCrate switch somehow had gotten broken a few versions ago. It was made to operate again and the logic to set the GGA/GSA/GSV NMEA messages at a slower rate (PCrate seconds) was revamped to be more reliable at both 2 & 3 second "slow" rates. The new logic may glitch if you try to start SHOWTIME withing about 10 seconds of the PC's Midnite marker.
- The [$] PCrate switch is now available on the [A]veraging screen in addition to the [G]PS Receiver Mode screen. On either screen, hitting [$] increments PCrate in a [1,2,3,1,2,3...] sequence. After hitting [$] on the [A]veraging screen, the entry changes to the ColorRED color and SHOWTIME resets to initialize the new rate on exiting with <esc>.

**Ver 2.80 — Nov. 6, 1995**
- Made a number of changes in the logic behind the Position/Timing window so that the top line more correctly reports the receiver's status and that the unlock detection is more reliable.
- Additional "sanity" checks were added to prevent bogus coordinates from being included in the position (especially heights).
- Cleaned up & tested the new widgets added in 2.72 for public release.

**Ver 2.81 — Nov. 8, 1995**
- A minor bug caused an error in [F]ile [L]oad — a new *.GPS file was not loaded correctly. A global variable got used for two different purposes during one of the recent changes.

**Ver 2.82 — Nov. 11, 1995 (minor maintenance fixes)**
- The earlier versions of SHOWTIME would report incorrect Lat/Lon if either Lat or Lon was between 00 and -01 degrees. This is a common problem with a lot of software since it is hard to represent a signed negative zero integer!  This minor problem is now fixed.
- The -00 problem was not trivial to fix. Added a new parsing function (Pd$) to make it possible. This resulted in a slight display change, namely that Longitudes under 100 degrees (+ or -) now have the degrees field zero-padded to 3 characters plus sign.
- I also made it possible to [P]osition [M]anual enter Lat/Lon in the -00 to -01 degree band.
- Fixed a minor bug that somehow crept in that made the [C]olor and [A]veraging screens not work right when in zero-D timing mode.
- The [&] "speedometer" has a second number displayed — this is the number of times thru the inner loop trying to read an NMEA message during the current second.
- A screen which shows the "Locked Since" and # Unlocked information appears when a non-operative menu key is struck. <esc> clears this information panel and resumes operation. (The same info also appears when you manually [S]et the PC's clock.)

**Ver 2.83 — Nov. 14, 1995 (minor maintenance fixes)**
- Found a minor glitch (which crept in from earlier changes) when running in forced 2-D mode with SHOWTIME not recognizing the reported rcvr state properly.
- Fixed glitch where [A]veraging [z]ero didn't reset all the reported statistical parameters — some variables had been left out of COMMON.

**Ver 2.84 — Nov 21, 1995 (minor maintenance fixes)**
- Fixed minor bug that caused program to lock up if you tried to [F]ile [L]oad a non-existent file — an IF test was wrong.
- It was possible for the [P]osition or [R]MS or [T]iming Sigma filter lengths to not "clamp" at the proper values if you decreased the numbers and they were already greater than the new filter lengths.
- The Pos/RMS filter weights had been a mish-mash of floating and integer values. They are now uniformly long integers and a single subroutine

handles incrementing them each time new data arrives.

- There had been some confusion on the Position screen about ÎAvg & ÎRef. The nomenclature was changed to Î(RA) (meaning the difference Ref-Avg), Î(AL) (meaning Avg-Last) and Î(RL) (meaning Ref-Last).
- Some essentially useless (and probably buggy) code that attempted to sort the "S-meter" display panel when two satellites are at the same elevation to have the rising satellites listed above the setting satellite was deleted. The ordering for this rare case is now only determined by the order the satellites are reported in the NMEA msg.

## Ver 2.85 — Dec 1,1995

- In response to a request, the 2-D or 3-D positions can now be averaged based on (1/HDOP)^2 [Lat/Lon] or (1/VDOP)^2 [Hgt]. A new switch [A]veraging [D]OP Weight has been added — pressing the [D] key will toggle the xDOP weighting on/off. In the normal Position window, you can see when the weighting is turned on by a letter "w" appearing before the positions differences and rms indicators.
- A new switch has been added to the *.GPS file called DOPWEIGHT. If the line is present, then the xDOP weighting is to be applied, if it is absent, then the weighting is not used.
- To squeeze the [D]OP Weight item into the [A]veraging screen, the [A]veraging screen layout was changed.
- To accomodate this change, the weighting filters inside SHOWTIME were changed from LONG (integer) to DOUBLE (floating).
- The filter length strategy is similar to that used before. See FAQ #23 for more details.

## Ver 3.00 — Jan.7, 1996

A major update release. Details in the file SHOWTM30.doc. Changes in 3.00 include the following:

- Support for both the older 6-channel and the new 8-channel Motorola ONCORE receivers.
- Inclusion of new debug diagnostics that display and permit logging of the incoming NMEA messages.
- A revision of the Tsigma accuracy predictor algorithm when in position (not timing) mode, and the ability for the user to set the model coefficients.

- A number of changes were made to improve the "smoothness" and reliability of the display updates. The PCrate philosophy was changed.
- The ability for the user to make minor changes in the H/VDOP averaging parameters.
- Menu and *.GPS file changes, mostly minor.
- An attempt (not yet tested) to support some of the Motorola RAIM options (some of which they haven't implemented yet!).
- A more graceful way to allow for a complete receiver coldstart was included.
- And the ongoing, continuing saga fixing of minor buglets reported to me.

## Ver 3.01 — Jan. 13, 1996 (minor maintenance update)

- Fixed a minor bug in the help menu triggerd by the [space bar]. The help menu now also displays the [_] NMEA message log key.

## Ver 3.02 — Jan. 16, 1996 (minor change)

- The reference hex checksum added in v3.00 didn't include all the parameters uploaded to the receiver in the Init@9600 binary load. This was changed and the checksum now is 'touched' by each and every bit sent to the receiver. The line in the [F]iles screen that reports the checksum was reworded slightly.

## Ver 3.03 — Jan. 19, 1996 (minor change)

- Back at Ver 2.60 I had added a hard reset for the PC's 8250/16450/ 16550 UART to try to improve error recovery. This caused problems on a COMPAQ (and perhaps other machines) so the hard reset was removed.
- The coding that generates the square boxes around the different frames was streamlined, saving nearly 200 bytes of code space.

## Ver 3.10 — April 1, 1996

- Corrected a leap-year error that made dates after Feb.29 be bad.
- Added 4th digit to decimal portion of last Lat/Lon since some versions of the firmware now report an extra digit.
- Restructured the NMEA parsing routines to make them more sanitary
- Added minimal support for the Garmin GPS-20 "TAC Lite". To use a Garmin, set ApType=5 in your *.GPS file.

- In anticipation of some future changes, the structure of the Rcvr: line has been revised.

## Ver 3.20 — May 28, 1996
- Hopefully we have made another incremental reliability improvement with a new "fix" to preclude against RS232 input buffer overruns.
- Expanded the GEOID switch to accommodate new (8.4?) ONCORE rcvrs.
- Added an option so that user can use [W] to toggle between MSL and WGS84 height display.
- Added some more Garmin GPS-20 support (not yet complete).
- Fixed a bug that crept in sometime (who knows when) that lost the ability to offset the msec portion of the 1PPS time epoch.
- See file SHOWTM32.TXT for additional details.

## Ver 3.21 — June 1, 1996
- Two of the revised GEOID switch settings were inadvertently reversed in 3.20, making for a minor incompatibility with earlier versions of SHOWTIME. This was fixed and SHOWTM32.TXT release notes were corrected.

## Ver 3.22 — June 17, 1996
- I still didn't have the signs right for the GEOID correction. Hopefully now they are correct!
- Changed the order that some information is posted to the screen. Now the position screen is updated immediately on receiving the $GPGGA message.

## Ver 3.30 — June 23, 1996
- MOTOROLA: SHOWTIME now interrogates the GPS receiver to get the software version and sets the GEOID switch automatically. The receiver configuration information is displayed after after INIT@9600. Hitting any key after INIT@4800 will stop SHOWTIME so you can read/save the configuration info,
- GARMIN: All the GPS-20 options now should work. When running with a GARMIN receiver, many of the menu screens are considerably abbreviated, deleting entries which are not applicable.
- SHOWTIME has limited ability to automatically detect MOTOROLA vs. GARMIN receivers, automatically setting the APTYPE parameter.
- The detailed structure of the *.GPS files has changed, but old files should work OK. After getting the

receiver to run, it is recommended that you do a [F]ile [U]pdate to re-write the new format *.GPS file. The *.GPS file for the GARMIN has fewer entries since many parameters are not applicable.
- The binary configuration checksum generated from the commands uploaded to the Motorola receiver has been deleted.

## Ver 3.31 — July 4, 1996 (minor changes)
- Minor formatting changes to line up the HGT+WGS above the height
- Deleted DCD timeout at 4800 baud
- Small display change in GARMIN mode
- Apparently the Motorola Geoid sign change applies for firmware >= 8.8, (not 8.7) so the automatic detection algorithm was changed accordingly.
- [G]PS mode screen streamlined a bit.
- The GPS week is defined as [0000-1023] and "rolls over" in August, 1999. The displayed GPS week (computed from the MJD in SHOWTIME) now rolls over properly.
- Improved reliability of logic to get MOTOROLA firmware revision

## Ver 3.32 — Sept 13, 1996
- Added a new capability: The [_] key that formerly turned on/off the writing of SHOWTIME.LOG file with NMEA input now has a 3rd position. When the 3rd position is selected, a different log is written. Once per minute (at second zero), a comma-separated (CSV) line is written with the time (in fractions of a day), the # of satellites visible above the elevation mask, the current PDOP/HDOP/VDOP, and 4 entries (PRN,EL,AN,SNR) per visible satellite. Satellites being used by the rcvr have positive PRN and non-zero SNR, while visible but unused satellites have negative PRN and zero SNR. CSV format is compatible with most spreadsheets.
- Fixed a minor error in the e[X]it return.
- stripped a lot of spurious and un-needed stuff out of a number of menus and menu items to make things more sanitary and to save code space.
- Added units (meters) to the (R-A),(A-L) & (R-L) position differences.

## Ver 3.33 — Oct.15, 1996 (bug maintenance)
- Several "instabilities" had crept into SHOWTIME. Occasionally a "String Space Corrupt" message appeared. When 12 satellites were visible, the

program would die. Under W95, moving the mouse cursor could cause the program to freeze. Ver 3.33 is a maintenance clean-up of the older code to improve space allocations and to "protect" several arrays from being any possibility over-written.

- There is a slight change in the elevation up/down arrows in the satellite display as a result of these changes. When a satellite appears for the first time (including when SHOWTIME is started) the satellite is shown as rising (not as blank). When SHOWTIME sees that the satellite's elevation is decreasing, the arrow then changes to "down".

## Ver 3.34 — Oct.20, 1996 (maintenance)

- The satellite status display now (should) handle the >12 satellites visible case better. If satellites 13-15 are up, the lowest elevation unused satellites are not displayed, but they are treated properly inside SHOWTIME.
- Fixed a couple of minor typos associated with the display of the ONCORE receiver Version/Rev/Serial number you see when doing a rcvr] initialization (like with [%] or when you change parameters). A row of ..... shows progress at getting the rcvr response synchronized.
- Fixed a minor bug from v3.33 that caused the display to flash when displaying local time.