1999

Light Aircraft Management System

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USE OF THESIS

"I certify that this thesis does not incorporate without acknowledgment, any material previously submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text".

Signature _

Date 16 JUN 90

THESIS

Light Aircraft Management System

By
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(UNDER THE DIRECTION OF DR STEPHEN HINCKLEY)

A thesis submitted in partial fulfillment of the requirements for the degree Bachelor of Engineering (communication systems) at Edith Cowan University (Joondalup Campus), School of Mathematics and Engineering, 1999.

ABSTRACT

This report details methods to construct a flight data logging system that can be used to manage student flight and aircraft maintenance records. These methods utilise GPS, embedded processors and associated software to depict the occurrence of landings, "Touch and Goes" and record aircraft total flight time. By manipulating these methods it was possible to produce a usable data-logging unit which facilitated the automation of flight maneuver recording. This data-logging unit was constructed from embedded components and interfaced with a user defined database.

PREFACE

Engineering in context, is validated in stature both in the academic and business worlds, in terms of integrity, advantages society gains, and also the ethical considerations. This reputation has evolved over the years, and in most cases can be initiated from and attributed to the physical and mental requirements of the Bachelor of Engineering Degree.

A major constituent of this degree is to compliment the skills acquired throughout their university time by undertaking a final year project. This effort is meant to engage all facets of the undergraduate degree including considerable technical ability, research and information collaboration techniques, management skills and the ability to work problems through on their own. This criterion is based on real world applications and is the underlying aim of such educational institutions to impart this type of knowledge.

For myself, winding up the fourth year as an engineering student (1999) at Edith Cowan University, meant an end to many years of striving to get the best grades and maintain a good average. Now I had to be content with what had been achieved over the last few years and look at what the next year had to offer. My initial drive entering the project year was very strong and aspirations' devising a successful project to change the world was not out of my reach. This, however, was short lived and I found that having strong and vivid ideas of where a project should head is only as good as the resources I have to get it there. Fortunately I was able to meet with Dr Stephen Hinckley who had some interesting ideas and had the means to make them happen.

The Engineering Department, like so many others around campus, has had the need to amalgamate with the Aviation Discipline at the Mt Lawley campus. This in itself has little effect on myself or my degree up until the beginning of the project year. Much of the technical concerns and interests this Aviation discipline has had in the past have gone unactioned as the expertise was not available within their school. Now they have access to the engineering body their hopes to overcome technical areas, and to better or automate daily tasks are alive. Through Dr Hinckley and in collaboration with Mr. Malcolm Yeo, I was offered a project to devise a data logger that would log flight information to determine when the light aircraft had performed certain maneuvers. Without going into specifics these maneuvers initially concerned landings, "Touch and Go's", and total flight time. My decision to accept this project was based on my interest of flying and my strong disinterest with the majority of existing projects offered by the engineering departments' academic staff.

This report outlines the details of my work during the academic year of 1999. Perusal of the details within should provide the reader with a clear understanding of the tasks involved with employing external equipment to log flight information and to implement this in a form that is beneficial to many users. The technical aspects of this report are twofold:

1. Active employment of electrical and communication based products to extrapolate raw flight information.
2. Implementation of logging program, database and operating system in order to manage raw flight information.

These technical aspects are embodied within detailed background information, multiple versions of implementation and an insight into future adaptations of what has already been achieved.

The outcome of this report will enable Aviation staff and others to automate the updating of student history and achievements towards their license, indicate to the airport an unbiased cost of flight and when the maintenance of their aircraft are due. This project has commercial interest and following the compellations of my findings will almost certainly find its way on to the light aircraft market.

For the subsequent report material I wish to extend thanks and gratitude to all those concerned, who provided me with direction, inspiration, and contributed to the timely progression of my work. Special thanks to David Lucus for his ongoing support and interest, without his programming genius I doubt the project would have got as far as it did. Also Special thanks to Mike Wetton who, although departing from the Joondalup campus early second semester always maintained contact and gave assistance where possible. Thankyou to Dr Steven Hinckley who gave me a little leverage as a project coordinator and had faith in the promised result. Thanks to the Aviation school and especially to Mal Yeo who organised the test flights at the department's expense. Lastly a huge thanks to my wife Natalina and the blessed two additions to my life Jesse and Gemma early this year, this major influence showed me that university is not my life but just a small step to the big picture.

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1. OVERVIEW

Student pilots experience intricate training in flight school for many reasons. Whether those reasons are for personal satisfaction or to create a living the fundamentals remain the same. The following is a description of certain air tasks those students have to learn and master to pass.

TOUCH AND GO

This maneuver is basically a landing and a subsequent take-off. As you progress through your flying and gain experience you will start doing "circuits". These are to let you practice handling the aircraft in the vicinity of the aerodrome. This encompasses quite a few things including the following:

- Circuit pattern
- radio procedures
- traffic separation
- take-off
- approach and landing

The touch and go is simply a means of landing and then taking off again without stopping.

THE APPROACH

This is one of the more difficult parts of flying to do well and consistently. In order to make a good landing, you must be able to set yourself up on a constant approach, and be able to maintain that. Unlike a car, in an aircraft you have to control your direction, speed and height. This is done by constantly adjusting the power and attitude (angle of the aircraft) to overcome sudden increases or decreases in lift due to gusts of wind etc. There is a desirable angle of approach - not too high, not too low, and it takes a while to get the "feel" of this and also co-ordinate all of the controls, watch out for other aircraft, talk on the radio and if there's any time left to enjoy themselves.

THE LANDING

Once you can fly a good approach, you then learn to land the aircraft. This is where a bit of finesse is required. Again judgement is the key. The main stages of landing the aircraft are as follows: Approach, flare at the correct height to fly level about 1 meter above the runway, power off and let the aircraft gently settle on the tarmac.

This project focuses on the above tasks with the ultimate goal to automate their recording.

2. PROJECT DEFINITION

2.1 AIM

The aim of this project was to determine how ""Touch and Goes"", landings and a determinate of flight time of a light aircraft could be logged with considerable accuracy. These measurement results could be manipulated for use within the airport and aviation department infrastructure, thus providing the avenue for non-interpretative invoice reports, student history and accurate aircraft workloads.

2.2 SCOPE

In order to implement the best system representative of the required aim, there existed a requirement to explore many measurement techniques and utilise a diverse range of test equipment. This involved an outcome-orientated study whereby the aim justified the mean hence consideration to many variations of implementation not always logical and sometimes beyond the scope of an Undergraduate Project.

A system of interest in this project is one that utilises its own technology and would stand alone within the normal operations of a light aircraft flight. This independent approach allows the project to bypass much of the stringent policy surrounding aircraft construction and modification. This system would rely on external sensors to monitor the aircraft state so that a flag could be raised once a predetermined event had occurred. There are two formats whereby sensors may output this information:

- Analog format
- Digital format

Subsequent material will show that the majority of effort is directed towards a sensor that passes sensor information in the digital format. A digital format is preferred as this eliminates the analog to digital conversion requirement so common in today's monitoring systems.

This sensor will provide a means to determine the "touch and go", landing and the total flight time.

2.3 STRATEGY

The strategic development of the project involved a series of sequential steps. These steps have been utilised to ensure that the project progressed in a logical and efficient manner. The proposed strategy, listed in chronological order for the academic year of 1999 was as follows:

ACTIVITY 1.

This requires a topic to be researched in ways that provide the understanding of whether the project can go ahead. During this time will be spent determining what interests lie within the project and whether this interest be maintained throughout the entire project. If it is feasible to acquire all the necessary equipment and whether it is within the budget. Do I have the knowledge or the time to complete this project or does it look imminent that the difficulty level will be too high. During this time literature searches will be performed to find out what resources are available, whether there is qualified staff to assist in some of the theoretical difficulties the project may come up against and also if there is sufficient literature to compensate this shortfall.

ACTIVITY 2.

A proposal is a requirement of the project in that all the intended tasks are listed so that the instructors can validate that work levels are of engineering standard. This part of the project is also beneficial to the student in that a sturdy platform can be formed from where they can systematically progress. This proposal is to be submitted before 1 April 1999.

ACTIVITY 3.

This period is allocated for reviewing certain testing techniques and refreshing myself on the engineering standards. Testing techniques will encompass basic test equipment operation and must be completed before the full systems check. Other microprocessor analysis methods must also be reviewed within this activity.

ACTIVITY 4.

A full equipment check will be required in this section. All the hardware calibration dates will need to be checked, as they may need recalibration. Any cables used need to be checked for continuity, (short and open circuits). The configuration of the interface (computer to GPS) will need to be established, as extra software may need to be purchased or written. The hardware tolerances need to be checked, as the scope of sensing ranges will be varied. Lastly a check to see whether everything is available to test the system

ACTIVITY 5.

There is a need to undergo a site check. Make a visit to the test aircraft and determine whether the construction of the device will interfere with any other instruments. Any limitations of design must be clarified at this time.

ACTIVITY 6.

This is the last activity expected to finish before the first semester break. During this time construction will commence for the major part of the GPS and the cables required, this also implies the antennas and their positions. The management of the aircraft by this stage will have made space and are ready for the project to move in. Once the test gear is in place continuations will continue to ensure there are no technical glitches within the system.

ACTIVITY 7.

This is where the measuring stage will take place. All the flight path measurements will be made and a crude data gathering mechanism will be in place.

ACTIVITY 8.

There will be a certain amount of research and reading required at this time as by this stage there will be some new hardware. This hardware is the fundamental drive behind the data processing.

ACTIVITY 9.

Once this new hardware is fully understood it will be time to construct the final project and make arrangements for another test at the airport.

ACTIVITY 10.

The project will almost be completed here, or there some loose ends to complete. During this phase it is important that all the documentation is in order. An oral talk is required at this point and overheads or handouts or both will need to be produced. If the schedule has been maintained there will be considerable extra time at this stage to polish up the whole performance. Obviously the project will also be submitted.

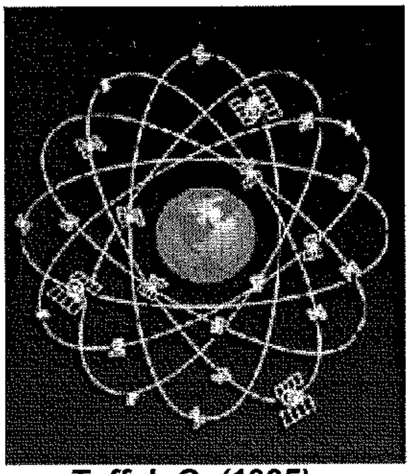
3. GPS

3.1 OVERVIEW

The Global Positioning System is based on the US Department of Defense's NAVSTAR Satellites. NAVSTAR (Navigation Satellite Timing and Ranging) satellites permit users to determine their position in three dimensions anywhere on the earth. Additionally, time and velocity are also available.

The GPS is a United States Government system operated by the Department of Defense (DoD). It consists of a twenty-four orbiting satellite constellation.

Figure 1: GPS constellation



Taff, L.G. (1985).

The system provides an aid to radio navigation which uses precise range measurements from the GPS satellites to enable accurate position fixes to be determined anywhere in the world. The satellites' measured orbital parameters (ephemeris data) are combined with precision onboard timing signals and broadcast as a composite signal. The receiver processes this information to determine its position in space.

GPS position information is expressed in the Cartesian, earth-centered, earth-fixed co-ordinates as specified in the World Geodetic System 1984 (WGS-84). Whilst there are other systems available, WGS-84 is the only system authorised for use in Australian airspace. Navigation values, such as distance and bearing to a waypoint, ground speed, etc., are computed from the aircraft's latitude/longitude and the location of the waypoint. Course guidance is usually provided as a deviation from the desired track of a Great Circle course between defined waypoints.

The United States DoD declared GPS had full operational capability (FOC) in April 1995. However, even after FOC, GPS by itself, does not meet all the integrity, accuracy, continuity of service and availability requirements needed for sole means IFR operations.

3.2 GPS SYSTEM SEGMENTS

There are three segments that make up the GPS system. They are Space, Control and User.

3.2.1 GPS SPACE SEGMENT.

The Navstar satellites make up the space segment. The more recent is the Block II shown in figure 2.

GPS SATELLITE

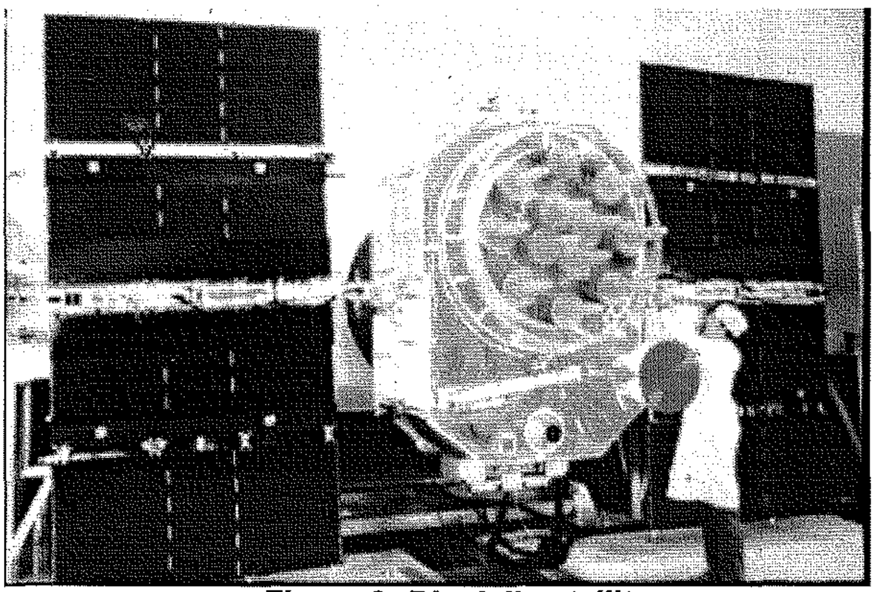


Figure 2: Block II satellite
(Denaro, 1988)

- The Block II satellites were made by Rockwell International.
- At time of insertion into orbit they weight 1860 LB.
- They have a planned life of 7.5 years.
- Power for the satellites comes from two 7.2 Square meter solar arrays.
- Each block IIA satellite contains four atomic clocks: two cesium (Cs) and two rubidium (Rb).
- The block IIR satellites are made by Martin Marietta.
- The DoD procured 20 Block IIR satellites between FY92-FY96
- Satellite signals for the Block IIR may not be as strong as the current satellites.
- The latest satellites, the Block IIR versions, include autonomous navigation. These satellites can operate 180 days between uploads like

the previous block IIA, they can generate their own navigation information. Thus the accuracy of the system can be maintained longer between uploads. The Block II satellites are made by Rockwell International. At time of insertion into orbit they weight 1860 LB.

Each block IIA satellite contains four atomic clocks: two cesium (Cs) and two rubidium (Rb).

The block IIR satellites each contain three atomic clocks: two Rubidium (Rb) and one cesium (Cs).

Martin Marietta made the block IIR satellites. The DoD procured 20 block IIR satellites between FY92-FY96 as part of a multi-year contract and had an option to buy one additional satellite in FY95, which they declined.

Block I Navstar satellites weighs 771 kilograms and contains both sun-tracking solar panels for power and nickel-cadmium batteries for backup operation when the vehicle is in the earth's shade. An altitude and velocity control subsystem orients the spacecraft to keep the satellite's antennas pointed toward the earth. Other subsystems include those for reaction control and orbital insertion, thermal control, telemetry, tracking and commands and navigation broadcasts. A triple redundant navigation processor controls the satellite functions. The processor stores the daily up loaded ephemeris and clock-drift predictions until they are needed for insertion into the 50 bit-per-second navigation message. After the codes are modulated on the carriers by phase modulation the signals power is boosted to about 24 dBW by a high-power amplifier and transmitted through a 12-helix-element phased array antenna.

Currently there are 27 operational GPS satellites in orbit. Launches are planned to "sustain" a usable 24-satellite constellation. There are two Block IIR launches scheduled for FY99, 22 April (firm, pending weather of course) and 15 September (tentative). The first Boeing block IIF satellite is scheduled for launch during the second quarter of FY-2003 (tentative schedule). Funds have been obligated for the first six block IIF satellites with an option for up to 27 more. There is a rigorous (albeit tentative) launch schedule for block IIF satellites through FY-2010. Each orbital plane is inclined at 55 degrees at an altitude of 10,898 Nautical miles, 20,180 Km, 12,600 statute miles. The spacing of satellites in orbit is arranged so that a minimum of five satellites will be in view to users worldwide. A minimum of three satellites are required to obtain your Latitude, Longitude and Time. Having a forth satellite in view permits the GPS receiver to compute altitude. In practice no more than nine GPS are ever in view.

3.2.2 GPS CONTROL SEGMENT.

The control segment consists of five Monitor Stations (Hawaii, Kwajalein, Ascension Island, Diego Garcia and Colorado Springs). There are three ground antennas, (Ascension Island, Diego Garcia, Kwajalien). The Master Control Station (MCS) is located at Falcon AFB 12 miles east of Colorado Springs, Colorado. The monitor stations passively track all satellites in view, accumulating ranging data. This data is processed at the Master Control Station to determine satellite orbits and to update each satellite's Navigation message. Updated information is transmitted to each satellite via the Ground Antennas. New navigation and ephemeris information is calculated from the monitored data and can be uploaded to the satellites once or twice daily. This information is sent to the satellite via an S band link. The satellites then send subsets of the orbital ephemeris data to GPS receivers over radio signals.

3.2.3 GPS USER SEGMENT

The User Segment consists of the receivers, processors and antennas that allow land, sea, or airborne operators to receive the GPS satellite broadcasts and compute their precise position, velocity and time.

The GPS concept of operation is based upon satellite ranging. Users figure their position on earth by measuring their distance from a group of satellites in space. The satellites act as precise reference points. Each GPS satellite transmits an accurate position and time signal. The user's receiver measures the time delay for the signal to reach the receiver, which is a direct measure of the apparent range to the satellite. Measurements collected simultaneously from four satellites are processed to solve for the three dimensions of position, velocity and time. The system continues to be refined and techniques continue to improve. Typically users are now able to expect accuracy's within a few meters. Time accuracy is measured in nanoseconds. Position is measured due to its relation to time. This can be compared to the way in which we measure and express the distance to stars. We say, they are so many light-years from us. If it seems odd that position is determined by time, consider that we use this concept in very ordinary life experiences. For instance, it is not unusual to hear someone express how far a town or city is by saying something to the effect: "Oh, it is about an hour and a half from here." On test equipment such as an oscilloscope or spectrum analyzer, there is a constant reminder of the relation of time and distance. Time is expressed as the inverse of frequency. For determining the exact position of a point on earth, we are now able to measure how long a signal takes to get to a particular spot in which we have a receiver. If we have very exact time we can also determine very exact position. When we triangulate with several satellites we then have extremely accurate position.
(Thompson, 1985)

APPLICATIONS

Oil Spill

In the event of a serious oil spill, detailed information about the location and movement of the resulting slick is critical to clean-up efforts. The U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and the Department of Interior's Minerals Management Service

(MMS) have each developed GPS-based devices that help observers collect information about offshore oil spills. (Advanstar Communications, Sept.1994, p.20)

Survey of India
Recognising the survey-level accuracy of GPS, the Survey of India's (SOI) Geodetic and Research Branch (G&RB) made it a priority to purchase several GPS receivers. SOI, a government agency based in Dehra Dun, is responsible for national mapping. The agency plans to use the coordinates mainly for mapping and engineering developmental projects that help in the developmental projects. (Advanstar Communications, Sept.1994, p.56)

Utility Company
Pole by pole, line by line, across two-thirds of Montana a state in America, the independent inspection company of Havre is using GPS to inspect and evaluate the condition of each of the 330,000 utility poles owned by the Montana Power Company. GPS technology can precisely link the consumer's name, electric meter number and the structure's specifications. According to this company, GPS has proven to be an economically sound way to collect data. (Advanstar Communications, Jan.1995, p.16)

Persian Gulf War
GPS technology was employed from the very start of the Gulf War. The new technology was able to provide precise location for deployment accuracy and GPS was also used as the timing reference for enhanced integration. (Advanstar Communications, Jan.1995, p.16)

Mapping Mexico Road Network
Mexico has put each of its 32 states' highway divisions to work using GPS. With the aid of these advanced technologies to inventory more than 91,000 kilometers of highways, the country expects the resulting data to help in the maintenance and the expansion of its national road network. (Advanstar Communications, Mar.1995, p.20)

Vehicular Navigation
Driving north from California to Washington and then south, along the Oregon Coast, Ed and Jan Wright use their GPS receiver to navigate to locations, estimate time arrival, and plan food, fuel, and rest stops. Ed Wright is the traffic-engineering technician for the City of Alhambra in the USA. He assisted with the development of the city's geographic information system in which GPS was used to generate the precise control network. He concludes: "When I decided to take the GPS receiver on our trip I envisioned it as something to play with--a fun experiment. Instead, Jan and I discovered a multipurpose tool that gave us the dynamic freedom to modify travel plans and immediately see the results. What started as a gadget with potential turned into an integral aspect of our driving experience. (Advanstar Communications, Jun.1995, p.22)

Astronomy
Astronomy is intimately tied to timekeeping through the rotation of the earth. To point a telescope accurately, or to navigate a boat at night using a sextant, one needs an accurate source of time. Observatories have maintained accurate time and have distributed it to civilian populations for centuries. (Advanstar Communications, Jun.1995, p.32)

Timing
"GPS makes it possible for anyone almost anywhere on the face of the earth to obtain extremely accurate time. As prices fall, we will see GPS antennas attached to observatory domes, both large and small, fixed and mobile. Most telescopes of any size are now computer controlled, and as inexpensive as computers have become, GPS prices are falling ever faster. Maybe in a few years, GPS receivers will be built into every notebook computer, then perhaps into every desktop system." (Dr Parkingson, 1980)

Merchant Navigation
At sea, merchant vessels equipped with GPS will be able to carry out port-to-port operations with a single navigation aid. By differencing GPS earth-referenced velocity with pitometer-log velocity, they will be able to directly calculate ocean currents at sea and insure that they stay in the most favorable regions of ocean currents by avoiding the maritime analogy of aircraft headwind. Additionally they will use GPS position and velocity information to continuously steer great circle routes very accurately which will save time and fuel. A study by the Maritime Administration estimated a potential savings of $17,000 per Trans-Atlantic passage for a large tanker will be possible with the new technology. Collision avoidance and safety have also become a very important international concern for large tankers, particularly because of ecological damage due to oil spills. The day may come when there is sea-traffic control, analogous to present air traffic control.

GPS will aid the commercial airlines. It will provide a digital display of three dimensions of position and velocity in the cockpit of an airliner. This information can be interrogated from the ground by an air traffic control system. As with sea going vessels, the air traffic will become more efficient and more safe. GPS can be used in the collision avoidance mode for the airlines. The technique would have all aircraft transmit a radio pulse of tone at the same precise time. During pauses between tones, all aircraft listen for signals from other aircraft. By timing the difference between their transmission and any received signal, they can infer range (time multiplied by the speed of light) to all aircraft within line-of-sight. In addition, by counting the Doppler shift on the incoming signal, closing rates can be directly estimated.

Both at sea and in the air, search and rescue operations can be greatly enhanced by GPS. This is because very precise position information prior to ditching an aircraft or abandoning a ship will allow the searchers to pinpoint the initial location and thereby speed up the rescue operations, saving both money and lives.

As we expand our search for fossil fuels, oilrigs are being put to sea in deeper and deeper waters. One of their major concerns is self-location. GPS can provide this to them continuously, and with time-averaging, potentially provide positioning accuracy of one to two meters. In the scientific area, GPS will act as a time distribution system. Precise timing is critical to radio astronomy and many other scientific applications. Also, GPS's two-frequency transmission allows direct measurement of ionospheric group delay, and hence measurement of the number of free electrons in the ionosphere in a wide range of geometrical relationships. The very precise position information provided by GPS can be time averaged for even greater accuracy and used as a very precise geodetic positioning technique. In designing GPS satellites, the needs of the radio astronomy service are borne in mind and given all practicable protection. (Thompson, 1985, p.40)

An example of a user system implementation is given in figure 3.

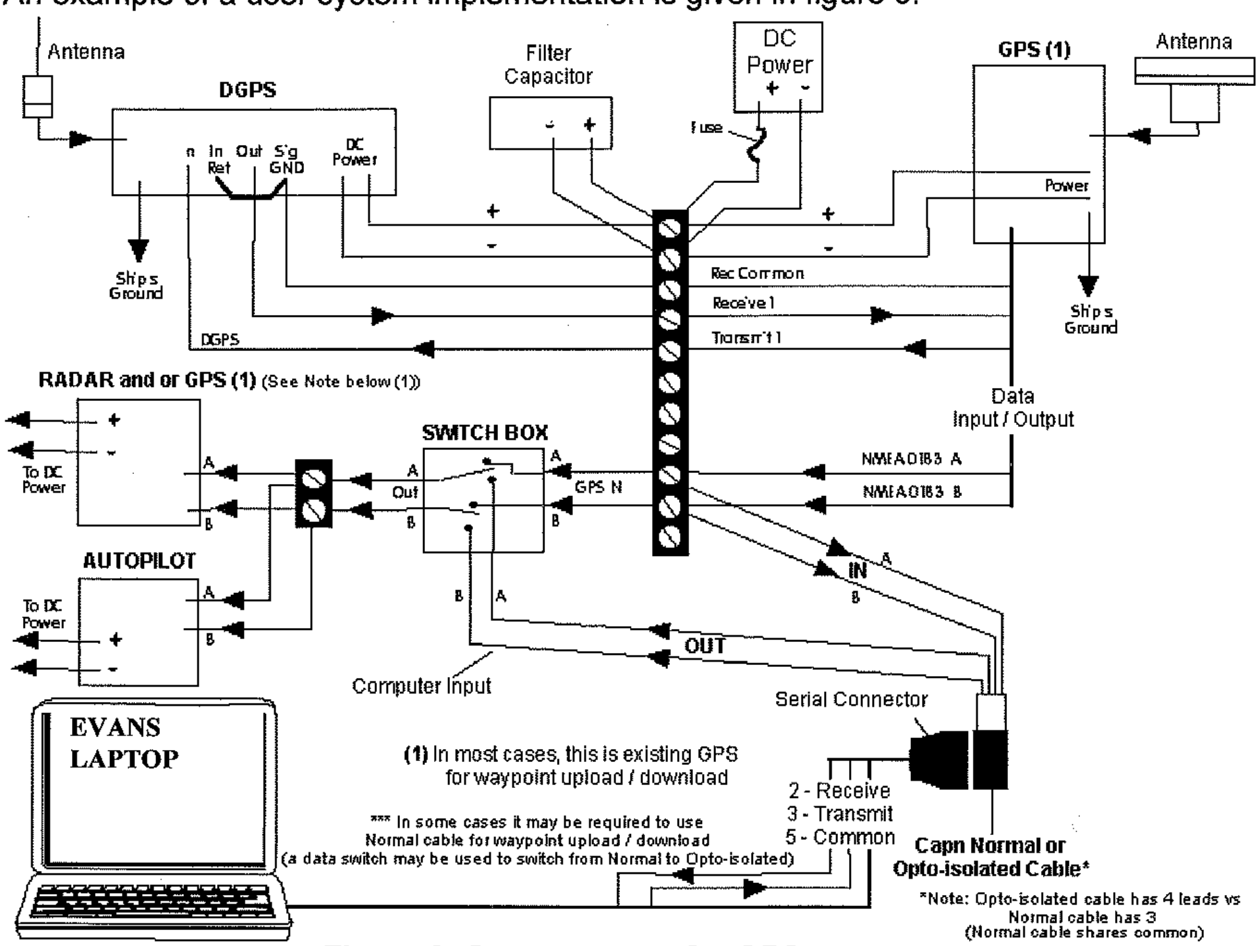


Figure 3: System setup for GPS

3.3 US GOVERNMENT POLICY

- The policy toward GPS users has shifted from a "User Charges for GPS" to a Free service and the DOD must remove S/A.

- The Korean Airline (KAL) 007 disaster prompted the White House and Congress to increased efforts toward assuring GPS availability to civil users worldwide.
- The FAA's need to fly more planes with fewer resources and to land these planes with a lower cost landing system worldwide, has resulted in a push to remove S/A and set standards for DGPS.

The cost of sustaining minimum GPS service, is approximately $400 Million per year. (FY1993 dollars) The cost is driven by the acquisition cost of satellites ($30-$40 Million each), and boosters ($30-$40 Million each) and by the launch costs ($15-$20 Million per launch). At current estimates of satellite life on-orbit, somewhere between three and four launches per year will be required to sustain minimum GPS availability.

3.4 SATELLITE POSITIONING

3.4.1 EACH SATELLITE

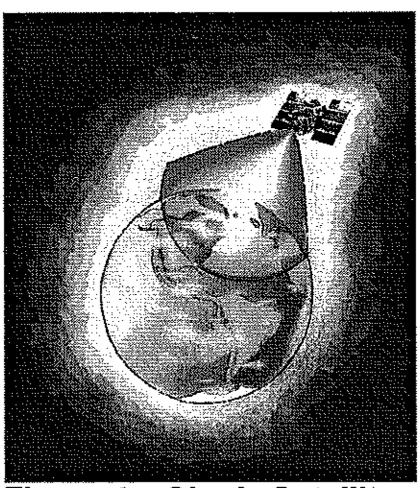


Figure 4a: Single Satellite

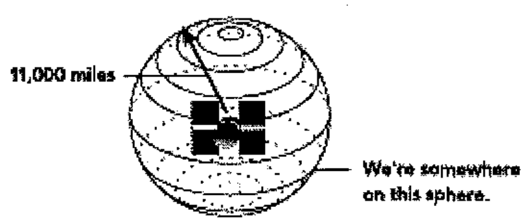


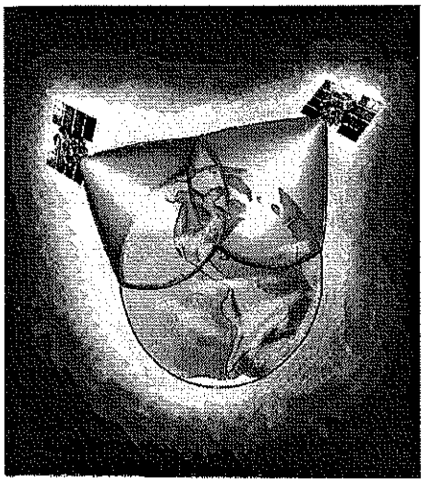
Figure 4b: Single Satellite

Taff, L.G. (1985).

Each satellites transmits the current time and information about its' orbit. By comparing the time we receive the signal with the time the signal was sent, we know how far away we are from the satellite. This is the slant range to the satellite. Slant range gives our position as some where on the surface of a semi-sphere.

The range to one satellite establishes a sphere about that satellite on which the user is located. The range to two satellites establishes a circle. A third satellite range reduces the circle to two points, one of which can be rejected as unreasonable.

3.4.2 SECOND SATELLITE



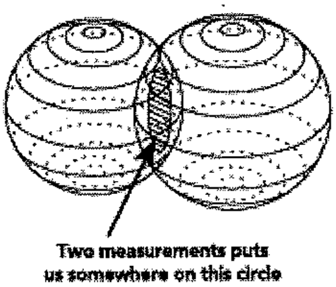


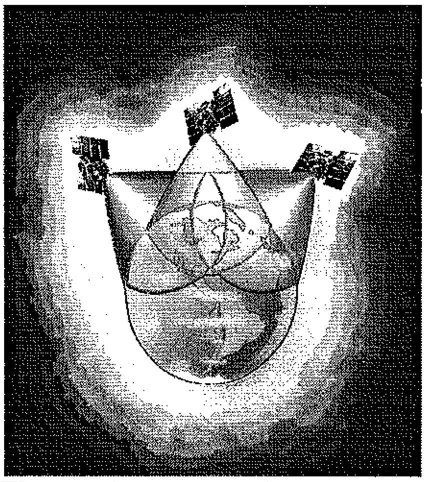
Figure 5b: Two Satellites

Figure 5a: Two Satellites

Taff, L.G. (1985).

Next, say we measure our distance to a second satellite and find out that it's 12,000 miles away. That tells us that we're not only on the first sphere but we're also on a sphere that's 12,000 miles from the second satellite. Or in other words, we're somewhere on the edge of a circle formed by the intersection of the two cone shaped patterns created by the signals from the two satellites or in the case of 6b on the circle where these two spheres intersect.

3.4.3 THIRD SATELLITE



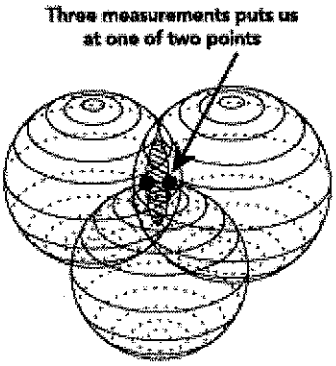


Figure 6b: Three Satellites

Figure 6a: Three Satellites

Taff, L.G. (1985).

If we then make a measurement from a third satellite and find that we're 13,000 miles from that one, that narrows our position down even farther, to the two points where the 13,000 mile sphere cuts through the circle that's the intersection of the first two spheres.

3.5 HISTORY

- NAVSTAR is the latest in a long history of navigation aids.
- The NAVSTAR satellite system improves Navigational accuracies by at least an order of magnitude over all other currently in use systems.

3.5.1 NAVIGATION AIDS

Type	Accuracy	Range
Celestial	?	world wide - Clear sky's
Triangulation	Depends on range	1000 to 1500 miles
Loran-C	60-300 feet (18-90 Meters)	1000 to 1500 miles
Deca	90 feet by day, 300 feet by night	100 miles +
VOR	600 feet	200 miles ?
TACAN	200 feet	200 miles
Omega	2 to 4 Nautical miles	world wide
Transit (US Navy)	35 meters	world wide (once per 6 hours)
Nav-Star GPS	17-100 meters	world wide 24 hours per day

Table 1. Navigation Aids

3.6 SATELLITE OPERATION

All GPS satellites transmit on the same two L-Band frequencies. L1 is at 1.57542 GHz and L2 is at 1.22760 GHz. Both L1 and L2 are modulated by a technique called 'spread spectrum'. The L1 carrier is modulated by two signals. The Coarse/Acquisition, C/A for short, is the first. This is the civilian code used by all GPS receivers. The second modulation carried by the L1 carrier is the Precise or "P-Code". The Military and some high-end GPS receivers use p-code. The L2 carrier carries the P-code modulation and Nav-Message. The Military view is that the C/A codes primary purpose is to acquire the P-code. Both the C/A and the P codes are modulated by the Nav message.

3.6.1 NAVIGATION MESSAGE

Nav/System data is transmitted at a rate of 50 Hz. This data stream contains orbital elements, clock accuracy, system time and satellite status. The Nav-Message is modulated onto the codes by binary phase shift keying (BPSK) modulation at a 50-baud rate. The intrinsic bandwidth of the data is only 100 Hz, twice the data rate of the 50 bits per second.

3.7 TIME IS OF THE ESSENCE

Navigation has never been more accurate than the clock it was based on. Accurate chronometers were the first major improvement in navigation since the invention of the compass. With the invention of the quartz clock chronometers, navigation took a quantum leap forward. New atomic time standards have accuracy of better than one second in 300,000 years. Radio waves travel 1 meter in 3 nanoseconds (0.000,000,003 seconds). To obtain accurate slant range we must know the time of day down to the nanosecond. Slant range with an uncorrected time-of-day clock is called "Pseudorange". Without atomic clocks this level of accuracy would not be possible. Atomic clocks are currently too expensive for use in GPS receivers. Most GPS receivers us a quartz crystal clock which is corrected to the current time.

Clocks in relative motion suffer (relativistic) time dilation, sometimes also called the second-order or transverse Doppler effect. This slows the atomic clocks on GPS satellites by 7,200 nanoseconds in 24 hours. The clock in the satellite has a speed of 3.9 kilometers per second.

If a GPS receiver has an accurate clock synchronised with GPS time, only three satellites would be required to obtain the parameters of X, Y and Z. Because current GPS receivers use inexpensive quartz crystal clocks, a forth satellite is required. This results in having to solve four simultaneous equations with four unknowns.

3.7.1 GPS SYSTEM TIME

GPS system time is referenced to the Master Clock (MC) at the USNO and is steered to UTC (USNO) system time. The Master Clock will not deviate by more than one microsecond from the UTC clock. GPS system time is given by its Composite Clock (CC), that was implemented on June 17,1990 at 0000 UT. GPS time does not include Leap seconds. The difference between GPS time and UTC time is included in the data sent in the Navigation message. The exact difference is contained in the navigation message in the form of two constants, A0 and A1. GPS is currently the most competent system for time transfer, the distribution of Precise Time and Time Interval. A precisely timed clock is not essential for the user because time is obtained in addition to position by measurement of Time of Arrival (TOA) of signals from four satellites. If altitude is known, then three satellites are sufficient. If time is being kept by an atomic clock and altitude is known, then only two satellites are required.

3.8 YEAR 2000 PROBLEM

GPS time will roll over at midnight August 21-22 1999. This is 132 days before the turn of the millennium If not corrected many GPS receivers will report the date as January 6,1980.

The GPS week started at midnight 5-6 January 1980. The week field is modulo 1024. This means the week count will roll over 1024/52= 19.69 years.

3.9 NAVSTAR SIGNALS

Navstar transmits its position and other information in three codes modulated on two different carries. The L1 signal is called the Course and acquisition (C/A) code. This is the less accurate of the two signals. This signal is also called the Standard Positioning service (SPS).

The L2 signal is the Precision or P code. Accesses to this signal is limited. When this signal is encrypted it is called the "Y" code.

The P code uses a much longer code with 235,469,592,765,000 bits and repeats once every 267 days.

The Navigation message is transmitted on both the L1 and the L2 carriers. The data rate for this signal is only 50 Hz.

3.9.1 C/A CODE

The L1 Coarse Acquisition (C/A) Signal has a data rate of 1.023 MHZ which provides the Standard Positioning Service (SPS). SPS provides a predictable positioning accuracy of horizontal 100 meters (95 percent), a vertical accuracy of 156 meters (95 percent) and at UTC time transfer accuracy to within 340 nanoseconds (95 percent of the time). The period of this data stream is one millisecond (MS). This signal is used to acquire the P code, the second half of the name "Acquisition".

3.9.2 "P" CODE

Precise Positioning Service (PPS) is the domain of the Department of defense. PPS is a more accurate military positioning, velocity and timing service, available to users authorised by the US Military. PPS provides a predictable positioning accuracy of horizontal 22 meters (95 percent), a vertical accuracy of 27.7 meters (95 percent) and at UTC time transfer accuracy to within 200 nanoseconds (95 percent of the time. Real time availability of transit-time ranges for instantaneous points positioning to 10-30 meters as well as several hour point positioning at the 1 meter level. The P code measuring accuracy is of the order of 10 cm on modern receivers. The encrypting sequence of this signal is classified. Limited nongovernment use of the P-Code, is allowed upon request and is authorised on a case-by-case basis. Under special agreement some GPS manufactures include processing of this code. The code is buried in silicon and the receiver is designed to shutdown if it is moved above a certain speed. This limit's its usefulness to an enemy. The Satellites P-Code data rate is 10.23MHZ at the receiver. To compensate for Satellite motion the signal transmitted by the satellites is 10.22999999543 MHz while on Earth. The P-code sub-period is seven days. All the satellite signals are derived from the common 10.23MHz source. The fact that all these signals are related allows high-end GPS receives to push the "Envelope of Accuracy".

The P-code clock is the base clock for all GPS timing. It is stabilised by the atomic clocks and is used to generate all the other transmitted signals.

- P-Code (10.23 MHz) /10 = 1.023 MHz (C/A code)
- P-Code (10.23 MHz) X 154 = 1575.42 MHz (L1).
- P-Code (10.23 MHz) X 120 = 1227.60 MHz (L2).

Coherent means that all the frequencies in the set are derived from the same source. Coherence is a definite advantage, as it minimises the unknowns in the equations.

3.9.3 Y CODE

The Y code replaces the P code when Anti-Spoofing (A-S) mode is activated. Anti-Spoofing guards against fake transmissions of satellite data by encrypting the P-code data to form the Y-code.

3.9.4 L3 CARRIER

The L3 carrier is not used by GPS, but is used by hardware that supports the Nuclear test band treaty.

3.9.5 L4 CARRIER

The L4 carrier is only a proposal at this time. It is designed to help model the lonosphere errors.

3.10 STANDARD POSITIONING

A GPS receiver determines its position by computing the position of four or more satellites within view and then measuring its range from each. By solving four simultaneous equations, with four unknowns, the receiver calculates its coordinates in an Earth Centered Earth Fixed coordinate system.

Without knowing the time and/or a satellite's position, we cannot determine the propagation time. Solving multiple unknowns is simple for a computer, as the computer looks upon this not as a circular argument, but as a recursive one. It simply repeats the calculation, adjusting parameters to make the answer more accurate, until the error is almost zero. With the satellite travelling around 5Km/s, the initial estimate may be 350m out. The uncorrected range measurements are called pseudorange, because without correction they are not true ranges.

By monitoring the propagation delay of each satellite against its internal clock, the receiver can track very accurately the relative delays of the four satellites in use. Once converted to meters, using the speed of light, they are known as the pseudo ranges to the satellites.

"A C/A code that has been delayed in transmission will arrive "late" at the user set, requiring the set to slew its internally generated code to correlate with the received code. The amount of time slew is the user set's measure of time of transit of the signal from the satellite to the user host vehicle. When multiplied by the speed of light and corrected for known biases, it gives a measure of range to that satellite. However it must be called a pseudo-range because the time slew magnitude also has an unknown contribution from the user's clock. " (Mattos, February 1993, pages 146-151)

"The satellite orbits at about 5kms/s, and the average propagation delay is around 70ms. Thus the satellite position would be out by 350 meters without correction." (Mattos, February 1993, pages 146-151)

3.10.1 SATELLITE POSITION

There are 24 operational satellites in six orbital planes. Each orbital plane is inclined at 55 degrees at an altitude of 10,898 Nautical miles, 20,180 Km, 12,600 statute miles. Each of the four satellites in an orbital plane completes an orbit in 12 hours. This results in a satellite being at the same position at the

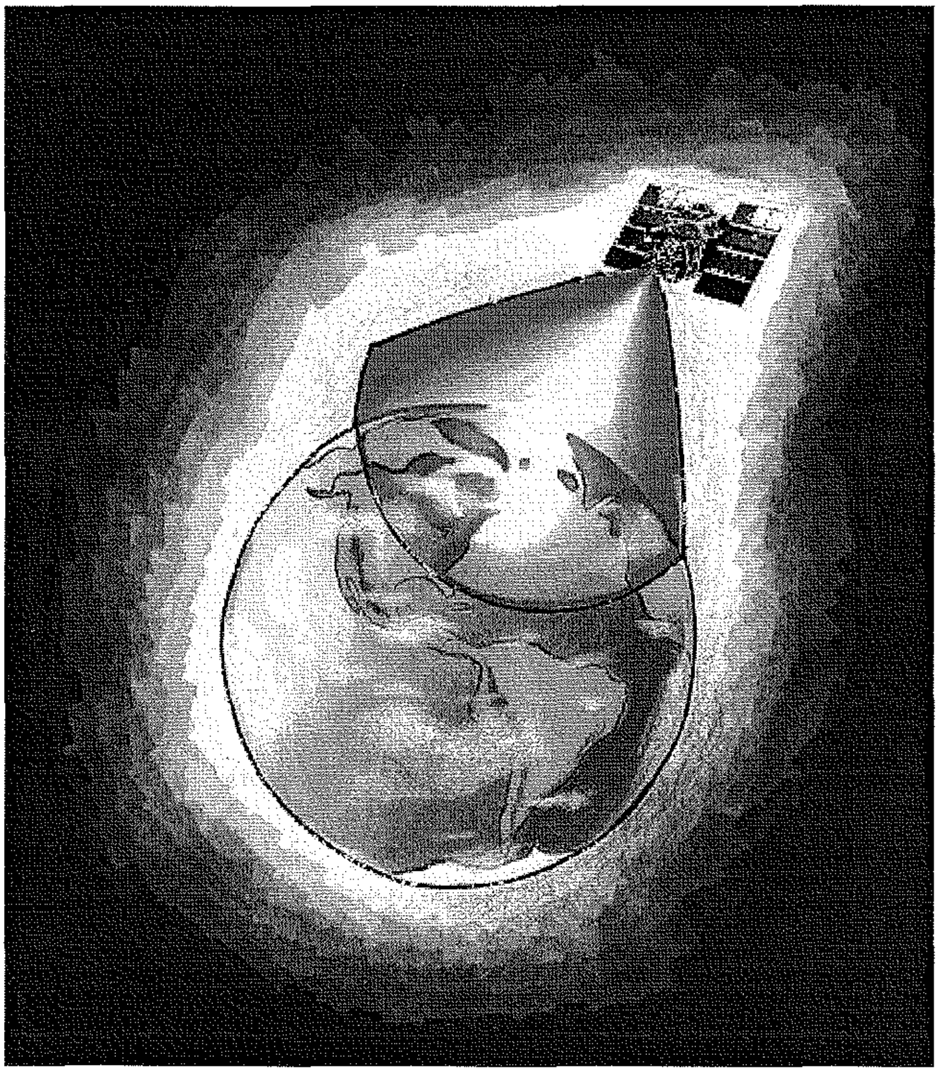


Figure 7: Satellite Positioning
Taff, L.G. (1985).

same sidereal time each day. The satellite will appear four minutes earlier each day by our time. The spacing of satellites in orbit is arranged so that a minimum of five satellites will be in view to users worldwide. Satellite position can be described by using the six classical Keplerian orbital elements. This collection of elements is called the ephemeris data and is found in the Nav-Message.

3.11 WEAK SIGNALS

Signal strength depends on transmit power and area covered. The GPS signals have are lost in the ambient noise. They have about the same signal strength as the L band TV signals currently broadcast from Geo-Positional satellites. While an eight foot disk antenna works well to receive these signals for TV, GPS needs some way to receive these signals with a simple antenna. To provide the "GAIN" needed to pull these signals from the background noise, GPS uses "Spread Spectrum" modulation.

3.12 CHANNELS

When we think of channels we quickly envision the TV with each channel having it's own frequency. This is not what is meant by channels in GPS. All GPS satellite's use the same two frequencies. The satellites are selected by the coding sequence (PRN) used in the spread spectrum modulation. There are two forms of Spread spectrum modulations, frequency hopping and direct sequence.

In AM, SSB or FM the modulation sidebands are scarcely wider than the data they contain. This leaves all the energy concentrated close to the center frequency of the carrier. In Spread Spectrum the energy of the carrier is deliberately spread out over a wide band, so that it is much harder to detect or jam.

3.12.1 GPS SIGNALS AND CODING

The Chipping rate of the C/A code is 1.023 MHz with a virtual wavelength of 290m. Chipping rate for the P code is 10.23Mhz that has a virtual wavelength of 29 meters. Each satellite uses its own unique code. The C/A code uses a 1023 bit Gold code with a period of one millisecond. A spread spectrum signal can only be received if the code is known ahead of time. The Gold code assigned to each satellite is published in the Interface Control Document ICD-GPS-200 published by Rockwell Space Systems Division.

For GPS the L1 and L2 spread spectrum code is added to the carriers by binary phase shift keying (BPSK) modulation. The C/A code generator produces a different 1023 chip sequence for each phase tap setting. In a shift register implementation the code chips are shifted in time by skewing the clock that controls the shift registers. In a memory lookup scheme (the most common system) the required code chips are retrieved from memory. In either case the C/A code generator repeats the same 1023 PRN-code sequence every millisecond. The receiver slides a replica of the code in time until there is correlation (in synchronisation) with the Satellite code. If the receiver applies a different PRN code to a satellite signal there is no correlation. When the receiver uses the same code as the satellite and the codes begin to line up, some signal power is detected.

As the satellite and receiver codes line up completely, the spread-spectrum carrier signal is de-spread and full signal power is detected. Because the signals must be in synchronization we also have the exact time the signal was received.

3.12.2 GPS MESSAGE

The GPS message is phase modulated onto the C/A and P codes which in turn are phase modulated onto their respective carrier frequencies.

3.12.2.1 GPS MESSAGE STRUCTURE

The basic message is defined as a frame and repeats once every thirty seconds. The basic message frame is sub-divided into 5 sub-frames that require 6 seconds to receive. The sub-frames are divided into 10 words of 30 bits each. Data required for positioning is found in the first three frames. This is the ephemeris and clock correction data. The last two sub-frames provide the "Almanac". This is information on all the currently operational satellites in the constellation. Because of the size of the Almanac the data is spread over 25 successive message frames. The pair of sub-frames (4 & 5) are referred to as a page. A Master frame consists of all 25 pages with sub-frames 1 through 3 repeated with each page. The master frame requires 12.5 minutes to transmit all 37,500 bits.

The GPS Navigation Message consists of time-tagged data bits marking the time of transmission of each sub-frame at the time they are transmitted by the satellite. A data bit frame consists of 1500 bits divided in to five 300-bit sub-frames. A data frame is transmitted every 30 seconds. Three six-second sub-frames contain orbital and clock data. Clock corrections are sent in sub-frame one and precise satellite orbital data sets (ephemeris data parameters) for the transmitting satellite are send in sub-frames two and three. Sub-frames four and five are used to transmit different pages of system Data. An entire set of twenty-five frames (125 sub-frames) makes up the complete Navigation Message that is sent over 12.5 minute period.

Data frames (1500 bits) are sent every thirty seconds. Each frame consists of five sub-frames.

Clock data parameters describe the satellite clock and its relationship to GPS. Ephemeris data parameters describe the satellite orbits for short sections of the satellite orbits. Normally, a receiver gathers new ephemeris data each hour, but can use old data for up to four hours without much error. The ephemeris parameters are used with an algorithm that computes the satellite position for any time within the period of the orbit described by the ephemeris parameter set.

3.13 SOURCE OF ERRORS

The sources of error in order of significance are:

- Selective Availability (SA)
- GDOP (Geometric Dilution of Precision)
- Ionosphere errors (upper atmosphere errors)
- Troposphere errors (lower atmosphere errors
- Ephemeris errors (Satellite position errors)
- Satellite Clock errors
- Multi-path errors (ghosts)
- Receiver errors

The three key elements to high quality geodetic GPS measurements are using a stable atomic clock, obtaining accurate satellite orbits, and removing propagation effects.

3.13.1 SELECTIVE AVAILABILITY (SA).

The largest single error source for GPS is deliberate. Selective Availability reduces the accuracy of the L1 signal. This is done to limit the usability of GPS to an enemy or terrorist group. The object of Selective Availability is to limit single receiver accuracy to no better than 100 meters horizontally 95% of the time with a Vertical accuracy of 156 meters 95% of the time. Time accuracy compared to UTC is within 340 nanoseconds (95 percent). Because of the demand for accuracy GPS data Selective Availability will be phase out. The effectiveness of SA has been on the decline in the last few years. Differential GPS, GLONASS and other developments have bypassed this counter measure. SA is accomplished by manipulating navigation message orbit data (epsilon) and/or dithering the satellite clock. SA will be discontinued with in the next several years.

3.13.2 SATELLITE LOCATION GEOMETRY

Second only to SA, Satellite Geometry has a large effect the precision. This is called "Geometric Dilution of Precision" or GDOP. GDOP is the measure of goodness of the current satellite position for measuring your position. The best GDOP is achieved when three satellites are at 120 degrees from your location and a forth is directly over head.

In general, ranging errors from the satellite signals are multiplied by the appropriate GDOP term to estimate the resulting position or time error.

Normal (Selective Availability off) broadcast orbital errors reach 20 to 25 meters.

3.13.2 EPHEMERIS DATA ERRORS.

These are errors in predicting the satellites orbit. Ephemeris data errors equal about 1 meter.

3.13.3 ATMOSPHERIC ERRORS

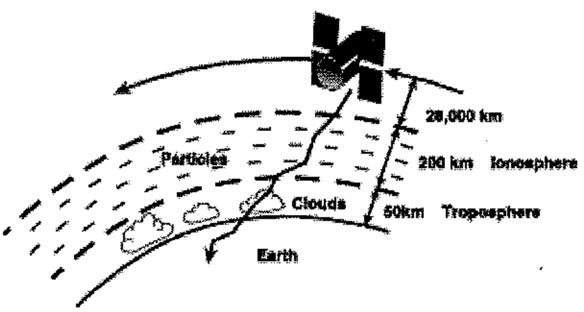


Figure 8: Atmospheric Effects
NAVIGATION, (1986).

The Ionosphere and Troposphere effect the time of receipt by slowing down the signal. The degree to which a signal is slowed depends on its frequency. By comparing the delay between the L1 and L2 carries a correction for this can be made. There is currently a dialogue regarding adding a third frequency (L4) to improve this correction. Single frequency receivers, which are most of the ones on the market today, use mathematical models to try to correct for the delay. Spilker, J.J. (1984 – 85).

Uncorrected ionospheric delay is one of the factors limiting the accuracy in geodetic relative positioning with single frequency GPS carrier phase observations. Unmodeled ionosphere delays equal 10 meters. The ionosphere is the layer of atmosphere from 50 to 500 km. The transmitted model can only remove about half of the possible 70 ns delay leaving a ten meter unmodeled residual. Presently, during solar activity minimum, baseline errors up to several parts per million are attributed to dispersive delay experienced by the signal in the ionosphere. This effect is likely to be more pronounced during the upcoming maximum of the solar activity cycle. Dual frequency measurements can be combined to eliminate the ionospheric delay in the observations. However, since less expensive single frequency GPS receivers are widely used for precise geodetic baseline determination, the effects of ionospheric refraction on relative positioning deserve a thorough investigation. Due to the dispersive character of the ionospheric propagation delay, it can be effectively accounted for if phases of both coherent L1 and L2 carrier signals are observed simultaneously. The maximum differential delay is obtained for elevations of 15 degrees.

The ionosphere essentially disappears each night and reconstitutes itself in the morning. It is created by the X-rays and ultraviolet radiation from the sun quite rapidly, but has a slow relaxation time of several hours. Ionospheric error is almost zero at 0200-0300 local time as the ionosphere is then stable after yesterday's sum and not yet affected by today's. Avoiding low angle satellites also reduces it.

Ionospheric scintillation, which consists in a rapid fluctuation of the Total Electron content, is unpredictable, correlated with the solar cycle in magnitude and is particularly sever in high latitudes. Scintillation results in a variation of amplitude and Doppler shift of the incoming signals.

Taking all the variables of day/night, solar activity, and elevation angle into account, the effects on L1 GPS measurements vary from 0.15 m to 50m. At solar minimum the largest effect will be about 20 m.

3.13.4 TROPOSPHERE

Tropospheric delays equal about 1 meter. The troposphere is the lower part (ground level to 8-13 km) of the atmosphere that experiences the changes in temperature, pressure, and humidity associated with weather changes. (Clynch, 1996, p. 52)

3.13.6 MULTI-PATH

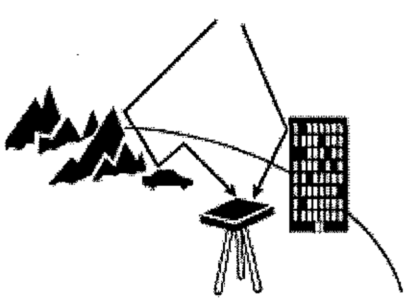


Figure 9: Multipathing NAVIGATION, (1986).

Your TVs ghosts are caused by the TV signal being received directly from the TV station and by the same signal arriving via a reflection off one or more objects. The reflected signals have a longer path to follow and so are delayed. On the TV this Multi-path signal results in the image being repeated slightly to the right of the real image. Spread spectrum receives lock on to the strongest signal much like FM radio receivers do. The interference from a multi-path signal can prevent the satellite from being tracked. Multi-path has its worse effects in the middle of cities with large buildings. Filtering and the chose of antenna can reduce the problems of multi-path. Multi-path error equals about 0.5 meters Multi-path causes the code measurements to be about 100 times noisier than the carrier phase measurements. Choking ground plane antennas should be used to decrease multi-path effects, at least at the monitor stations.

3.14 GPS POSITION ENHANCEMENTS

3.14.1 WAAS

The Wide Area Augmentation System (WAAS), in addition to providing higher positioning accuracy's to aviation users, will afford integrity enhancements necessary for all phases of flight, up to and including Category I approaches. Upon completion, the WAAS ground system will continuously assess the integrity of GPS satellite signals as well as its own corrections, warning WAAS users when a failure is encountered. For Category I operation, for example, an alarm will be provided within 5.2 seconds of failure. This WAAS feature increases availability by obviating the requirement for redundant position calculations.

3.14.2 LAAS

The Local Area Augmentation System (LAAS) will provide an even higher level of integrity. For a Category III landing, the probability of an undetected system failure cannot exceed 5 2 10^{-9}. One approach to providing the required integrity employs pseudolites -- low-power, ground-based transmitters functioning as pseudo-GPS satellites -- in conjunction with a conventional-DGPS airport reference station. Situated in pairs on either side of a runway approach path, pseudolites can provide an aircraft with enough ranging sources to initialize DGPS to centimeter-level accuracy with the required degree of integrity.

3.14.3 DIFFERENTIAL GPS (DGPS)

Differential GPS requires two receivers. The first one is at a know location and is constantly recording the difference between it's know position and the position received from each satellite. The data may be transmitted in real time or may be logged for post processing. These correction signals correct errors induced by SA, Satellite hardware, ionospheric and tropospheric delays.

The second receiver is the mobile one, called the rover. It may use a separate data receiver to receive the corrections or it may log the data for post processing correction. Differential GPS can provide accuracy of better than a meter, but only if the corrections are made at a high enough rate. The Coast Guard system transmits the corrections at a slow rate so it is only capable of about 10 meter accuracy. Over base lines of 600 NM these correction signals are basically the same. The corrections must be made for each satellite to obtain highest accuracy. The errors induced by SA are different for each satellite. If we averaged all the errors together the largest error would have the greatest effect all the pseudoranges. This is because GPS uses the least square reduction to compute pseudo-range. GPS makes all of its calculations using the Cartesian coordinate ECEF system. The stationary receiver must transmit its true position in ECEF coordinates.

As a rule, the accuracy that can be obtained from DGPS is proportional to the distance from the user to the monitor/ reference site. Stationary users, less than a mile from the DGPS site, are able to arrive at position solutions, over time, that have errors measured in centimeters, while mobile users can expect errors of 2-3 meters (ships and cars) 3-5 meters Aircraft.

3.14.4 CARRIER-PHASE TRACKING

Carrier-phase tracking of GPS signals has resulted in a revolution in land surveying. A line of sight along the ground is no longer necessary for precise positioning. Positions can be measured up to 30 KM form a reference point without intermediate points. The use of GPS requires specially equipped carrier tracking receivers. Receivers can now track the carrier wave, which has 600ps period.

3.14.5 KINEMATIC GPS LAND SURVEY

The Kinematic method of GPS surveying uses a static survey system at one station (master) while another survey system (rover) is moved from one station to the next until all locations are mapped. The rover briefly (2-10 min.) occupies each station. Both receivers continuously track the same satellites during the entire session.

Unlike differential GPS, where coordinate corrections are determined, the Kinematic method uses a phase difference technique to determine the intersecting vectors. To achieve sub-centimeter accuracy data, free of cycle slips, four or more satellites are required. This method counts the L1 carrier cycles at both the master and the rover.

A procedure that improves the data reduction is returning to the previous locations in reverse order. If there has been any cycle slips they will be detected by a mismatch in locations

The L1 and/or the L2 carrier signals are used in carrier phase surveying. L1 carrier cycles have a wavelength of 19 centimeters. If tracked and measured these carrier signals can provide ranging measurements with relative accuracy's of millimeters under special circumstances.

Carrier phase signals provide no time of transmission information. The carrier signals, while modulated with time tagged binary codes, carry no time-tags that distinguish one cycle from another. The measurements used in carrier phase tracking are differences in carrier phase cycles and fractions of cycles over time. At least two receivers track multiple satellite signals at the same time.

Ionospheric delay differences at the two receivers must be small enough to insure that carrier phase cycles are properly accounted for. This usually requires that the two receivers be within about 30 Km of each other.
Precise GPS surveys 1-2 PPM are accomplished using the carrier phase measurements.

3.14.6 U.S. COAST GUARD DIFFERENTIAL GPS

The U.S. Coast Guard is the only constituent that provides free differential GPS correction data. This service began initial operational capability (IOC) on January 30, 1996. Using the USCG signals accuracy can be improved from 100 meters for Standard Positioning Service to 10 meters. Many DGPS services, like the one available on a JJJ sideband, provide better than 2-meter accuracy. The 10 meter accuracy is due primary to the slow update rate. In addition the USCG signal provides an independent check of each satellite signal and reports its status. The USCG signals are transmitted using USGC marine radiobeacons. These are on a frequency of around 300KZ. This low frequency carrier limits the data transmission rate. All USCG corrections are transmitted using the Radio Technical Commission Maritime (RTCM) SC-104 Version 2.1 standard. The data is transmitted using Minimum Shift Keying (MSK) modulation on the medium frequency radiobeacon. Some of these errors vary very quickly with time or space and cannot be treated with "differential" techniques. However some vary rather slowly with time and space and can therefore be reduced by using a technique known as differential GPS (DGPS). DGPS data is digitally modulated with a message information rate of 50 BPS. The frequency of the radiobeacons, 285-300kHz, means user equipment is extremely inexpensive to realise.

3.14.7 DIFFERENTIAL SUBSCRIBER SERVICES.

Around the world Differential correction are available as a subscriber service.

3.14.7.1 FM RADIO SUBCARRIER

Some subscriber services add a sub-carrier simulate to the background music service found in elevators. FM radio stations utilising RBDS standard are capable of transmitting corrections on a sub-carrier. At the moment the ABC provide a differential signal for Perth metropolitan area. This signal is superimposed upon a JJJ sideband and with its specific encoding is available for commercial and recreational use within approximately 100km radius of Perth.

3.14.7.2 SATELLITE PROVIDED DGPS

Corrections may be computed at land-based stations and then relayed to a large geographic area via a satellite in geo-stationary orbit.

In Australia we only have access to the FM subscribers.

3.14.8 REAL-TIME VS. POST-PROCESSING

The biggest difference between real-time and post-processed DGPS is that real-time DGPS tells you where you are and post-processing DGPS tells you where you have been. Real-time DGPS you can get the DGPS accuracy's in the present moment, but only if you can maintain the real-time data link with the base station. It the real-time data link is lost, the differential accuracy is gone for good.

Post-processing DGPS will require a logging computer at both the base and remote sites. There is a need for a fairly large hard drive to support data recording over long operations.

3.15 GLONASS

The GLONASS constellation is composed of 24 satellites. Eight satellites in each of three-orbital planes set at an inclination angle of 64.8 degrees. This provides an orbital period of 11 hours 15 minutes and 44 seconds. The semi-axis is at 25,510 Km and has a period of 11 hours 15. The L band frequencies for these satellites will be changed, but for how the L1 group is at 1602 MHz, while the L2 group is starts at 1246 MHz. The GLONASS signals carry both a Standard precision Navigation signal (SP) and a High precision navigation signal (HP). GLONASS SP horizontal positioning accuracy is within 57-70 meters (99.7% probability) and a vertical positioning accuracy within 70 meters (99.7% probability). Timing accuracy is within 1 us (99.7% probability). Like the US system the HP code is encrypted for military use. Unlike the US system the SP is never dithered by SA. The first GLONASS type spacecraft (cosmos 1413) was launched on October 12,1982. GLONASS system was officially put into operation on September 24, 1993. The SP signal L1 have a frequency division multiple access in the L-band. L1= 1602MHz + n0.5625Mhz, Where "n" is the frequency channel number (n=0,1,2...). It means that each satellite transmits on its own frequency. However some satellites have the same frequencies, but those satellites are placed in antipodal slots of orbit planes and they do not appear at the same time within the users view. "n" can also be expressed as 9/16 MHz. The channels for the L2 band are 1246+k*7/16. When "k" is the channel number. GLONASS M are planned for a 5 year life. The current GLONASS IIc have a design life of three years. The GLONASS L1 band will be moved for two reasons. First Radio Astronomy (RA) uses 1610.6 to 1613.8 MHz that is GLONASS channels 15-21. Second frequencies 1610 - 1626.5 are assigned to mobile satellite service. This is the center frequency of the upper-third of the GLONASS channels. GLONASS currently uses the SGS85 coordinate system. This will be changed to the WGS84 system in the future.

3.15.1 GLONASS System Time

GLONASS satellites are equipped with Cesium clock, daily frequency instabilities of which are no more than 5x10E(-13). GLONASS clocks are updated twice a day to within 15 nanoseconds (one sigma). Currently there is a constant offset of three hours between GLONASST (time) and UTC (CIS). UTC as maintained in Russia (UTCžSUŽ) is off by about 7 Microseconds and GLONASS Time by about25 microseconds.

According to Ashtech position accuracy of combine GPS/GLONASS is 7 to 15 meters with out differential correction (11 satellites out of 48) and 40 centimeters using standard RTCM for real time correction.

3.15.2 Combined GPS/GLONASS

Satellite	***GPS***	***GLONASS***
Orbit height	20,180 Km, 12,600 Statute miles, 10,898 Nautical miles	19,100 km
Number of satellites per orbit	4	8
orbital planes	6	3
Orbit inclination	55 +- 3 degrees	64.8 degrees Drift up to 5 degrees
Eccentricity	< 0.020	< 0.005
Period	718 minutes	676 minutes or 11 hours 15 minutes 44 seconds
Signal separation technique	CDMA	FDMA
L1 carrier center frequencies	1.57542 GHz	1602 + (K x 0.5625)MHZ after 2005 1598.0625 Mhz k -7 to +4 {1602.5625-1615.5}
L2 carrier center frequencies	1.22760 GHz	1246 + (k x 0.4375) Mhz {1246.4375-1256.5
C/A SP chip rate	1,023 MHz	0.511 Mhz
P HP chip rate	10.23 Mhz	5.11 Mhz
PRN length (chips) C/A code	1023	511
PRN length (chips) P code	6.187104 x 10-12	5.11 x 10-6
Navigation message super-frame duration	12.5 minutes	2.5 minutes
Navigation message word duration	0.6 seconds	2.0 seconds
Technique for specifying satellite ephemeris	Keplerian orbit elements and perturbation factors	Geocentric Carlesian coordinates and their derivatives

Time Reference	UTC(USNO)	UTC (SU)
Position reference	WGS 84	SGS-85
C/A SP accuracy SA on	100M Horizontal, 156M Vertical, 167 Ns	57-70M Horizontal, 70M Vertical, 1 us.
C/A SP accuracy SA off	17.8M Horizontal, 27.7M Vertical, ?? Ns	57-70M Horizontal, 70M Vertical, 1 us.
UTC error	<100 nanoseconds >	25 microsecond today
Weight	930 Kilograms	1,480 Kilograms
Lifetime	7.5 years	5-7 years
Orbit Radius	26,560 KM	25,510 km
Number of spare satellites	3	3
Ascending Nodes spacing between planes:		120 degrees
Separation of satellites in plane:	90 degrees	45 degrees
Navigation message superframe Capacity	37,500 bits	7,500 bits
Navigation message word Capacity	30 bits	100 bits
Navigation message words within a frame	30 bits	100 bits
Antenna polarized	Right Circular Polarized (RHCP)	Right Circular Polarized (RHCP)
L1 signal strength	-160 dBW	-161 dBM
L1 signal main Lobe Bandwidth	2.046 MHz	
L2 signal strength	-166 dbm	?
Processor speeds	to 30 mip	.5 to .6 mip
Solar power		1.6 Kilowatts
Additional Attitude sensors		geomagnetic, Laser corner-cube

Table 2. GPS/GLONASS

3.16 SPECTRUM BATTLES

As GPS becomes a depended upon service, lose of usability of the service can have great impact. The major issue at this time is the potential signal interference from mobile satellite services (MSS) to the frequencies reservec for GPS. Mobile satellite services will use constellations of satellites at various orbits to provide worldwide telecommunications connections. Companies such as Motorola (the Iridium system), the Loral-Qualcomm Partnership or LQP (Globalstar), and ICO Global Communications (ICO) will begin launching satellites into orbit in the last couple of years. Service to started in 1998. The American Mobile Satellite Corporation (AMSC), an exception, has a single geosynchronous satellite in orbit. Through international coordination, Frequencies have been set aside for MSS, including the band 1610-1626.5 currently used by GLONASS . The FAA is moving toward satellite navigation to meet its increasing demands. GPS would allow "Free Flight", greatly increasing the number of planes in the air.

The Radio Technical Commission for Aeronautics, Inc (RTCA) wants radio-frequency interference emissions levels of -70dBMW/Mhz for broadband emissions in the 4-MHz band centered on the GPS's L1 frequency. The FAA wants the same protection for the GLONASS as it too is a GPS system. (Divis, June 96)

3.17 SATELLITE PERIODIC MAINTENANCE

The cesium clocks on-board the block II/IIA satellites require periodic, (approximately twice per year), pumping of the beam to maintain working order. This maintenance requires, on the average, 18 hours of unusable time for each satellite.

Momentum wheels maintain the satellites direction. These must be de-spun from time to time.

3.18 SATELLITE STATION KEEPING

Satellite requires a station-keeping maneuver, also referred to as repositioning, to move the satellite back to its original orbital position. These maneuvers require, on average 12 hours of unusable time for each satellite. The satellites have a tendency to "drift" from their assigned orbital positions due to Gravitational pull and solar wind. For satellites at altitudes of 20,000 Kilometers, Earth's gravitational anomalies have little effect on the orbit. Gravitational orbital drift is caused by the pull of the sun and moon. These perturbing influences are small, so orbit corrections are made only once or twice a year.

If GPS solar radiation pressure effects are left unmodeled GPS downtrack errors can grow to over 1 km after 1-2 weeks of integration of the equations of motion. Thus even a small percentage error in one of the solar parameters can result in significant orbit errors. The force model represents the GPS spacecraft with 13 surfaces, each specified as either a flat surface or as a cylindrical surface.

4. NMEA MESSAGE FORMAT

4.1 WHAT IS NMEA?

"The National Marine Electronics Association is dedicated to the education and advancement of the marine electronics industry and the market which it serves. It is a non-profit association composed of manufacturers, distributors, dealers, educational institutions, and others interested in peripheral marine electronics occupations."

(quoted from a promo in "NMEA News")

4.1.1 WHAT IS AN NMEA STANDARD?

For the purposes of this article, an NMEA standard defines an electrical interface and data protocol for communications between GPS and positional instrumentation. (They may also have standards for other things.)

4.1.2 NMEA ADDRESS

P.O. Box 3435
New Bern NC, 28564-3435
U.S.A.
Phone: 919-638-2626
Fax: 919-638-4885

4.2 ELECTRICAL INTERFACE

These standards allow a single "talker", and several "listeners" on one circuit. The recommended interconnect wiring is a shielded twisted pair, with the shield grounded only at the talker. The standards do not specify the use of any particular connector.

The NMEA-0180 and 0182 standards say that the talker output maybe RS-232, or from a TTL buffer, capable of delivering 10 mA at 4 V. A sample circuit would show an open collector TTL buffer with a 680 ohm resistor to +12 V, and a diode to prevent the output voltage from rising above +5.7 V.

NMEA-0183 accepts this, but recommends that the talker output comply with EIA-422. This is a differential system, having two signal lines, A and B. The voltages on the "A" line correspond to those on the older TTL single wire, while the "B" voltages are reversed (while "A" is at +5, "B" is at ground, and vice versa).

In either case, the recommended receive circuit uses an opto-isolator with suitable protection circuitry. The input should be isolated from the receiver's ground. In practice, the single wire, or the EIA-422 "A" wire may be directly connected to a computer's RS-232 input.

4.3 NMEA-0180 AND NMEA 0182

NMEA-0180 and 0182 are very limited, and just deal with communications from a GPS (or other navigation receiver, although the standards specifically mention GPS), and an autopilot or external processor. From the information I have, it appears that 0180 and 0182 are identical. I suspect that equipment claiming to use NMEA-0180 will use the "simple" format described below, while those using NMEA-0182 will use the "complex" format.

4.3.1 "SIMPLE" DATA FORMAT

The simple format consists of a single data byte transmitted at intervals of 0.8 to 5 seconds, at 1200 baud with odd parity. Bits 5 - 0 give the cross-track error in units of 0.1 uS or 0.01 nautical mile. The error is given in offset binary, with a count of 1 representing full scale right error, 32 (hex 20) for on course, and 63 (hex 3f) full scale left error. Bit 6 is a 1 if the data is valid, and bit 7 is 0 to indicate the simple data format.

4.3.2 "COMPLEX" DATA FORMAT

The complex format consists of a data block of 37 bytes of (mostly) readable ASCII text giving cross-track error, bearing to waypoint, present Lat./Long, and a binary status byte. The data block shall be sent at intervals of 2 to 8 seconds. All bytes in the complex format have bit 7 = 1 to distinguish them from the simple format. It is permissible for a sending device to send both simple and complex data, and even to send a "simple" data byte in the middle of a "complex" data block.

Byte	Data	Notes
1	$	nothing
2	M	device
3	P	address
4	K	kilometers cross track
	N	nautical miles error
	U	microseconds units
5 – 8	0 – 9	cross error value

9	L or R	cross track error position
10	T or M	True or Magnetic bearing
11 – 13	0 – 9	bearing to next waypoint
14 – 23	12D34'56"N	present latitude
24 – 34	123D45'56"W	present longitude
35	bit 0 = 1	for manual cycle clock
	1 = 1	low SNR
	2 = 1	cycle jump
	3 = 1	blink
	4 = 1	arrival alarm
	5 = 1	discontinuity of TDs
	6 = 1	always
36	"NUL"	character (hex 80 reserved status byte)
37	"ETX"	character (hex 83 any unavailable data is filled with "NUL" bytes.)

Table 3: Complex Data Format

4.4 NMEA-0183

4.4.1 General Sentence Format

Under the NMEA-0183 standard, all characters used are printable ASCII text (plus carriage return and line feed). NMEA-0183 data is sent at 4800 baud.

The data is transmitted in the form of "sentences". Each sentence starts with a "$", a two letter "talker ID", a three letter "sentence ID", followed by a number of data fields separated by commas, and terminated by an optional checksum, and a carriage return/line feed. A sentence may contain up to 82 characters including the "$" and CR/LF.

If data for a field is not available, the field is simply omitted, but the commas that would delimit it are still sent, with no space between them.

Since some fields are variable width, or may be omitted as above, the receiver should locate desired data fields by counting commas, rather than by character position within the sentence.

The optional checksum field consists of a "*" and two hex digits representing the exclusive OR of all characters between, but not including, the "$" and "*". A checksum is required on some sentences.

The standard allows individual manufacturers to define proprietary sentence formats. These sentences start with "$P", then a 3 letter manufacturer ID, followed by whatever data the manufacturer wishes, following the general format of the standard sentences.

Some common talker IDs are:

- GP Global Positioning System receiver
- LC Loran-C receiver
- M Omega Navigation receiver
- II Integrated Instrumentation (eg. AutoHelm Seatalk system)

4.4.2 SENTENCES SENT BY SPECIFIC EQUIPMENT

As mentioned in the above section there are two general categories of messages that may be sent and received. These are the common NMEA 0183 messages, and the GPS Proprietary Messages. These two message types may be intermixed in the data stream. As described below, when GPS Private Messages are being handled, they must be detected and processed under the described protocol for that particular Private Messages, while the standard NMEA 0183 messages are handled differently.

When a request has been sent to a GPS unit and the described "handshake" protocol is in use, it is possible that the unit may be sending real time information. The "handshake" protocol must not respond to the general NMEA messages, but must to the particular Private Message of the GPS. Most GPS units do not interrupt the transmission of a single message to insert another message. In all cases, a complete message is sent of one type or another.

This section lists the sentence types used by various equipment. The format and data included in each sentence type is given in **Sample Sentences Dissected** below.

Eagle AccuNav
Standard: RMB, RMC, GLL, and APB
Proprietary: PSLIB
It also pretends it's a Loran, sending LCGLL, as well as GPGLL

Garmin GPS-38, NMEA-0183 V. 1.5 mode
Standard: GLL, RMB, RMC, WPL, BOD, XTE, VTG, and BWC
Proprietary: PGRMM (map datum), PGRMZ (altitude), and PSLIB (DGPS ctrl)

Garmin GPS-38, NMEA-0183 V. 2.0 mode
Standard: GLL, RMB, RMC, WPL, BOD, GSA, GSV, RTE, and GGA
Proprietary: PGRME (estimated error), PGRMM, PGRMZ, PSLIB

Garmin GPS-45 (and probably GPS-40 and GPS-90)
Standard: BOD, GLL, RTE, RMB, RMC, GGA, GSA, and GSV
Proprietary: PGRME, PGRMM, and PGRMZ

Garmin GPS-65 (and probably GPS-75)
Standard: BWC, GLL, RMB, RMC, R00, WPL, XTE, and VTG
Proprietary: PGRMM, PGRMZ, and PSLIB

Magellan Trailblazer
Standard: APB, BWC, GGA, GLL, RMB, RMC, and VTG

Trimble Ensign XL
Standard: APA, BWC, BWR, GGA, GLL, and RMB

Trimble Flightmate Pro and Scoutmaster
Standard: APA, APB, BWC, GGA, GLL, GSA, GSV, RMB, RMC, VTG, WCV, XTE, ZTC

Autohelm Seatalk

Autohelm Seatalk is a proprietary bus for communications between various interments. Some of the instruments can act as NMEA-0183 talkers or listeners. Data received from an external NMEA-0183 device will, if Seatalk understands the sentence, be re-transmitted, but not necessarily in the same sentence type.

The specific sentences sent will depend on the data available on the Seatalk bus (i.e. sentences containing wind speed and direction will only be sent if the system includes a wind instrument).

Seatalk output:
Standard: APB, BPI, BWC, VWR, VHW, DBT, GLL, HDM, HDT, HCS, MTW, and VTG
Seatalk input:
Standard: APA, APB, RMB, XTE, XTR, BPI, BWR, BWC, BER,BEC,WDR, WDC, BOD, WCV, VHW, VWR, DBT

4.4.3 SAMPLE SENTENCES DISSECTED

4.4.3.1 STANDARD SENTENCES

A talker typically sends a group of sentences at intervals determined by the unit's update rate, but generally not more often than once per second. Characters following the "*" are a checksum. Checksums are optional for most sentences, according to the standard.

APB Autopilot format B

APB,A,A,0.10,R,N,V,V,011,M,DEST,011,M,011,M

A	Loran-C blink/SNR warning
A	Loran-C cycle warning
0.10	cross-track error distance
R	steer Right to correct (or L for Left)
N	cross-track error units - nautical miles
V	arrival alarm - circle
V	arrival alarm - perpendicular
011,M	magnetic bearing, origin to destination
DEST	destination waypoint ID
011,M	magnetic bearing, present position to destination
011,M	magnetic heading to steer (bearings could be given in True as 033,T)

Table 4: Autopilot format

(Note: some pilots misinterpret "bearing from origin to destination" as "bearing from present position destination". This apparently results in poor performance if the boat or aircraft is sufficiently off-course that the two bearings are different.)

BOD - Bearing - origin to destination waypoint

BOD,045.,T,023.,M,DEST,START

045.,T	Bearing 045 True from "START" to "DEST"
023.,M	Bearing 023 Magnetic from "START" "DEST"
DEST	Destination waypoint ID
START	Origin waypoint ID

Table 5: Bearing to Destination

BWC - Bearing and distance to waypoint - great circle

BWC,225444,4917.24,N,12309.57,W,051.9,T,031.6,M,001.3,N,004*29

225444	UTC time of fix 22:54:44
4917.24,N	Latitude of waypoint
12309.57,W	Longitude of waypoint
051.9,T	Bearing to waypoint, degrees true
031.6,M	Bearing to waypoint, degrees magnetic
001.3,N	Distance to waypoint, Nautical miles
004	Waypoint ID

Table 6: Bearing and distance to waypoint

BWR - Bearing and distance to waypoint - rhumb line
(format same as BWC)

DBT - Depth below transducer

DBT,0017.6,f,0005.4,M

0017.6,f	17.6 feet
0005.4,M	5.4 Meters

Table 7. Depth below transducer

GGA - Global Positioning System Fix Data

GGA,123519,4807.038,N,01131.324,E,1,08,0.9,545.4,M,46.9,M, , *42

123519	Fix taken at 12:35:19 UTC
4807.038,N	Latitude 48 deg 07.038' N
01131.324,E	Longitude 11 deg 31.324' E
1	Fix quality, 0 = invalid
	1 = GPS fix
	2 = DGPS fix
0.8	number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Altitude, Meters, above mean sea level
46.9,M	Height of geoid (mean sea level) above WGS84 ellipsoid (empty field) seconds since last DGPS update (empty field) DGPS station ID number

Table 8: Global Positioning System Fix Data

GLL - Geographic position, Latitude and Longitude

GLL,4916.45,N,12311.12,W,225444,A

4916.46,N	Latitude 49 deg. 16.45 min. North
12311.12,W	Longitude 123 deg. 11.12 min. West
225444	Fix taken at 22:54:44 UTC
A	Data valid

Table 9: Geographic position, Latitude and Longitude

GSA - GPS DOP and active satellites

GSA,A,3,04,05,,09,12,,,24,,,,,2.5,1.3,2.1*39

A	Auto selection of 2D or 3D fix (M = manual)
3	3D fix
04,05...	PRNs of satellites used for fix (space for12)
2.5	PDOP (dilution of precision)
1.3	Horizontal dilution of precision (HDOP)
2.1	Vertical dilution of precision (VDOP)

Table 10: GPS DOP and active satellites

(DOP is an indication of effect of satellite geometry on accuracy of fix.)

GSV - Satellites in view

GSV,2,1,08,01,40,083,46,02,17,308,41,12,07,344,39,14,22,228,45*75

2	Number of sentences for full data
1	sentence 1 of 2
08	Number of satellites in view
01	Satellite PRN number
40	Elevation, degrees
083	Azimuth, degrees
46	Signal strength - higher is better

Table 11: Satellites in view

(Repeat for up to 4 satellites per sentence. There my be up to three GSV sentences in a data packet.)

HDM - Heading, Magnetic

HDM,235.,M

HDM	Heading, Magnetic
235.,M	Heading 235 deg. Magnetic

Table 12: Heading Magnetic

(HDG, which includes deviation and variation, is recommended instead)

HSC - Command heading to steer

HSC,258.,T,236.,M

258.,T	258 deg. True
236.,M	136 deg. Magnetic

Table 13: Command heading to steer

MTW - Water temperature, Celsius

MTW,11.,C

11.,C	11 deg. C

RMB - Recommended minimum navigation information

RMB,A,0.66,L,003,004,4917.24,N,12309.57,W,001.3,052.5,000.5,V*0B

A	Data status A = OK, V = warning
0.66,L	Cross-track error (nautical miles, 9.9 max.), steer Left to correct (or R = right)
003	Origin waypoint ID
004	Dest. waypoint ID
4917.24,N	Dest. waypoint latitude 49 deg. 17.24 min. N
12309.57,W	Dest. waypoint longitude 123 deg. 09.57 min. W
001.3	Range to destination, nautical miles
052.5	True bearing to destination
000.5	Velocity towards destination, knots
V	Arrival alarm A = arrived, V = not arrived
*0B	Mandatory checksum

Table 14: Recommended minimum navigation information

RMC - Recommended minimum specific GPS/Transit data

RMC,225446,A,4916.45,N,12311.12,W,00.5,054.7,191194,020.3,E*68

225446	Time of fix 22:54:46 UTC
A	Navigation receiver warning A = OK, V = warning
4916.45,N	Latitude 49 deg. 16.45 min North
12311.12,W	Longitude 123 deg. 11.12 min West
00.5	Speed over ground, Knots
054.7	Course Made Good, True
191099	Date of fix: 19 October 1999
020.3,E	Magnetic variation 20.3 deg East
*68	mandatory checksum

Table 15: Recommended minimum specific GPS/Transit data

RTE - Waypoints in active route

RTE,2,1,c,0,W3IWI,DRIVWY,32CEDR,32-29,32BKLD,32-I95,32-US1,BW-32,BW-198*69

2	two sentences for full data
1This is sentence 1 of 2	
C	c = complete list of waypoints in this route w = first listed waypoint is start of current leg
0	Route identifier
W3IWI... Waypoint identifiers	

Table 16: Waypoints in active route

VHW - Water speed and heading

VHW,259.,T,237.,M,05.00,N,09.26,K

259.,T	Heading 259 deg. True
237.,M	Heading 237 deg. Magnetic
05.00,N	Speed 5 knots through the water
09.26,K	Speed 9.26 KPH

Table 17: Water speed and heading

VWR - Relative wind direction and speed

VWR,148.,L,02.4,N,01.2,M,04.4,K

148.,L	Wind from 148 deg Left of bow
02.4,N	Speed 2.4 Knots
01.2,M	1.2 Meters/Sec
04.4,K	Speed 4.4 Kilometers/Hr

Table 18: Relative wind direction and speed

VTG - Track made good and ground speed

VTG,054.7,T,034.4,M,005.5,N,010.2,K

054.7,T	True track made good
034.4,M	Magnetic track made good
005.5,N	Ground speed, knots
010.2,K	Ground speed, Kilometers per hour

Table 19: Track made good and ground speed

WPL - Waypoint location

WPL,4917.16,N,12310.64,W,003*65

4917.16,N	Latitude of waypoint
12310.64,W	Longitude of waypoint
003	Waypoint ID

Table 20: Waypoint location

(When a route is active, this sentence is sent once for each waypoint in the route, in sequence. When all waypoints have been reported, GPR00 is sent in the next data set. In any group of sentences, only one WPL sentence, or an R00 sentence, will be sent.)

XTE - Cross track error, measured

XTE,A,A,0.67,L,N

A	General warning flag V = warning (Loran-C Blink or SNR warning)
A	Not used for GPS (Loran-C cycle lock flag)
0.67	cross track error distance
L	Steer left to correct error (or R for right)
N	Distance units - Nautical miles

Table 21: Cross track error, measured

XTR - Cross-Track Error - Dead Reckoning

XTR,0.67,L,N

0.67	cross track error distance
L	Steer left to correct error (or R for right)
N	Distance units - Nautical miles

Table 22: Cross-Track Error - Dead Reckoning

4.4.3.2 PROPRIETARY SENTENCES

The following are Garmin proprietary sentences. "P" denotes proprietary, "GRM" Is Garmin's manufacturer code, and "M" or "Z" indicates the specific sentence type. These sentences can be used within the Garmin GPS 25-LVS system.

$PGRME,15.0,M,45.0,M,25.0,M*22

15.0,M	Estimated horizontal position error in meter's (HPE)
45.0,M	Estimated vertical error (VPE) in meters
25.0,M	Overall spherical equivalent position error

Table 23: Estimated position errors

$PGRMZ,93,f,3*21

93,f	Altitude in feet
3	Position fix dimensions:
	2 = user altitude
	3 = GPS altitude

Table 24: Fix Dimensions

(This sentence shows in feet, regardless of units shown on the display.)

Proprietary sentences to control a Starlink differential beacon receiver. (I assume Garmin's DBR is made by Starlink)

$PSLIB,,,J*22
$PSLIB,,,K*23

These two sentences are normally sent together in each group of sentences from the GPS. The three fields are: Frequency, Bit Rate, Request Type. The value in the third field may be:

J = status request
K = configuration request
Blank = tuning message

When the GPS receiver is set to change the DBR frequency or baud rate, the "J" sentence is replaced (just once) by (for example):
*$PSLIB,320.0,200*59 to set the DBR to 320 kHz, 200 baud.*

4.5 RS-232 CONNECTIONS

Although this is not really related to NMEA, many people want to connect a GPS to a computer, so need to know about the RS-232 serial ports on a computer. The RS-232 standard defines two classes of devices that may communicate using RS-232 serial data - Data Terminal Equipment (DTE), and Data Communication Equipment (DCE). Computers and terminals are considered DTE, while modems are DCE. The standard defines pinouts for DTE and DCE such that a "straight through" cable (pin 2 to pin 2, 3 to 3, etc) can be used between a DTE and DCE. To connect two DTEs together, you need a "null modem".

Computer (DTE)			***Modem***	
DB-25	DE-9	Signal	Direction	DB-25
2	3	Tx Data	->	2
3	2	Rx Data	<-	3
4	7	Request to send	->	4
5	8	Clear to send	<-	5
6	6	Data Set Ready	<-	6
7	5	Signal ground		7
8	1	Data Carrier Detect	<-	8
20	4	Data Terminal Ready	->	20
22	9	Ring Indicator	<-	22

Table 25: NMEA RS-232 Connections

Most units do not implement the full RS-232 hardware protocol, but rather, only provide three wires, Data Transmit, Data Receive, and Ground. Serial Communications devices connected to GPS units must hard wire to the appropriate signal level any signals required to enable data to be sent or received. Data transmitted under this specification shall meet the format as shown in the NMEA 0183 specification and will consist of 8 bits, no parity, and one stop bit as defined in RS-232

NMEA 0183 specifies that a baud rate of 4800 is to be used. All GPS units that support this communications protocol utilise 4800 baud at power up with the exception of some Aviation Products that utilise a 9600-baud data rate.

4.6 RS-232C LEVELS VS NMEA LEVELS USED BY GPS

RS-232C (the "C" spec revision) RECEIVER devices are designed to operate from +3vdc to +25vdc for the "high" logic level and about +1V to -25Vdc for the "low" logic level. This spec was changed from the RS-232B spec many years ago to permit inter operation of a serial RS-232 port with a TTL logic signal.

However, the normal RS-232C noise margins are not maintained when TTL signals are interconnected. "Almost" all computer manufacturers design their RS-232 serial port to operate with TTL logic signals and all of the consumer model GPS receivers I have examined use a "TTL or CMOS type" logic signal for the serial output signal.

> *Note: The transmitters of RS-232C devices normally output from +6 to +12volts for the "high" level (space on data channel) and from -6vdc to -12vdc for the "low" level (mark on data channel). GPS receivers are designed to accept these levels on the serial input and operate properly without damage.*

By Comparison, NMEA signal output voltages run from about +5vdc to 0vdc. Thus, if you feed this signal into a RS-232C input, then when the NMEA signal is at +5vdc, you will get one logic level and when it is 0vdc, you will get the other out of your RS-232C receiver. The noise margins are not up to RS-232C standards, but with reasonably short cables (lets say 10 feet and less) in "normal" environments, all will work well. If the equipment is other than handheld GPS equipment, or if the equipment is designed for primary navigation use where safety of life is a concern, the manufacturers of the equipment should be consulted to insure that the two items of equipment would properly interconnect.

In any case, bonding of the common ground of all permanently mounted equipment is required to insure that all equipment shares a common ground potential. I have been told that there is an RS-232D specification out now, but I am not aware of differences between this and the older RS-232C specification.

4.7 TROUBLESHOOTING

First check that the talker (usually GPS) can send NMEA-0183, and determine what sentences it sends. Also, verify that the listener understands NMEA-0183, and that it understands the sentences the talker is sending. In some cases the same information may be sent in two or more different sentences. If the talker and listener don't both use the same sentences, there will be no communication. It may be possible to change the sentences sent by the talker, to match those understood by the listener.

Next, check that the talker is indeed set to send NMEA-0183 data. Some talkers may have provision to send NMEA-0180 or 0182, or some proprietary format.

A computer, using any convenient terminal program (Telix, Procomm, Windows Terminal, etc.) set to 4800 baud, can be used to monitor the NMEA data, and confirm what sentences are sent, and that the data is in the correct format. Verify that the wiring is correct - that the talker data output is connected to the listener data input, and that a signal ground line is connected between the two pieces of equipment. If you have multiple listeners connected to a single talker, you may be overloading the talker port. Try connecting only one listener at a time. On any NMEA-0183 circuit, there can only be one talker. If you must have more than one talker, and one of the talker devices can also act as a listener, you may be able to connect things "in series", so a talker-only output is connected to a listener/talker input, and the listener/talker output is connected to other listeners. However, some listener/talker devices may reformat the data, or only pass data they understand. (The Autohelm Seatalk system does this, and claims the data as it's own, starting all output sentences with "$II".)

Particularly with older equipment, the equipment may claim to comply with NMEA-0183, but in fact have an error in the data format. (A Kings 8001 Loran-C claims to send an APB sentence, but gets some of the fields in the wrong order, such that an Autopilot can't understand it.) This sort of problem can be verified by capturing the NMEA-0183 data on a computer, and comparing the data formats with those given above.

4.8 USER ACTIONS

It is expected that once a Personal Computer or other such device has been attached to the GPS Unit, all user interfacing will be handled on the PC. The user is not expected to enter commands or to take action on the GPS Unit while this protocol is being used. In fact, most of the necessary communications commands are not accessible from the GPS itself.

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5. PROJECT SOFTWARE

5.1 OVERVIEW

The software required for NMEA message handling is plentiful available on the WWW. Most of this software is free and the few that are not free offer evaluation copies at their respective home pages. Initially it was felt an urgency to download all programs, one's with fantastic graphics and impressive control and data storage capabilities. This urge to download blinded the project focus somewhat it was found priorities concerned with getting the biggest and smartest program superceded ones following objectives. Realising this concentrations were aligned to the few relative jobs at hand.

The aim of this task was to find out:

- What can be achieved with a software driven NMEA handler.
- The range and capabilities of current NMEA handling software.
- Whether there is similar software that logs data in ways required.
- Selected, particular software which can be used to demonstrate capabilities of the NMEA signals to supervisors and interested parties based on:
  - Cost
  - Size
  - Portability
  - Robustness
  - Complexity

Following this theory component, the next task was to construct a NMEA handling program that would consist of a NMEA data logger, some real time processes and a means to store and update incoming NMEA data.

Once all the programming had been constructed an operating system needed to be devised which would run these processes in the most efficient manner, whilst being reducible and robust. Cost was also a factor.

5.2 NMEA APPLICATION SOFTWARE

5.2.1 THE NMEA HANDLER

Basically anything which is transmitted to a GPS receiver has potential to provide useful information to the user. As can be seen in the previous section regarding NMEA transmission, there is a multitude of information that can be accessed and processed depending on requirements. Just in one version of this marine originating language there are over 80 explicit areas of interest ranging from position and speed of the receiver to signal strength and the noise within the received signal.

The NMEA data output of a GPS is of little consequence to a user unless they have a means to view or use this data. The easiest method is to connect the output directly to a COM port of a standard computer, and using a terminal program, witness streams of ASCII filling the monitor in updated packets every second. The only problem with this method is that the user must sort through the high concentration of data, and using known format of NMEA sentences, decode these ASCII characters just to establish incidental particulars of the receiver's position.

The other and more popular method, often used by the majority of semi-technical GPS users, is to apply this NMEA output to a Positional Application Program (PAP). Now that the tiresome effort required decoding masses of information is done automatically.

These PAP's are can be very useful. They avail the user with a vast array of information. Positional, Directional, Speeds, basically anything stemming from the transmitted information mentioned in the previous NMEA section has a potential to find its way towards a users application. All this information can be overwhelming and for the project application it is considered overkill. As the GPS system that logs NMEA information need only be stock standard, it was useless in considering all of the following application programs. Below is a list of all the programs acquired when searching for an adequate basic NMEA data logger. Each of these programs has a small description for future reference.

5.2.2 GPS DATA COLLECTION AND AUTO-MAPPING SOFTWARE

5.2.2.1 MACINTOSH

GPSView: Constructs an azimuth/elevation plot of the GPS constellation for a given position and time.

GPSyTM: Macintosh GPS Communications; NMEA-0183, -0182; Sony IPS; Rockwell NavCore and Zodiac support; Trimble TSIP support; Eagle/Lowrance, Garmin, and Magellan transfers; & GPSyLinks to other databases ($30-$100; commercial).

GPSy ProTM: Adds BSB nautical chart support and tools for high-end chart users to GPSy. ($100-$250; commercial)

GPS for Macintosh: Older program that works with Sony units. (freeware)

MacAPRS: For Ham users and more. ($50; shareware)

MacGPS: Good software but large program. (previous version freeware)

NavimaQ: Mac BSB marine navigation software. ($195; commercial)
MaxSea: Maritime navigation software. (~$350++; commerical)

Jeppeson FlightPro: High-end aviation mapping software. ($250 +)

FlightMaster: Simple VFR flight plan construction kit. ($35 shareware)

5.2.2.2 NEWTON

MapPad: Newton GPS.

GPS Map: Lite on function. ($100 and up)

Teletype GPS: Auto-mapping for Newton and WinCE platforms.

Tripmate/e-Mate: Vehicle software. (expensive)

FieldWorker: Good for data collection.

Although this is not meant to be a criticism of any particular Newton GPS product, many users of this type of software advise people to buy only after demoing the software or with a money-back-guarantee since the usability of these products vary. I've heard the best reports about TeleType for Newton/WinCE.

5.2.2.3 WINDOWS

APRS: For Windows. ($50)

DSH: Navigator for Bitmaps. (shareware)

FreeFlight: 3D flight simulator + GPS. (cool.. but $280+)

Fugawi: Mapping and more. (commercial; ~$95)

GarTrack: A Windows95 for boat performance analysis for regatta sailors using Garmin GPS units.

GARtrip: Upload/download of waypoints and track logs to Garmins. ($30; shareware)

Gardown: Simple MSDOS Garmin data transfer utility. (free)

GeoLink: GPS/GIS Mapping System.

GPSComm: For Windows 95/NT -- hooks with Street Atlas. (R)

GPSdb: Signal to noise determination.

GPS Positioner Pro: Freewrae for Windows 95/NT.

GPS Pro: High end mapping, digital raster graphics. ($295-$495)

5.2.2.4 GPS PROGRAM FOR WIN

GPSS: Global Position System Software. (free software; free maps; annoying sales blurbs)

MagPoint: Magellan GPS software for Windows 3.1/95/NT.

StellarNav's MapSite: Mapping, waypoints, etc. ($129 + s/h)

Navigate-GPS: Optimised for laptops.

OziExplorer: Reliable system been around a while.

QuoVadis Germany: Moving map, GPS navigation for Windows.

Nobeltec's Visual Navigation Suite (formerly Navtrek)

Waypoint+: Upload/download waypoints to Garmins.

WinWaypoint: Upload/download waypoints to Magellan units.

5.2.2.5 OTHER/MISC

HP Handheld: GarHP, HP S/Sx/G/Gx based Garmin handheld GPS software.

HP 48, GxPS: A library of programs for the HP 48 and Garmin GPS.

HP 100/200LX: HPLX, HP LX GPS software.

HP 100/200LX: Freeware GPS logging and navigation program primarily for glider pilots that runs under DOS.

HP 100/200LX, 4w: GPS data logger.

Java: Steve Dimse's Java APRS.

Linux:	Mayko Xmap.
MS-DOS:	Garnix/GEO, coordinate transforms and garmin transfers.
Pilot:	GPSPilot.
Pilot:	HandMap, downloadable maps.
Pilot:	PilotGPS, alpha 2 (emailware).
Pilot:	PlaceTrace, commercial GPS software for PalmPilot.
WinCE:	HandMap, vector mapping for Windows CE.
WinCE:	TeleType GPS, demo version available.
WinCE:	WinPilot, cockpit aid.
WinCE:	HandMap, downloadable maps.
Standalone:	Harper Technologies Remote GPS Display Units.
Standalone:	ERIC, NMEA remote unit with voice synthesis (looks quite neat).

5.2.2 Display Software

The following List of software I constructed to influence the academic staff in order to acquire resources for the project. I feel that in order to generate interest in this area I need to have dramatic software to demonstrate GPS capabilities.

GPS Software Comparison

Features	Trimble ASPEN	Trimble Direct GPS	Juniper Systems LandMark GPS	EDS DataPlus For DOS	EDS HydroPlus GPS
Platform Software Runs On	PC or Penbase	PC	Pro2000 or PC	DOS Hand Held Computers	Pro2000 or PC
Real Time Spreadsheet Data Capability	NO	NO	NO	YES	YES
On Screen Map	YES	YES	YES	NO	NO
Background Map Capability	YES	YES	YES	NO	NO
Navigation Features	YES	NO	YES	NO	YES
Waypoint Recording	YES	YES	YES	NO	NO
Feature Recording	YES	YES	YES	NO	NO
External Sensors Data Storage	YES	NO	NO	YES	YES
External Sensors Data Storage with Position Tag	NO	NO	NO	YES	YES
Post Processing Capability	YES	NO	NO	NO	NO
GIS Conversion Available	YES	YES	ASCII Only	ASCII Only	ASCII Only
Maintain & Calibrate Hydrolab Multiprobes	NO	NO	NO	NO	YES
Price	$2,500	$1,000	$395	$249	$375

Table 26: GPS Software Comparison

Any software mentioned in Table 26 would adequately demonstrate GPS potential and provide a good learning platform.

5.3 NMEA LOGGING SOFTWARE OVERVIEW

There were a few standard dos and windows data loggers, that is, programs that would send the incoming NMEA data from the com port to a determined file. Unfortunately there were no Unix variations that could be used or modified. As it was prefered to operate in on a bare linux environment there was a need to come up with a C program which would do the tasks required.

The backup system would involve preparing an almost identical program in assembler using debug. Using this program the project was able to failsafe any adversities which may arise as a result of using linux, an operating system that was not commonly used by me. This dos based program performed the same functions at a cost, this would be performance and the larger operating system size.

5.4 PROJECT DATA LOGGING AND REAL TIME SOFTWARE

The following information describes the steps I took in deriving suitable application software for the purpose of data logging within the Light Aircraft Project.

5.4.1 PROGRAM REQUIREMENTS

The ultimate requirements of the program is that it has the ability to do the following:

a. Determine and log "Touch and Goes"
b. Determine and log Landings
c. Determine and log Flight time

These following tasks are simple and straightforward but although easily defined the business of completing the objectives has to be made exact and correct. In order to encompass all the requirements and turn out a professional and reliable product there was a need to consider external conditions and thoughts.

5.4.2 INITIAL CONSIDERATIONS

5.4.2.1 "TOUCH AND GO'S"

"Touch and Goes" whilst obviously playing a major part in the students flight training also contributes to the day to day running of the airport. Many airports charge for the pleasure of performing "Touch and Goes" on their runways. It is for this reason the airport would like to log the number of touch an goes a student makes in one flight so that they can be invoiced accordingly.

Devising a program to recognise when the aircraft is performing a touch and go requires its understanding of the following parameters:

- height
- time
- speed
- heading

These four crucial parameters play an integral part in deciphering the actions of the aircraft. As the GPS output will provide all of the factors required, it is a relatively simple matter of parsi.g the data for an indicator that will lead the user to assume a touch a go.

The indication will be in the form of all four parameters being at a certain level or within a certain tolerance. This level or tolerance is yet to be determined but needless to say it will easily be defined in a test flight.

5.4.2.2 LANDINGS

Along the same lines as the "Touch and Goes" the student and the airport will need a record of the landings performed during a chartered practice flight. These landings, like the "Touch and Goes", have a cost and depending on the particular airport these costs will vary.

At this stage the programming to determine a landing will depend on the previously mentioned parameters. The major difference between the landing and the touch and go is the duration at height, and speed. This time, like the touch and go, is yet to be determined.

5.4.2.3 FLIGHT TIME

The difference between the flight time and the total engine time is another area that needs consideration. To determine this difference and estimate the actual flight time represents a considerable cost saving due to cuts in the regularity of service within the maintenance contracts.

As flight time generally occurs at and beyond a specific speed the program indication would need to rely on this parameter. What speed is yet to be determined.

5.4.3 REVIEW

At this stage it was determined what the system needed to achieve. It was also determined that by using a GPS there would be access to avail all the relevant parameters for the system program. This program then parses these parameters and correlates them against predefined indicators. A verification of such an indicator would alert the user to an occurrence of a program requirement.

To encompass a program of this nature it is necessary to dissect its makeup into two distinct parts. For ease of understanding and explanation it will refered to in this report as the smart and dumb programs. These two programs work together to achieve the project goals.

5.4.3.1 DUMB PROGRAM

The dumb program resides within a processor that is fitted to a designed cradle within the aircraft. This unit will log on to incoming satellite positional data via a GPS. The program will be written in C for Unix and in assembler for dos and will be simple and well documented.

The dumb program is a well designed data logger that has the ability to log all the raw data or only the basic minimal data required for later use. As the initial uses for both logged data will be identical, it is useful to know that the memory requirement to store the entire raw data for a complete flight vastly supercedes the minimal requirement. This is generally in the order of 20:1 memory saving.

The reason the initial program is to have this logging option would be that a memory trial should be performed to calculate the worst and best case scenarios available to the user. This statistical analysis adds depth to the program, if at a later date more logging memory may need to be incorporated to satisfy new functions, interdependence between more functions and log space can be determined. As the cost of flash memory rises exponentially with capacity, this information also provides a useful cost analysis base.

As the main parameters of interest are:

- height
- time
- speed
- heading

The minimal log file should contain the above relevant information and no more. Abstractions of this can occur but must at least contain the minimal amount. Once the aircraft is started the dumb program is begun. The parameters, sent from the GPS, are in the form of ASCII sentences of varying length delimited by commas. These sentences are formally known as NMEA. This concept has been fully explained in chapter five.

As the sentences arrive via a COM port it is necessary to construct some basic io routines to handle the incoming data. Once the data has been captured the next stage is to allocate the prescribed data to its relevant log file. One log file with all the data and one with only the minimal amount. On termination of flight the log files close and the information can then be downloaded to the smart program.

5.4.3.2 SMART PROGRAM

This program should be generally located at home base or where ever the needs of the users lie. This program uses the product of the Dumb program to generate and update the trip records. These records can then be added to a database and reports can be generated. For example cost of weekly flight for aircraft number one or student 20's performed "Touch and Goes" for today and the previous month. The main conclusion to draw here is that all the aims of the system can be satisfied within the smart program from data collected by the dumb program.

The smart program is essentially a database with macros written in visual basic attached to extract the relevant data from the downloaded log files. It then relies on procedures constructed to generate reports called for by the requirements of the user. This database should be written in such a form that new fields could easily be added or replaced. Essentially this database may serve as the main systems database of the airport.

Possible initial fields to be included are:

- aircraft maintenance report
- customer invoice report
- student flight history
- instructor flight history

These fields are only a sample of what could be included, as until further consultation with flight instructors and their coordinators can be initiated, the full extent of the program boundaries cannot be encapsulated.

For initial testing and to demonstrate the project there will be a simple database in place which will encompass all of the project aims.

5.4.4 TESTING AND FURTHER CONSIDERATIONS

During this section the opportunity will be taken to expand on the difficulties faced in customising the linux operating system for use with the embedded processor. Another important area that should be discussed is the testing procedure used to determine the program interpretation of flight indicators.

Unfortunately the data logger written in C for use within the linux operating environment, which performed well during tests using the non embedded system of phase one, had to be substituted for its assembler counterpart. This decision was sadly made after spending considerable time hacking and reducing the linux shell to an embedded size only to realise that the flash disk of the MicroPC would not be recognised. This device termed 'DiskOnChip 2000', is a relatively new but now widely used product within the embedded industries. This concept and specifications will be further explained in Chapter seven.

In order to use the DiskOnChip as a disk drive, special drivers are required. Normally, these drivers are installed automatically when the PC is booted up. The drivers are loaded in by the BIOS from the ROM extension firmware located in the DiskOnChip itself. However, there are cases where this method will not work, such as a BIOS that has a non-standard ROMSCAN routine, or when debugging a new system. In addition, there are applications in which the DiskOnChip is placed on purpose in a non-standard location. An example for such typical application is a DiskOnChip which is used as data-storage-device only, while the OS and the code are booted from Hard Disk.

The DiskOnChip 2000 can contain the operating system, but to allow the system to boot, Linux must configure the drive. After speeking with the M – systems distributor they said it required the project use a dated version of linux. Once this dated version was purchased the company would provide patches which would enable the DiskOnChip 2000 to recognise the drive assigned.

The major problem faced was not to acquire this old Linux but to somehow configure it to run the logger program which required classed not released in that version. Unable to fully grasp the magnitude of such a task my first thought was to find or create other patches to which could be interfaced to version 2.X Linux with the DiskOnChip 2000.

Major restraints here were the product being new, the seemingly uncooperative nature of M –systems (distributor), and the fact these issues ran a close second to lack of time remaining in the accademic year. Another consideration at this stage was the project database.

For the project to go ahead successfully and be completed by the end of 1999 there was a need to truncate the database to only contain the functions required in the initial aim. It is for this reason that the testing performed will on concern the "Touch and Goes", landings, and the flight time. Further adaptation of this program can be made in future projects.

On the 26 of August there was an arrangement made so that I could partake in a test flight in one of the student flight aircraft Edith Cowan University had at its disposal. It was a miserable day as the whether hammered the runway at Jandakot Airport.

The main aim of the days testing was to establish timing, speed and heading constants or ranges that could be used as indicators in determining the aims of the project.

The test would be performed in the 4 seated aircraft using the Magellan GPS 320 connected to a notebook computer having the data-logging program in C installed. The Operating system used for this test was a full version of linux.

The logged test data would be correlated with a timed event log kept manually during the flight.

The results are as follows:

5.4.4.1 TOUCH AND GO

Consider the time under 150 meters.

1st Instance 61615 – 61447 = 1 min 38 sec
2nd Instance 62106– 61919 = 1 min 47 sec

Average is. 1 min 43 sec

5.4.4.2 LANDING

Under 150 meters to park.

640.37 – 63717 = 3 min 20 sec

5.4.4.3 FLIGHT TIME

Ground speed < 60kn
Height relatively constant

***Note Speed on take off and land is ~ 60 Kn.*
***Note a landing will not incur time above 150 meters.*

5.4.4.4 RECOMMENDATIONS

Touch and Go: Time under 150 meters <= 3 mins
Speed under 150 meters <=100 kn.
Heading constant under 150 meters

Landing: Time under 150 meters > 3 mins
Heading not constant

Flight Time: Time > 60 kn.
Time above apparent 0 meters

Both touch and go and Landing speed < 60 Kn.

One more important factor was gathered in the testing procedure that was the determination of memory requirement. In the one hour we were in the air the raw data consumed 850 Kb where the minimal effort only consumed 120 Kb.

5.4.7 FINAL STAGE CODING

It was found that there was need to make little changes in the actual coding for the data logging software. As it was elected to utilise two program representatives there was no real need to adjust or modify an original program. Initially, much thought and consideration went into the design and the planning of the program. It can be seen that it paid off as there was little effort required within this section.

6. PHASE ONE – NON EMBEDDED

6.1 AIM

The main aim of this phase is to establish a communications link between the Magellan GPS or the Garmin GPS with a Laptop PC..

6.2 MAGELLAN GPS 315A

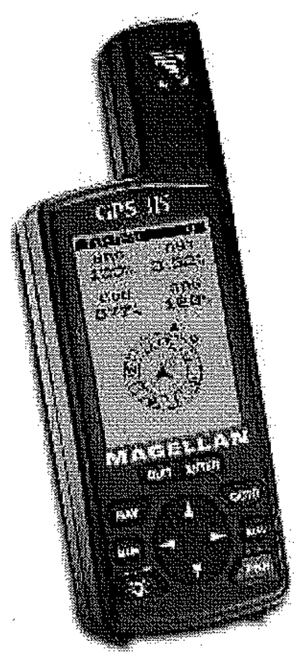


Figure 10: Magellan GPS 315A (Magellan Manual, 1999)

The Magellan 315A aviation handheld GPS is new on the market has many features and is already at an affordable price. The Magellan 315 is a 12 parallel channel receiver and a quadrifier helix antenna aids superior tracking. This GPS also has an ultra high resolution display (104x160), and an easy to use menu operating system.

The 315A includes a CD-ROM which contains the worldwide Jeppesen aviation database, a combination PC interface/ cigarette lighter power adapter, and a wrist strap. The DataSend Aviation CD-ROM can be used to upload aviation information into the unit from several different categories for whatever region choosen. The Magellan 315A has nine graphic navigation screens (customisable) which clearly show speed, heading, distance, bearing to waypoint, and position.

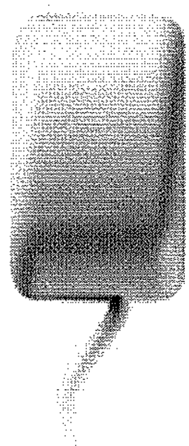
This GPS receiver also features up to 15-hour battery life from 2 "AA" batteries, backlit display, and NMEA/DGPS data capability. 1 year warranty. Size 15cm H x 5cm W x 3.3cm D. Weight 200g with batteries.

6.2.1 Key Features Of The Magellan 315A Aviation GPS

- Up to 15 Hours of operation from only 2 AA alkaline batteries..
- Rugged and Weatherproof Construction with a rubber grip.

- 10-Year Lithium Battery Backup for Memory.
- 1200 point SmartTrack records your flight and displays it on a plot screen.
- Aviation information includes Airport locations, elevation, communication and weather frequencies, VOR's, NDB's, and Intersections.

6.3 GARMIN GPS 36 TRACPAK



The GARMIN GPS 36 TracPak is a complete GPS receiver and embedded antenna designed for a broad spectrum of OEM (Original Equipment Manufacturers) system applications.

Figure 11: Garmin GPS 36 (Garmin Manual, 1999)

Based on the proven technology found in other GARMIN 12-channel GPS receivers, the GPS 36 will track up to twelve satellites at a time while providing one-second navigation updates and low power consumption. This capability meets the sensitivity requirements of land navigation as well as the dynamics requirements of high-performance aircraft.

The GPS 36 TracPak design utilises the latest technology and high-level circuit integration to achieve superior performance while minimising space and power requirements. Utilising Garmin's own proprietary chipset, all critical components of the system including the RF/IF receiver hardware and the digital baseband are designed and manufactured by GARMIN to ensure interface compatibility.

The GPS 36 TracPak is housed in a white, water-resistant case and designed to withstand rugged operating conditions. While the GPS 36 TracPak is designed as a "plug 'n play" GPS solution, the minimum system must provide a source of power and a clear view of the GPS satellites. The system may communicate with the GPS 36 via a choice of two RS-232 compatible bi-directional communication channels. Internal memory backup allows the GPS 36 to retain critical data such as satellite orbital parameters, last position, date, and time. The GPS 36 TracPak also comes with a thirty-foot interface cable which is useful for marine implementations.

6.4 MAGELLAN VS. GARMIN

A few years back the 12 channel parallel units made their debut and the Magellan units were the 2000XL/3000XL/4000XL while Garmin introduced the GPS 12XL, a 12 channel version of the very successful G-45XL. The G-45XL was actually the top member of a family of products that included the G-40 and the G-38. Therefore it wasn't long before a GPS 36 filled the bottom of the family and later the G-48 for the top. These units seemed to take the GPS community by storm. Magellan responded by making their models into 12 channel units but didn't change the model numbers that led to confusion in the marketplace.

To combat the lagging sales Magellan introduced the tracker family that consists of two members. The Tracker was a copy of the G-12XL in a lot of respects while the ColorTrak unit had an innovative pressure sensor, but the color was not bright and both were a bit bulky for handheld use. Both are still available in the Magellan stable and have avid followers. They are nice units but not the Garmin breakers they were meant to be. To combat the cost of the GPS 36 Magellan introduced an inexpensive model called the pioneer (later renamed to GPS-300). This was not a 12 channel parallel unit and clearly came in at the bottom of any comparison. Magellan then released a 12-channel version with similar features call the blazer 12.

Recently Magellan released a new family of units consisting of the GPS-315 and the GPS-320. The major difference in these units is the addition of a cable for the 320 and it comes pre-loaded with a navigational aid database. Both have city databases and a CD-ROM is available to upload city data points and "points of interest" and/or more navaids. The rest of this description consists of a table comparing the Magellan-315 family with the Garmin GPS 36.

6.4.1 NOTES FOR TABLE 27

Y means feature is present, N means not present.
A model number means feature begins with the model and is not present on family members below this unit. The Garmin family consists of the GPS 36 and the G-35 in this order. The Magellan family consists of the M-315 and M-320.

There are features of Magellan Tracker family products and other Garmin products that are not addressed in this table.

There is also a M-315A that has airport data (Jeppsen data). It is a specially packaged 315 so the table applies to it as well. The package includes the 315, aviation CD-ROM, and a remote power adapter (10 - 32V).

Although the two products are largely different in that the Garmin model does not have a screen the technology and cost is the main concern of the comparison.

Feature	***Magellan***	***Garmin***	***Notes***
Waypoints	500	0	Magellan stores altitude as part of waypoint
Waypoint names	6	0	characters
Waypoint comments	20	0	characters
Waypoint icons	20	0	.
Nearest Waypoint	20 achieved by sorting the main waypoint list	0	.
Routes	20	0	.
Route names	12 (two waypoint names)	0	Both names can be automatically generated. Garmin can also be manually named.
legs/route	30	0	.
Datums	72 + user defined	107 + user defined	The datum list is different so one could be better in one part of the world than the other.
2D mode	Anytime you wish.	Anytime you wish	.
Overdetermined Solution	N	Y	.
Warm Start	15 sec	15 sec	.
Cold Start	60 sec	45 sec	.
Waterproof	Y (floats)	Y	Neither battery compartment is waterproof
City Database	Y	N	Magellan is updateable
Navaid Database	M-320	N	Magellan is updateable and can be loaded into a 315
Weight	7.0 oz	4.4 oz	.
Temp	14F to 140F	5F to 158F	Operating range
Screens	2 to 9 customisable	N	
Screen Size	2.2x1.33	N	inches
Screen Resolution	104x160	N	.
Gray Scale	4 levels	N	.
Grids			
DDD.ddddd	N	N	Lat/Lon
DDD/MM.mmm	Y	N	Magellan also has DDD/MM.mm
DDD/MM/SS	Y	N	Garmin is actually SS.s
TD	Y	N	Loran
UTM	Y	N	Garmin has UPS also
MGRS	Y	N	Military
OSGB	Y	N	Great Britain
Irish	Y	N	.

Swiss	Y	N	.
Swedish	Y	N	.
Finnish	Y	N	.
German	Y	N	.
French	Y	N	.
Indo So LCO	N	N	.
India	N	N	O, IA, IB, IIA, IIB, IIIA, IIIB, IVA, IVB
Maidenhead	N	Y	.
New Zealand	N	Y	.
Taiwan	N	Y	.
W. Malayan RSO	N	Y	.
User Grid	Y	Y	.
Battery Life	15 on 2 batteries	External Power	Up to
Batteries	2	N	AA cells
Backup battery	> 12 hours - Magellan states it is a ten year battery	3 months - rechargable lithium with a ten year life.	.
Dimensions	15.75x5.0x3.3 cm	2.230" (w) x 3.796" (l) x 1.047" (h)	
Sun/Moon positions	Y	N	Northfinder
Tracklog	1200	N	
Discontinuous Tracklogs	N	N	.
Tracklog collection	Automatic or adjustable based on distance	N	.
Tracklog modes	Wrap	N	.
Back track routes	Y	N	Magellan can also backtrack the tracklog directly
Dead Reckoning	N	30 sec's.	.
Project Track	Y	N	.
Pan & Zoom Map screen	One or the other, not both	N	.
Fish calculator	Y	N	When to fish/hunt
Sunrise/sunset	Y	N	Magellan attempts to change time zones for remote sunrise/sunset but gets in wrong often, according to their FAQ
Position averaging	automatic	Y	.
Time zones	Manually	Manually	No Daylight savings setting on either unit
Antenna	quadrifilar	Patch	
External Antenna	N	GPS 36	.
Backlit lamp levels	2	N	.
Lunar phase	Y	N	.

Trip Odometer	Y	N	.
Another Odometer	Y	N	.
Max Speed	N	Y	.
Speed Limit	951	999	.
Average Speed	Y (graphic display only)	Y	Magellan can customise averaging
Speed Filtering	N	N	.
Trip Time	Y	N	.
Elapsed Time	N	N	.
Compass Settings	Magnetic, True degrees/mils	Magnetic, True, Grid North, User defined degrees/mils	.
DGPS ready	Y	Y	.
Upload/download routes	Y	N	Note 1
Upload/download Waypoints	Y	N	Note 1
Upload/download tracklog	Y	N	Note 1, Only ozi seems to support upload on Magellan so far
Audible Alarms	Y	N	.
Anchor Alarm	Y	N	.
Proximity Alarms	> 11	N	All Magellan proximity waypoints must have the same alarm distance
Arrival Alarms	based on distance	N	Garmin has automatic rollover to next route leg even if alarm criteria isn't met.
Simulation Mode	Mainly useful for training. Creates a route and runs it. You can create the route.	N	Garmin saves battery power in this mode
Language Support	1	N	.
Cost (Australian Dollars)			
M315	500		.
G-36		500	.

Table 27: Comparison of Magellan and Garmin

6.4.2 OTHER SPECIFICATIONS THAT ARE SIMILAR BETWEEN THE TWO MODELS

Note 1: Both units have 3rd party support for upload and download.

Navigation Data in both units are different – The Magellan only computes BRG, DST, SPD, TRK, XTE, CTS, VMG, TRN, ETE, ETA, Trip distance, Time, Altitude and Position. This is one of the major differences in using the units. Accompanying software enables the Garmin to do what the Magellan does on its own. The only drawback the Magellan has is that its quadrifier helix antenna performs worse than the G-36 patch antenna indoors and that its size and cost is slightly greater.

I own a Magellan 315 but have used a GPS 36 family unit on many occasions. The above comparison was made from the associated Manual information, and news group information and first hand experience.

6.5 CONNECTION TO PC FROM MAGELLAN 315

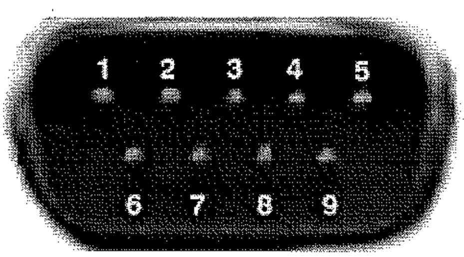
The following is a description on how a Magellan 315 can be connected to a PC.

Initially when the Magellan 315 was purchased there was not a concern to acquire the power/data cable. To manufacture a cable to interface the GPS 315 certain information needed to be known:

- RS 232 serial interface pin layout to the PC for data in and data out.
- Pin layout on the rear of the Magellan GPS 315 for NMEA data out and NMEA data in, power + and -.
- Knowledge of GPS software that will enable the viewing of incoming port data in the NMEA GPS formats.
- The ability to manufacture the cable with limited resources.

6.5.1 SERIAL INPUT PIN LAYOUT FOR PC COM PORT

Figure 12: PC COM Port



Pin	*Signal*	*Dir*	*GPS*	*Description*
1	DCD	I		Data Carrier Detect
2	RXD	I	Serial Data from GPS	Receive Data
3	TXD	O	Information Upload	Transmit Data
4	DTR	O		Data Terminal Ready
5	GND	N/A	GPS signal and power	Signal Ground

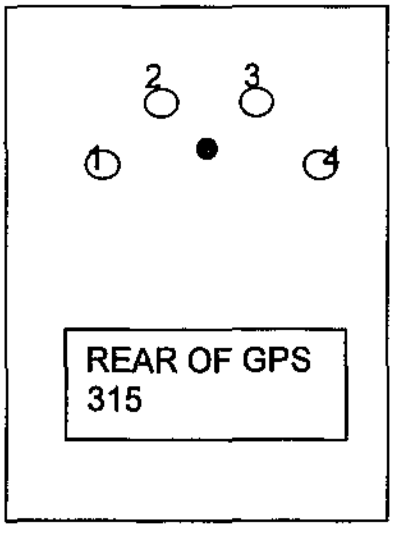
6	DSR	I		Data Set Ready
7	RTS	O		Request To Send
8	CTS	I		Clear To Send
9	RI	I		Ring Indicator

Table 28: PC COM Port

"Dir" is direction of signal with respect to the computer

6.5.2 MAGELLAN GPS 315 PIN LAYOUT

This information was not readily available in manuals or through customer service so to correctly ascertain the pin outs the back of the device had to be removed and an oscilloscope was used to monitor the outputs. From this the following was determined:



PIN 1: NMEA IN
Pin 2: Power in
PIN 3: COMMON (1,2,4)
Pin 4: NMEA out

Figure 13: Rear Of GPS 315

6.5.3 CABLE MANUFACTURE

The aim of this part was to produce an interface cable from limited resources. This task was accomplished with and old mouse (the cable), a small piece of non-etched PCB and a few small screws (the GPS plug). Basically if a structure rigid enough was created, to ensure reliable contacts with the rear of the Magellan GPS 315, the interface would work. As the computer interface task was taken care by the mouse cable having a serial 'D' type connector the majority of the time was spent forming the GPS plug.

The GPS plug design had three constraints. The first was being the rigidity, neatness and personal appeal. Second consider the pin layout which would influence the physical size of the plug. Lastly the method used to affix the mouse cable wires. Considering the pin layout: (Scale 1:1)

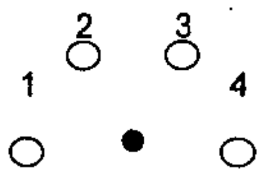


Figure 14: GPS 315 Pin Layout

If the PCB could be cut square to cover the entire pin area

Figure 15: PCB Required

Then for appeal round the edges whilst not sacrificing strength

Figure 16: Shaped PCB

Drill the appropriate holes to insert the contact screws

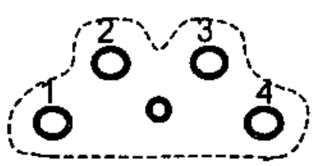


Figure 17: Contact Screws

Remove the in-between copper track to isolate each pin (Scale 1:2)

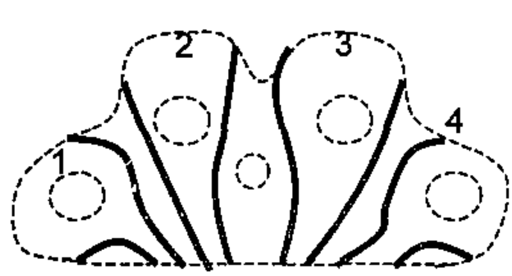


Figure 18: PCB Etching

Insert the four contact screws and solder them into the PCB (Scale 1:2)

Figure 19: Side View

Drill four small holes with a finger drill so that mouse cable wires can be attached

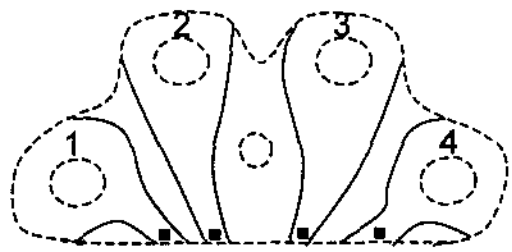


Figure 20: Drill Terminal Holes

Solder appropriate connections

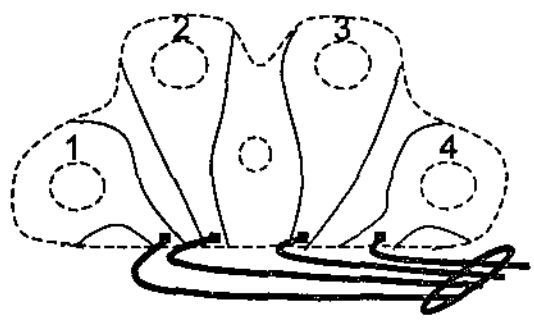


Figure 21: Attach Interface Cable

The design of the cable and interface connector is entirely my own and although proud of my creation I must admit it had some crucial flaws which took some sorting in the early part.

One of the problems with this was that the contact screws, although from the same design and same packet, their entry tips were rugged and uneven. All four of the screws required fine filing to acquire a flat and conductive surface.

Another dilemma with the plug was that the terminals of the GPS were on different physical levels. This caused an intermitted connection as the plug would 'rock' between each set of pins. The upper pins two and three were slightly lowered within the molded plastic to that of the lower pins one and four. The file was used once more to compensate the varied levels. After filing the plug looked like:

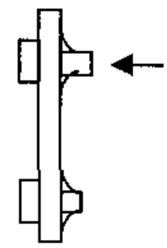


Figure 22: Contact Screw Adjustments

The only other consideration for the cable was the fact that all the tension on the cable would be felt on the four solder points of the plug. To insulate this force a crimp connector with a ring end was attached to the cable and then adhered to the PCB structure effectively taking the strain off the bare wires and solder joints.

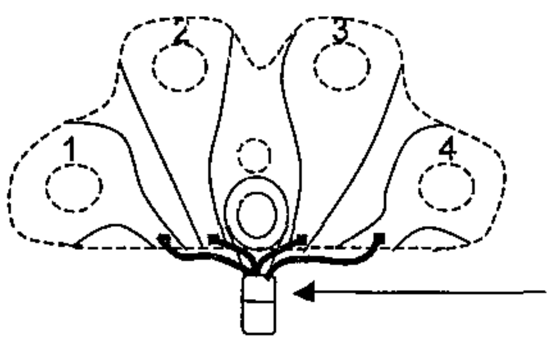


Figure 23: Cable Strength

A small screw with a thread matching the one inside the pin constellation of the GPS was obtained to attach the plug to the GPS. The screw chosen had to be removable without tools. The best one found had an end like a hexagon, which made it easy to grip with the fingers, and could be tightened and released without tools.

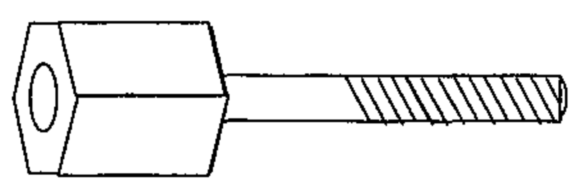


Figure 23: Connection Screw

6.6 CONNECTION TO PC FROM GARMIN 36

This task was made relatively simple for the fact that the Garmin 36 GPS has output and input bare wires in place to begin with. These wires are easily addressable as most of the information can be found in its associated manual documentation.

6.6.1 GARMIN 36 WIRING DESCRIPTION

The GPS 35/36 features a stripped and pre-tinned cable assembly for the greatest connection flexibility. The following is a functional description of each wire in the cable assembly.

Red: VIN - Unregulated 10 - 30VDC 200 mA (maximum). Typical operating current is 150 mA.

Black: GND - Power and Signal Ground

White: TXD1 - First Serial Asynchronous Output. RS-232 compatible electrical specification. This output normally provides serial data which is formatted per "NMEA 0183, Version 2.0". Switchable to 1200, 2400, 4800 and 9600 BAUD. This output functions in parallel with the NMEA output.

Blue: RXD1 - First Serial Asynchronous input. RS-232 compatible with maximum input voltage range-25<V <25. This input may be used to receive serial initialisation/ configuration data.

Purple: TXD2 - Second Serial Asynchronous Output. Electrically identical to TXD1.

Green: RXD2 - Second Serial Asynchronous Input. Electrically identical to RXD1. This input may be used to receive serial differential GPS data formatted per "RTCM Recommended Standards For Differential Navstar GPS Service, Version 2.0".

Gray: NMEA-NMEA0183, Version 1.5 electrical specification compatible serial output. This output is also CMOS compatible with a no load voltage swing of 0.2Vdc to 4.8Vdc. This output normally provides ASCII sentences formatted per "NMEA 0183, Version 2.0". User selectable baud rates of 1200, 2400, 4800, and 9600 are available. The data output on this pin is identical to the data output on TXD1.

Yellow: VAUX - Optional External Backup Power Connection. This is an optional connection. Internal battery capacity is 180 mA hour. Typical current requirement is 65 uA @ 5VDC. If used, a 4VDC to 30 VDC power source is required.

6.6.2 SERIAL PIN LAYOUT FOR PC COM PORT

As mentioned in the Magellan 315 GPS, the output of the GPS is interfaced to the computer via a 9 pin COM port. Both the Garmin and the Magellan models are identical in this instance.

Pin	*Signal*	*Dir*	*GPS*	*Description*
1	DCD	I		Data Carrier Detect
2	RXD	I		Receive Data
3	TXD	O		Transmit Data
4	DTR	O		Data Terminal Ready
5	GND	N/A		Signal Ground
6	DSR	I		Data Set Ready
7	RTS	O		Request To Send
8	CTS	I		Clear To Send
9	RI	I		Ring Indicator

Table 29: Same as Table 28

"Dir" is direction of signal with respect to the computer

6.7 LAPTOP INTERFACE

Testing for both the Magellan and the Garmin receivers required some form of computer linkage to run the application programs and store the data. As most of the testing would be carried out in a nonstationary situation the best computer to use was a Laptop, or notebook PC.

The only Laptop available to this undergraduate project was a dated Duel Group Dx4 100. This PC had been brought to me in an unserviceable condition and required repair before it could be used in the project. As this was the only Laptop hardware available it would have to do. On approaching the support staff to inquire about a work order to begin repairs it was found that because of the budget and the obsellecance of this device there was little chance to get the order approved. The next port of call was to my own workplace to borrow some test gear to fix it myself.

The main faults with this computer was that there was no output to the monochrome LCD screen, and the system would not boot without the mains cable attached. These problems would have to solved before the project could continue.

After some probing around it was found that there were video signals present at the output of the computer/screen socket interface. This was bad news, as this would mean lengthy fault finding to establish a DC line problem. In my experience these were invariably the more serious and time-consuming tasks. Fortunately on inspecting the plug solder connections on the LCD PCB, a thin crack in the board, was noticed, separating the earth rail. This is probably the result of repetitive torsion between the screen and the keyboard when the lid is up. This is a common fault in earlier models before the advent of stability struts in the middle and ends of the hinge. On bridging the gap in the earth rail the project continued with an operational LCD.

My next task proved to be a mechanical fault within the battery latch of the Laptop. It seemed that with the rechargeable battery once inside the computer, the latch required to secure and maintain this in the home position, had become brittle and broke. This meant that when the Laptop was in other than a horizontal position, the battery would loose contact and the system would fail. To ensure the battery remained in the correct position a band of masking tape was used sdto hold it there. This worked very well for the remainder of the project.

Once the Laptop was operational, it was discovered that the rechargeable battery had developed a memory or had reached its useby date and would only provide 10 – 15 minutes, depending on drive access, total operation time before the system would shut down. This meant that a test flight greater than this time could not be achieved with this battery inside. An external means to provide the Laptop with 24 v had to be realised the system could be tested in the aircraft. It was obvious that the aircraft would not supply mains power so there was three options, use what power the aircraft could offer, buy a new rechargeable battery compatible with the Laptop or supply my own battery supply and feed it into the external power input. As the latter 2 either cost too much or would take up too much room the initial thought was followed.

On speaking to Malcolm Yeo it appeared that the aircraft operated on a 24 v DC system. This meant the Laptop would run directly off the output of the cigarette lighter. To channel this power to the Laptop an interface cable had to be manufactured. One end of this cable was a standard male cigarette lighter plug but on the other was a rare 4 pin mini din. I had not come across this type of connector before and was worried whether I would. After some inquiries ending abruptly I simply decided to snip of the mains power adapter and solder it back on later. This mains power plug had the illusive mini din end and could be joined directly to the cigarette plug mentioned earlier. This ended in success and enabled the project to continue with flight tests. These tests were used to fine tune the smart program mentioned in chapter 5.

7. PHASE TWO - EMBEDDED

7.1 AIM

The main aim of this phase is to apply similar principles of the previous phase to a system that supports lesser resources, has a lesser cost and can be considered as a saleable product. A complication within this phase is that the new GPS sensor used must be fully understood before implementation. Things that will differ are the power requirements, mounting, data storage, real time indicators, GPS sensor and the Processor. Things that will not change are the Data Flow Diagrams and the main processing arguments of the shell program.

7.2 INTRODUCTION

A complication within this phase is that the new GPS sensor used must be fully understood before implementation. Things that will differ are the power requirements, mounting, data storage, real time indicators, GPS sensor and the Processor. Things that will not change are the Data Flow Diagrams and the main processing arguments of the shell program.

7.2.1 THE EXTERNAL ANTENNA ACTIVE ANTENNA

In order to select the correct external antenna for the purpose of the project it is necessary to summarise certain qualities and perform distinctive comparisons. This section will begin with explaining the factors that need to be considered in order to fully understand the project situation. First this section considers cable loss.

7.2.1.1 RF CABLE LOSS AT GPS L1

From the Times Fiber Communications, Inc 'Nominal Loss Characteristics' table, and help from David Salonimer and George Bynum, I determined the loss in dB per meter for a couple of popular RF cables at the GPS L1 center frequency (1575.42MHz).

Type	loss (dB/m)	outer diam. (mm)	impedance (Ohms)
RG8	0.39	10.29	50
RG8X	0.6(?)	6.15	50
RG58C	0.90	4.95	50
RG59	0.51	6.15	75
RG142/RG400	0.59	4.95	50
RG174	1.39	2.8	50
RG188	1.26	2.74	50
RG316	1.28	2.49	50
Belden 9913 (RG8/U)	0.20`	10.29	50

Table 30: Cable Losses

Another consideration when choosing an antenna is whether differential measurements will need to be made at some stage and how certain antennae perform against noise and multipathing effects

7.2.1.2 DETERMINATION OF PSEUDORANGE AND CARRIER PHASE NOISE

"With the current quality of GPS receivers, multipath on the pseudorange may very well be the determining factor for (sub) meter level code differential GPS, and multipath and receiver noise on both pseudorange and carrier phase may determine the ability of the receiver for cm level carrier phase differential GPS."

(Wanminger, L. July, 1991).

It is therefore required:

A. To gain knowledge about these quantities and

B. To control multipath by a careful antenna selection and antenna location.

This section gives an explanation on how to determine pseudorange and carrier phase noise. Experience shows, that the noise level of both pseudorange and carrier phase often depends on the satellite elevation.

"Low elevation satellites have a longer path through the atmosphere, and are thus more damped, and can be noisier because of ionospheric scintillation, and thus deliver more noisy observations than high elevation satellites."
(Wanminger, L. July, 1991).

Forming double differences (DD's) removes common errors such as satellite clock error, satellite position error, ionospheric error, tropospheric error, receiver multipath error and receiver clock error. Remaining errors are the DD receiver noise, and, in case of the carrier phase, the DD cycle ambiguity. However, the noise level on a DD is higher than the noise level on an undifferenced observation.

Usually, the noise of observations of satellites with a high elevation (say more than 60 deg) is constant, say S. If one assumes that the noise between satellites and between receivers is uncorrelated and gaussian (a reasonable assumption), the noise of a Double Differenced (DD) observation of two high satellites can be determined with the propagation law: $S_{DD} = sqrt(S^2 + S^2 + S^2 + S^2) = 2 * S$, or : $S = S_{DD} / 2$.

This property is used to determine the noise of high satellites first.

The aim of the following is to determine the noise of lower satellites. This is determined using the high satellite noise and again the propagation law.

Method

1. Find a friend with an identical receiver.
2. Buy (WR Inc), or build an antenna splitter.
3. Connect the receivers to the splitter outputs, connect an (active) antenna to the splitter input, and connect PC's with download s/w to the receiver outputs.
4. Power up the receivers, start the downloading s/w on both PC's (download should include pseudoranges and carrier phases).
5. Record data at a rate of 1/sec for several time slices of about 5 minutes, until a full range of satellite elevations has been covered (this may take several hours).
6. Select for each time slice the satellite with the highest elevation - this is the reference satellite for that time slice.
7. Form DD's of the pseudorange and carrier phase observations.
8. Determine for each DD in the time slice the average and the standard deviation. (Note: the average of the pseudo range should be close to zero, the average of the carrier phase (expressed in cycles) should be close to an integer value). Note: in the case of DD carrier phase: check that the time slices are free from sudden jumps, caused by cycle slips.
9. Start with a high (> 60 deg) satellite, determine the noise level of the reference satellite as described above (S_{ref}).
10. For all other satellites and time slices the noise is calculated using $S_{sat} = sqrt\ (S_{DD}^2 / 2 - S_{ref}^2)$. This calculation can be carried out for both pseudorange and carrier phase.
11. Finally plot the satellite noise as a function of the elevation.

7.2.1.3 DETERMINATION OF PSEUDORANGE AND CARRIER PHASE MULTIPATH

Pseudorange multipath is mainly governed by the following factors:

- The location of the antenna: is a ground plane or choke ring available, are higher conducting obstacles nearby.
- The quality of the antenna: does the antenna have low sensitivity for low elevation signals.
- The quality of the receiver: do the tracking algorithms of the receiver channels poses multipath reduction techniques.

"For a reference station the location can be optimised, a high quality antenna with a choke ring can further minimise multipath. The users however can often not optimise location and antenna type. It is therefore advantageous to know the multipath behavior of antenna/receiver under optimal conditions, and under the normal usage conditions. Estimates can then be made for the antenna contribution and for the receiver contribution."

(Wanminger, L. July, 1991)

7.2.1.3.1 Pseudorange multipath

Pseudorange multipath is fairly easy to determine. The following Method can be used.

Method

1. Set up the receiver and antenna for either optimal or normal usage. Power up the receiver and start downloading of pseudoranges and carrier phases. Record data for several hours at a rate of once per second, until the full range of satellite elevations has been covered.

2. Convert pseudoranges and carrier phases to length units (usually pseudoranges are already in meters, but carrier phases in cycles. To convert from cycles to meters multiply by the speed of light (c = 299792458 m/s) and divide by the L1 frequency (1575.42 MHz).

3. Subtract for each satellite and for each moment the carrier range from the pseudorange. This cancels common errors, such as satellite clock error, satellite position error, tropospheric error, and receiver clock error. Remaining errors are:

- Twice the ionospheric error.
- Pseudorange multipath error.
- Carrier phase multipath error.
- Receiver pseudorange noise.
- Receiver carrier phase noise.
- The carrier phase ambiguity.

The carrier phase multipath and noise are very small compared to pseudorange multipath and noise respectively, and can be neglected. As long as the receiver remains in track (no cycle slips) the carrier phase ambiguity is a constant number.

4. Select per satellite time slices of about 15 minutes, which are free from cycle slips. Remove the ambiguity and the double ionospheric error by fitting a second order polynomial through the data and subsequently subtracting the second order curve. The thus obtained residuals contain to a large extend the pseudorange multipath, some pseudorange noise and possibly a small and slowly varying residual iono term.

5. Determine the average elevation for the satellite in the 15-min time slice.

6. Determine the standard deviation of the residuals and subtract the pseudorange noise contribution (as earlier determined for that elevation, see the "noise" section) using the propagation law $S_{mul} = sqrt(S_{residual}^2 - S_{noise}^2)$.

7. Finally plot the multipath as a function of the elevation.

7.2.1.3.2 Carrier phase multipath

Carrier phase multipath is very difficult to determine. However, this form of multipath is only important to users who want to use the receiver in the differential carrier mode (with one or more reference receivers) and thus determine position differences (or 'baselines') to the cm, or even mm level. In the following recipe, a procedure is described which gives a rough idea only of the carrier phase multipath for normal usage conditions.

1. Find a friend with an identical receiver, or a receiver of whom the multipath is known, and preferably low.

2. Connect one receiver to an antenna with at least a proper ground plane (a circular plate of 50 cm diameter), or better a choke ring ground plane, and connects the other receiver to the 'normal' antenna installation. Locate the ground plane antenna in a flat area with no obstacles protruding above this antenna. Locate the other antenna close by, preferably about 10 m.

2. Connect both receivers to PC's. Power up and start downloading carrier phases.

4. Record data for a couple of hours until the full range of satellite elevations have been covered.

5. Form carrier phase double differences (DD's) for 15 min time slices with the highest satellite as reference satellite. This cancels common errors such as satellite clock error, satellite position error, ionospheric error, tropospheric error, and receiver clock error. Remaining errors are the combined receiver noise, the combined multipath and the combined carrier phase ambiguity.

6. Select 15 minute time slices, which contain no cycle slips. In these time slices the combined carrier phase ambiguity is a constant. Remove this constant and the effect of the changing satellite - receiver geometry by fitting a second order polynomial through the DD's and subsequently subtracting the second order curve. The residuals contain the combined multipath and -noise. If we assume the multipath contribution of the reference satellite for both receivers low (a reasonable assumption since only low elevation (less than 40 deg) satellites may show significant multipath), the residual is largely made up by the multipath of the 'normal' receiver's carrier phase measurement to the other (not the reference) satellite.

7. Determine the average elevation for the 15 min time slice.

8. Determine the standard deviation of the residuals and subtract the DD carrier phase noise contribution (as earlier determined for that elevation, see the "noise" section) using the propagation law $S_{mul} = \text{sqrt}(S_{DDmul}^2 - S_{DDnoise}^2)$.

9. Finally plot the multipath as a function of elevation.

If the above obtained noise remains below a few (let's say 3) cm, ambiguity fixing becomes a real option. Now some of the more important variables and methods have been explained the antenna to use for the task at hand will be considered.

7.2.1.4 EXTERNAL ANTENNAS

Manufacturer	Trimble	Motorola (1)	MuRata (1)	Lowe (2)	Garmin	Tri-M	Matsushita
Type	28367-00	GNAC1121A	ANGD003A520	active	GA26(3)	Garmin GA 27A	VIC1
Dimensions (mm)	40x47x13	50x43x18	50x50x15	50x42x14	50x71x15	58x48x15	50x43x18.5
Cable length (m)	5	6	5	5	2.5	5	6
mount	Magnetic	magnetic	magnetic	magnetic/ screw down	magnetic/ suction	magnetic/ screw down	magnetic
connector	SMB	BNC	SMB	BNC	BNC	(see note 5)	many types
power	5V@25mA	5V@20mA	5V@30mA	5V@32mA	5V@30mA	5V@10mA	5V@25mA
gain (dB)(4)	23 (+)	24(+)	25 (-)	23 (+)	15 (?)	26(?)	25 (+)
noise (dB)	1.6	1.8	2.5	1.6	2	1.5typ,2.5 max	?
gain pattern	+3dB@90deg - 5Db@20deg	+3dB@90deg 0dB@30deg - 10dB@0deg	+2dB@90deg - 2dB>20deg - 6dB>15deg	+3dB@90deg - 5dB@20deg	+1.5dB@90deg - 1dB@45deg - 6dB@10deg	+5dB@90deg - 1dB@10deg	0dB>30deg - 7dB@0deg
axial ratio	4dB@90deg	?	3dB@90deg	4dB@90deg	3dB@90deg	3dBmax	?
rejection	7dB@20MHz 12dB@30MHZ 20dB@50MHz 30dB@100MHz	25dB@100MHz	18dB@50MHz	7dB@20MHz 12dB@30MHz 20dB@50MHz 30dB@100MHz	15dB@50MHz 25dB@100MHz	?	?
op.temp.range (C)	-40/+85	-40/+100	-30/+85	-30/+80	-55/+85	-30/+85	?
price (US$)	50	56	100	65	100	59	?

Table 31: Overview of Low-Cost GPS Antennas

1. Various other types available.
2. Actual measurements by Lowe show a max current of 20.9 mA, a max noise figure of 1.38 dB and a min gain of 27.9 dB
3. Also available with MCX connector (GA 27) and marine (GA 28).
4. Preferably the overall gain (antenna + pre-amp + cable) is given. The following symbols are used:

   ? : don't know

   - : gain without cable loss

   + : gain with cable loss included.
5. FME connector with adapters to BNC, TNC, SMA, SMB, MCX included.

7.2.1.4.2 Test Results of some Low Cost GPS Antennas

Some low-cost GPS antennas were obtained and a perfect platform for test was designed : the popular Garmin XL hand-held GPS receiver (s.w. v 3.62). The antennas are:

Garmin GA 27A

Garmin GA 27 (Enhanced)

Lowe active

NovAtel model 511 aircraft certified antenna

(Expensive antenna benchmark).

It's the aim of this section to compare the low-cost antennas and try to pinpoint the differences. This will help me to decide which antenna is suited best for the application.

7.2.1.4.2.1 Actual power consumption test

The actual current delivered by the Garmin GPS to the antenna has been measured directly by interrupting the power cable between receiver and antenna.

The results are:

Garmin GA 27A	10 mA
Garmin GA 27 (Enhanced)	28 mA
Lowe active	20 mA
NovAtel 511	20mA

Table 32: Power Consumption

The Garmin GA 27A scores very good, Garmin GA 27 (Enhanced)'s higher gain comes at a cost.

7.2.1.4.2.2 Azimuth Sensitivity Test

The purpose of this test is to determine the effect of irregularities in the axial radiation pattern of the antenna on the receiver signal to noise ratio (SNR), and obtain an idea about the radiation pattern of the antenna as a function of the satellite elevation.

The test is carried out as follows:

1. The antenna under test is mounted on a small, round ground plane (diameter 27 cm) in order to suppress Multipath effects, which may obscure the test result. The ground plane is mounted on a pole on the roof of my house, with an unobstructed view to the sky.

2. The antenna is connected to the Garmin 25 LVS with its own connector (MCX, GME Electrophone) or a small adapter cable (Lowe).

3. The Garmin is set up to output NMEA messages - the message reporting satellite elevation, azimuth and SNR is the one of interest.

   GSV = Number of SVs in view, PRN numbers, elevation, azimuth & SNR values.

4. The 25 LVS is connected to a PC running a proper download program.

5. The antenna is rotated to the start position with the pigtail pointing towards the North direction.

6. The antenna is rotated over 360 degrees with steps of 10 deg, the rotation is recorded.

This procedure is repeated for all antennas under test within a short time interval, aiming at marginal satellite configuration changes only.

The results are listed in table 33. For each antenna and for each satellite in view the satellite elevation and azimuth are listed with the SNR averaged over one full rotation (36 values), the minimum SNR and the maximum SNR.

Garmin GA 27 (Enhanced)						Garmin GA 27A					Lowe Active					NovAtel 511				
prn	El	az	avg	min	max	el	az	Avg	min	max	el	az	avg	min	max	el	az	avg	min	max
1	36	77	52.2	51	54	36	81	49.1	47	51	35	86	51.5	50	54	36	70	50.5	49	52
2	22	297	48.9	48	50	22	301	45.3	43	46	22	304	48.1	46	50	21	292	46.9	46	49
3	10	150	45.9	44	48	13	150	43.8	40	47	17	149	46.7	42	49	5	151	41.7	39	43
9	3	12	42.3	39	46	3	15	39.7	36	42	2	18	41.6	37	45	3	8	40.7	38	42
14	25	221	50	48	51	22	220	46.6	44	48	18	219	47.6	45	50	30	223	49.8	49	51
15	68	287	53.3	53	55	65	285	51.3	50	53	60	281	53.6	52	54	73	293	50	49	51
21	23	55	48.3	46	49	26	55	46.6	44	48	29	55	49.2	48	51	18	55	45.5	44	47
29	37	127	52.1	50	53	34	129	48.9	47	50	31	132	50.1	49	52	40	121	50.8	49	52
31	49	171	53.1	52	55	52	171	51.2	49	53	57	173	52.9	48	54	44	170	51.4	50	54

Table 33: Satellite Elevation, Azimuth And SNR

Some observations on the table:

1. For low elevation satellites the minimum and maximum SNR values vary significantly: 6 to 7 SNR units for the low-cost antennas and 4 units for the reference. Under sub-optimal reception conditions (e.g. under heavy foliage or inside) the 'dip' in sensitivity may result in a loss of lock. As an example the SNR values of satellite 9 as received by Garmin GA 27 (Enhanced) are given in the radial plot below. The outer ring represents a value of 46 SNR units, then a ring representing 42 units, then 38 and 34.

   A symmetry around the Y-axis can clearly be seen. The misclosure at about 11 deg is due to increasing SNR because of the increasing satellite elevation during the measurement.

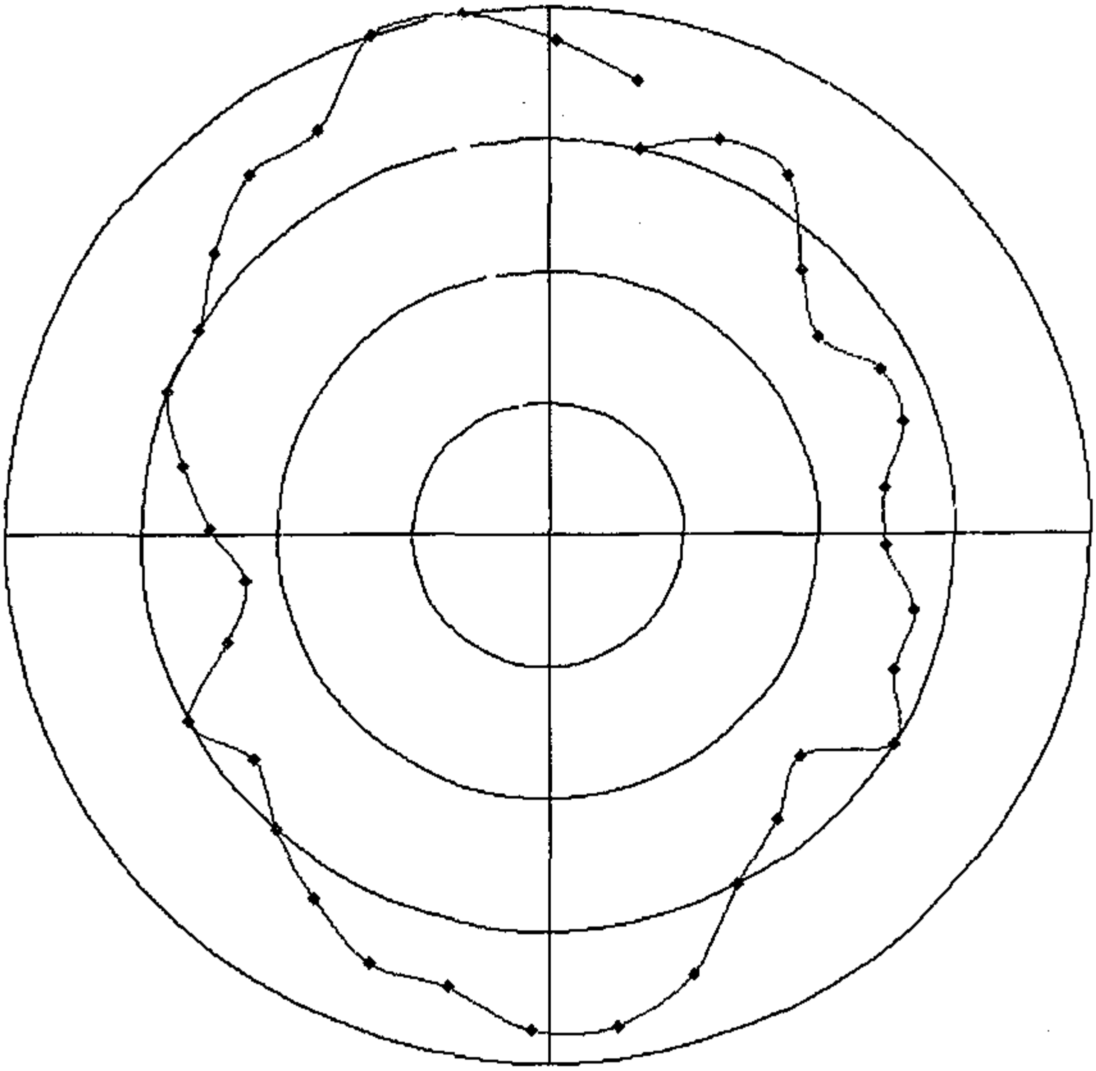


Figure 25: Signal To Noise

Satellite Number	Garmin GA 27 (Enhanced)	Garmin GA 27A	Lowe Active	NovAtel 511
	AVE S/N	AVE S/N	AVE S/N	AVE S/N
1	52.2	49.1	51.5	50.5
2	48.9	45.3	48.1	46.9
3	45.9	43.8	46.7	41.7
9	42.3	39.7	41.6	40.7
14	50	46.6	47.6	49.8
15	53.3	51.3	53.6	50
21	48.3	46.6	49.2	45.5
29	52.1	48.9	50.1	50.8
31	53.1	51.2	52.9	51.4
TOTAL	**49.57**	**46.94**	**49.03**	**47.48**

Table 34: Antenna SNR

Garmin GA 27 (Enhanced)'s SNR values are roughly 3 units larger than Garmin GA 27A, Lowe active lies in between. This last observation is detailed on figure 26 in the plot of average SNR values against the satellite elevation.

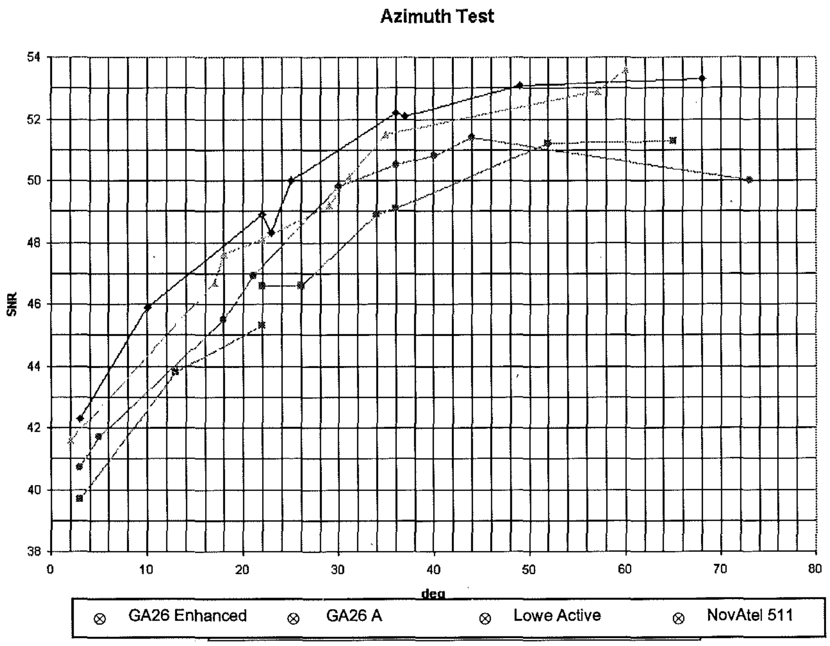


Figure 26: Azimuth Test

7.2.1.4.2.3 Signal to Noise Over Time

Setup during this test is identical to above, the antenna cable points towards North.

The NovAtel 511 was connected to the Garmin on April 29 and recorded data from roughly 19:00 to 23:00 local time (UTC + 1 hour). The next antenna was hooked up the Garmin GA 27A but recording occured during a smaller interval because the batteries in the Garmin were drained (curve Garmin GA 27A 2). On May 1 Garmin GA 27 (Enhanced) was under test, May 2 saw the Lowe Active, and May 4 (we commemorate the WWII victims) saw the Garmin GA 27A again.

The plot below shows the signal strength for satellite 15 on the successive recording days. May 1 was taken as reference day shifting the other curves by 4 minutes per day (the satellite configuration repeats itself after 23 hour 56 minutes). The SNR values have been obtained by averaging the raw SNR values from the Garmin over 2 minutes. The time axis shows UTC time of day (seconds).

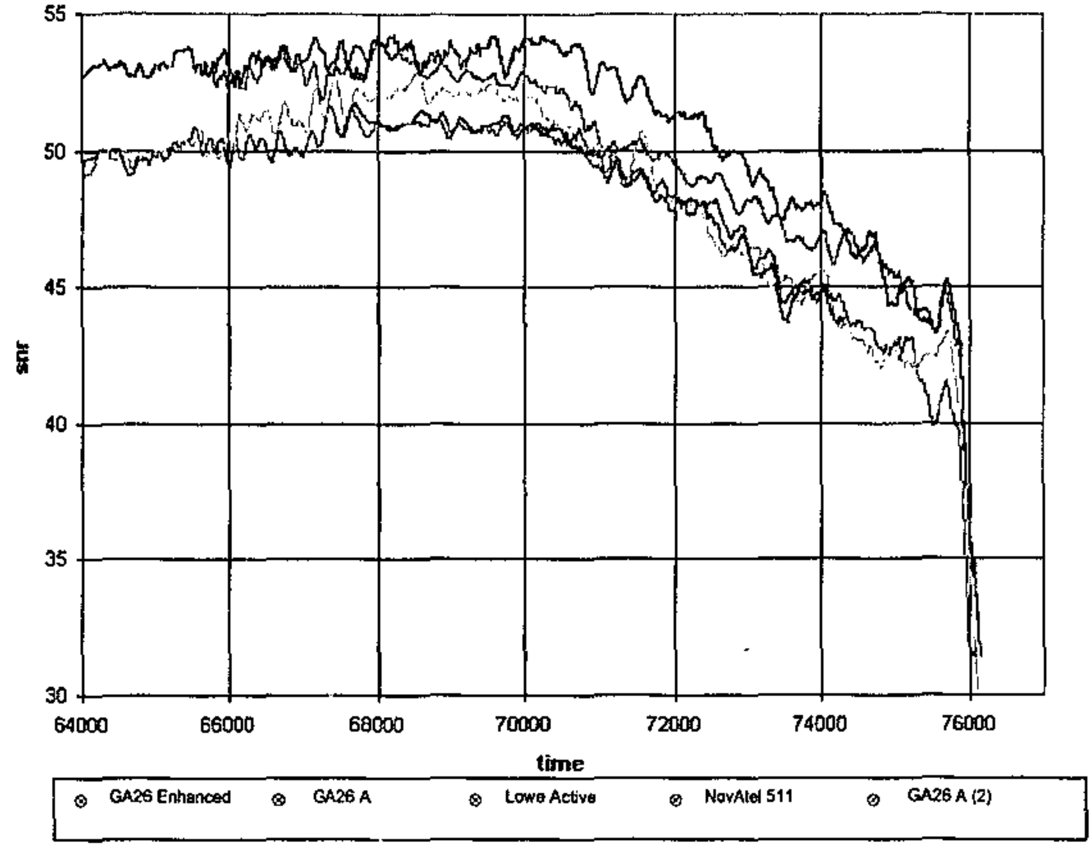


Figure 27: Signal to Noise Over Time

For reference the elevation and azimuth, satellite 15 was plotted in figure 28 during the same time interval (obtain the azimuth by multiplying the plotted value by 4).

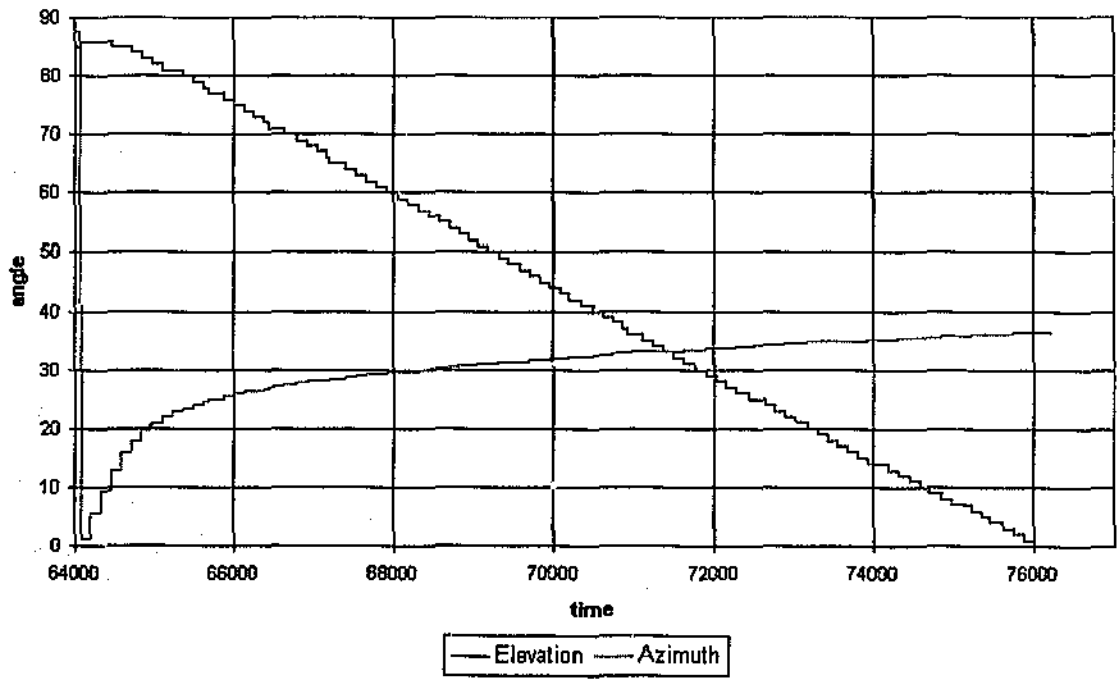


Figure 28: Elevation and Azimuth

A number of remarks can be made:

- The repeatability is good: compare Garmin GA 27A with Garmin GA 27A 2.
- The signal strength reaches its maximum not at the highest elevation but approximately at 50 deg. This is not due to the radiation pattern of the antennas, but to the radiation pattern of the satellite: its radiation pattern allows for atmospheric attenuation at lower elevations !
- Garmin GA 27 (Enhanced) is again the clear winner, Garmin GA 27A somewhat lower, and Lowe Active in between.
- All plots show some bumps at the same time. It cannot be determined about the cause, the best estimate would be some effects of multipath.

7.2.1.4.2.4 Road Test the Antenna under Sub-Optimal Conditions

The test vehicle was driven to the only place within a radius of 50 km with some decent trees: the Gnangarra pine forest. This terrestrial test platform was parked on a location that was fully covered by trees. The receiver was placed on the upper most level of the terrestrial test platform (roof), and was then hooked it up to a laptop to record the NMEA output.

Data was collected for about one minute using the 25 LVS's internal antenna. The Garmin GA 27 A was attached to the receiver, following this the Garmin GA 27 (Enhanced) was positioned at the same location on the "roof", recorded for about one minute. Following this Lowe Active was hooked up, recorded data, hooked up the NovAtel, recorded, and re-run the whole sequence two times just to be sure. What was established with this test was the behavior of the antennae under typical, i.e. sub-optimal conditions with efforts to pinpoint some differences.

First some statistics on the number of satellites tracked. The receiver tracked the 6 highest satellites during all tests, although more were available during the test interval, but at a too low elevation. When using the Garmin internal antenna, the signal strength value was often at or close to the critical low value of 30 units, and sometimes 0 units (the receiver lost lock). The number of observations with the Garmin GA 27A, Lowe Active and Garmin GA 27 (Enhanced) were identical almost no loss of lock occurred with the external antennas.

Next the signal strength analysis. An average of the signal strength values for each satellite was performed during the observation interval of 1 minute. Then a comparison was made between the external antenna average with the internal antenna average, table 34 gives the additional signal strength of the external antennas. For this analysis the benchmark was omitted.

	Garmin GA 27 (Enhanced)	Lowe Active	Garmin GA 27A
run 1	+6.0	+4.1	+4.7
run 2	+5.8	+4.7	+4.4
run 3	+5.0	+3.4	+2.1
average	+5.6	+4.1	+3.7

Table 35: Additional Received Signal Strength Of Tested Antennae

The trend of the earlier tests is again visible: Garmin GA 27 (Enhanced) delivers a stronger signal than the Lowe Active and the Garmin GA 27A, the latter two perform nearly equal.

Another conclusion (which is evident and not surprising): the external antennas perform significantly better than the 25 LVS's internal antenna, although during this particular test the number of satellites tracked was only marginally lower with the internal antenna compared to the external antennae.

7.2.1.4.2.5 Strong points and weak points

Table 35 lists my impression of the strong and weak points of the three low-cost antennas.

Garmin GA 27 (Enhanced)		Garmin GA 27A		Lowe active	
+	-	+	-	+	-
high gain great connector set	high power larger size	very low power great connector set	Larger size	very small	medium power

Table 36: Strong and Week Points of External Antennae

All antennas show a fairly large amount of radial asymmetry with satellites at low elevations. The external antennas show their advantage when working under sub-optimal reception conditions.

Prices are nearly identical, around $100 (Australian).

7.2.1.4.2.6 Antenna Patterns and perceived "sensitivity" of GPS receivers

Sometimes people do side-by-side comparisons of GPS receivers for sensitivity and come to incorrect conclusions. This had been done for the project until an article was read on the effects that certain receivers have on one another.
(Hofmann-Wekllenhof, Lichtenegger, 1992).

1) Some GPS receivers emit small amounts of Electro Magnetic Interference (EMI) which can desense the receivers of other GPS receivers a few feet away. One example of this is that the Eagle Explorer EMI causes desense of the receiver in the Garmin G-25 LVS, but not the other way around. Thus, if you put the two side by side you will always find that the EE receives better. On the other hand, if you separate them by 5 feet, things are pretty equal.

2) Antenna patterns are another cause of wrong conclusions about "which GPS has a more sensitive receiver. Many GPS receivers use the patch antenna that has the antenna gain fall off as you near the horizon. (Examples: G-25 LVS, EE, M-4000). Others use the wrapped "helix" style antenna that has good coverage almost all the way to the horizon (Examples: Magellan 315). Outside in the open spaces, both perform very well. The patch antenna is conceivably superior since it tends to reject signals very low on the horizon and thus is somewhat less sensitive to multipath errors. On the other hand, if you are indoors (or in a car), the lower pattern coverage angles of the helix style antenna may pick up SVs lower on the horizon (or multipath signals) through side windows and stay locked where you might not with the patch. If multipath signals are received and processed, you may see your GPS position move hundreds and even thousands of meters away from your actual position.

In actual practice, little difference have been found in "real world" performance between the two antenna types under normal clear view of the sky situations. The questionable results come when someone takes his GPS unit inside and does a comparison test for receiver sensitivity. In such cases, almost all of the direct signals from overhead SVs are blocked and signals from off to the side through windows and/or walls may be stronger than any of the overhead SV signals. In such cases, the helix type antennas will almost always prove 'better' due to the fact that they have the ability to see signals LOW ON THE HORIZON and so can look out windows better than the patch antenna equipped units. However! The fact that the helix style antennas can look off to the side better does not indicate that the GPS they are attached to will (or will not) perform better in a normal environment with an unobstructed overhead view.

7.2.1.4.2.7 When to use which antenna?

If the antenna has a clear view to the sky, don't bother about external antennas. The 25 LVS's internal antenna performs well.

If the receiver is used in a location with an obstructed view (inside a building or vehicle, obstruction by your body, to name a few examples), or if serious attenuation of the signal (in the forest) is expected, the application would be better off with an external antenna.

If the equipment is operated on batteries, the Garmin GA 27A is the best choice. If the application needs those extra dB's because of a very long cable to your antenna, or in very dense forest, take Garmin GA 27 (Enhanced). The Lowe Active scores with its lowest weight at moderate power consumption.

7.2.1.4.2.8 Conclusions towards Project Selection

Due to the above determinations, and considering the relatively low loss of the associated cable and the aircraft fuselage attenuation and the relatively low chance of multipathing, the lowest gain and consequently cheapest variety of active antennae is selected. In the test cases it would be the Garmin GA 27A because of its low power consumption, small size, low cost and substantial gain. For actual project implementation keep in mind the relative inconsequential choice of antennae for clear sky applications.

7.2.2 MICRO PC

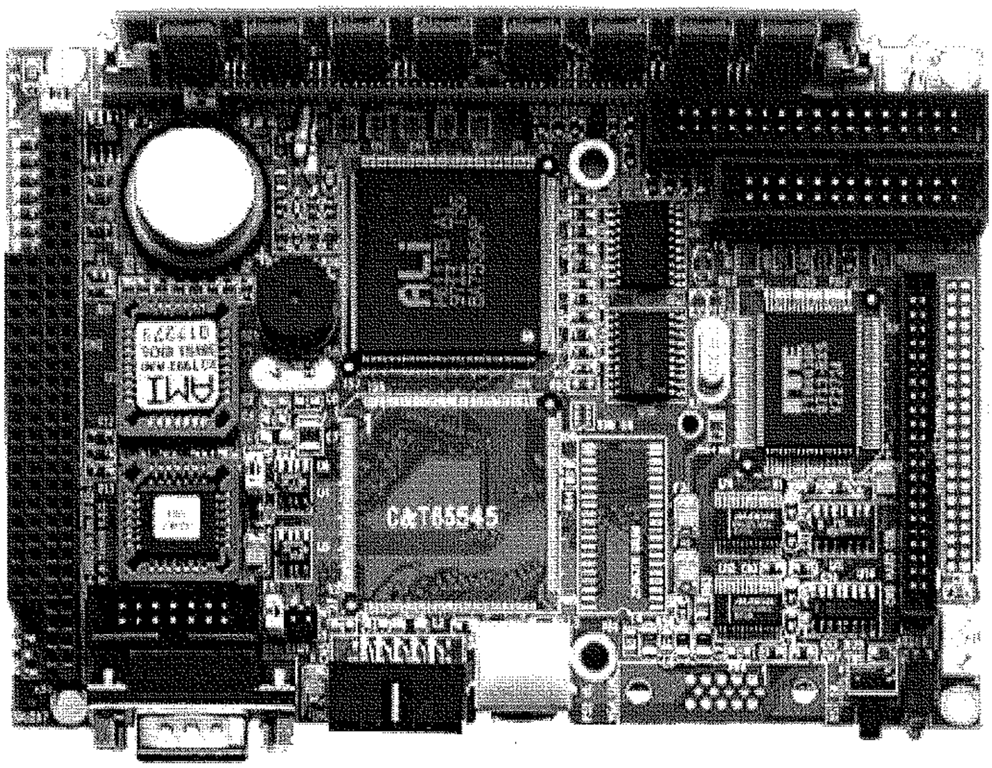


Figure 29: Micro PC
(M-Syetems Manual, 1999)

7.2.2.1 OVERVIEW

In choosing a controller to compute, monitor, and manage the incoming positional data a number of factors were considered. Initially cost was a major consideration. To produce a system to be used in industry and to be an attractive commodity it must perform the tasks required reliably, be an attractive package and be competitively priced. There are many embedded type processors currently available of which most have the capabilities that the project requires. These processors ranged from dedicated controllers with one chip surrounded by slight I/O management to entire PC's, minus peripherals, jammed onto one single card. In order to correctly debug or develop this project, the advantages a micro PC were strongly considered. A micro PC provides the user with exactly the same resource a regular desktop PC would provide. Alternatively, in order to establish a system that could be made saleable and competitive on a niche market it needed to have the price of a system embedded with a dedicated controller. This problem was difficult to overcome as a student does not have the means to cover the research and development shortfalls. Either acquire the expensive Micro PC, develop the system to operate within embedded constraints, and pass on the project effort and glory to the next person who comes along. Or, risk successful outcomes, and move blindly into the dark world that is dedicated controllers and hope for the best.

The PCM-4825/4825L is the ultimate cost-effective solution for limited space applications. It offers all the functions of an AT-compatible industrial computer on a single board and only occupies the space of a 3 1/2" hard drive. The PCM-4825/4825L comes with an embedded high-performance 5x86 processor and audio on-board. For maximum performance, the PCM-4825/ 4825L also supports an EDO/FPM DRAM SIMM socket that can accept up to 32-MB memory.

On-board features include a 16-bit audio controller (PCM-4825 only), support for a VL-Bus Enhanced IDE interface with up to Mode 3 transfer protocol, one parallel port, two serial ports (RS-232 and RS-232/422/485) with DB-9 connector as COM1 and a mini-DIN PS/2 keyboard/mouse interface. A local bus SVGA/ LCD display controller (LCD, EL and CRT displays) allows LCD screen resolutions up to 1024 x 768 and CRT resolutions up to 1280 x 1024 at 16 colors.

The PCM-4825/4825L complies with the "Green Function" standard and supports three types of power saving features: Normal, Doze, and Sleep modes.

The display type configuration is done through software. A single Flash chip holds the system BIOS and the VGA BIOS. This minimises the number of chips and eases configuration. You can change the display BIOS simply by programming the Flash chip.

If you need any additional functions, the PCM-4825/4825L has a PC/104 connector for future upgrades.

7.2.2.2 FEATURES

- Ultra-compact size single board computer as small as a 3 1/2" hard disk drive (145 mm x 102 mm)
- On-board 5x86-133 (DX5-133) CPU
- Up to 32 MB on-board EDO/Fast Page-mode DRAM
- Local-bus SVGA display controller (LCD, EL and CRT displays), flat panel type configured by programming the Flash chip
- 16-bit audio interface (PCM-4825 only)
- Supports M-Systems DiskOnChip ® 2000 flash memory
- Built-in VL-Bus Enhanced IDE (AT bus) hard disk drive interface
- On-board mini-DIN PS/2 keyboard/mouse connector
- Two serial ports: one RS-232, one RS-232/422/485 or infrared selectable (uses 16C550 UARTs with 16 byte FIFO)
- Upgradeable through PC/104 module

- Green engine with sleep mode and low power consumption
- Single +5 V power supply

7.2.2.3 SPECIFICATIONS

- CPU: Embedded AMD 5x86-133 (DX5-133) processor.
- BIOS: AWARD 128 KB Flash memory.
- Chipset: VIA VT82C496G.
- System memory: One 72-pin SIMM sockets (accepts 1 MB, 2 MB, 4 MB, 8 MB, 16 MB and 32 MB). Supports FPM or EDO DRAM from 1 MB to 32 MB.
- Enhanced IDE hard disk drive interface: Supports up to two IDE (VL-bus) hard disks. BIOS auto-detect and PIO Mode 3 transfer protocol.
- Serial ports: One serial RS-232 port, one serial RS-232/422/485 port. Two 16550 serial UARTs.
- Parallel port: One parallel port, supports SPP/EPP/ECP mode.
- Infrared port: Shared with COM2. Transfer rate up to 115 kbps.
- Keyboard/mouse connector: Mini-DIN connector supports standard PC/AT keyboard and a PS/2 mouse.
- Power management: Supports power saving modes including Normal/ Doze/Sleep modes. APM 1.1 compliant.

7.2.2.4 LOCAL-BUS FLAT PANEL/VGA INTERFACE

- Chipset: C&T 65550
- Display memory: 1 MB DRAM
- Display type: Supports CRT and flat panel (EL, LCD and gas plasma flat panel) displays. Can display CRT and flat panel simultaneously.
- Flat panel display mode: Panel resolution supports up to 1024 x 768.
- CRT display mode: Non-interlaced CRT monitors resolutions up to 1280 x 1024 @ 16 colors.

7.2.2.5 AUDIO FUNCTION (PCM-4825)

- Chipset: ESS 1868.
- Audio controller: 16-bit Sound Blaster Pro compatible.
- Stereo sound: Full duplex, integrated 3D audio.
- Audio interface: Mic. in, Line in, CD audio in; Line out, Stereo Speaker out.

7.2.2.6 MECHANICAL AND ENVIRONMENTAL

- Dimension: 5.9" (L) x 4.2" (W) (145 mm x 102 mm)
- Power supply voltage: +5 V (4.75 V to 5.25 V)
- Max. power requirements: +5 V @ 2 A (typical)
- Operating temperature: 32° F to 140° F (0° C to 60° C)

- Weight: 0.65 kg (weight of total package)

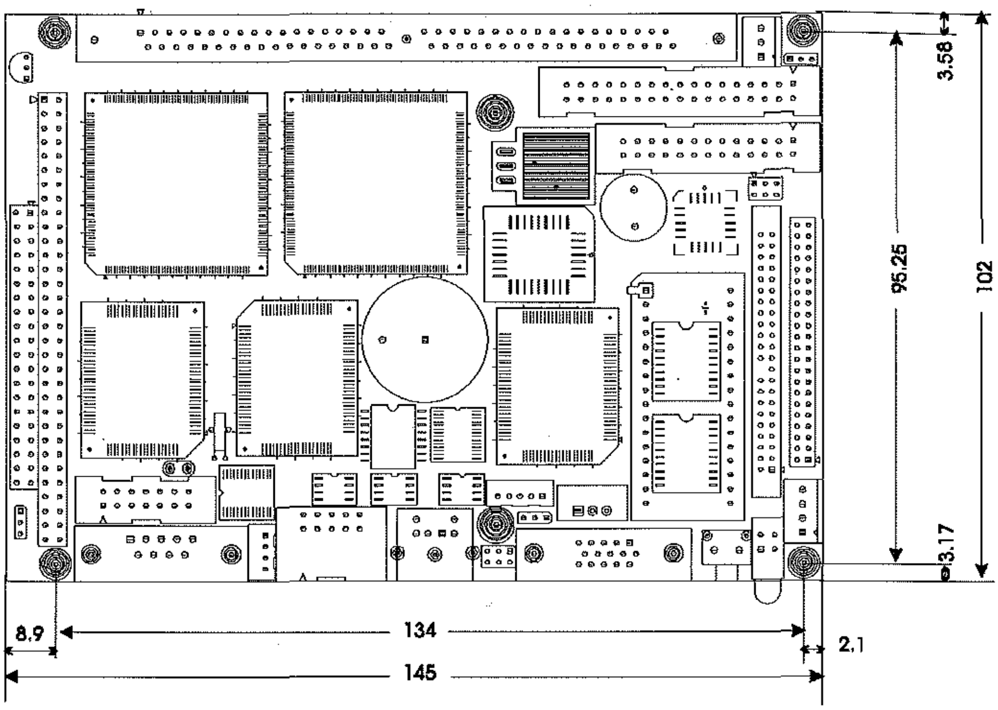


Figure 30: Dimensions of the Micro PC (M-Syetems Manual, 1999)

7.2.2.7 PARTS LIST

The Micro PC kit is made up of:

- 1 PCM-4825/4825L All-in-One Single Board Computer
- 1 utility disk with system BIOS, VGA BIOS utility programs
- 3 SVGA driver disks
- 1 audio driver disk (PCM-4825 only)
- 1 audio cable (PCM-4825 only)
- 1 3.5" IDE flat cable
- 1 keyboard/mouse cable
- 1 secondary serial port cable (RS-232/422/485)
- 1 parallel cable
- 1 floppy cable

Not all the additional items were required but to ensure the Micro PC's reusability for other students' projects, an effort was made to ensure the entire kit was complete on delivery.

7.2.3 DISKONCHIP

The DiskOnChip 2000 is a single chip FlashDisk designed to plug into a standard 32- pin EEPROM socket. The DiskOnChip 2000 should be mapped into an 8KByte window in the BIOS expansion address space of the PC, which is usually located between address 0C0000H to 0EFFFFH.

The DiskOnChip 2000 contains a built-in copy of the M-Systems industry-standard TrueFFS software, which makes the DiskOnChip operate as a standard disk drive. The DiskOnChip 2000 can contain the operating system in it to allow systems to boot without a hard disk. The DiskOnChip 2000 can also be configured as the boot device in systems with a hard disk.

The DiskOnChip is a self-contained device. The installation of the DiskOnChip does not require any software installation. The design of the DiskOnChip allows for full upward and downward compatibility. While available today in capacities of 2 to 72MBytes, future DiskOnChip devices with higher densities, will be fully compatible with standard DiskOnChip sockets.

The DiskOnChip is to be used within the Micro PC as the bootable hard disk. The initial size of this device will be 16 MB, but as the system is debugged and refined, it will become clear that memory of this size in not required. This As I have established previously, concerning the nature of the Micro PC purchase, cost is not the issue in this instance and having a larger memory store will alleviate the pressure of downsizing operating systems and application programs. Having 16 MB will safely allow me to install a standard Dos operating system, the application program, and still have enough memory to store up to 6 hours of flight time.

7.2.4 EMBEDDED GPS (OEM)

7.2.4.1 OVERVIEW OF GPS RECEIVERS THAT PRODUCE NMEA OUTPUT DATA

Table 36 gives an overview of low-cost GPS receivers which output the 'raw' GPS data, such as pseudorange, integrated carrier phase, Doppler shift, satellite ephemeris, and 'processed' data such as position and velocity. These receivers are usually OEM bare board receivers.

1	Manufacturer	Garmin	Conexant	CMC	Rojone	u-blox	Motorola	Furuno	Ashtech	Trimble
	Type	25-LVS	Jupiter	Allstar	Genius OEM	GPS-MS1	VPOncore	GN-74 (c)	G8	Lassen SK8
2#	Channels	12	12	12	12	12	8	8	8	8
3#	Pseudorange	Y	Y	Y	Y	Y	Y	?	?	Y
4#	carrier phase	Y	Y	Y	Y	Y	Y	?	N	Y
5#	Doppler	N	Y	Y	Y	Y	Y	?	?	Y
6#	iono	N	Y	?	Y	Y	?	?	?	Y
7#	Ephemeris	Y	Y	Y	Y	Y	Y	?	?	Y
8#	position	Y	Y	Y	Y	Y	Y	Y	Y	Y
9#	velocity	Y	Y	Y	Y	Y	Y	Y	Y	Y
10#	1 PPS	Y	Y	Y	Y	Y	Y	Y	Y	Y
11#	1 PPS acc (ns)	1000	1000	200	0.5 msec	180	130	1 msec ?	1000	500
12#	clock sync	1	1	1	3?	3	2 (b)	?	?	2
13#	clock sync acc	?	200	200	?	n.a.	1	?	?	0.5
14#	cold start	300	?	300	60	60	120	120	120	120
15#	hot start	15	15	30	8	4	20	20	15	20
16#	re-acquisition	2	2	3	0.1	0.1	2.5	3	1	2
17#	NMEA-183 out	Y	Y	Y	Y	Y	Y	Y	Y	Y
18#	DGPS in	RTCM	RTCM	RTCM	RTCM	RTCM	RTCM	RTCM	RTCM	RTCM
19#	DGPS out	N	N	RTCM	N	N	binary	N	N	N
20#	DGPS accuracy	5m RMS	1-5 m	1m CEP	1-5 m	2 m CEP	1-5m	3m	3m CEP	2m CEP
21	pseudor. noise	0.8 m	?	?	?	?	?	?	?	?
22	Pr. multip. opt.	2.3 m	2 m	?	?	?	?	?	?	?
23	Pr. multip. typ.	5 m	2 m	?	?	?	?	?	?	?
24	Carrier noise	4-8 mm	2-3 mm	1 cm	?	?	?	?	?	20 cm(a)
25	Cr. multip. opt.	?	?	?	?	?	?	?	?	?

26	Cr. multip. typ	?	?	?	?	?	?	?	?	?
27 #	max alt (km).	18	18	18	18	18	18	?	18	18
28 #	max speed (m/s)	515	500	500	515	515	515	?	515	515
29 #	max accel (g)	6	?	4	4	4	4	5	2	4
30 #	max jerk (m/s3)	60	?	2	20	20	5	?	?	20
31 #	Temp range (C)	-30/+85	-40/+85	-30/+70	0/+70	-40/+85	-30/+85	-30/+80	-30/+80	-10/+60
32 #	Data rate (s-1)	1	1	1 to 10	1	1	1	1	1	1
33 #	Power	3.6 to 6V/ 0.115A	5V/0.205A	5V/0.24A	5V/0.18A	3.3V/0.15A (e)	5V/0.22A	5V/0.13A	5V/0.15A	5V/0.175A
33 #	chipset	Garmin	Zodiac	GECPlessey	SiRF	SiRF	Oncore	?	Philips	Sierra

Table 37: Embedded GPS Comparison

All row numbers marked with a # contain data taken from manufacturers data sheets. When comparing the figures consider that the manufacturers may use complete different definitions for their data.

Noise and multipath measured values are 1 sigma values, unless other identified.

NOTES

1. Receiver type
2. Number of parallel channels
3. Pseudorange is the primary measurement of the receiver; it is the range between the satellite and the receiver, plus a number of errors.
4. Integrated carrier phase is another range measurement, again with a number of errors.
5. Doppler is the instantaneous frequency difference between the receiver's internal oscillator and the received carrier from the satellite.
6. The Iono parameters allow the receiver to calculate an estimate for the ionospheric delay, which can be applied as a correction to the measured pseudorange.
7. Ephemeris is the parameters to allow the receiver to calculate the satellite's position. The ephemeris data are a part of the 'navigation message'.
8. No comment. (self explanatory)
9. No comment. (self explanatory)
10. 1PPS is the ability of the receiver to output a discrete pulse on the full GPS second.

11. 1PPS accuracy is the possible deviation of the 1PPS pulse from the GPS time.
    1. 'Clock sync' is the receiver's ability to 'measure' the raw data exactly on the full GPS second.
    2. Type 1 receivers keep their internal clock continuously synced to the GPS time.
    3. Type 2 receivers reset their clock once it has drifted away a few milliseconds from GPS time.
    4. Type 3 receivers let their internal clock drift away from GPS time for ever (usually they reset their internal clock after power-up once the first valid position calculation is completed).
12. This number gives the possible deviation of the raw data measurement time from the full GPS second, for type 1 in nanoseconds, for type 2 in milliseconds, and for type 3 not applicable.
13. Cold start: the time the receiver requires from power up to the first position solution, while starting without initial position, time, almanac and ephemeris.
14. Hot start: the time the receiver requires from power up to the first position solution, starting with initial position, time, almanac and ephemeris.
15. Re-acquisition: the time the receiver requires to track again a satellite, which was lost shortly before.
16. No comment. (self explanatory)
17. The ability of the receiver to process differential corrections in the mentioned format.
18. The ability of the receiver to generate differential corrections (reference station) in the mentioned format.
19. The DGPS accuracy as specified by the manufacturer. Sometimes it is not clear how this number is defined by the manufacturer, e.g. 2D or 3D, CEP/SEP or RMS.
20. Pseudorange noise is determined largely by the quality of the receiver. It can be determined with a so-called Zero Base Line (ZBL) test: connect two identical receivers to one antenna via an antenna splitter. Subtracting a pseudorange as measured by receiver A from a pseudorange to the same satellite as measured by receiver B cancels all common errors, the noise contribution remains. For a more detailed description go to noise.
21. The quality of the antenna, the location of the antenna and the quality of the receiver determine multipath. Multipath may very well be the largest error for DGPS. Multipath can be determined with a Short Base Line (SBL) test: place two receivers, each with their own antenna, close to each other. Subtracting pseudoranges as above and correct for receiver noise (from the ZBL) gives an indication of the multipath error. Using a high quality antenna (e.g. with choke rings) in a flat area without obstructions should result in a minimal multipath error. For more details go to multipath.
22. A typical multipath error can be determined using a 'normal' antenna (as recommended by the manufacturer) in your 'normal' working area.

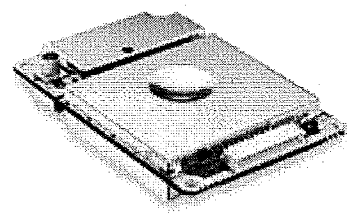
Minimal multipath error can be in the sub-meter range for a high quality receiver, typical multipath can be in the order of many meters, even tens of meters.

23. As in 20, but applied on the integrated carrier phases.
24. As in 21, see above.
25. As in 22, see above.
26. United States export restrictions limit most receivers to 60000 ft or 18000 m.
27. United States export restrictions limit most receivers to 999 kts or 515 m/s.
28. This is the acceleration at which the tracking loops of the receiver loose lock on the satellite, important for high-dynamic applications.
29. The rate-of-change of the acceleration at which the tracking loops loose lock.
30. The operating temperature range. Sometimes, extended ranges are available as an option.
31. The maximum rate (samples/second) at which the receiver can deliver data. If more than once per second, this is usually an option.
32. The typical power consumption.
33. This is the chipset that forms the heart of the receiver, and determines to a large extent its quality.
34. An estimate of the price for one receiver, based on information that I collected from various sources.

a. Firmware version 7.52 has been updated with a new TSIP message called 0x6F. This packet contains filtered pseudoranges, and integrated carrier phases. Unfortunately the carrier phases have been truncated to the integer value, which equals to one wavelength or 20 cm.
b. The Oncore's clock is offset by 20 kHz, which theoretically means that a clock reset is carried out every 89 sec.
c. Also available as PCMCIA card.
d. Price for the option with 1PPS and raw data US$ 290 (as per 12 Jan 98).
e. In the 'trickle power mode' the power drops down to 100 mA for 1 Hz rate, to 60 mA for 0.5 Hz rate and to 36 mA for 0.25 Hz rate.

Due to the availability and cost this section is dedicated to closely comparing the Garmin 25 LP and the Motorola Oncore GP

7.2.4.2 GARMIN 25 LP



The GARMIN GPS 25-LVS Series are GPS sensor boards designed for a broad spectrum of OEM (Original Equipment Manufacturer) system applications.

FIGURE 31: OEM GARMIN 25 (Garmin Manual, 1998)

The GPS 25-LVSs will simultaneously track up to twelve satellites providing fast time-to-first-fix, one second navigation updates and low power consumption. Their far-reaching capability meets the sensitivity requirements of land navigation as well as the dynamics requirements of high performance aircraft.

The GPS 25-LVS design utilises the latest surface mount technology as well as high-level circuit integration to achieve superior performance while minimizing space and power requirements. All critical components of the system including the RF/IF receiver hardware and the digital baseband are designed and manufactured by GARMIN to ensure the quality and capability of the GPS 25-LVS sensor board. This hardware capability combined with software intelligence makes the board set easy to integrate and use.

The GPS 25-LVS is designed to withstand rugged operating conditions, however it should be mounted in an enclosure as part of a larger system designed by an OEM or system integrator. A minimum system must provide the sensor board with conditioned input power and L1 GPS RF signal. The system may communicate with the board set via a choice of two CMOS/TTL or two RS-232 compatible bi-directional communications channels. A highly accurate one-pulse-per-second (PPS) output can be utilised in applications requiring precise timing measurements. An on-board memory rechargeable backup battery allows the sensor board to retain critical data such as satellite orbital parameters, last position, date and time. Non-volatile memory is also used to retain board configuration settings even if backup battery power fails. End user interfaces such as keyboards and displays are added by the application designer.

7.2.4.2.1 Features

The GPS 25-LVS sensor boards provide a host of features that make it easy to integrate and use.

1) Full navigation accuracy provided by Standard Positioning Service (SPS)

2) Compact design ideal for applications with minimal space

3) High performance receiver tracks up to 12 satellites while providing fast first fix and low power consumption

4) Differential capability utilizes real-time RTCM corrections producing less than 5 meter position accuracy

5) On-board clock and memory are sustained by a rechargeable memory backup battery that recharges during normal operation or by optional external standby power

6) User initialisation is not required.

7) Two communication channels and user selectable baud rates allow maximum interface capability and flexibility. The standard channels are CMOS/TTL levels for the -xVC version or RS-232 for the xVS versions.

8) Highly accurate one-pulse-per-second output for precise timing measurements. The default pulse width is 100 msec, however it is configurable in 20 msec increments from 20 msec to 980 msec.

9) Binary Format Phase Data Output on TXD2

10) Flexible input voltage levels of 3.6Vdc to 6.0Vdc with overvoltage protection in the -LVx, and 6.0Vdc to 40Vdc in the -HVx versions.

11) Fully shielded construction for maximum EMI and RFI protection

12) FLASH based program memory. New software revisions upgradeable through serial interface

7.2.4.2.2 Performance

Receiver:

Differential-ready 12 parallel channel receiver tracks and uses up to twelve satellites to compute and update a position.

Acquisition Times:

- 15 seconds warm (all data known)
- 45 seconds cold (initial position, time and almanac known, ephemeris unknown)
- 5 minutes AutoLocate (almanac known, initial position and time unknown)
- 5 minutes search the sky (no data known)

Update Rate: 1 second, continuous (programmable from 1 second to 15 minutes)

Accuracy:

- Position accuracy:
- Differential GPS (DGPS): 5 meters RMS
- Non-differential GPS: 15 meters RMS (100 meters with Selective Availability at maximum)

Velocity accuracy:

- 0.1 m/s RMS steady state (subject to Selective Availability)

Dynamics: 999 knots; 6g's

Interfaces: Dual-channel RS-232 compatible with user-selectable baud rate (1200, 2400, 4800, 9600) NMEA 0183 version 2.0 ASCII output (GPALM, GPGGA, GPGSA, GPGSV, GPRMC, GPVTG, PGRME, PGRMT, PGRMV, PGRMF, LCGLL, LCVTG)

Inputs:

- Initial position, date, and time (not required)
- Earth datum and differential mode configuration command, almanac
- PWR_DN power down power management under logic level control
- Real-time differential correction input (RTCM SC-104 format)

Outputs:

- Position, velocity, and time
- Receiver and satellite status
- Differential reference station ID and RTCM data age
- Geometry and error estimates
- Raw measurement output for both pseudorange and phase data
- PPS (pulse per second) output

7.2.4.2.3 Physical Specifications

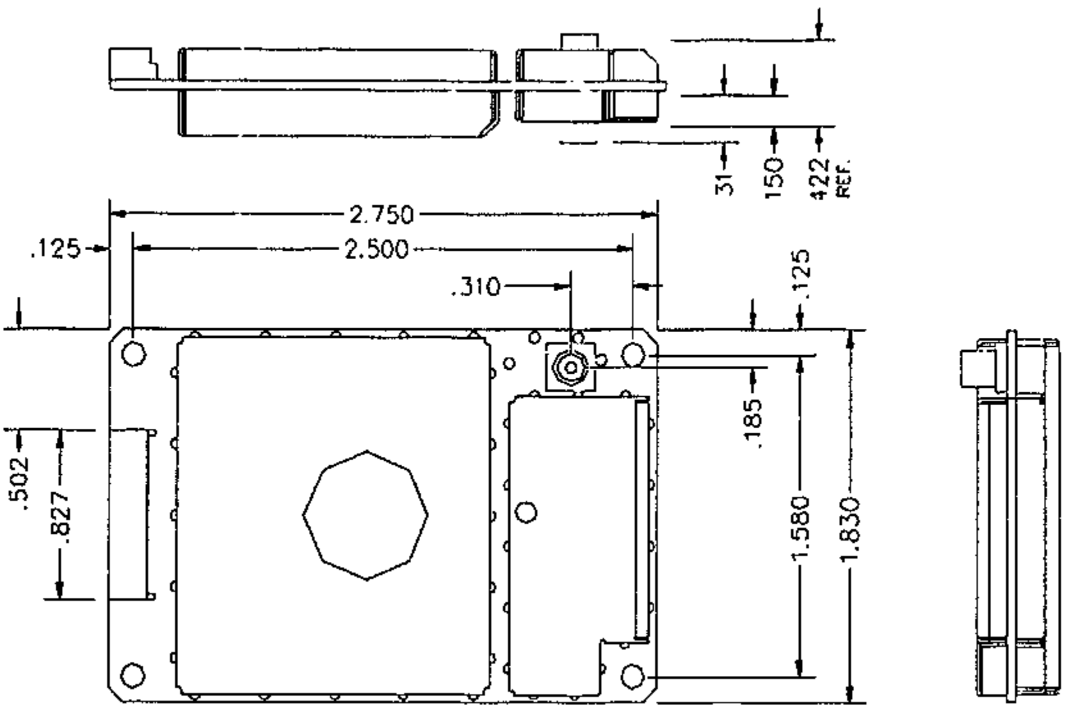


Figure 32: 25 LP Physical Dimensions (Garmin Manual, 1999)

Size: 1.83" (w) x 2.75" (l) x 0.45" (h) (46.5 mm x 69.9 mm x 11.4 mm)

Weight: 1.3 oz., (38 g), not including interface cable or remote antenna

Environmental:

- Operating temperature: -30°C to +85°C (internal temperature)
- Storage temperature: -40°C to +90°C

7.2.4.3 *ONCORE GT*

The Oncore receiver provides position, velocity, time, and satellite tracking status information via a serial port. The Oncore Receiver has an eight parallel channel design capable of tracking eight satellites simultaneously.

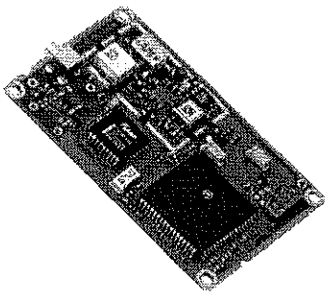


Figure 32: Oncore GT (Oncore Manual, 1999)

The module receives the L1 GPS signal (1575.42 MHz) from the antenna and operates off the course/acquisition (C/A) code tracking. The code tracking is carrier aided. The Oncore receiver must be powered with regulated 5 VDC power. Time recovery capability is inherent in the architecture.

The UT Oncore is designed specifically for precise timing applications.
The L1 band signals transmitted from GPS satellites are collected by a low-profile, microstrip patch antenna, passed through a narrow-band bandpass filter, and then amplified by a signal preamplifier contained within the antenna module.

Filtered and amplified L1 band signals from the antenna module are then routed to the RF signal processing section of the receiver module via a single coaxial interconnecting cable. This interconnecting cable also provides the +5V power required for signal preamplification in the antenna module.

The RF signal processing section of the Oncore receiver printed circuit board (PCB) contains the required circuitry for downconverting the GPS signals received from the antenna module. The resulting intermediate frequency (IF) signal is then passed to the eight channel code and carrier correlator section of the Oncore receiver PCB where a single, high-speed analog-to-digital (AD) converter converts the IF signal to a digital sequence prior to channel separation. This digitised IF signal is then routed to the digital signal processor (also contained within the eight channel code and carrier correlator section) where the signal is split into eight parallel channels for signal detection, code correlation, carrier tracking, and filtering.

The processed signals are synchronously routed to the position microprocessor (MPU) section. This section controls the GPS receiver operating modes and decodes and processes satellite data and the pseudorange and delta range measurements used to compute position, velocity, and time. In addition, the position processor section contains the inverted TTL serial interface. Below, is a simplified block diagram of the engine.

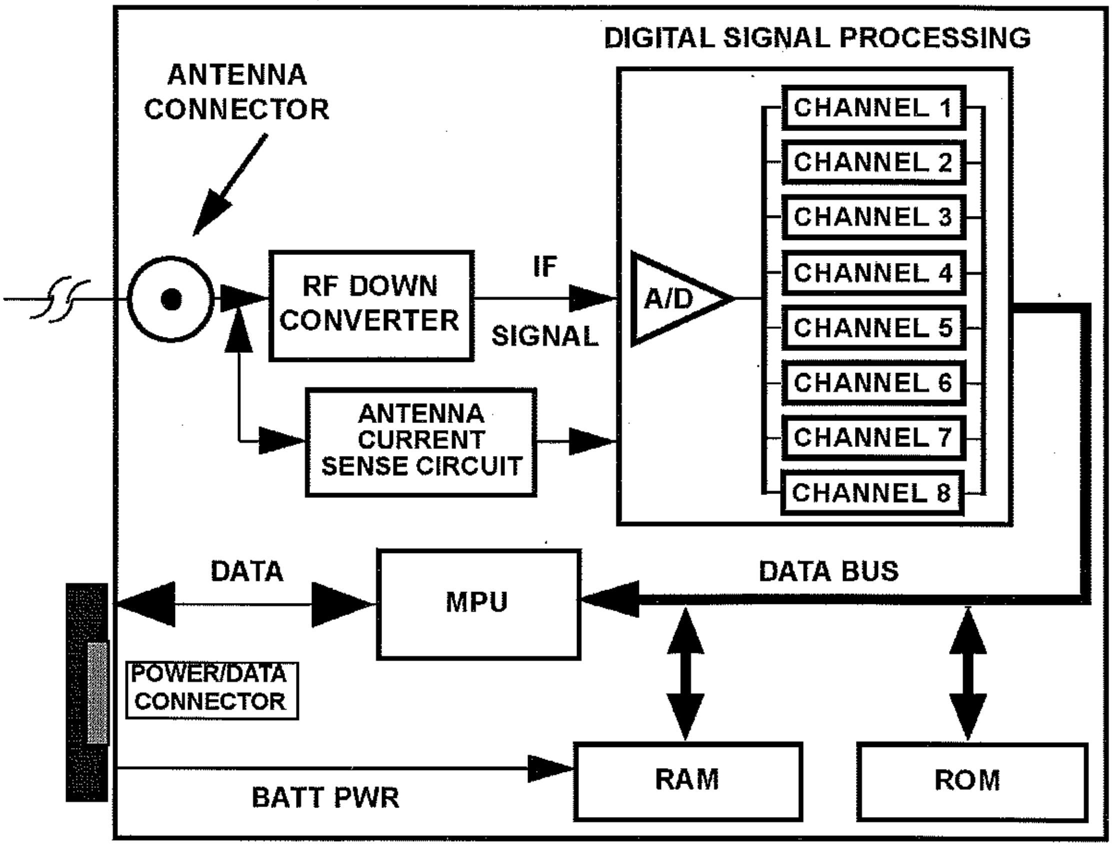


Figure 34: ***Oncore Functional Block Diagram]***
(Oncore Manual, 1999)

7.2.4.3.1 GENERAL CHARACTERISTICS

Receiver Architecture:

- 8 parallel channel
- L1 1575.42 MHz
- C/A code (1.023 MHz chip rate)
- Code plus carrier tracking (carrier aided tracking)

Tracking Capability:

- 8 simultaneous satellite vehicles

7.2.4.3.2 Performance Characteristics

Dynamics:

- Velocity: 1000 knots (515 m/s); > 1000 knots at altitudes < 60,000 ft.
- Acceleration: 4 g Jerk: 5 m/s 3
- Vibration: 7.7G per Military Standard 810E

Acquisition Time (Time to First Fix, TTFF):

- < 15 s typical TTFF-hot (with current almanac, position, time and ephemeris)
- < 45 s typical TTFF-warm (with current almanac, position and time)
- < 90 s typical TTFF-cold < 1.0 s internal reacquisition (typical) (Tested at -30 to +85°C)

Positioning Accuracy:

- 100 m 2dRMS with SA as per DOD specification Less than 25 m SEP without SA

Timing Accuracy (1 Pulse Per Second, 1 PPS):

- Time RAIM algorithm
- 130 ns observed (1 sigma) with SA on In position hold mode,
- < 50 ns observed (1 sigma) with SA on

Jamming Immunity:

- Immune to the following CW jamming signal levels measured at the input to the Oncore Active Antenna when the receiver is in position-hold mode. Values are typical.
- -50 dBm @ 1570 MHz
- -79 dBm @ 1575.42 MHz
- -56 dBm @ 1580 MHz

ANTENNA:

- Active micro strip patch antenna module
- Powered by receiver module (5-80 mA @ 5 Vdc)

Datum: WGS-84

7.2.4.3.3 . Physical Characteristics

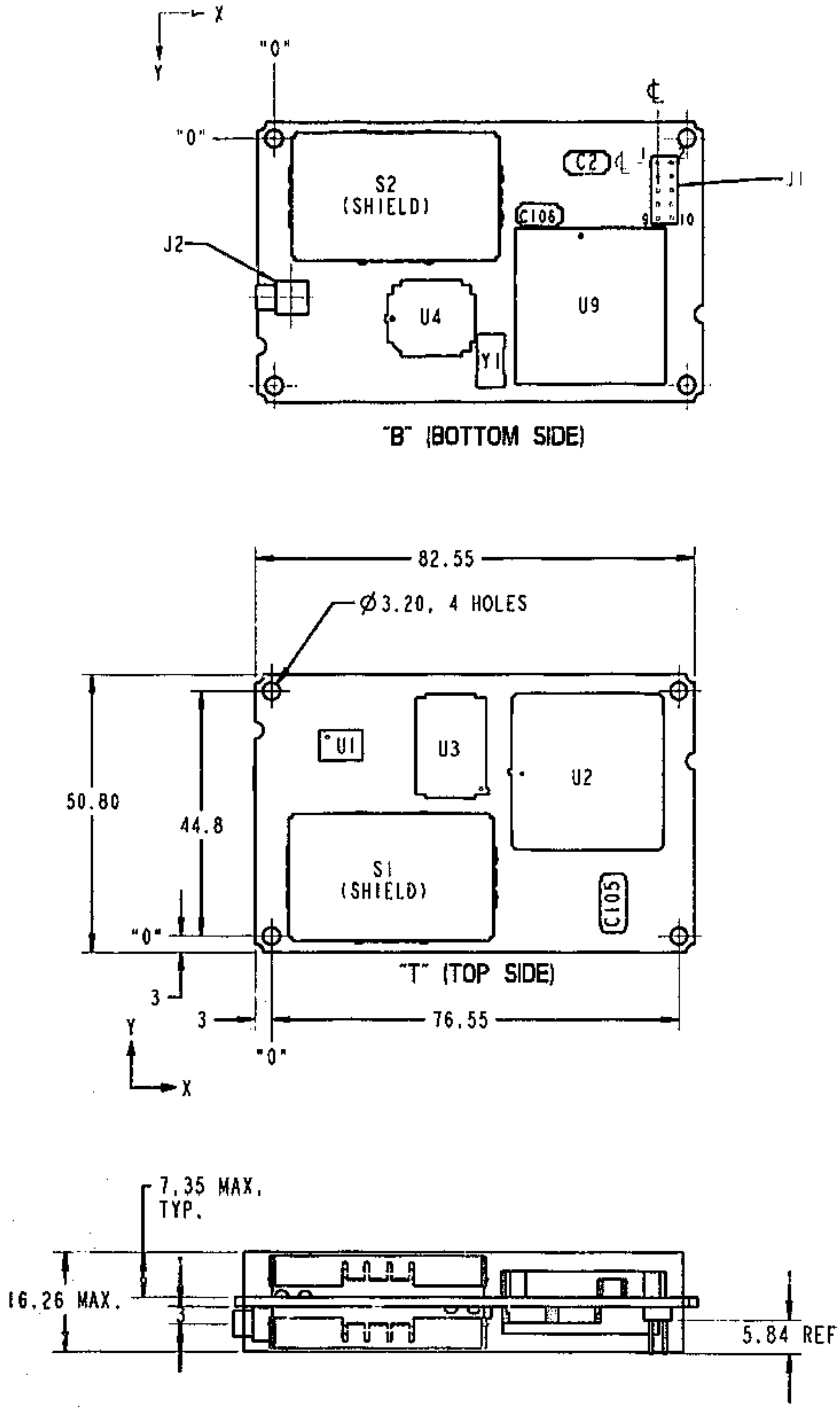


Figure 34: Oncore Dimensions
(Oncore Manual, 1999)

7.2.4.3.4 Electrical Connections

The Oncore receives electrical power and receives/transmits I/O signals through a 10-pin power/data connector mounted on the Oncore. Table 37 lists the assigned signal connections of the Oncore receiver's power/data connector.

Pin #	Signal Name	Description
1	BATTERY	Externally applied backup power (≤ + 5 Vdc)
2	+5V PWR	+5 Vdc regulated main power
3	GROUND	Ground (receiver)
4	VPP	Flash memory programming voltage
5	RTCM IN	RTCM input
6	1PPS	One pulse per second signal
7	1PPS RTN	One pulse per second return
8	TTL TXD	Transmit 5V logic
9	TTL RXD	Receive 5V logic
10	TTL RTN	Transmit/receive return

Table 38: Oncore Receiver's Power/Data Connector

7.2.4.3.5 SERIAL COMMUNICATION

Output Messages:

- Latitude, longitude, height, velocity, heading, time (Motorola binary protocol)
- Software selectable output rate (continuous or poll)
- TTL interface (0 to 5 V)

7.2.4.3.6 ELECTRICAL CHARACTERISTICS

Power Requirements: 5 ± 0.25 Vdc; 50 mVp-p ripple (max.)

7.3 PROJECT APPLICATION

The method for testing the embedded system is very similar to the previously stated in phase one. Differences lie in areas of construction, power and how the hardware is housed.

The new system needs to be constructed as most of the components are in module form to facilitate diverse applications. In the previous phase the system required power for the laptop and internal battery power was used for the GPS. Phase two system also requires two distinct power sources although the levels differ from the one's used in phase one. As the system is in kit and module form, and to enable safe operation and rejection from external interference, the project hardware is required to be enclosed or encased in a shielded container.

7.3.1 MATERIALS

There are two distinct parts to the construction of phase two. There is the embedded Micro PC and there is the GPS engine. These two parts have there associated ancillary devices and connectors:

7.3.1.1 MICRO PC

- 1 PCM-4825L All-in-One Single Board Computer
- 1 utility disk with system BIOS, VGA BIOS utility programs
- 3 SVGA driver disks
- 1 3.5" IDE flat cable
- 1 keyboard/mouse cable
- 1 secondary serial port cable (RS-232/422/485)
- 1 parallel cable
- 1 floppy cable

Figure 35 illustrates the position of the main connectors:

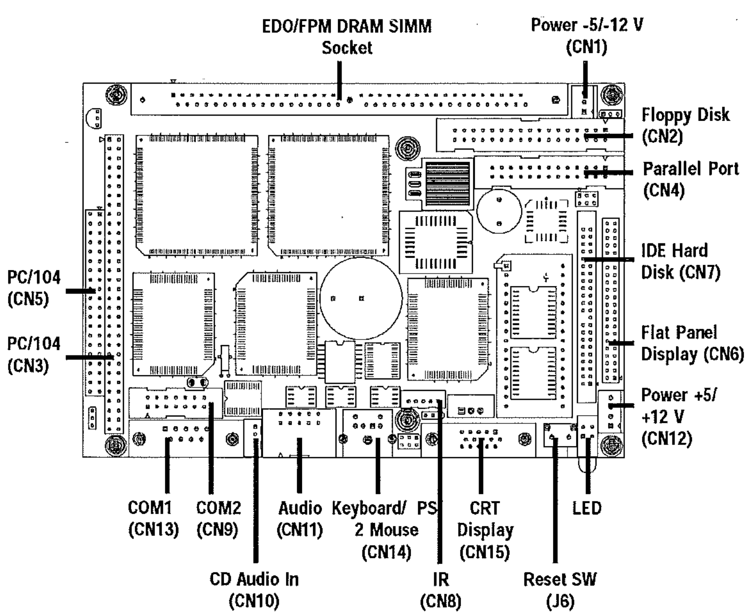


Figure 35: Micro PC Main Connectors (M-Syetems Manual, 1999)

Figure 36 illustrates the jumpers located on the Micro PC:

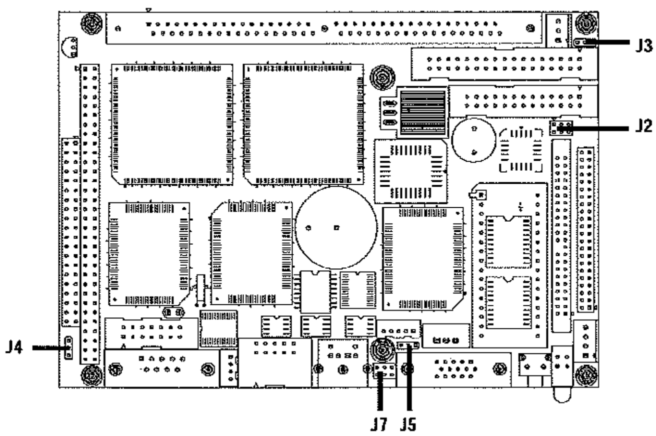


Figure 36: Micro PC Jumpers
(M-Syetems Manual, 1999)

Connectors on the board link it to external devices such as hard disk drives, a keyboard or expansion bus connectors. In addition, the board has a number of jumpers that allow you to configure your system to suit your application. Table 38 lists the function of each of the board jumpers and connectors:

7.3.1.1.1 PCM-4825L jumpers

Label	Function
J2	DOC 2000 address setting
J3	LCD power selector
J4	Clear CMOS
J5	Audio AMP power selector
J7	COM2 selector

Table 39: Project Jumpers of Concern

7.3.1.1.2 PCM-4825L connectors

Label	Function
CN1	Power connector (-5 V, -12 V)
CN2	Floppy disk connector
CN3	PC/104 connector
CN4	Parallel port connector
CN5	PC/104 connector
CN6	Flat panel connector
CN7	Hard disk connector
CN8	IR connector (infrared)
CN9	COM2 connector

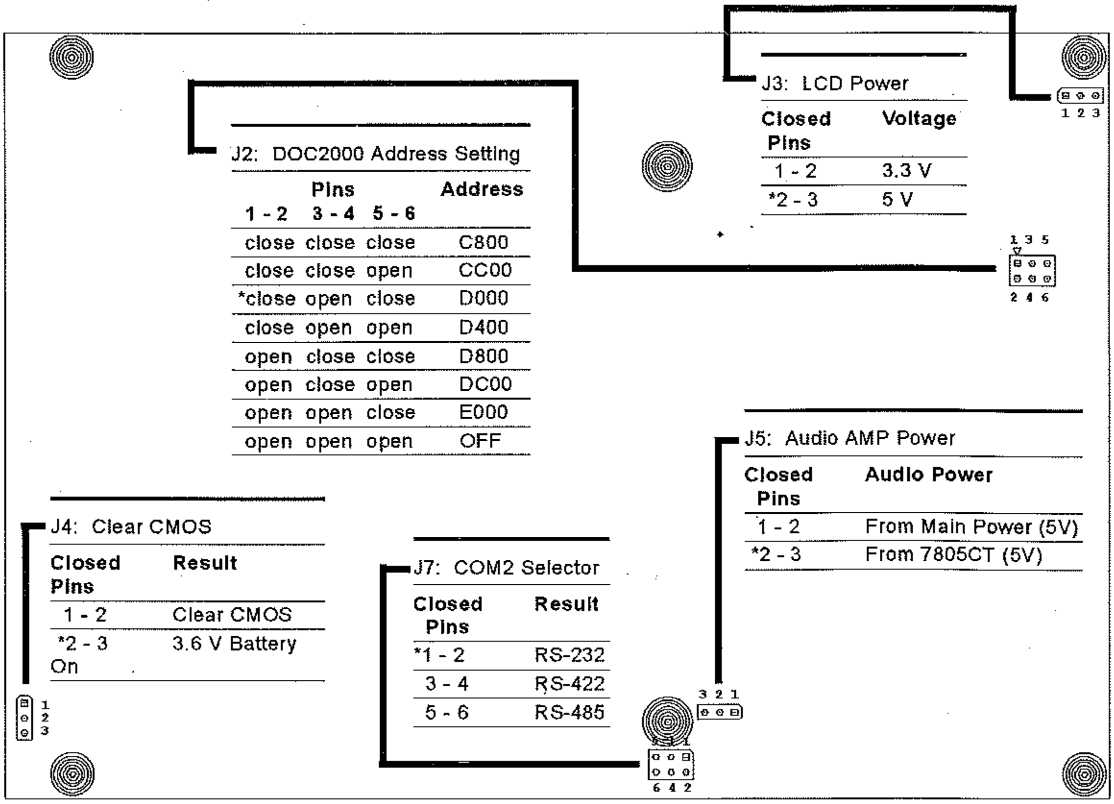
CN10	CD audio in connector
CN11	Audio connector
CN12	Power connector (+5 V, +12 V)
CN13	COM1 connector
CN14	PS/2 keyboard + PS/2 mouse
CN15	CRT display connector J6 Reset switch

Table 40: Micro PC Connectors

The connectors most interesting to the project were:

- COM 1 (CN 13)
- CRT Display (CN 15)
- Keyboard (CN 14)
- Floppy Disk (CN 2)
- Power 5 and 12 volts (CN 1)

The Micro PC was configured to match the needs of the application by setting jumpers. A jumper is the simplest kind of electrical switch. It consists of two metal pins and a small metal clip (often protected by a plastic cover) that slides over the pins to connect them. To "close" a jumper, connect the pins with the clip. To "open" a jumper you remove the clip. Sometimes a jumper will have three pins, labeled 1, 2, and 3. In this case connect either pins 1 and 2 or 2 and 3.



J2: DOC2000 Address Setting

Pins 1 - 2	3 - 4	5 - 6	Address
close	close	close	C800
close	close	open	CC00
*close	open	close	D000
close	open	open	D400
open	close	close	D800
open	close	open	DC00
open	open	close	E000
open	open	open	OFF

J3: LCD Power

Closed Pins	Voltage
1 - 2	3.3 V
*2 - 3	5 V

J4: Clear CMOS

Closed Pins	Result
1 - 2	Clear CMOS
*2 - 3 On	3.6 V Battery

J7: COM2 Selector

Closed Pins	Result
*1 - 2	RS-232
3 - 4	RS-422
5 - 6	RS-485

J5: Audio AMP Power

Closed Pins	Audio Power
1 - 2	From Main Power (5V)
*2 - 3	From 7805CT (5V)

Table 40: Default Jumpers For The Project (M-Syetems Manual, 1999)

The * refers to the default settings. These settings will remain unchanged for use with the system. As the system diversifies and more functions are required from the Micro PC, there may be a need to assess the jumper positions further. In that instance jumper settings are schematically depicted in most manuals as seen in figure 37.

Figure 37: Jumper Setting

A pair of needle-nose pliers may be helpful when working with jumpers.

7.3.1.2 GARMIN GPS 25-LVS

- 1 Garmin GPS 25-LVS
- 1 Garmin GPS-25 Data Interface Cable
- 1 Garmin GA 27A Active Antenna

7.3.1.2.1 Pin Out Information

The following is a functional description of each pin of the interface connector. The pins are numbered from left to right as viewed from the connector end of the board with the connector on top.

Pin 1: TXD2 - Second Serial Asynchronous Output. Electrically identical to TXD1. This output provides phase data (Ver 2.03).

Pin 2: RXD2 - Second Serial Asynchronous Input. Electrically identical to RXD1. This input may be used to receive serial differential GPS data formatted per *"RTCM Recommended Standards For Differential Navstar GPS Service, Version 2.1"*.

Pin 3: PPS - One-Pulse-Per-Second Output. Typical voltage rise and fall times are 300 nSec. Impedance is 250 ohms. Open circuit output voltage is 0V and Vin. The default format is a 100 millisecond high pulse at a 1Hz rate, the pulse width is programmable from a configuration command in 20msec increments. Rising edge is synchronized to the start of each GPS second. This output will provide a nominal 700 mVp-p signal into a 50 Ohm load. The pulse time measured at the 50% voltage point will be about 50 nSec earlier with a 50 Ohm load than with no load.

Pin 4: TXD1 - First Serial Asynchronous Output. CMOS/TTL output levels vary between 0V and Vin in the -LVC version. In the -LVS and -HVS versions a RS-232 compatible output driver is available. This output normally provides serial data which is formatted per *"NMEA 0183, Version 2.0"*. Switchable to 300, 600, 1200, 2400, 4800, 9600 or 19200 BAUD. The default BAUD is 4800. This output data functions in parallel with pin 12.

Pin 5: RXD1 - First Serial Asynchronous Input. RS-232 compatible with maximum input voltage range $-25 < V < 25$. This input may be directly connected to standard 3 to 5Vdc CMOS logic. The minimum low signal voltage requirement is 0.8V, and the maximum high signal voltage requirement is 2.4V. Maximum load impedance is 4.7K ohms. This input may be used to receive serial initialization/configuration data.

Pin 6: POWER DOWN - External Power Down Input. Inactive if not connected or less than 0.5V. Active if greater than 2.7V. Typical switch point is 2.0V at 0.34 mA. Input impedance is 15K Ohms. Activation of this input powers the internal regulators off and drops the supply current below 20mA in the -LVx version and below 1mA in the -HVx version. The computer will be reset when power is restored.

Pin 7: VAUX - Auxiliary External Backup Battery Charge circuit. If used, a 4VDC to 35VDC @ 4mA power source is required to supply a trickle charge to the battery. During normal operation a trickle charge is supplied to the battery from an internal regulator. On-board rechargeable battery capacity is 7 mA hour.

Pin 8: GND - Power and Signal Ground

Pin 9: Vin - Connected to Pin 10 (VER 11 and above).

Pin 10: Vin - Regulated +3.6V to +6V, 200 mA (maximum) in the -LVx versions. Typical operating current is 120 mA plus antenna power. An internal 6.8V transient zener diode and a positive temperature coefficient thermistor protect transients and overvoltages. With voltages greater than 6.8Vdc the thermistor will power the unit off until proper supply voltages are returned. Antenna supply is derived from Vin after passing through a 50mA current limiter. The CMOS/TTL output buffers are powered by Vin, therefore a 3.6Vdc supply will create 3.6V logic output levels.

In the -HVS version, Vin can be an unregulated 6.0Vdc to 40Vdc. This voltage drives a switching regulator with a nominal 4.4Vdc output, which powers the antenna connector current limiter, the internal linear regulators, and the CMOS output buffers.

Pin 11: NC - This pin is floating on GPS 25-LVS but reserved for future.

Pin 12: NMEA - NMEA 0183, Version 1.5 electrical specification compatible serial output. This output is CMOS compatible with a no load voltage swing of 0.2Vdc to 0.9xVCC. This output normally provides ASCII sentences formatted per "NMEA 0183, Version 2.0". User selectable baud rates of 300, 600, 1200, 2400, 4800, 9600 and 19200 are available, with 4800 as the default. The data output on this pin is identical to the data output on pin 4.

Signal	Pin	Description
TXD2	1	Serial Data Output 2
RXD2	2	Serial Data Input 2
PPS	3	Pulse/Second Output
TXD1	4	Serial Data Output 1
RXD1	5	Serial Data Input 1
PWR_DN	6	Power Down Control
VAUX	7	Auxiliary Backup Battery Recharge Input
GND	8	Signal and Power Ground
VIN	9	Input 3.6V to 6.0V
VIN	10	Connected to Pin 9
NC	11	**RESERVED**
NMEA	12	NMEA Output

Figure 39: 25 LP Pin Out

7.3.1.2.2 Garmin GPS 25-LVS Data Interface Cable

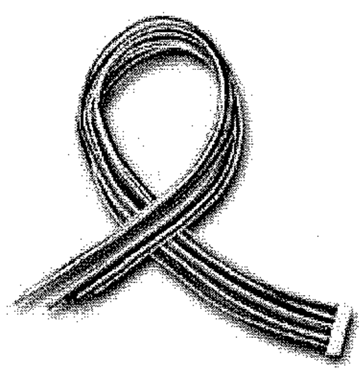
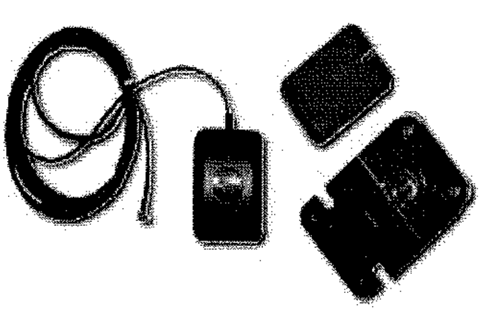


Figure 40: Data Interface Cable

7.3.1.2.3 Garmin GA 27A Active Antenna



Supplied with mounting brackets
Cable included. This piece of equipment has been previously described and validated in the introduction of this chapter.

Figure 41: Garmin Antenna

7.3.2 EMBEDDING THE GPS

The Garmin GPS 25-LVS receiver is an intelligent GPS sensor intended to be used as a component in a precision positioning, navigation or timing system. The Garmin receiver is capable of providing autonomous position, velocity, and time information over a serial COM port. The minimum usable system combines the Garmin receiver, antenna, and an intelligent system controller device.

To adequately cater for all the functions of the project the GPS needs to interconnect with a host computer to monitor this positional information. The following is a method where the sensor board will be connected to a personal computer, or Micro PC, via a standard RS-232 interface.

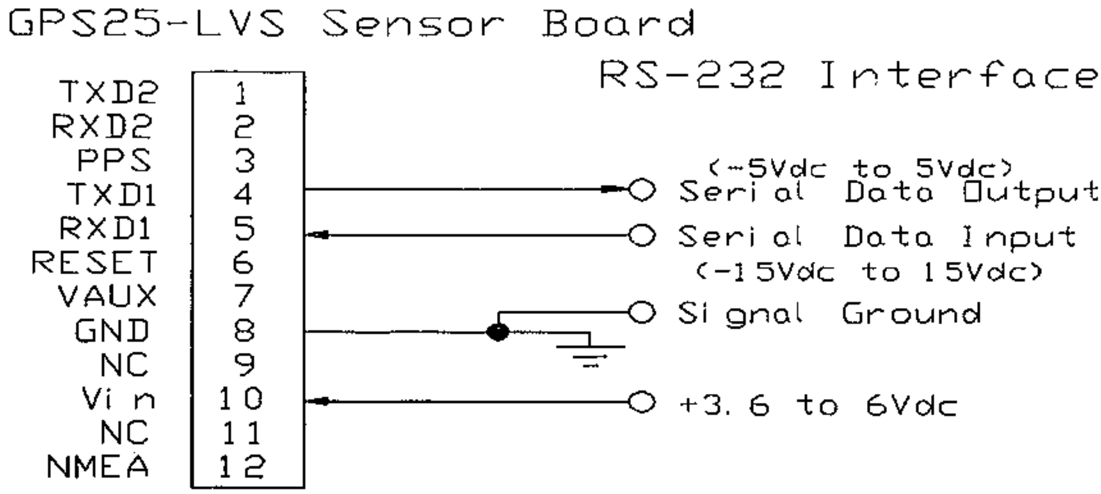


Figure 42: Embedding Process

7.3.2.1 COLOUR CORRESPONDENCE TO INTERFACE CABLE

Process	*Pin Number*	*Colour*
TXD1	pin 4	White
RXD1	pin 5	Blue
GND	pin 8	Black
Vin	pin 10	Red

Table 42: Cable Colour Code

7.3.3 ANTENNA INSTALLATION

The GPS 25-LVS sensor boards make their antenna connections via a 50 ohm MCX style connector attached directly to the sensor board (+Vin-0.4V @ 15 mA power is supplied on the center conductor for the antenna).
Coaxial cable supplies +Vin-0.4V @15 mA to antenna/preamp. 1.57542 GHz signal returns to the sensor board.

Figure 42: Antenna Described

The recommended GARMIN remote antenna for the GPS 25-LVS series is the GA27. It has eight feet of RG-174A/U type cable with a MCX connector installed for attachment to the sensor board. An extension cable with up to -5dB additional attenuation at 1.5 GHz may be used with the GA27 (either 50 Ohm or 75 Ohm impedance cable is permitted).

A passive antenna may be used with the GPS 25-LVS series sensor boards, provided no more than -2dB or -3dB cable loss is inserted between the antenna and the sensor.

Higher gain antennas may be used provided there is adequate cable attenuation to prevent overloading the sensitive GPS 25-LVS receiver. 15dB excessive antenna system gain (LNA Gain - Cable Loss) should be considered a maximum. Check to insure that the antenna in question will operate properly with the antenna bias voltage that is supplied by the GPS 25-LVS, when powered by the desired Vin voltage. The GPS 25-LVS will current limit for loads above 50mA to prevent damage, should the antenna cable become accidentally shorted.

7.3.4 Receiver and Processor Module Installation

As with any piece of electronic equipment, proper installation is essential before you can use the equipment. When mounting the Garmin receiver board and the Micro PC into the housing system, special precautions need to be considered.

7.3.5 Installation Precautions and Considerations

The following considerations are what was adhered to when constructing the electronic modules of the project.

7.3.5.1 ELECTROSTATIC PRECAUTIONS

The Garmin Receiver and Micro PC printed circuit boards (PCBs) contain parts and assemblies sensitive to damage by electrostatic discharge (ESD). By using ESD precautionary procedures when handling the PCB, grounding wrist bands and anti-static bags, the hardware was safely protected against ESD damage.

7.3.5.2 ELECTROMAGNETIC CONSIDERATIONS

The Garmin Receiver PCB contained a very sensitive RF receiver; certain precautions had to be preserved to prevent possible interference from the host system. Because the electromagnetic environment may vary for each later OEM application, it is not possible to define exact guidelines to assure electromagnetic compatibility. The frequency of GPS is 1.575 GHz. Frequencies or harmonics close to the GPS frequency may interfere with the operation of the receiver, desensitising the performance. Symptoms include lower signal to noise values, longer TTFFs (Time To First Fix) and the inability to acquire and track signals.

7.3.5.3 RF SHIELDING

The RF circuitry sections on the Garmin GPS receiver board are protected with a tin plate shield to guard against potential interference from external sources. When a design calls for the GPS to be near or around RF sources such as aircraft radios in the cockpit, it was required that the GPS be tested and tried in the target environment to identify potential interference issues prior to final design.

As the proximity of the Two Way radio was in the immediate vicinity of the GPS I felt that the Garmin receiver PCB may require an additional enclosure in a metal shield to eliminate electromagnetic compatibility (EMC) problems.

7.3.5.4 REAL-TIME CLOCK (RTC)

When powered up, the RTC in the Garmin receiver will have an incorrect time unless it was previously set and maintained by external backup power. To ensure a faster TTFF, the time, date, and GMT offset should be input if both the main power and battery backup power have been disconnected.

7.3.5.5 THERMAL CONSIDERATIONS

The receiver and Micro PC operating temperature range is -40¡C to +85¡C, and the storage temperature range is -40¡C to +105¡C. The antenna operating range is -40°C to +100°C. Before installation, I had the chance to perform a thermal analysis of the housing environment to ensure that temperatures did not exceed +85¡C when operating (+105¡C stored). This was particularly important as:

- Air circulation in the aircraft cockpit was relatively poor
- There was more than one electronic module installed in the one enclosure.
- The Garmin receiver PCB and the Micro PC had to be enclosed within a shielded container due to electromagnetic interference (EMI) requirements.

7.3.5.6 GROUNDING CONSIDERATIONS

The Garmin receiver had a different grounding scheme than what was needed for the Micro PC. The RF shields on both sides of the module are connected to ground at multiple points. The ground plane of the receiver is connected to the four mounting holes. The Micro PC had one grounding point and it was determined that this point could be split to match the Garmin receivers' scheme. I felt this would enhance the (ESD) and (EMI) rejection.

For best performance, it was recommended in the manual that mounting standoffs in the application be grounded. The GPS receiver and the Micro PC will still function properly if it is not grounded via the mounting holes, but the shields may be less effective.

7.3.6 SYSTEM POWER

There were two discrete electronic components that required distinct power sources. The Micro PC required a 12 and 5 volt input while the GPS required a 6 volt input.

7.3.6.1 MICRO PC

In the initial test phase it was found that a power supply from a desktop PC would be adequate in powering the Micro PC. By borrowing a floppy drive power connector, the Micro PC and all of its drives could be powered.

Pin	*Signal*
1	+12 V
2	GND
3	GND
4	+5 V

Table 43: Main Power Connector of the Micro PC

Once the system was satisfactorily debugged the implemented voltage regulator had to be manufactured. This voltage regulator stepped down 24 volts to 5v and 12v. This regulator was a simple design produced by Altronics in Nothbridge WA.

7.3.6.2 GPS RECEIVER

During the test phase it was necessary to apply a dry cell or mains adapter to the input power pin of the Garmin GPS 25-LVS (LVS Low Voltage Source). This input would accept the voltage range 3.6 – 6.0 v dc.

Input voltage:	+3.6VDC to 6.0VDC regulated, 150 mVp-p ripple -LVx versions. +6.0VDC to 40VDC unregulated -HVx version.
Input current:	120 mA typical 140 mA max -LVx versions, 20 mA while in power down. 870mW typical 1000mW max -HVx version, 300uA while in power down.
Backup power:	3V Rechargeable Lithium cell battery, up to 6 month charge

Auxiliary battery recharge voltage: 4Vdc to 35Vdc at 4mA typical.

Receiver sensitivity: -165dBW minimum

The necessary power for project implementation was the 3.6 – 6.0 volts. I found the stepped down 5v obtained from the voltage regulator was sufficient to drive both the GPS engine and the active antenna.

8. CONCLUSION

The aim of this project was to devise and construct a practical data logging system that could depict landings, "Touch and Go's" and record total flight time of light aircraft. This objective has been achieved, within the methods and analysis presented in Sections 6 and 7 respectively.

One of the most important phases of this project was to develop a robust foundation on which to begin constructing suitable solutions to the data logging problem. Being aware of current positional and processing instruments available, learning how to apply them, and whilst monitoring their performance, is an obvious but often overlooked prerequisite.

Considerable extra time was required to conduct literature searches, to thoroughly explain concepts that were new to me. At times it seemed some concepts were also new to a greater majority of the communications industry as I endeavored to completely understand some of the projects discrete components. As I feel it is difficult to give 100 percent to a task of which I know less than that, I substantiate this extra time by considerable theoretical descriptions laid out within this document.

Further comparisons were required to narrow down much equipment that would adequately fulfill the necessary tasks. This involved rigorous testing and evaluation of external antennae, personal and OEM GPS products, and advanced miniature PC technology. This analysis, illustrated in Sections 6 and 7, builds a platform from which further expansion can be embarked upon.

I hope, in future projects, the data logging system can be reduced in size and cost. In my research I found that there was cheaper alternatives to achieve the end results without substituting any of the systems aims. My only concern was that with limited time and resources, as with the university undergraduate project, my drive was bias towards producing a system which worked. By limiting my equipment to a bare minimum I would be reducing my chances of successfully debugging and developing an operable system. Although the project was structured giving the developer every chance of success it wasn't built on serene waters.

During my study I researched, developed and implemented two independent data logging systems for which I am very happy to say worked well. The major disrupters to the progression of the project were the inability to acquire the project components quickly and the incompatibility between some hardware with software.

Once I had determined the materials required to make the project a full success, orders had to be placed with the suppliers. Some equipment was sourced from places as far as the USA. This in itself was not a problem but in the case of undergraduate project Vs equipment procurement within the university system, my fervor and the anticipation for a successful outcome had been reduced significantly. In the end perseverance and some unauthadox persuasions enabled a delay of only 6 weeks unfortunately still blowing out the project float. If a recommendation could be made at this point I would say to all 4th year students who can foresee a requirement for equipment not available within the immediate university system to make tentative inquiries well in advance of this requirement.

In building an embedded system from scratch there are certain important issues that must be addressed as to limit any chance of the system suffering from hardware and software incompatibilities. On electing the Micro PC to perform the processing requirements of the project, one of the initial considerations was whether the board would run a linux operating system. If so how would the addressing suffer using a flash chip. Unfortunately the literature available was limited and did not indicate that the DiskOnChip memory system used in the Micro PC, had limited patches for linux implementation. Consequently the software written for a 3.xx version of Linux to log the flight data could not be accommodated within the DiskOnChip's 2.xx capabilities. This meant the embedded logging system had to employ the DOS based logging program for which the DiskOnChip could manage. Future projects within light aircraft logging systems may develop linux patches to enable the use of a Linux operating system and the greater developed logging program to take advantage of 32 bit processing full memory access.

In conclusion, the research, methods and analysis' presented provide accurate information with respect to GPS, ways of accessing GPS positional information, relevant comparisons of positional and processing technology which aid various facets of system design and construction of an implemented light aircraft data logging system.

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10. APPENDIX

10.1 ANNEX A

C VERSION

This program was produced with the assistance of David Lucus and all coding in this section is attributed to his contribution

```
# Uncomment the following line for Solaris
# C_LINK = -lsocket -lnsl

# Uncomment this for SCO. (Note, this has only been reported to work with
# Revision 3.2.4 with the "SCO TCP/IP Development System" package
installed.
# C_LINK = -lsocket

# Comment the following line if you are not using the gnu c compiler
# C_ARGS = -Wall

# You might have to change this if your c compiler is not cc
CC = cc

# You shouldn't need to make any more changes below this line.

all: nmea

clean:
rm -f *.o
rm -f *~
rm -f *.log
rm -f *.raw
touch nmea.log
touch nmea.raw

distclean: clean
rm -f nmea

nmea: nmea.c
$(CC) $(C_ARGS) $(C_LINK) -o nmea nmea.c
```

This is the NMEA Daemon v0.1

The current socket only connection interface is in nmead.c This only pretends to do something useful.

The file serial.c contains the serial setup and logging routines. These should be integrated into the nmead.c file, just before it starts to listen on the allocated port. Geoffrey Bennett (I think that is right) who wrote the PERL Daemon seemed to be using port 9000 as the nmea port.

This should now start to do both the logging and the tcp port handling. The parsing functionality is now in the signal handler (my original test file nmea_parse.c is included).

The logging to a file has not been implemented, but this is a trivial task and should be easy to insert.

The commands that can be passed to the Daemon via port 9000 (or whatever) do nothing at this point in time. This will need to be implemented in some manner.

(18/8/99)

It would seem that the way I wrote the Signal handler was a touch overdone. As the device driver setting were such that the input processing was Canonical, there did not appear to be a need for all that buffer management. The read() function would only return the data when a complete line was available. Given that the file control was also set to be asynchronous, this meant that the read function would return immediately, only to send the SIGIO signal, once data was available.

To try and clarify, only when there is a SIGIO signal does the signal handler read from the serial port (dev/ttyS?). It reads one line, as the device driver has been nice and only returned when the complete line is available. This one line is processed and the Signal Handler completes, only to be called again once there is a new line to be processed.

This has meant the code required for the signal handler is much simpler than my original attempts, and actually works in conjunction with the tcp handler.

I have also included some logging (just the raw nmead data) functionality.

Still to be done are the command sets for the tcp handler. I have included two new instuctions, "autoupdate" and "noautoupdate". The function of these should be plainly obvious. None of the instructions have any functionality as yet.

Also need to handle a way of stopping the daemon and its loggin gracefully. I am not satisfied with just killing the process.

(19/8/99)

```
/* nmead 0.1
Daemon to listen to nmea device.


Usage: nmead [-b <baud>] [-d <device>] [-l <logfilename>] [-p port] [-t]
-b: set serial baud rate 4800/9600
-d: select device/named pipe to listen from (default /dev/ttyS0)
-l: file to log NMEA data to (default nmead.log)
-p: TCP port to take connections on (default 9000)
-t: test mode - equivalent to '-d testpipe -l /dev/null'(not yet implemented)

Thanks to Peter H. Baumann, <Peter.Baumann@dlr.de>
and Geoffrey D. Bennett <geoffrey@netcraft.com.au>
*/

#include <termios.h>
#include <stdio.h>
#include <unistd.h>
#include <fcntl.h>
#include <signal.h>
#include <string.h>
#include <ctype.h>
#include <sys/signal.h>
#include <sys/types.h>
#include <sys/wait.h>

#define DEFAULT_BAUDRATE B4800
#define DEFAULT_DEVICE "/dev/ttyS0"
#define DEFAULT_LOGFILE "nmea.log"
#define FALSE 0
#define TRUE 1
#define VERSION "0.1"

void signal_handler_IO (int status); /* definition of signal handler */
int fd; /* File handler for the ttyS? */
int fl; /* File handler for the log file */
int fr; /* File handler for the raw nmea data file */

char device[64], *proto, logfile[64], portstr[16];
int baudrate;

int datacomplete = FALSE;
```

```
double lat,lon,time;
float speed;
long int ht;
char latt,lont,hgt,c;

int parse_cmd_line(int argc, char *argv[])
{
int count;

for(count=0;count<argc;count++) {
if(argv[count][0]='-') {
switch(argv[count][1]) {
case 'b': count++;
if(!strcmp(argv[count],"4800"))
baudrate=B4800;
else if(!strcmp(argv[count],"9600"))
baudrate=B9600;
else printf("Baud Rate %s not supported, setting default value.\n",argv[count]);
break;
case 'd': strcpy(device,argv[++count]);
break;
case 'l': strcpy(logfile,argv[++count]);
break;
}
}
}
}

/* This waits for all children, so that they don't become zombies. */
void sig_chld(int signal_type)
{
int pid;
int status;

while ( (pid = wait3(&status, WNOHANG, NULL)) > 0);
}

int main(int argc, char *argv[])
{
char buffer[1024],sockstr[255];
int port = -1;
struct sigaction act, oldact, saio;
struct termios oldtio,newtio;

/* Set default values if not parsed via the command line */
strcpy(device,"/dev/ttyS0");
strcpy(logfile,DEFAULT_LOGFILE);
```

```
baudrate=DEFAULT_BAUDRATE;

/* Parse any command line parameters */
parse_cmd_line(argc, argv);

printf("device=%s\n",device);
printf("logfile=%s\n",logfile);
printf("baudrate=%i\n",baudrate);
printf("port=%s\n",portstr);

/* open the iserial device to be non-blocking (read will return immediately) */
fd = open(device, O_RDWR | O_NOCTTY | O_NONBLOCK);
if (fd <0) {perror(device); exit(-1); }

/* open the log file for writing */
fl = open(logfile,O_WRONLY | O_CREAT | O_APPEND | O_SYNC);
if (fl < 0) {perror(logfile); exit (-1); }

/* open the nmea raw data file for writing */
fr = open("nmea.raw",O_WRONLY | O_CREAT | O_APPEND | O_SYNC);
if (fr < 0) {perror("nmea.raw"); exit (-1); }

/* install the signal handler before making the device asynchronous */
saio.sa_handler = signal_handler_IO;
sigemptyset(&saio.sa_mask);
saio.sa_flags = 0;
saio.sa_restorer = NULL;
sigaction(SIGIO,&saio,NULL);

/* allow the process to receive SIGIO */
fcntl(fd, F_SETOWN, getpid());
/* Make the file descriptor asynchronous (the manual page says only
O_APPEND and O_NONBLOCK, will work with F_SETFL...) */
fcntl(fd, F_SETFL, FASYNC);

tcgetattr(fd,&oldtio); /* save current port settings */
/* set new port settings for canonical input processing */
newtio.c_cflag = baudrate | CRTSCTS | CS8 | CLOCAL | CREAD;
newtio.c_iflag = IGNPAR;
newtio.c_oflag = 0;
newtio.c_lflag = ICANON;
newtio.c_cc[VMIN]=1;
newtio.c_cc[VTIME]=0;
tcflush(fd, TCIFLUSH);
tcsetattr(fd,TCSANOW,&newtio);

sigemptyset(&act.sa_mask);
act.sa_flags = 0;
```

```
act.sa_handler = sig_chld;
sigaction(SIGCHLD, &act, &oldact);

printf("Starting.....\n");

/* Throw away the begining of the serial buffer */
c=read(fd,&c,1);

for(;;) {
sleep(5);
}

/* restore old serial port settings */
tcsetattr(fd,TCSANOW,&oldtio);

return 0;
}

/***************************************************************************
* serial signal handler. *
***************************************************************************/

void signal_handler_IO (int status)
{
volatile int autoupdate = FALSE;
int readsize,writesize;
char readbuf[255], writebuf[255];

if (readsize=read(fd,readbuf,255)) {
/* Write the raw data */
write(fr,readbuf,readsize);
}
else printf("Error scanning buffer\n");
if (sscanf(readbuf, "$GPRMC,%*lf,%*c,%*lf,%*c,%*lf,%*c,%f,%*s",&speed)) {
datacomplete=TRUE;
}
else {
sscanf(readbuf,
"$GPGGA,%lf,%lf,%c,%lf,%c,%*d,%*lf,%*lf,%li,%c,%*s",&time,&lat,&latt,&lon,
&lont,&ht,&hgt);
datacomplete=FALSE;
}

if(datacomplete) {
writesize=sprintf(writebuf, "Time=%lf Lt=%lf,%c Lg=%lf,%c Ht=%li,%c
Spd=%3.1f\n",time,lat,latt,lon,lont,ht,hgt,speed);
printf("%s",writebuf);
write(fl,writebuf,writesize);
```

```
}
return;
}
```

10.2 ANNEX B

ASSEMBLER VERSION

This program was produced with the assistance of Mike Wetton and all coding in this section is attributed to his contribution.

```
;     This program performs the following tasks:

; 0/  Initialises the PC system.

; 1/  Input DATA from serial port.

; 2/  Every CR and LF detected in order to find the end of a block of data.

; 3   Store serial data in memory (CS:4000+).

; 4/  Display the latest block of data on the screen.

; 5/  Log block of data to the file GPSLOG.TXT

; 6/  Close file and clear screen at the end of a logging session.


STACK  SEGMENT PARA PUBLIC 'STACK'
       DB 1024h DUP (255)
STACK  ENDS
;
;
DATA   SEGMENT PARA PUBLIC 'DATA'
;
MODE      DB   03h
ROW       DB   05h
COL       DB   16h
COLOUR    DB   02h
CHARACTER DB   0DBh
BUFFSIZE  DW   02D0h
BUFFADD   DW   0200h
MSG       DB   "GPS DATA LOGGING SYSTEM$"
STARTBUF  DW   0500h
CR        DB   0Dh
LF        DB   0Ah
```

```
DATASIZE  DW    02D0h       ; data area buffer size
DATAADDR  DW     4000h       ; start address of data buffer

SERPORT   DW    03F8h       ; serial port 1 address
ROWBUF    DB    08h
COLBUF    DB    00h
OLDTIME   DW    0000h       ; time of last CR and LF

HANDLE    DW    0000h
FILENAME  DB    "GPSLOG.TXT" , 00
ERRORMSG  DB     "File  ERROR  Detected  $"
CRCR      DB    0Dh, 0Ah, 23h, 0Dh, 0Ah, 23h, 0Dh, 0Ah ; CR LF  # CR LF
# CR LF

ORG    0400h

BUFFER  DB    0410h DUP (41h)
;
DATA   ENDS
;
;
CODE SEGMENT PARA PUBLIC 'CODE'
MAIN   PROC FAR
;
       ASSUME  CS:CODE
       PUSH    DS            ; save PSP address
       MOV     AX , 0        ; on the stack
       PUSH    AX
       NOP
       MOV     AX , DATA
       MOV     DS , AX
       ASSUME  DS:DATA
       NOP
       MOV     SP , 0A000h    ; initialise the stack pointer
       ASSUME  SS:STACK
       NOP
       MOV     AX , 0B800h    ; initialise the screen address
       MOV     ES , AX
       NOP
       CALL    INITSYS       ; initialise the system
       NOP
       MOV     CX , 000Ah
       NOP
LOGGER: PUSH   CX
       NOP
       CALL    CLRDATA        ; clear data buffer in memory
       NOP
       CALL    BLOCK         ; find end of a serial block cf data
```

```
        NOP
        CALL   INPUTSER      ; input data from serial port
        NOP
        CALL   CLRBUFF       ; clear screen data area
        NOP
        CALL   DISPLAYD      ; display one block of data on VDU screen
        NOP
        CALL   FILEGAP       ; write 6 spacing characters to file
        NOP
        CALL   LOGDATA       ; write data to file
        NOP
        POP    CX
        LOOP   LOGGER
        NOP
        CALL   CLOSFILE      ; close logging file
        NOP
        MOV    AH , 00       ; reset the screen mode
        MOV    AL , MODE
        INT    10h
        NOP
        INT    3
        NOP
        MOV    AH , 4Ch      ; exit program (to DOS?)
        MOV    AL , 00h
        INT    21h
;
MAIN   ENDP

INITSYS PROC   NEAR
;
        MOV    AH , 00       ; to set the screen mode
        MOV    AL , MODE
        INT    10h
        NOP
        CALL   DISPLAY       ; display message routine
        NOP
        CALL   CLRDATA       ; clear databarea of memory
        NOP
        CALL   CLRBUFF       ; clear window on screen
        NOP
        CALL   INITSER       ; initialise serial port
        NOP
        CALL   OPENFILE      ; open file GPSLOG.TXT
        NOP
        RET
;
INITSYS ENDP
```

```
DISPLAY PROC    NEAR
;
        MOV    AH , 02         ; move cursor
        MOV    BX , 0
        MOV    DH , ROW
        MOV    DL , COL
        INT    10h
        NOP
        MOV    AH , 09h        ; write message to screen
        MOV    DX , offset MSG
        INT    21h
        NOP
        MOV    AH , 0Eh        ; write character to screen
        MOV    BH , 00h
        MOV    BL , 0
        MOV    AL , LF
        INT    10h
        NOP
        MOV    AH , 0Eh        ; write character to screen
        MOV    BH , 00h
        MOV    BL , 0
        MOV    AL , CR
        INT    10h
        NOP
        RET
        MOV    AH , 0Eh        ; write character to screen
        MOV    BH , 00h
        MOV    BL , 0
        MOV    AL , CR
        INT    10h
        NOP
        RET
;
DISPLAY ENDP


CLRBUFF PROC NEAR

        MOV    CX , BUFFSIZE   ; clear data buffer
        MOV    DI , STARTBUF
        CALL   CLEARBUF
        NOP
        MOV    DI , 0500h      ; start of screen buffer pointer
        MOV    SI , 0500h
        RET

CLRBUFF ENDP
```

```
CLRDATA PROC NEAR

        PUSH  ES
        MOV   AX , CS
        MOV   ES , AX
        NOP
        MOV   CX , DATASIZE  ; clear data from memory
        MOV   DI , DATAADDR  ; start address of data area of memory
        MOV   AL , 20h
        REP   STOSB
        NOP
        POP   ES
        RET

CLRDATA ENDP



INITSER PROC NEAR

        MOV   AH , 00        ; initialise serial port
        MOV   AL , 0C3h      ; 4800 baud, 0 par, 1 stop, 8 DATA bits
        MOV   BX , 0000h
        MOV   DX , 0000h     ; 0 = COM1
        INT   14h
        NOP
        MOV   DX , 03FCh     ; modem control register
        MOV   AL , 03h       ;
        OUT   DX , AL
        NOP
        MOV   DX , 03F9h     ; UART interrupt enable register
        MOV   AL , 00h       ; disable interrupts
        OUT   DX , AL
        NOP
        RET

INITSER ENDP


OPENFILE  PROC NEAR

        MOV   AH , 3Ch       ; open file
        MOV   AL , 02h
        MOV   DX , offset FILENAME
        INT   21h
        NOP
        JB    TROUBLE
```

```
        NOP
        MOV     HANDLE , AX
        RET

TROUBLE:MOV     AH , 09h
        MOV     DX , offset ERRORMSG
        INT     21h
        NOP
        RET
OPENFILE ENDP


FILEGAP  PROC NEAR

        MOV     AH , 40h        ; write six characters to file
        MOV     BX , HANDLE
        MOV     CX , 0008h
        MOV     DX , offset CRCR        ; CR LF  # CR LF  # CR LF
        INT     21h
        NOP
        JB      TROUBLG
        NOP
        RET

TROUBLG: MOV    AH , 09h
        MOV     DX , offset ERRORMSG
        INT     21h
        NOP
        RET

FILEGAP ENDP


WRITFILE  PROC NEAR

        MOV     BX , HANDLE
        PUSH    DS
        MOV     AX , CS
        MOV     DS , AX
        NOP
        MOV     AH , 40h        ; write to file
        MOV     CX , 00C4h      ; first 3 sentences
        MOV     DX , 4000h
        INT     21h
        NOP
        JB      TROUBLW
        NOP
        POP     DS
```

```
        RET

TROUBLW:MOV    AH , 09h
        MOV    DX , offset ERRORMSG
        INT    21h
        NOP
        POP    DS
        RET

WRITFILE ENDP



CLOSFILE  PROC NEAR

        MOV    AH , 3Eh      ; close file
        MOV    BX , HANDLE
        INT    21h
        NOP
        JB     TROUBLC
        NOP
        MOV    HANDLE , AX
        RET

TROUBLC:MOV    AH , 09h
        MOV    DX , offset ERRORMSG
        INT    21h
        NOP
        RET
        NOP
        NOP

CLOSFILE ENDP


BLOCK PROC NEAR

SAGAIN: MOV    BL , 0Dh       ; CR character
        CALL   CHEKCHAR       ;   detect end of sentence character
        CMP    BH , 0FFh
        JZ     SAGAIN         ; CR character not found
        MOV    BL , 0Ah       ; LF character
        CALL   CHEKCHAR       ;   detect end of sentence character
        CMP    BH , 0FFh
        JZ     SAGAIN         ; LF character not found
        NOP
        MOV    AH , 01h
```

```
        INT    16h
        JNZ    EXITS
        NOP
        MOV    AH , 00h
        INT    1Ah
        MOV    OLDTIME , DX
        NOP
        MOV    BP , 0001h      ; CR and LF counter
        NOP
AGAIN:  MOV    BL , 0Dh        ; CR character
        CALL   CHEKCHAR        ;   detect end of sentence character
        CMP    BH , 0FFh
        JZ     AGAIN           ; CR character not found
        MOV    BL , 0Ah        ; LF character
        CALL   CHEKCHAR        ;   detect end of sentence character
        CMP    BH , 0FFh
        JZ     AGAIN           ; LF character not found
        NOP
        MOV    AH , 01h
        INT    16h
        JNZ    EXITS
        NOP
        MOV    AH , 00h
        INT    1Ah
        NOP
        MOV    BX , DX         ; time in TICKS
        MOV    AX , OLDTIME
        CMP    DH , AH
        JNE    YYYY
        AND    DL , 7Fh
        AND    AL , 7Fh
        SUB    DL , AL
XXXX:   CMP    DL , 05h
        JA     STARTBL         ; start of new block detected
        NOP
MIDDLE: MOV    OLDTIME , BX    ; in middle of a block of serial data
        INC    BP
        CMP    BP , 0009h
        JE     ENDBLOCK
        JA     TOOBIG
        JMP    AGAIN

YYYY:   NEG    AL              ; high byte of TICK value had a carry
        ADD    DL , AL
        JMP    XXXX

STARTBL:                       ; detected the start of a new block
        MOV    BP , 0001h
```

```
      MOV    OLDTIME , BX
      JMP    AGAIN

TOOBIG:                 ; something has gone wrong
;     MOV    BP , 0000h
;     MOV    OLDTIME , BX
      JMP    SAGAIN
      NOP

ENDBLOCK:               ; end of a block of serial data detected
      RET
      NOP
EXITS: CALL   CLOSFILE      ; close file
      NOP
      INT    3          ; exit program
      NOP

BLOCK  ENDP


CHEKCHAR PROC NEAR

       MOV   BH , 00h      ; good character found marker
CHEKNEXT: MOV   DX , 3FDh      ; input serial port status
       IN     AL , DX
      TEST   AL , 01h
      JNZ    OKAY
      JMP    CHEKNEXT
      NOP
OKAY:  MOV    DX , 3F8h     ; input character from serial port
      IN     AL , DX
      CMP    AL ,BL       ; check for LF character
      JZ     EXITBL
      MOV    BH , 0FFh     ; character not found marker
EXITBL: RET

      NOP
EXITB: INT    3
      NOP

CHEKCHAR ENDP


INPUTSER PROC NEAR

      PUSH   ES
      MOV    AX , CS
      MOV    ES , AX
```

```
      MOV   DI , 4000h
      MOV   SI , 4000h
NEXTCHAR: NOP
      MOV  DX , 3FDh      ; input serial port status
      IN    AL , DX
      TEST  AL , 01       ; testing status for received character
      JNZ   RECEIVE
      JMP   NEXTCHAR
      NOP
RECEIVE: MOV   DX , 3F8h      ; input character from serial port
       IN    AL , DX
      NOP
      MOV   ES:[DI] , AL   ; store character input from serial port
      INC   DI
      CMP   DI , 42D0h     ; check for end of block
      JZ    NEWBLOCK
      NOP
      MOV   AH , 01h      ; has keyboard been used
      INT   16h
      JNZ   EXITSER
      NOP
      JMP   NEXTCHAR

DISPERR: MOV   DX , 03F8h     ; input character from serial port
       IN   AL , DX
      NOP
      MOV   AH , 71h      ; attribute
      MOV   AH , 3Fh      ; ? character
      MOV   ES:[DI] , AL   ; store character input from serial port
      INC   DI
      NOP
      JMP   NEXTCHAR
      NOP

NEWLINE:
;     ADD   SI , 0050h    ; move screen buffer pointer to a new line
;     MOV   DI , SI
;     CMP   SI , 42D0h
;     JE    NEWBLOCK
;     JMP   NEXTCHAR
;     NOP
NEWBLOCK:
      NOP               ; return to main routine
      POP   ES
      RET
      NOP

EXITSER:  CALL  CLOSFILE      ; close file
```

```
        NOP
        POP   ES
        INT   3            ; exit program
        NOP

INPUTSER ENDP


DISPLAYD PROC NEAR

        PUSH   DS
        MOV    AX , CS
        MOV    DS , AX
        NOP
        MOV    SI , 4000h     ; source address (memory)
        MOV    DI , 0500h     ; destination address (screen)
        MOV    BP , DI
DISPLOOP:
        MOV    AH , 74h
        MOV    AL , [SI]     ; fetch next character from memory
        INC    SI
        CMP    AL , 0Ah       ; detect end of a GPS sentence
        JE     ENDLINE
        MOV    ES:[DI] , AX
        INC    DI
        INC    DI
        JMP    DISPLOOP

ENDLINE:
        ADD    BP , 0A0h
        MOV    DI , BP
        CMP    BP , 0AA0h
        JNE    DISPLOOP
        NOP
        POP    DS
        RET

DISPLAYD ENDP


DELAY   PROC NEAR

        PUSH   CX
        PUSH   BX
        NOP
        MOV    CX , 0100h
CCCC:   MOV    BX , 0FFFFh
DDDD:   DEC    BX
```

```
        JNE    DDDD
        LOOP   CCCC
        NOP
        POP    BX
        POP    CX
        RET

DELAY   ENDP


LOGDATA PROC    NEAR
;
        CALL    WRITFILE        ; write data from BUFFER to file
        NOP
;       MOV     AH , 00h        ; input a character from KBD
;       INT     16h
;       NOP
        RET                     ; return to main routine
;
LOGDATA ENDP


 CLEARBUF PROC NEAR

        MOV    AH , 02      ; move cursor
        MOV    BX , 0
        MOV    DH , 11h
        MOV    DL , 00h
        INT    10h
        NOP
        MOV    AL , 20h
        MOV    AH , 14h
        REP    STOSW
        RET

 CLEARBUF ENDP

CODE    ENDS
        END    MAIN
```

10.3 ANNEX C

SMART PROGRAM

As the database was set up with a wizard in a Microsoft format, and much of the intelligent processing is done within Visual Basic routines called by macros, an explanation of the program and directions on how to reproduce it must be followed through by the block diagrams in Annex D.

10.4 ANNEX D