# A PERSPECTIVE ON LAND NAVIGATION – THE EVOLUTION FROM MAN-PACKS TO MODULES

Alison Brown, *NAVSYS Corporation*

## ABSTRACT

Over the last two decades there has been a significant evolutionary change in GPS user equipment that has resulted in an explosive growth of applications of GPS for land navigation. In this paper, the history of the GPS satellite constellation, user equipment and applications is briefly covered over the 1980s and 1990s.

With the expected advances in electronics and computer technology, the evolutionary trend to smaller, lighter, more efficient GPS modules is expected to continue. The paper covers the author's predictions for the next decade for GPS user equipment, enhancements to the levels of positioning and navigation services available and potential new applications for land navigation in the next decade.

## A STAR IS BORN IN THE 1980s

The first GPS Block I satellites, Navstars 1-4, were launched in 1978. By 1980 a total of six Navstar satellites were in orbit providing a limited GPS test capability for system development. The satellite constellation was configured so that there was adequate dilution of precision provided for about four hours of testing daily over the United States. GPS system developers of that era learned to set their "internal clocks" to follow sidereal time throughout the year. Since the GPS satellite coverage pattern repeated each day, but 4 minutes earlier, testing was in daylight hours for six months of the year and at night for the other six months.

Because of the limited satellite availability, the first GPS receivers that were marketed addressed the needs of the surveying community. These were considered by the standards of the day to be "transportable" equipment, but for example one of the first receiver's produced was the Macrometer V-1000 which included two boxes of electronics and weighed 91 kg. A helicopter was used to transport it to survey sites. The Macrometer was also a completely "codeless" receiver, and did not take advantage of the C/A code signal in any of its data processing. The perception of the day was that this would result in a solution that was independent of any "monkeying around" that the US military might do with the GPS signal coding. Ofcourse, when Selective Availability errors were introduced with the Block II satellites, codeless and coded GPS receivers were equally affected by that error source.

## The first "portable" GPS receiver

The surveying community eagerly adopted GPS as it proved to provide significantly better surveying accuracy than the TRANSIT satellite navigation system. Other GPS receivers were produced by Magnavox, TI, Litton and Rockwell providing C/A code and P(Y) code tracking capability. The Wild-Magnavox WM-101 receiver was introduced in the mid 80s providing a true suitcase-type receiver portability. A "man-portable" military receiver was also introduced – the Manpack/Vehicular User Equipment (MVUE) although this required a back-pack to carry it and weighed 11 kg.

## GPS Receivers of the 80s

- Macrometer V-1000
  - Codeless receiver
  - 2 boxes and 91 kg
- WM-101
  - 1-ch Fast sequencing receiver
  - 18 kg
- TI-4100
  - 1-ch Fast sequencing receiver
  - 25 kg
- Manpack/Vehicular User Equipment (MVUE)
  - 1 ch sequencing receiver
  - 11 kg

## Military and Civil Portables

MVUE

WM-101

The surveying precision possible with GPS was impressive. Although it took time for the GPS positioning service to meet its specified navigation performance level of 16 m (SEP), the surveying community rapidly developed carrier-phase positioning techniques that could position long baselines (e.g. 15 km) to 1 part in a million accuracy using only short runs of data (e.g. 15 minutes). This established a new baseline for surveying precision as previously the best quality survey (a First Order Survey) was only specified to 1:100,000. By the mid 80s, the first dynamic carrier phase positioning techniques were also developed, demonstrating 1 to 10 cm positioning capability for moving platforms.

At the end of the 1980s, the first hand-held GPS receivers were introduced. The Magellan NAV 1000 was the first of these, weighing only 850 gram – a huge reduction from the 11 kg MVUE! Trimble shortly after released their Trimpak handheld receiver which weighed in at 1.5 kg.

**Figure 1 - Magellian NAV 1000**

**THE "GOLD RUSH" OF THE 1990s**

The 1990s started with a rush-order for GPS to support land navigation as the US military entered the Gulf War. The Block II satellite launch schedule was moved ahead, with II-9 and II-10 launched to optimize the coverage over the Gulf War theater of operations. This provided 2-D navigation coverage 24 hours a day and 3-D coverage was available for 20 hours a day.


The ability that GPS provided to navigate through the desert region became essential for the warfighters operating in theater. The military rush-ordered quantities of commercial GPS receivers, mostly Magellan and Trimpak hand-helds, which became such hot items that troops even purchased their own when the supply could not keep up with demand! The testimonials from the Gulf War troops were lyrical in nature. Many claimed that "GPS won the war…".

## GPS use in the Gulf War

- Commercial receivers rushed to theater
  - Troops even purchase their own equipment!

    *1Lt, USMC "I sincerely hope my check covers the cost ..as I am sure you understand that any delay in receiving the TRIMPACK GPS receiver might be measured in lives lost"*

    *CPL, Britain "As you are no doubt aware, navigation in this desert is an absolute nightmare, and for this reason I find it necessary that I obtain a satellite navigation system by whatever means possible"*

## Gulf War Testimonials

- "GPS was the saviour! *If you did not have GPS, you were screwed!"*, CPT Mike Klingele, 1st Cav Division
- *"I love my GPS receiver so much, if it made coffee I'd marry it!"*, Sergeant
- Told of Army cooks using GPS to find moving front-line troops and deliver meals, *"No matter how bad the food is, if it's lost, it's even worse"*

1990 was also notable as the year that Inmarsat announced their plans to include GPS navigation repeater payloads on their Inmarsat-3 geostationary satellites. These satellites of course became the mainstay of the FAA's and EGNOS' Wide Area Augmentation Systems (WAAS). Olof Lundberg, the Director General, of Inmarsat prophesized a great future for GPS services. A direct quote from sections of his keynote address to NAV '91 is included below. I would like my own predictions to be proved as accurate!

The farmer and the boy scouts

A farm manager by the name of John Fenton entered the space age on 30 August this year with the world's first combine harvester to be fitted with a satellite navigation field mapping system.[1] Its on-board computer is linked to GPS satellites as it works through fields of wheat in North Humberside, in the north of England. The exact position of the combine coupled with data received from a yield-metering machine on board the combine, provides a computerized record of the amount of grain harvested yard by yard. With a map crated by the data, individual parts of the field can be investigated and its soils analyzed and treated accordingly.

In Iceland, fishing boats equipped with GPS receivers, Inmarsat-C satellite communications terminals and small computers now enjoy integrated communications and positioning service under a project called "Hooksat." Fish accounts for 75 per cent of Iceland exports and modern technology is helping to make the industry safer and more effective. Not only does the system provide automatic position reporting, but boats receive up-to-the minute market price reports for their catch.

A number of software companies have introduced desktop mapping programmes which allow an operator sitting at an ordinary personal computer to track moving vehicles equipped with GPS receivers. Their locations are displayed on the map in real time.

A potentially huge market for satellite navigation – pleasure craft – is already being tapped through the new generation of low-cost receivers. More than two million pleasure craft ply US waters along, more than a quarter of a million in Japan, and more than five million worldwide.

The point of these stories is that navigation and position determination are moving swiftly from a relatively obscure, arcane area of technology, of interest to a few specialists in the maritime and aviation industries, to what many predict will be virtually a mass market. Already, the sands are shifting. The specialist manufacturers who traditionally dominated the navigation equipment market are being joined by the consumer electronics giants. Engineers and scientists now rub shoulders with marketing managers in an area which, until now, has not been known for commercialism. If these newcomers – these marketing managers – are worth their salt, they'll soon unearth navigational needs we didn't know we had.

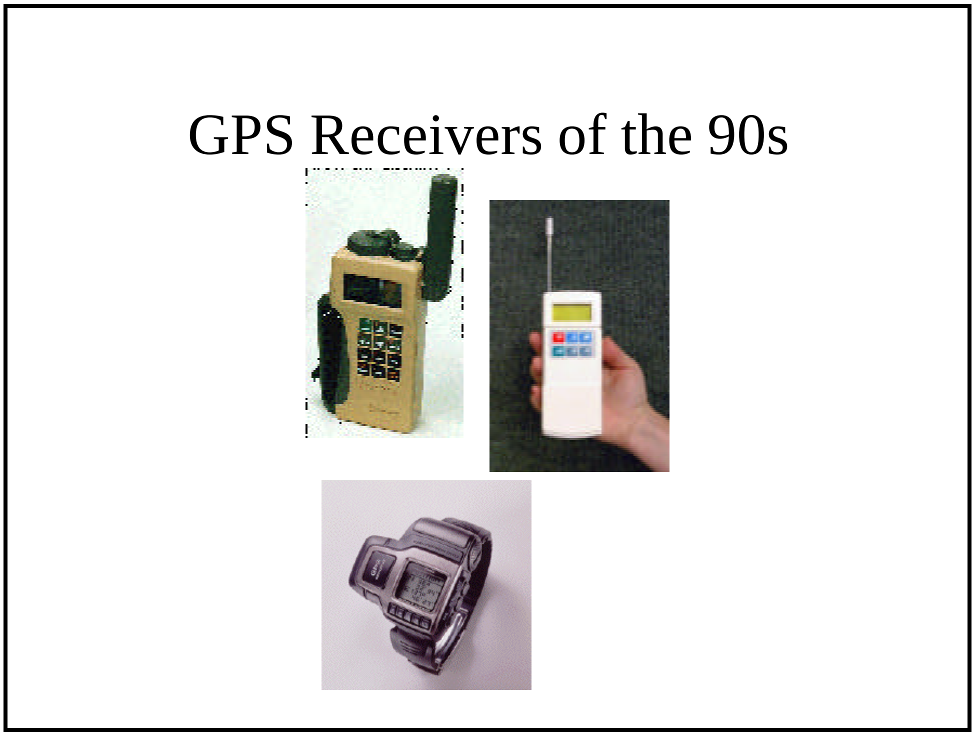
A recent article even predicted – with no tongue in cheek – that boy scouts may eventually turn in their compasses in favour of hand-held satellite navigation receivers.

Satellite navigation could well become – like electrical power and telecommunications before it – the next utility.

From Notes for an address by Olof Lundberg, Director General, Inmarsat, at NAV '91: The 1991 International Conference of the Royal Institute of Navigation, London, England, 6 November 1991.

[1] As reported in the Daily Telegraph, 31 August 1991.

The continuing trend for smaller, lighter, cheaper GPS user equipment continued through the 1990s. The MVUE was moth-balled (no one wanted to carry it after using hand-helds in the Gulf War!) and replaced by the Precision Lightweight GPS Receiver (PLGR). Commercial GPS user equipment continued to lead military receivers in terms of new technology. Throughout the 1990s GPS card sets were developed, allowing GPS capabilities to be embedded in other systems, followed by GPS modules and even chip sets. By 1999, GPS technology was even available in such consumer products as watches and cell-phones!




**PREDICTIONS FOR THE 2000s**

Looking forward to the future for the next decade, this trend in miniaturization of the GPS receiver technology can be expected to continue with further advances in electronics. Multi-function chip sets that include GPS and other capabilities, such as receivers for other navigation services, communications and computer processing capabilities.

The space segment for the 00's is also predicted to evolve to a multi-national system with less dependence on the United State's GPS satellites. Today we have 27 healthy GPS satellites in orbit. However, many of these have exceeded their design life and some have single-string critical hardware components that could fail at any time, ending their operational capability. The US is committed to maintaining a 24 satellite constellation. However, users expectations are now for a level of service above this minimum threshold!

Although the Glonass satellite navigation system has had problems maintaining an operational constellation, users of integrated GPS/Glonass receivers have long benefited from the increased coverage and performance possible when using signals from both of these satellite services. The bottom line is that "more is better" when signals-in-space are concerned. The space-based augmentation services, WAAS, EGNOS and the Japanese' MT-SAT will all become operational shortly, also increasing the signal availability and improving the level of accuracy and integrity that this "system-of-systems" can deliver.

The challenge for the next decade is for the different international organizations involved with operating these satellite constellations to develop interoperability standards to allow seamless integration of signals-in-space within the next generation of user equipment. The level of service that could be delivered from a combined GPS+Glonass+SBAS+Galileo constellation is mind-boggling. Expand this vision to including signals-in-space from digital communication links such as GSM, CDMA or PCS and navigation outages such as urban canyons or in-building drop-outs could be a problem of the past. This transition from a system-centric to a service-centric focus for radionavigation is the vision of GPS-3 Independent Review Team for the next generation Global Positioning and Timing Service (GPtS) architecture.

Today, GPS provides a navigation accuracy of 100 meters. When the WAAS services become operational, commercial user equipment will enjoy real-time positioning accuracies of better than 5 meters. Within the next ten years, commercial users can also expect to receive GPS and other satellite services with multi-frequency capability that will allow real-time positioning to sub-meter accuracies and kinematic relative positioning to centimeter level precision!

Applications for the GPtS will continue to evolve. I can't hope to predict all of the creative ways that entrepreneurs will find to take advantage of these expanded levels of service coverage. I have listed below some of those that I find most intriguing.

- Mobile location – using GPtS to provide E-9-1-1 (or 9-9-9) location services for the mobile communication community.
- Personal services – recreational information access, geographic "yellow pages", stolen goods recovery, monitoring services for parolees, animals, children or Alzheimer patients.
- Autonomous navigation – precision guided robot vehicles for farming, mining or construction
- Safety monitoring services – railroad control, collision avoidance
- GIS data collection – sensor georegistration (GPtS in every camera?), targeting, automatic mapping

The future is always exciting, and never quite as predicted. Some of the safe bets however that I would make for the future of GPtS are:

- GPS chipsets will become the norm for embedded positioning, navigation and timing services
- Volume of existing applications will increase dramatically
- Many new applications will be enabled
- Global positioning and timing services will continue to improve in terms of accuracy, coverage, availability and integrity