
Door prof. David Last

# Global Navigation Satellite Systems

## Part 1.The Present Imperfect

**GPS is one of the very great technical achievements of the late twentieth century. It is normally accurate and robust but there are weaknesses which, if unchecked, could lead to errors with potentially catastrophic consequences. These include jamming and spoofing. These weaknesses are known to technical experts but inadequately understood by maritime policy makers and practising navigators. In this article, David Last outlines some of the problems with GPS. He argues that future systems, such as Galileo, may be equally vulnerable, but there is a solution: combining GPS with enhanced Loran.**

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GPS is one of the great technical achievements of the late twentieth century, the foundation of our current and future radionavigation technology at sea. Satellite navigation has been a star among science-based industries, with vigorous growth and products that are ever more powerful, user-friendly, and cost-effective. In the eyes of the public, GPS is a magical, new technology, despite the fact that the first satellite was actually launched 29 years ago. The only sour note is that, with the advent of in-vehicle units, GPS leads huge foreign trucks through pretty English villages. But technically, to most people it appears to operate perfectly. Let me cite in evidence that great work of contemporary literature, The Da Vinci Code. We thrill as Captain Bezu Fache uses a tiny GPS device to track our hero and his lady friend unknowingly, and with an accuracy of two feet, while they explore the deep underground crypt beneath the Louvre Museum in Paris. This story manages to combine in a single paragraph three great myths concerning GPS: first, that GPS is itself a tracking system; second, that it works everywhere; and third, that it has near-pinpoint accuracy. Also, by the way, Captain Fache's GPS only needs a single satellite to work, not three or four like ours. That is a pretty good collection of errors for a book that purports to be a revelation of truth, hidden from us for two millennia! But people, including many in the maritime world, often believe these things. They certainly cannot see what could possibly be unsafe about navigating a ship by GPS. Theirs always seems to work. More prudent navigators, and those responsible for providing aids to navigation on which the safety of life and the protection of the environment depend, need to identify and assess more realistically the weaknesses of the systems on which they rely. So I want to think about some of the weaknesses of GPS. I will also consider whether other satellite systems are likely to suffer from similar concerns. Alternatively, could Russia's GLONASS, Europe's possible Galileo, and future systems from China, Japan or India actually save the day? First, I will look at failures of satellites or their control system from the mariner's perspective. I will take just one incident – there have been others, of course.

On New Year's Day 2004, when fortunately not many people were out and about, the last atomic clock in GPS satellite SVN23 failed. Because of the nature of the failure and the location of the satellite, the ground stations did not detect the emergency promptly. Indeed, it took nearly three hours for the satellite to be declared unusable. The consequences for normal, standalone, GPS receivers in Europe were catastrophic. Errors in the horizontal positions they measured started small and gradually built up, without warning, to between ten and forty kilometres. Errors in vertical positions – of no interest to mariners, but vital for many other GPS users – were even larger. Marine Automatic Identification Systems (AIS) showed ships travelling over land. This was a very serious event. Happily, most augmentation systems detected the errors promptly and warned users' receivers to exclude the faulty satellite from their navigation solutions. The position errors of stand-alone GPS receivers without the European Geostationary Navigation Overlay Service (EGNOS) built up to over a hundred metres in less than three minutes. In contrast, for a receiver with EGNOS protection the mean position error was just 1.05 metres. Another protection scheme employed in certain GPS receivers, especially airborne ones, is RAIM (Receiver Autonomous Integrity Monitoring). This, too, detected and excluded the faulty satellite, keeping errors within the tight limits required for aviation. And mariners who were using the familiar IALA coastal Differential Global Positioning System (DGPS) radiobeacons were also protected. This event demonstrated clearly the vital role played by the integrity of monitoring systems, of which there are many available to mariners: they include EGNOS, the US WAAS (Wide Area Augmentation System), Japan's MSAS (MTSAT Satellite-based Augmentation System), coastal radiobeacons and Eurofix. It also underlines the danger of operating a GPS receiver without such protection. Most GPS receivers on the market now include protection. The handbook will state that the receiver is 'WAAS enabled' (which includes regional variations like EGNOS) or has 'RAIM' capability, and explains how to turn it on and use it safely. What would have happened if Galileo (or another new satellite system) had been operational and a receiver for both systems had been used? Receiving more satellites would certainly have made detection of the faulty satellite easier. It would probably have reduced the magnitude of the position errors due to the failure of this individual satellite. But mariners with stand-alone receivers and no protection system would still have experienced very large errors, Galileo or no Galileo.

## Solar Flares

Most other vulnerabilities of satellite navigation are due to the extremely weak signals that reach the receiver. Each GPS satellite broadcasts from space a signal no more powerful than a car headlight, to be shared out over nearly half the earth's surface. For the shipborne receiver, finding the satellite's signal is like trying to spot a torch from 20,000 kilometres away. The signal is easily swamped by noise or interference reaching the receiver. On 6 December 2006, a flare occurred on the sun that caused an unprecedented period of solar radio noise on earth. Many GPS receivers stopped working. Although solar flares are not uncommon, this event was ten times more powerful than the previous maximum. It was the first flare strong enough to affect the WAAS; the aviation guided approach service was lost for about fifteen minutes. The flare produced 20,000 times more radio noise than the rest of the sun, swamping GPS receivers over the entire sunlit side of the earth. A concern for the future is that, given we are currently in a period of minimum solar activity, how often we can expect solar radio bursts like this – or even stronger – as we build up to the next solar maximum over the coming five years? These flares cannot currently be forecast. Warnings of possible system disturbances are broadcast once a flare has been observed on the sun, but they are imprecise. Solar flares affect not only GPS but all satellite navigation systems. So adding new systems such as Galileo would offer no protection. Flares do not threaten the 'integrity' of the system – our ability to know for sure that we are where the equipment says we are, to be warned promptly not to use it as soon as it goes wrong. Receivers simply stopped working, for no apparent reason. Also, flares do not occur very often, but when they do their effects can be very severe, as this event showed.

## Jamming

What about man-made interference to GPS, unintentional or intentional? The US government's Volpe Report studied this in depth. It concluded that interference to GPS could be reduced, but never eliminated. Losing GPS would cause severe safety damage to the US, and also economic damage since GPS is now used by industry and commerce in hundreds of ways that have nothing to do with conventional navigation. Also, the report recognised that GPS is a tempting target to individuals, groups, or countries hostile to the US. Unintentional interference to GPS is relatively common. Northern Italy used to be notorious for unwanted harmonics of television transmitters that blocked GPS reception. This kind of interference is usually completely innocent, but still deadly, as the following example shows. In the harbour of Moss Landing, California, a couple of cheap Radio Shack TV antenna units on boats went wrong and inadvertently radiated jamming signals. GPS receivers either stopped working, or gave wrong positions, on every vessel in the port and for a kilometre out to sea. It took months to track down this purely accidental interference. The Federal Communications Commission were apparently not interested. The antenna units were eventually located by technically competent volunteers. Intentional jamming of GPS is not difficult to achieve, either. The little jammer hidden in the dice in the picture – although it radiates only thousandths of a watt of power – kills GPS throughout a building or across a dock. A more powerful jammer can wipe out reception throughout a city, or a harbour and its approaches. Unfortunately, there is generally no one around equipped, trained and authorised to deal with GPS jamming. A particular challenge would be a powerful jammer in a car, operated intermittently. There are GPS jammers advertised on the internet. They use simple technology: it does not take al Qaida to jam GPS, just a bored kid in his bedroom with acne and no girlfriend. The same companies who sell police radar and mobile phone jammers, now sell GPS jammers, and I suspect we will see jamming increase as GPS is employed for road user pricing. And such jamming, being indiscriminate, could well affect shipping. GPS currently feels a bit like the computer business before the first virus. Among the more active operators of GPS jammers are governments conducting tests. A recent trial in Wales affected a radius of 320 nautical miles. Governments, however, usually announce when they are going to deny us GPS. I trust that every mariner receives and punctiliously notes all such warnings. GPS was lost for two hours across the whole San Diego area this January. The US Navy had been carrying out a communications jamming exercise. Their own ships' GPS systems all failed. So, after a couple of hours they terminated the test. By that time, maritime GPS receivers, telephone systems, cell-phones and a hospital paging system in the city had all failed. It took the US Coast Guard three days to finger the culprits. Incidentally, San Diego is the home of SPAWAR, the US Navy's experts on GPS jamming; this time, they were victims, not the cause… Using Galileo would be little defence against jamming. There are so few radio frequency bands available for satellite navigation that systems have to share them (they would choose to do so in any case in order to minimise the costs of receivers capable of using multiple satellite systems). So, if you jam the L1, L2 and L5 channels used by GPS, you should also hit Galileo and all the other proposed future systems. Only GLONASS works on frequencies different from these and so offers a degree of protection. Like solar noise, interference is not usually an integrity issue, since receivers quietly stop working, to the bewilderment of their users. In engineering terms, interference and jamming affect the 'availability and continuity' of the service. But if it happens to you during a critical manoeuvre, and you have no immediate fallback, that is little consolation.

## Spoofing

One vulnerability of GPS that we rarely speak about is spoofing. Spoofing is the transmission of legitimate-looking false signals the GPS receiver will lock on to in place of the satellites' signals. The receiver will display position, velocity, and time values that are misleading, maybe dangerously so. In one particularly sinister scenario, the receiver is walked off the desired path so slowly that the spoofing is hard to detect and correct. The Volpe Report points out that even if a spoofer is not fully successful, it can still create significant errors and jam GPS over large areas. And because it transmits apparently normal GPS signals, the spoofer can also defeat nearly all anti-jamming equipment. It is also possible to spoof WAAS, EGNOS and most other differential augmentations. Spoofing comes in some strange forms, which include 'meaconing': receiving, delaying, and re-broadcasting radionavigation signals to confuse a system or user. It is, of course, much easier to jam a GPS signal – even a crude device will do that – than to spoof it. But make no mistake: spoofing is not difficult. If you are sceptical about GPS spoofing, I refer you to

the expert: James Bond. In Tomorrow Never Dies, a British ship is sunk by the Chinese in international waters. The only clue: a fake GPS signal controlled by a techno-terrorist. James Bond discovers the GPS device – and, naturally, wins the girl. Do not laugh at this evidence: remember, James Bond had a video communicator on his wrist, long before the rest of us. Spoofing is certainly an integrity issue; it is hard to think of a more dangerous form of interference to GPS. Unfortunately, civil satellite navigation receivers are poorly equipped to detect it. If only GPS is spoofed, a second satellite system is certainly a help in warning the user, provided the receiver is designed to detect the danger. But a terrestrial back-up is much less likely to be spoofed at the same time.
I have reviewed some of the weaknesses of GPS, a system that is normally accurate and robust. Most of what I have written is well known to technical experts. But unfortunately, it is not understood by many of the politicians or policy-makers in the maritime world, or by many practising navigators. They firmly believe that GPS, even unaugmented GPS, is safe at sea and all a man could need. Others think that Galileo, or China's proposed Compass system, or Russia's GLONASS, will compensate for the shortcomings of GPS. I hope I have made it clear why I think that that is a myth, and a dangerous one. However, there are solutions to all the problems I have identified. One is to combine GPS with the new enhanced version of Loran, which not only has very high accuracy, but also shares none of the vulnerabilities of satellite navigation I have identified. A small, relatively low-cost, eLoran unit integrated within future GPS receivers has the potential to take over seamlessly when GPS fails. Provided we implement such fallbacks sensibly as we move into e-navigation, we have every chance of achieving the substantial step-up we are seeking in safety and effectiveness at sea.

## In Memoriam

# Mr. A.B. van den Engel

Op 17 februari 2008 overleed op 78-jarige leeftijd mr. A.B. van den Engel. Tot en met 2006 schreef hij voor Schip en Werf de Zee verslagen van uitspraken van de Raad voor de Scheepvaart. Hij nam deze taak eind 1999 over van de heer E. IJssel de Schepper.
Ad van den Engel was een geboren Rotterdammer wiens gehele loopbaan met de scheepvaart verbonden is geweest.
Na het behalen van zijn stuurmansdiploma in 1949 aan de Gemeentelijke Zeevaartschool te Rotterdam voer hij als stuurman en vanaf 1964 als kapitein voor de Rederij Van Ommeren. In 1984 kwam hij definitief aan de wal in diverse adviesfuncties variërend van automatisering tot speciale ladingen en schadeclaims.
In de periode 1977 tot 1984 vond hij tijd om een universitaire studie Nederlands privaatrecht met de einddoctoraalvakken Vervoerrecht, Zeerecht en Verzekeringsrecht te volbrengen. Zijn einddoctoraal-scriptie ging over Garantiebrieven en schone Cognossementen (Letter of Indemnity).
Van 1988 tot 1995 was hij docent Wetten en Routering/Reisplanning aan de Polytechnische Faculteit van de Hogeschool Rotterdam en Omstreken (Afdeling Maritieme Bedrijfsvoering) en coördinator van de cursus Scheepvaartkunde (Maritieme Opleiding Rangen).
Na zijn pensionering bij Van Ommeren (Shipping) in 1989 was hij nog jaren actief, onder andere als Tutor Institute of Chartered Shipbrokers (Londen), waarvan hij Fellow was, als docent aan de International Maritime Transport Academy te Rotterdam en als plaatsvervangend lid Commissie Bezwaar- en Beroepschriften in zijn woonplaats Maarn.
Hij was tevens auteur van de Cremers Editie Vervoerrecht.
Hij was een bijzonder mens en voor mij een aimabele collega bij Schip en Werf de Zee.

*J.L.A. van Aalst*