THE JOURNAL OF NAVIGATION

VOL. 51 SEPTEMBER 1998 NO. 3

Technology, Implementation and Policy Issues for the Modernisation of GPS and its Role in a GNSS

Keith D. McDonald

(*Sat Tech Systems, Alexandria, VA USA*)

This and the following six papers were selected from the many papers presented at the 9th World Congress of the International Association of Institutes of Navigation (IAIN) held in Amsterdam, The Netherlands, 17–21 November 1997.

During the past several years, a number of important investigations, policy initiatives and national commitments relating to the future of GPS, GLONASS and their augmentations have occurred. Substantive and on-going studies of the character and configuration of a Global Navigation Satellite System (GNSS) have also been evaluated worldwide, especially by the International Civil Aviation Organization (ICAO). These efforts have been principally directed toward the definition of near- and far-term GNSS implementations that meet the needs and concerns of the international community. This paper briefly reviews some of the investigations and addresses, in particular, the concerns and requirements that may affect the future capabilities and the dual (civil/military) character of GPS. The main issues relating to the modernisation of GPS and its subsequent transition to a component of a GNSS with a viable international character are presented. These include a discussion of new signal structure options, certain changes in operating frequencies, increased signal power levels, other system alternatives and their potential impact on system performance. International issues are briefly addressed, including future performance capabilities, assurance of service, economic participation and benefit, reasonable cost, standards and international participation.

1. INTRODUCTION. Research into a US Defense Navigation Satellite System and the initial development of the Navstar Global Positioning System (GPS)

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

occurred in the early 1970s. The basic characteristics of the system were reasonably well defined after about three years of effort by a Joint Services Defense Navigation Satellite Executive Steering Group headquartered in the Pentagon. This group, with the writer as Scientific Director and supported by representatives from the military laboratories and research centres, defined the preliminary system characteristics that included:

(i) a spacecraft constellation of medium altitude near circular orbit satellites.
(ii) the autonomous character of the satellites (transmit only with stable clocks).
(iii) the monitor/upload control segment functions.
(iv) use of the pseudoranging technique for position determination of the user.
(v) the basic features of the pseudorandom noise (PRN) coded signal structure.
(vi) the recommended operating frequency bands for the GPS carrier signals.

This was accomplished in the process of examining the feasibility, viability and cost of a navigation satellite system for military applications. Documentation was prepared (a Development Concept Paper, or DCP) to obtain approval and funding for a navigation satellite development program by the Defense Systems Acquisition Review Committee (DSARC). The DCP addressed technology development areas and provided a plan for the development and test of a developmental GPS satellite constellation, a control system and GPS receivers. If the test and demonstration program was successful, the operational development of GPS would likely follow.

The GPS program received approval in 1973 as a joint service program with the USAF as the Executive Agent. A GPS Joint Program Office (JPO) was established to manage the GPS program at the Air Force Space and Missile Systems Organization in Los Angeles, California. As we are aware, the test program involving twelve Block I GPS spacecraft was successful. The subsequent procurement and operational deployment of 28 Block II and Block IIA GPS spacecraft was also successful. Further, the replenishment of these first operational GPS spacecraft has been initiated with the successful launch of the first Block IIR spacecraft in July of 1997. The Block IIR spacecraft will replenish the constellation until the next generation of 33 Block IIF (for Follow-on) spacecraft start to be deployed in about 2002.

GPS has proven to have excellent capabilities in its defense role and to have even more extensive civil applications. Many current applications and plans were not considered in the original planning and configuring of the system in the early 1970s. The system has proven its military value and has become an important civil system as well. For these and other reasons, there has been some concern and considerable activity during the past few years to investigate the adequacy of the current GPS configuration and the desired direction of the GPS in the future.

2. THE FUTURE OF GPS. The current interest in a careful review and

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

assessment of the future of GPS occurs at a time when, as we know, GPS is doing extremely well. Literally, over a million GPS receivers are now produced annually and its applications are growing rapidly. Projections are for GPS to be a 10–12 billion dollar market by 2005; about a four-fold growth in eight years. We are now looking to the deployment of the next generation GPS (Block IIF) spacecraft that have a planned lifetime in orbit of over three times that of the first GPS spacecraft! The combination of the current spacecraft, the IIR replenishment spacecraft and the IIF follow-on spacecraft will take GPS through the next 20–25 years. Questions can be reasonably asked, such as:

(i) Is the 25-year-old GPS signal structure adequate for the future?
(ii) Is the dual-mode (civil/military) character of GPS operating satisfactorily?
(iii) What changes are needed in GPS to meet future needs or provide new services?
(iv) What are the improvements that will make the system more useful and capable for defense and civil applications?

This is a critical time for GPS. The main system architectural improvements and other features to be provided by the new generation of IIF GPS satellites need to be clearly established. This is urgent in that the Department of Defense (DoD) has informed the Department of Transportation (DoT) and the navigation community that recommendations and decisions relating to new civil capabilities for the GPS Block IIF spacecraft need to be completed by August of 1998 for them to be included in the IIF production. A first step toward meeting the August deadline was completed with the March 1998 decision that a second coded civil frequency for GPS will be placed in the GPS L2 band. A Memorandum of Agreement (MOA) between the US DoD and the DoT, signed in 1997, required the decision to be made on this schedule. Failure of the civil community to establish and justify the desired new capabilities by the August 1998 deadline could result in a lost opportunity with serious consequences for the future. The JPO has announced that the schedule for influencing the first six (of 33) GPS IIF satellites has already expired!

3. GPS MODERNISATION. The 'modernisation' of GPS involves a wide range of options. Significant recommendations have been made for new technical features and improvements, as well as policy, by a number of panels and committees, including:

(i) The National Academy of Public Administration study and report entitled *The Global Positioning System – Charting the Future*, chaired by Dr James R. Schlesinger.
(ii) The National Academy of Sciences/National Research Council study and report on *The Global Positioning System – A Shared National Asset*, chaired by Mr Laurence J. Adams.
(iii) The Defense Science Board investigation, chaired by Mr William Delaney.
(iv) The USAF Scientific Advisory Board Activity, chaired by Dr Gene McCall.

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

Table 1. GPS military and civil issues

GPS system architecture
- System functions and configuration: retention or separation of dual mode services
- Spectrum considerations; placement of Lm, L1c, L2c and L3c
- Signal structure; new Lm, Lc and compromises
- Augmentations: role of GLONASS use with WAAS, LAAS; availability, integrity
- Data message: direct Y-code access, inclusion of selected DGPS and integrity data
- Constellation enhancement: increase to 30 satellites, other configurations

Performance characteristics
- Interference, spoofing and jamming concerns: Lm and Lc mitigation of effects
- Signal power level increase: increase in Lm (and Lc) signal power; GPS spacecraft narrow beam antennas
- Solar max concerns: performance improvements through inclusion of L2c
- Millenium and GPS week 1024 rollover: effect on GPS receivers
- Civil 'best' performance: removal of SA and other degradations; accuracy improvement

GPS management/institutional concerns
- Operation, control and stewardship: DoD as service provider; combined civil/military control
- International considerations: use of GPS international GNSS resource; protection from adversaries

(v) The RAND Critical Technologies Institute study and report on *The Global Positioning System – Assessing National Priorities*, for the White House OSTP, directed by Dr Scott Pace.

(vi) The Presidential Decision Directive (PDD) on GPS of March 1996.

The Department of Defense, and in particular the GPS Joint Program Office (JPO), deserve much credit for aggressively investigating a wide range of GPS future options and their feasibility. The Acquisition Master Plan (AMP), published by the JPO in August 1997, is an excellent survey and analysis of many of the available options. The Department of Transportation (DoT), the Federal Aviation Administration (FAA), and others have also taken an active role in this area. The President's Decision Directive (PDD) established an Interagency GPS Executive Board (IGEB), to manage GPS and to address GPS and GNSS issues. The IGEB is co-chaired by representatives of the Secretaries of Defense and Transportation, a significant step in civil representation. Direct support of the IGEB is provided by the GPS Interagency Advisory Council (GIAC), chaired by the Director of the National Geodetic Survey.

4. GIAC/ION MODERNISATION CONFERENCES. The GIAC, with the US Institute of Navigation (ION) and the National Geodetic Survey (NGS), has sponsored a series of conferences to develop a consensus on new technical features that are proposed for the IIF spacecraft. This civil GPS modernisation activity involves assisting in the investigation and resolution of the civil GPS architecture options, and in obtaining civil community consensus recommendations to the DoT and other concerned organisations. The initial March, 1998 deadline addressed the selection of a second coded civil frequency with some preliminary investigation of the need and location of a future third civil frequency.

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

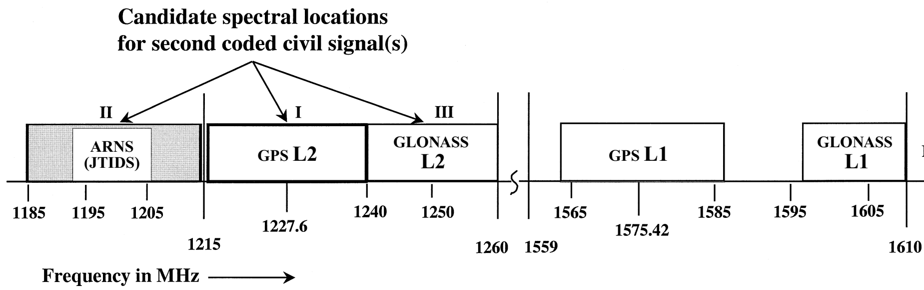

Fig. 1. GPS signal placement alternatives/band assignments

The writer chairs this activity, ably supported Mr Carl Andren, Technical Director of the US ION and Cdr David Minkek of NGS who serves as an advisor to the GIAC. Four civil GPS meetings were held between August, 1997 and March, 1998 in support of the March decision on the selection of the second civil frequency.

What are the wide-ranging options and issues that are being addressed? Table 1, entitled 'GPS Military and Civil Issues,' lists the principal issues of concern. There are others, but these provide a reasonable perspective of the areas of concern. A summary of these follows.

5. GPS SYSTEM ARCHITECTURE. This broad area includes the basic architecture of GPS as it was originally configured in the early 1970s, changes which have occurred with the deployment of the first generation of the operational satellites (Block II, IIA) and the changes associated with the operational replenishment spacecraft (Block IIR). The DoD through the JPO has analysed various GPS architecture scenarios in the AMP. Prior to this, the National Research Council (NRC) investigated various architectural improvements appropriate for GPS in their investigation of *The Future of GPS* during the 1994–95 time period. Additionally, the Defense Science Board (DSB) analysed overall system requirements and architectural changes, in their study that was completed in late 1995. The USAF Scientific Advisory Board (SAB) also investigated architectural changes which could improve the performance and military capabilities of GPS in the future. For our discussion, GPS system architecture includes the overall system functions and configuration, details of the signal structure, augmentations to improve GPS capabilities and constellation enhancements.

5.1 *System functions and configurations*. The dual-mode use of GPS implies both civil and military applications of the same frequencies and in some cases the same signals. Although this is feasible, and has operated reasonably well over the years, it is clear that this constraint limits substantially the flexibility of GPS military applications. For example, the ability of the military to change signal structure or frequencies is largely precluded if the civil community is dependent on the same signals and frequencies. For this and other reasons, the DoD finds it desirable to have differing signal structures and frequencies for civil and military users. Studies of GPS architecture appear to recognise this; however, the practicalities of implementing separate systems are extremely difficult, largely

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

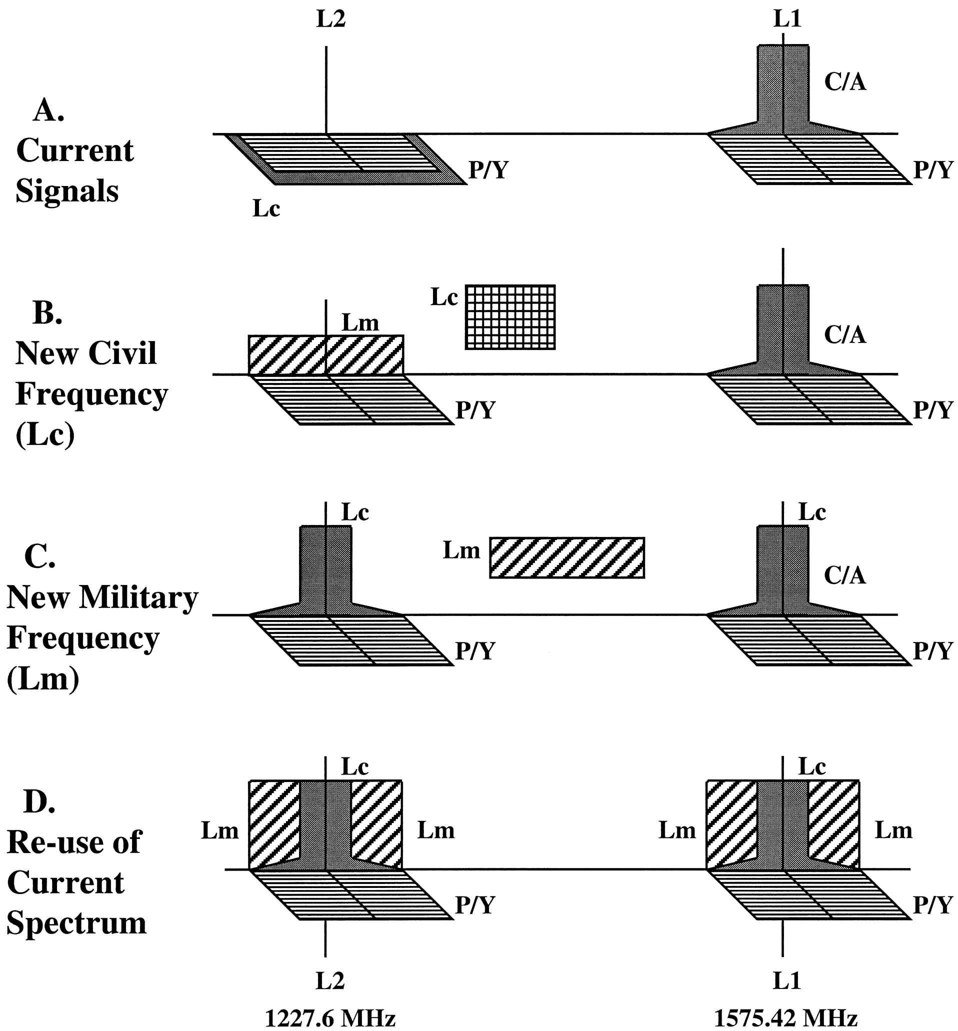

Fig. 2. Four GPS signal options

because of the unavailability of additional operating frequencies in the L-band region. This is especially difficult if one attempts to find frequencies in the 'radionavigation satellite' part of the L-band.

5.2 *Spectrum considerations*. The search for new GPS second civil coded frequencies in L-band has not been successful. Recent investigations have focussed on the three principal regions shown in Fig. 1. The first region is in the lower part of L-band, just below the GPS L2 band. This is the aeronautical radionavigation services (ARNS) band, currently occupied by JTIDS (the DoD's Joint Tactical Information Distribution System), TACAN (Tactical Air Communications and Navigation System) and the civil air traffic control radar beacon system, including the Mode-Select radar surveillance and data link system. Second, the GLONASS L2-band (1240–1260 MHz) has been considered. The upper

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

8–12 MHz of the GLONASS L2 band is a viable region in that GLONASS carrier frequencies will be moving to the lower end of their L1 and L2 bands in the coming years. However, coordination with the Russian Federation is needed. The third region is in the GPS L2 band. Investigations have analysed the frequencies available throughout the entire ITU allocated radionavigation satellite band (1559–1610 MHz) as well as frequencies outside these bands. It appears that the current GPS L1 and L2 bands, although not ideal, are excellent candidates and, in fact, have been selected as future bands for GPS civil L1 and L2 signals.

5.3 *Signal structure.* As mentioned, the current signal structure of GPS dates back to the early 1970s. Fortunately, both the coarse/acquisition (C/A) code and the precise/encrypted (P/Y) code have many excellent properties that have served well both military and civil users over the years, as shown in Fig. 2A.

The DoD has investigated new signal structures and, in order to have full access to L2, a new civil signal (designated Lc) has been proposed, as shown in Fig. 2B. If Lc is placed at L2, then a new military link, designated Lm, is needed as shown in Fig. 2C. Signal architectures have been proposed by JPO in which the existing L1 and L2 bands are 're-used' for civil and military applications, as shown in Figure 2D. The 'frequency re-use' proposal appears promising to the JPO and to others, especially since there has been no success to date in locating a new military or civil frequency (Lm or Lc).

5.3.1 *L1/L2 frequency re-use proposal.* The re-use proposal addresses the entire 24 MHz allocations at the GPS L1 and L2 frequencies. The 24 MHz L1 and L2 allocations are about 4 MHz greater at each frequency than the 20·46 MHz P/Y-code main spectral lobe. The C/A-code modulation would remain the same with the civil users having access to the entire 24 MHz band. The military P/Y-code modulation would also remain unchanged, including its phase quadrature relationship to the C/A-code. The P/Y-code would be continued or could be phased out with the transition of military users to a new Lm signal.

The new Lm signal has a spectrum arrangement which places most of its signal power into two symmetrical 8 MHz band pairs, located above and below L1 and L2. This Lm spectral distribution can be accomplished by Manchester coding or similar techniques. The centres of the Lm band pairs are separated from either L1 or L2 by 8 MHz, leaving a third 8 MHz region centered at L1 and L2 that has very little Lm signal power.

The civil C/A-code occupies the center spectral region at L1 and L2 and this 8 MHz band contains almost all (about 99%) of the C/A-code signal power. Since civil users have access to the entire 24 MHz band, the operation of narrow correlator receivers (now configured for 8–20 MHz) and the use of wide-band techniques for civil multi-path mitigation should not be affected.

Analyses are now being conducted by JPO and others to determine the performance characteristics of the re-use option. One concern is the isolation between the new military signal, Lm, and the C/A-code. Preliminary analytical results indicate that interference levels are low.

The frequency re-use option appears to be a viable and possibly acceptable method for achieving civil and military use of the existing ITU radionavigation

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

satellite allocations for GPS. However, there has been some concern relating to the compatibility of this technique with full use of L2 by an Lm signal.

Civil availability of clear signals (i.e. unencrypted codes) on L2 from a constellation of 15 or more GPS spacecraft is estimated to occur at about 2008–2010.

5.3.2 *The GPS dual signal configuration.* A signal arrangement that has several advantageous features is shown at the GPS L2 band in Fig. 3. This split spectrum, or dual signal, configuration was originally proposed by the writer at the August 1997 meeting of the Civil GPS Modernisation Group at the National Oceanographic and Atmospheric Administration auditorium in Silver Spring, MD. It was also briefed at the November, January and March meetings.

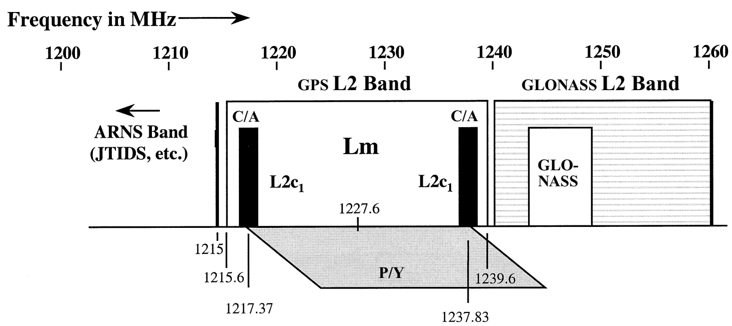

Fig. 3. Candidate GPS L2 dual signal locations. This technique addresses real time carrier phase ambiguity resolution and the use of multiple signals to obtain substantial system performance improvements (proposed by K. D. McDonald, August 1997). The technique is also recommended for improved code performance (proposed by J. Spilker, March 1998). Lm, Military link signal; ARNS, aeronautical radionavigation service; JTIDS, joint tactical information distribution system (DoD); GLONASS, global orbiting navigation satellite system of the Russian Federation.

Principal advantages of the dual signal arrangement include: a) the Lm signals have nearly full use of the GPS L1 and L2 bands with minimal interaction with Lc signals; b) the pair of coded civil signals (C/A-coded, or a variant) placed at, or near, the P/Y-code nulls provides a 'very wide lane' capability for resolving the integer wavelength ambiguity associated with precise carrier phase measurements; and, c) the C/A, or other, codes provide a redundant and more robust arrangement for code ranging. The 20·46 MHz difference between P/Y-code nulls provides a very wide lane of about 14·7 meters.

The dual signal arrangement in one band with the use of a second civil frequency in a different band allows the determination of ionospheric group delay as well as a step-wise resolution of carrier phase. For example, the initial use of the 14·7 meter very wide lane is followed by the use of the 86 cm wide lane obtained from L1/L2 measurements, and this is followed by direct measurement of the carrier phase at either L1 or L2 (or both). In this way centimeter to decimeter levels of accuracy can be unambiguously achieved.

The dual signal arrangement also avoids the degradation effects (which the DoD calls fratricide) on the military P/Y-code 'legacy' signal in the event that

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

the civil signals need to be denied to an adversary. Placing the signals at the extremities of the GPS band(s) also provides increased flexibility to the DoD in their selection of a new military link (Lm). Manchester coding, or similar techniques, to move the signal power away from the center of the band would not be necessary. A new Lm could occupy the entire band, as we have now with the P/Y-coded signals. Additionally, Dr James Spilker recently demonstrated that this signal arrangement has excellent properties for obtaining substantially improved code measurements. Processing of the dual C/A-coded signals provides accuracy better than from P/Y-code receivers and indications are that performance is comparable to that of GPS narrow correlator receivers.

Many of the signal advantages (excellent accuracy, very low multipath, rapid reacquisition, etc.) would benefit aviation users. However, aviation spectrum managers are wary of L2 because of its unprotected character. Many believe that the use of L2 could jeopardize safety of life applications unless the band is exclusively for GPS operations.

The dual signal arrangement would be appropriate and highly desirable for L1, as shown in Fig. 4, offering substantial advantages to future users. However, if a dual C/A-code at L1 is to replace the currently available single C/A-code signal at L1, a long phase-over interval may be required.

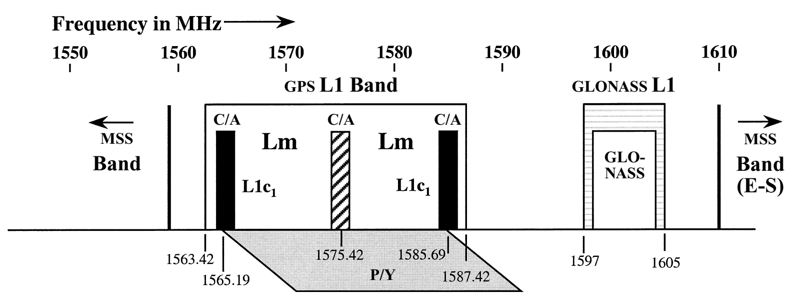

Fig. 4. Candidate GPS L1 dual signal locations. MSS, Mobile Satellite Services (below 1559 MHz and 1610–1626·5 MHz). Dual coded signal recommendation to GPS Civil Modernization Group Meetings in Aug. 97, Nov. 97, Jan. 98 and Mar. 98 by K. D. McDonald.

Other signal options have been considered including the use of higher chipping rates (20–100 Mbps), longer C/A-codes (2–20 Kbps) as well as the use of higher carrier frequencies (e.g. C-band) and composite techniques including PN-codes with frequency hopping.

5.4 *GPS augmentations*. The accuracy for most civil applications of GPS requires considerably better performance than is achievable with stand-alone GPS. This is especially true when SA degrades the accuracy to the 60–100 meter 2drms level. For this reason, differential corrections are normally applied to provide substantially better GPS accuracies. Differential code corrections can provide GPS accuracies better than 5 meters and in some cases to the sub-meter level. Carrier phase corrections of GPS, similar to techniques which surveyors and others use, can provide real time kinematic (RTK) accuracies to the centimeter level.

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

5.4.1 *WAAS, EGNOS and LAAS*. The FAA Wide Area Augmentation System (WAAS) as well as the European Geostationary Navigation Overlay System (EGNOS) plan to employ code differential corrections through geostationary satellites to provide Cat I landing capabilities to properly equipped aircraft. The FAA's Local Area Augmentation System (LAAS) plans to use differential reference stations and pseudolites to obtain accuracies to the sub-meter level for all categories of precision approach and landing. These systems also plan to provide integrity, differential corrections and related data to users. It may be feasible for future GPS systems to provide some of the integrity and differential augmentation requirements of the civil community. This is an issue area under investigation.

5.4.2 *GLONASS*. The Russian Global Orbital Navigation Satellite System (GLONASS) provides an additional satellite constellation which has some favorable properties. Although the GLONASS constellation is currently operating at a reduced level, it plans to provide a constellation of 24 satellites. These additional satellites provide improved availability when used in combination with GPS. The determination of receiver autonomous integrity monitoring (RAIM) is substantially improved using GLONASS, partly because of the increased number of satellites and partly because of the absence of any SA-like degradation on the GLONASS signals.

5.5. *Constellation enhancement*. Although the current GPS constellation has been configured to meet military requirements, it has been recognised as having shortcomings in the civil aviation safety environment. A larger constellation of spacecraft would improve civil system capabilities and would also improve many aspects of military performance. An investigation is underway to increase the current GPS constellation to 30 satellites.

6. PERFORMANCE CHARACTERISTICS. There are a number of factors influencing the performance of GPS. These include the level of the signal interference (jamming and spoofing) as well as the availability of adequate received signal power. The performance of GPS can also be influenced by a variety of environmental factors such as ionospheric and tropospheric group delay and multipath. The coming solar maximum conditions will adversely affect the performance of single frequency GPS equipment.

6.1 *Interference, spoofing and jamming concerns*. The low signal power level of the received GPS signals cause the system to be susceptible to interference and jamming. The spread spectrum signal structure provides some benefits; however, the low level of receiver power is an overriding concern. The military is investigating the possible use of new signal structures and power levels as well as improvements in existing techniques. Existing techniques include the use of null-steering antennas which can provide as much as 30–50 dB of anti-jamming improvement. Signal spoofing is of concern to the civil user primarily since the military employ signal encryption which avoids spoofing of the signal.

6.2 *Signal power level increase and direct Y acquisition*. The capabilities of modern spacecraft are such that increased power levels are possible for GPS signals. This increased power is of particular interest to the military since their signals may be jammed in a tactical area. For example, if an adversary is using the C/A-code on L1, then a counter to this would be to jam L1, denying the GPS capability to the adversary. However, this would also deny the friendly user

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

access to L1, forcing the friendly to use only L2. A difficulty arises in that access to the Y-code on L1 and L2 requires initial access to the C/A-code data message on L1. Hence the military would require direct access to the Y-code on L2 without access to the C/A-code on L1. This issue is under investigation.

6.3 *Solar max concerns*. Since the current civil SPS normally involves use of only the C/A-code on L1, compensation for ionospheric group delay must be estimated from an ionospheric model. The model coefficients are provided to the SPS user by the control segment through the satellites. The GPS ionospheric model typically corrects for about half of the ionospheric group delay. The ionospheric activity follows an 11-year solar cycle, hence a maximum is reached periodically. The next solar maximum occurs in the year 2000 and will be significant for a year or two before and for several years following 2000. The ionospheric group delay is the single largest error component in GPS (once SA is removed). Mitigation of the ionospheric effect requires either continuous differential correction or the use of a second civil frequency, appropriately separated from L1. For this reason, there has been interest for several years in finding a second civil frequency for ionospheric correction.

6.4 *Millenium and GPS week 1024 rollover*. These two items relate to GPS receiver implementation. The year 2000-millenium concern is similar to that which has been documented and investigated extensively in the computer field. When the last two digits (99) recycle to zero, many receivers (and computers) may not correctly interpret this transition.

The GPS week 1024 rollover problem relates to the 10 bit week designator in every GPS Subframe 1. These 10 bits indicate the number of weeks elapsed (10 bits = 1024) since 5–6 Jan. 1980. The 1024th week after this 1980 date occurs in August 1999. The 1024 rollover concern relates to the capability of the receiver properly to interpret the 10 bit cycling to the zero state as the subsequent week, i.e. the 1025th week since 5–6 Jan. 1980. Indications are that receivers produced in the last few years have taken into account the week 1024 rollover. Older receivers may have a problem. The recommended way to validate the performance of a receiver is to have it tested on a simulator which can provide the appropriate week rollover transition. The JPO and many other organisations have such simulators which can determine the proper operation of a receiver.

6.5 *Civil undegraded performance*. There has been considerable interest in the scientific and other communities for the civil performance of GPS to be the best obtainable under the prevailing environmental and system constraints. The DoD has for many years been concerned that the accuracy available to civil users of the Standard Positioning Service (SPS) exceeds that which is consistent with national security concerns. For this reason, the DoD has degraded the SPS to a level of about 60–100 meters 2drms by the imposition of selective availability (S/A). The NRC and other advisory committees have strongly recommended the removal of SA .The Presidential Decision Directive (PDD) of 1996 specified that S/A would be removed from GPS by 2006 and that initial consideration for its removal would commence in the year 2000.

Once SA is removed, and a second (clear code) civil frequency is provided, the accuracy of the SPS should progressively improve to the 5–10 meter 2drms level

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

(or better) in a few years. At issue is the acceptability of this civil undegraded performance operational concept to the service providers and their willingness to implement improvements.

6.5.1 *A third civil frequency*. If the dual signal arrangement is not agreed to and implemented, then a separate, third, properly located frequency could be implemented to provide a very wide lane. The possibility of obtaining continental-wide and possibly worldwide centimeter to decimeter position determination capabilities and comparable velocity measurements appear feasible if a third civil frequency could be implemented. The third civil frequency (L3C) could be arranged so as to provide a very wide lane of 5–15 meters (20–60 MHz separation). This measurement could be used with the stand-alone accuracy of the SPS receiver to resolve the integer cycle ambiguities of both the 5–15 meter very wide lane and the narrower wide-lane (i.e. the current 86 cm L1/L2 wide-lane).

The use of an L3C provides the potential for future high accuracy wide area measurements using equipment that is not dependent on expensive ambiguity resolving software. The scientific community as well as the aviation and other communities would find extensive uses for this performance enhancement if the dual signal arrangement is not employed. Also, a C/A-coded L3C could provide a back-up to L2C if it included a recognisable PRN code and data message. Since L2 is not protected to ITU standards in several parts of the world, there is some concern about its use in safety critical applications. However, if L3C were available (even without full protection) it could possibly be used with L2C to provide improved levels of availability and integrity.

7. GPS MANAGEMENT/INSTITUTIONAL CONCERNS. The management of GPS has only recently progressed from exclusive military control to a combined civil-military arrangement. This occurred following the publication of the PDD, which established an Interagency GPS Executive Board (IGEB), Chaired by Deputy Secretaries of Defense and Transportation. Other civil agencies including the Department of State and Department of the Interior are involved. It appears sensible for the DoD to continue as the developer, operator and service provider of GPS, however, the PDD indicates a combined civil/military control for GPS. The details of the DoD stewardship and operation of the GPS system and future priorities, which may be associated with its use, are under discussion.

7.1 *International considerations*. There is considerable interest worldwide in the development and implementation of a Global Navigation Satellite System (GNSS). The International Civil Aviation Organisation (ICAO) has a GNSS Panel which is working to establish future GNSS capabilities. Additionally, various states and groups of states, such as Japan and the European community, have initiated the development of separate GNSS components to meet their specific requirements.

There has been some reluctance, in Europe in particular, to accept GPS because of the military control and the degradation of the civil signal (S/A). These may be of concern; however, of possibly greater concern, is their understandable interest in participating and economically sharing in the growth of a GNSS industry.

8. CONCLUDING COMMENT. The implementation of GPS has created an

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press

industry in the US and worldwide that is quite large and growing rapidly. The GPS industry is at this point very likely supporting the cost of the system and its modernization. The GPS 'economic engine' has substantial implications in terms of the appropriate federal support and encouragement to be provided for civil GPS applications. The national security concerns need to be considered and appropriately addressed. There appear to be complex future trade-offs associated with the pervasive civil applications of GPS and its role in the related GNSS.

KEY WORDS

1. Navaids. 2. GNSS. 3. GPS. 4. Modernisation.

https://doi.org/10.1017/S0373463398007991 Published online by Cambridge University Press