Synchronised Low-Frequency Augmentation of GPS (SYLFA)

William F. Roland

(Megapulse, Inc., Bedford, MA U.S.A.)

As new technologies contribute to the expanded functionality of Loran-C, and as concerns for limitations in GPS and its augmentations are raised, specific aspects of Loran-C have been developed and applied to ameliorate those limitations. Specifically, GPS availability is a concern, particularly in over-land applications. This paper discusses recent developments using very high-precision synchronisation of Loran-C transmissions, new data compression and Loran-C signal modulation techniques to augment GPS accuracy, availability and integrity over a very wide area at very low cost.

1. WHY SYLFA/GPS? It is generally acknowledged that for safety and precision accuracy applications, GPS requires augmentation. There are three parameters of GPS which create the requirements: accuracy limitations due to the ionosphere and to Selective Availability (S/A), the selected frequency band, and the lack of rapid integrity signalling. For example, S/A is sufficient for weapons delivery but not for all civil uses. The frequency band is such that it is line-of-sight, and does not easily pass through solid materials or even heavy foliage. Also, all satellites operate on exactly the same frequency, giving maximum effect to interfering signals. In the event of a fault in the satellite requiring an integrity message, it may be hours before the satellite passes over a monitor site which is capable of determining that a fault exists, and can then update the satellite's navigation message to advise the users of faulty position information.

The roots of the deficiencies lie in the origin of GPS development for military weapons applications, wherein these limited performance characteristics were addressed by other parts of the weapons systems. Accuracy, integrity and availability are sufficient for military applications, where these characteristics are not required to perform to the same standards as those needed for the navigation of commercial ships and aircraft.

The various forms of augmentation in use or in development address one or more of the performance characteristics of GPS in the indicated manner:

1.1 *Accuracy*. GPS accuracy, whether with S/A on or off, is insufficient for the terminal phases of vessel and aircraft operations. The means to improve accuracy is to monitor the observed errors in the GPS signal at a fixed station (or stations) in a region, and communicate the calculated corrections to the users on a broadcast channel. The USCG has developed and implemented radiobeacon-based DGPS (RDGPS) to provide the correction broadcast to mariners for use in restricted waters. The FAA is in the process of developing the Wide Area Augmentation System (WAAS) based on the establishment of GPS monitoring sites distributed over the US land area, communicating corrections to a central

https://doi.org/10.1017/S0373463398008005 Published online by Cambridge University Press

computational facility, which then sends DGPS corrections to special synchronous orbit satellites, which in turn broadcast the DGPS signals to aircraft using special WAAS-qualified GPS receivers. These broadcast systems are capable of providing GPS service horizontal accuracies of 5 meters, 2 drms (95%) or less.

1.2 *Integrity*. Integrity is the ability of a service to provide communication to the users in the event that the service's signals-in-space are not able to provide the specified accuracy or other signal performance parameter. The communication is specified to reach the user within a certain maximum period of time after the anomalous performance is detected. Both RDGPS and WAAS provide for the integrity monitoring and communications functions, and are specified to respond in less than 10 seconds.

1.3 *Availability*. GPS is specified to provide 99·8 percent availability. However, some applications operate under conditions with availability nowhere near that figure. The augmentation services provided by RDGPS and WAAS do not improve on that availability as they only provide a communications function. A future development of WAAS is called for to increase slightly the availability figure. The value of this future development is called to question by many who note that the potential causes which may limit the GPS signal availability also limit WAAS signal availability; that is, interference sources and blockage will deny both the GPS and WAAS signals, and so loss of availability due to that cause will not be improved by a WAAS navigation signal.

Availability has been identified as a major limitation of primary or sole-means dependence on the GPS signal, with or without augmentation of the service accuracy and integrity. There are potential solar and space environment events (magnetic storms and meteorites), both of which will peak within the next few years, which have enormous uncertainty as to their effects on both the GPS and the WAAS satellites. There is no thorough knowledge of the potential of these effects to disrupt the service.

Another limitation on availability derives from the line-of-sight characteristics of GPS signals. Numerous applications, especially land applications, require navigation where GPS signals simply do not penetrate. Urban and forest navigation are particularly difficult, requiring either augmentation of availability or a method of dead reckoning between selected points in open areas where GPS fixes may be obtained.

Additionally, the GPS and WAAS signals are at extremely low levels compared to potential terrestrial interfering sources. There have already been confirmed incidences of GPS receiver front-end blockage by aircraft communications equipment, microwave links which pass over the paths of ships, and television transmitter harmonics. There is great concern for interference from new wireless technology which will be operating in a band adjacent to the GPS frequency band. Further, at a recent air show in Moscow a vendor was actively selling a GPS jammer, and noted to the US DoS reporting officer that he had active discussions with certain Middle Eastern customers. Beyond interference, there is the known potential for the US DoD specifically to deny the availability of the GPS signal. The US has been given assurance that the use of this capability is directly under the control of the President, and will not be used unless absolutely necessary. But foreign nations, with which the US desires to harmonise radionavigation services, point to the military capability as a potential limitation of GPS availability.

Each of these conditions is cause for concern for the availability of the GPS and DGPS signals, and draws one to the conclusion that the augmentation service should include an availability augmentation, such that some navigation capability remains if the GPS signal is unavailable. This is the unique characteristic of Synchronised Low Frequency Augmentation of GPS (SYLFA/GPS).

2. CURRENT AUGMENTATIONS AND DEVELOPMENTS. Prior to introducing the functions of SYLFA/GPS, it is appropriate to point out the relevant characteristics of current GPS augmentations:

2.1 RADIOBEACON DGPS. Utilises transmitters in the marine radiobeacon band by modulating a sub-carrier with the DGPS information. Generally, existing radiobeacon transmitters are modified to provide the communications modulation, and the site is upgraded with a bigger antenna, dual DGPS reference receivers, and an un-interruptible power source. The signal range is typically 100 to 200 kilometers, greater in the day than at night. There are about 60–100 of these RDGPS sites in North America, and numerous sites have been installed throughout the world. RDGPS contributes substantially to the accuracy and integrity of the GPS service, but does nothing for availability.

2.1.1 *Accuracy*. RDGPS is capable of accuracies of 1 to 5 meters, 2 drms (95%) at ranges to 100 kilometers, with degradation from that point due to spatial decorrelation. Night-time performance is reduced by skywaves which cause signal fading beyond 100 kilometers. The transition between use of one beacon and the next may cause discontinuities in the observed track.

2.1.2 *Integrity*. RDGPS is capable of providing integrity messaging for both the GPS signal and its own signal.

2.1.3 *Availability*. RDGPS does not contribute to the availability of the GPS navigation service.

2.2 WAAS AND EGNOS. WAAS and EGNOS are proposed DGPS services, which utilise a network of monitoring sites over the region for which the service is implemented. These monitoring sites are separated by 400 to 800 kilometers. Each monitoring site receives all satellites in view, and sends the data and the current pseudo-range to each satellite to a remote computing center. There, the data from all sites is processed to determine the separate clock, ephemeris and ionospheric errors for each satellite and for each region of the sky. This data is then sent to a synchronous orbit communications satellite where it is rebroadcast to the entire region on the same frequency as the GPS signal.

2.2.1 *Accuracy*. The service provides an accuracy of the same order as the RDGPS service, with reasonably smooth transitions across the area of coverage, but at considerably higher cost.

2.2.2 *Integrity*. The service provides integrity messaging, both for the GPS service and for the WAAS signal.

2.2.3 *Availability*. The initial implementation of the service as planned does not address availability, but it is expected that a future expansion of the service will include a pseudo-ranging signal on the WAAS service.

2.3 COMMERCIAL DGPS SERVICES. There are a number of commercial DGPS services which offer sub-meter performance and are being applied in non-safety related applications. These services use existing radio data services, such as communications satellites and data sub-carriers on commercial FM broadcast stations. Current regulations prohibit the use of privately owned and operated radionavigation services for safety-related applications. These commercial DGPS services are interpreted by DoT to be radionavigation services, and so are prevented from providing communication services for safety-related applications. This discussion does not address the potential of commercial services.

3. SYLFA/GPS FUNCTIONS. SYLFA/GPS is an integration of two separate Loran-C development efforts. It is implemented at Loran-C stations, wherein the Loran timing equipment is synchronised to GPS and the transmitted signal is modulated (Eurofix) to carry the GPS differential data. It requires the user to have a GPS[1] receiver capable of using RTCM-SC-104 data, in addition to a Loran-C receiver capable of providing pseudo-ranges and of demodulating the Eurofix data.[2] SYLFA/GPS is specifically designed to provide the same type of service as the RDGPS service, and to add the major improvement of availability augmentation for the radionavigation service. The substantially different characteristics of the Loran-C signal, as compared to the GPS signal, limit any single thread faults which might otherwise affect radionavigation service availability.[3] SYLFA/GPS synchronises the Loran signal to the GPS signal so that satellite pseudo-ranges and Loran station pseudo-ranges may be used in a single common position solution and can be used in a RAIM algorithm to further improve on the SYLFA/GPS provided integrity messaging.[4] SYLFA/GPS also adds the Eurofix communications channel, providing differential corrections to GPS pseudo-ranges and integrity messaging.[5]

In application, the SYLFA/GPS signals and data are used with the primary GPS signals, to provide a 3–4 meter 2 drms accuracy DGPS position. Because the basic Loran-C service provides at least three receivable signals to the user in the coverage area, the DGPS data can be enhanced using a regional (multi-Eurofix station) data processing algorithm which reduces spatial de-correlation of the DGPS data.[6] Additionally, the DGPS position is used to calculate the variable component of the Loran atmospheric propagation velocity (Additional Secondary Factor-ASF). With this real-time ASF correction, should there be a sudden loss of GPS signals, the Loran service can continue to provide positioning service with DGPS accuracy, only gradually degrading with time and position change.

3.1 GPS TIMING AND DIFFERENTIAL REFERENCE. At each Loran-C transmitting station, a GPS reference receiver provides continuing observation of pseudo-ranges to all satellites in view. The reference receiver also provides 1-pps timing signals for comparison with the Loran-C station's primary time and frequency reference. The reference receiver computes the differential pseudo-range errors, which are used to calculate the DGPS pseudo-range and pseudo-range-rate corrections for each satellite in view.

3.2 CESIUM BEAM OSCILLATOR CONTROL. Each Loran-C transmitting station is equipped with two independent cesium beam primary reference oscillators. These frequency standards are precisely synchronised to the GPS constellation clock using a computer to permit averaging over many days to eliminate all sources of noise in the alignment process, and to control the precise frequency offset of the station time reference. Typically, the SYLFA cesium standard is set so as to provide timing accuracy for Loran-C navigation equivalent to less than a meter of position accuracy.

3.3 LORAN-C TIMING AND CONTROL. All Loran-C timers are designed to provide exact synchronisation of the timer reference waveforms to the time reference of the transmitted Loran-C pulses' antenna current. The timer reference is compared to each cesium standard every 6 seconds to maintain the ability to detect conditions requiring a Loran integrity message (blink) within that time period. Long-term averages assure exact synchronisation of the transmitted pulses to the cesium standard.

3.4 TRANSMITTER MODULATION. The transmitted Loran-C pulses are pulse position modulated according to the algorithms developed by the Eurofix development team at the Technical University of Delft. Transmitter modulation is applied in such a way as to assure that there is minimum effect on the accuracy of the Loran-C navigation service.[7] There are always two unmodulated pulses in each pulse group and an equal number of advanced and retarded pulses. The timer reference signal and the antenna current are simultaneously modulated so that the exact synchronisation of every transmitted pulse is assured.

3.5 LORAN AND GPS INTEGRITY MONITORING. The SYLFA/GPS equipment monitors the GPS signal integrity to the same standards as required by the 'aviation blink' requirements imposed by the FAA on USCG blink automation. The SYLFA/GPS also monitors the Eurofix message to insure the integrity of the DGPS message content. GPS integrity messages are sent using the Eurofix message format. Loran-C signal integrity and DGPS message integrity are signalled using the Loran-C blink.

3.6 SYLFA/GPS RECEIVERS[4]. SYLFA/GPS receivers may come in at least three forms: Integrated GPS/Loran-C/DGPS, Loran-C and DGPS with RTCM SC-104 output (for use with a separate GPS receiver), and DGPS only with RTCM SC-104 output.

3.6.1 *Integrated GPS/Loran-C/DGPS receiver*. In normal operation, this receiver functions as a GPS receiver with DGPS correction inputs. While in this mode, the receiver provides positions with DGPS accuracy and continuously updates the observed ASF corrections for Loran-C. This process permits continuous precision navigation using Loran-C plus any remaining GPS satellites through short outages of GPS, improving continuity of service, and allowing time for implementing alternate procedures should a longer term outage occur. It also allows continuous GPS operation through any Loran-C outage, with reduced accuracy due to loss of DGPS data. In Loran-C navigation coverage areas, there are at least three independent sources of DGPS data, vastly increasing the availability of DGPS data, and providing the option for regional calculation of DGPS corrections which markedly decreases spatial de-correlation.

3.6.2 *Loran-C and DGPS receiver*. This receiver provides continuous Loran-C position information for use in independently determining position as an integrity check on the GPS service. The receiver also provides DGPS data and integrity messages to the GPS receiver for precision navigation. It allows continuous operation through any Loran-C or GPS outage, with reduced accuracy due to loss of DGPS. In Loran-C navigation coverage areas there are at least three independent sources of DGPS data, vastly increasing the availability of DGPS data. The option for regional calculation of DGPS corrections is not provided because of the form and content of the RTCM SC-104 data.

3.6.3. *DGPS-only receiver*. The DGPS-only receiver is capable of providing DGPS data to the GPS receiver, but does not provide an independent position fix. Its main advantages are the low cost of obtaining DGPS data, and the reliability of the data due to the minimum of three transmitter sources of data. Typically, the DGPS-only receiver can be implemented in a hand-held device with a small loop antenna for receiving the Eurofix/Loran-C signals.[8]

4. SYLFA/GPS TRANSMITTING STATION EQUIPMENT (see Fig. 1).

4.1. *GPS receivers*. Fully automated GPS time transfer can be used to determine the cesium standard time offset to an accuracy of better than 10 nanoseconds. The long-term stability of the cesium standard is necessary for this determination. Measurements of 1pps(CS)–1pps(GPS) are made using a time interval counter with at least 0.1 nsec accuracy. Using at least 48 hours of data, the computer determines the time and frequency offset of the cesium and makes precise changes to the CS frequency to eliminate the errors. Demonstrated accuracies of ± 8 nsec and ± 3 parts in 10^{14} have been routinely achieved with three-day data periods, and using a linear least squares fit.

4.2 *Loran signal monitoring*, *TOC*. The SYLFA/GPS computer monitors either the timer reference signal or the actual antenna current depending on the particular timer type. The time of the reference signal is compared to the CS 1pps. In this manner, the time stability and the timer reference to GPS time is checked every 6 seconds. This method provides both an integrity check and accuracy control over the radiated signal. Measurements have shown a ± 2 nsec 2-sigma variation of the timing error.

4.3 *Control & communications computers*. All time interval measurements are made with a time interval counter card under computer control, with a measurement resolution of 0·1 nsec, and a clock derived from the CS, assuring accuracy of better than $\pm 0{\cdot}2$ nsec. The computer is also equipped with a clock card driven by the CS, set to Atomic time, and readable at high speed on the computer bus. The clock is used to determine the time of coincidence and the Loran offset at any second.

The computer is interfaced to the CS, Timer, GPS Reference Receiver, UPS, and to the network which includes the computer managing the other timer, and the computers managing external (to the station) communications.

5. SYLFA/GPS PERFORMANCE.

5.1 TIMING ACCURACY, LORAN TIME OF TRANSMISSION CONTROL. The recently completed installation of the UTC Synchronisation System (USS) at the Pohang (Korea) Loran-C transmitting station has confirmed the effectiveness of GPS time transfer. The USS uses the US Naval Observatory's 'melting pot'[9] method for robust and automated time transfer. The cesium standard is synchronised to GPS time within ± 8 nsec, 2 sigma. The 2 sigma stability of the transmitted Loran-C signal reference is an additional ± 2 nsec.

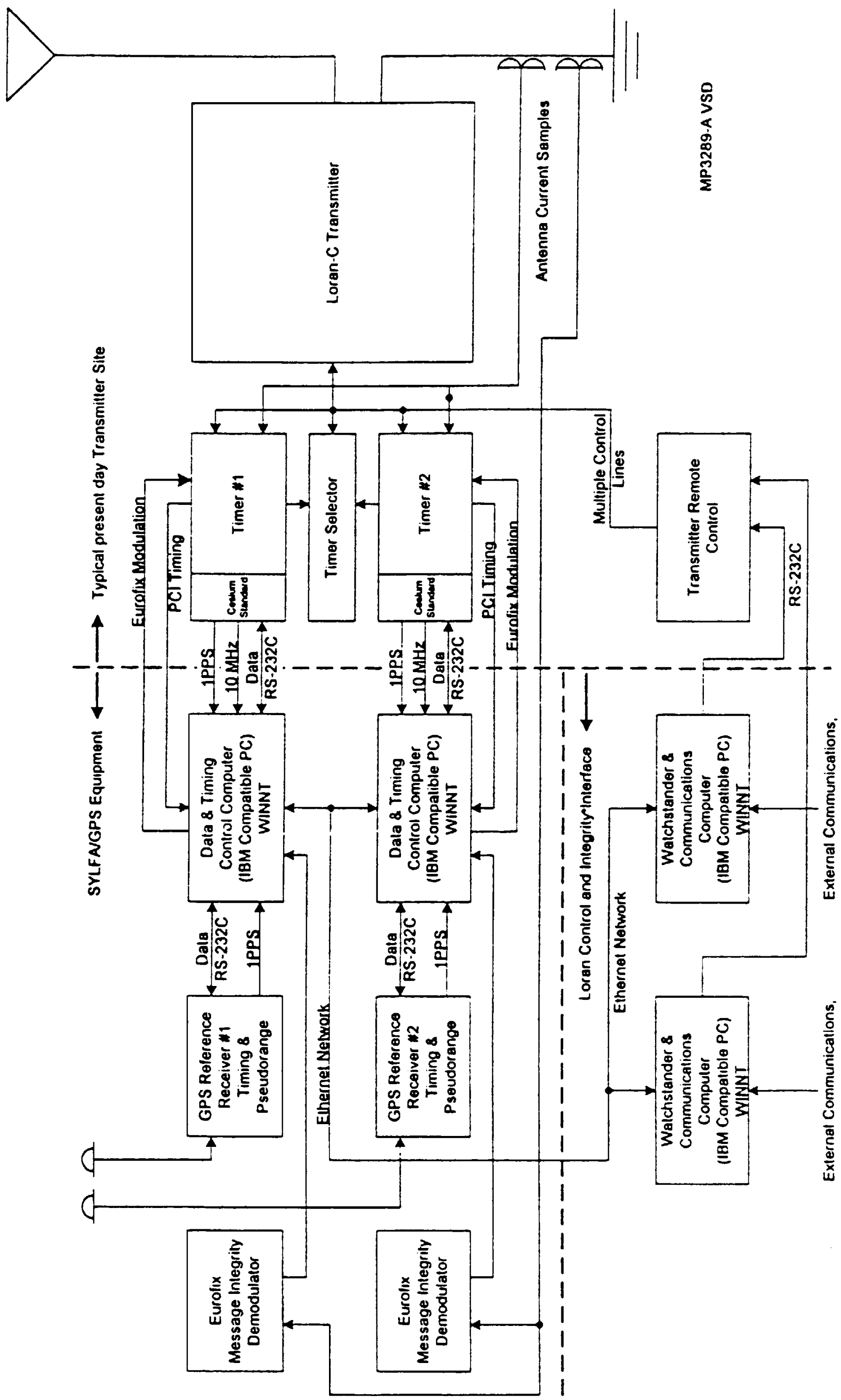

Fig. 1. SYLFA/GPS functional block diagram for the Loran-C transmitting site

5.2 DIFFERENTIAL GPS CORRECTION ACCURACY. The GPS reference receivers used in the Sylt, Germany tests are NovaTel 12-channel DGPS reference receivers. They are capable of providing corrected GPS positions with less than 1 meter of error when there is no time or spacial de-correlation.

5.2.1 *Accuracy and de-correlation effects*. In static tests at 400 km from the Loran transmitting site, Delft University investigators have reported 2·5 meter 2 drms accuracies, with peak errors of 5 meters. At 1000 km the 2 drms accuracy increases to about 3·5 meters, with the same peak errors.

5.2.2 *Time de-correlation and channel bandwidth*. The Loran-C communications channel bandwidth limits the accuracy of the DGPS service because of time de-correlation. By the use of data compression, error detection and correction the Eurofix DGPS has demonstrated a data bit rate of over 30 bits per second. This is twice the previously achieved communications performance and contributes directly to the much lower effects of time de-correlation.

5.2.2.1 *Spacial de-correlation, multi-site DGPS*. Spacial de-correlation becomes a significant contributor to position errors at the distances proposed in the Eurofix research. However, the Loran-C service is designed to provide no less than three independent signals everywhere in the coverage area, and these signals can provide DGPS corrections from widely dispersed sites around the user's position. This provides the opportunity for the sophisticated user to calculate the effect of spatial de-correlation as described in Reference 6.

5.2.2.2 *Communications channel robustness*. The testing reported by Delft University researchers also included the effects of very strong cross-rate signals on the channel performance. At −20 db signal-to-cross-rate ratio, and at 800 km from the Eurofix transmitter, there was no measurable message error rate.

5.3 INTEGRITY RESPONSE TIME.

5.3.1 *GPS integrity*. The Timing Control Computer is programmed to check the integrity of the DGPS position every 6 seconds to determine if there is any space vehicle (SV) with an out-of-tolerance signal. On detection of an integrity fault, an integrity message is sent at the next opportunity, which is nominally within 2–3 seconds. It is variable depending on the Loran-C pulse rate (GRI). The messaging function has been tested; however, the Delft experiments have not implemented integrity messaging.

5.3.2 *Loran-C integrity, 'Aviation blink'*. The Timing Control Computer (TCC) detects Loran-C timing anomalies with measurements every 6 seconds. The Loran-C blink is implemented within the next PCI ($< 0·2$ seconds).

5.3.3 *Eurofix modulation integrity*. The Eurofix modulation of the Loran-C pulse is demodulated from the antenna current by the Message Integrity Monitor. This device compares the individual bits in the modulated signal with the modulation signal used to create it. Any discrepancy is cause for an integrity message on the Eurofix channel.

5.3.4 *Eurofix message integrity*. Both TCC 1 and 2 compare their respective messages to the other TCC. Disagreement on the data to be transmitted for a particular satellite generates an integrity message for that satellite. These comparisons are made as the data are generated and checked over the Ethernet network in real time.

5.4 EQUIPMENT AVAILABILITY, REDUNDANCY AND GRACEFUL DEGRADATION. The UTC synchronisation and Eurofix communication equipment is built to the same standards as the navigation transmitter. Because it is physically separate, and the timer and transmitter can run without it, failures in the equipment will, at worst, result in loss of Eurofix messages, and UTC synchronisation which degrades over several days or a week depending on the Cesium Standard. Experience to date, with over 9 months of operating data on each system, is that there have been no transmitter site hardware or software failures.

6. RESULTS AND ANALYSIS OF US COAST GUARD TESTS OF EUROFIX, APRIL 1998. 'Eurofix' is the acronym given to the Loran-C communications modulation and differential GPS coding scheme developed by the Technical University of Delft and implemented at the Loran-C transmitting station at Sylt, Germany. The experimental service has been operational since February, 1997. The test results have been highly successful, demonstrating an accuracy of 3 meters, 2 drms at Delft, a distance of 350 km from the transmitter. Further, during the entire test, no erroneous messages have been passed to the DGPS receiver by the Eurofix receiver. Successful tests have been conducted at distances of up to 1000 km, demonstrating accuracies of 5 meters, 2 drms at the maximum distances, still with no erroneous messages.

The dramatic results of these tests have evoked the interest of the US Coast Guard Headquarters in the Eurofix system. A short demonstration and test was scheduled for 30 March to 3 April, 1998, to take place at the Coast Guard Loran Support Unit (LSU) at Wildwood, NJ, USA. Delft University and Megapulse, Inc. combined forces to implement a temporary Eurofix modulator using the Loran-C transmitter at the LSU. The transmissions were monitored at the USCG NavCen at Alexandria, VA, the USCG Academy at New London, CT, and the Megapulse, Inc. Laboratory at Bedford, MA.

The Coast Guard has not issued a report of these tests as yet; however, Megapulse engineers have completed analysis of the data observed at their laboratory. Megapulse is located 506 km from Wildwood. The equipment setup included two DGPS receivers (Novatel and Magellan), three Loran-C receivers (Locus, Micrologic and Megapulse) and one Eurofix receiver, implemented in an IBM-compatible PC and providing corrections to both DGPS receivers. Observations were made of data link integrity, DGPS accuracy, and Loran-C time difference errors due to Eurofix modulation.

The Eurofix data link again demonstrated remarkably high integrity. During the entire test, no erroneous messages were sent to the DGPS receivers by the Eurofix receiver and 'failed' messages were detected and inhibited whenever the modulation was turned off. Text messages, equivalent to station and satellite health messages, were inserted between DGPS messages on occasion, without disrupting DGPS.

Eurofix accuracy, observed at Megapulse was 3 meters, 2 drms. The accuracy proved to be quite dependent on multipath, as should be expected. For effective use of any DGPS data source, the GPS receiving antenna must be multipath-free. There was not sufficient time in the program to permit use of mobile instrumentation, especially for establishing the service range.

Lastly, the Loran-C receivers were observed for the possibility of offsets in the time difference readings due to modulation. As expected, the hard-limited signal processing receivers were least affected by the modulation, showing under 10 nsec variations between modulated and unmodulated signals. The linear receiver showed a greater offset, at 35 nsec difference between modulated and unmodulated signals. This is not considered significant; firstly, because it would normally be expected that both stations on a base-line would be modulated, so the net time-difference offset would be zero. Secondly, in a linear receiver, the offset is constant with variations in signal-to-noise ratio, so the offset could be calibrated, or more likely, the signal could be demodulated and the tracking offset removed. The conclusion is that the modulation should be symmetrical (+1 or −1 usec), and the receiver should provide whatever compensation might be required.

The Megapulse, Inc. conclusion from these tests is that the data accuracy and link integrity are repeatable as compared to measurements in Sylt, that long-range DGPS is quite feasible, and that the modification required to install Eurofix is insignificant. Therefore Eurofix is capable of providing DGPS service over most of North America using the existing Loran-C facility.

REFERENCES

[1] Roland, W. F. (1997). UTC synchronisation of Loran-C time of transmission using GPS time transfer techniques. *Proceedings*, 26th Annual Technical Symposium of the International Loran Association, Ottawa, Ontario, Canada.

[2] van Willigen, D. (1989). Eurofix. This *Journal*, **42**, 375–381.

[3] Anderson, J. H. and Sweet, C. M. (1994). *Proceedings*, 23rd Annual Technical Symposium of the Wild Goose Association, Newport, Rhode Island.

[4] Helwig, A. W. S., Offermans, G. W. G. and van Willigen, D. W. (1996). Implementation and testing of Eurofix in standard Loran-C receiver technology. *Proceedings*, 25th Annual Technical Symposium of the International Loran Association, San Diego, CA.

[5] Helwig, A. W. S., Offermans, G. W. G. and van Willigen, D. W. (1996). The Eurofix datalink concept: reliable data transmission using Loran-C. *Proceedings*, 25th Annual Technical Symposium of the International Loran Association, San Diego, CA.

[6] van Essen, R. F., Offermans, G. W. G., Helwig, A. W. S. and van Willigen, D. (1997). Regional area augmentation concept for Eurofix. *Proceedings*, 26th Annual Technical Symposium of the International Loran Association, Ottawa, Ontario, Canada.

[7] Helwig, A. W. S., Offermans, G. W. G. and van Willigen, D. W. (1997). Eurofix DGPS service through the Sylt Loran-C transmitter: static and dynamic test results. *Proceedings*, 26th Annual Technical Symposium of the International Loran Association, Ottawa, Ontario, Canada.

[8] Peterson, B., Novick, Y. and Dykstra, K. U. (1997). Magnetic loop base Loran receiver for urban canyon applications, 1997 update. *Proceedings*, 26th Annual Technical Symposium of the International Loran Association, Ottawa, Ontario, Canada.

[9] Miranian, M. and Klepczynski, W. J. (1991). Time transfer *via* GPS at US Naval Observatory. *Proceedings*, US Institute of Navigation's *GPS'91*.

KEY WORDS

1. Navaids. 2. Loran-C. 3. Augmentation. 4. GPS.