# Loran in 2003

Loran receiver technology has made major advancements over the last decade, largely due to contemporary digital signal processing (DSP) hardware and software, and this article reviews these technological advancements and performance improvements. However, Loran is a "system" comprised of the transmitter/control infrastructure and the individual receiver, and Loran receiver performance in 2003 is limited by an antiquated infrastructure. Fortunately, the United States Loran infrastructure modernization will be completed in a few years. The title "Loran in 2003" indicates results discussed here will improve when that modernization is complete.

A modern Loran system can operate as an independent backup to the global positioning satellite (GPS) system in all modalities (i.e. aviation, marine, terrestrial, and timing applications), and the systems are synergistic (e.g. GPS can be used to generate ground conductivity correction factors that greatly enhance Loran's absolute accuracy, and Loran can be used to transmit differential GPS corrections and integrity messages to improve GPS performance). Some GPS/Loran synergies are included to address these attributes of a modern Loran system.

## Modern Loran Receivers

Loran is a ground-based radionavigation system, with signals that propagate along the surface of the earth (i.e. groundwaves) and reflect off the ionosphere to return to the earth's surface (i.e. skywaves). Groundwaves and skywaves impinge on a receiver, plus other noise present in the spectrum around 100 kHz (e.g. noise from a nearby power line or lightning). In general, groundwaves are useful for navigation purposes, but skywaves contribute unwanted noise and distort groundwaves. In order to resolve the most useful groundwaves accurately and to reduce noise introduced by skywaves, less useful groundwaves, and other interference sources, a modern Loran receiver must track, separate, and process all these signals simultaneously to achieve the performance now possible with Loran.

Older Loran receivers were typically hybrid analog/digital devices with little processing power. Most tracked only 5-7 Loran stations and had limited signal resolution and noise handling capabilities. In contrast, modern Loran receivers are DSP-based and "all-in-view," meaning they track up to 40 stations simultaneously and use DSP technology to enhance useful signals and remove or reduce unwanted noise.

Tracking all these stations might appear to be overkill, but in fact, is necessary. Loran's relatively low frequency signals travel great distances with little attenuation, so a receiver can track distant as well as nearby stations. Moreover, signals from distant transmitters are often significantly stronger than those from nearby transmitters, and those signal levels can vary rapidly, depending on topography, weather, time-of-day, transmitter power levels, etc. Identifying, quantifying and, in some cases, removing other Loran signals, plus other background noise, is a complex process requiring sophisticated software and hardware.

Data from an all-in-view receiver illustrate this point (Tables 1a and 1b). Table 1a shows data from 6 of 35 stations across the US and Canada tracked simultaneously in Madison, Wisconsin. Note signals from the Caribou, Maine (1076 miles distant) and Nantucket, Massachusetts transmitters (1000 miles distant) have signal to noise ratios that vary by 15 dB (a factor of about 6), despite transmission paths that are only 76 miles different. Table 1b shows just a few of the skywave and groundwave signals that can be received at Fairbanks, Alaska. Here, groundwaves from Shoal Cove, Alaska (862 miles from Fairbanks) are 17 dB uV/M, but skywaves from Ejde, Norway (3441 miles distant) are 44 dB uV/M. Since Shoal Cove signals are more important to the Alaskan user than Ejde signals, the all-in-view receiver must be able to remove the much larger Ejde signal without distorting the smaller, but essential, Shoal Cove signal.

| Chain / Station | Location | Distance | SNR | Time of Arrival |
|---|---|---|---|---|
| 5930Y | Cape Race, Canada | 1775 Mi | -13 S/N | 32510363 |
| 7980Y | Jupiter, FL | 1224 Mi | -5 S/N | 47121889 |
| 9610W | Searchlight, NV | 1462 Mi | -15 S/N | 31890672 |
| 9960W | Caribou, ME | 1076 Mi | -11 S/N | 16173428 |
| 9960X | Nantucket, MA | 1000 Mi | 4 S/N | 28933526 |
| 9960Z | Dana, IN | 245 Mi | 23 S/N | 55068549 |

**Table 1a.** Data from 6 of 35 stations simultaneously tracked by an all-in-view receiver in Madison, Wisconsin. Columns show station identifier, location, distance from Madison, signal to noise ratio, and time difference between the master station and identified station in nanoseconds.

| GRI/Chain | Station | Distance (miles) | Signal Level |
|---|---|---|---|
| 7960 / Gulf of Alaska | TOK (M) | 185 | 78 (G) |
| | Narrow Cape (X) | 533 | 54 (G) |
| | Shoal Cove (Y) | 862 | 17 (G) |
| 8290 / North Central U.S. | Havre (M) | 1774 | 44 (S) |
| | Baudette (W) | 2225 | 48 (S) |
| | Gillette (X) | 2162 | 31 (S) |
| | Williams Lake (Y) | 1268 | 54 (S) |
| | Port Clarence (Z) | 555 | 54 (G) |
| 7970 / Norwegian Sea | Ejde (M) | 3441 | 44 (S) |
| | Bo (W) | 3188 | 33 (S) |
| | Sandur (Y) | 3055 | 41 (S) |
| | Jan Mayen (Z) | 2872 | 30 (S) |

**Table 1b.** Data from a few of the Loran transmitters tracked by an all-in-view receiver located in Fairbanks, Alaska. Columns show the group rate interval (GRI) and chain name, the station and its identifier, the distance from Fairbanks, and the maximum signal level (in dB uV/M) reached during a 24-hour recording period. G indicates groundwave, and S indicates skywave signals.

All-in-view receivers address this fundamental problem because they remove background noise and resolve nearby Loran signals much better. Effective signal to noise ratios are improved by about 24 dB (a factor of about 16) for the closest 10-15 Loran signals most important to navigation. This is a huge improvement and enhances Loran accuracy, dynamics, reliability, coverage, etc. – just about all aspects of the system's performance. Representative DSP processes include:

1. Crossrate interference cancellation. Groundwaves from distant Loran stations generate what is termed crossrate interference, and since crossrate is predictable, it can be digitally identified and removed.
2. Adaptive skywave compensation. Loran skywaves vary rapidly and fluctuate greatly in size, frequency, and range in a manner that is not a simple function of transmitter power and distance. Special DSP techniques adapt to these changes in real time and compensate for skywave distortion of groundwaves.
3. Adaptive digital filtering. Strong, time-variant noise from non-Loran sources must be identified and removed, eliminating approximately 24 non-Loran interferers.
4. Impulse noise blanking. Impulsive noise emanates from a variety of sources, most commonly lightning, and can be digitally blanked. This information is processed so quickly that receiver recovery is virtually instantaneous, leaving navigation function unaffected.

The overall performance improvement from all-in-view, DSP-based receivers is dramatic, as exemplified by two comparisons with older technology receivers. All-in-view receivers are linear devices, which accurately resolve the time differences (TDs) used to calculate receiver position to 1 nanosecond. Older receivers were so-called hard-limited devices, only able to resolve TDs to 100 nanoseconds. Higher, more accurate TD resolution improves receiver accuracy, and in fact, all-in-view receivers identified the need for more accurate control of the Loran infrastructure (i.e. older technology monitoring receivers masked these control problems). Another useful comparison is envelope-to-cycle distortion (ECD), which a receiver uses to determine the correct zero crossing of the Loran pulse for the TD measurement. All-in-view receivers have improved ECD noise by a factor of 6 or more, meaning they only need to average 1/36 as many samples as older technology receivers. In practice, this advancement means dynamic receiver performance is greatly improved and cycle slips (i.e. identification of an incorrect zero crossing) are virtually non-existent in modern receivers.

Some performance improvements seen with all-in-view technology are shown in recent data obtained by the Federal Aviation Administration's Technology Center (FAATC) during flight tests comparing all-in-view receiver performance with GPS and legacy Loran receiver performance (Figures 1a and 1b). This figure also introduces the concept of additional secondary factor (ASF) corrections for Loran, which is analogous to ionospheric and tropospheric corrections used to improve GPS accuracy.

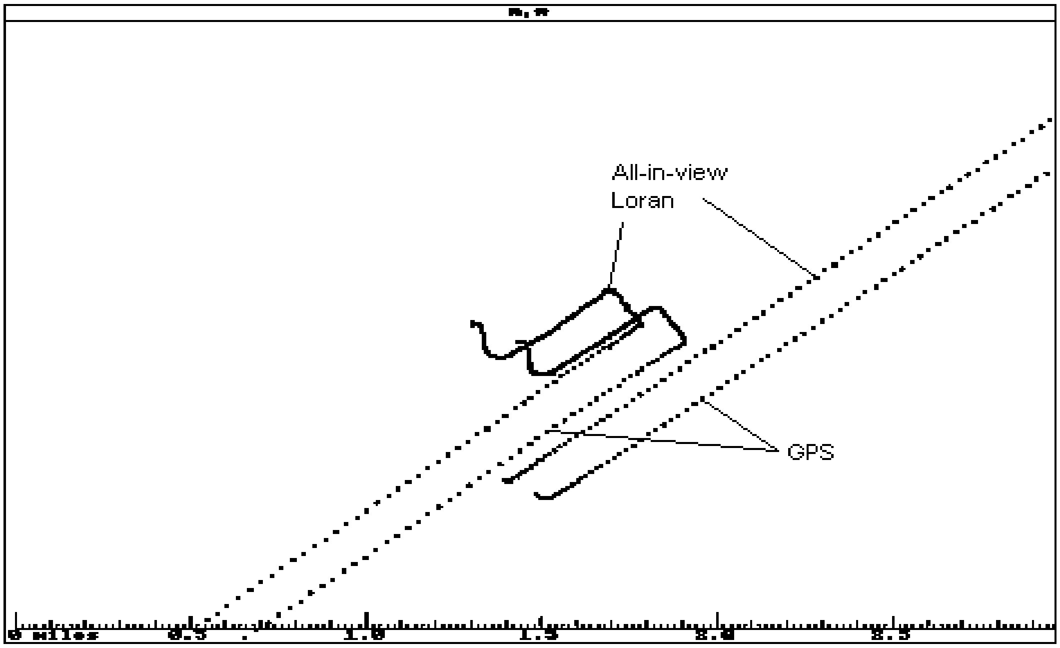

**Figure 1a.** Takeoff (top tracks) and landing (bottom tracks) data from Sacramento, California airport. Above data taken during flight tests conducted in August 2001 by the FAA Technical Center to compare GPS, all-in-view Loran, and legacy Loran receivers. No ASF corrections were applied to the Loran data, which if used, would correct the consistent offset between the Loran and GPS tracks. Scale is in miles.

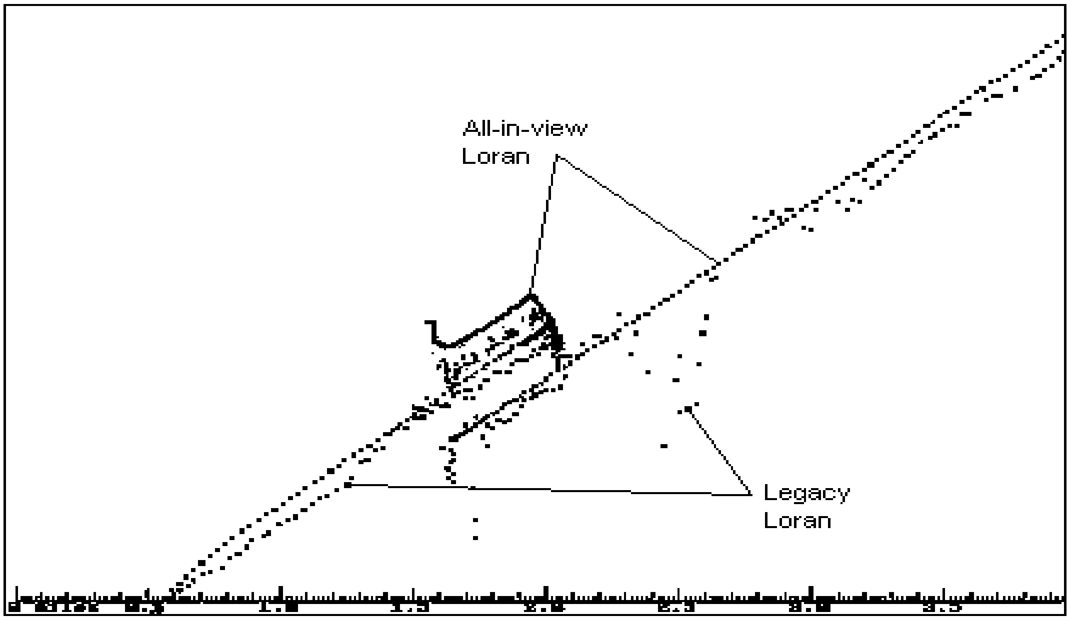

**Figure 1b.** Takeoff and landing data from Sacramento, California. All-in-view Loran and legacy Loran data only.

In an 8-day trial, the FAATC flew northern and southern routes over the continental US, including a leg to Anchorage, Alaska. A computer logged data from each receiver once every second, and representative data from the takeoff and landing at Sacramento, California are graphed (Figure 1). It is immediately evident the all-in-view and GPS data are quite similar, except for a consistent offset in positions generated by the two receivers (Figure 1a).

This offset is largely due to Loran signal propagation delays caused by land, which are a function of the conductivity of the land path between the Loran transmitters and the receiver. Since ground conductivity tends to vary slowly, mostly as the result of seasonal cycles, individual time delays between transmitters and specified geographic positions can be measured periodically to form a map of ASF corrections, which an all-in-view receiver can apply in real time. In fact, the FAA and USCG are currently developing a plan to produce an ASF map for the United States.

The most salient feature of the two data sets in Figure 1a is their remarkable similarity in form. If ASF corrections were applied to the all-in-view Loran data, these points would superimpose on the GPS track. For contrast, simultaneous data from an all-in-view and a legacy receiver are shown, with GPS data removed for clarity (Figure 1b). The performance improvement provided by all-in-view technology is obvious, even ignoring ASF corrections.

Figure 2 illustrates results when ASF corrections are applied to all-in-view receiver data collected during May 2002 flight tests conducted around Madison, Wisconsin by the Ohio University Avionics Engineering Center. The tests included 10 instrument landing system (ILS) guided approaches to the main airport runway, indicated by the single circle. Data were recorded once a second from a wide area augmentation system (WAAS) enhanced GPS receiver and an all-in-view Loran receiver.

ASF corrections were generated approximately one week before the flight trials at a location in the middle of the circular flight patterns in the southwest quadrant of the figure, approximately 14 kilometers from the main runway. These ASF corrections were derived from simultaneously recorded GPS and all-in-view Loran receiver data, and then applied to the flight data post-hoc. All Loran data in Figure 2 were ASF corrected.

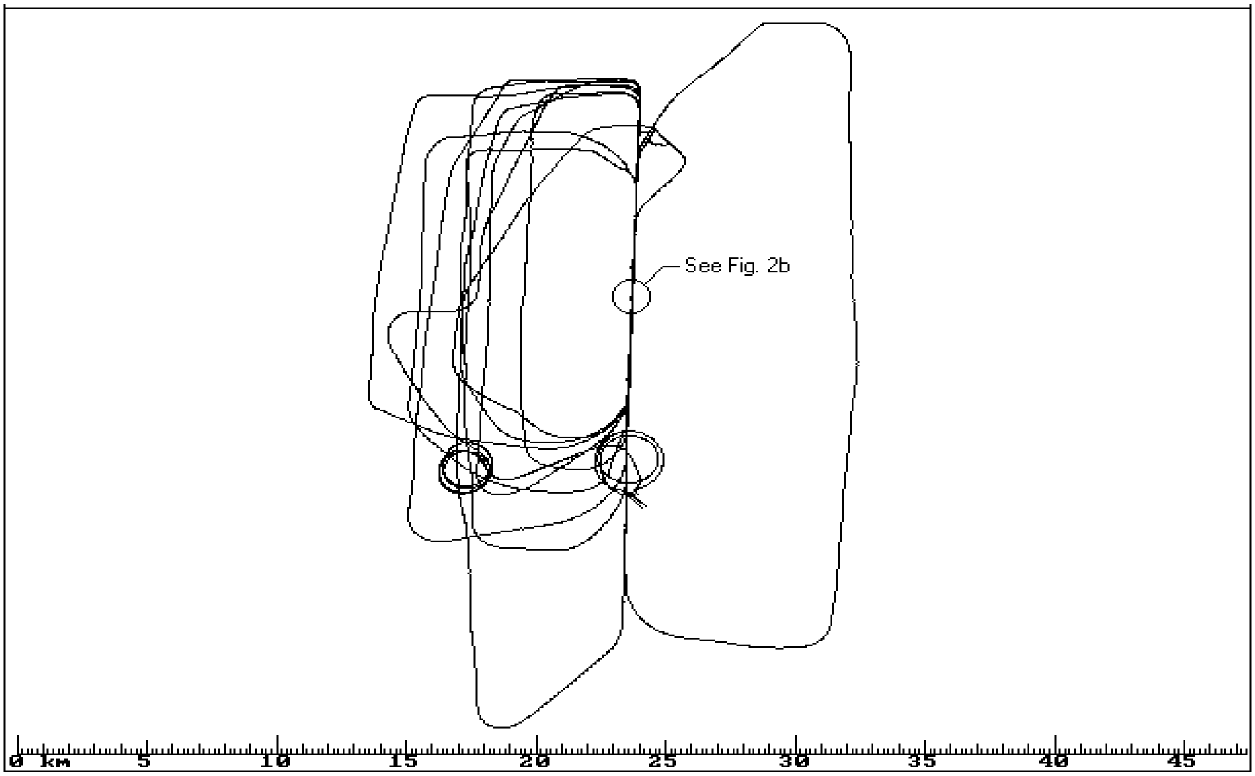

**Figure 2a.** GPS and all-in-view Loran receiver data.
Data collected during May 2002 flight tests in Madison, Wisconsin, including 10 ILS-guided approaches to the main airport runway, as indicated by the single circle just above figure center. ASF corrections applied to Loran data were derived from GPS and Loran recordings made approximately 1 week earlier near the center of the flight loops made in the southwest quadrant. Scale is in kilometers.

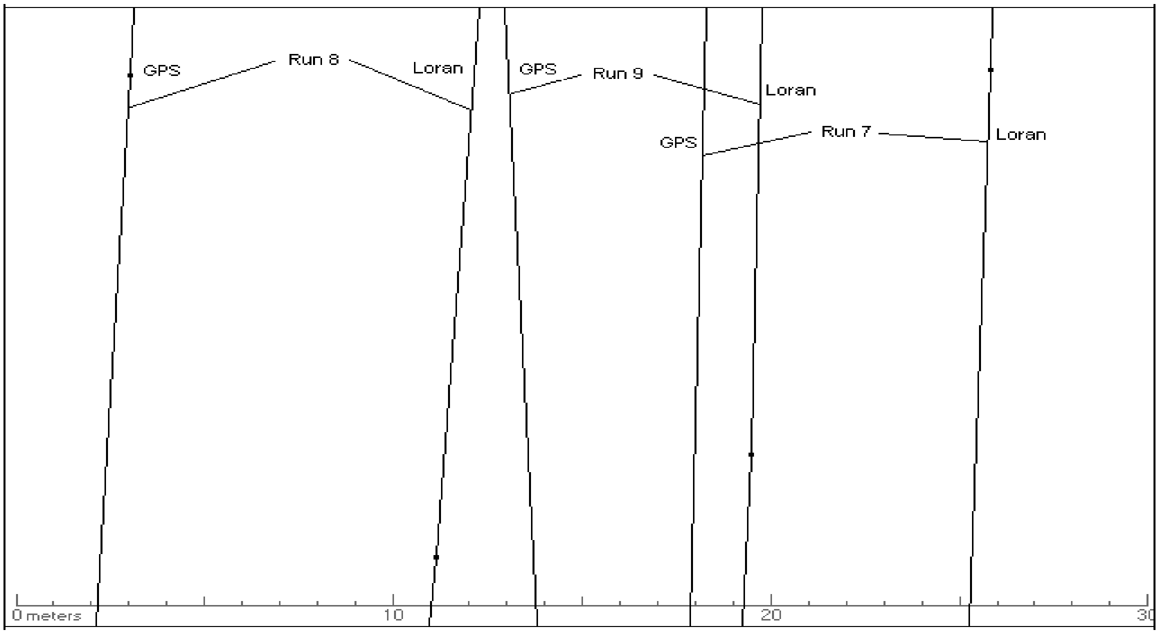

**Figure 2b.** Close-up of 3 representative examples from circle in Figure 2a.
These data indicate ILS-guided approaches to the Madison, Wisconsin airport. ASF corrections for the Loran data were generated approximately 14 kilometers from the airport. Scale is in meters.

Figure 2a shows the entire flight trial in kilometers, making it impossible to distinguish GPS and all-in-view Loran data at this scale. Figure 2b is a close-up, meter scale view within the single circle drawn in Figure 2a, with representative data from 3 of the 10 ILS-guided approaches; individual GPS and all-in-view data runs are identified. At this magnification, data indicate the cross-track difference (i.e. the horizontal difference between the two parallel tracks) between an ASF-corrected, all-in-view Loran solution can be within 5-10 meters of a WAAS-corrected GPS solution. While these results are preliminary and it is still necessary to determine the exact offset between GPS and Loran when the receiver outputs are precisely synchronized (i.e. along track error), the results are especially promising for several reasons:

1. Loran infrastructure modernization was far from complete during these tests; when control of the Loran transmitters is optimized, results will improve.
2. ASF corrections were generated 8 miles from the airport; corrections generated at the airport would provide more accurate results.
3. The all-in-view Loran receiver used an alpha prototype magnetic antenna, which produced signal levels 5-10 dB below normal; improvements in antenna shielding and grounding will provide more accurate results.
4. Software used to steer the magnetic antenna was first prototype; later versions will provide more accurate results.

## Modern Loran Antennas

Loran receiver performance is highly dependent upon antenna performance, and technology has mainly advanced in magnetic, or H-field, antennas. The primary reason for developing H-field antenna technology is magnetic antennas are immune to precipitation-static (P-static) noise that can occur on an airplane during stormy weather. Under these conditions, ionized particles accumulate on an airplane's skin, often generating potentials in the 20,000 – 40,000 volt range. The spontaneous discharge of these high potentials disrupts reception by Loran E-field antennas, thus H-field antennas have a distinct advantage in aviation.

H-field antennas also have several other important advantages:

1. Theoretically, they have an inherent 3 dB SNR advantage over E-field antennas, which can be significant, particularly in marginal situations.
2. They produce lower ECD values, so identification of the correct zero crossing is more rapid and reliable.
3. They require no grounding, which means H-field antennas are easier to install and will operate closer to the ground.
4. H-field antennas can be quite small; they can be integrated with a GPS antenna into a single unit.

H-field antenna advantages come with a price, mainly in the demands they place on the associated receiver. For example, they have separate poles, which often require a separate input channel to the receiver, adding hardware and software. Also, special receiver software must "steer" each antenna pole. Fortunately, DSP-based receivers have the processing power to meet these demands, and both receiver and antenna technologies have advanced overall Loran system performance.

All-in-view receiver data shown in this article have included data derived from both E-field (Figure 1) and H-field (Figure 2) antennas. The last illustration (Figure 3) shows a mechanical drawing of a combined GPS and Loran H-field antenna, as integrated within a single radome for avionics testing. Here, a GPS microstrip patch antenna is positioned in the center of a Loran H-field antenna. The dimensions of the H-field are 130mm x 130mm x 50mm. Tests on a combined GPS/Loran prototype antenna have demonstrated that neither GPS nor Loran reception is compromised by the presence of the other antenna.

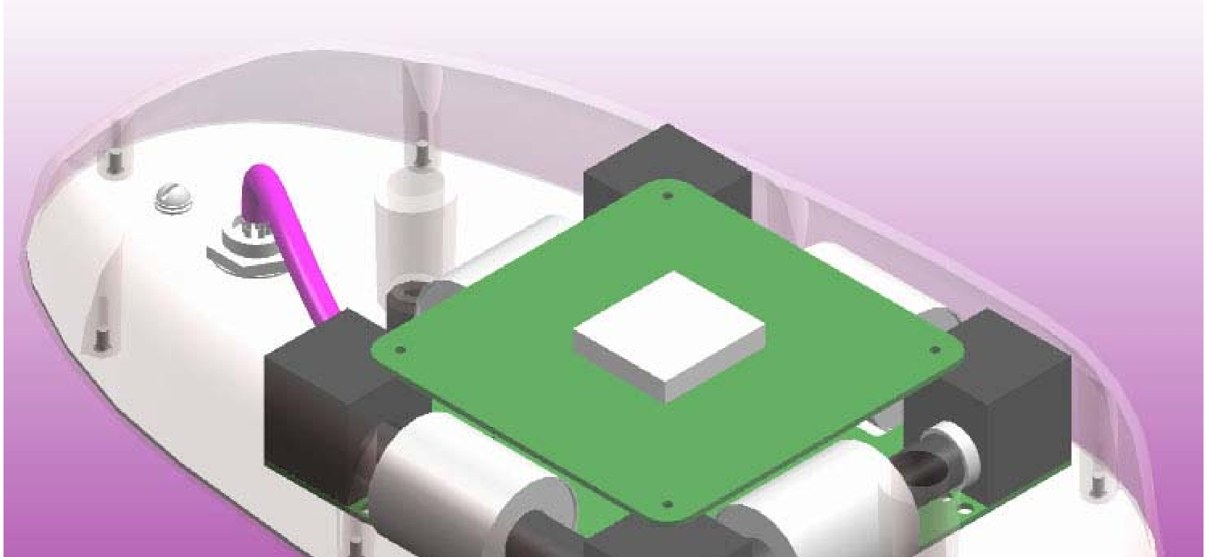

**Figure 3.** A mechanical drawing of a combined GPS and Loran H-field (magnetic) antenna. The combined unit has been mounted in a certified radome to expedite aviation tests, and the GPS microstrip antenna is mounted in the center of the Loran antenna. The actual dimension of the H-field is 130mm x 130mm x 50mm.

## Summary

This article has reviewed some of the technological advances in Loran receivers and antennas over the last decade. These advances revealed that the performance of the Loran system is much better than previously appreciated and an antiquated US Loran transmitter and control infrastructure now limits overall Loran system performance. With a modernized infrastructure, performance of the Loran system will continue to improve.

Finally, GPS and Loran are synergistic systems that complement one another. A combined system provides performance advantages over any single system and eliminates sole-means vulnerabilities. Loran receiver technology will continue to advance, and integrated GPS/Loran systems will be demonstrated in 2003.

## Author

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## Additional Readings

1. Roth, G. Linn. "The Case for Loran." The Journal of Air Traffic Control, July-September, 1999.

2. Roth, G. Linn, et al. "Performance of DSP-Loran/H-field Antenna System and Implications for Complementing GPS." Proceedings of the National Technical Meeting of the Institute of Navigation, January 2002.
3. Roth, G. Linn and Schick, Paul W. "New Loran Capabilities Enhance Performance of GPS/Loran Receivers." NAVIGATION, Journal of the Institute of Navigation, Vol. 46, No. 4, Winter 1999 – 2000.
4. Peterson, B., et al. "Integrated GPS/Loran: Structure and Issues." NAVIGATION, Journal of the Institute of Navigation, Vol. 45, No. 3, Winter 1998-1999.
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## Websites

USCG Navigation Center: http://www.navcen.uscg.gov/
International Loran Association: http://www.loran.org/