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DIRECT SENSOR TO WEAPON NETWORK (DSTWN) ARCHITECTURE[1]

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ABSTRACT

In order to increase the responsiveness of precision guided weapons, in-flight retargeting is needed. Stand-off guided weapons are capable of being guided to target to sub-meter accuracy. These weapons can currently only be used to attack stationary targets due to the length of the time-of-flight (often exceeding three minutes). With the capability to update target coordinates, while the weapon is in-flight, the same precision guided weapon can be employed against both static and moving targets.

In this paper, an architecture for direct sensor-to-weapon connectivity is described that enables target coordinates to be routed in real-time from a targeting sensor to the weapon while it is in flight. The architecture is based on a network centric approach that leverages advances in mobile radio technology and precision GPS guidance systems. This direct-sensor-to-weapon network is being developed under contract to the U.S. Navy.

INTRODUCTION

Joint Vision 2010[1] is the conceptual template for how America's Armed Forces will achieve new levels of effectiveness in joint warfighting. One of the four operational concepts developed in this vision is *precision engagement*. Precision engagement will leverage the advancing technology trend towards improved precision for long-range stand-off weapons using a wide range of delivery systems, increasing the combat power against selective objectives and resulting in enhanced economy of force and a higher tempo of operations.

Precision engagement will consist of a system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain the flexibility to reengage with precision when required. Even from extended ranges, precision engagement will allow us to shape the battlespace, enhancing the protection of our forces. Information operations will tie together high fidelity target acquisition, prioritized requirements, and command and control of joint forces within the battlespace. This combination will provide a greater assurance of delivering the desired effect, lessen the risk to our forces, and minimize collateral damage.

Precision engagement will build on current US advantages in delivery accuracy and low observable technologies. It will use a wide variety of means, including very accurate aerial deliveries or airdrops, discriminate weapon strikes, and precise, all-weather stand-off capability. The combination of these technology trends will provide an order of magnitude improvement in lethality. Commanders will be able to attack targets successfully with fewer platforms and less ordnance while achieving objectives more rapidly and with reduced risk. Individual warfighters will be empowered, as never before, with an array of targeting and communications equipment that will greatly magnify the power of small units.

Implementation of precision engagement will rely on the following leading edge technology enhancements, which are being developed in the DSTWN program.

- Precision, timely target location
- Robust connectivity to link target location data to the most effective weapon system
- Precision weapon delivery to target

PROBLEM

The Global Positioning System (GPS) is the fundamental underpinning for precision strike. Existing GPS-guided munitions being used today, or are in development, include ERGM, XM-80, SLAM, Tomahawk, JDAM and JSOW. These all have the benefit of precision guidance, using GPS for navigation, but their effectiveness is limited by the problem of attaining precise, timely target coordinates.

The goal of the DSTWN program is to provide precision targeting information and precision terminal guidance to increase the performance of existing GPS-guided weapons. This network-centric architecture will provide connectivity from the targeting sensor to the weapon while it is in-flight.

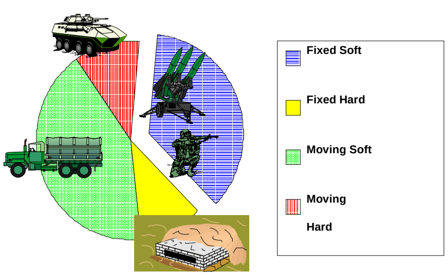

Figure 1 NSFS Target Set

Current stand-off GPS-guided weapons are only effective against soft static targets, which comprise only 36% of the current Naval Surface Fire Support (NSFS) target set. With the capability to perform precision in-flight retargeting, the existing GPS-guided munitions will become effective against moving targets.

The DSTWN connectivity can also be used to increase the precision of the GPS-guided weapons, enabling their use against hardened targets. By expanding the target set against which GPS-guided weapons become effective, operational improvements can be recognized from a reduced logistics tail.

ARCHITECTURE DESCRIPTION

The DSTWN architecture is directed toward satisfying the military users need for precision targeting and terminal guidance for precision strike. The goal is to provide an architecture which will produce seeker-like accuracy (1 meter CEP) for terminal guidance using GPS for target geolocation and precision navigation, with the capability to update target coordinates with less than 2 seconds of data latency.

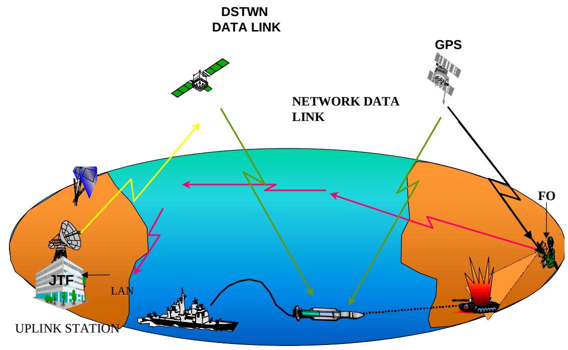

Figure 2 DSTWN Architecture

The proposed DSTWN architecture is shown in Figure 2. The target coordinates are obtained in real-time from a sensor, either operated by a Forward Observer/Forward Air Controller (FO/FAC) or obtained from a remote surveillance sensor, such as a UAV. The target coordinates are routed through the battlefield command and control system where a weapon is selected and designated against the target. Using the network architecture, the target coordinates are addressed over a SATCOM data link directly to the weapon designated against that particular target providing in-flight updates from the targeting sensor.

The three technology areas being developed by NAVSYS for implementation of the DSTWN architecture are: precision targeting; networked Sensor-to-weapon connectivity; and precision weapon navigation for guidance to target. These are described further in the following sections of this paper.

PRECISION TARGETING

Current generation targeting systems in use by FO/FACs can locate a target's coordinates to, at best, an accuracy of 50 meters. In order to effectively employ GPS-guided munitions, against fixed and moving targets, a precision targeting system that can rapidly and precisely determine a targets coordinates is needed.

NAVSYS has developed a precision targeting system, the GI-Eye, which is capable of determining precise target coordinates from digital video images. The GI-Eye operates using a GPS receiver to provide the location of the imaging sensor, and an inertial navigation system (INS) to provide the precision attitude of the sensor. This "smart camera" approach enables the images to be georeferenced at the sensor source, eliminating the need for any complex image processing or cross-correlation with point databases to extract target coordinates from the imagery.

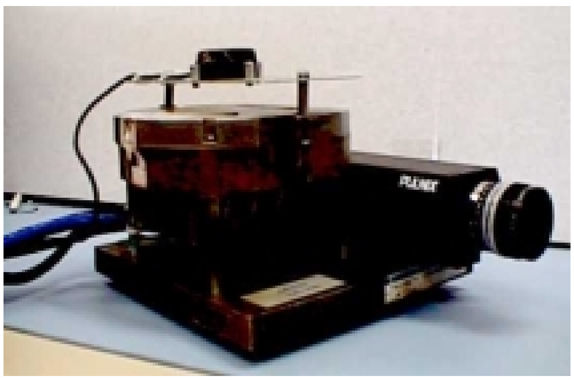

Figure 3 GI-Eye Targeting Sensor

The GI-Eye sensor is currently configured for installation in a ground-based or airborne vehicle (such as a UAV), and uses a PC-laptop running the GI-View targeting software as a user interface. The simple "point-and-click" user interface speeds target extraction, providing the bearing to target from the georeferenced imagery (Figure 4). The GI-View data processing uses

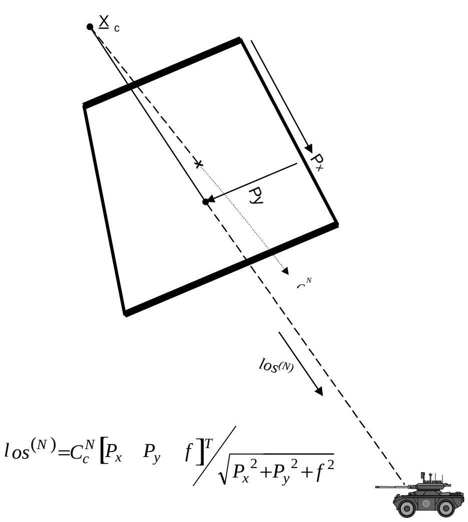

Figure 4 GI-View Target Location

this information to estimate the target's coordinates for routing through the DSTWN. Accuracies on the order of 1-2 meters have been demonstrated using this system for targets located at distances of up to 1 km from the sensor[2]. Under a cooperative research agreement with NSWC, Dahlgren, a precision version of this sensor is being developed that will be able to extract target coordinates from an airborne sensor at distances of up to 10 kms from the sensor.

A man-portable version of the GI-Eye is also under development, SPOTS, under contract to ONR. This sensor uses a miniaturized GPS and inertial sensor for position and attitude determination, and includes a rangefinder for measuring the range to the target. By using the inertial sensor to determine the bearing to the target, in place of the digital magnetic compasses currently used in the US Marine Corp's Target Location and Designation Hand-off System (TLDHS), the azimuth accuracy is improved from 10 mrad (at best) to 1 mrad accuracy. This allows the target location to be determined to an accuracy of 1 meter at distances of 1 km from the FO/FAC.

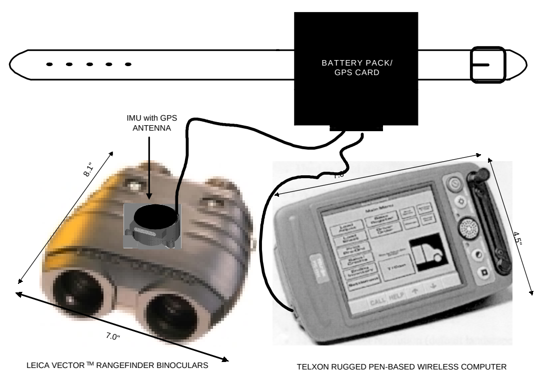

Figure 5 Prototype SPOTS Targeting Sensor

The prototype system being built under contract to ONR is shown in Figure 5. This uses a Leica Vector laser rangefinder to provide the range to the target. A hand-held computer provides the user interface and targeting data for output to the DSTWN data link. A passive rangefinder system is also under evaluation. This uses a stereo video rangefinder to determine the range to the target, further minimizing the possibility of compromise for the FO/FAC (Figure 6).

Figure 6 Conceptual Drawing of Passive Targeting Sensor Configuration

SENSOR-TO-WEAPON CONNECTIVITY

Once the precise coordinates of the target have been calculated, the next step is to route this information through the battlefield network. The targeting information is provided to the command and control structure in the call-for-fire as well for the in-flight re-targeting updates once the weapon has been fired. Because line-of-sight cannot be guaranteed between the sensor and the weapon, the DSTWN architecture uses a satellite communication (SATCOM) data link to provide wide-area connectivity across the battlefield to multiple weapons simultaneously.

In order to be able to use a GPS-guided weapon effectively against moving targets, data latency must be minimized through the network link. A Kalman filter is included in the targeting sensor to estimate both the position and velocity of the target in the DSTWN targeting message. The targeting error is therefore a function of the target vehicle's acceleration. Land-based vehicles can accelerate at rates between 0.25gs under normal conditions to 1g under evasive conditions or during an emergency stop. With a 1-second data latency in the DSTWN data link, this would result in a total targeting error of 1-5 meters from the vehicle acceleration. With a 2-second latency, the error would build to 4-20 meters.

Another option being investigated for reducing the error against moving targets is to integrate a low cost sensor with the weapon for terminal guidance to the moving target. This would enhance the effectiveness of the DSTWN architecture against moving, high dynamic targets without requiring the expense of a complete seeker for terminal guidance.

The three components of the sensor to weapon connectivity are the data link to transmit the target coordinates out of the battlefield, the network to route the data to the DSTWN satellite uplink station, and the DSTWN SATCOM broadcast addressed to each specific weapon while it is in flight. These three components are described in the following paragraphs and are illustrated in Figure 7.

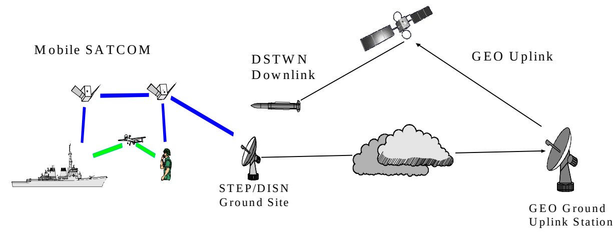

Figure 7 - Sensor to Weapon Connectivity

The battlefield portion of the sensor-to-weapon connectivity will leverage advances in mobile radio technology, being fielded by the Navy and US Marine Corps. This includes, mobile radios such as the "Soldier Phone" which provides secure voice and data connectivity across a battlefield network using a radio-relay architecture, and commercial mobile SATCOM options, such as the Motorola Iridium phones which provide a global voice and data capability. Other mobile network data links provided by DARPA and ONR are also planned to be trialed in the DSTWN technology demonstration being scheduled by the US Navy, including the Airborne Communication Node (ACN) and the data network being developed under the Extended Littoral Battlefield ACTD.

Once the target data is connected to the battlefield network, it must be routed to the DSTWN satellite uplink facility for transmission to the weapon. The architecture uses the Defense Information Systems Network (DISN) as the backbone for this functionality, and heavily leverages commercial networking technology and protocols.

The DSTWN uses a network routing architecture leveraging commercial protocols developed for web-based paging to perform the association between the target and the weapon designated by the command and control link (sensor-to-shooter connectivity). A message processor being designed by NAVSYS under contract to the US Navy, is used to assimilate the data, queue it, and provide it to the satellite uplink system for transmission to the specific weapon to which the message is addressed (Figure 8).

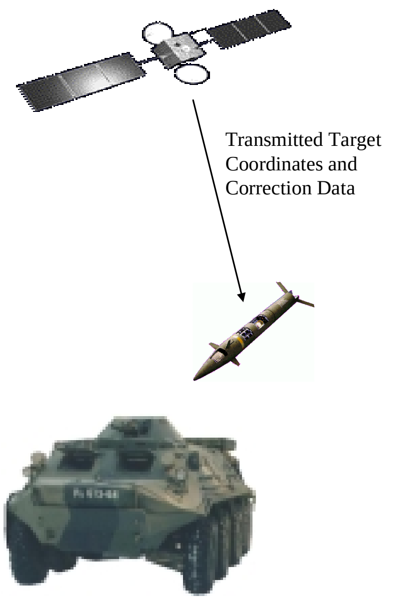

Figure 8 DSTWN Downlink

Initial testing on the DSTWN connectivity has been performed using the Inmarsat-3 Pacific Ocean Region satellite to provide the DSTWN data link. A DSTWN architecture using a U.S. Navy geostationary satellite, such as the UHF Follow-On (UFO) satellite, is in development. This will provide a military, secure data link for weapon connectivity. Details on this data link will be released in a later publication. Upgrades to the ERGM and Best Buy munitions are being worked with NAVSEA to take advantage of this in-flight retargeting data link.

The initial test architecture is illustrated in Figure 9. This architecture was designed to simulate a Forward Observer (FO) determining the coordinates of a moving target, the target coordinates being relayed out of the battlefield using the FO's personal communications system, receipt of the target coordinates at a geostationary uplink station, transmission of the target coordinates over the satellite, and receipt of the target coordinates by an emulated munition. To test this architecture, a NAVSYS designed and developed Message Entry Device (MED) was used. The MED was connected to a GPS device and installed in a vehicle. The vehicle was driven around to simulate the track of a moving target and the tracking of a target by a FO. The coordinates of the vehicle were automatically transmitted from the vehicle to the DSTWN ground station equipment using a mobile communications link. The ground station equipment consists of a Communications Server/Signal Generator (SIGGEN) Controller, SIGGEN, and Control Receiver all designed and developed by NAVSYS. This equipment is used to first close the loop with the satellite and then ensure that the simulated target coordinates are properly formatted, Forward Error Corrected (FEC) and modulated on the Intermediate Frequency (IF) for transmission to the satellite. The IF output of the SIGGEN was up-converted to C-Band and transmitted to the INMARSAT-3 POR satellite. The satellite transmitted the data stream back down to the ground over its L-Band transponder. The target coordinates, modulated on a DSTWN low data rate (500 bps) message were received by a DSTWN data-link receiver and outputted to a PC based Message Data Unit (MDU). This final process simulated receipt of target coordinates by an in-flight munition and output of the target coordinates to the munition's guidance system. The MDU FEC decoded the messages and recorded the data and the receipt time.

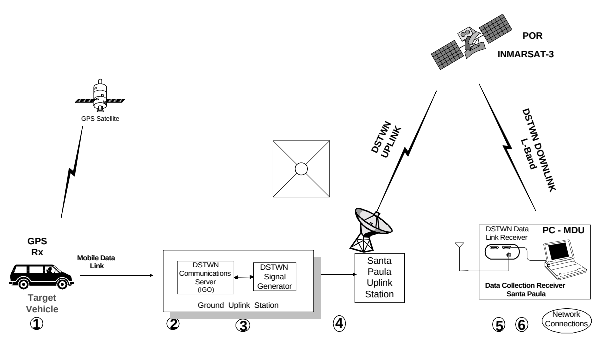

Figure 9 DSTWN Test Architecture with Data Collection Points

The primary purpose of this demonstration was to determine the latency of the data as it transited the communications path. This was accomplished by establishing data collection points at six different places along the communications path. The data collection points are shown in Figure 9. To ensure accuracy and time synchronization, GPS time was used as the time reference. The data analysis was two-fold. First we determined the overall data latency for the DSTWN test architecture to be 2.312 seconds by taking the difference between the time the GPS coordinates were received in the MED and the time FEC decoding was complete in the MDU. Figure 10 shows a plot of the overall data latency for 500 messages. The second phase of

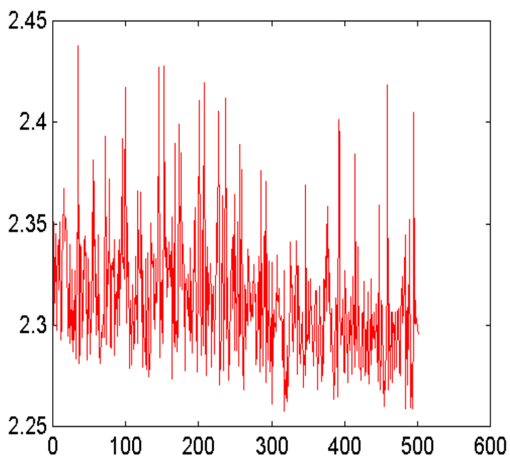

Figure 10 End-To-End Data latency Plot

the data analysis was to determine the data latency for individual segments of the communication path. This was conducted to help quantify the sources of delay (Table 1), and determine opportunities for improving the performance of the network architecture. The primary opportunities identified were to change the data format to eliminate the high overhead and processing time for the FEC and to reduce the frame rate below 1 Hz. These changes should reduce the latency in communication network segments 2-3, 4-5, and 5-6 (as shown in Figure 9) and allow us to achieve our overall system latency goal of less than 2 seconds. Implementations of these modifications are being scheduled into follow-on DSTWN projects.

Data Points	Mean Delay (sec)
1 to 6	2.312
1 to 2	0.097
2 to 3	0.718
3 to 4	0.051
4 to 5	0.621
5 to 6	0.825

Table 1 Communications Segment Data Latency

PRECISION WEAPONS DELIVERY

The accuracy of the current generation of GPS guided munitions is limited by the precision of the GPS system itself. The Precision Positioning Service (PPS) provides an accuracy of 16 meters SEP relative to the World Geodetic System (WSG-84) reference grid. By leveraging the connectivity between the sensor and the weapon system, the weapon can be placed on the same relative navigation frame as the sensor, resulting in significantly better navigation accuracy. By keeping the sensor, target and weapon on a common reference frame, the GPS navigation errors between the sensor GPS solution (the reference for this frame) and the weapon's navigation solution can be cancelled.

By using the sensor as the reference system for the relative navigation solution, similar accuracies can be achieved as have been demonstrated using local area differential or kinematic GPS techniques. The FAA has demonstrated accuracies of less than 1 meter at distances of up to 20 miles using these methods for the Local Area Augmentation System (LAAS).

In the DSTWN architecture, the GPS receiver in the targeting sensor is used to provide GPS corrections to the weapon guidance system through the sensor-to-weapon data link. This architecture leverages the precision kinematic positioning techniques developed for commercial GPS applications and demonstrated in the FAA's LAAS program.

The GPS corrections generated by the targeting sensor are transmitted through the DSTWN data link with the target location data to the weapon. This approach places the FO/FAC, target coordinates, and the weapon on the same reference system. The weapon's guidance system will use this data to guide the weapon to the target. Analysis and test data has shown that sub-meter guidance errors can be achieved using this method. Implementation of this precision navigation capability will require some software modifications to the weapon's guidance computer.

To prove the kinematic GPS accuracy from a high-dynamic moving platform, NAVSYS performed a sled test on the surveyed track at Holloman AFB. The purpose of this test was to optimize the GPS receiver's tracking loops for high dynamics[3] and to demonstrate the performance possible using carrier phase data to compute a kinematic GPS solution.

The accuracy of the kinematic solution was demonstrated to be within 1-2 cm per axis once the receiver tracking loops were optimized (Figure 11). In Figure 12 a comparison is shown of the DGPS navigation solution and the kinematic navigation solution along the test track. The kinematic solution is hard to differentiate from the reference coordinates for the track, while the random noise from the DGPS solution is quite apparent.

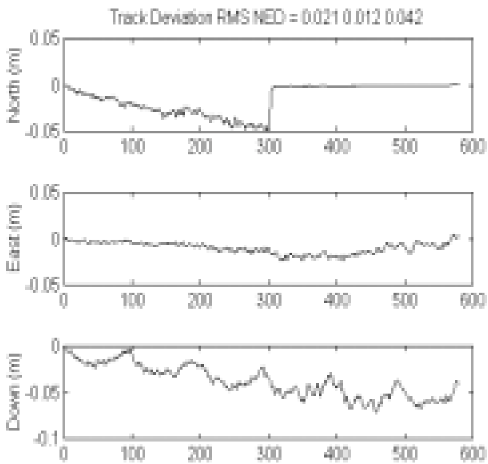

Figure 11 Kinematic GPS Test Data

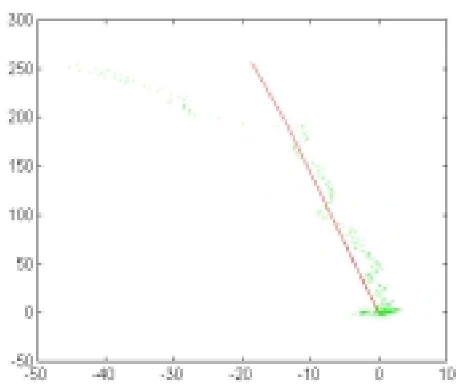

Figure 12 Comparison of DGPS and Kinematic Solution

TECHNOLOGY DEMONSTRATIONS

NAVSYS is currently under contract to ONR, NSWC, and DARPA to demonstrate the viability of the different DSTWN technology areas. Those technology areas being addressed are the sensor-to-weapon connectivity, precision targeting, and precision guidance. Test results to date have shown positive results for each of these technology areas. Testing will continue on the DSTWN architecture culminating with a full precision engagement system demonstration using a GPS-guided munition provided by NAVSEA.

CONCLUSIONS

Under the DSTWN program, the capability to rapidly determine the coordinates of a static or moving target using a precision targeting sensor will be demonstrated. The DSTWN architecture provides the capability to link these coordinates to a weapon designated against that target, enabling in-flight re-targeting for GPS-guided weapons. The DSTWN data link is also used to pass kinematic GPS corrections between the sensor and weapon to lock the weapon to the targeting sensor's reference frame. This provides submeter guidance accuracy for existing GPS-guided weapons when linked to the DSTWN.

The combination of precision targeting, in-flight re-targeting and precision guidance will enable GPS-guided weapons to be used effectively against static and moving targets, and both soft and hardened targets. The flexible network-centric architecture developed by NAVSYS will facilitate integration of sensor data from a variety of different sources and will provide standards for connectivity to all GPS-guided weapons.

The DSTWN architecture will provide leading edge technology enhancements that can be leveraged to develop new operational concepts for precision engagement to support implementation of Joint Vision 2010 for the US Armed Forces.

[1] Joint Vision 2010, Chairman of the Joint Chiefs of Staff, 5126 Joint Staff, Pentagon, Washington, D.C. 20318-5126

[2] A. Brown, “High Accuracy Targeting using a GPS-aided Inertial Measurement Unit”, Proceedings of the Institute of Navigation Annual Meeting, June 1998, Denver CO

[3] A. Brown, A. Matini, D. Caffery, “High Dynamic, Dual Frequency Tracking With A Low Bandwidth Digital Translator”, Proceedings of ION GPS 96, September 1996, Kansas City, KS