Naval Space Surveillance Center Uses of Time, Frequency and Phase

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The Naval Space Surveillance Center (NAVSPASUR) is an operational naval command that has the mission of determining the location of all manmade objects in space and transmitting information on objects of interest to the fleet. NAVSPASUR operates a 217 MHz radar fence that has 9 transmitting and receiving stations deployed in a line across southern CONUS. This surveillance fence provides unalerted detection of all satellites overflying CONUS. NAVSPASUR also maintains a space catalog of all orbiting space objects, including payloads, rocket bodies and debris, and distributes information on satellite orbits to the fleet and other users by means of Navy tactical communication circuits and other means. NAVSPASUR plays an important role as operational alternate to the primary national Space Surveillance Center (SSC) and Space Defence Operations Center (SPADOC) located in Colorado Springs, Colorado. In executing these responsibilities, NAVSPASUR has need of precise and/or standardized time and frequency in a number of applications. These include maintenance of the radar fence references to specification, and coordination with other commands and agencies for data receipt and dissemination. Precise time and frequency must be maintained within each site to enable proper operation of the interferometry phasing technique used. Precise time-of-day clocking must exist between sites for proper intersite coordination. After 'time tags' are attached to the data at the receiver sites, proper referencing and standardization are necessary at the Dahlgren, Va. operations center to ensure proper data synchronization and communications with the fleet and other agencies.

Time as such is not required at the transmitters as presently configured because of the continuous wave (A0) modulation used. If possible plans to make the entire phase-coherent for VLBI operation are implemented, this requirement Time is required at the receiver sites with an accuracy at the millisecond level. The basic timing accuracy needed is controlled by satellite kinematics that result in a near-earth satellite velocity of about 7.5 kilometers per second. Planned sensor improvements are expected to result in an achievable sensor accuracy of about 50 meters. To avoid adding error the station timing should be at least 10X more precise. This results in a required timing accuracy of ± 0.5 millisecond for an equivalent position error of less than 5 meters. While this accuracy is well within the current state of the art, it is not achieved by the HF WWV receivers used at present. HF timing suffers from unreliable propagation and can have errors of several milliseconds. The planned installation of GPS timing will result in a timing accuracy more than sufficient for NAVSPASUR's needs.

Frequency is presently precisely controlled. Frequency at both transmitter sites (three) and receiver sites (six) is controlled by cesium beam frequency standards, which maintain the 216.980 MHz. carrier frequency and all local oscillators within ± 0.001 Hz. Spurious control on the transmitter emissions is -80 dBc or better.

Phase may be considered a derivative of time and frequency. Its control within each transmitter or receiver site is of great importance to NAVSPASUR because of the operation of the sensor as an interferometer system, with source direction angles as the primary observable. Determination of the angular position of a satellite is directly dependent on the accuracy with which the differential phase between spaced subarrays can be measured at each receiver site. Interferometer lobe width is about 11 arcminutes on the sky. The high signal to noise ratio for many satellites means that angular accuracies of 0.1 arcminutes or less can be achieved. This corresponds to a phase angle accuracy of about 2 degrees. Since one 217 MHz wavelength is equivalent to about 5 nanoseconds of time, a 2 degree phase accuracy requires about 25 picoseconds relative time control. Thus, NAVSPASUR has a requirement for very precise time control within the up to 2 mile confines of each site. If VLBI techniques are instituted in the future, between-sites phase control to this precision will also be necessary.

NAVSPASUR also attaches great importance to minimizing a quantity that may be called timeliness. Timeliness refers to the time interval required for processing and communication in analyzing and transmitting data to customers. While not customarily thought of as precise time, minimization of processing delays is of great importance to the utility of NAVSPASUR's perishable data product.

Figures 1 and 2 show simplified views of time/frequency/phase usage at NAVSPASUR receiver and transmitter sites. Installation of dual-frequency GPS receivers at all sites is planned. This will serve several purposes. It will eliminate the timing errors of up to 5 milliseconds that presently reduce accuracy on fence observations. It will allow better calibration and monitoring of the performance of our cesium beam frequency standards. It will allow a direct correction for the effect of the ionosphere, which causes a significant uncalibrateable refraction error in our measured direction angles at present.

Another important application of innovative technology is in the use of fiber-optics cables to provide within-site phase calibration. As mentioned above, NAVSPASUR requires maintenance of carrier phase to within ±25 picoseconds throughout each site over a wide variety of environmental conditions. The current technique, implemented when the radar system was first constructed 30+ years ago, uses air-dielectric coaxial calibration cables, and has proven unsatisfactory because of well-known coaxial cable stability deficiencies. This problem is especially crucial at our main Lake Kickapoo, Texas transmitter site, so a fiber optics calibration design was developed for installation there [1]. Although use of fiber optics for digital data transmission is well developed, phase-stable distribution of an analog signal required development of state- of-the-art techniques. The basic configuration of the fiber optics system is shown in Figure 3. The physical layout of the Kickapoo transmitter consists of a two-mile long array of dipoles, each with its own power amplifier. For control purposes, this array is divided into 18 bays. The phase calibration is applied at the bay level. The basic requirement for the fiber optics system is that it maintain a phase stability within ±2 degrees across all bays, over the expected range of environmental variations at this north Texas site. It must be reliable, easily maintainable and have an expected service life of at least 15 years. Several operating modes were considered, including active (closed loop phase compensation) and passive (open loop operator adjusted) and comparison at the central site or at each bay. The passive central site approach was chosen as providing adequate performance at minimum cost. It will utilize existing phase monitor and control equipment and software. A loose-tube single mode optical fiber manufactured by Siecor was chosen. Transmitters at each bay are temperature-controlled to minimize variations with temperature.

The above two projects are two items being undertaken as part of a comprehensive effort being undertaken under the direction of the Commanding Officer, Capt. H.W. Turner IV, to optimize the performance of our sensor . Figure 4 shows the overall plan. Emphasis is placed on utilizing in-house capability to the maximum extent possible. The overall plan includes emphases in improved communications with other sensor sites and users, on improved sensor electronics and on improved reliability/maintainability. Areas of particular importance to precision time/frequency/phase include improved use of time/frequency standards and improved site phase control. There are also several new initiatives being undertaken in the central operations center software that are of importance. These include optimization of the software used to reduce observations, compensation for the space environment, improvement of the propagator used for observation comparison, and an improved sensor performance monitoring system.

The present complex routine used to determine angular position, known as ADR, is being rewritten to provide proper time synchronization between sites used to form a triangulated position. This will eliminate a differential timing error that could result in the worst case in up to 50 milliseconds misalignment between observations. In addition, this rewrite will result in an optimized extraction of all possible information from each pass, and should result for the first time in significant single-pass capability for NAVSPASUR. Increased attention is also being paid to calibration of the system phases via software. We are using certain precision orbits that are seen by the fence on a regular basis to calibrate system constants including antenna separations and station parameters.

The ionosphere perturbs the apparent direction of arrival, especially near the horizon, by up to several arcminutes in a way that cannot be modeled well a priori. Use of dual-frequency GPS receivers should greatly reduce errors from this source. Use of calibration satellites with accurately known positions can also provide a somewhat less effective alternative.

The largest single error source for most low-altitude satellite orbits is the uncertainty in the atmospheric drag. NAVSPASUR is implementing a procedure using a Kalman filter sequential estimator technique for real-time measurement and compensation of this effect. This should result in significantly better performance and fewer lost satellites (UCTs), especially under worst case or solar storm conditions.

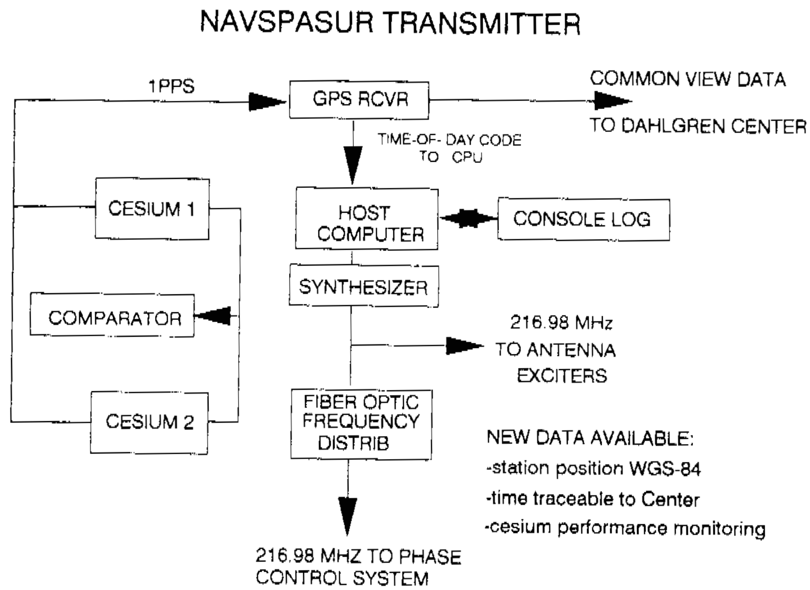
A final area of improvement is in the propagator used. NAVSPASUR presently uses an orbital propagator developed by Dirk Brouwer in 1959. This propagator has an expected accuracy of only about 500 meters for near-earth orbit. An improved propagator when installed should result in a significantly improved accuracy. Standardization of the propagators is an equally important issue. The surveillance community has suffered from the existence of different software at different installations that, while each capable of providing an adequate representation of the motion of a body, produce discordant results when using another group's elements. The United States Space Command (USSPACECOM) is presently undertaking an initiative to standardize these astrodynamic codes and constants, in which NAVSPASUR is participating. This work when completed should have significant impact on the precision GPS orbits used in much PTTI work.

These initiatives when fully implemented should result in an improvement in our observational accuracy from the present 400 meters nominal to a goal of between 50 and 100 meters.

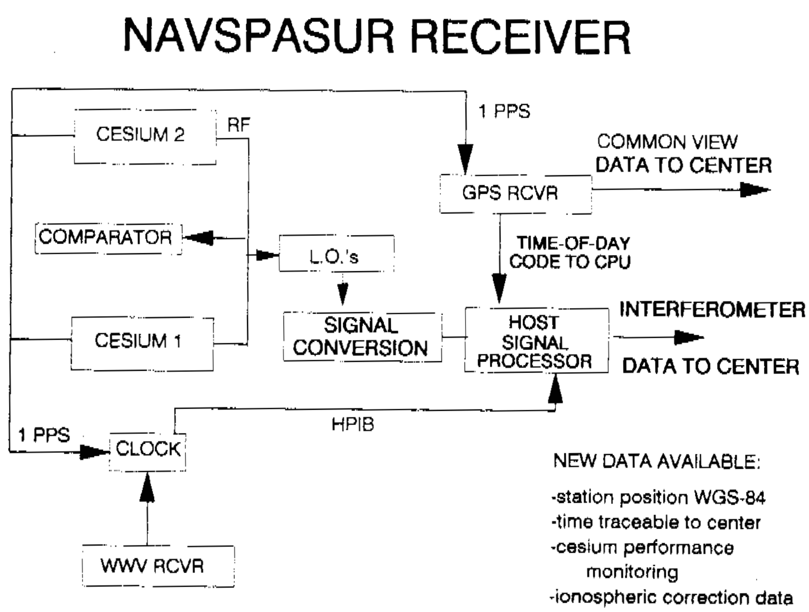
In summary, time and frequency referencing will play a critical role in NAVSPASUR's meeting future operational requirements. NAVSPASUR is working together with other DoD organizations, including USSPACECOM, our parent Naval Space Command, SPAWAR, the Naval Observatory, the Naval Research Laboratory and other naval commands, as well as with such non-DoD groups as NASA and the AIAA, to ensure optimum use of time, frequency and phase in engineering our system.

References

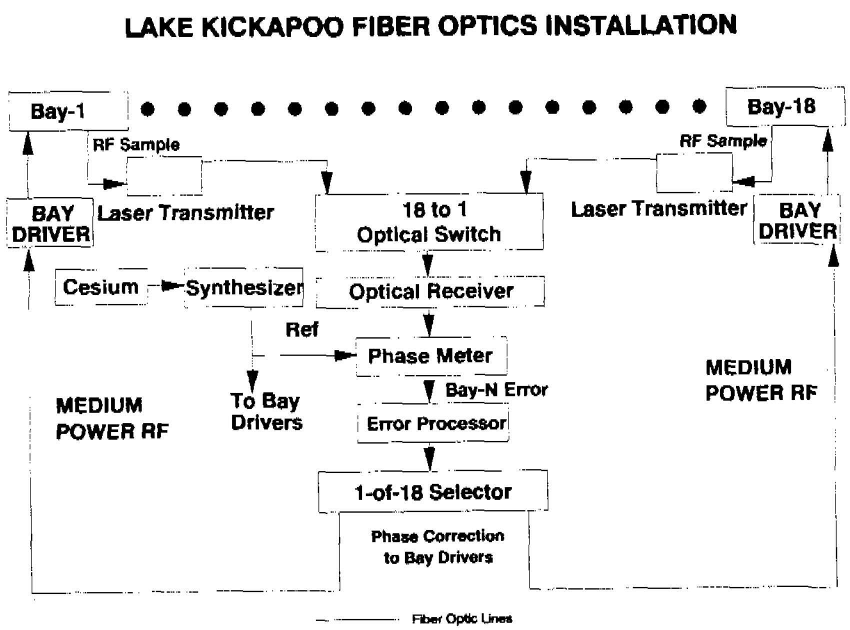
1. J. Webber and D.L. Thacker, *"Phase Distribution on Fiber Optic Cable"*, Proc. 21st Ann. P.T.T.I. meeting, 11/28-30/1989, Redondo Beach, Ca., p. 139



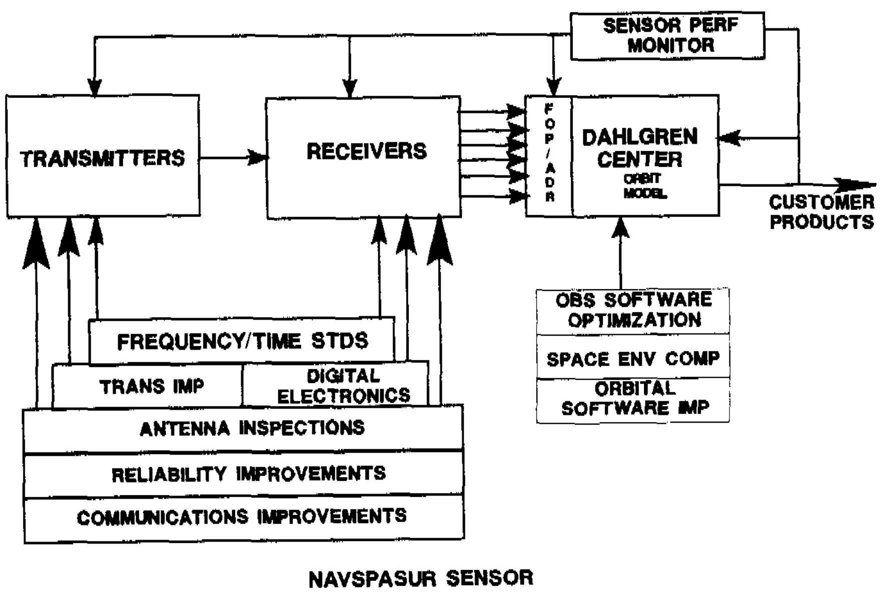
1 - Transmitter block diagram



2 - Receiver block diagram



3 - Fiber optics block diagram



NAVSPASUR SENSOR DEVELOPMENT PLAN

4 - NAVSPASUR sensor development plan