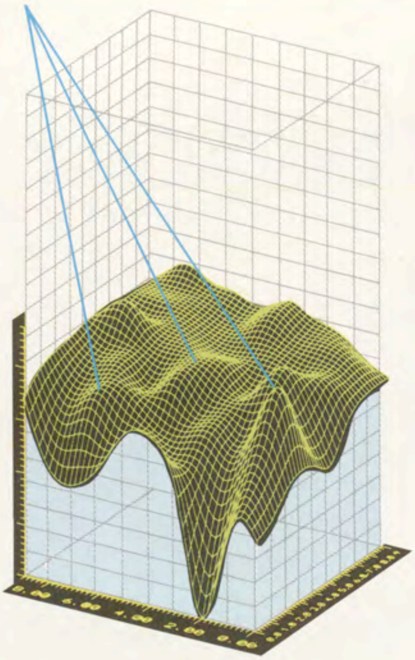

Detecting Nuclear Detonations with GPS

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Most users of GPS are unaware that the GPS satellites serve a dual role. In addition to carrying the navigation and timing payload, the satellites carry a payload that enables them to detect nuclear weapons bursts; this system is called the Nuclear Detonation (NUDET) Detection System. Starting with the launch of satellite vehicle 8 (PRN 11), the GPS satellites have formed an important component in the U.S. arsenal for monitoring compliance with the nuclear weapon Non-Proliferation Treaty. In this month's column, Paul Higbie and Norman Blocker describe the GPS NUDET system. Dr. Higbie is a staff member in the Nonproliferation and International Security Division of Los Alamos National Laboratory in Los Alamos, New Mexico. He is currently the principal investigator for the X-ray instruments on board the GPS satellites. Norman Blocker is on the staff of Sandia National Laboratories in Albuquerque. He is the team leader for the deployment of the optical sensors on board the GPS satellites. He is also the project manager for Sandia's Laser Applications Facility, which is used to stimulate the optical sensors.

"Innovation" is a regular column in GPS World *featuring discussions on recent advances in GPS technology and its applications, as well as on the fundamentals of GPS positioning. The column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick. We appreciate receiving your comments as well as suggestions of topics for future columns.*

When President Kennedy and Chairman Khrushchev signed the Limited Test Ban Treaty (LTBT) on August 5, 1963, one of the conditions was that each party to the treaty could use its own technical means to monitor the ban on nuclear testing in the atmosphere or in space. The Vela satellites were developed for this purpose in a joint effort by the U.S. Air Force (USAF) and the Atomic Energy Commission, the predecessor organization to the Department of Energy (DoE). USAF launched the first Vela satellite more than 30 years ago, on October 17, 1963.

Vela was based on the considerable experience obtained from developing the measurement instruments for the rockets flown during the Dominic series of atmospheric nuclear tests conducted between April 25 and November 4, 1962. Vela could therefore be a quick response to the LTBT. President Kennedy inspected a mock-up of the Vela satellite when he visited Los Alamos National Laboratory and Sandia National Laboratories in Albuquerque, New Mexico, in December 1962.

The relationship between the United States and the members of the former Soviet Union has improved greatly since the early steps taken by Kennedy and Khrushchev. However, nuclear technology and modern techniques are now widely diffused throughout the world. Should the Non-Proliferation Treaty (NPT) — which bans nuclear weapons development by its signatories — fail, the United States, as the world's remaining superpower, still has the capability to detect clandestine nuclear tests conducted anywhere in the world.

Part of the United States' capabilities are carried on the GPS satellites. The fact that the GPS satellites have the capability to detect nuclear detonations has been neither classified nor well advertised. In this article, we will give a qualitative overview of the GPS capabilities. The GPS Nuclear Detonation (NUDET) Detection System is — as Vela was — a joint program between the U.S. Air Force and DoE. The Air Force provides the "platform" — the GPS satellites in this case — and operates the system, while DoE, through its national laboratories, Sandia and Los Alamos, provides the sensors.

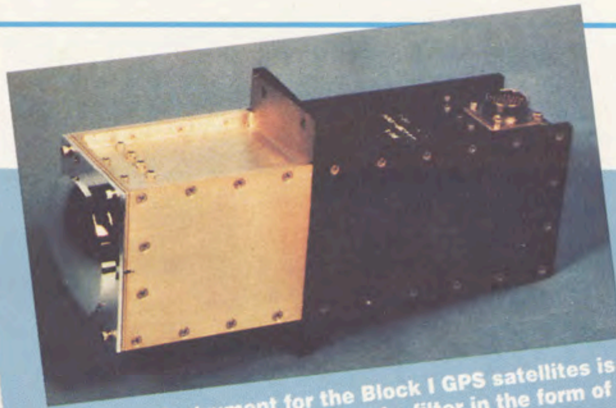
The NPT was initially signed by the U.K., U.S., and Soviet governments on July 1, 1968. The treaty currently has more than 140 signatories; notable holdouts include India, Pakistan, Argentina, Brazil, and Israel. Article X.2 of the treaty states that a conference must be convened in 1995 — 25 years after the treaty entered into force in 1970 — to decide whether it will be continued.

NUCLEAR DETONATION SENSORS

The physical output — light, gamma rays, X rays, neutrons — from a nuclear explosion, as well as the secondary effects due to the interactions with the atmosphere of these primary forms of energy output, is well known. The standard reference for a detailed discussion of these phenomena is still Samuel Glasstone's book *The Effects of Nuclear Weapons,* first published in 1950. (The third edition, published in 1977, is available from the U.S. Government Printing Office.) Measuring the outputs of an event using instruments sensitive to different phenomena helps prevent incorrectly identifying an event due to some natural phenomenon (for example, a lightning flash) as a nuclear detonation.

The sensors on the GPS satellites have been designed to measure the outputs due to various phenomena. In particular, visible light, radio waves, and X rays are measured by sensors on the satellites. In addition, background measurements of the radiation environment are also performed by instruments on some of the GPS satellites. The GPS orbits at 4.1 R_E (with one mean earth radius being equivalent to 6,371 kilometers) run through a region of intense charged particle radiation known as the *outer Van Allen radiation belt.*

X-ray Measurement Devices. The X-ray instruments carried on the GPS Block I satellites are simple sensors designed to measure the intense burst of X rays that would accompany



The X-ray instrument for the Block I GPS satellites is a simple detector consisting of a filter in the form of a dome that reduces the flux of particles passing through it and thereby reduces the background. Dual sensors behind the dome provide redundancy for the instrument.

President Kennedy viewed a model of the Vela satellite in December 1962. Other figures in the photograph (from left to right) include McGeorge Bundy, national security advisor; Glenn Seaborg, chairman of the Atomic Energy Commission; and S.P. Schwartz, president of Sandia National Laboratories.

The background instrument features four thick domes that are used to reduce the counting rate to a limit that can be conveniently handled by the electronics. The holes allow a sampling of the flux over a hemisphere. A hemispherical filter inside each of the domes defines an energy threshold for the particles entering the holes. Thus four energy channels can be defined for the dose measured by the instrument.

the exoatmospheric detonation of a nuclear weapon. Because such a burst would occur in an interval of less than 1 microsecond, the sensors must continuously monitor for such an event. Should such an event occur, data from all the satellites observing the event are transmitted to ground terminals for processing.

Because the X rays from a nuclear detonation would travel outward from the location of the event in what would be essentially a spherical shell expanding at the speed of light, the location of the event can be determined from accurate timing information as part of the measurement at each responding satellite. This case is essentially the reverse of what occurs during navigation operations, in which a receiver at a fixed point receives accurate time marks from several satellites to determine its location. In the first case, the detonation acts as an impulse transmitter. The time differences of arrival (TDOA) at four or more satellites must be measured to calculate the time of the event and its *x, y, z* coordinates.

In addition to providing the timing information needed to calculate the location, the sensor itself measures the intensity of the X rays impinging upon it. This information, together with range obtained with the TDOA technique described earlier, can be used to calculate the yield of the device that was detonated.

Background Sensors. For adequate coverage, most of the satellites in the constellation of 24 satellites have X-ray detectors on them. However, a few satellites in the constellation have a background sensor — to measure the natural particle fluxes in the radiation belt through which the satellites pass — instead of an X-ray instrument. This background information is important to ensure the proper interpretation of data from the X-ray detectors and other sensors. The background instrument's interface to the spacecraft is identical to that of the X-ray instrument so that the differences between the two are invisible to the spacecraft manufacturer. The essential difference is that the background monitor operates continuously, providing a steady stream of data. In contrast, one hopes the X-ray instrument never has the occasion to report a nuclear event.

Of the constellation of 24 GPS satellites, 3 have a background instrument on board instead of an X-ray instrument. The head of a Block I background instrument features holes in a composite dome designed to reduce the background fluxes of energetic electrons to acceptable counting-rate levels. The holes allow a sampling of the fluxes over one hemisphere. A filter at the bottom of the holes provides an energy threshold so that the dose can be measured for a certain range of equivalent radiation shielding. Besides supplying information for interpretation of data from other sensors and also providing information on the total dose received by the satellites, the data from these sensors are valuable for scientific purposes. The background sensors measure a part of the *magnetosphere* (the region surrounding the earth to which the earth's magnetic field is confined by the stream of particles from the sun known as the *solar wind*) not routinely investigated, and the long span of data available makes a valuable scientific data set, albeit the instruments are very crude by the standards of most scientific instruments used today.

The Bhangmeter: A Non-imaging Radiometer. Sandia National Laboratories has developed an optical radiometer, called a *bhangmeter,* which records signals from nuclear explosions in the atmosphere. The most prominent effect of atmospheric nuclear explosions is the formation of a fireball whose light intensity, as it appears to a distant observer, undergoes fluctuations that result in two distinct peaks. Detection of these peaks is a critical step in identifying optical events generated by nuclear explosions. The bhangmeter is a non-imaging radiometer that continuously monitors the full earth disk for these double-peaked signals. When a flash of light within its field of view exceeds a preset level and exhibits other characteristics of nuclear explosion signals, the bhangmeter triggers and records the optical intensity history.

With the lights of Albuquerque as a backdrop, a neodymium laser pulse at the Sandia calibration facility is test fired. The actual calibration pulses for the bhangmeter use a short pulse from a ruby laser.

An antenna for the calibration of the EMP monitor on the GPS satellites is at Los Alamos National Laboratory. During calibration, the antenna is directed at the satellite, and then a short burst of radio-frequency energy is radiated toward the satellite.

Bhangmeters, like other optical instruments on earth-orbiting satellites, respond to many signals that have nothing to do with nuclear explosions. The most significant of these is reflected sunlight from the earth. A fully sunlit earth disk illuminates the sensor with more than 10,000 times the intensity seen from some nuclear explosions. The slowly varying signal from the earth-reflected sunlight is electronically suppressed to permit the sensor to detect the much dimmer but fast-rising signal from a nuclear explosion. Transient false alarm signals result from lightning, an event that occurs many thousands of times each day over the earth, and from sun glints off water surfaces. False signals can also result when high-energy particles strike the bhangmeter's detector elements. The bhangmeter is designed to reject these false triggers, thereby maintaining a high probability of detection of atmospheric nuclear explosions.

Calibration of the GPS satellite bhangmeters is accomplished using a ground-based ruby laser system located at Sandia. Fast-rising laser pulses are accurately time-tagged using GPS clocks at the laser site and their times-of-arrival are recorded by the bhangmeter system aboard the satellite. The result obtained from this procedure provides an end-to-end test of all the processing functions involved in the calculation of satellite positions and corrections to timing data. Data sets from different satellites are combined to evaluate the location capability of the optical sensors by the TDOA location technique described earlier.

Radio Wave Detectors. Intense radio waves are also generated by a nuclear explosion. This phenomenon arises from energized electrons (Compton currents) produced by the interaction of the primary bomb radiation with the atmosphere. The Compton currents are turned by the earth's magnetic field to produce an electromagnetic pulse (EMP). The satellite carries a specialized antenna and set of electronics to detect and measure the EMP from a nuclear detonation. A ground-based antenna developed at Los Alamos is used to stimulate the EMP detector on the GPS satellites.

THE FUTURE

The United States has the technological capability to determine whether an emerging nuclear power has conducted a test of a nuclear weapon. The same detection system can be used to monitor the progress of a nuclear war, should that ever occur. Until the time comes when the political shape of the world will have so changed that the possibility of the use of nuclear weapons will have disappeared, such systems as the GPS NUDET system are vital to the nation's security.

ACKNOWLEDGMENTS

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A number of treaties touching on nuclear weapons and arms control exist. In addition, several documents on this subject are available — for example, *Agreements for Arms Control: A Critical Survey* and *Twenty Years of the Non-Proliferation Treaty: Implementation and Prospects*, both by J. Goldblat, and *Beyond 1995: The Future of the NPT Regime*, written by J.E. Pilat and R.E. Pendley. An interesting historical document of the very early Vela work is "Identifying Nuclear Weapons Tests," in the *Hearings before the Joint Committee on Atomic Energy*, March 5–12, 1963. ■