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# MULTIPATH EFFECTS IN A GLOBAL POSITIONING SATELLITE SYSTEM RECEIVER


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## Multipath Effects in a Global Positioning Satellite System Receiver

### I. Introduction

The Global Positioning Satellite (GPS) system consists of eighteen satellites orbiting earth in six well-defined orbits. The orbits are inclined 55 degrees with respect to the equator, and the orbital planes are uniformly spaced to provide widespread satellite coverage over most of the earth's surface. Generally speaking, four or more GPS satellites are visible at any populated location on the earth's surface at almost any time. The view of GPS satellites is even better from the vantage point of space vehicles orbiting a few hundred kilometers above the earth's surface.

The GPS satellites orbit at an average height above the earth's surface slightly in excess of 20,000 kilometers with an orbital period of one-half a sidereal day (a sidereal day is the time required for the earth to rotate once on its axis, relative to a distant star. It is about four minutes shorter than the synodic "ordinary" day, which is defined using the sun as a reference). Thus the GPS satellites orbit the earth approximately twice a "day".

Each GPS satellite broadcasts a unique pseudorandom number (PRN)-encoded spread-spectrum signal on a carrier frequency of 1.57542 gigahertz. The PRN code rate ("chip rate", as it is known) is 1.023 megahertz. The method for spreading the spectrum is bi-phase shift key (BPSK) modulation. The signal is further modulated with a 50 bit-per-second data code. The data includes satellite ephemerides, satellite clock correction offsets, ionospheric transmission characteristics, etc. This description pertains to the C/A ("clear access", or "coarse acquisition"; interpretations vary) encoded signal. There is simultaneously a second encoding scheme (known as P-code) and another carrier frequency broadcast by the GPS satellites which has no bearing on this study.

The GPS system consists of three "segments": a) the Control Segment, b) the Space Segment, and c) the User Segment. The Control Segment is a master station and a system of ground stations which rigorously monitor the orbits and the health of the GPS satellites and strictly maintain an accurate system time reference. The Space Segment refers to the eighteen GPS satellite vehicles (SV's) which receive and re-broadcast the data sent up to them by the Control Segment. Each satellite broadcasts data about itself as well as the other satellites in the Space Segment. The User Segment consists of users who operate GPS receivers capable of receiving and decoding the GPS satellite signals.

The purpose of the GPS system is to enable accurate determination of user position (on earth, or in the space above it). In principle the method of determining position is quite straightforward, assuming that the user and all the GPS SV's have perfectly synchronized clocks and the satellites' positions are accurately known at all times. Then, by knowing the exact location of each of the SV's, the exact time a signal was broadcast by a given SV, and the exact time each SV signal was received by the user (GPS receiver) after having traversed the SV-to-user distance at the constant "speed of light", it is a trivial problem to compute how far the user is from each of the SV's. Observation of four SV signals determines a unique fix of user location. In actual practice several small corrections have to be applied in order to produce precise user location.

This study, as a part of a larger continuing investigation being conducted by the Communications Systems Branch of the Information and Electronic Systems Laboratory at the Marshall Space Flight

Center, was undertaken to explore the multipath response characteristics of a particular GPS receiver which was available in the laboratory at the beginning and throughout the entirety of the study, and to develop a suitable regime of experimental procedure which can be applied to other state-of-the-art GPS receivers in the larger investigation.

The underlying question which drives this research is: how much user position uncertainty can be anticipated when a GPS receiver is being operated in a space vehicle that is subjected to varying levels of multipath reflections of a particular SV signal which is being relied upon for the user's position fix. In other words, should one expect a multipath problem in GPS receiver operation, say in the environs of a large reflective space structure, such as the Space Station Freedom, for example, and, if so, how serious might that problem be?

## II. Experimental Procedures

The measurements of multipath effects were performed with instrumentation and equipment available in the laboratory at MSFC. The principal instruments were: a) a GPS Satellite Signal Simulator (SSS) (manufactured by Stanford Telecommunications, Model 7200 NAVSTAR) and b) a GPS receiver (manufactured by Trimble, Model 4000-AX). In addition, radio frequency (RF) amplifiers, power meters, signal attenuators, signal splitters and combiners, a carrier-wave phase shifter, various lengths of RG-214/U coaxial signal transmission cable, two computers, and a spectrum analyzer were configured in the experimental circuit illustrated by the block diagram in Figure 1.

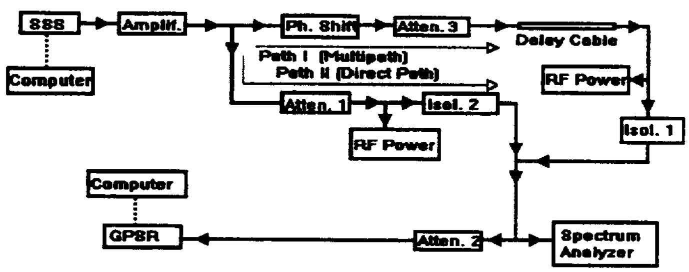


Fig. 1. Block Diagram of Experimental Circuit

The SSS generates a "constellation" of up to five fully encoded GPS satellite signals appropriate for a specified user location and time. The SSS further permits simulation of the satellite signals appropriate for a user presumed to be undergoing motion along a programmed trajectory. This latter capability provided an opportunity to establish a GPS satellite simulation scenario wherein the GPS receiver platform was assumed to be moving along a trajectory near the earth's surface in such a manner as to maintain a near-constant pseudorange (defined as the detected satellite-to-user distance) from one of the satellites (identified as SV01, for satellite vehicle number 1) for a protracted period of time. During this time interval in the simulated scenario the Doppler shifts of the SV01 signal were quite small, advancing through a zero Doppler value.

While the SV01 was standing still (relative to the GPS receiver) in the simulated scenario pseudorange and time data, as detected by the GPS receiver (GPSR) were recorded. The SSS signal for the SV01 satellite was split into two components, a "direct" component and a "multipath" component, as indicated in Figure 1, and recombined as an input to the GPSR. Provisions in the circuit allowed the multipath component to be time-delayed (by insertion of various lengths of transmission cable), phase-shifted by up to three-fourths of a carrier cycle, and attenuated, as needed, to allow control of the relative power level of the multipath component.

The simulated scenario was repeated in successive runs with different cable lengths inserted in the multipath line. On each run, a somewhat systematic pattern of inserting and removing the multipath component while its phase was being swept by the phase shifter was undertaken. Raw pseudorange and time information was sampled at the GPSR.

## III. Results and Conclusions

Graphical plots of the raw pseudorange versus time data for SV01 demonstrated the GPSR's response to the various injected multipath conditions. Data were recorded for cable lengths of approximately 15 meters, 32 meters, and 61 meters. These delays were the equivalents of space path differences of approximately 23 meters, 48 meters, and 92 meters, respectively. In each of the delays, the power levels of the multipath component was adjusted on successive runs to being a) equal to the direct component, b) down by 3 dB, c) down by 6 dB, and d) down by 10 dB.

Preliminary observations of the graphs demonstrate that: 1) the longer time delays (cable lengths) produce larger pseudorange excursion from the nominal, and 2) for any given delay, stronger multipath signals (relative to the direct signal) produce larger pseudorange excursions. The maximum observed pseudorange excursions (occurring with 92 meter (space equivalent) multipath delay and relatively strong multipath signal power) were on the order of 240 meters. When the multipath signal traveled an additional path length of 23 meters equivalent and was at a power level ten dB below that of the direct signal the pseudorange excursions were on the order of ten meters.

It should be noted that the worst pseudorange excursions for each delay accompanied the carrier wave phasing conditions where the nearest-to-a-null spectrum analyzer power display was observed. It happens that near-total nulling occurs for the very short time delays (yet those led to the smallest pseudorange changes) and the apparent severity of the nulling dimishes as the multipath component is delayed a larger portion of a "chip". The longest delay (92 meter space equivalent) is equal to approximately one-third of a chip.

It should be noted further that the effects observed and reported here concern raw pseudorange for a single satellite, not actual position. Also, these data represent no attempts to "smooth" or condition.