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MULTIPATH MEASUREMENTS FOR LAND MOBILE SATELLITE SERVICE USING GLOBAL POSITIONING SYSTEM SIGNALS

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ABSTRACT

A proposed multipath measurement system for the land mobile satellite radio channel using the Global Positioning System (GPS) is presented. The measurement technique and equipment used to make multipath measurements on communications links are briefly described. Then the system configuration and performance specifications of the proposed measurement system are discussed.

INTRODUCTION

For many years the Institute for Telecommunication Sciences (ITS) has been active in the area of multipath measurements over radio transmission channels. Using channel probes developed at ITS, such measurements have been made over line-of-sight microwave, troposcatter, and land mobile communication links, and are discussed in Linfield et al. (1976), Hubbard (1983), Hubbard et al. (1978), Hufford et al. (1982), and Lemmon (1987). Briefly, the channel probe transmitter develops a signal that is biphase modulated by a pseudonoise (PN) binary code; the probe receiver performs a cross-correlation between the received signal and a locally generated signal that is modulated by the same PN code developed by a "slow clock." Thus, the local PN code is allowed to slip very slowly in time with respect to the received PN code, thereby enabling one to measure the impulse response (and hence, the multipath) of the radio channel as a function of time delay.

As part of the National Aeronautics and Space Administration's Mobile Satellite Communications Program, ITS has been funded to perform multipath measurements in the land mobile satellite radio channel using signals from the Global Positioning System (GPS) satellites and a GPS receiver modified to develop the necessary time-multiplexed correlator signal. The feasibility of such an experiment and various measurement strategies have been discussed by Lemmon and Hubbard (1985). The objective is to measure the impulse response function of the radio channel using a multipath measurement system (MMS) installed in a mobile van. The data so obtained will provide an initial assessment of multipath propagation in the land mobile satellite channel and will be valuable in planning mobile satellite services.

GPS APPROACH TO MULTIPATH MEASUREMENTS

The GPS signal consists of two components, Link 1 (L1) and Link 2 (L2), at center frequencies of 1575.42 MHz and 1227.6 MHz, respectively. Each of these two signals (L1 and L2) is phase modulated by two binary signals: a 10.23 MHz clock rate precision P signal, and/or a 1.023 MHz course/acquisition C/A signal. Each of these two signals (P and C/A) has been formed by a P code or a C/A code which is modulo-2 added to a 50 bps data stream D, to form P+D and C/A+D, respectively.

The P code for each satellite is a pseudonoise (PN) binary sequence with a clock rate of 10.23 Mbps and a period of exactly 1 week. The C/A code is a Gold code with 1023 bits and a clock rate of 1.023 Mbps. The C/A code therefore has a period of exactly 1 ms. The 50 bps data stream D is also a binary sequence that contains navigational information (time, satellite position, etc.) as well as the current P code epoch time.

In its normal mode of operation, a GPS receiver acquires and tracks a GPS signal using the C/A signal and obtains a navigational fix upon extracting the data from four or more satellites. With knowledge of the P code epoch time, the P signal can be acquired and a more precise fix can be obtained. The signals are acquired and tracked by performing a cross-correlation between the received signal and a locally generated signal modulated with the same PN code as the received signal. Once the correlation peak of the PN sequence has been located and locked onto (i.e., zero relative time delay and Doppler between the received and locally generated PN codes), the data can be recovered by modulo-2 subtraction of the PN sequence from the received signal.

In order to perform multipath measurements with a GPS receiver, the locally generated PN code must be allowed to slip in time relative to the received PN code. However, due to variations in time delay and Doppler in the propagation channel, the tracking loops in the receiver cannot be disturbed if one is to maintain control over the time delay (and Doppler) between the two PN codes used to make an impulse response measurement. Thus, a dual-channel receiver is required. The first channel will operate in the normal GPS mode to acquire and lock onto the signal and recover the 50 bps data stream. The second channel will be used to make the impulse response measurements by shifting the local PN code relative to that of the received signal, which is being tracked by the first channel. The proposed measurement system is shown schematically in Figure 1.

ITS intends to award a subcontract for the development of a GPS multipath measurement system. The measurement system shall be a GPS receiver capable of tracking the GPS L1 P-code signal and extracting multipath signal information. In order to be eligible for acceptance, the MMS shall conform to the system configuration and performance specifications below.

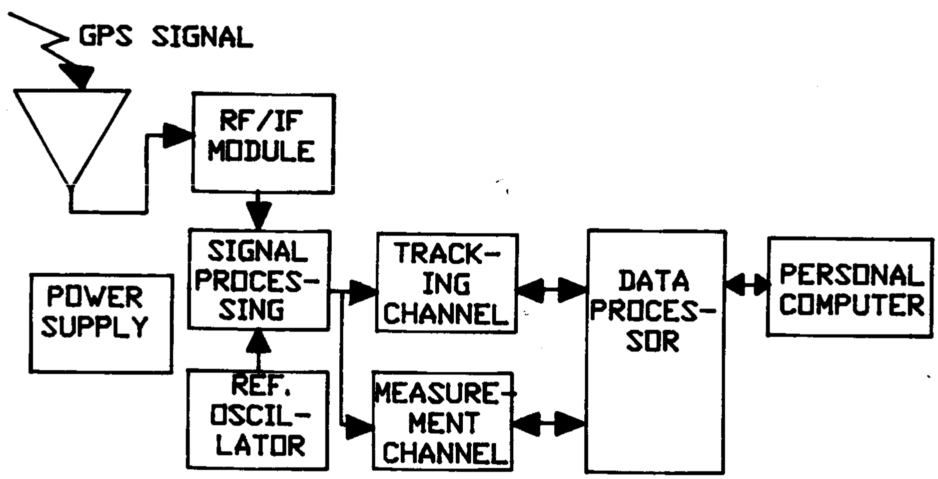

Figure 1. Multipath measurement system.

MMS CONFIGURATION

The MMS shall be comprised of the following functions:

1. Antenna. The antenna shall be omnidirectional that multipath signals are not discriminated against.

2. RF/IF Module. The RF/IF sections of the receiver shall provide the necessary low-noise amplification and conversions to IF necessary for further signal processing.

3. Signal Processing. Signal processing shall be required to convert IF signals to information required for dual channel processing.

4. Reference Oscillator. A reference oscillator shall be provided with the receiver from which all required local oscillators and clocking shall be derived.

5. Tracking Channel. The tracking channel shall be capable of acquiring and tracking one GPS L1 signal at a time and providing pseudorange, pseudorange rate, and AGC information necessary to aid the measurement of multipath signals in the measurement channel. The GPS navigation data shall also be provided.

6. Measurement Channel. The measurement channel shall be capable of measuring post-correlation signals delayed from that of the signal tracked in the tracking channel. Simultaneous measurements at 15 delays, one-half P-chip (50 ns) apart, shall be provided. An

incrementing capability shall also be provided so that finer resolution delays can be measured.

7. Data Processor. A data processor shall be provided to control the two channels, to coordinate their activities, to collect the measurement data, and to provide that data and other pertinent data to the personal computer.

8. Personal Computer. The personal computer will be provided by ITS. However, any interfacing board required for communications to the receiver shall be provided by the contractor.

9. Power Supply and Chassis. The power supply shall convert 115 VAC-60 cycle power to voltage required by the MMS functions, with the exception of the personal computer. The MMS, except the personal computer, shall be packaged in a chassis appropriate for installation in a van.

PERFORMANCE SPECIFICATIONS

Input Signal Levels

The input GPS L1 signal level will be the nominal GPS P-code signal power level of -133 dBm. The C/A signal may be used for acquisition and will have a nominal power level of -130 dBm. The MMS shall track these signals in relatively extreme multipath environments.

Output Signal-to-Noise Ratio

The signal-to-noise density ratio (for zero relative delay between the local and received PN codes) at the correlator outputs will have a nominal value of 37 dB-Hz. Thus, the signal-to-noise ratio in a 50 Hz bandwidth (corresponding to a 20 ms integration time) will have a nominal value of 20 dB.

Tracking Accuracy

The tracking accuracy of the tracking channel with the signal levels specified above shall be as follows:

1. Pseudorange error $\leq$ 0.075 P-chips, one sigma
2. Pseudorange rate error $\leq$ 0.03 P-chips/second, one sigma

These accuracies shall be applicable to independent measurements taken at 1-second intervals. In a multipath environment, the pseudorange is allowed to deviate from the "true" pseudorange at rates consistent with that environment, but the one sigma accuracy about that deviation shall apply.

GPS Navigation Data and Bit Error Rate

The MMS shall decode the GPS navigation data with a bit error rate less than 1×10^{-5}. Bit errors shall be detected. The GPS navigation data shall be provided for possible modulation of the multipath measurement data.

Interchannel Bias

The pseudorange bias between channels shall be less than 0.1 P-chips.

Measurement Channel Performance

Measurement channel capabilities. The measurement channel is not required to track the GPS signal. Instead, using data provided via the data processor from the tracking channel (pseudorange, pseudorange rate, and AGC level), the measurement channel shall be capable of positioning its code generator relative to the code state tracked in the tracking channel in order to measure the received multipath signals that arrive after the signal tracked in the tracking channel. The measurement channel shall measure 15 code states simultaneously, positioned one-half P-chip apart. It shall also have the capability to "slew" the code state in increments so that finer resolution measurements can be accomplished. Pseudorange measurements shall be made to verify code state positions.

The following data for each of the code states shall be provided at a 50 Hz rate:

1. I integrated over the 20 ms data bit
2. Q integrated over the 20 ms data bit
3. $\sum_{1}^{20} (I^2 + Q^2)$ for I's and Q's integrated over 1 ms

where I and Q are the in-phase and quadrature phase baseband components, respectively. A gain control capability shall be provided to allow adjustment of the I and Q levels relative to the tracking channel AGC level.

Measurement channel accuracy. Each of the three quantities specified above shall be a 16-bit number for a total of 90 bytes every 20 ms (4.5 Kbaud).

Data Processor Performance

The data processor shall control the MMS receiver to acquire an assigned GPS signal, to track that signal, to aid the multipath measurement channel with measurements from the tracking channel, to control the measurement channel code phase position, and to collect the GPS navigation data and the measurement data specified above. It shall buffer that data in appropriate data blocks and provide that data to the personal computer for processing.

Testing

The capabilities of the MMS shall be verified by testing with a simulated multipath environment (sum of two GPS signals with the same PN code, variably delayed with respect to one another). Failure to meet the performance specifications above will be cause for rejection of the equipment.

DATA ANALYSIS

The MMS will be installed in a mobile van and multipath measurements will be made in a variety of urban, suburban, rural, and mountain environments in the Denver/Boulder area. The data will be analyzed for relative multipath power and phase, delay spread, and the time rates-of-change of these quantities in various source/receiver geometries and environments. In addition, the signal-to-noise ratio can be computed by measuring $(I^2 + Q^2)$ over two different bandwidths. For example, let $(I^2 + Q^2) = P_N$ for I's and Q's integrated over 20 ms and $(I^2 + Q^2) = P_W$ for I's and Q's integrated over 1 ms. Then P_N is the total power (signal plus noise) in a 50 Hz bandwidth and P_W is the total power in a 1 kHz bandwidth. Let N denote the noise power in a 50 Hz bandwidth and let S denote the signal power. Then it follows that

$$S + N = P_N$$

and

$$S + 20N = P_W$$

which imply that the signal-to-noise ratio in a 50 Hz bandwidth is

$$\frac{S}{N} = \frac{20\,P_N - P_W}{P_W - P_N} .$$

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