BACKPACK VLBI TERMINAL WITH SUBCENTIMETER CAPABILITY

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The measurement of short vector baselines with subcentimeter repeatability and accuracy using radio interferometric observations of quasars has already been demonstrated (reference 1). This paper describes our plans to achieve comparable performance using inexpensive, backpack portable equipment that processes less than one second of data per baseline redetermination. Figure 1 summarizes some of these objectives.

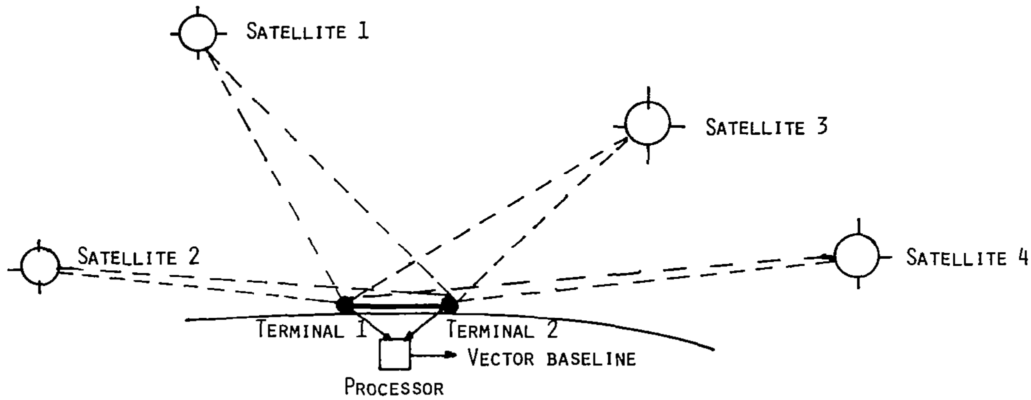
Our approach exploits the full measurement accuracy inherent in the precise radio signals that will be broadcast by each satellite in the NAVSTAR Global Positioning System (GPS) (reference 2). Figure 2 illustrates the measurement concept. The user equipment at each end of the unknown baseline receives signals from the same set of four or more GPS satellites. The equipment consists of a simple antenna, a GPS receiver, a microprocessor unit and a recording unit (reference 3). "Real-time" baseline determination can be accomplished by linking the microprocessor units with a communication channel that can transmit at the rate of about 1 kilobit per baseline redetermination.

Each GPS receiver measures its range to each satellite by means of the wide-band pseudo-noise P-Code modulation that is impressed on the GPS radio frequency carriers which are at 1.226 GHz and 1.57542 GHz (reference 4). These measurements will typically have a precision of about 0.5 meters, which is approximately 2.5 wavelengths at a frequency of 1.57542 GHz. The primary use of these relatively coarse measurements in the proposed program is to assist in resolving ambiguities of the more precise carrier-phase measurements that will also be made (see below).

- TO DEVELOP BACKPACK PORTABLE EQUIPMENT TO MEASURE VECTOR BASELINES FROM ~ 1 KM TO ~ 100 KM IN LENGTH WITH SUBCENTIMETER TO FEW CENTIMETER ACCURACY.

- TO DEVELOP EQUIPMENT THAT IS
  - SIMPLE IN CONCEPT AND IMPLEMENTATION
  - RELIABLE IN UNATTENDED OPERATION
  - INEXPENSIVE - LESS THAN $15,000 PER UNIT

Figure 1. Objectives.



INSTRUMENTATION

- WIDEBAND OMNIDIRECTIONAL ANTENNA TO RECEIVE 1.6 GHz AND 1.2 GHz GPS TRANSMISSIONS
- SIMULTANEOUS RECEPTION FROM ALL SATELLITES
- MICROPROCESSOR-CONTROLLED SYSTEM FOR DATA COLLECTION AND FORMATTING
- DATA STORAGE AND/OR LOW-VOLUME DATA LINK TO MICROPROCESSOR-BASED DATA ANALYZER

Figure 2. GPS measurement concept.

The same knowledge of the pseudo-noise modulation on the transmitted GPS signal that enables the receiver to make coarse range measurements also enables that modulation to be stripped from the received signal, leaving a sinusoidal component that is modulated only by a low speed (50 bit/second) biphase encoded data signal. This data modulated carrier is tracked in current GPS receivers by a "Costas" phase detector, which uses a phase doubling nonlinearity to remove the effect of the biphase modulation (reference 5). The output of the loop is an unmodulated tone. The phase tracking error will be approximately 8° in typical noise environments; this value corresponds to approximately 4 mm at the GPS carrier frequencies (reference 6). The measurement is ambiguous by multiples of half the wavelength (approximately 10 cm) because the Costas loop output does not distinguish between input phases that differ by 180°. However, by using knowledge of the data signal format, one can regain the "lost" factor of two and obtain whole-wavelength (20 cm) spacing of the ambiguities.

The carrier phases obtained from the signals from four or more satellites (see figure 3) at each end of a baseline yield an extremely precise, albeit ambiguous, determination of the vector baseline (reference 3). One primary objective of the current plan is to assess the adequacy and flexibility of several alternatives for resolution of the ambiguities with simple equipment. Two leading approaches are:

1. Collect data from satellite observations over several hours during which the satellite geometry changes significantly. If the number of potential ambiguities from observations of each satellite is small, then the set of ambiguity values, one value for each satellite, that corresponds to the weighted least squares fit to the data will usually be the correct one.

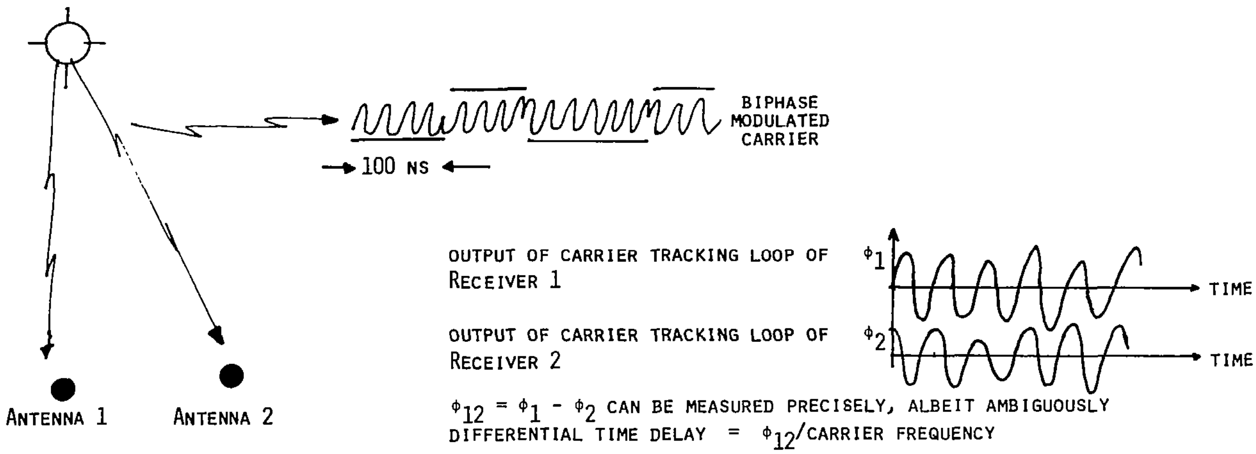


Figure 3. GPS signal processing concept ("reconstructed carrier").

This technique is described in reference 1. We note that all data used to resolve ambiguities are usable also for accurate determination of the baseline vector, after the ambiguities are resolved.

2. Measure the phase difference between the two GPS carriers received at each end of the baseline from each satellite to within a few degrees (note that both GPS carriers are synthesized coherently from the same oscillator). The corresponding phase-delay ambiguities will be light-time equivalents of integral multiples of the 0.43 m half-wavelength for the difference frequency (349 MHz). This approach is similar to the use of multiple tones in OMEGA to resolve "lane" ambiguities (reference 7). Used in conjunction with the coarse range measurement, the phase from both GPS carriers will allow a reduction in the initial ambiguities of the phase delay estimates. As the baseline length increases, the effectiveness of this technique will decrease because of ionospheric effects.

As the first phase in the development of the intended system, we plan to conduct an experimental program using commercially supplied GPS receivers. One or more standard baselines defined by receiving antennas will be established and surveyed. Each leg will be less than 100 meters in length. GPS signals received by the antennas will be processed to make a series of baseline determinations under a wide range of environmental conditions. The objectives of this experiment are:

1. to ascertain whether the accuracy of the baseline determination meets our goal (see figure 4);

2. to assess different techniques for ambiguity resolution; and

3. to determine whether the present GPS signal structure will allow the development of inexpensive and effective ground equipment.

1) EXPLOITATION OF KNOWN "PSEUDORANDOM" SIGNAL STRUCTURE (RECONSTRUCTED CARRIER APPROACH) YIELDS MORE THAN 60 DB GAIN.

2) SATELLITE TRANSMITTED POWER AND SIGNAL PROCESSING GAIN YIELD A MEASUREMENT SNR EXCEEDING 35 DB PER HZ, EVEN USING A MODEST RECEIVER. T_N = 430°K (NOISE FIGURE = 4.0 DB).

3) GPS BROADCASTS ACCURATE EPHEMERIS DATA.

4) GPS SUPPORTS CLOCK SYNCHRONIZATION TO 10'S OF NS SO THAT INHERENT EPHEMERIS ACCURACY CAN BE EASILY EXPLOITED.

Figure 4. Why size, weight and complexity objectives are feasible.

REFERENCES

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ACTION	CONSEQUENCE
USE DETERMINISTIC PROPERTIES OF GPS SIGNALS	HIGH MEASUREMENT SNR
HIGH MEASUREMENT SNR	CAN USE OMNIDIRECTIONAL ANTENNA; INEXPENSIVE RECEIVER
OMNIDIRECTIONAL ANTENNA	NO BEAM STEERING SIMULTANEOUS OBSERVATION OF ALL SATELLITES
SIMULTANEOUS OBSERVATION AND PARALLEL CHANNEL RECEIVER AND HIGH MEASUREMENT SNR	CARRIER PHASE MEASUREMENTS IN ABOUT 1 SECOND AND BASELINE UPDATE EVERY SECOND IN STEADY STATE*
SHORT MEASUREMENT INTERVALS	QUARTZ CRYSTAL CLOCKS
DIRECT CARRIER PHASE MEASUREMENTS	SIMPLE NUMERICAL PROCESSING IN STEADY STATE, BASED ON SOLUTION OF LINEAR EQUATIONS

*STEADY STATE = AMBIGUITY REMOVED

Figure 5. Properties of GPS-based system.

- AMBIGUITY RESOLUTION REQUIRED AT START AND OCCASIONALLY THEREAFTER:
  - I.E., WHENEVER THERE IS A "LONG" ENOUGH INTERVAL BETWEEN BASELINE MEASUREMENTS THAT THE BASELINE MAY CHANGE SIGNIFICANTLY
- RESOLVE AMBIGUITIES BY APPLYING CONCEPTS TESTED IN HAYSTACK-WESTFORD EXPERIMENTS AND AUGMENTED BY USE OF TWO FREQUENCY BANDS FOR IONOSPHERE REDUCTION
  - USE CODE MODULATION (GROUP DELAY) FOR COARSE, BUT UNAMBIGUOUS BASELINE DETERMINATION

    TIME REQUIRED DEPENDS ON EXTENT OF GROUND CLUTTER (MULTIPATH)
  - USE CARRIER PHASES FOR REFINED BASELINE DETERMINATION

Figure 6. Ambiguity resolution.

OBJECTIVES

- ASSESS AMBIGUITY RESOLUTION TECHNIQUES.
- DEMONSTRATE ACCURACY OF BASELINE DETERMINATION.

Figure 7. Experimental program.

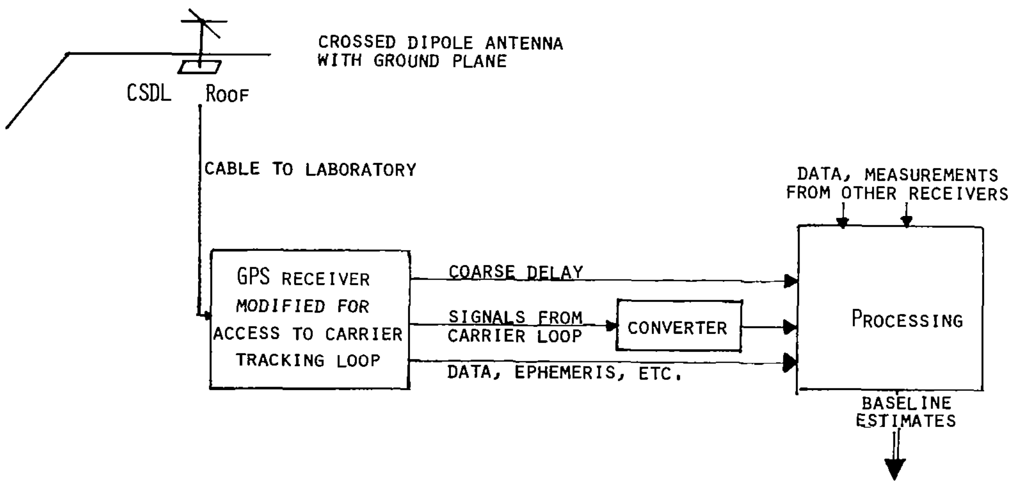

Figure 8. Experimental configuration.

FEATURES

- VERY SHORT BASELINE - < 100 METERS
  (RESULTS CAN BE ACCURATELY CHECKED BY INDEPENDENT TECHNIQUES. IONOSPHERIC REMOVAL NOT TESTED.)
- GPS 4-CHANNEL RECEIVERS
- CROSSED DIPOLE ANTENNAS WITH GROUNDPLANE
- PRECISE PHASE MEASUREMENTS ON RECONSTRUCTED CARRIER
- LOW DATA VOLUME FOR EACH BASELINE REDETERMINATION
  (LESS THAN 1 K BIT)

Figure 9. Experimental program.