SATELLITE EMISSION RADIO INTERFEROMETRIC EARTH SURVEYING (SERIES)

P. F. MacDoran

Jet Propulsion Laboratory
California Institute of Technology

ABSTRACT

The satellites of the Global Positioning System (GPS) offer an important new geodetic resource making possible a highly accurate portable radio geodetic system. A concept called Satellite Emission Interferometric Earth Surveying (SERIES) makes use of GPS radio transmissions without any satellite modifications. By employing the techniques of very long baseline interferometry (VLBI) and its calibration methods, 0.5 to 3 cm three-dimensional baseline accuracy can be achieved over distances of 2 to 200 km respectively, with only a few hours of on-site data acquisition. The use of quasar referenced ARIES Mobile VLBI to establish a sparse fundamental control grid will provide a basis for making SERIES GPS measurements traceable to the time-invariant quasar directions. Using four SERIES stations deployed at previously established ARIES sites, allows the GPS satellites apparent positions to be determined. These apparent positions then serve as calibrations for roving SERIES stations at unknown locations to determine their positions in a manner traceable to the quasars. Because this proposed radio interferometric configuration accomplishes its signal detection by crosscorrelation, there is no dependence upon knowledge of the GPS transmitted waveform which might be encrypted. Since GPS radio signal strengths are 10^5 stronger than quasar signals, a great reduction in telecommunications sophistication is possible which will result in an order-of-magnitude-less cost for a SERIES GPS station compared to a quasar based mobile VLBI system. The virtual all-weather capability of SERIES offers cost-effective geodetic monitoring with applications to crustal dynamics and earthquake research.

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration.

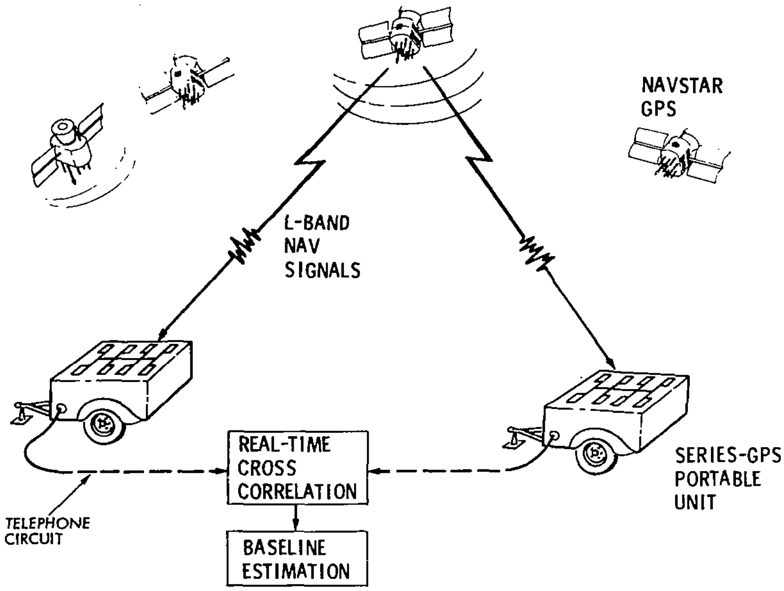


Figure 1. SERIES-GPS.

GOALS: TO EXPLOIT EXISTING SATELLITE RADIO EMISSIONS, ESPECIALLY THOSE OF THE GLOBAL POSITIONING SYSTEM (GPS), AS A RESOURCE FOR COST-EFFECTIVE HIGH ACCURACY GEODETIC MEASUREMENTS WITH EMPHASIS ON GEODYNAMICS APPLICATIONS.

OBJECTIVES: TO DEVELOP AND DEMONSTRATE A SYSTEM CAPABLE OF SUB-DECIMETER THREE DIMENSIONAL ACCURACY ON BASELINES OF SEVERAL HUNDRED KILOMETERS WITH CHARACTERISTICS OF:

- LOW COST PER POINT MEASURED (<$2K)
- LOW COST FIELD EQUIPMENT (≤ $100K)
- SHORT TIME ON-SITE (< 2 HOURS)
- REAL-TIME OPERATIONS OPTION
- ALL-WEATHER OPERATIONS
- UNATTENDED STATION OPERATIONS OPTION
- USE OF GPS EMISSIONS WITHOUT KNOWLEDGE OF CODED WAVEFORMS
- GPS AND GEODETIC POSITIONS TRACEABLE TO TIME-INVARIANT QUASAR DIRECTIONS

Figure 2. Satellite Emission Radio Interferometric Earth Surveying (SERIES).

ANTENNA (2.8m^2 PHASED-ARRAY, MICROPROCESSOR STEERED)	27 db GAIN
RECEIVER TEMPERATURE	100 Kelvin
BANDWIDTH SYNTHESIZED	10 MHz
SATELLITE RADIO SIGNAL FLUX (eg. to -158dBW, L_2 ch.)	1.7×10^5 Jansky
DIGITAL DATA RECORDING RATE (CASSETT RECORDER)	10 kb/sec
OBSERVATION TIME PER SATELLITE (4 ch. SAMPLING)	1 sec

SIGNAL TO NOISE RATIO: 24:1

TIME DELAY PRECISION: 190 psec (~6cm), 100sec of DATA (PHASE RESOLVER)

PHASE DELAY PRECISION: 1mm

BASELINE PRECISION LIMIT: 0.8 mm GIVEN 100 sec OF DATA

Figure 3. SERIES-GPS system configuration.

	BASELINE EQUIVALENT
• PHASE DELAY PRECISION PER SATELLITE OBSERVATION	0.3 cm
• TIME AND FREQUENCY ($\Delta f/_f = 2 \times 10^{-12}$, $\tau = 4$ sec.)	0.3 cm
• TROPOSPHERE	
• DRY (SURFACE METEOROLOGY)	1.0 cm
• WET (LOW-COST WATER VAPOR RADIOMETER)	1.5 cm
• IONOSPHERE (RESIDUAL FROM DUAL L-BAND CALIBRATION)	1.0 cm
• SATELLITE POSITIONAL UNCERTAINTIES (ARIES NET OF 2 cm ACCURACY AT 200 KM SPACING; GPS SATELLITE RANGE TO 1 KM ACCURACY)	1.0 cm
ROOT SUM SQUARE PER 4 SECONDS:	2.4 cm
1 min. AVERAGE:	0.6 cm

Figure 4. Randon error sources for SERIES-GPS system (≤100 km baselines).

	BASELINE EQUIVALENT
• SATELLITE POSITIONAL UNCERTAINTIES:	1.0 cm
(ARIES NET OF 2 cm ACCURACY AT 200 KM SPACING; GPS SATELLITE RANGE TO 1 KM ACCURACY)	
• TIME AND FREQUENCY($\Delta f/f$ = 6×10^{-11}, τ = 16 sec)	0.3 cm
(INCOHERENT AVERAGING OF 60, 16 sec DATA BLOCKS)	
• TROPOSPHERE	
• DRY (SURFACE METEOROLOGY)	1.0 cm
• WET (LOW-COST WATER VAPOR RADIOMETRY)	1.5 cm
• IONOSPHERE (RESIDUAL FROM DUAL L-BAND CALIB)	1.0 cm
ROOT SUM SQUARE:	2.3 cm
COMBINED RANDOM AND SYSTEMATIC ERRORS:	2.4 cm

Figure 5. Systematic error sources for SERIES-GPS system (≤100 km baselines).

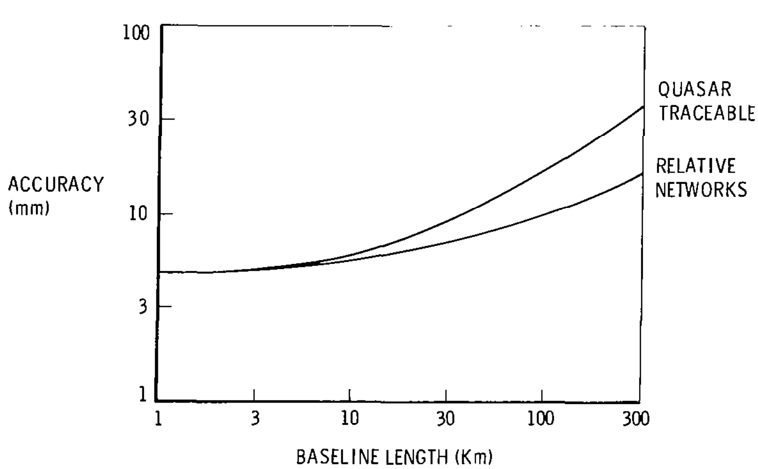


Figure 6. SERIES-GPS accuracy estimates.

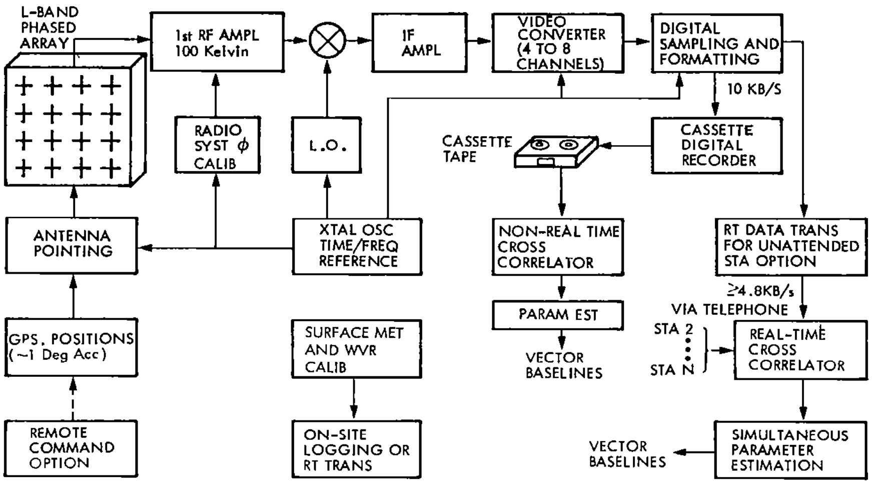
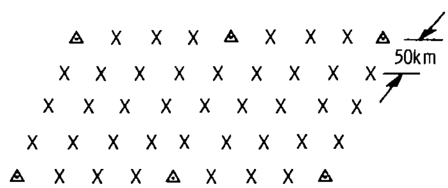


Figure 7. SERIES field station conceptual design.



△ ARIES DERIVED FUNDAMENTAL CONTROL GRID

X UNKNOWN SITES TO BE MEASURED

OBSERVING STRATEGY

1. FOUR SERIES STATIONS OCCUPY ARIES (△) SITES AND PROVIDE GPS SATELLITE POSITION CALIBRATIONS
2. FOUR ROVING SERIES STATIONS OCCUPY UNKNOWN (X) SITES

Figure 8. SERIES network densification with quasar traceability.

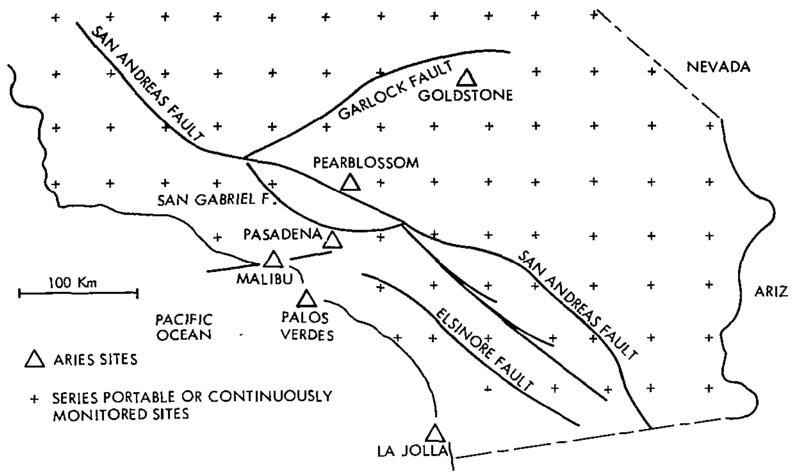


Figure 9. SERIES-GPS monitoring strategy for southern California.

- GEODETIC NETWORK DENSIFICATION (20 to 100 km SPACINGS)
- RAPID MULTI-STATION DEPLOYMENT INTO ZONES OF EARTHQUAKE PRECURSORS
- UNATTENDED STATION GEODETIC MONITORING
  - EARTHQUAKE FORECAST REGIONS
  - KNOWN HAZARDOUS AREAS (i.e., VOLCANOES, NUCLEAR WASTE DISPOSAL SITES)
- GPS SATELLITE ANGULAR POSITIONS RELATIVE TO QUASAR TRACEABLE ARIES GEODETIC POSITIONS
- MEASUREMENT PRECISION AND TEMPORAL RESOLUTION IN A REGIME BETWEEN CONVENTIONAL GEODESY AND SEISMOLOGY
- OCEANOGRAPHY - OPEN OCEAN TIDES, GEODETIC CONTROL AND TRENCH MOVEMENT via BOTTOM SONAR TRANSPONDERS

Figure 10. Applications SERIES-GPS.

- RF CYCLE AMBIGUITY RESOLUTION
- DUAL L-BAND IONOSPHERIC CALIBRATION AND HIGH PRECISION DELAY MEASUREMENTS
- SATURATION EFFECTS IN DATA SYSTEM DUE TO STRONG GPS SIGNALS
- ASSUMPTION OF ARIES CONTROL FOR SERIES OPERATIONS - HOW OFTEN MUST ARIES REMEASUREMENTS BE DONE TO HOLD 2 cm ACCURACY AT 200 km SPACING?

Figure 11. Challenges SERIES-GPS.