# VERY LONG BASELINE INTERFEROMETRY

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The area of technology involved in this presentation is the metric tracking of remotely located vehicles with earthbound tracking devices. In particular this discussion will present the new technology of determining the distance between two vehicles located on the surface of the moon, while one vehicle is in motion with respect to the other.

Figure 1 defines the problem more precisely and shows both the geometric situation and the hardware used to gather and reduce the data. The tracking objective is to determine the distance "D" between the Lunar Rover Vehicle (LRV) (depicted as radio frequency source 1) and the stationary Lunar Module (LM) (radio source 2) as the Rover moves about on the lunar surface.

This is accomplished by simultaneously receiving both monochromatic radio signal emissions at each of two separated earth receiving stations. These stations collect N-count Doppler data on each source and then transmit this data to a central processing facility. At the central processing facility, the Doppler data from both sites on source 1 is used in an algorithm which essentially differences the Doppler to compute $\dot{\theta}_1$ ; $\dot{\theta}_2$ is similarly determined. The difference between these angular rates is then computed and geometry provides $\dot{D}$ in the plane of the presentation screen. If a third site is used, $\dot{D}$ in two dimensions can be calculated. Thus it is possible to determine the motion of the lunar rover vehicle with respect to the LM in two selenographic directions. If we have an initial position or epic location for the LRV, it is possible to integrate the rate data and determine distance. Goddard Unified S-band stations with dual tracking capability have been used to gather double differential very long baseline interferometry (DDVLBI) data on Apollo-16 and Apollo-17.

This technique has some delightful properties which enhance its accuracy beyond that expected when computing the normal VLBI or single difference $\dot{\theta}$ measurement. Since a double differencing of the Doppler raw observable occurs in the algorithm to obtain $\dot{D}$, systematic or environmental errors common to both sources or both sites cancel at least to the first order. Thus effects that we have difficulty in accurately modeling, such as ionospherics, motion of the moon, distance between tracking sites, and differences in frequency standards all tend to cancel, yielding surprisingly accurate results. Therefore precise VLBI angular rate measurements to determine the rate of change in distance between two remote monochromatic sources is theoretically attractive and, from a hardware point of view, completely practical.

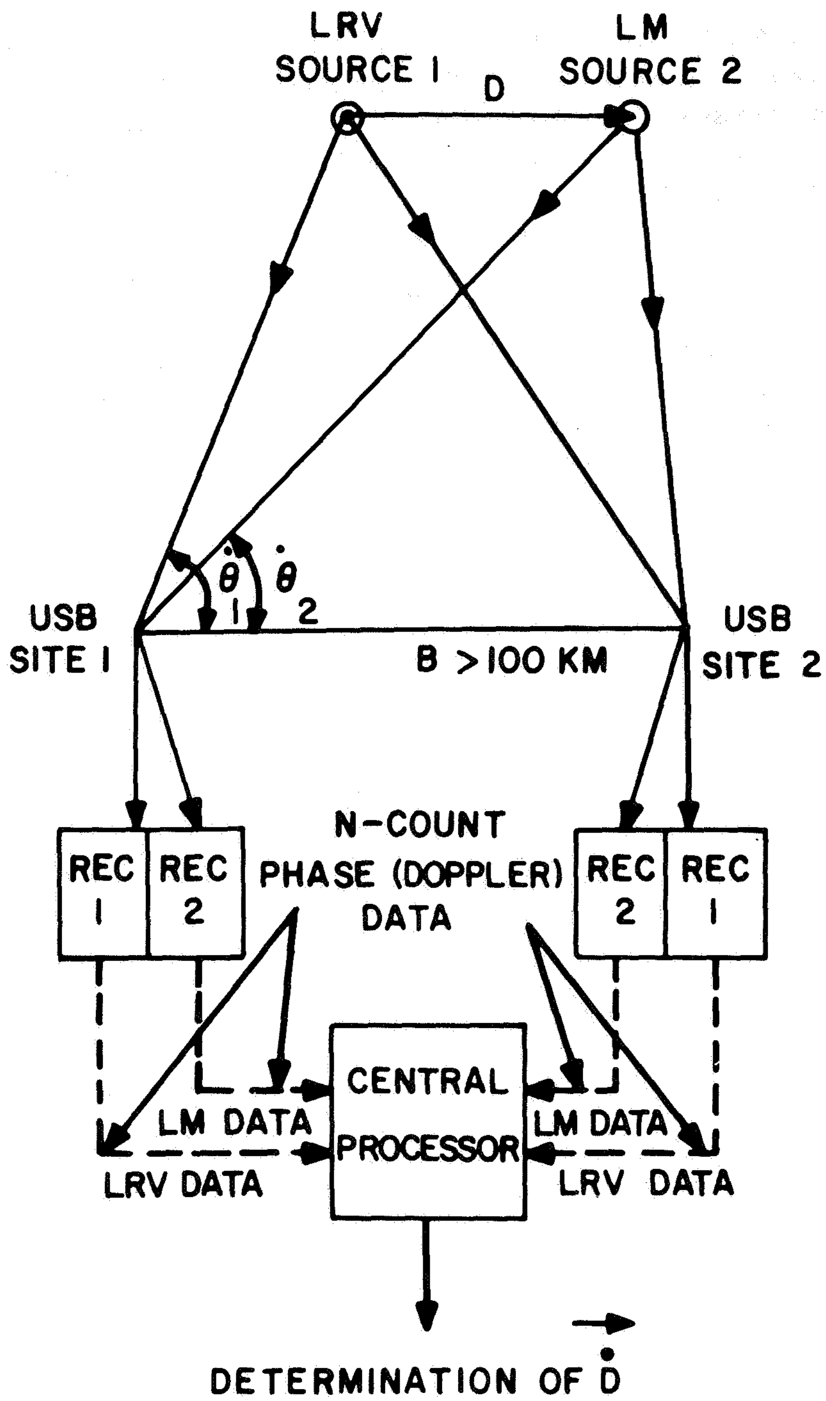


Figure 1. Double difference monochromatic VLBI.

We have now defined the tracking objective and outlined the software and hardware technology required for its solution. Let's go on to the results obtained when DDVLBI tracking was actually accomplished during the Apollo-16 mission.

Figure 2 depicts, as a function of time, the pertinent events of the LRV traverse for Apollo-16 EVA 1. The traverse commenced at 20 hours, 50 minutes, 40 seconds on April 21, 1972. The epic selenographic location of the LRV was approximately 84 meters south and 54 meters west of the LM. Madrid, Ascension, and Merritt Island dual USB stations were tracking the LRV and LM at this time when the LRV transmitter was switched to the monochromatic transmission mode. Within seconds the LRV departed from the LM, heading towards Plum Crater. Arriving at Plum Crater, the LRV transmitter was switched from the monochromatic transmission mode and was not reconfigured until seconds prior to the LRV's departure from Plum Crater heading towards Spook Crater. After a 25-minute stay at Spook Crater the LRV returned to the LM and parked approximately three meters from it. Redundant Goldstone data was available for the second and third portions of the traverse. The darkened boxes shown in the first and third traverse portions are of particular significance. During these periods the LRV was stationary and DDVLBI data was available.

Summarizing the statistics of these two periods, we find that noise on the determined North-South, East-West lunar separation distance never exceeded one meter (Figure 3). DDVLBI data did indicate, however, that the LRV was moving at about 15 mm/sec when in actuality it was motionless with respect to the LM. This difficulty is attributed to systematic drifts in the hardware between receivers at one site. Hardware improvements were implemented for Apollo-17 to reduce this drift.

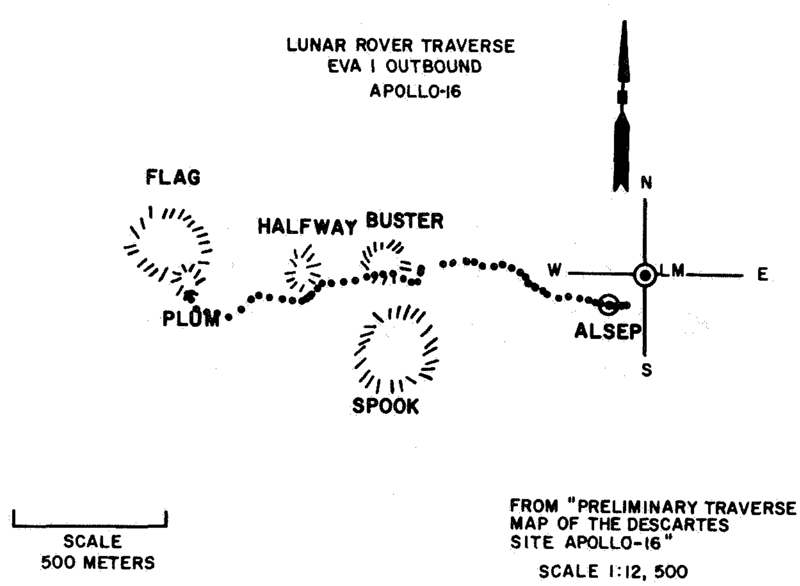


Figure 2. EVA 1, Apollo-16

Integrating angular data every 20 seconds starting from the provided epic position yields the results shown in Figure 4 for portion one of the traverse. Similar results are available for the return trip which place the computed parked position of the LRV approximately ten meters from the position indicated by the astronauts.

| | BIAS (DRIFT) (MM/S) | NOISE (METERS) |
|---|---|---|
| 21:06:40 TO 21:12:40 | | |
| N–S | -8 | 0.98 |
| E–W | -12 | 0.42 |
| 22:55:00 TO 23:01:40 | | |
| N–S | -9 | 0.67 |
| E–W | -2 | 0.58 |

Figure 3. Noise and bias of DDVLBI data.

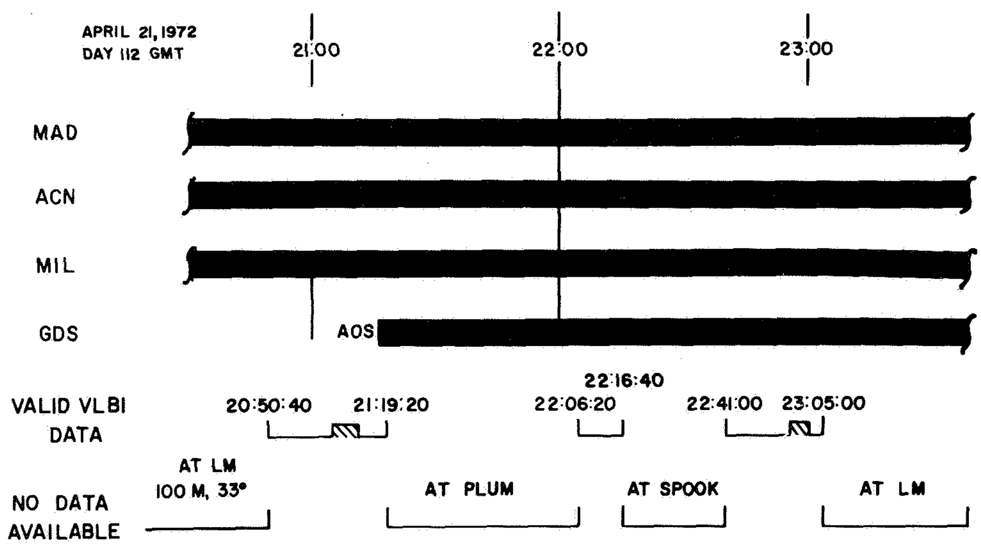


Figure 4. Events and time line for traverse of EVA 1, Apollo-16.

Based upon the nature and size of the drift rates, noise, and closure figures, a conservative estimate of the LRV position error when using DDVLBI computation techniques is 25 meters with noise of less than one meter (Figure 5). This technology was used on Apollo-17 to aid lunar scientists in reconstructing the path taken by the astronauts in the LRV for all three EVA's. It is felt that with minor hardware modifications DDVLBI tracking has direct application in more precisely defining lunar librations and may also have direct application in determining precise distances between mother-daughter class satellites.

TECHNOLOGY AREA: EARTH-BASED TRACKING AND POSITION DETERMINATION OF SPACE VEHICLES

PROBLEM: ACCURATELY DETERMINE THE DISTANCE BETWEEN THE LUNAR ROVER VEHICLE (LRV) AND THE LUNAR MODULE (LM) WHILE THE LRV IS IN MOTION FOR SUPPORT OF APOLLO LUNAR RESEARCH.

NEW TECHNOLOGY: DEVELOPMENT OF DOUBLE DIFFERENCED VLBI.

RESULTS: APOLLO-16 LRV TRACKED ON THE MOON TO AN ACCURACY OF 25 METERS WITH NOISE OF LESS THAN 1 METER, DRIFT BIASES OF 15 mm/S.

POTENTIAL UTILIZATION OF NEW TECHNOLOGY: LUNAR LIBRATION STUDIES, PRECISE MOTHER-DAUGTHER SATELLITE TRACKING.

Figure 5. Summary.