in all three experiments were donated by P. Perlman, Schering Corp., Bloomfield, N.J.
7. The criterion for meters was a continuous display of mounting activity for at least 12
minutes after the first mount, or until ejaculation. Mating activity was considered dis-
continuous if there were more than 5 minutes between successive mounting bouts. To be in-
cluded animals must have achieved criterion in at least two tests. Of the animals that
were excluded for failure to meet criterion, three females and one male did not mount
at all, three males achieved criterion in one test only, and three females and one male
mounted sporadically.
8. This experiment was conducted at the Uni-
versity of Connecticut. Long-Evans hooded
rats were from Blue Spruce Farms, Altamont,
N.Y.
9. The males had received two precastra-
tion tests. In order to better equate experi-
mental variables, the first postcastrational test was omitted from analysis.
10. Further analysis revealed that those mea-
sures (ejaculation latency, number of intro-
misions, postejaculatory interval) that nor-
mally vary as a function of ejaculatory series
did vary significantly with series in this experi-
ment, indicating that the data were suf-
ciently reliable to detect expected changes in
behavior. The obtained differences be-
 tween groups in ejaculatory latency and
number of intromissions may again be at-
tributable to differences in genital sensitivity.
However, there were no significant differ-
ences between the two groups in phallic
length, weight, or number of papillae (E. I.
Pollak and B. D. Sachs, paper presented at
Eastern Psychological Association conven-
11. Holgate Ultrasonic Receiver, Holgate's
of Totton, Southampton, SO4 3EF, England.
12. R. J. Barfield and L. A. Geyer, Science 176,
1349 (1972).
13. Supported by PHS research grants HD-
04048 to B.D.N. and HD-04484 to R.J.B.
15 March 1973

Precision Selenodesy via Differential Interferometry

Recently (1), we described some
astronomical applications of differential
interferometry and the results from
tracking the Apollo 16 Lunar Rover.

The accuracy of this tracking and of
similar interferometric observations of
ALSEP (2) telemetry transmitters was
degraded mainly by instrumental errors
corresponding to uncertainties of tens
of meters on the lunar surface. We re-
port here the first results from the de-
velopment and use of a new type of dif-
f erential receiver to determine the rela-
tive locations on the lunar surface of
two ALSEP transmitters. This receiver
has made it possible to reduce random
and systematic instrumental errors to
nearly negligible levels—the equivalent
of displacement uncertainties of
centimeters on the lunar surface.

With the new differential receiver,
the same S-band antenna, radio-fre-
quency amplifier, frequency converters,
and intermediate-frequency (IF) am-
plifiers are used to receive the signals
from two ALSEP's simultaneously at
each tracking station. Thus, the ALSEP
signals, which originate at frequencies
between 2275.5 and 2279.5 MHz, ap-
pear at corresponding frequencies
within an IF band centered at 10 MHz.

Any phase noise or drift introduced by
the receiving system before this point
(which includes all of the critical high-
frequency portions) affects both ALSEP
signals equally. From the IF signals, a
system of phase-locked oscillators and
single-sideband frequency converters
then generates a frequency equal to
360 times the difference between the
two ALSEP carrier frequencies, minus
a constant bias (3). Cycles of this multi-
plicated difference frequency are counted
digitally. Subtraction of the numerical
values of the counts obtained simultane-
ously at separate receiving stations
yields the differential interferometric
phase-delay observable.

This technique was used to observe
the Apollo 12 and Apollo 14 ALSEP
transmitters from stations at Merritt
Island, Florida, and Goldstone, Cali-
ifornia (4), between approximately
06:30 and 12:30 U.T. on 28 October
1972. From these data we estimated four parameters representing the selen-
ographic latitude and longitude of one
ALSEP (5), the arbitrary initial value
of the difference counter readings, and
the zenith delay of the atmosphere
assumed the same at both stations). The estimates for the relative positions
of the ALSEP's are given in Table 1
and the postfit residuals in Fig. 1. The
root-mean-square of the high-frequency
"noise" in the residuals, equivalent in
displacement on the moon to less than
15 cm, could easily have been lowered.

The observations, spaced 1 minute
apart and representing merely 0.05
second of signal averaging each, yielded
formal standard errors of 50 cm for the
components of the position on the lunar
surface of ALSEP 14 relative to AL-
SEP 12. Had each point represented
the full minute of averaging, the
formal error would have been about
1.5 cm and the high-frequency "noise"
correspondingly reduced.

With the random and instrumental
effects reducible to such a low level,
the accuracy in the determination of the
relative positions of the ALSEP's be-
comes limited by other factors. We
discuss these in order of increasing
importance.

Differential effects of the neutral
atmosphere influence the observable.
These were modeled by a modified
secant-zenith-angle law. At the begin-
ing of the observation period when

Table 1. Solution for selenographic coordinates of ALSEP 14 from differential interferometry
and coordinates of ALSEP 12. All coordinates except those describing the selenographic
latitude and longitude of ALSEP 14 were held fixed at their nominal values, derived from
analysis of Apollo Lunar Module tracking data (13). See text for a discussion of errors.

<table>
<thead>
<tr>
<th>Site</th>
<th>Selenographic</th>
<th>Radius (km)</th>
<th>Baseline (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALSEP 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td>2.9903</td>
<td>23.4031</td>
<td>1736.00</td>
</tr>
<tr>
<td>ALSEP 14</td>
<td>3.6656</td>
<td>17.4783</td>
<td>1736.393</td>
</tr>
<tr>
<td>New minus</td>
<td>-0.0042*</td>
<td>0.0221†</td>
<td></td>
</tr>
<tr>
<td>ALSEP 12 to ALSEP 14</td>
<td>180.315</td>
<td>0.531</td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New minus</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 1.249 km. † 0.668 km.
the elevation of the moon at Goldstone was 6°, the calculated value of the differential atmospheric delay was 0.2 nsec, equivalent to a 6-m displacement on the moon. One hour later, when the moon had risen to 17°, the equivalent displacement was less than 0.8 m. The accuracy of the differential interferometric phase measurements is so high, however, that using only the one data sample per minute we obtained for the estimate of the (undifferenced) zenith atmospheric delay a value of 7.1 ± 0.3 nsec, in good agreement with the expected average delay of about 7 nsec for these stations.

Thus, inadequacies in our atmospheric model probably make only a small contribution to the error in ALSEP position determination.

Systematic errors equivalent to about 30 cm of displacement on the moon may be introduced by differential ionospheric effects, which were ignored in our simple model. In fact, the abrupt increase of ionospheric density produced by sunrise at the Florida station may be responsible for the slight systematic trend of the residuals in Fig. 1. The failure of ionospheric effects to cancel completely in the differential observable is due mainly to the slight difference, about 1 MHz, between the frequencies transmitted by ALSEP's 12 and 14. Use of a simple model to account for the ionosphere might reduce this error by 70 percent, the remainder being equivalent to a 10-cm uncertainty on the lunar surface. But this refinement will be of little value until improved tracking station coordinates and an improved lunar ephemeris are available (6), as discussed below.

Uncertainty in our present knowledge of the receiving station locations is believed to be of the order of 10 m; the corresponding error introduced into the determination of the relative ALSEP positions is about 1 m.

Errors in the lunar ephemeris (7) probably introduces errors on the order of 1 to 3 m in the differential interferometric determination of relative ALSEP positions. This estimate for the contribution of the lunar ephemeris errors to the uncertainty in the relative ALSEP positions follows from our assuming an uncertainty of 1 km in the position of the moon's center of mass and in the position of ALSEP 12 relative to the center of mass.

The largest uncertainty of all is concerned with the expression of the relative ALSEP positions in terms of a particular set of selenographic coordinates. One must know the relation of this coordinate system to those defined by the earth's rotation and the moon’s geocentric orbital motion since the latter two most strongly affect the time variations of our observations. This relation is determined in essence by the lunar libration model used (8); differences between currently used models of the libration and the “correct” model might correspond to changes in the ALSEP 14–ALSEP 12 relative selenographic coordinates as great as 30 m (9). Of course, this strong dependence implies that similar ALSEP observations, if continued over a long period of time, would provide an excellent means for attacking the problem of determining the moon's physical libration (I, 10).

We should emphasize that the important sources of error discussed above, with the possible exception of the ionosphere, do not impose any intrinsic limit on the ultimate accuracy achievable. Thus, for example, when improved ephemerides become available for the moon (11), the differential interferometric data can be reprocessed to yield a corresponding improvement in the determination of the relative positions of the ALSEP's.

We conclude by listing the important advantages of this differential technique:

1) Tape recording of raw signals and subsequent cross-correlation of the recordings, the time-consuming hallmark of conventional very-long-baseline interferometry, are eliminated.

2) The experimenter can tell at the start of observations whether valid data are being obtained (12).

3) Neither highly stable local oscillators nor atomic frequency standards are required.

4) The cost of the accessory IF differencing and multiplying device, which makes it possible for nearly error-free differential interferometric data to be obtained by an STDN tracking station (4), is less than $200.

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References and Notes

2. ALSEP is an acronym for Apollo Lunar Surface Experiments Package. These ALSEP observations, suggested by us early in 1969, were made in 1971 by the Spacecraft Tracking and Data Network stations. This is less than $200.
4. Stations of the Spacecraft Tracking and Data Network (STDN) operated by the Goddard Space Flight Center of the National Aeronautics and Space Administration.
5. By differential interferometry we are able to measure directly only the relative angular positions, that is, the relative ALSEP positions projected onto a plane perpendicular to the line of sight. Thus, we cannot yet determine the differential selenocentric radii of the ALSEP's. However, computer simulations show that the radius difference may be determined also, with uncertainty increased by about a factor of 3 over that for the differential surface coordinates, by combining observations made from different directions.
6. At such time, a further error reduction can be achieved by observing all of the ALSEP's simultaneously and using the known frequency differences to separate ionospheric effects from ALSEP position effects. A multiplexing device, presently under construction, will enable all five ALSEP's to be monitored simultaneously at each STDN station.
7. We used the lunar ephemeris obtained by M. Slade [thesis, Massachusetts Institute of Technology (1971)] from analysis of about 30 years of optical observations, coupled with modern radar and spacecraft data.
8. The relative ALSEP position reported here is based on the physical libration model of D. H. Eckhardt [Moon 1, 264 (1970)], with parameter values $\beta = 6.30 \times 10^{-4}$ and $\gamma = 2.28 \times 10^{-4}$.
9. This estimate is based on information provided by P. L. Bender (personal communication) on the effect of the libration model on the estimated selenographic coordinates of the laser retroreflectors.
10. The moon's physical libration is also ex-
Short-Range Order and Crystallinity?

The substance of the report of Konnert et al. (1) is stated in their conclusion that “the comparisons with the functions calculated from crystalline phases of nearly the same density as the glasses imply a great similarity between glasses and crystals on the atomic level.” Essentially this same conclusion was reached by Zachariasen (2) 40 years ago and experimentally supported very shortly after. In his abstract of a 1933 paper Warren (3) stated: “On the random network hypothesis it is postulated that the atoms are bound together in the same way as in the crystalline forms of silica, but forming a continuous noncrystalline network.”

In the intervening years controversy has periodically raged, and silica glass has been called quartz-like, cristobalite-like, and now, by Konnert et al., tridymite-like. One wonders what agreement might be found between their data and broadened Bragg diffraction peaks of keatite, a silica polymorph of known structure (4) with a density between that of quartz and that of cristobalite and a thermal expansion coefficient more nearly like that of vitreous silica. We are disquieted by the fact that fitting the x-ray data according to the tridymite model required a mixture of 11-A and 20-A particle sizes of a crystal whose unit cell size is about 82 × 10 × 17 A. Even more disquieting is the fact that the cristobalite structure must be added since “details at large r [interatomic distance] suggest the possibility of a small amount of cristobalite-like ordering.” Konnert et al. have therefore proposed a crystallite model of at least two different sizes for regions having at least two different kinds of crystallities. This model is less satisfying to us than a random network model in which the Si-O-Si angle is the only structural variable. Random network models have been built and reported upon (5). It is clear that they can be extended indefinitely and that they may have an average density of 2.2 g/cm³. It is also clear that peaks in the distances between Si-O, O-O, and Si-Si atoms taken in pairs in the largest of these models extend up to at least 12 A (6).

Mozzi and Warren (7) used a technique which eliminated the troublesome Compton scattering, thus allowing them to collect usable data over a larger range of data collection s than Konnert et al. They did not report structurally significant detail beyond 12 A.

This lack of detail beyond 12 A suggests that the extra detail comes from the data reduction procedures. Clearly then, either the procedures of Konnert et al. are a significant advance or the extra detail is spurious. It would therefore be of interest to know just how this detail changes with physically reasonable changes in the constraints imposed. In particular, will it change if the distance between near-neighbor Si pairs is allowed to vary as it does in the random network hypothesis? It is also of interest to inquire how the differences in fine detail, at all values of r, arise between the silica glass radial distribution function of Konnert et al. and that first published by Konnert and Karle (8).

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