TRANSLOCATION by NAVIGATION SATELLITE

The present status of world-wide navigation capability using the observed doppler shift on radio transmissions from near-earth satellites has been well summarized in a recent issue of the *Digest*[1]. In that summary it was pointed out that navigation fixes taken at two points separated by distances up to 1,000 miles or so, and therefore based on a satellite orbit arc that is completely or partially intervisible at the two points, can be subtracted to give a measurement of the distance between the points, this measurement not being subject to most of the errors that apply to the absolute accuracy of a single navigation fix. This article will discuss the background and status of this application of the Satellite Navigation System.

In the early spring of 1964, a series of tests was conducted with navigation equipment at the Applied Physics Laboratory using signals from navigation satellites then in use to verify the adequacy of the computing programs used in calculating the fix results from a satellite pass. During these tests two navigation sets of the same type were operated from a common receiving antenna. It was reasoned that the two navigation fixes obtained from these sets when operated simultaneously should agree within the limits imposed by equipment and computing program design. Specifically, errors in absolute fix position due to inaccuracy of the satellite orbital data transmitted from the satellite memory (and used in computing the fix) should be the same for both equipments. A plot of the differences between pairs of simultaneous fix results taken in this way is shown in Fig. 1. For these colocated equipments the average radial fix difference is 5.8 meters, and the RMS radial dispersion is 7.3 meters. The mean latitude and longitude differences for the group of 12 points are small enough to be neglected as a bias (0.87 meter in latitude, 0.33 meter in longitude). If it be assumed that these differential errors are ran-

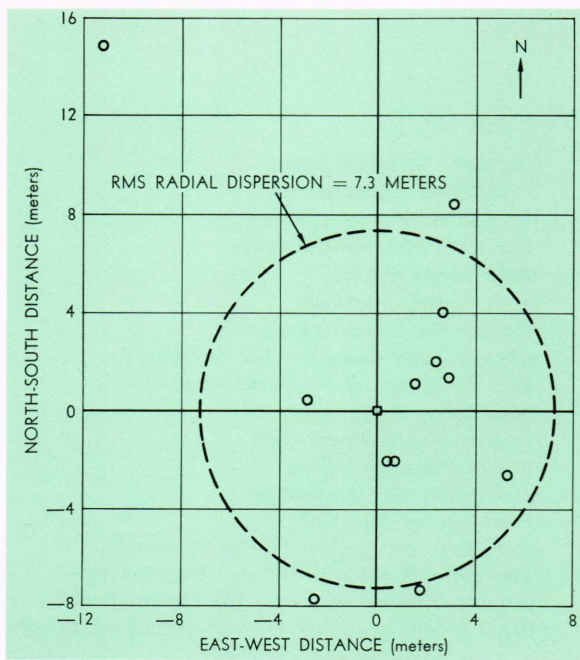
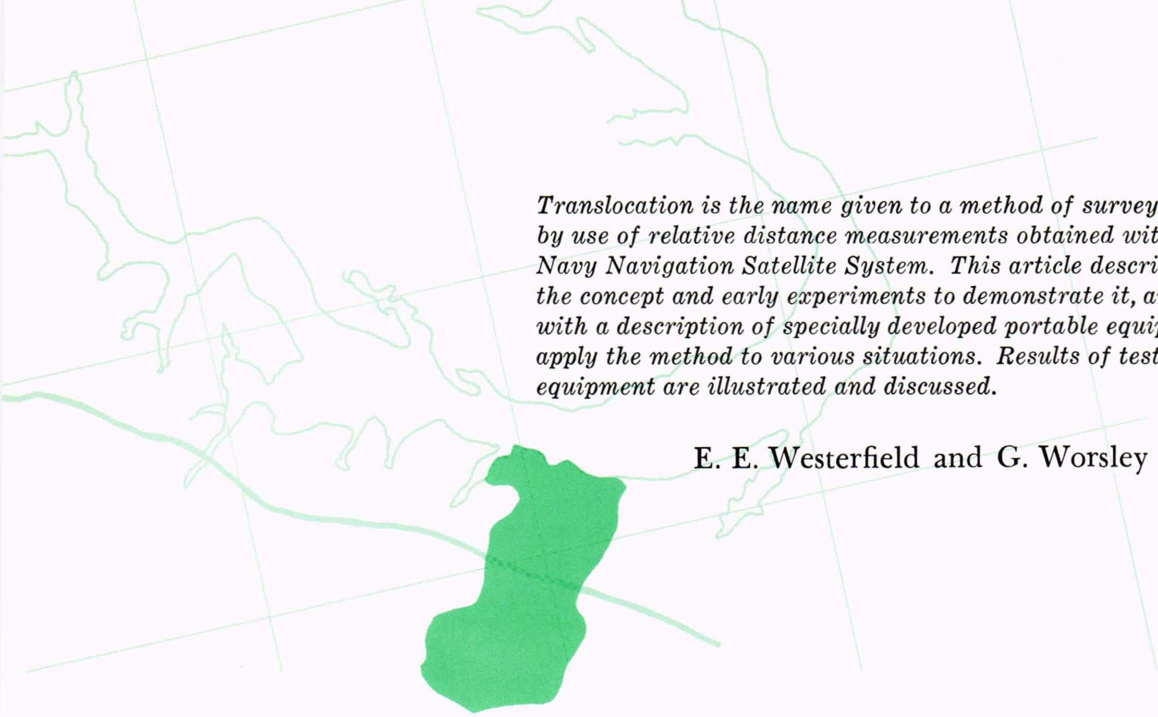


Fig. 1—Colocation results for two navigation sets operated simultaneously from the same antenna. Each point shows the amount by which the two sets differed in the fix result obtained.

[1] R. B. Kershner, "Present State of Navigation by Doppler Measurement from Near Earth Satellites," *APL Technical Digest*, **5**, No. 2, November-December 1965, 2–9.



Translocation is the name given to a method of surveying by use of relative distance measurements obtained with the Navy Navigation Satellite System. This article describes the concept and early experiments to demonstrate it, and continues with a description of specially developed portable equipment to apply the method to various situations. Results of tests with this equipment are illustrated and discussed.

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dom and noncorrelated between the two navigaton sets, the RMS radial equipment error for either set is 5.2 meters, a number which should apply equally in all situations if equipment performance remains constant. By comparison, the errors in navigation fixes due to imperfect knowledge of the earth's gravity field and to time-extrapolation of satellite position in orbit have been measured[2] as 99 meters radial standard deviation with present knowledge of geodesy. This is clearly a major factor compared with equipment errors of about 5 meters.

A logical extension of this result is to treat two navigation sets as a pair of surveying tools, which when separated could be used to measure a distance by subtracting the simultaneous fix results obtained. The accuracy of such a measurement would be expected to decrease as the distance between the receiving antennas is increased because the orbit arcs observed at the two stations will no longer be identical. This is illustrated in Fig. 2, which shows schematically two observing stations separated by a distance OP, taking data from a satellite in orbit $T_0 \ldots T_4$. Because of the imperfect knowledge of the detailed structure of the earth's gravity field, the orbit as described by transmission from the satellite's memory is $T_0' \ldots T_4'$ so that one observer calculates his position as A rather than O and similarly the position fix of the other observer is at B instead of P. The absolute fix errors OA and PB are due in large part to the prediction and geodesy errors $T_0T_0' \ldots T_4T_4'$, and these tend to cancel when the difference is taken between the fix latitudes and longitudes at the two stations; thus the distance so determined (AB) should be close to the true distance OP.

The fact that measurement accuracy will degrade with increasing distance can be inferred from Fig. 2 and the preceding discussion by noting that one station computes a fix on the basis of an orbit arc such as $T_0' \ldots T_3'$ whereas the second station uses the arc $T_1' \ldots T_4'$ so that the intervisible portion is limited to $T_1' \ldots T_3'$. When the distance increases to the extent that there is no intervisible arc, the accuracy degrades to that of a single navigation fix as shown in Fig. 3 of the summary already published[1]. By extension of the word "colocation" (measurements made at the same point), the name "translocation" was coined to describe the simultaneous use of navigation sets at separate points to determine the relative position of one point with respect to another.

The preceding discussion deals primarily with cases in which the two locations lie along a line that is roughly parallel to the subtrack of the satellite orbit. If the two locations lie on a line perpendicular to the subtrack of the satellite orbit (an east-west line), the segment of satellite orbit used will be approximately the same for both navigation receivers.

But another factor that applies to this particular case will degrade the translocation accuracy as the length of the base line increases; this is the navigation fix error due to altitude of the satellite or of the observer being in error. The navigation fix calculation is based on determinations of slant range increments from satellite to observer, so that altitude errors transform into fix errors to an

[2] R. R. Newton, "The Navy Navigation Satellite System," *Proc. COSPAR 7th International Space Science Symposium*, May 1966 (in publication).

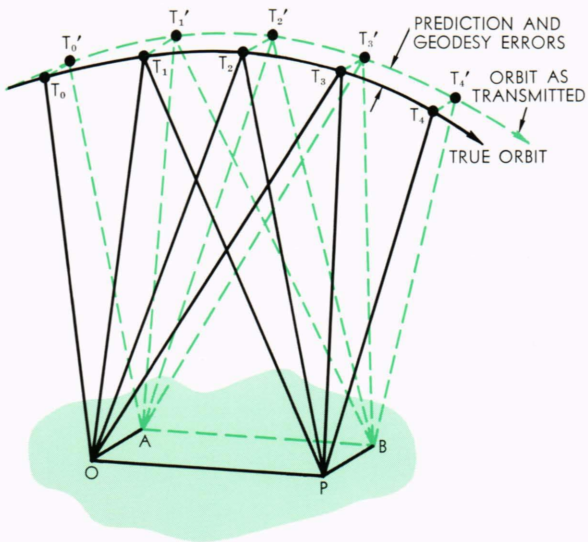

Fig. 2—Relationship between absolute fix error and translocation measurement, as affected by satellite position errors.

extent that depends on the elevation angle subtended at the navigator's location by the satellite. These errors will not cancel in the translocation calculation, and will in fact increase as the base line is lengthened even though the duration of the satellite pass may be the same for both locations.

In the summer of 1964, there occurred a period of evaluation of the Satellite Navigation System. As part of this exercise, fixes were again taken with two navigation sets, one connected to an antenna on the roof of one of the laboratory buildings at APL and the other contained in a van parked outside. Simultaneous fix results from the two sets were examined for agreement, and it was noted that a discrepancy of some 13 meters existed between the mean position of the van antenna as determined by translocation and as measured with respect to the antenna on the roof. The results are shown in the plot of Fig. 3 where the coordinate origin is at the initial survey point. Since the translocation measurements were reproducible within the expected dispersion (RMS deviation of 7.0 meters), the surveyed position was rechecked. It was found that a measurement error had indeed been made in locating the position of the van; a corrected survey agreed with the translocation measurement within 1½ meters as is seen in Fig. 3.

APL-Quantico Tests

To test the translocation principle at longer ranges, a comprehensive series of experiments[3] was performed in December 1964 with navigation sets located at APL and at Quantico Marine Base, Virginia, a distance of about 45 miles. The "true" positions of the antennas were taken as the surveyed latitude and longitude of the two sites, both surveys being referenced to the same (North American) datum. The translocation measurements were made in the following way:

1. Counts of the number of doppler cycles on the received satellite signal, integrated over 2-minute intervals, were recorded simultaneously at both locations by the navigation sets. That is, counts such as:

$$N_{1,2} = \int_{t_1+\Delta t_1}^{t_2+\Delta t_2} (f_G - f_R)\, dt$$

were recorded, where t_1 and t_2 are the times at which the satellite emits its 2-minute timing signals, Δt_1 and Δt_2 are the corresponding transmission times from satellite to observer at instants t_1 and t_2, f_G is the frequency of the stable reference in the navigation set and f_R the frequency of the signal as received. As already explained in the previous summary[1], this is the form in which satellite doppler data are recorded by navigation receivers of this type.

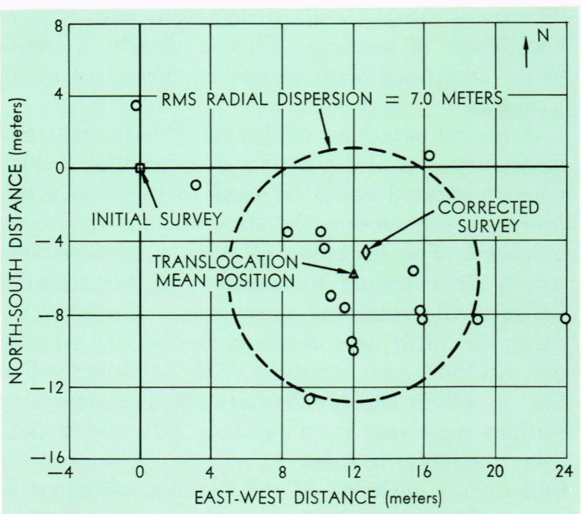

Fig. 3—Translocation used to check an initial survey for gross error.

[3] J. P. Reilly, *Results of Quantico Translocation Experiments,* The Johns Hopkins University, Applied Physics Laboratory, TG 468-5A, July 1965.

2. The navigation set at APL also recorded the satellite orbital position data transmitted by phase modulation on the satellite radio signals. In a translocation measurement these data need only be recovered at one site since the satellite orbit described by them is the same for both sites in a simultaneous operation. Advantage can be taken of this fact in simplifying equipment specially designed for the translocation application.
3. Fix calculations for both locations were then run on a computer at APL, using the same satellite orbital position data for both fixes plus the applicable 2-minute doppler frequency counts as originally recorded.
4. The translocation measure of the Quantico location with respect to the APL location was then found by subtracting the navigated APL latitude from the navigated Quantico latitude (giving the incremental latitude of Quantico with respect to APL) and similarly by subtracting the navigated APL longitude from the navigated Quantico longitude (to get the incremental longitude of Quantico with respect to APL).
5. Taking the surveyed APL coordinates as reference point, the incremental latitude and longitude of Quantico, as found in Step 4, were added to the surveyed APL coordinates to give the translocation determination of the latitude and longitude of the Quantico location. This determination was then compared with the surveyed Quantico position.

The results are shown in Fig. 4 where the origin of coordinates is taken as the surveyed position of the Quantico location and the plotted points show the positions determined by translocation for 23 satellite passes. The mean translocated position differs by only 5 meters from the surveyed position (−3.8 meters in latitude and +3.8 meters in longitude) for this 45-mile base line, or by about 7 parts per 100,000. With results this close it is justifiable to question whether the 5-meter discrepancy is to be attributed more to the translocation or to the survey. The question can only be resolved by repeated measurements against a surveyed base line known to be good to 1 part in 10^5 or better, since the surveyed locations used in this experiment were obtained at different dates and are almost certainly not of first-order accuracy at both ends of the base line. The RMS radial dispersion of the 23 measurements is 14.8 meters, which agrees well with estimated accuracies at other ranges[1] in view of the degradation to be expected as the base line length increases.

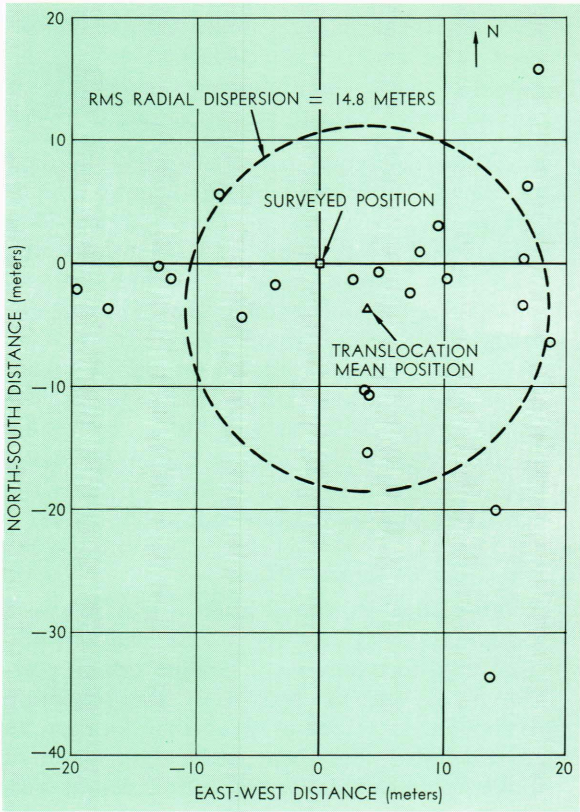

Fig. 4—Results of translocation tests over a 45-mile base line. Computation performed at APL using doppler counts taken simultaneously at APL and Quantico.

The Quantico experiment also included data taken under a variety of conditions to examine the contribution of errors from various sources. The findings from this part of the experiment can be summarized as follows:

1. *Single-Frequency Operation.*

   In normal use, navigation receivers eliminate the major part of the error due to ionospheric refraction by combining the signals received on two coherently generated frequencies (150 Mc/s and 400 Mc/s). As discussed elsewhere[2,4] this technique is a first-order correction for refraction due to the ionosphere and assumes that the frequency shift in the signal due to refraction varies inversely as the frequency. Residual errors due to higher-order terms in the expression for frequency shift due to refraction as a function of frequency have been found to yield contributions of 5 meters maximum to

[4] G. C. Weiffenbach, "Measurement of the Doppler Shift of Radio Transmissions from Satellites," *Proc. IRE,* **48,** No. 4, April 1960, 750–754.

navigation calculations under normal conditions. The results plotted in Fig. 4 were all obtained with dual-frequency reception as normally used with these navigation receivers.

Since portable equipment that might be used for translocation could be significantly simplified if only one radio frequency channel (400 Mc/s) were used, auxiliary data were taken during the Quantico tests on 400 Mc/s only to see what errors would result. It was found that neither the average translocation error nor the RMS radial dispersion differed significantly from the dual-frequency results. But with single-frequency operation at 150 Mc/s, the results became considerably worse—the mean radial bias increased from 5 to 15.5 meters, and the RMS radial dispersion from 14.8 to 50 meters.

2. *Use of Remote Refraction Data.*

Another possible simplification would be to use a dual-frequency receiver at one location only (that used for recovery of satellite orbital position data) and to then apply the refraction correction data measured at that location to the single-frequency 400 Mc/s data taken at the other location. Translocation results calculated in this way showed little or no degradation when compared to results obtained using dual-frequency reception at both locations.

3. *Effect of Pass Elevation Angle.*

The results shown in Fig. 4 were obtained for satellite passes whose maximum elevation angles at the observer varied from 15° to 70° above the horizon, this being a normal operating range. High passes above 70° exhibit unfavorable geometry for the navigation solution and are therefore usually avoided while low passes may be excessively affected by tropospheric refraction and may also yield insufficient doppler data (due to the shorter duration of the pass) for an optimum navigation solution. Several high and low passes were taken during the Quantico experiments, in addition to those already discussed, and a significant degradation in accuracy was found. The mean radial bias increased from 5 to 8 meters and the RMS radial dispersion from 14.8 to 75 meters for a group of such passes whose maximum elevation was outside the normal operating limits of 15° to 70°.

4. *Use of Corresponding Data Intervals.*

The navigation equipment used in the Quantico experiments accumulates the necessary satellite doppler data by counting the number of cycles of the received doppler frequency that occur during the 2-minute intervals defined by the satellite's transmitted time signals. Three such 2-minute counts are required to compute a navigation fix, but from five to eight 2-minute counts are usually received in the time span of a satellite pass. The results shown in Fig. 4 were obtained under the restriction that the doppler counts used in computing the two navigation fixes be obtained during the same 2-minute intervals at APL and at Quantico. Other calculations were made with the same raw data to see how the results would vary in the absence of such a constraint. Using all possible combinations of doppler count intervals and taking the variance of all the fix solutions thus generated, it was found that both the mean radial bias and the RMS radial dispersion were increased by a factor of about three over the results given in Fig. 4. It therefore seems necessary to retain the "common interval" restriction if good results are to be obtained in translocation with this type of equipment.

Applications

Several applications of the translocation principle have seemed worthy of exploitation. Determination of the position of an outlying observer station with respect to a base station would be a valuable aid in surveying uncharted territory, particularly since the intervening space need not be traversed or even occupied at all if translocation is used. The corresponding military application to control of forward operations by deployment of a forward observer equipped with portable equipment would bring a new technique to bear on spotting operations in which the forward

Fig. 5—Experimental translocation receiver (left) and auxiliary communications transmitter (right) at forward observer station.

observer might be able to determine range and bearing to a desired point with much less error than could be achieved directly from the base station. In the case of ships at sea, relative position determination at ranges greater than line of sight or under conditions of darkness or foul weather could be a valuable aid in station keeping or coordinated search operations. As a beginning, portable equipment suitable for back-pack transportation by one man has been designed and experimental models have been built and tested. These will now be described.

Equipment Design

Figure 5 shows the first experimental model built at APL. The tripod-mounted antenna and ground plane at the left which is connected to the portable receiver, can be collapsed and carried in the canvas pocket at the side of the receiver. The design objectives of the portable receiver were as shown in Table I.

TABLE I

DESIGN OBJECTIVES

Weight and Size	Approximately 40 pounds, small enough to be slung and carried as a back-pack.
Power	Self-contained rechargeable battery supply, good for several days intermittent operation without recharging.
Receiving Channels	Either 400 or 150 Mc/s single-frequency operation, or dual-frequency operation with refraction correction.
Satellite Data	Receive and store up to eight 2-minute doppler frequency counts.
Auxiliary Data	Accept (by manual insertion) and store range, azimuth, and elevation of designated point with respect to forward station location, and also the estimated antenna height of the forward station and an appropriate message code.
Retransmission	Capable of modulating either an auxiliary radio transmitter or a self-contained 100-watt burst transmitter for relay of stored data to base station.
Signal Acquisition	Manual or automatic.
Memory Storage	Sufficient for satellite and auxiliary data for one satellite pass.
Accuracy	The self-contained frequency standard and all critical circuitry to permit accuracy comparable with that demonstrated using navigation sets for translocation: e.g. 15 meters RMS radial dispersion (and negligible bias) at 50-mile range.

Figures 6 and 7, respectively, show the operating panel and a simplified block diagram of the portable translocation receiver. Provision is made for both 400 and 150 Mc/s RF receiving channels. The 400 Mc/s receiver is a dual-conversion phase-locked design, using intermediate frequencies of 28 Mc/s and 500 kc/s and a voltage-controlled oscillator for the phase-locked loop operating at or near 15.5 Mc/s. The injection frequency of 372 Mc/s required at the first mixer is obtained by multiplying the output frequency of the voltage-controlled oscillator by 24. Thus when the receiver is tracking a satellite signal, the doppler shift of the incoming signal constrains the voltage-controlled oscillator to follow it by means of the phase-locked loop, so that the signal frequency within the first and second intermediate frequency amplifiers remains fixed. The injection frequency of 27.5 Mc/s required at the second mixer is obtained by frequency synthesis from the 5 Mc/s frequency standard, which also supplies a reference signal (at 500 kc/s) for the phase comparator which provides the error signal that (with suitable amplification) drives the voltage-controlled oscillator so as to maintain phase lock. The 5 Mc/s frequency standard, which thus becomes the frequency (and phase) reference against which the satellite doppler signal is compared for counting purposes, was developed for this application by an outside contractor. It has exhibited acceptable frequency stability under laboratory test conditions (short-term drift of 1 part in 10^{11} over 2-minute intervals; long-term drift of 2 parts in 10^{10} per day), but as yet its performance under conditions of shock, vibration, and other unfavorable environments has not been fully investigated. The immunity of the frequency standard to performance degradation under conditions of rough handling seems to be the most critical factor affecting the successful design and test of portable satellite navigation receivers. The absolute value of the frequency generated by the standard is not important. Stability (both short-term and long-term) is the factor that must be provided and maintained for the useful life of the equipment.

Other electronic design features of the receiver are: (a) Use of a 400 Mc/s helical resonator as a filter of 2 Mc/s bandwidth after the first stage of RF amplification, as protection against external RF interference. (b) Use of a 10 kc/s bandwidth

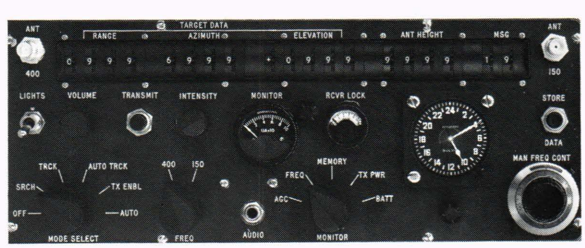

Fig. 6—Operating panel of translocation receiver.

crystal filter in the first intermediate frequency amplifier (at 28 Mc/s). This is the primary narrow-banding device in the receiver, and since the doppler frequency shift is no longer present at this point in the circuit, the crystal filter does not have to handle frequency excursions so that variations in its phase delay as a function of frequency are of no concern. (c) Use of a 500 kc/s mechanical filter in the second intermediate frequency amplifier as a secondary narrow-banding device. (d) Use of a small self-contained magnetic-core memory, of 512-bit capacity, to provide storage and non-destruct readout for the 2-minute doppler counts and preset information generated during any one satellite pass. Maximum use is made of low-power consumption integrated-circuit flat-packs in the control circuitry for the memory. (e) The circuitry of the data-processing portion of the receiver also uses low-power integrated circuit elements for all logic functions. (f) As a measure of safety towards error-free transmission of data over the radio link from the forward station to the base station, the information to be transmitted is encoded for error correction before storage in the memory. (g) Use of the small built-in chronometer seen on the front panel permits the translocation receiver to be set up for unattended operation, including automatic acquisition of satellite signals and subsequent burst-transmission of data, at a preset time.

Components and Packaging

To facilitate development and experimental evaluation of each part of the translocation receiver, an early decision was made to use individual sheet-metal boxes for the RF and analog parts of the circuitry, and conventional printed circuit boards for the logic and counting circuitry. The total circuitry of the receiver can then be treated as a number of boxes or subassemblies. All logic and counting circuitry in the data processor section of the receiver is contained on three printed-circuit boards. The RF and analog part of the receiver is split into 19 subassemblies each contained in a sheet-metal module.

The total normal power consumption of the translocation receiver is 7½ watts and battery capacity is sufficient for operation over the period of two satellite passes per day for four days without recharging.

The total number of parts used in construction of one translocation receiver (without self-contained transmitter) is approximately 2832, which does not include front-panel components. It is estimated that the retail cost of the individual parts for one translocation receiver is between $10,000 and $12,000.

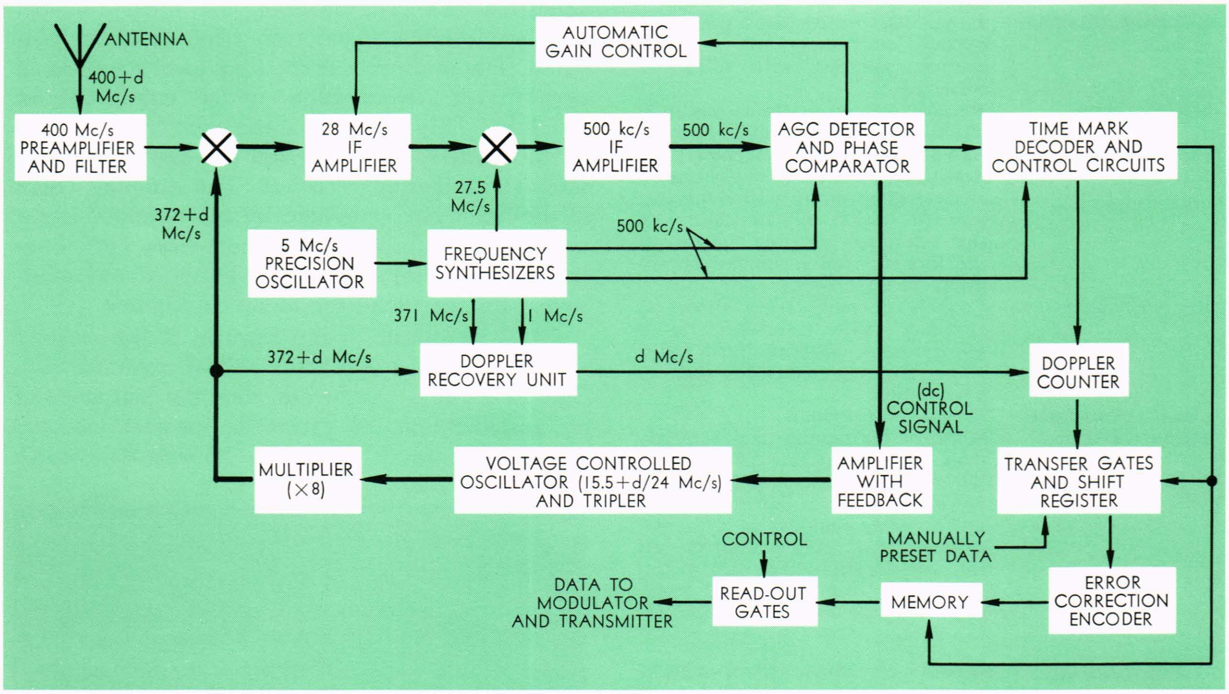

Fig. 7—Simplified block diagram of translocation receiver, showing 400 Mc/s receiving channel only. Heavy lines indicate closed phase-locked tracking loop. Symbol "d" represents algebraic sum of satellite signal offset frequency (nominally −32 kc/s) and doppler shift due to satellite motion.

Operation

Referring to the photograph of the operating panel, Fig. 6, and assuming that power has been applied to the precision oscillator for sufficient time for the output frequency to become stable, the receiver is placed in the search mode (mode select switch) at time of rise of a suitable satellite pass, and the manual frequency control is used, in conjunction with a set of headphones plugged into the audio socket, to locate a signal and tune the receiver to zero beat, which condition is also indicated by the receiver lock meter. The mode select switch is then advanced to the track position, which action closes the phase-locked tracking loop within the receiver. Unless lock is lost again during the pass due to weak received signal strength or strong external interference, the action of the receiver during the rest of the satellite pass is automatic and requires no intervention. Upon recognition of successive satellite 2-minute time signals (a bit sequence consisting of a binary zero, 23 binary ones, and another binary zero), the doppler cycle count accumulated during the 2-minute interval just ended is transferred to the memory and held there. Successive increments to the memory storage content can be observed on the monitor meter with the monitor switch set at the memory position. Similarly, the monitor switch and meter enable the operator to observe AGC level (indicative of signal strength), the change as the voltage-controlled oscillator tracks the changing satellite doppler frequency throughout the pass, battery voltage and the operation of a self-contained transmitter used to send data from the forward station back to the base station. At the end of the satellite pass, the operator can enter (by means of a set of thumbwheels) the range, azimuth, and angular elevation of the desired target point as determined by other means with respect to his own position. In the event the observer's own position is the objective of the translocation measurement, these quantities would of course be set to zero. The operator may also enter the numerical code for one of a number of preset messages, for example, weather data at his location. When all pertinent data have been properly set by means of the thumbwheels, the store data button is depressed to add these data to the 2-minute doppler frequency cycle-counts already stored in the memory.

Meanwhile, a similar translocation receiver at the base station has received and stored in its buffer memory the 2-minute doppler counts observed there, and at the same time has recovered the orbital parameters transmitted from the satellite and transferred them to the memory of an auxiliary computer used at the base station for calculation of the result. A communications receiver at the base station, pretuned to the transmission frequency used at the forward station, enables the forward station data stored in the receiver's memory to be received at the base station when the forward observer pushes the transmit button on his front panel, which action completes his activity.

Data from the forward station (doppler counts, target position relative to the forward observer, and message code) plus data taken at the base station (doppler counts, satellite orbital parameters) are now available for computation of the result.

Computation and Results

Calculation of the distance between the forward and base stations uses the same method as previously described[1] to determine a position fix with the satellite navigation system. In this case two independent position fixes for the locations of the forward and base stations are determined, using for both the same set of satellite orbital position data, recovered at the base station. The remaining mathematical operation is to compute the range of the forward station from the base station, separated into north and east distance measurements. Computer programs to perform the process have been written for IBM-7094, Honeywell H-21, and Army FADAC computers using appropriate input-output devices.

Preliminary tests were made at APL with two experimental translocation receivers, like that shown in Fig. 5, connected to the same antenna and feeding data into an H-21 computer programmed to compute the translocation distance represented by the two sets of doppler measurements. The results showed a negligible average bias between the two sets (0.56 meter) with an RMS radial dispersion of 8.6 meters, not too different from the dispersion of 7.3 meters for the original colocation experiments shown in Fig. 1. The two translocation receivers were operated in the single-frequency (400 Mc/s) mode.

Translocation Test Results

Beginning in May 1966, a series of tests was run, both to determine the feasibility and reliability of the operating procedures and equipment, and also to accumulate a number of translocation test results as a measure of the accuracy and repeatability to be expected with the equipment and computer programs devised. With one equipment separated 1100 meters from the other, repeated tests showed translocation measurement accuracy and consistency over this short distance that differed little from the colocation tests run in the laboratory; that is, a negligible bias and an RMS radial dispersion of about 8 meters. In one such demonstration, the distance between the two receivers as determined by translocation differed from the surveyed distance by only 1 meter in latitude and 0.8 meter in longitude.

Following this check, one receiver was located over a survey bench mark at a Civil Defense site at Brookville, Maryland, and operated in conjunction with the second set at APL as a base station. The forward station data were transmitted back by modulating a service-type AN/PRC-47 communications transmitter with a burst transmission about 5 seconds in duration. From the survey coordinates of the Brookville and APL sites, it was calculated that the Brookville antenna should be 5164.5 meters north and 16,527.0 meters west of that at APL, assuming both sets of survey data to be referenced to the same coordinate system. A number of simultaneous satellite passes were taken and the translocation measurements of these same distances compared with those calculated from the survey. Figure 8 shows a plot of the differences between the calculated and measured distances for 16 satellite passes whose maximum elevation lay within the operating limits of 15° to 70° above the horizon. Several conclusions are evident from these initial tests over a range of 17.3 km (10.7 miles):

1. There is a radial bias of 6.5 meters (3.1 meters in latitude, 5.7 meters in longitude). Since the previous tests showed no comparable bias, it is presumed that most of this discrepancy is caused by inconsistency or inaccuracy in the survey data used to establish the base line.
2. The RMS radial dispersion of the measurements is 12.3 meters. This is somewhat less than the dispersion of the earlier Quantico-APL translocation measurements (14.8 meters) over a longer base line (45 miles), as would be expected from the earlier discussion.
3. The plot of Fig. 8 excludes three data points that were evidently widely scattered with respect to the 16 results shown. A re-examination of the raw data from these three passes disclosed that in all three cases the 2-minute doppler counts obtained at the forward site were quite asymmetrical about the middle of the satellite pass (in two cases, time of closest approach of the satellite occurred during the last recorded 2-minute interval, and in the third case during the first recorded interval). This indicates that criteria for data acceptance or rejection should be established and included in revised computer programs for use with translocation equipment.

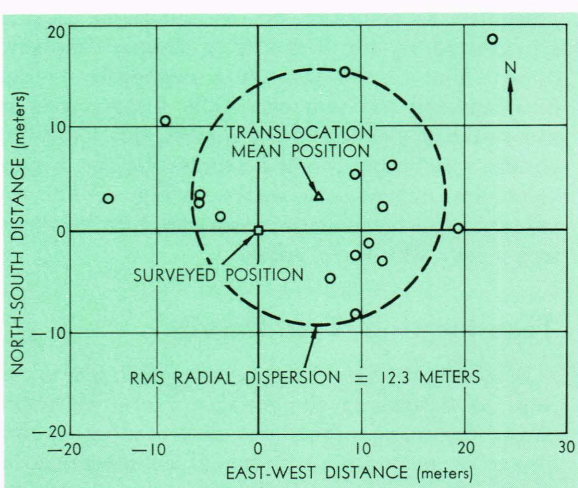

Fig. 8—Results of translocation tests over 10.7 mile base line using two portable translocation receivers.

Further tests with the portable equipment described are under way using longer base lines. The results obtained will be compared with existing surveys, and also with the performance that was obtained some months ago using van-mounted tracking station equipment[5].

Advanced Design Features

The portable equipment that has been described and illustrated could be classed as an engineering model. Refinement is obviously possible in design and in packaging for a service-use equipment. Studies have been made[6] and development undertaken to achieve a more uniform distribution of errors contributed by various components of the receiver design, and to enable such portable equipment to be used with a larger variety of near-earth satellites at different orbit inclinations. It appears that both position determination and relative distance measurement by means of satellite radio doppler measurements using equipment of the type discussed in this article will have wide application for many purposes.

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[5] C. A. Dunnell, *Southeastern United States Survey,* The Johns Hopkins University, Applied Physics Laboratory, TG–738, November 1965.

[6] T. A. Stansell, et al, *GEOCEIVER: An Integrated Doppler Geodetic Receiver,* The Johns Hopkins University, Applied Physics Laboratory, TG–710, July 1965.