INSTRUMENTATION FOR ONE-WAY SATELLITE PTTI APPLICATIONS*

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ABSTRACT

A review of general principles and operational procedures illustrates how the typical passive user and omni receiving antenna can recover PTTI information from a low altitude navigation satellite system for clock calibration and synchronization. The paper presents detailed discussions of concepts and theory of the receiver design. The importance of RF correlation of the received and local PN encoded sequences is emphasized as a means of reducing delay uncertainties of the instrumentation to values compatible with nanosecond to submicrosecond PTTI objectives. Two receiver configurations were fabricated for use in satellite-to-laboratory experiments. In one receiver the delay-locked loop for PN signals synchronization uses a dithered amplitude detection process while the second receiver uses a complex sums phase detection method for measurement of delay error. The necessity for compensation of doppler shift is treated. Differences in theoretical signal acquisition and tracking performance of the design concepts are noted.

INTRODUCTION

Tests are underway in which an experimental satellite in polar orbit at 450 n. mi. altitude having a PN modulation of 3.6 MHz bandwidth and 2^{15} length at a 400 MHz carrier provides the source signals for evaluation of the receiving instrumentation just described and for fundamental demonstrations that reflect the inherent capability of the system for PTTI applications. Included are test results which show the instrumentation noise levels during the period of reception as the satellite passes the laboratory. The differential jitter of the two receivers operating with the same satellite signal gave variations in measured delay at about 10 nanosecond. When the two PN receivers were connected to separate antennas it was possible to discriminate their physical separation to distances of less than 10 feet. These preliminary results infer very accurate global clock synchronization systems of various complexity and cost with ultimate accuracies approaching nanosecond levels. Degradation of synchronization accuracy from the limiting value will be dependent on variations among the radio path(s) between the satellite and widely separated receiving points principally due to refraction effects and also the errors inherent in the navigation process required for estimation of

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the required compensation for delay due to path length. (Experiments in clock synchronization between two remotely located receiving points are planned but have not yet been performed.)

From the work conducted to date we believe the following conclusions to be supported by the preliminary tests: (1) the satellite PN modulation and radiated power levels at the 150/400 MHz channels will be satisfactory for nanosecond to submicrosecond. PTTI applications; (2) progress in correlation receiver design for PN recovery has eliminated the instrumentation delay uncertainties as a major source of PTTI error. Thus the low altitude orbiting clock satellite system is a viable means for clock synchronization of navigating as well as fixed site users.

In contrast to the satellite navigation systems being proposed for high and quasi synchronous altitudes which systems require as many as four satellites in suitable simultaneous view of the navigating user, this low altitude global satellite system can provide the desired PTTI service with a single satellite in orbit with waiting intervals at the users location of 8 to 12 hours. Current schedules suggest than an operational PTTI service, contingent upon demand by users in the national interest, could be available from the improved satellite of the navigation system by 1975.

It is a privilege to report to the PTTI community on evolutionary improvements of the "Operational" Navy Navigation Satellite System. TRANSIT has been and remains dedicated to providing service as a radio navigation aid, however some of the developments in instrumentation are of interest since they provide a means for independent and cooperative users to calibrate and synchronize their clocks. The purpose of this paper is to review the system concept, describe new satellite and user equipment developments, and to present some measured data obtained in exploratory tests with the TRIAD satellite which transmit a new PN synchronizing signal. The tests indicate that the improved TRANSIT system anticipated during CY 1975 will be capable of satisfying many of the submicrosecond timing requirements of navigating as well as fixed site users. The progress in correlation receiver designs has eliminated the PN receiving sets as significant sources of error in submicrosecond PTTI applications.

REVIEW OF GENERAL CONCEPT

Time disciplined signals, broadcast in the VHF/UHF bands from an orbiting satellite clock can be used by any number of remote receiving stations or navigators for timing purposes with essentially the same basic procedures and processes that would be applicable to other one-way radio systems. For example, as illustrated generally in Figure 1, a navigation solution is required to determine range compensations for the distance traveled by the signals from the satellite source to the user. Submicrosecond accuracies require that further compensations be made for ionospheric and atmospheric refraction effects on propagation delay. The instrumentation will introduce errors in the nature of (1) a fixed bias and (2) random variations of the observed satellite timing marks as received. The fixed bias can be corrected by a local delay calibration of the receiving set using a precisely simulated satellite signal, injected effectively at the receiving antenna terminals. The random variations of the data will be smoothed by the statistical processing over a segment of the available satellite pass to determine an average variance and a least squares fit of the mean values to a straight line from which the synchronization "date" error of the user's clock relative to the satellite reference is indicated. A slope of the mean value time indicates error in time interval between the satellite and user's clocks. Generally the processes just described will be performed by a local computer if the user is an independent navigator. If the user is at a fixed site part or all of the computations can be performed at some centralized facility.

Distinctions as to the type of time service that one-way satellite broadcasts may provide should be recognized since there are important implications for both the user and the ground support network of the satellite constellation. First, there is a "date" dissemination mode that permits a fully instrumented independent user, at a fixed site, or on a moving platform, to calibrate and synchronize "date and time interval" of his clock to UTC(USNO) via the satellite, to the full accuracy of the system.

The second type of service can be referred to as a "uniform time interval" broadcast mode. For this service the satellite clock "date" control may be entirely absent or too coarse to qualify for PTTI. This mode permits clock synchronization among two or more cooperative users who transfer their own definition of "date" and "interval" among themselves from a designated master clock to the cooperative slaves. The basis for the clock transfers is the relative comparison(s) of the respective master and slave calibrations to the satellite reference. The best accuracy in transfer is obtained when the satellite reference signals are "co-visible" among the cooperative users.

The UTC(USNO) "date" dissemination mode is the ultimate system objective for it can service all types of users, those that are independent and passive as well as the cooperative users. Indeed the TRANSIT system currently operates in the "date" dissemination mode, however according to USNO reports,[1] improvement in accuracy of about two orders magnitude would now be useful.

The "date" dissemination mode requires accurate maintenance of the satellite clock by a system ground support network of satellite monitors (including a

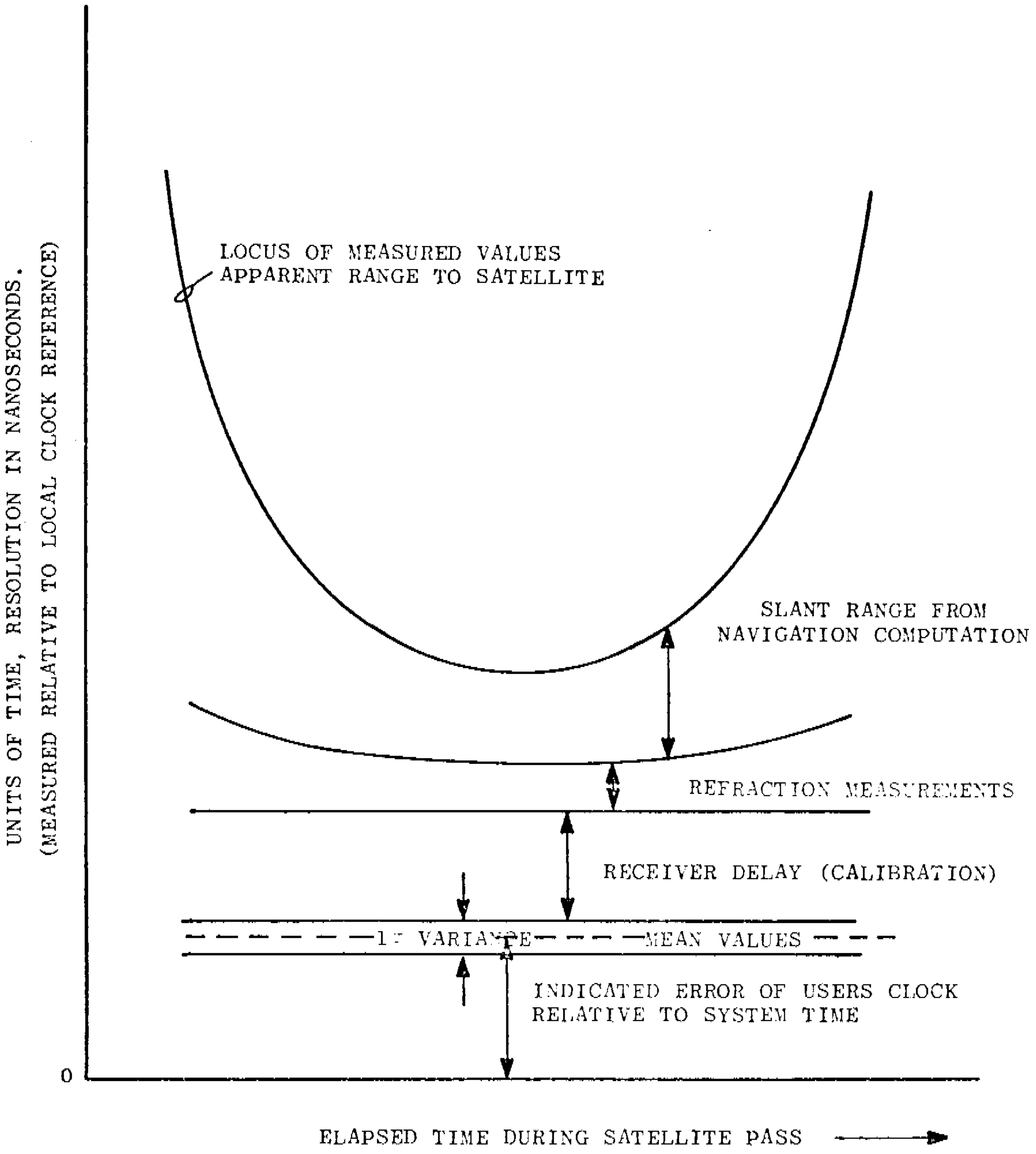


Figure 1. User's Process for Time Calibration of His Local Clock

receiver at USNO—Washington, D. C. or adjacent thereto), orbit tracking stations, computing facilities, and a command transmitting station arranged ideally as in Figure 2. In the ideal network there are four basic timing functions, namely:

1. A cooperative time transfer by satellite direct from UTC(USNO) to the TRANSIT system working clock reference. With a single satellite transfer opportunities occur regularly every eight to twelve hours when co-visible conditions exist.

2. Calibrations of the orbiting satellite clock to UTC. Opportunities to calibrate to UTC (TRANSIT) occur every orbit (110 minutes) and to UTC (USNO) every eight to twelve hours.

3. Adjustment of the orbiting satellite clock to UTC by radio command. Opportunities occur once per 110 minute orbit.

4. Satellite time dissemination by one-way broadcast to users. Availability per satellite will be dependent upon the user's position in latitude, but in no case would it exceed eight to twelve hours.

With this level of ground network support the reliability of the satellite UTC transmissions will be dependent upon the predictability of the satellite oscillator and clock over the calibration and adjustment intervals of only 110 minutes. With a one-in-view continuous satellite coverage it could be possible for any user on earth to effectively obtain periodic clock calibration updates to UTC(USNO) within a lapse of no more than 110 minutes.

The PPTI community must be warned that before this level of satellite UTC service can be expected a tradeoff analysis of timing requirements vs. performance and cost would be needed to support the ground system deployment.

PROGRESS IN IMPROVING BASIC INSTRUMENTATION

A transition period is planned during which improvements will be deployed. All improvements will be designed to avoid incompatibility or obsolescence of the more than 700 military and commercial navigation units now in service. During the transition period a wide variety of user equipment designs can be phased in to satisfy new requirements.

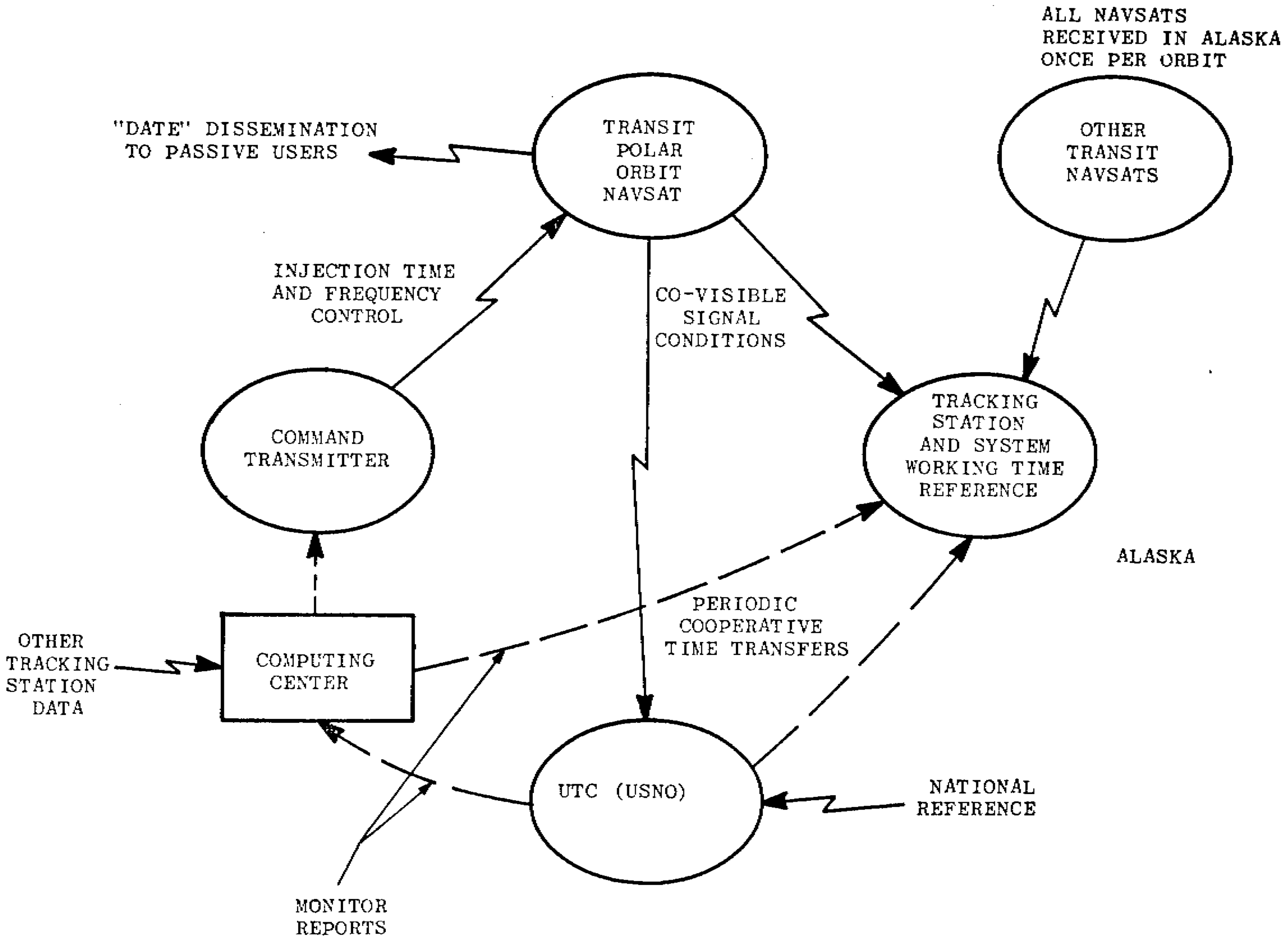


Figure 2. Ground Support to Maintain Satellite Clock for "Date" Disseminations

SATELLITE INSTRUMENTATION

New (TIP) satellite designs include features for improving the dedicated navigation service. Fortunately some developments are significant to PTTI users.

1. A disturbance compensation (DISCOS) and orbit maintenance subsystem will be provided. Its purpose is to eliminate the effects of atmospheric drag and allow a means for control of the orbital trajectory in space so that location of the satellite is more accurately predicted and reported to users; for example, for use in range compensation to timing measurements. TRIAD experiments with DISCOS indicate an uncertainty of three meters for the improved satellite at TRANSIT altitudes, compared to a current uncertainty of ten meters.

2. The RF signals that are broadcast from space will be redesigned to include a partial PN phase modulation with repetitive sequences that are uniquely related to the RF carrier frequencies and the variable message modulation. The PN phase deviation of ±45 degrees allocates half of the radiated RF energy to the PN spectrum, the other half to carrier and message spectra which can therefore be received "in-the-clear" by all now existing equipment.

   The FCC allocations permit a 2^{15} code length with a chip interval of 600 nanoseconds and a PN information bandwidth of 10/3 MHz on the 400 MHz radiating channel. The 150 MHz channel has a 2^{12} code length, chip interval of 4.8 microseconds, and PN information bandwidth of 5/12 MHz. When operational the PN sequences are synchronized and uniformly repeat 6103 times in exactly 120 seconds of UTC with fiducial time coincident at the even two minute UTC dates. The TRIAD satellite can broadcast the PN modulation on the 400 MHz channel.

3. The satellite frequency reference will be supplemented by a digitally programmable synthesizer. This allows delayed adjustments during the orbit of frequency offset with compensation for drift rate so that a uniform clock time scale is maintained. A control strategy can be used to steer "clock date" and indirectly the PN modulation for coincidence to "UTC date" referred to radiations from the satellite antenna. The programmable synthesizer has a fine resolution in the range of 2×10^{-12} to 4×10^{-13}. The effective operating reference frequency is $5(10^6 - 84.48)$ Hz from which all modulation waveforms and carrier frequencies are coherently generated, with the PN and information bit intervals being 120/6103 seconds.

   Currently the TRIAD satellite operates in a free running crystal oscillator mode at a nominal frequency near $5(10^6 - 140)$ Hz which avoids use of the experimental satellite by any navigator. "Date" of the TRIAD clock is not controlled but a uniform interval is broadcast giving 6103 reference pulses in about $(120 + 6.6 \times 10^{-3})$ seconds.

RECEIVING SET INSTRUMENTATION

The 150 and 400 MHz satellite signals available at the terminals of omnidirectional dipole and volute receiving antennas will range between -115 and -140 dbm. It is therefore necessary in the power limited system to recover the PN timing code under negative SNR conditions. The delay-locked PN recovery loop especially designed with correlation at RF allows synchronization and tracking with minimum delay error under the negative SNR conditions.

Two PN receiving equipments have been constructed as modifications to existing AN/BRN-3 and AN/SRN-9A navigation sets. Figures 3 and 4 respectively. Industry sources have completed production design studies for PN capabilities integrated into the SRN-9A and the new AN-WRN-5, Figure 5.

The delay-locked feedback loop performs a cross correlation between the PN encoded information of the received RF signal with noise and a local signal, noise free, appropriately modulated by the same encoded information waveform. The local modulating waveform is delay shifted to bring its sequence into time synchronization with the received code. Under this condition the correlator then produces a signal that can be used as a loop driving force to automatically maintain synchronization. Error correcting feedback is via the voltage controlled clock (VCC), local PN code generator, modulator, and correlator circuits.

The PN receiving set must be wideband up to the correlation circuit if it is to achieve the full accuracy potential of the spread spectrum PN modulation. In the correlation process the convolution of the received and local PN signals, under conditions of synchronized tracking, results in a redistribution of the received PN spectral energy into an enhanced coherent carrier signal which may then be amplified in very narrowband circuits for eventual detection of the synchronization error. In contrast the convolution of the local PN with received noise and non-coherent interfering signals results in a spreading redistribution of the interfering energy across a wide band of frequencies.

RF CORRELATION

A key concept in the design of PN recovery equipment is the combination of the processes of correlation with frequency translation from the RF to the first IF,

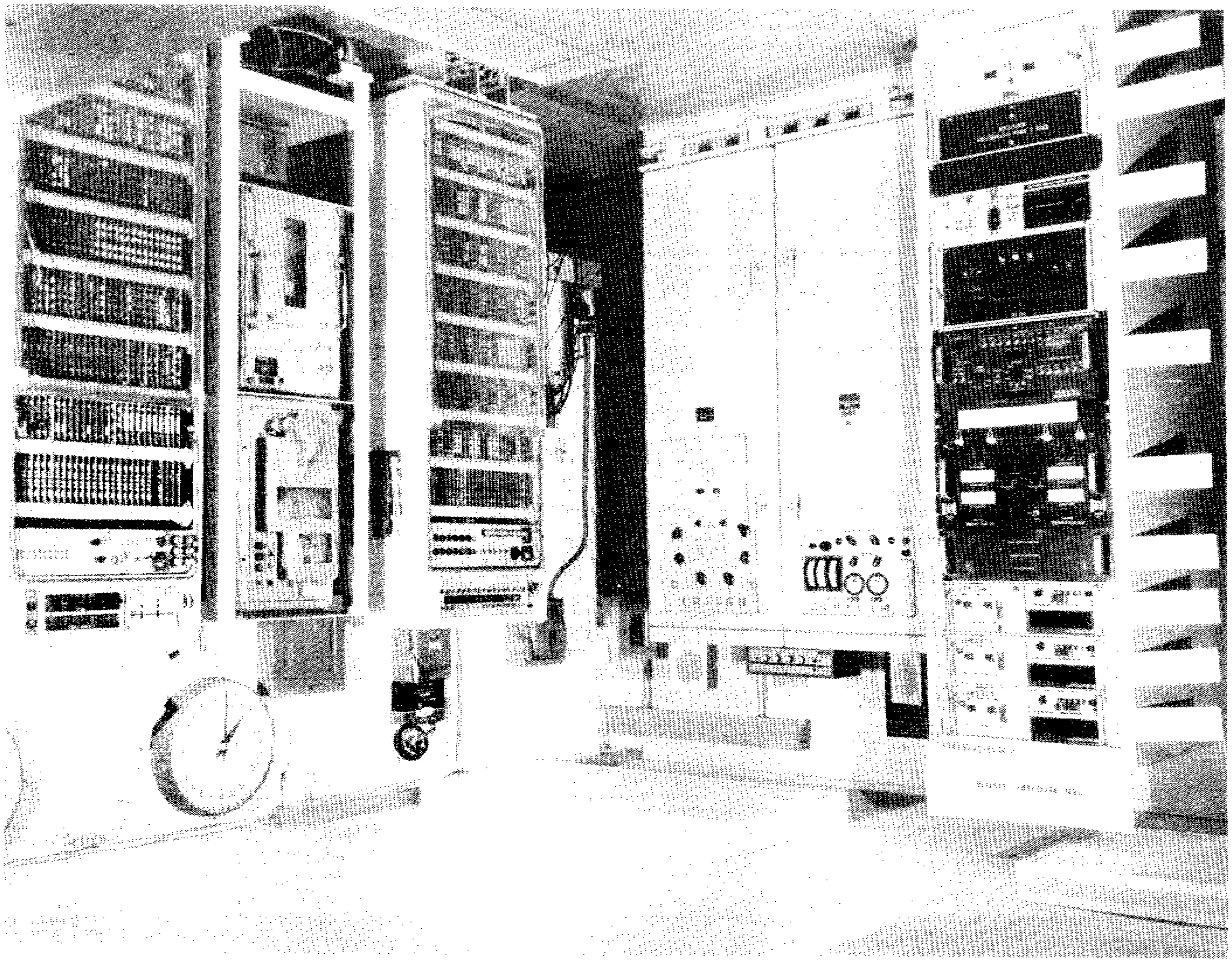


Figure 3. AN/BRN Navigation Set with PRN Modifications

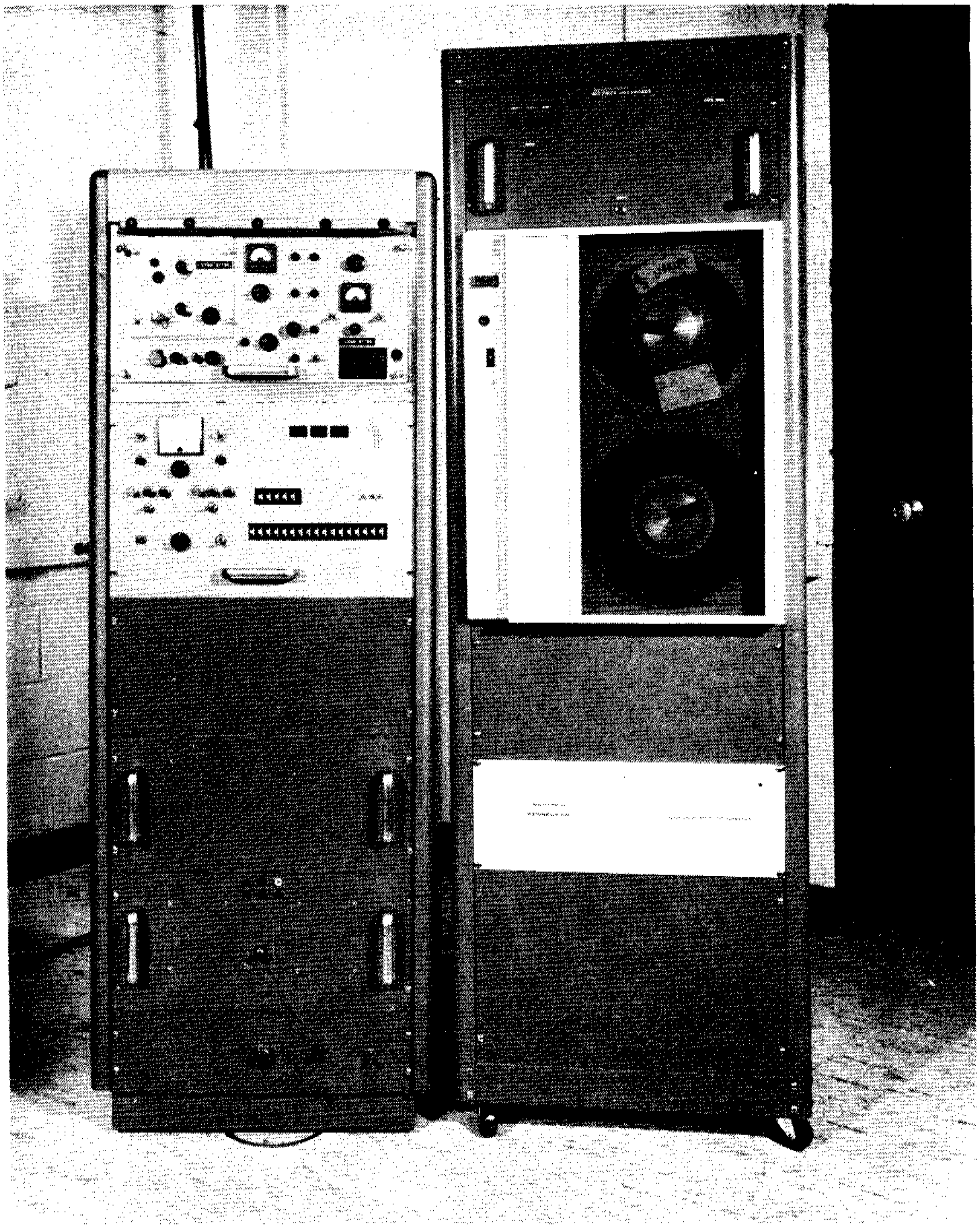


Figure 4. AN/SRN-9A Navigation Set with PRN Modification

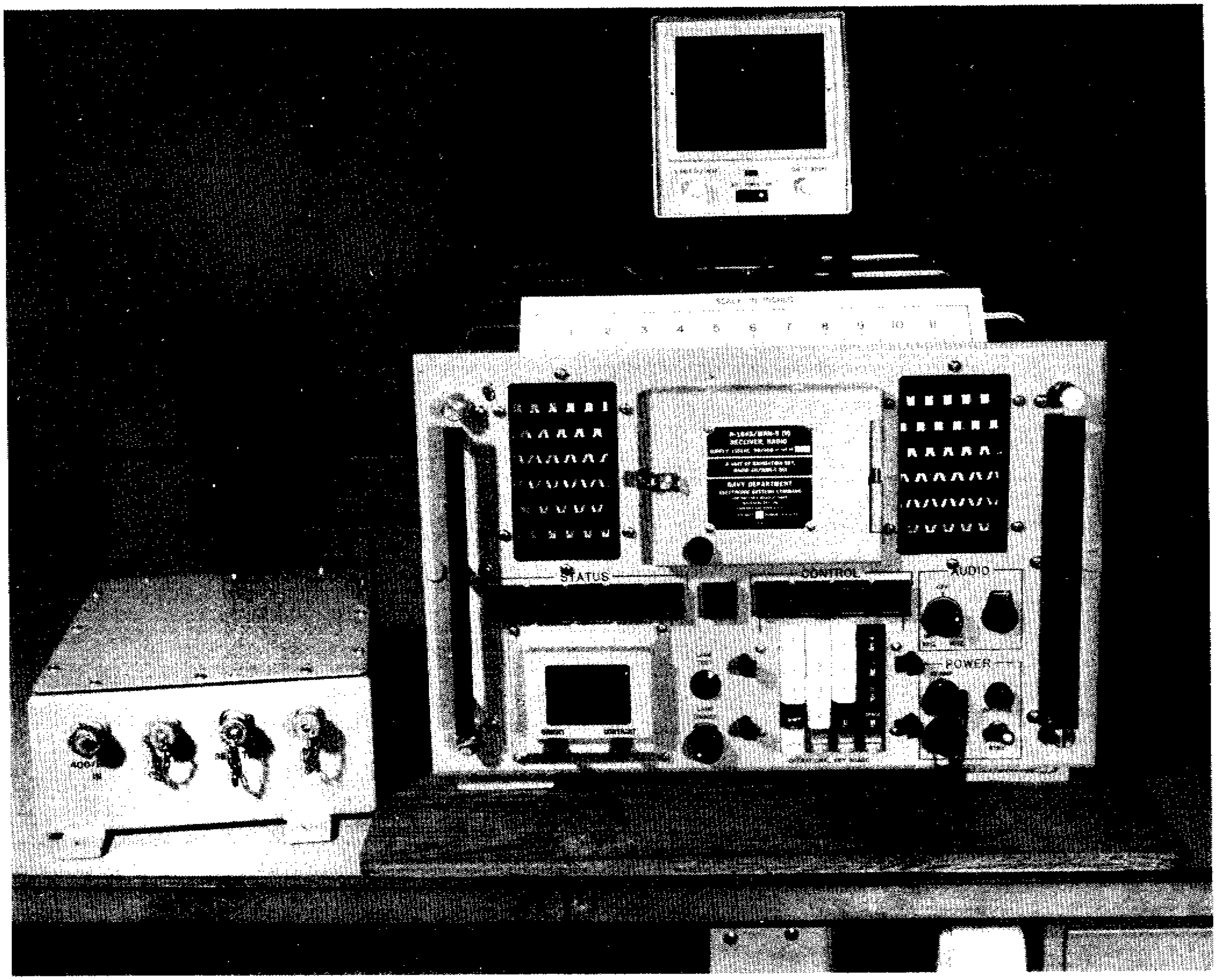


Figure 5. AN/WRN-5 Navigation Set

Figures 6 and 7. The significance of RF correlation lie in performance and cost since it provides:

1. A low and very stable value of receiver time delay which may be determined by calibration and used with confidence. The major delay instabilities of amplifying IF strips are avoided.

2. Frequency spreading, while the total energy remains small, of noncoherent noise and interfering signals into wideband spectra that can be attenuated by filtering relative to the desired information.

3. An optimum distribution of bandwidth, gain, and power dissipation leading to an easy economical design. Most of the signal amplification is in the narrowband IF circuits. Precorrelator RF gain must be sufficient to preserve noise figure.

In the modification of the SRN-9, Figure 6, it was imperative that RF correlation be used as choices of bandwidth and gains had been previously set by the narrowband requirements of coherent carrier tracking and the recovery of the 50 bps information phase modulation used for transmitting definitions of satellite orbits to the user.

DOPPLER COMPENSATION

Another feature of high performance-low cost PN receiver designs, to be used in applications characterized by dynamic motion, is compensation of doppler frequency shift. At TRANSIT altitudes the maximum doppler effect is less than 25 parts in 10^6. The compensation is applied in two ways. First, the frequency of the PN modulated local reference signal to the RF-to-IF frequency converter (also the PN cross correlator) is adjusted for the doppler shift. The converter output is therefore completely stabilized in frequency to a unique carrier allowing a minimum practical IF bandwidth with maximum discrimination against noise power and interference.

The second compensation is applied via a synthesizing network to adjust the clocking frequency input to the local PN code generator. All spectral components of the local PN modulating waveform will therefore match corresponding doppler shifted frequencies of the received PN signal. Basically, this is a form of signal derived aided tracking that relieves the delay-locked loop of the burden of tracking rate variables. Small effective noise bandwidths may therefore be used for PN recovery which results in a very low random jitter of the PN output timing pulses.

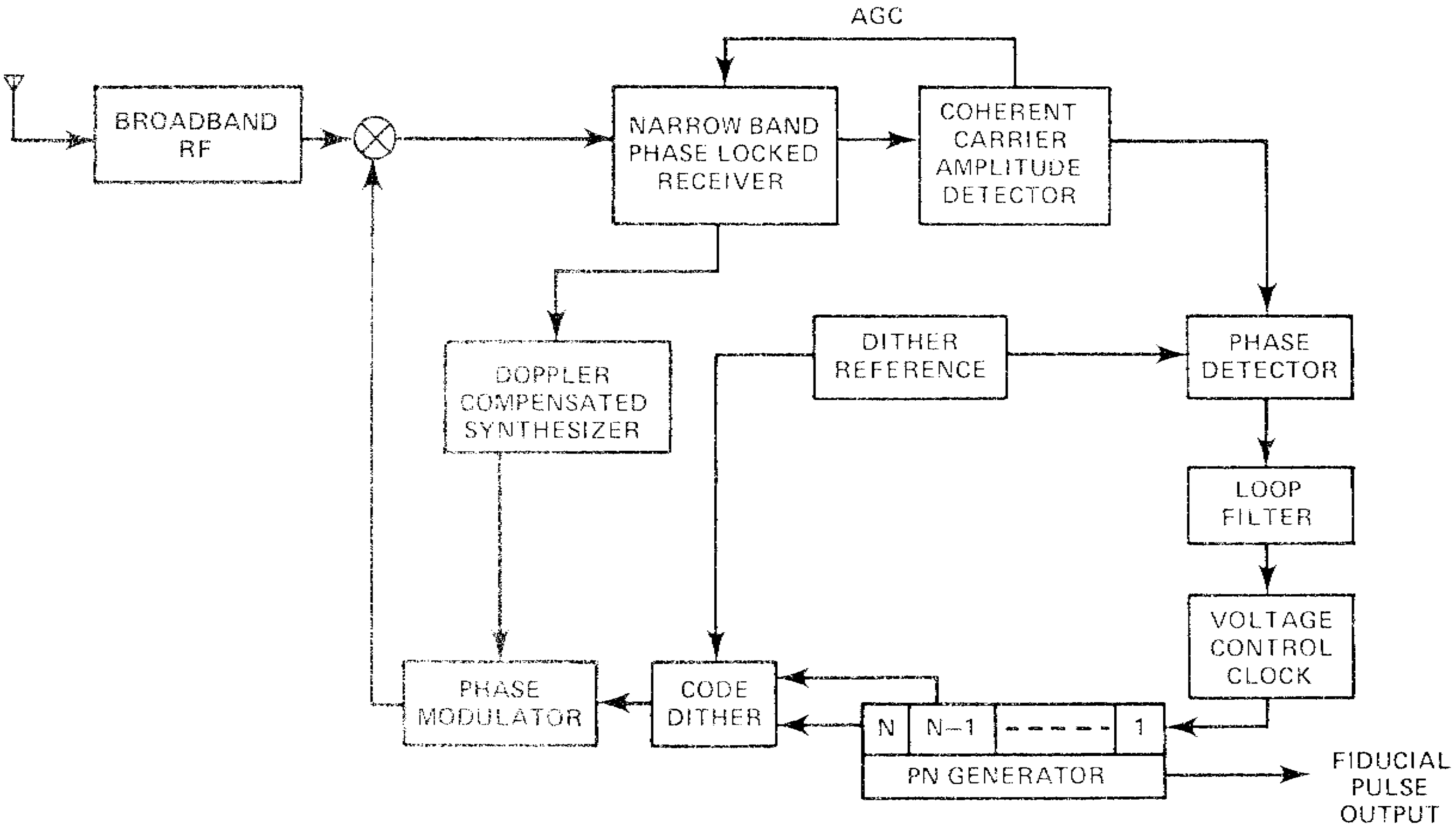


Figure 6. Amplitude Dithered Delay-Locked Receiver for PN Reception

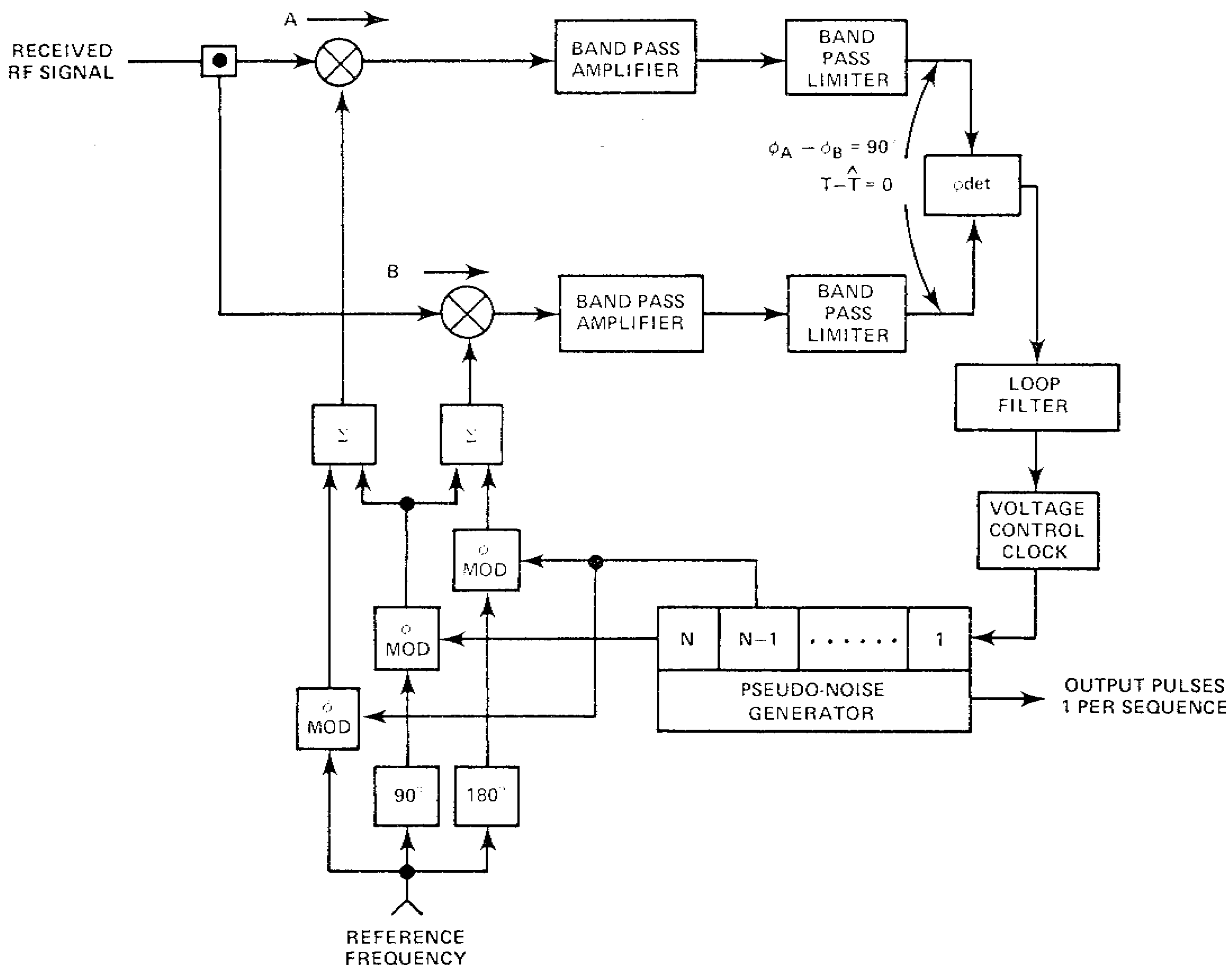


Figure 7. Complex Sums Delay Locked Receiver

PN RECEIVER CONFIGURATIONS AND DETECTION PRINCIPLES

The BRN-3 and SRN-9 PN receivers have important features in common such as correlation at RF, doppler compensation and a common objective of functional isolation and independent PN measurement with no impact on performance in doppler recovery from carrier tracking or in message demodulation. However, detailed requirements peculiar to the mission and environment of the BRN-3 submarine user as contrasted to those of the SRN-9 surface users lead to dramatic differences in design philosophy and circuit configurations. A full discussion is beyond the scope of this report but some comment is useful.

The modified SRN-9, Figure 6, is a common channel receiver. It uses circuits in the receiver for the dual purpose of doppler recovery by phase locked carrier tracking simultaneously with PN recovery by delay tracking the encoded sequences. For PN recovery the synchronization delay error signal for loop control is detected in a 3 step process. First, the RF correlator provides an enhanced output carrier whose amplitude is a function of the delay error. The amplitude will be a maximum when the delay error is zero. In order to obtain a polarity sensitive control the local PN modulating waveform is delay dithered (advanced and retarded equal amounts at a frequency that is fast compared to the code interval). Now the IF carrier with dithered amplitudes indicating delay error and direction is amplified by the IF strip. The 2nd detector is the phase coherent amplitude detector normally used for receiver AGC. The baseband output of this AGC detector contains a signal at the dither frequency whose magnitude and polarity are determined in a 3rd level of synchronous detection to develop the final forcing function that drives the VCC and local PN code generator.

The modified BRN-3, Figure 7, except for antenna and RF preamplification, uses separate receiving circuits for carrier doppler and PN recovery, hence these operations are inherently isolated and independent. The particular PN configuration is called a complex sums phase sensing receiver. The error signal for feedback delay control via VCC and local code generator is developed by a 2 step detection process. First, a special RF correlator produces a resultant carrier phase angle which is indicative of the direction and magnitude of the delay error. The IF carrier is amplified and heavily filtered to obtain a positive SNR. The signal is then limited in level for the 2nd step detection of delay error by phase comparison. Dual channels of RF correlation and IF processing are used so that relative phase comparisons are sufficient for delay error measurement. Theoretical analysis of the complex sums PN receiver is given in Reference 2.

The major points of significance for these recovery techniques are outlined:

1. Common Channel Dithered Amplitude Sensing Receiver (SRN-9A)
    a. A minimum volume, weight, and power consumption is needed for the added PN capability.
    b. Superior performance in ultimate threshold sensitivity is obtained for a specific PN noise bandwidth. From Reference 3, the normalized (rms) noise tracking error is

$$\frac{\sigma T}{\Delta} = \sqrt{\frac{B_n N_o}{2P_s}}, \text{ where}$$

Δ = the chip interval of the encoded PN waveform
B_n = the effective loop noise bandwidth
N_o = the noise spectral power density
P_s = the received energy in the PN signal

    c. The amplitude enhancement of carrier signals in the common channel by the RF correlation process effectively improves the SNR available for carrier phase locked tracking (+3 db maximum when the PN phase deviation at the satellite is 45 deg), except when large delay dither magnitudes are required for initial acquisition or for automatic reacquisition on loss of lock due to signal fading.

2. Separate Complex Sums Phase Sensing Receiver (BRN-3)
    a. The use of bandpass limiters for IF signal level control provides a delay error detection capability that is insensitive to a wide range of dynamic rates of amplitude fluctuation of the received RF signal that would exceed the regulating limits of coherent AGC. The circuit is independent of and insensitive to phase errors in coherent tracking.
    b. In the complex sums receiver, the normalized (rms) noise error for delay locked tracking is estimated to be in the range:

$$\frac{4}{\pi}\sqrt{\frac{B_n N_o}{2P_s}} \leqslant \frac{\sigma T}{\Delta} \leqslant \sqrt{\frac{B_n N_o}{2P_s}}$$

where the factor $4/\pi$ is contributed by the IF bandpass limiters operating at threshold SNR conditions. The circuit sacrifices about 1 db in threshold sensitivity in return for accurate error detection in the presence of fast fading and for the inherent simplicity of the limiter design.

    c. The circuit has superior acquisition performance in allowable search velocity (2.7 to 1 compared to best amplitude sensing circuit) and can acquire and track without phase coherent doppler compensation. A programmed frequency synthesis to maintain the carrier signals within the narrow IF passband is adequate.

d. Local phase modulation indices for PN correlation can be arbitrarily set without regard to reconstruction of carrier and message modulation (90 deg is optimum for interference discrimination in the PN receiver). Also, the circuit performs best when the remote PN source totally suppresses the carrier.

EXPLORATORY TESTS WITH SATELLITE SIGNALS

A few tests of limited scope have been performed with the TRIAD experimental satellite to obtain a "quick look" at the instrumentation noise levels and the basic resolution of the PN design for ranging and timing measurements.

The objective of the first test was to determine the relative stability and the jitter of the system (not including the radio propagation medium). This was done by differential measurements between the two PN receiving sets while they simultaneously tracked the TRIAD signal received from space. The test circuit is shown in Figure 8 and resulting measured data is plotted in Figure 9. The standard deviation and the mean values are plotted along with the level of the signal received at the output of the common antenna terminals. Except when the signal level became marginal the differential (rms) jitter of the two sets was in the range of 15 to 25 nanoseconds. Following the test a calibration of the BRN-3/PN was obtained with local test signals with results shown in Figure 10.

The objective of the second test was to check the inherent resolving capability of the PN instrumentation in determining the distance in physical separation of two antennas co-located with a baseline oriented approximately parallel to the satellite N-S orbital subtrack. The general test circuit is shown in Figure 11 where separations of 50, 24.5 and 10 feet were used. Variations in the measured mean delays between the PN outputs of the two receivers over the interval from satellite rise to set should follow a shallow S-curve indicating the antenna distance separations. The peak-to-peak delay variation in nanoseconds will be approximately numerically twice the value of the separations in feet for a direct overhead satellite pass. Figure 12 shows the 50 feet antenna separation rather dramatically even with the 80 to 100 nanosec rms differential noise jitter measused when the BRN-3/PN tracking loop was in wideband position.

The indications for the 24.5 and 10 feet separations are naturally less dramatic. The interesting result to note in Figures 13 and 14 is the substantial improvement

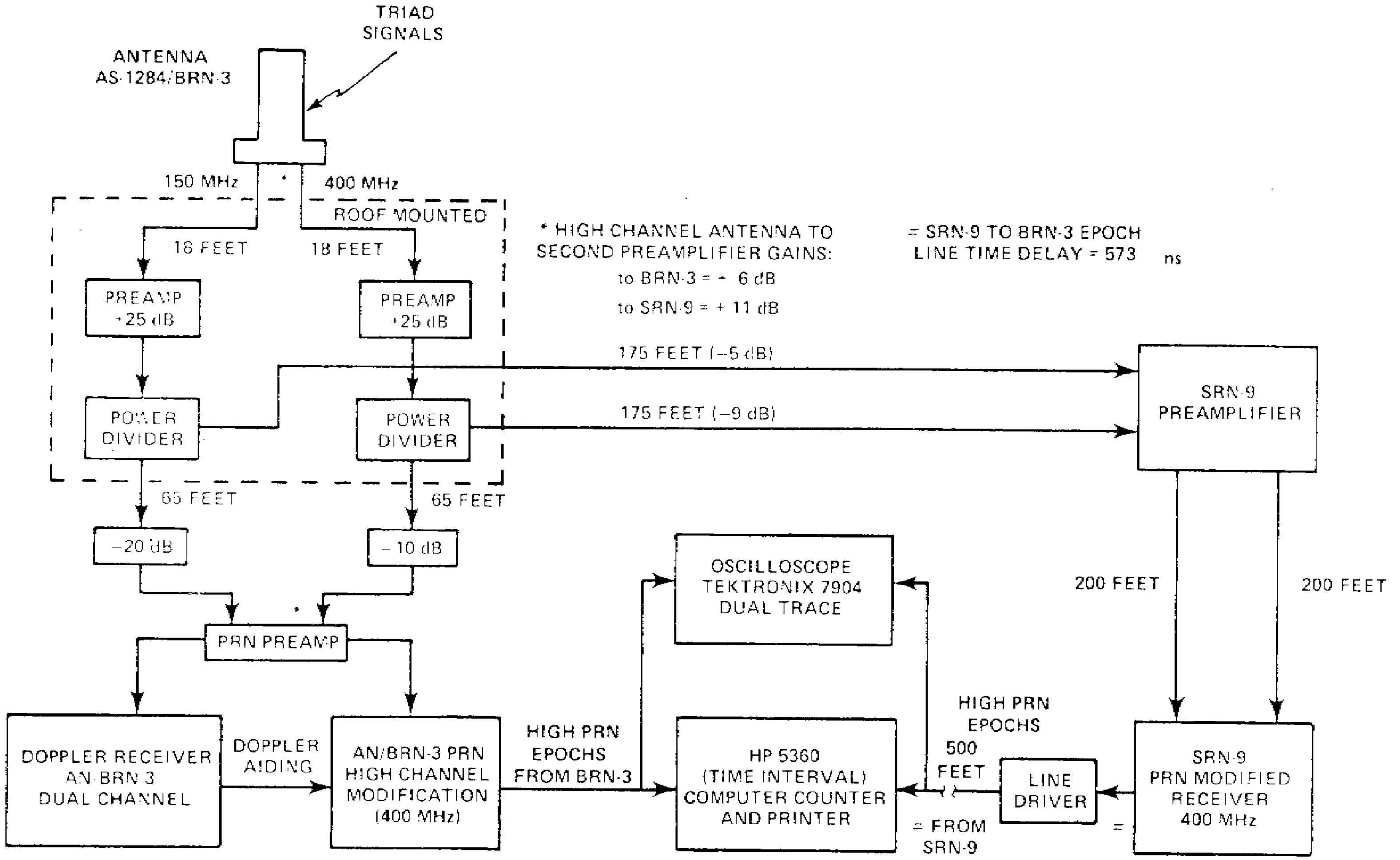


Figure 8. Test Circuit for Measurement of Instrumentation Delay Jitter

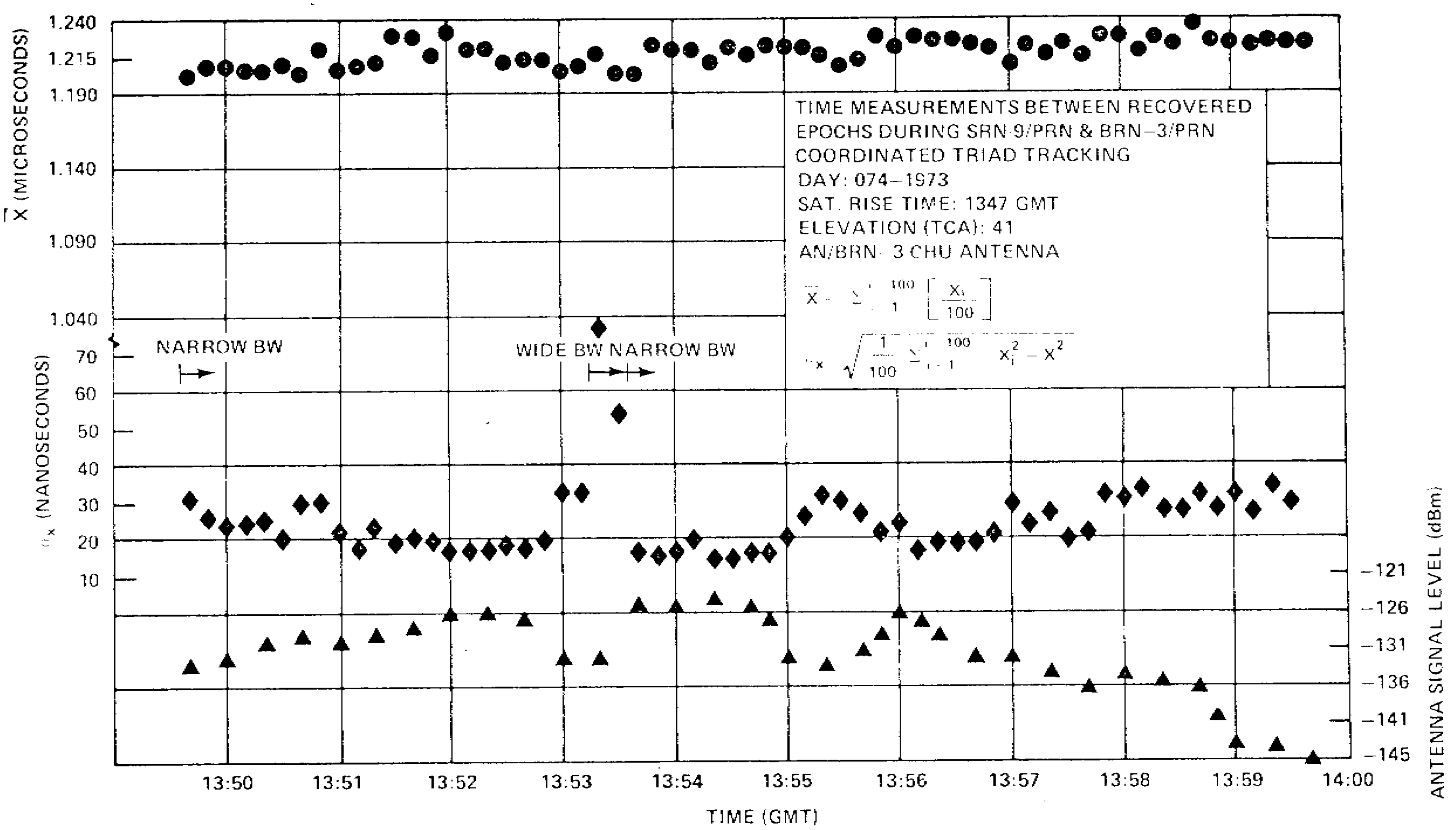
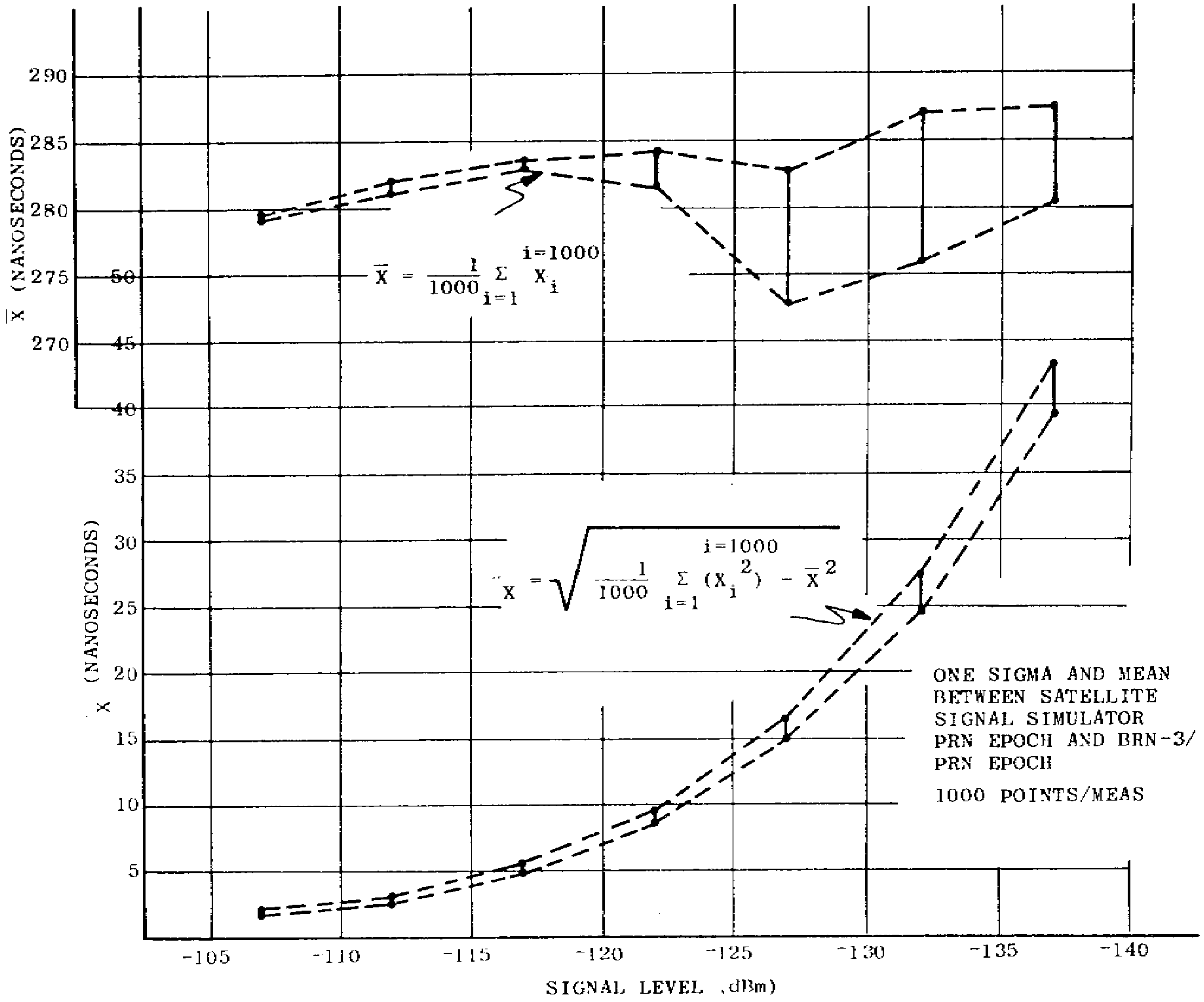


Figure 9. Satellite Data Indicating Receiver Instrumentation Delay Jitter


$\bar{X}$ (NANOSECONDS)
290
285
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45
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X (NANOSECONDS)
$\bar{X} = \frac{1}{1000} \sum_{i=1}^{i=1000} X_i$
$X = \sqrt{\frac{1}{1000} \sum_{i=1}^{i=1000} (X_i^2) - \bar{X}^2}$
ONE SIGMA AND MEAN
BETWEEN SATELLITE
SIGNAL SIMULATOR
PRN EPOCH AND BRN-3/
PRN EPOCH
1000 POINTS/MEAS
-105
-110
-115
-120
-125
-130
-135
-140
SIGNAL LEVEL (dBm)

Figure 10

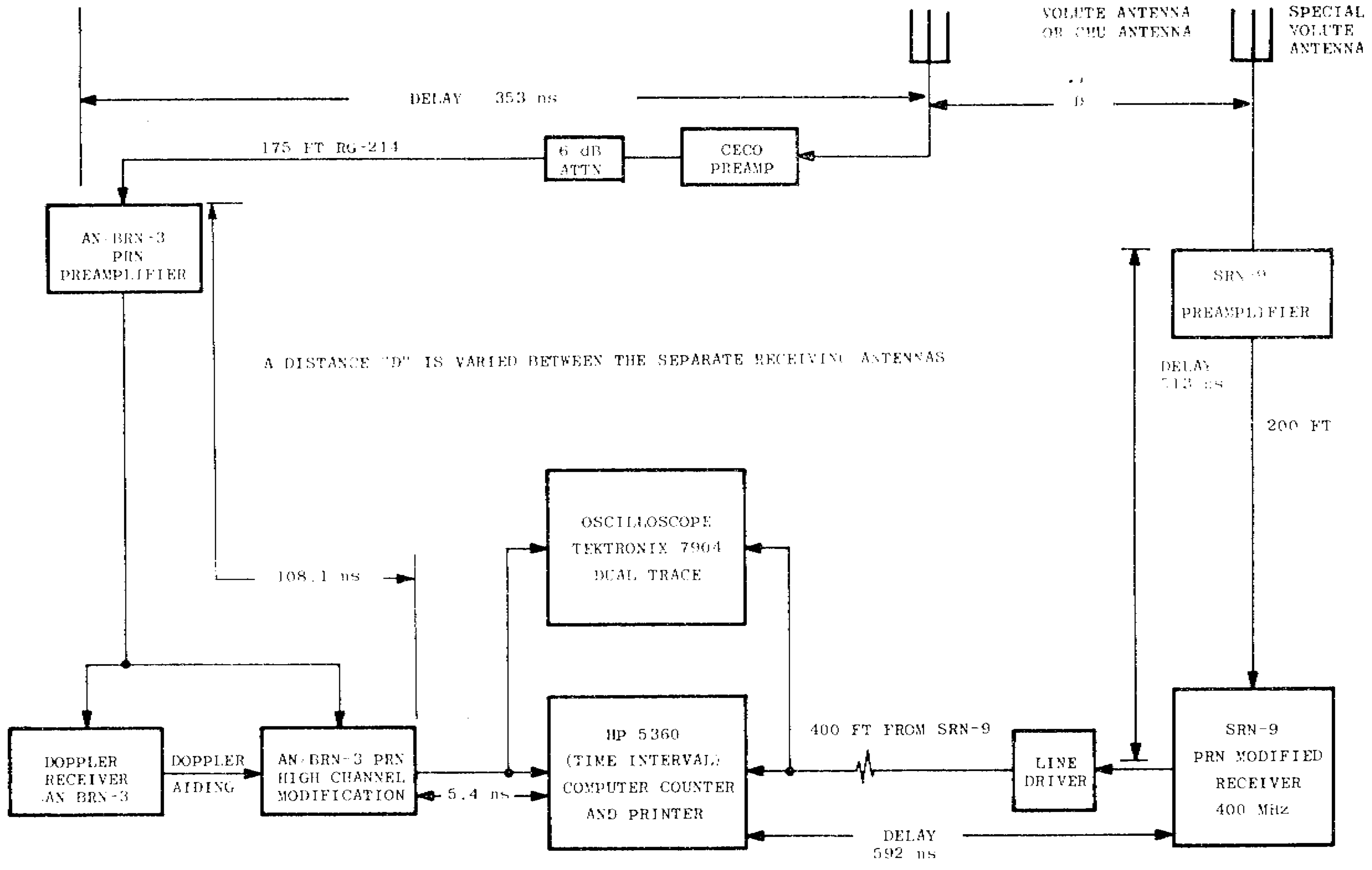

Figure 11. Simplified Block Diagram of PRN Jitter Test Between BRN 3 and SRN-9 Epochs From TRIAD 1 Using Separate Antennas

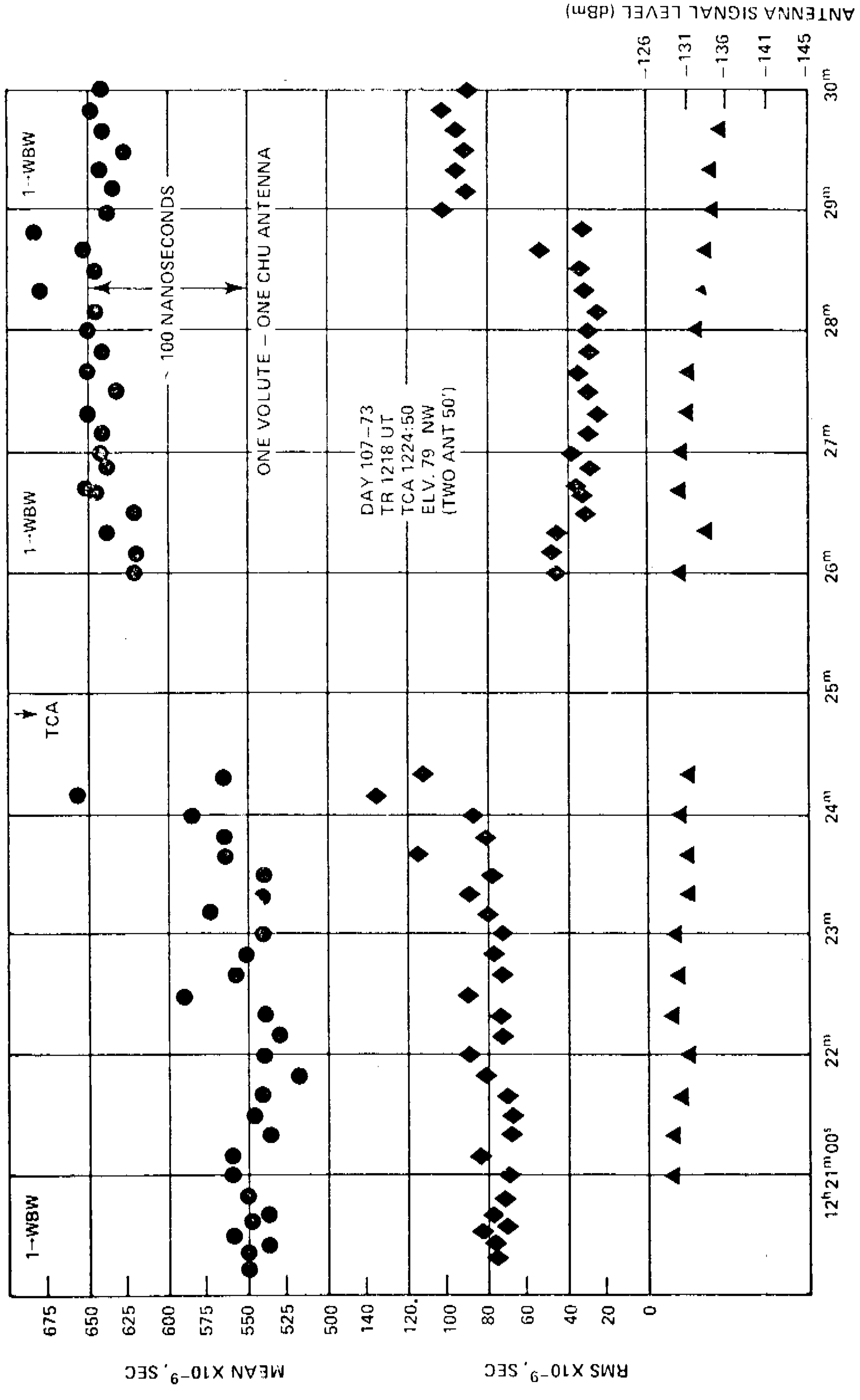

Figure 12. Discrimination of Antenna Separation Distance Using TRIAD Satellite Signals

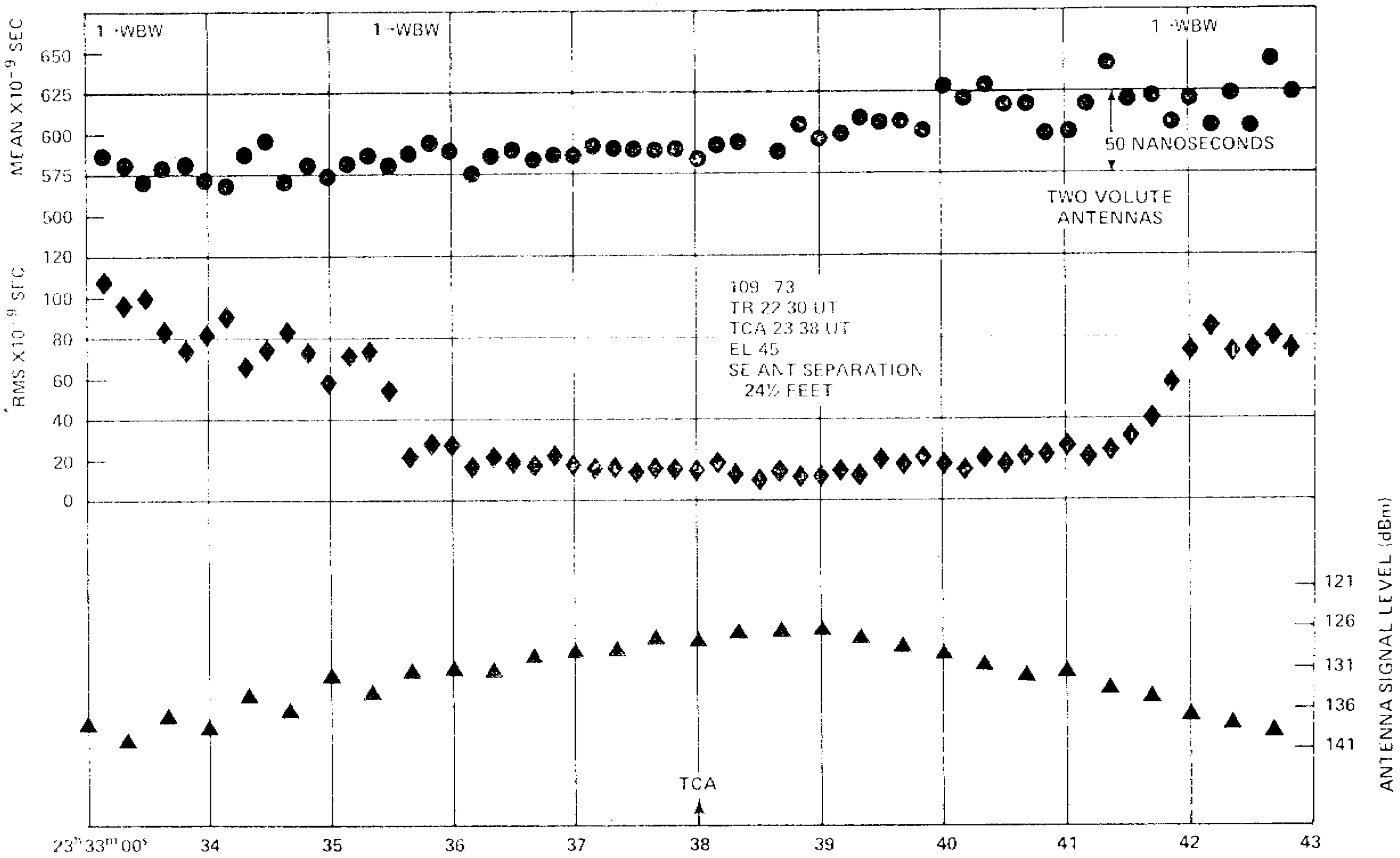

Figure 13. Discrimination of Antenna Separation Distance Using TRIAD Satellite Signals

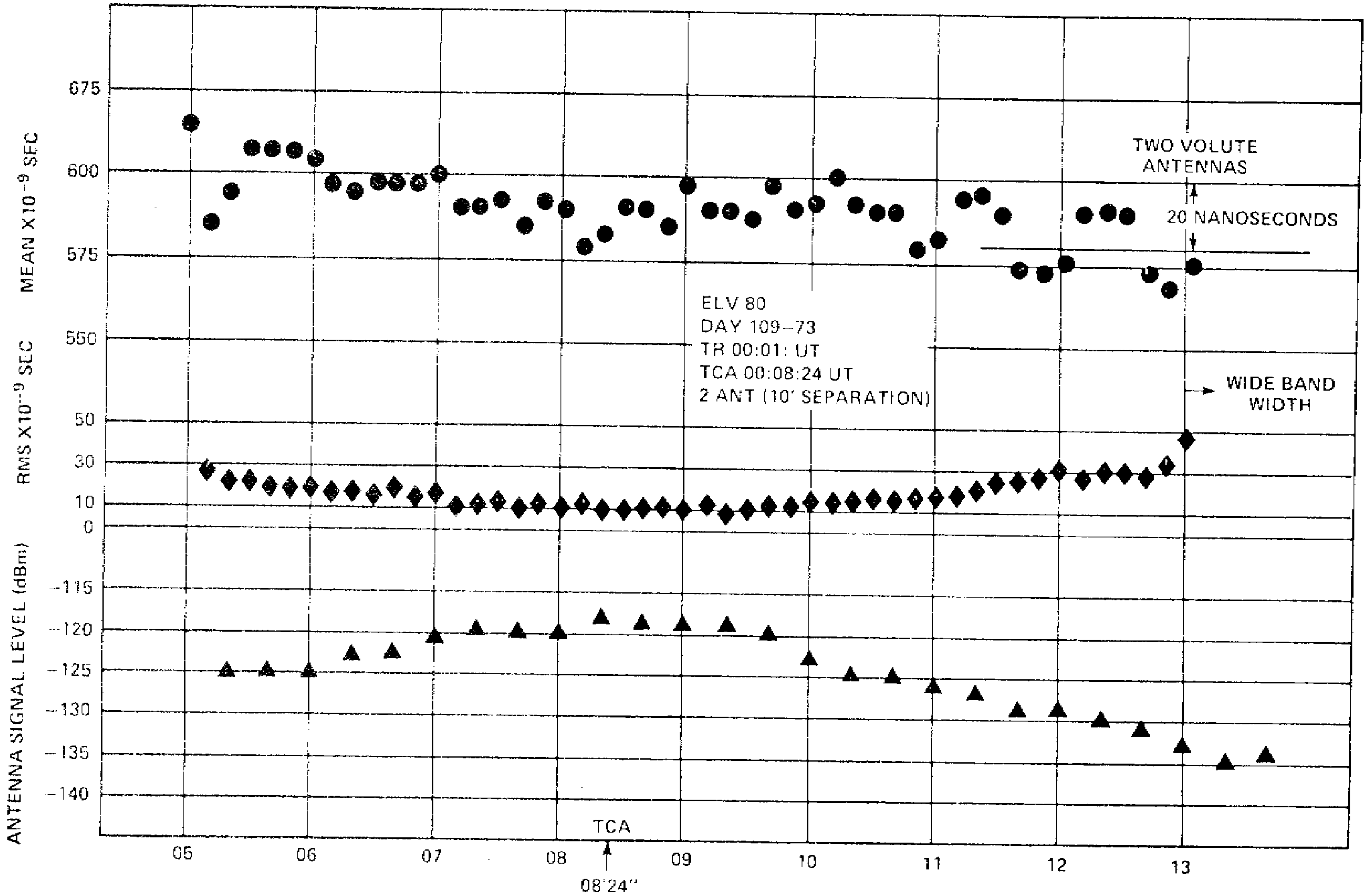

Figure 14. Discrimination of Antenna Separation Distance Using TRIAD Satellite Signals

in the differential rms tracking noise when volute antenna were used for both BRN-3 and SRN-9 receiving sets.

In the third test it was desired to measure the apparent delay to the satellite clock pulses transmitted by PN *vs.* elapsed time during the satellite pass. For this quasi absolute propagation delay measurement the single BRN-3/PN receiving set was used with volute antenna. The local reference clock time interval scale was adjusted on the basis of previous satellite observations to approximate the -140 PPM offset satellite time interval scale. Data obtained during a short segment of the pass, centered about the time of closest approach (TCA), is plotted in Figure 15. The smoothness of the locus of measured values is of interest since the data includes the refraction uncertainties of the radio propagation path as well as the PN instrumentation errors.

These basic and rather elementary tests constitute only the beginning of the full evaluation of the performance capabilities of the TRANSIT system for applications in local clock calibration and synchronization. In the next 3 to 4 months some additional effort is scheduled. Selected satellite passes will be tracked and measured data will be processed to perform the compensations indicated in Figure 1. The objectives will be to establish more completely the technical feasibility, to analyze the measured data for a definition of the dominating sources of error, and to demonstrate time transfers between master and slave clock systems by monitoring the satellite PN broadcasts.

Even from the fragmentary work performed to date we think the following conclusions can be supported: (1) the satellite PN modulation design and the radiated power levels will be adequate for PTTI applications in the submicrosecond ranges of accuracy, (2) progress in correlation receiving set design for PN recovery has eliminated the receiving set instrumentation delay uncertainties as a significant source of error. The low altitude one-way transmitting satellite provides a viable means for the accurate calibration and synchronization of clocks distributed globally among fixed site and navigating users.

ACKNOWLEDGMENT

The material reported herein is the work product of many persons associated with the TRANSIT Navigation System. Special acknowledgement is due Mr. E. F. Prozeller for the PN subsystems of the improved satellites and the modified AN/SRN-9 receiving set. The test data was collected and plotted by Mr. R. E. Dove and by Dr. R. J. Taylor.

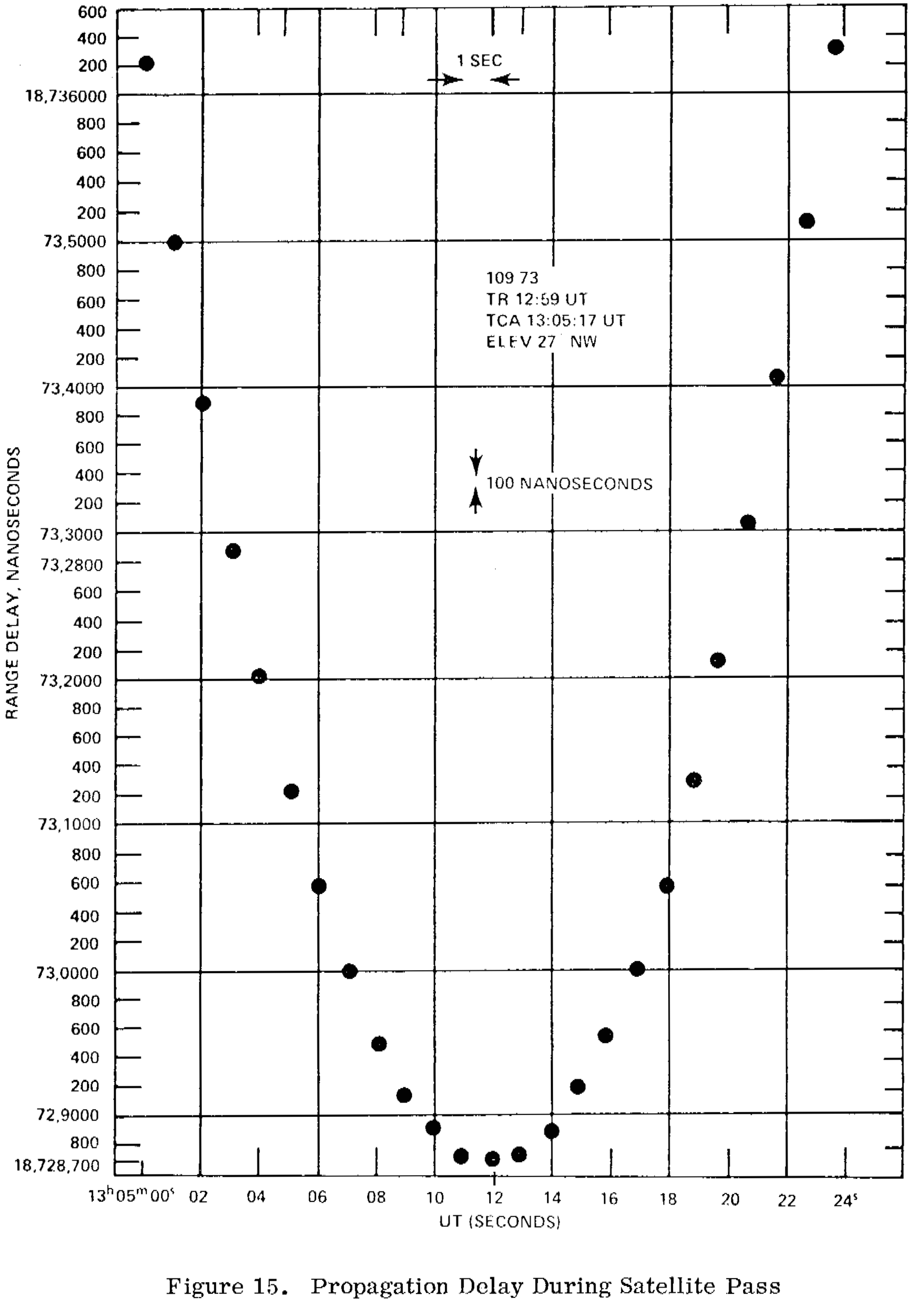

Figure 15. Propagation Delay During Satellite Pass

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1. U.S. Naval Observatory, "Series 17, TRANSIT Satellite Report", issued periodically.

2. E. F. Osborne and T. A. Schonhoff, "Delay-Locked Receivers with Phase Sensing of the Correlation (Error) Function", Conf. Record of the NTC 1973, Atlanta, Ga., paper 26B.

3. W. J. Gill, "A Comparison of Binary Delay-Lock Tracking-Loop Implementations", IEEE TRANS. on Aerospace and Electronic Systems, Vol AES-2, No 4, July 1966, pp 415-424.

QUESTION AND ANSWER PERIOD

DR. WINKLER:

Thank you, Mr. Osborne. Are there any questions?

I, of course, am in complete agreement with you. I think we have a resource here which we have not yet used. We have left that to the French who are using transit satellites for routine time transfers and you will find a report on their experience in the special issue of Time and Frequency, IEEE, May of 1972.

There is one question here.

QUESTION:

It is kind of a compound question. I am not sure just what the Triad satellite is. What I want to know is, will the Triad satellite be able to be used for navigational purposes? Also, can the satellite, the new satellite that just went up, 2016, can that be used in the mode that you are talking about now to provide timing after it is used up as a navigational satellite? And also, can, say, the two satellites, 10 and 18, can they be used in any way as a timing satellite?

DR. OSBORNE:

Yes, the current satellite that went up two weeks ago or thereabouts is one of the traditional designs that does provide a time service, but it does not have the pseudo-random capability. The performance you will get with it would be similar to that of the other four or five that are already in the system.

As to the Triad satellite, it was the first satellite of the experimental improvement program. While it was intended to eventually have an operational role in the system for navigational purposes, there was some unfortunate failure in the equipment, and the satellite is available generally only for experimental purposes. And that does not say that if we had a national catastrophe or something, we might possibly use it; but there are absolutely no plans to use the Triad satellite ever for operational navigation.

DR. WINKLER:

Here is another question.

MR. MAZUR:

Bill Mazur, Goddard.

Do you have any idea of the cost of these pseudo-random code receivers?

DR. OSBORNE:

Well, that is a very difficult thing to get into and I hesitate to talk about costs, especially if you put it in the connotation of low cost, because, you know, low cost is like beauty, it is in the eyes of the beholder.

There have been two units built, and we suspect that adding the pseudo-random code, at least until somebody finds a need for substantial numbers of them, is apt to cost you maybe $30,000 to add that feature to existing equipment.

Now, one should point out, of these some 700 units that I said were in the field, these units are for navigators, and they do an awful lot of things that many, many people interested in time would not require.

So, it is unfair to say that, you know, the cost of one of these devices is unreasonable, because, you know, you fit the device to whatever you need, and don't buy something that you don't need.