# A PASSIVE SUBMICROSECOND TIME DISSEMINATION SYSTEM

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## ABSTRACT

A submicrosecond Time Dissemination System has been developed by the Johns Hopkins University Applied Physics Laboratory. The System is composed of an experimental transit improvement satellite (TRIAD), TRANET Satellite Tracking System, and special satellite signal receivers each tied to separate cesium clocks. The 400 MHz signal from the satellite is phase modulated $\pm 45^{\circ}$ by a pseudo-random noise (PRN) digital code with a bit rate of 5/3 MHz.

Evaluation of this system has shown that satellite oscillator frequency instabilities are the major source of error. During a three day observation of the satellite, the maximum excursion of the satellite oscillator frequency from a straight line fit to the observed frequency was $7 \times 10^{-12} \left(\frac{\Delta f \text{ diff}}{f}\right)$. Experiments indicate that Global time transfers can be made with errors less than 100 nanoseconds.

## INTRODUCTION

Improvement of the Navy Navigation (Transit) Satellite System has led to the development of a new series of satellites which incorporate the following improvements:

1. Wide Band Pseudo-Random Noise (PRN) Phase Modulation of the carrier for range navigation and precise dissemination of time.

2. Disturbance Compensation System (DISCOS) which compensates for the aerodynamic drag forces and solar radiation pressure.

3. Programmable frequency synthesizer which compensates for frequency drift of the satellite quartz crystal reference oscillator.

This paper shall discuss nanosecond clock experiments utilizing the improvement mentioned under number 1. With the implementation of broad bandwidth digital pseudo-random noise (PRN) high frequency phase modulation on the carrier frequencies of the new Transit Improvement Satellite, TRIAD, came the ability to resolve timing marks with greatly increased precision using practical electronic circuitry. One key advantage of the Transit Satellites for disseminating time is that these satellites transfer time in a passive mode (one way signals from satellite to user). The advantages of this passive time dissemination system over an active or two way timing system are the following:

1. No limit to number of simultaneous terrestrial users.

2. User need not compromise his position by transmission of radio signals.

3. Use of portable omni-directional antennas.

## DISCUSSION

The purpose of the nanosecond clock experiment was to determine what level of accuracy time can be disseminated using PRN signals which are broadcast from the TRIAD Satellite. The task was to investigate how accurately the Clock Epoch Difference between two cesium beam clocks could be determined using the PRN modulation transmitted from the TRIAD Satellite. The various sources of errors were examined and their order-of-magnitude contributions to the total were determined.

The experimental system is shown in Figure 1. The experiment was to determine the clock epoch difference or error between two cesium clocks when they are used as recovery system clocks for receivers monitoring

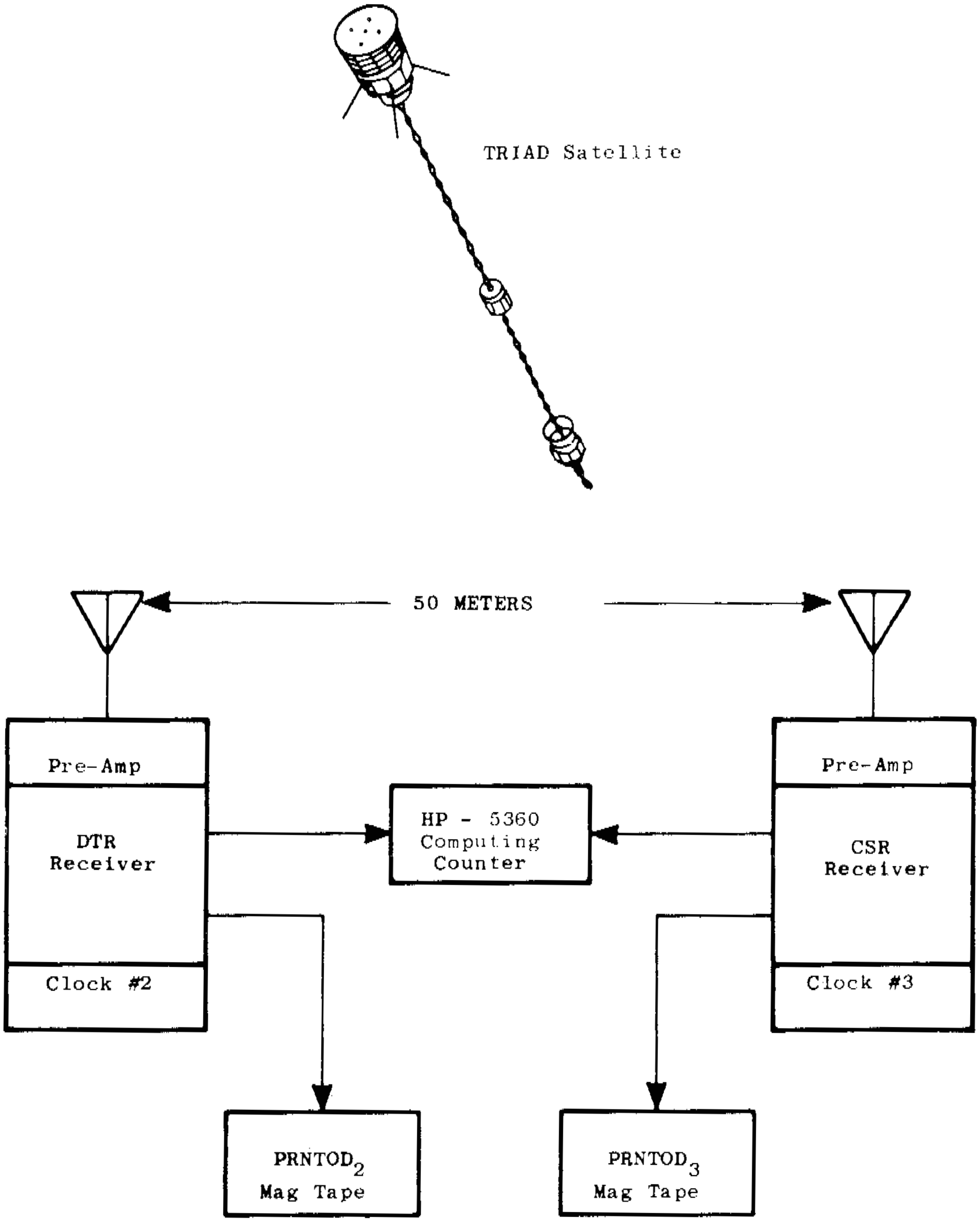

FIG. 1 SATELLITE AND RECEIVER EQUIPMENT DIAGRAM

the TRAID Satellite PRN digital code modulations on the 400 MHz signal. The two modes for determining the clock epoch error were the Regional Clock Transfer Mode and the Global Clock Transfer Mode. For the Regional Clock Transfer, both receivers monitor the same satellite signal simultaneously. For the Global Clock Transfer, measured PRN epoch times of arrival using one receiver are compared with predicted PRN epoch times of arrival using data from previous satellite passes measured with the other receiver. Satellite oscillator drift predictions are essential for predictions of PRN epoch times of arrival. Slant range propagation delays, ionospheric and tropospheric refraction delays, and equipment delays must be determined in order to determine the clock epochs error between the two cesium clocks on the ground. These time delays and their variation during a satellite pass are schematically shown in Figure 2. By subtracting these delays from the PRN times of arrival, one can determine the PRN times of transmission from the satellite. The PRN times of transmission are determined using two different clocks. The difference in time is the clock epoch difference between the two cesium clocks.

The clock epoch differences as determined by ground simulation of satellite signals and when the two receivers are simultaneously viewing the orbiting satellite (Regional Clock Synchronization) are shown in Figure 3. The maximum variation between these two methods to determine the clock epoch error is 43 nanoseconds with a mean bias of +22 nanoseconds for the satellite passes compared to the ground simulated satellite signals. The standard deviation of the satellite data from the general curve is only nine nanoseconds, however.

The bias in the Regional Clock Synchronization Data compared to the satellite simulator could come from several sources. Differences in antenna delays for the two receivers could account for part of the bias and/or dynamic response differences between the two receivers.

Data for the Global Clock Transfer Mode are generated by using PRN epoch receipt times as measured by the BRN-3 receiver for one pass to predict when PRN epochs should arrive at the SRN-9 receiver for the next pass and comparing the measured times of arrival with the predicted

# CLOCK SYNCHRONIZATION METHOD

COMPARE PRN SATELLITE TRANSMISSION TIMES USING DIFFERENT CLOCKS

↑ PRN TRANSMISSION TIME, CLOCK #1

↑ PRN TRANSMISSION TIME, CLOCK #2

→| |← CLOCK EPOCH DIFFERENCE

TIME OF TRANSMISSION = TIME OF RECEPTION $-\rho/C - \Delta t_{ion} - \Delta t_{trop} - \Delta t_{eq}$

$\rho$ SLANT RANGE, FROM SATELLITE EPHEMERIS AND RECEIVER COORDINATES.

$\Delta t_{ion}$ FROM REFRACTION CORRECTION FREQUENCY DERIVED BY MIXING THE 150 and 400 MHz CARRIERS TOGETHER.

$\Delta t_{trop}$ FROM TROPOSPHERIC MODEL USING TEMPERATURE, PRESSURE, AND HUMIDITY.

$\Delta t_{eq}$ FROM EQUIPMENT DELAY CALIBRATIONS.

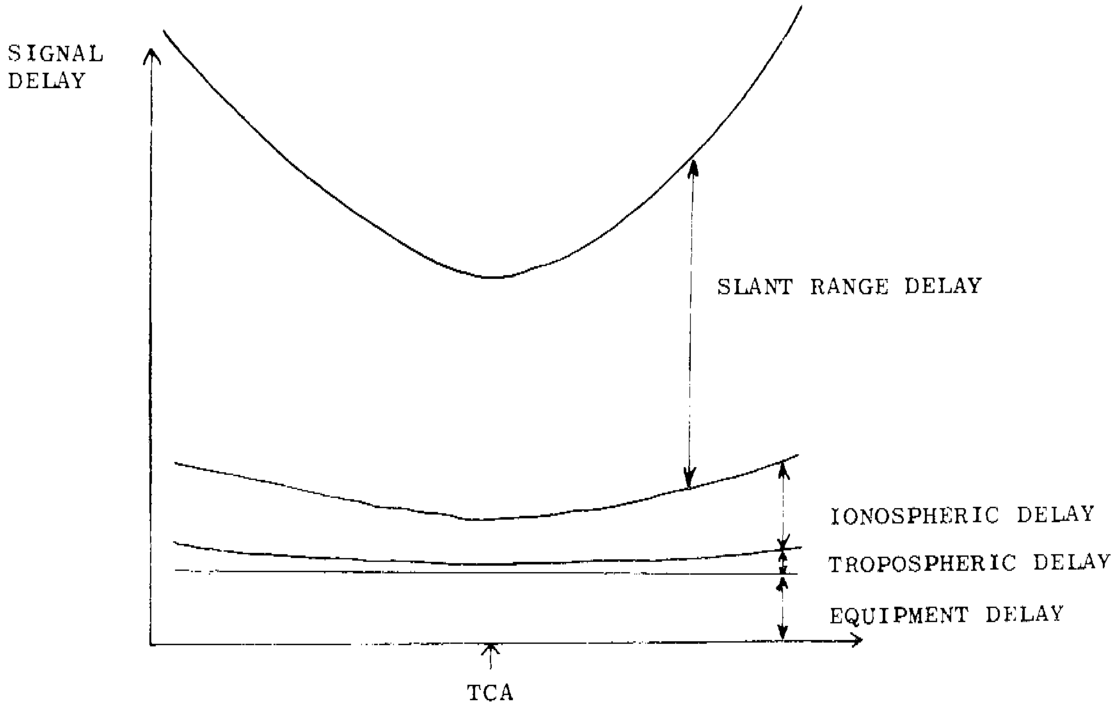

FIG. 2 CLOCK SYNCHRONIZATION METHOD

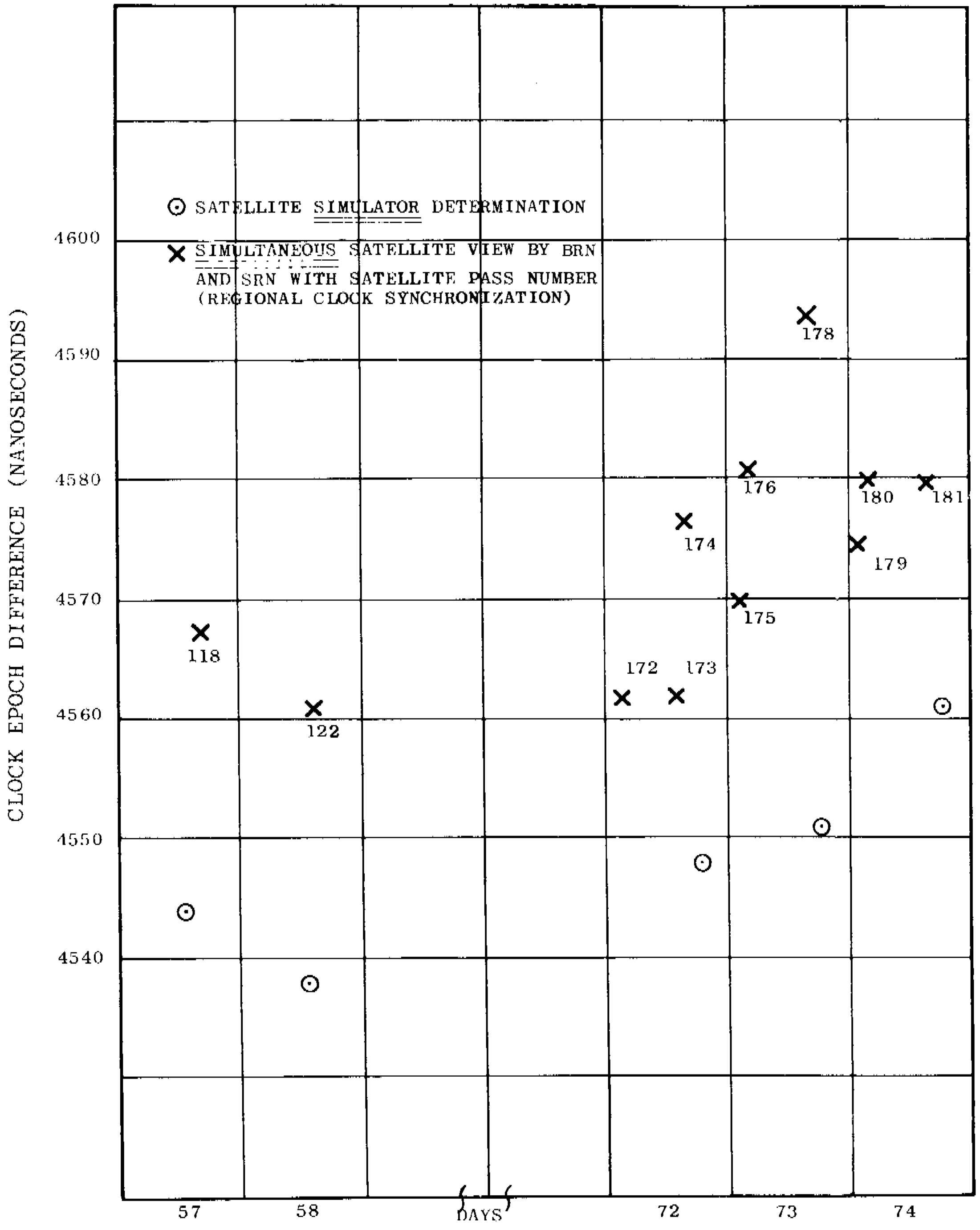

FIG. 3 REGIONAL CLOCK SYNCHRONIZATION DATA

times. The difference between these predicted times and the measured times is the clock epoch difference, determined in the Global Clock Transfer Mode (See Figure 4). The predicted PRN times of transmission from the satellite are based upon estimates of the satellite oscillator frequency drift. The measured TRIAD oscillator frequency between days 72 and 74, 1974 is shown in Figure 5. The largest departure of the measured frequency from a straight line fit was $7 \times 10^{-12} \frac{(\Delta f\ \mathrm{diff})}{f}$.

Prediction errors can also be generated by BRN-3 to BRN-3 predictions just like the BRN-3 to SRN-9 predictions (Global Clock Transfer Mode). From such predictions and the data shown in Figure 4, we learn that clock synchronizations on a global basis can be made with errors less than 75 nanoseconds when the time transfers between the satellite and the two clocks being synchronized are made within 100 minutes. The largest error observed during this experiment was 200 nanoseconds for twelve hour prediction times. The mean bias error for the twelve hour predictions was 90 nanoseconds.

One of the purposes of this experiment was to generate the error budget shown in Table 1. This error budget was generated from the data used to generate Figure 4, ephemeris determinations for the TRIAD Satellite, ground equipment noise analysis, and a theoretical study of error sources.

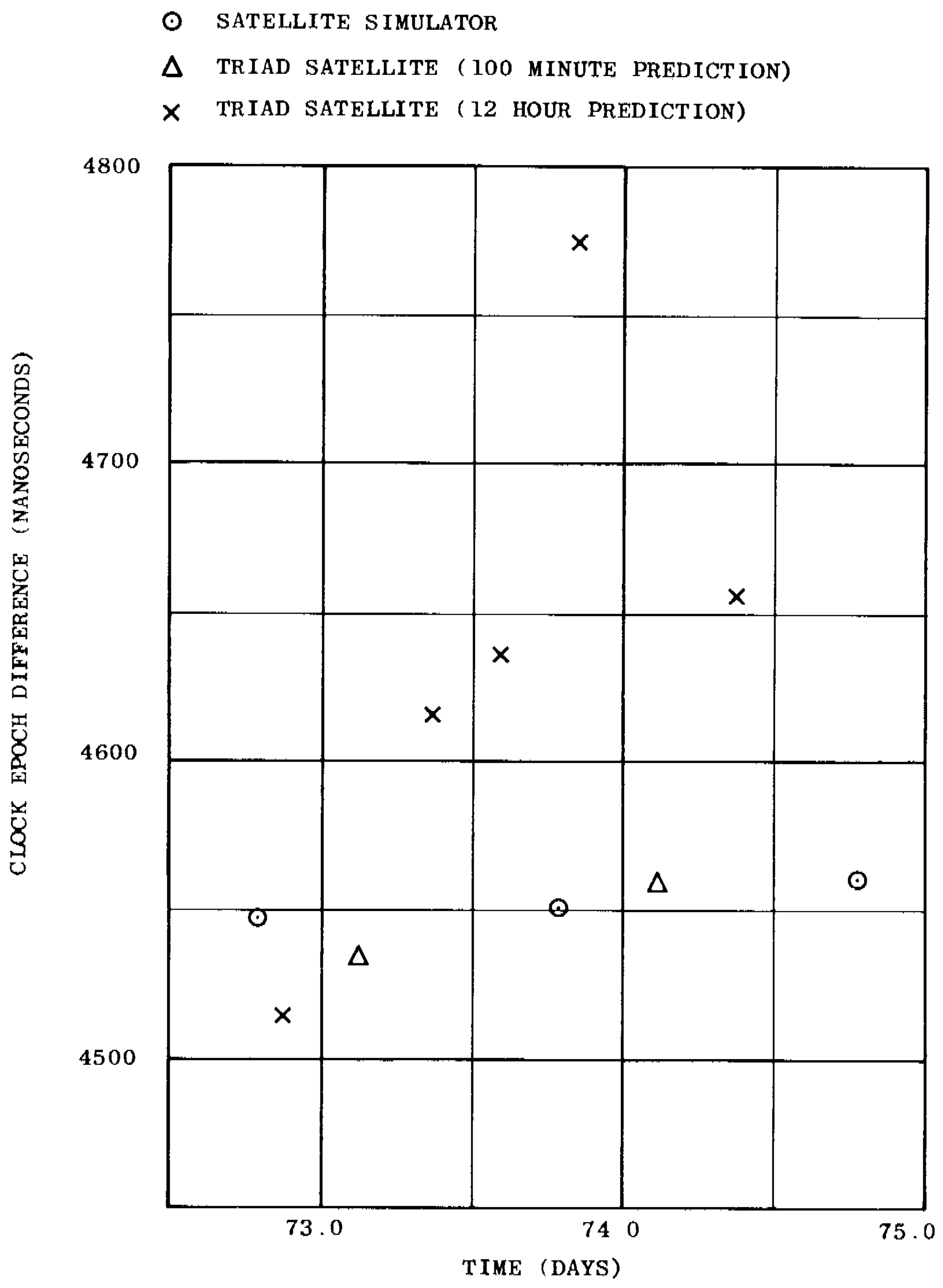

FIG. 4 GLOBAL CLOCK SYNCHRONIZATION DATA

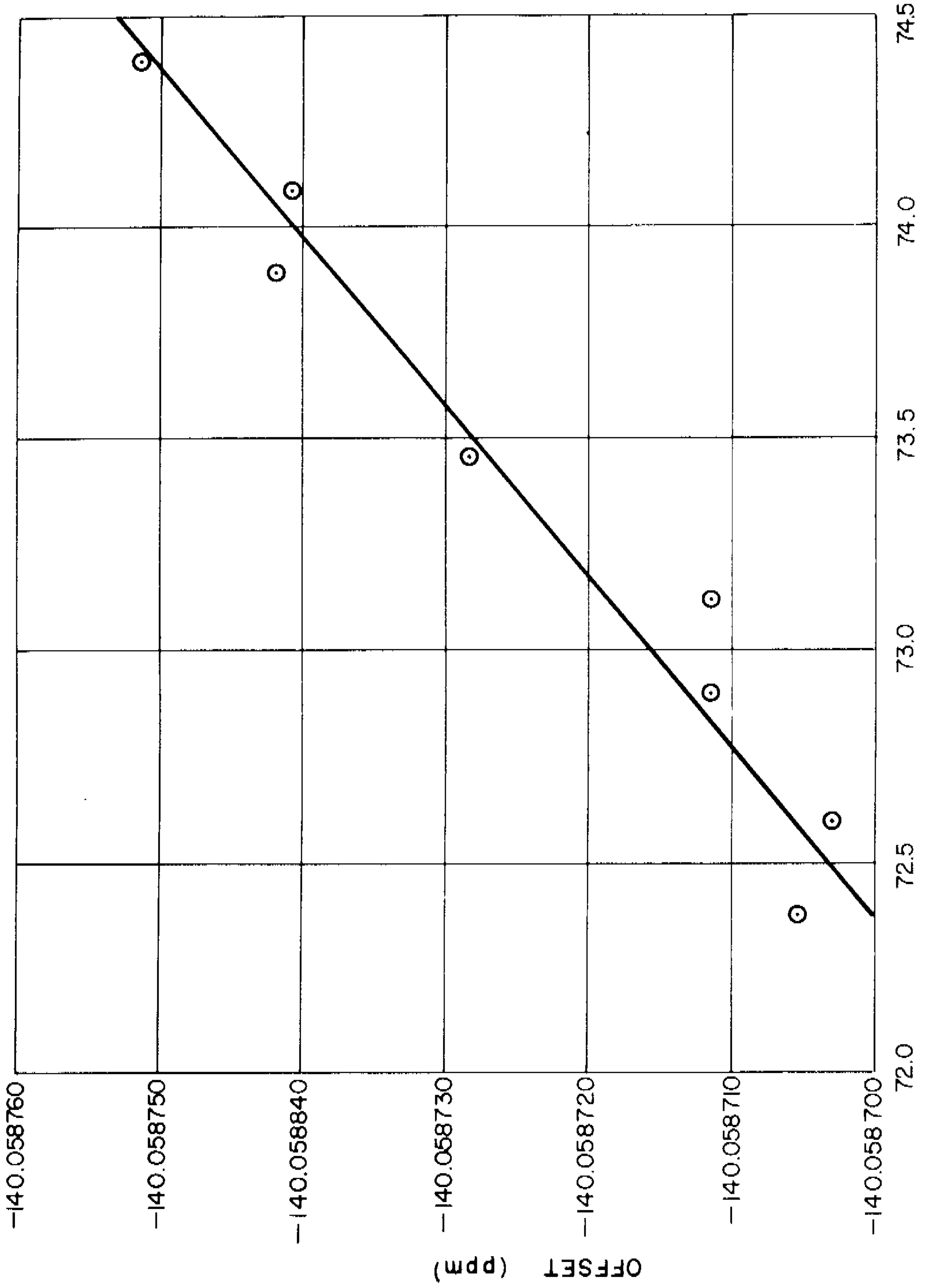

FIG. 5 SATELLITE OSCILLATOR FREQUENCY OFFSET

# GLOBAL CLOCK SYNCHRONIZATION
# ERROR BUDGET

|  | Item | Time Error |
|---|---|---|
| A. | Scientific Problems: |  |
|  | 1. Satellite Position | ~ 75 ns |
|  | 2. Refraction | < 30 ns (90% Prediction) |
|  | 3. Gravity Red Shift[1] | 10 ns |
| B. | Engineering Problems: |  |
|  | 1. Satellite Oscillator | 200 ns/12 hrs. |
|  | 2. Receivers (Two) | ~ 20 ns |

TABLE 1 GLOBAL CLOCK SYNCHRONIZATION ERROR BUDGET

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[1] While orbiting the earth, the satellite experiences a varying gravitation field and thus the magnitude of its velocity fluctuates. Because of this, the satellite oscillator frequency changes during each revolution. These fluctuations were not modeled during this experiment, thus they contributed to the error budget.

## FUTURE DIRECTION

During the next year experiments involving receivers spread over a greater geographic distribution should be initiated to confirm the indicated global capability. An experiment tying the Naval Observatory to Hawaii would be of great experimental value as the data can be confirmed by an existing active time link. Future satellites are planned which will incorporate the use of PRN modulation on their signal at higher power and with less uncertainty of orbit position. One of the satellites in this series is TIP II, which will broadcast on approximately 2.25 watts CW and PRN component on the 400 MHz channel and the 150 MHz channel will have .9 watts CW and PRN component. This increased power should increase the received signal by approximately 10 dB on the ground. The advantages of TIP II should be the following:

1. Greater frequency stability and frequency control.

2. Higher orbit, thus decreasing the satellite position uncertainties from the gravitational model at least by a factor of two.

3. Stronger signal level decreasing PRN TOD jitter.

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## APPRECIATION

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