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A TEST OF THE EFFECT OF SATELLITE SPIN ON TWO-WAY DOPPLER RANGE-RATE MEASUREMENTS

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GSFC

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GREENBELT, MARYLAND

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ABSTRACT

It has been predicted theoretically that the rotation of certain types of satellite antennas will cause a range-rate error in two-way Doppler tracking systems of the magnitude $\Delta\dot{r} = (1 \pm 1/K)\,\lambda_t\, f_s/2$ where K is the effective turn-around ratio of the satellite transponder, λ_t is the wavelength of the ground based transmitter, and f_s is the satellite spin rate. This equation was tested experimentally by ground-based simulation. Excellent agreement was obtained.

A TEST OF THE EFFECT OF SATELLITE SPIN ON TWO-WAY DOPPLER RANGE-RATE MEASUREMENTS

I. Introduction

In a previous report [1] it was shown theoretically that the spin of a satellite using a turnstile antenna must be taken into consideration when the range rate of the satellite is measured by a coherent two-way Doppler tracking system. In this report, the results of an experimental test of the theory are presented. The test was performed in March, 1970 at the Goddard Range and Range Rate (GRARR) facility at Rosman, North Carolina, using S-band frequencies and a once-per-second recording rate.

II. Equation for Range-Rate

The theoretical equation for the range-rate of the spinning satellite as measured by the GRARR system was given [Reference 1, equation 20] as

$$\dot{r} = \frac{\left(\dfrac{f_b - f_0}{2\, f_t}\right)}{1 - \left(\dfrac{f_b - f_0}{2\, f_t}\right)}\, c + \frac{S_r + S_t\,(N/M)}{2}\, \lambda_t\, f_s \tag{1}$$

where, in the first term, f_0 is the output frequency of the GRARR receiver, f_t is the carrier frequency of the ground-based transmitter, f_b is a bias frequency used to remove ambiguity in the sign of the measured frequency shifts, and c is the speed of light. In the second term, λ_t is the wavelength of the transmitter, $\lambda_t = c/f_t$, f_s is the spin rate of the satellite, and M/N is the effective turn-around ratio of the satellite transponder. The quantity S_r is defined to have the value +1 if the circular polarization of the receiving antenna of the satellite and the rotation of the satellite both are given by a right hand or both by a left hand rule along the propagation path. If the rotation and polarization have opposite senses, S_r is to be set equal to -1. The quantity S_t obeys the same rule as S_r, but applies to the transmitting antenna of the satellite.

The first term in (1) is the conventional one for calculating the range-rate in the absense of satellite spin. Thus, if an apparent range rate $\dot{r}_a$ is defined as

$$\dot{r}_a \equiv \frac{\left(\dfrac{f_b - f_0}{2\, f_t}\right)}{1 - \left(\dfrac{f_b - f_0}{2\, f_t}\right)} c \tag{2}$$

equation (1) can be written as

$$\dot{r} = \dot{r}_a + \frac{S_r + S_t\,(N/M)}{2} \lambda_t\, f_s \tag{3}$$

where the second term may be regarded as the correction for satellite spin that must be added to the apparent range-rate $\dot{r}_a$ to obtain the true range-rate $\dot{r}$.

III. GRARR S-Band System

In the GRARR S-Band System at Rosman, the bias frequency is derived from the transmitter frequency by division [2, 3]. The bias frequency is

$$f_b = f_t/3600 \tag{4}$$

which, at the S-band transmitter frequencies used ($f_t \stackrel{\circ}{=} 1.8$ GHz) is approximately

$$f_b \doteq 500 \text{ kHz} \tag{5}$$

The output frequency f_0 is measured by means of a counter. The test was conducted using a recording rate of 1/sec, and in this case the counter is started by one of the cycles of the receiver output frequency f_0, and continues to operate until a total of 229,263 cycles of f_0 have occured, at which time the number of counter cycles is read out. Thus the length of the counting period is

$$\text{Counting time} = 229,263/f_0 \text{ sec.} \tag{6}$$

Since f_0 never departed greatly from the bias frequency, the counting time was roughly

$$\begin{aligned} \text{Counting time} &\overset{\circ}{=} 229.263/500 \times 10^3 \\ &= 1/2 \text{ second} \end{aligned} \tag{7}$$

The rate at which the counter operates, like the bias frequency, is controlled by the transmitter frequency. The counter is driven at a rate of

$$\text{Counting rate} = f_t/180 \text{ counts per sec} \tag{8}$$

which is about a 10 MHz rate. Multiplying (6) and (8) together, the counter output c_0 is given by

$$c_0 = \frac{229.263}{180} \; \frac{f_t}{f_0} \tag{9}$$

Substituting (4) and (9) into (2), the equation for apparent range rate in terms of the counter output c_0 is

$$\dot{r}_a = \frac{\left(\frac{1}{7200} - \frac{229.263}{360\ c_0}\right)}{1 - \left(\frac{1}{7200} - \frac{229.263}{360\ c_0}\right)} c \tag{10}$$

IV. Test Antenna

For reasons of convenience, the test of equation (3) was carried out at S-band, although in tracking applications the effect is larger at VHF frequencies because of the longer transmitter wavelength. Also a turnstile antenna, which was the type analyzed in reference [1] was not used. Instead, the test was performed* [4] using a motor-driven rotatable antenna especially constructed for the test by the Andrew Corporation. The antenna was a S-band helicone spiral antenna having right-hand circular polarization along the axis of the cone which was also the axis of rotation. The type "N" rotary joint did not appear to affect the phase appreciably as the antenna rotated.

The use of this antenna to simulate a turnstile should not affect the test results. The physical principle involved is clear. Maxwell's equations express a relationship between currents and charges and the associated electromagnetic field. The source of the currents and charges or any motion thereof is immaterial. Thus if an antenna, electrically driven to radiate a circularly polarized wave, is rotated mechanically about the direction of propagation, the mechanical motion is superposed on the electrically-induced motion of the radiating currents and charges on the antenna, the result being a change, equal to the mechanical spin rate, of the frequency of the radiated circularly polarized wave.

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* The test was performed for Goddard Space Flight Center by RCA under contract NAS 5-10600

The speed of test antenna rotation was determined optically, using a reflecting surface on the antenna cone, with the time interval between alternate* light impulses measured by the appropriate circuitry.**

V. Test Results

The test was conducted with the helicone antenna (mounted on a collimation tower) with its axis directed approximately at the GRARR antennas. The helicone antenna was cabled to a transponder simulator located at the base of the tower. The effective turn-around ratio of the transponder was

$$M/N = 60/48 = 1.25 \tag{11}$$

Since the helicone antenna, although rotating, was not in linear motion in this test, the true range-rate in equation (3) was

$$\dot{r} = 0 \tag{12}$$

Since the same test antenna was used for both transmission and reception, the symbols S_r and S_t assumed equal values

$$S_r = S_t = \pm 1 \tag{13}$$

where the positive sign was used when the antenna was rotating counter-clockwise when viewed from the GRARR transmit-receive complex, since this motion

* In some cases the counter measured the length of a single period of the antenna spin rate rather than the intended two periods. The ambiguity was easily resolved, however, since the approximate spin rate was known from a previously calibrated dial reading.

**Designed by A. Jackson of RCA.

adds to the right-hand circular polarization of the test antenna. The minus sign was used for clockwise rotation. Thus, applied to the test conditions, equation (3) becomes

$$\dot{r}_s = 0.9 \lambda_t f_s \tag{14}$$

where S_r and S_t have been absorbed into f_s by making the latter positive for clockwise (cw) rotation and negative for counter-clockwise (ccw) rotation. Equation (14) is the theoretical equation, that applies under the test conditions, for the apparent range rate that should be measured by the GRARR system when the helicone antenna rotates. It is a straight line, passing through the origin and having a slope $0.9 \lambda_t$. The equation is plotted in Figures 1 and 2 for the two different transmitter frequencies used in the test.

The experimental test of equation (14) was carried out by rotating the helicone at selected constant speeds for periods of about one minute each, during which time the once-per-second readouts c_0 of the GRARR Doppler counter were recorded, as well as the lengths of successive double periods of rotational rate of the helicone. Consequently, for each helicone speed selected, there were obtained about 60 counter measurements. The number of readings of rotational double-period, however, varied inversely with the speed, and was excessive at higher speeds, so that, in some cases, the double-periods were recorded only for a short length of time within the 60 second measurement interval.

Histograms of typical data are shown in Figures 3, 4, and 5. In Figure 3 is a histogram of the counter output with the helicone at rest. The output was relatively noise-free, with the count during the one minute interval never deviating by more than one unit from the theoretical value 4585260.

In Figure 4 the counter output is shown when the antenna was rotating at about 800 revolutions per minute, and in Figure 5 are the measurements of the antenna rotational period taken concurrently.

The periods and counter readings obtained at each speed were averaged. The results are listed the first and fourth columns of Tables 1 and 2.

An average spin rate f_s was calculated by taking the reciprocal of the mean period, and is given in the second column of the Tables. Similarly an average apparent range rate was calculated from the mean count using equation (10), and is given in the fifth column of the tables. The experimental points, column 2 and 5 of the Tables are plotted in Figures 1 and 2. The agreement with the theoretical curves is excellent.

VI. Summary

The effect of satellite antenna rotation on the range-rate output of the GRARR system was tested by simulating the satellite antenna with a ground-based rotating antenna. The observed range-rate error caused by the antenna rotation was in almost exact agreement with that predicted by theory.

Acknowledgements

The efforts of A. Jackson and W. Buckett of RCA in the designing and conducting of the test, and the help of T. Grenchik and P. Schmid of GSFC in obtaining and testing the Andrew helicone antenna is gratefully acknowledged.

REFERENCES

1. Marini, J., "The Effect of Satellite Spin on Two-Way Doppler Range-Rate Measurements," GSFC X-551-69-104, March 1969.
2. "GRARR Design Evaluation Report," General Dynamics Electronics Division Report R-67-042, 13 December 1967, Contract No. NAS 5-10555; p. 3-137.
3. Zillig, D., "Data Formats of the Goddard Range and Range Rate System and the Application Technological Satellite Range and Range Rate System," GSFC X-571-69-149 April, 1967.
4. Jackson, A., "Report on test to verify the theoretical calculation on the effects of a spinning antenna on range rate measurements," Memorandum, 17 April 1970.

Table 1

Averages of Measured Data, $f_t = 1.7992$ GHz

Mean Measured Single or Double Period (sec.)	f_s = 1/Period	Predicted Apparent Range-Rate (eqn. 14)	Mean Measured Doppler Count C_0	Measured Apparent Range-Rate (eqn. 10)
—	0 Hz	0 cm/sec	4585259.95	-0.05 cm/sec
5.3496 (cw)	0.3739	5.61	4585266.22	+5.65
1.2661 "	0.7898	11.84	4585273.07	11.87
0.61592 "	1.624	24.35	4585286.88	24.41
0.30001 "	3.333	49.99	4585314.89	49.84
0.39571 "	5.054	75.79	4585343.68	75.99
0.14806 "	6.754	101.28	4585371.43	101.18
0.23768 "	8.415	126.19	4585398.95	126.17
0.19856 "	10.07	151.05	4585426.37	151.07
0.17093 "	11.70	175.47	4585453.34	175.56
0.14940 "	13.39	200.74	4585480.87	200.56
0.13452 "	14.87	222.96	4585505.30	222.74
0.12615 "	15.85	237.75	4585521.59	237.53
5.3625 (ccw)	- 0.3730	- 5.59	4585253.87	- 5.57
2.5013 "	- 0.7996	- 11.99	4585247.05	- 11.76
1.2147 "	- 1.647	- 24.69	4585232.85	- 24.65
0.59704 "	- 3.350	- 50.24	4585204.64	- 50.27
0.39459 "	- 5.069	- 76.01	4585176.08	- 76.21
0.29471 "	- 6.786	-101.77	4585148.05	-101.66
0.23556 "	- 8.490	-127.32	4585120.00	-127.14
0.19633 "	-10.19	-152.77	4585091.81	-152.74
0.16827 "	-11.89	-178.24	4585063.79	-178.18
0.14759 "	-13.55	-203.21	4585036.25	-203.19

Table 2

Averages of Measured Data, $f_t = 1.8052$ GHz

Measured Mean Single or Double Period (sec.)	f_s = 1/Period	Predicted Apparent Range Rate (eqn. 12)	Mean Measured Doppler Count C_0	Measured Apparent Range Rate (Eqn. 8)
–	0 Hz	0 cm/sec	4585260.06	+ 0.05 cm/sec
5.4205 (ccw)	- 0.3690	- 5.51	4585254.11	- 5.39
1.2235 (ccw)	- 1.635	- 24.43	4585233.15	- 24.38
0.29459 (ccw)	- 6.789	-101.47	4585148.36	-101.38
0.12915 (ccw)	-15.49	-231.46	4585004.41	-232.11
5.3913 (cw)	+ 0.3710	+ 5.54	4585266.16	+ 5.59
1.2205 (cw)	+ 1.639	+ 24.49	4585287.03	+ 24.55
0.29523 (cw)	+ 6.774	+101.25	4585371.37	+101.13
0.12881 (cw)	+15.53	+232.07	4585515.98	+232.44

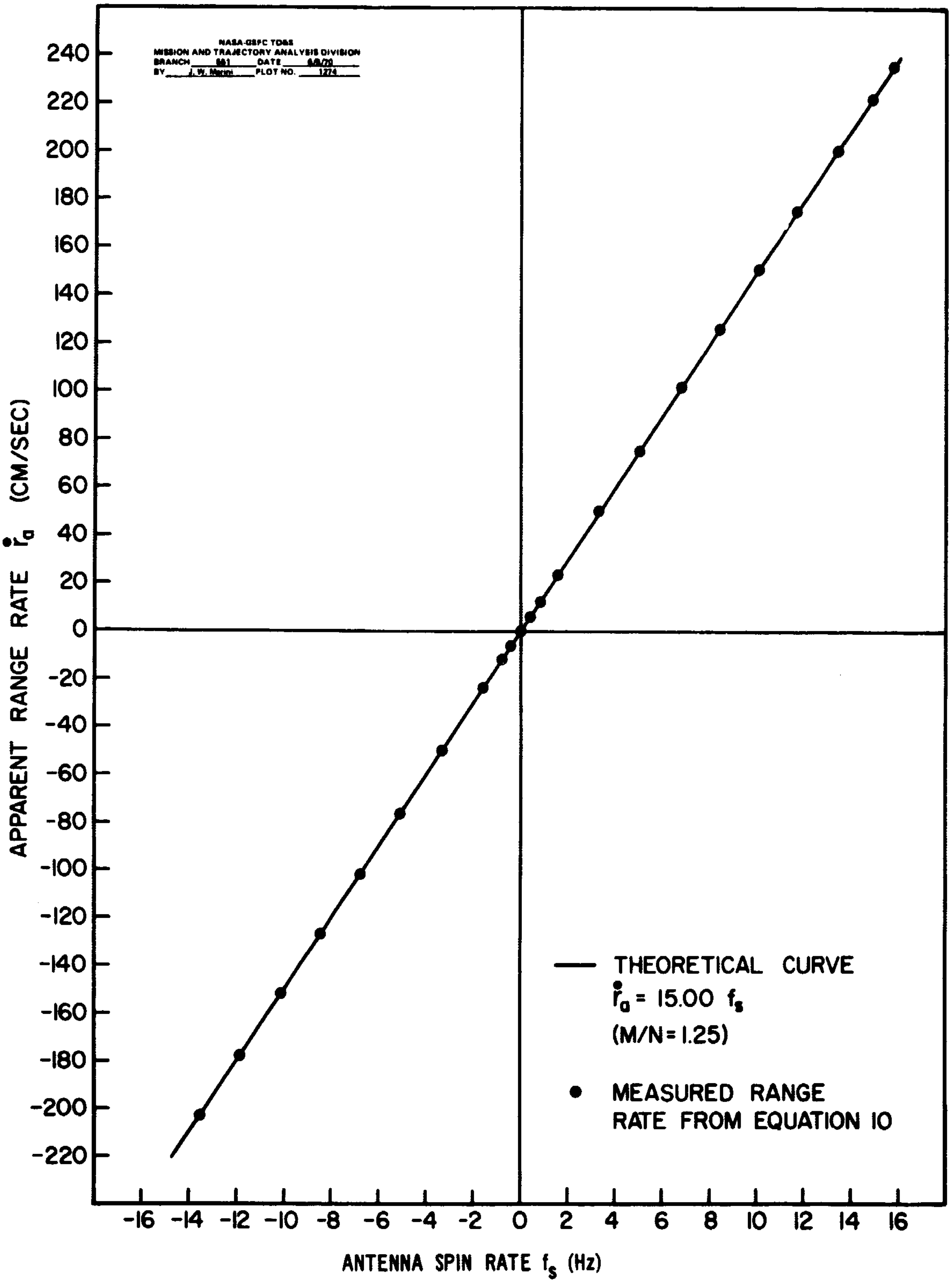

Figure 1. Theoretical vs. Measured Apparent Range Rate, f_t = 1.7992 GHz

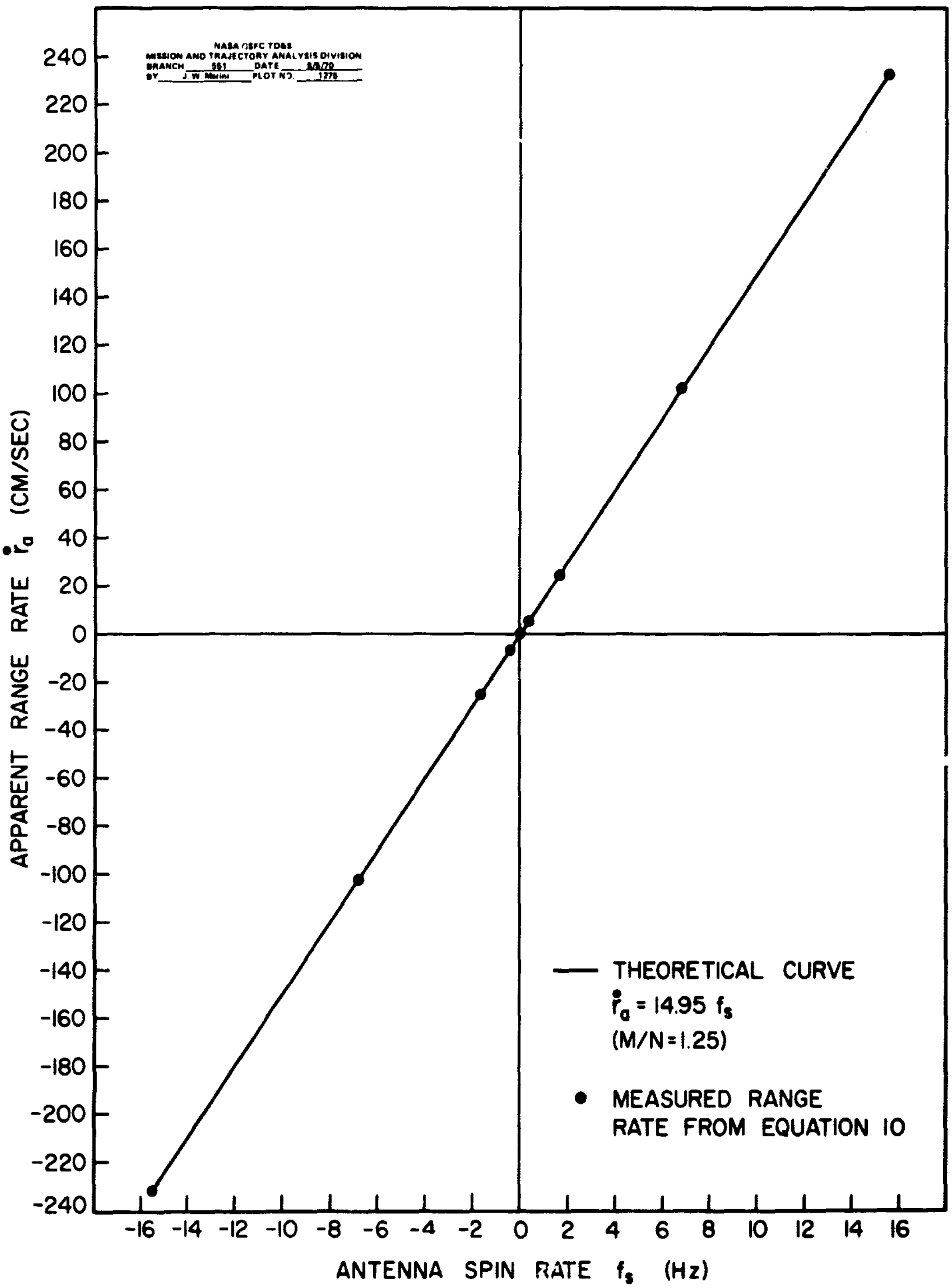

Figure 2. Theoretical vs. Measured Apparent Range Rate, f_t = 1.8052 GHz

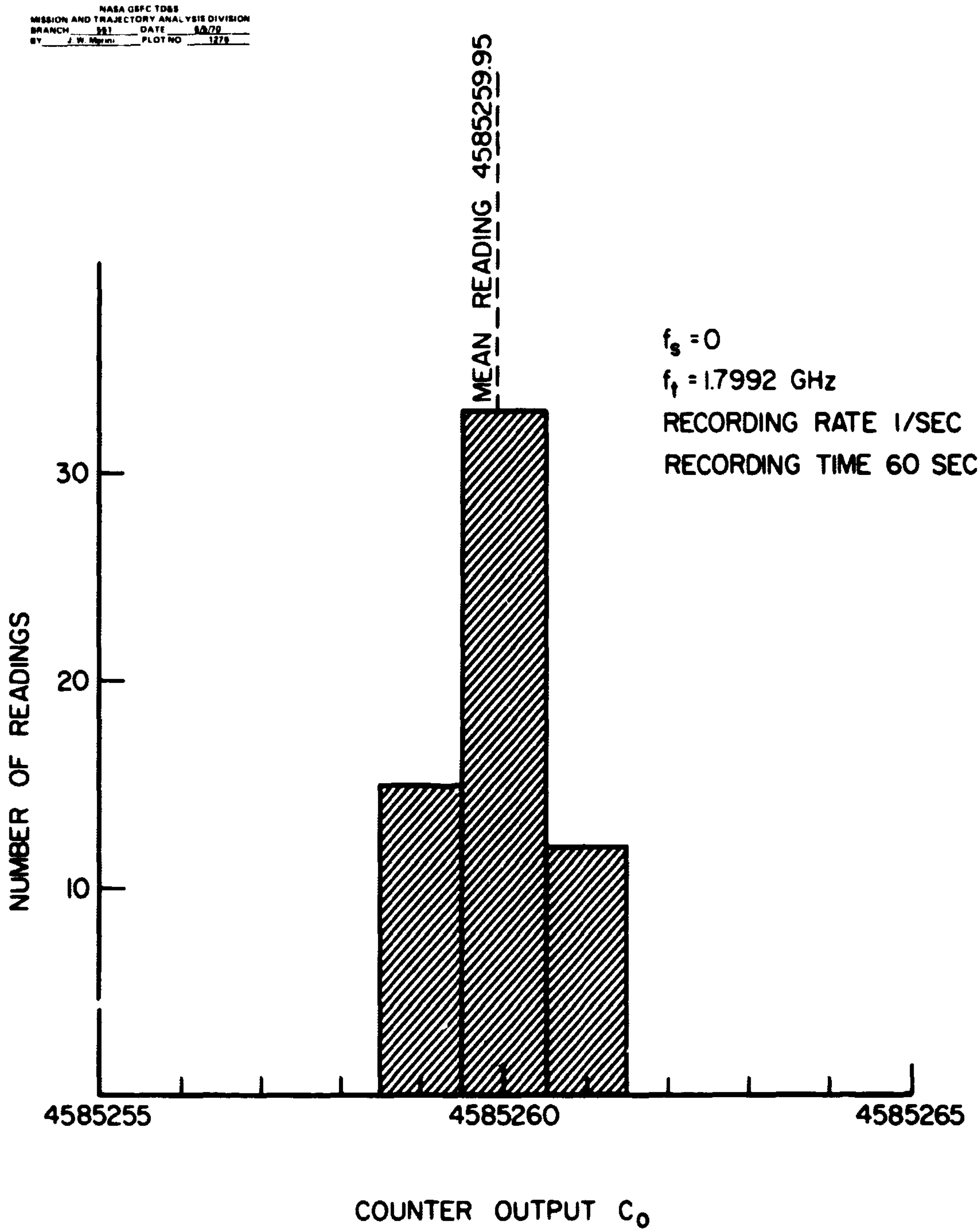

Figure 3. Histogram of Counter Output, $f_s = 0$

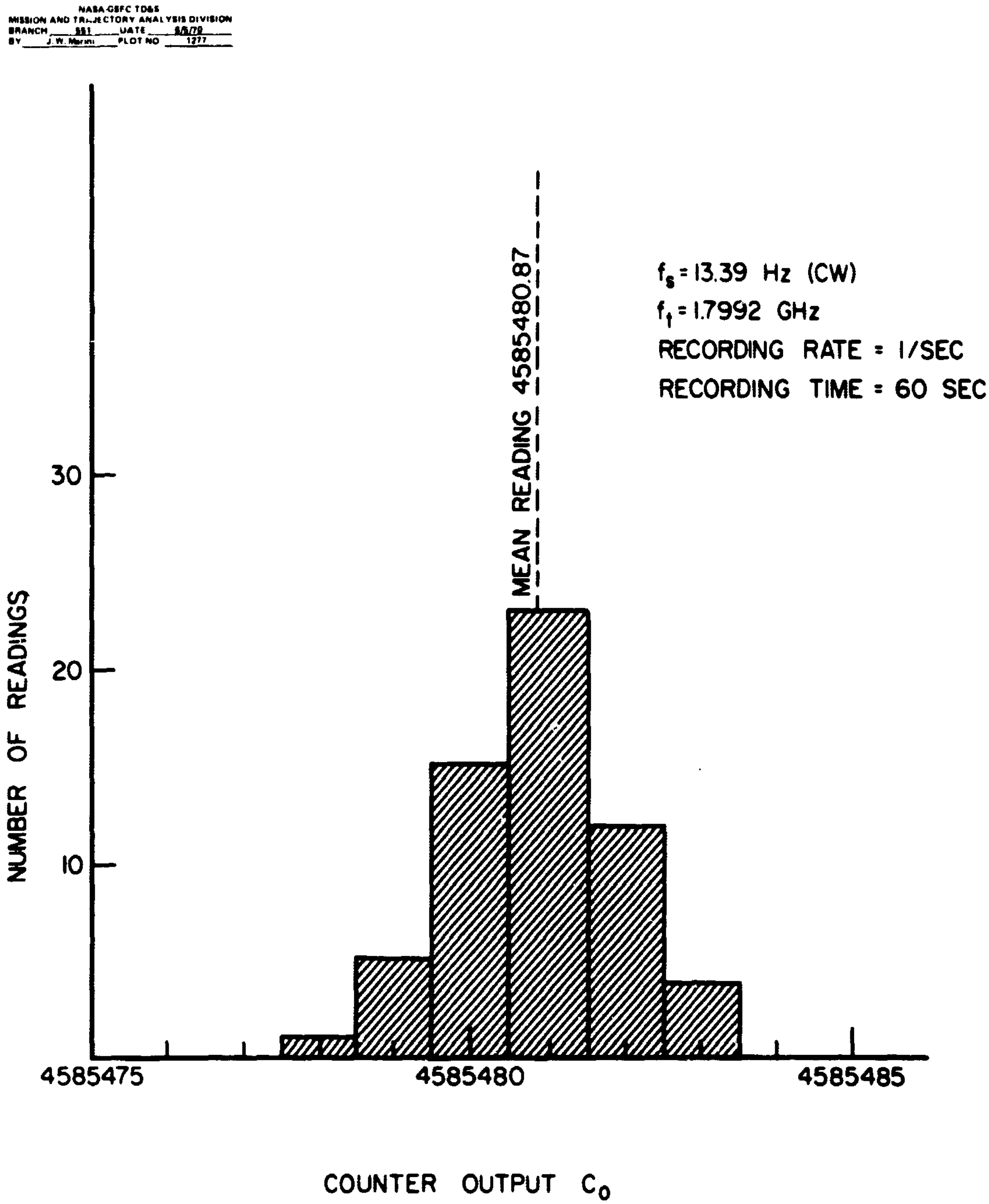

Figure 4. Histogram of Counter Output, $f_s \doteq 800$ r/min

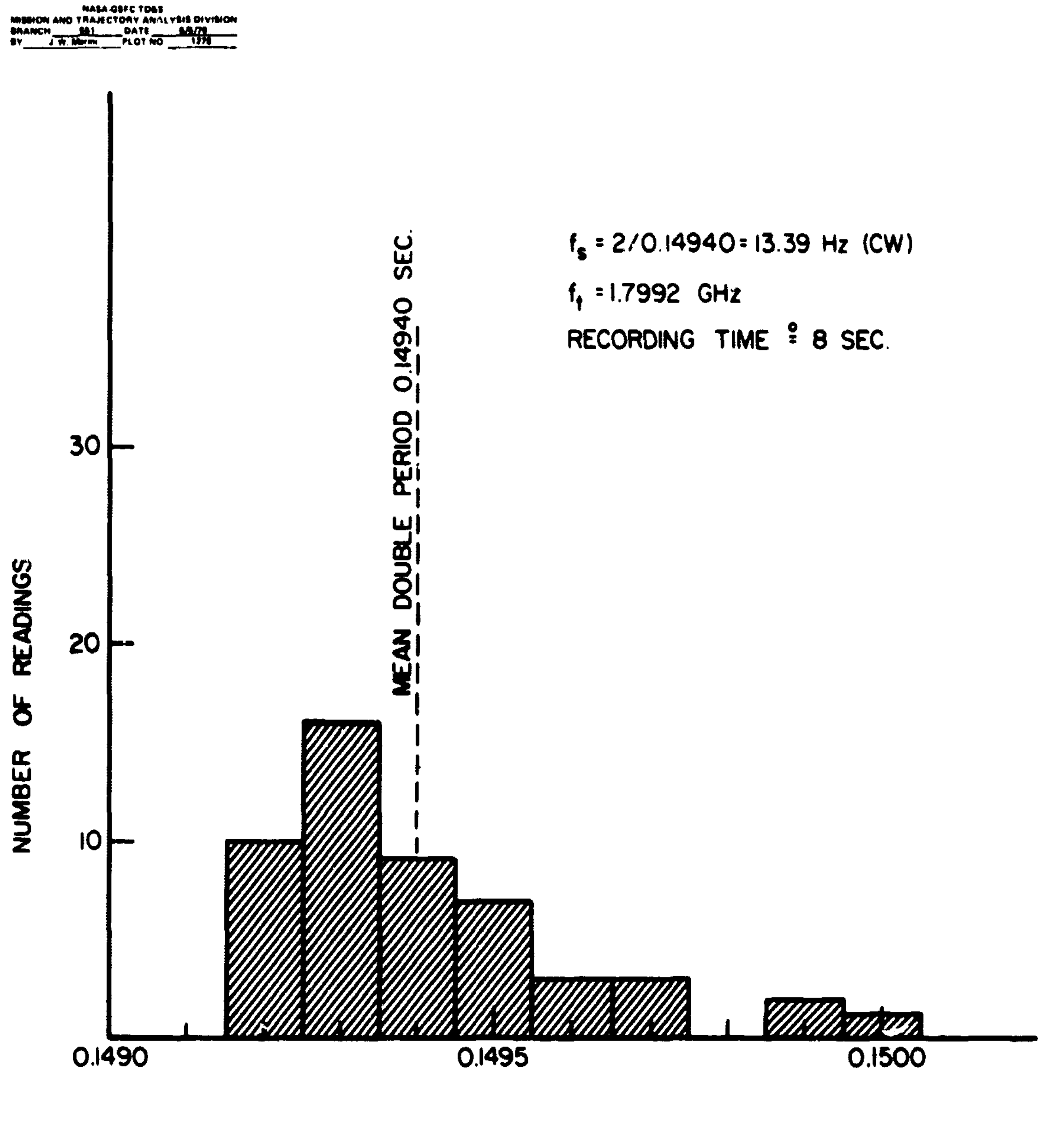

Figure 5. Antenna Rotational Period, f_s ± 800 r/min