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CONTROL SYSTEMS DEVELOPMENT DIVISION

INTERNAL NOTE 74—EG—18

PROJECT SPACE SHUTTLE

GYROFLEX DATA TRANSMITTAL AND DATA ACQUISITION SYSTEM ANALYSIS

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National Aeronautics and Space Administration

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CONTROL SYSTEMS DEVELOPMENT DIVISION

INTERNAL NOTE 74-EG-18

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GYROFLEX DATA TRANSMITTAL AND DATA ACQUISITION SYSTEM ANALYSIS

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ABSTRACT

Data obtained from the evaluation of GYROFLEX gyro, serial number 4778, is presented herein, along with a description of the data acquisition system. In addition, the appendices contain an analysis of the voltmeter used for data collection, and the filtering technique employed.

It is shown that the test setup is satisfactory for testing GYROFLEX gyros.

It is also shown that repeatable data can be obtained, using a digital filter and a one-second voltmeter integration time, which greatly reduces the amount of time required to perform any given test.

There were two problem areas associated with the test setup. Both involved the test table. One is a random error in the table position servo. At times the table goes to the wrong table angle. Data at these positions is rejected. There is also a random error of ±0.5 degrees in the tilt axis setting. The tilt axis readout has been corrected and drift terms effected by this error source are not included in this report. Specifically the DXS and DYS terms in tables 1, 2, and 3 and several CRSX and CRSY terms in table 3.

ACKNOWLEDGEMENTS

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The author would like to thank the personnel at MSFC for providing the Gyroflex gyro for evaluation, especially Mr. Tom Morgan, who handled the paper work and allowed the transfer to take place.

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TABLES

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1.0 INTRODUCTION

This report is a summary of tests performed on GYROFLEX gyro serial number 4778, during the period of February-March 1974. A data transmittal was previously issued on this gyro (ref. 1).

The gyro, obtained from MSFC, is being evaluated under A.D. 540946, "Preparation for Evaluation of Space Shuttle Orbiter IMU Components." Data from this test program is being used to develop a data acquisition system suitable for multiple component testing, and to structure the test procedures for the IMU components test program. It is planned to use a single voltmeter for six gyros and one for the six accelerometers, therefore one of the requirements for the data acquisition system is to be able to obtain data as quick as possible and still maintain good data resolution (0.0001 deg/hr) and accuracy. A discussion of the various test methods used and the data acquisition system, is included in this report.

2.0 DATA ACQUISITION SYSTEM

The data acquisition system, which will be used for all GYROFLEX gyro testing, is based on the Hewlett-Packard 2570 Coupler/Controller and a H.P.9100B calculator. The operation of the coupler can best be described as providing I/O capability for the calculator. Any device (counter, voltmeter, etc.) that is capable of providing BCD formatted digital output can be interfaced with the coupler.

A block diagram of the system, as it is now configured, is shown in figure 1. The following features are included in the system.

- Offline analysis of data, by using the calculator and peripherals
- Real time plots of data, by using the H.P. 581 D/A converter, and H.P. 580 chart recorder.
- Full alphanumeric capability, by using the teletype
- Data stored on paper tape

The basic programs used for the GYROFLEX tested, are listed in figure 1. The program list will be expanded as the need arises.

The present system configuration was achieved only after numerous tests were performed to evaluate several different data collection techniques. The data acquisition system configuration used for these tests is shown in figure 2.

The effect of the following items on data repeatability was of specific interest.

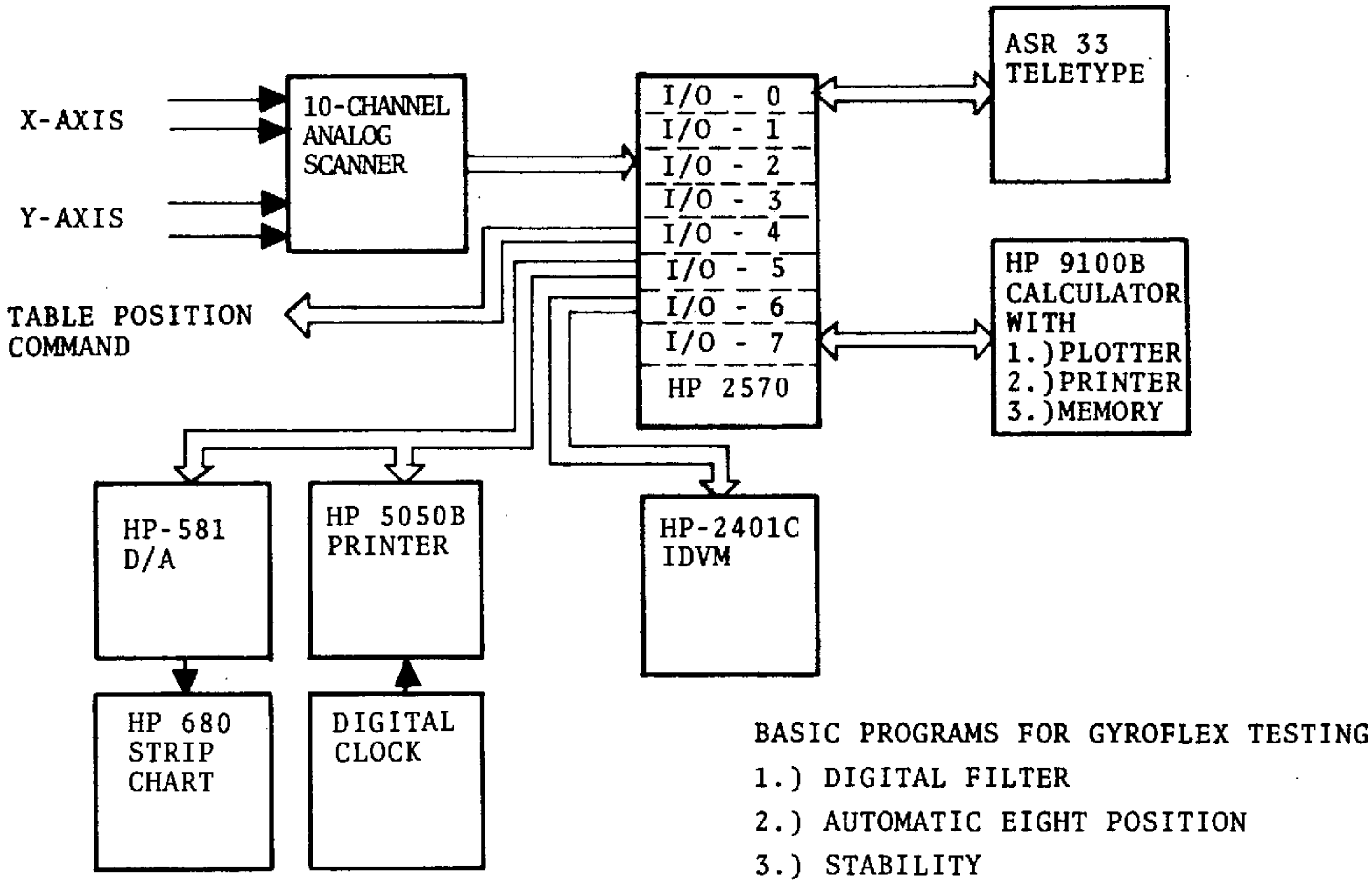


Figure 1. — Data acquisition system.

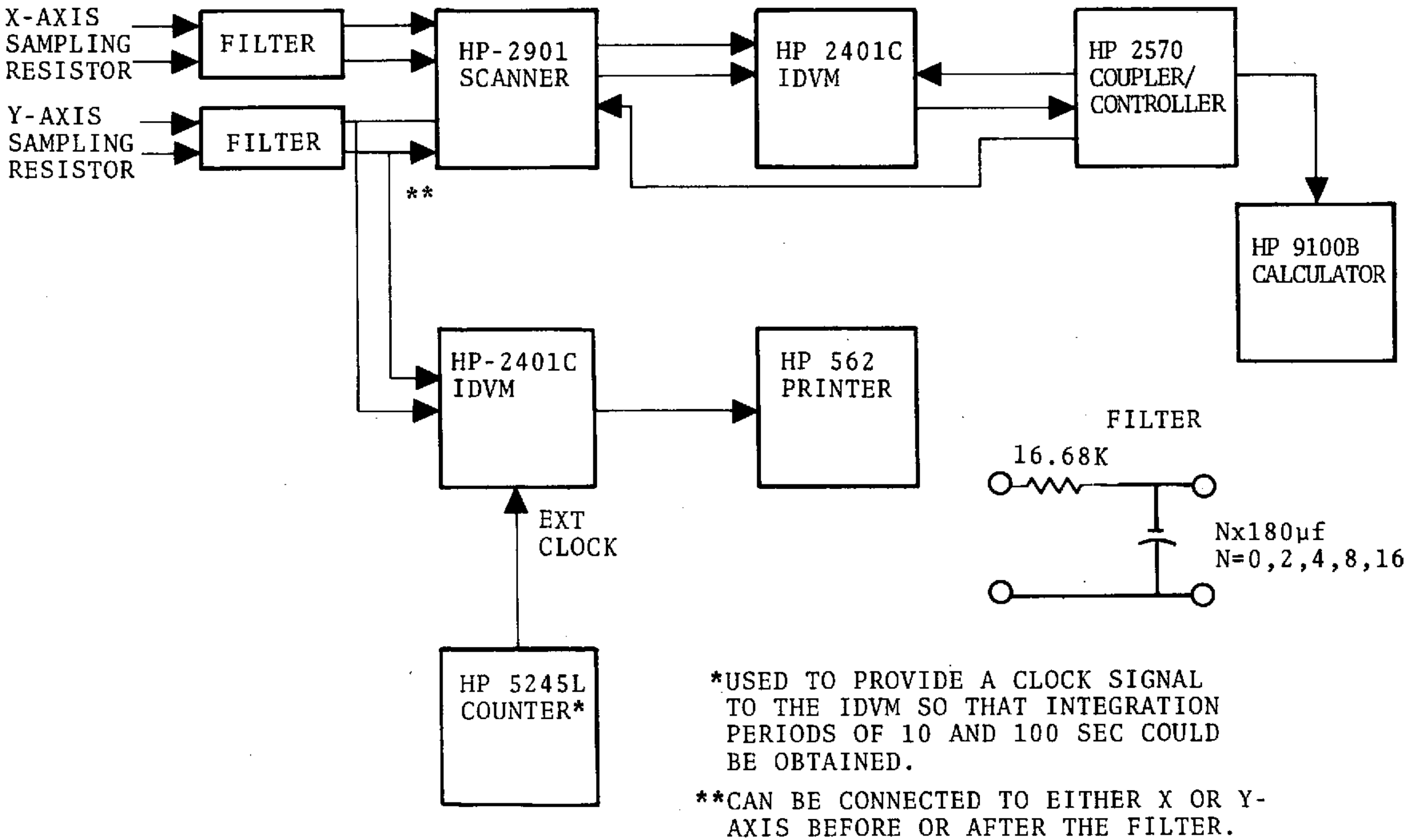


Figure 2. — Data acquisition test setup.

- Voltmeter integration time: 1 sec. versus 10 sec. versus 100 sec.
- Filter bandwidth, steady state error and transient behavior.
- Effect of replacing the analog filter with a digital filter.

Each of the above items are discussed in the following sections.

2.1 EFFECTS OF VARYING VOLTMETER INTEGRATION TIME

The output of the gyro X-axis rebalance loop was measured, using the H.P. 2401C IDVM, and the integration time was changed from 1 second to 10 seconds, and then 100 seconds. The time change was made by using an external clock signal which was derived from the H.P. 5245L counter. No filter was used between the rebalance loop output and the voltmeter.

The data analysis method used was to take the first difference of 21 data points and to compute the standard deviation of these differences. This is a technique that is similar to the technique used in reference 2.

A plot of the standard deviation of the first differences and voltmeter bandwidth versus integration time is shown in figure 3. As indicated on the graph, the bandwidth of the voltmeter is dependent on the integration time used. Frequency response curves for the voltmeter, for several integration times, are shown in Appendix A.

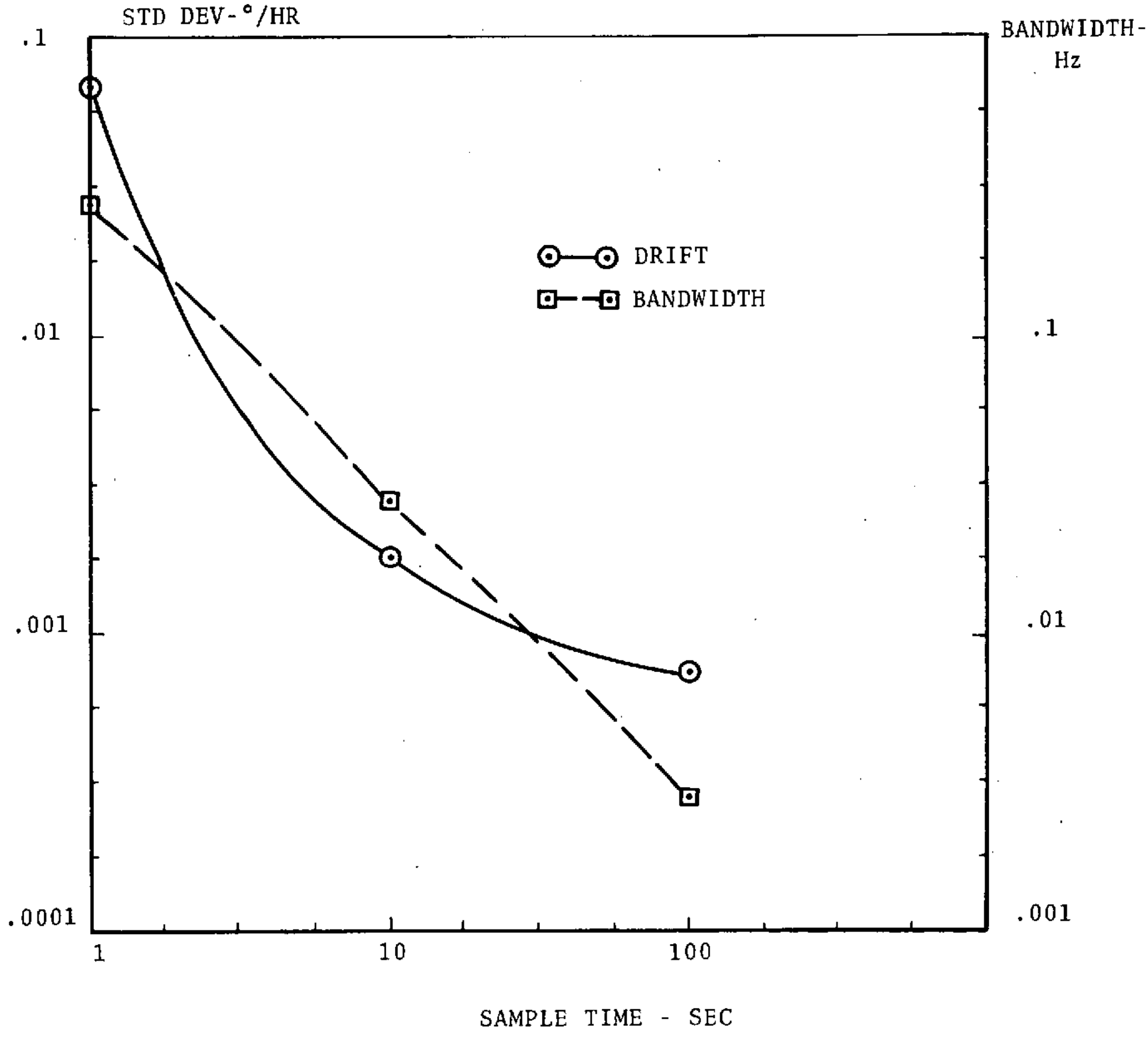


Figure 3. — Effects of varing voltmeter integration time.

Use of an integration time of 100 seconds limits the bandwidth, but good data repeatability and resolution can be obtained. Good data repeatability is necessary for multiposition tests where the average value at each position is required, but for stability tests (random drift tests), a compromise must be obtained between bandwidth and resolution. Severe bandlimiting of the measured gyro output can result in misleading data.

2.2 FILTERING OF THE GYRO OUTPUT

One of the accepted methods of obtaining data is to filter the gyro outputs by adding a filter between the current sampling resistor and the voltmeter (fig. 2). Normally a filter consisting of a single RC time constant of approximately 18 seconds is used.

The filter used for test purposes is shown in figure 2. The number of capacitors was changed by increments of two so the filter time constant was doubled each time. The time constant was varied from zero seconds (N = 0) to 50 seconds (N = 16).

One problem which was immediately obvious was that since a dedicated voltmeter is not used for each gyro axis, there was a transient response associated with switching the scanner from channel to channel. A plot of the transient response of the filter/voltmeter combination which occurs when the voltmeter is connected to the output of the filter is shown in figure 4. There is a transient error and a steady state error due to the filter and voltmeter combination. It should be noted that both of these error sources could be eliminated by using an active filter; however, the effects of amplifier drift and instability would then have to be minimized.

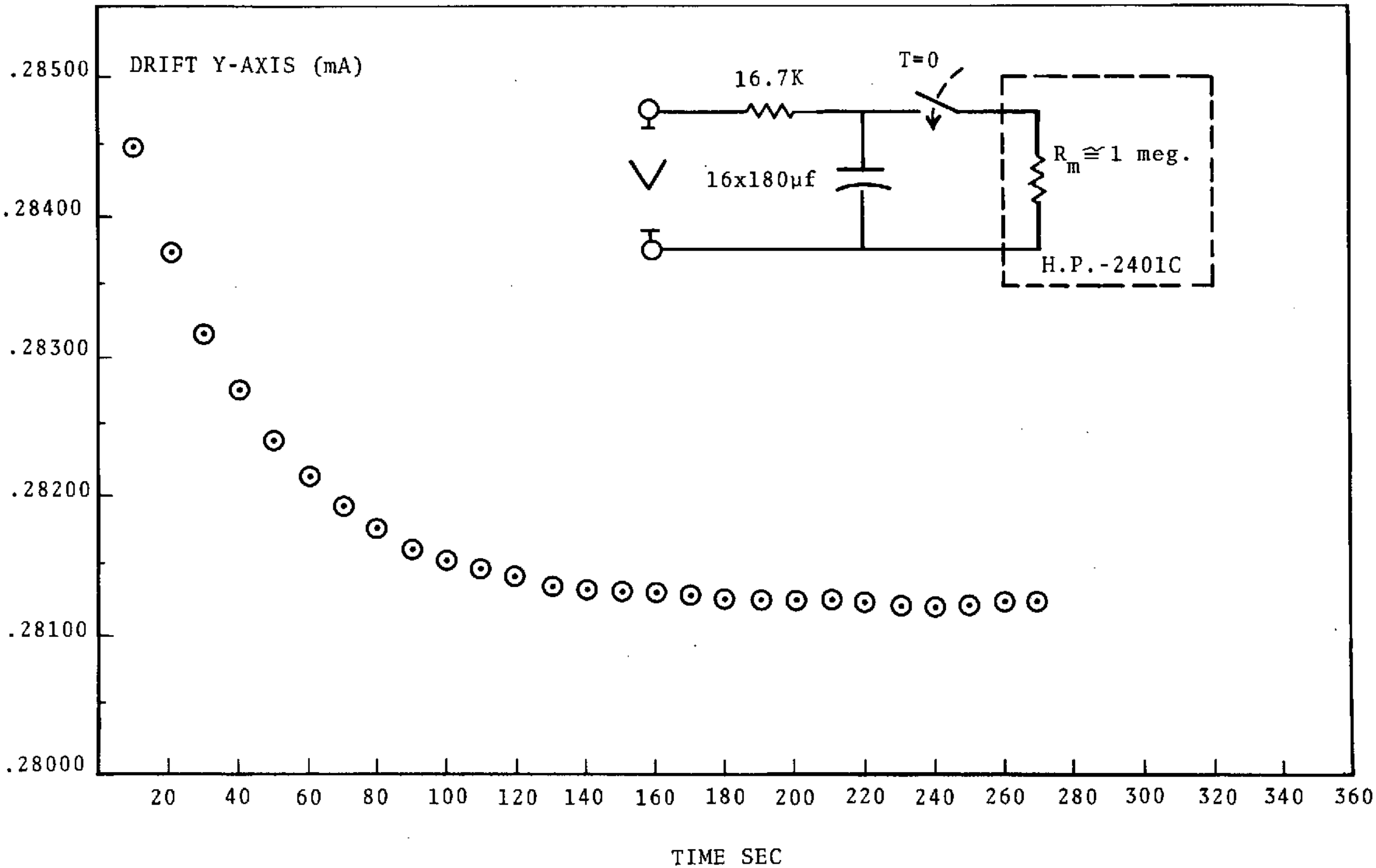


Figure 4. — Filter/voltmeter interaction.

The test procedure was to use two voltmeters; one was used with the calculator system, and one was used with the H.P. 562 printer (fig. 2). The gyro was positioned such that both axes had similar input rates, and then data was accumulated using different filter time constants.

The voltmeter used with the printer was set for a 100 second integration time and the effect of varying the filter time constant was negligible. This can be explained by the fact that for all cases except where $N = 16$ the voltmeter bandwidth is the limiting factor.

The voltmeter on the X-axis was controlled by the calculator, and two tests were performed on this axis. One with a voltmeter integration time of 1 second and one test with the voltmeter set at 0.1 second. The 0.1 second integration time results in the resolution being a tenth of the one second resolution.

The data obtained from the two tests is plotted in figure 5 versus filter bandwidth. The plotted points are the standard deviation of 100 consecutive data points. It is interesting to note that the only loss between the one second data and the 0.1 second data is in resolution. If a resolution of only 10 microvolts can be tolerated, then greater speed can be obtained.

An attempt was made to obtain long term stability data with the filters in the circuit but the filters were not stable. The instability was caused by low quality capacitors. No attempt was made to rectify this since the filters are not going to be used again.

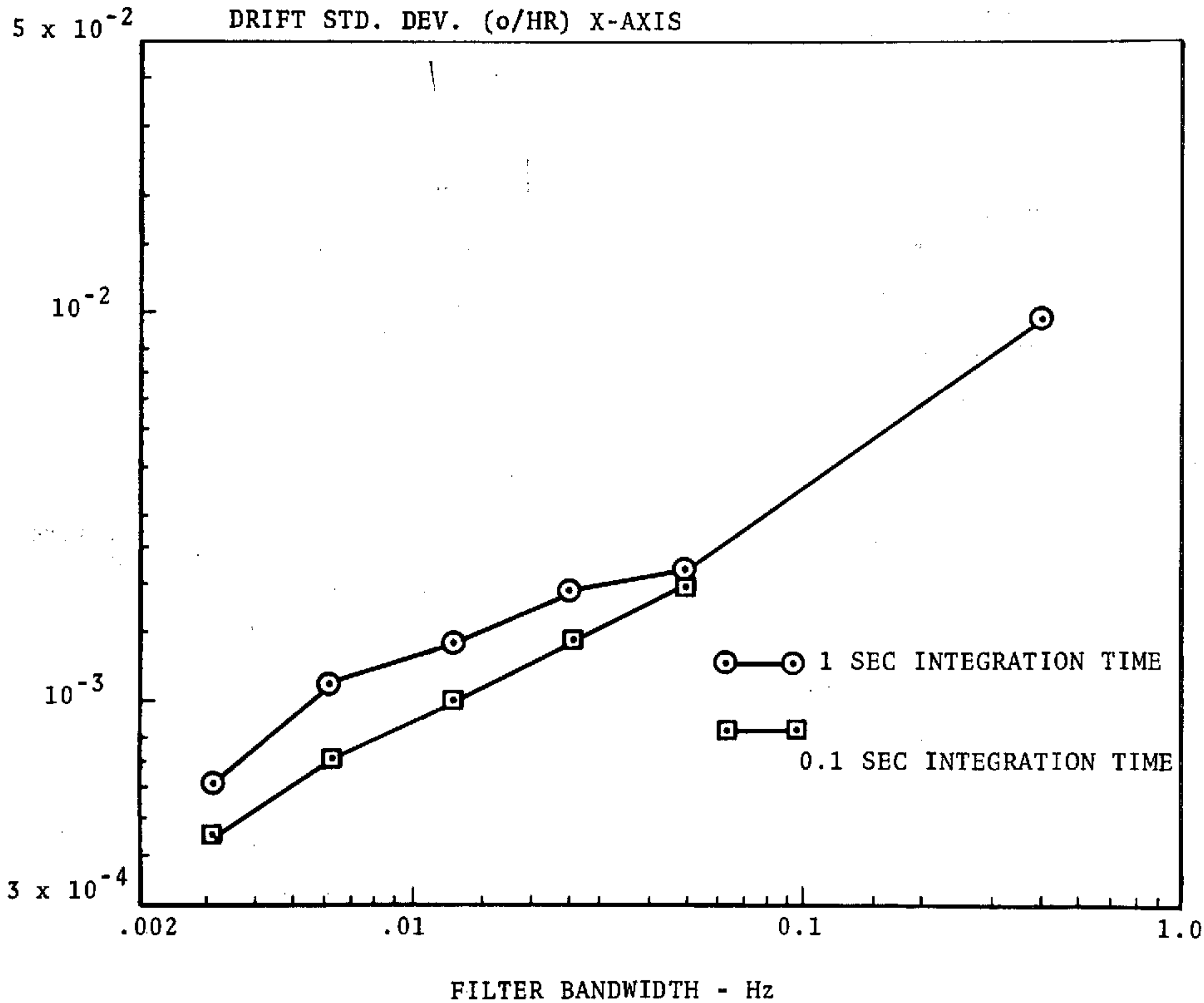


Figure 5. — Drift stability vs. filter bandwidth.

2.3 DIGITAL FILTERING OF THE GYRO DATA

Filtering of the gyro data is desirable but the performance of the analog filters was not considered adequate. The next approach was to program the calculator to filter the data. The design approach, which is documented in appendix B, was to design a digital filter with the same step response as the comparable analog filter.

The analog filter modeled was an RC low pass filter with a single time constant. A comparison of the step response of the analog and the digital filter is shown in figure 6.

The digital filter has several advantages over the analog filter. Several of the advantages are listed below:

- Accuracy – The accuracy of the digital filter is only dependent on the resolution of the calculator.
- Frequency variations – The digital filter frequency response can be changed easily to any frequency desired.
- The need for large capacitor values is eliminated.
- Initial Conditions – A digital filter can be initialized at the expected output value and, hence, eliminate the long settling time required for analog filters with long time constants.

Test results using the digital filter are discussed in section 3.2.

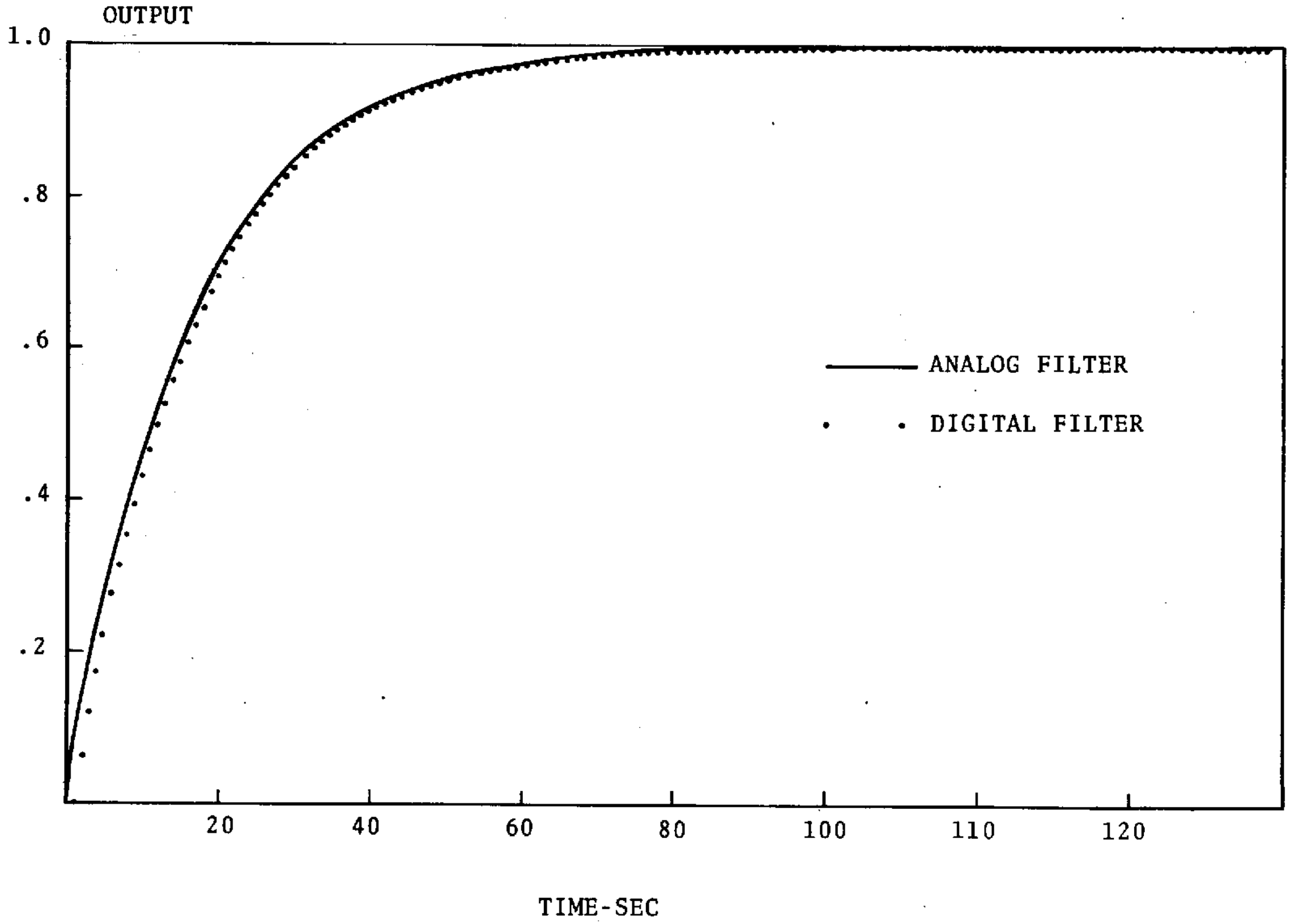


Figure 6. – 0.01 Hz digital filter step response.

3.0 TEST RESULTS

Testing to date has consisted of mainly two types of tests.

- Multiposition tests — Eight positions, four positions SAV and four positions SAH
- Random drift tests — 15 hour stability runs

Particular emphasis is placed on these tests because they are indicative of both gyro and test station performance.

Two methods were employed in performing the multiposition tests. One method used was to accumulate data without using any filters. Then the average and standard deviation were calculated for each position. This method was the most time consuming and was used until the digital filter was designed.

The second method uses the digital filter to filter the data and calculates the average and standard deviation for each position. The drift terms which are calculated from the eight position tests are:

RYX = restraint measured on the Y-axis due to torque about the X-axis

RXY = restraint measured on the X-axis due to torque about the Y-axis

DXAY = drift about the X-axis due to acceleration along the Y-axis

DYAX = drift about the Y-axis due to acceleration along the X-axis

DYS = drift about the Y-axis due to unbalance along the spin axis

DXS = drift about the X-axis due to unbalance along the spin axis

CRSY = command rate sensitivity of the Y-axis torquer

CRSX = command rate sensitivity of the X-axis torquer

Angle = Orthogonality of the X-axis and Y-axis torquer

The DXS and DYS terms are not included in this report and several CRSX and CRSY terms were eliminated in table 3. The reason is that there was an error in the table tilt axis readout of ±0.5 degree. A correction factor could have been used for these terms but it was decided that it would be more appropriate to not include these terms in this report. The problem with the tilt axis readout has since been corrected.

3.1 MULTIPOSITION TESTS USING METHOD ONE

This method was used in reference 1 and can be described as follows. One voltmeter, with an integration time of one second, is used for both axes, and an analog scanner is used to switch between the X and Y axes. One hundred data samples are accumulated in the calculator, and the average and standard deviation are calculated and printed. This process is repeated five to ten times for each position, and the averages are used to represent the gyro output for that position. This method required the most calculator memory and also required the longest time at each position (30-60 minutes).

Table I contains the drift coefficients calculated using this method. The first three tests shown in the table were performed with an analog filter on the Y-axis. This filter, a first order lag filter with a cutoff frequency of 0.01 Hz, is similar to the filter used by Kearfott in their testing.

The filter is responsible for two error sources in the data which have been discussed previously. This is the reason for the higher than normal scale factor on the Y-axis.

3.2 MULTIPOSITION TESTS USING METHOD TWO

An automatic eight position test program was developed which uses the calculator to command the Goerz Test Table and to collect data.

The gyro data is filtered using a digital filter with a bnadwidth of 0.005 Hz. Ten data points are averaged to obtain the drift in each position, however, each data point is spaced 25 data samples apart. The standard deviation of the 10 data samples is compared to a set value, and if the set value is exceeded, that position is repeated. Once the data is classified as good, the average is stored, and the test table is commanded to index to the next position. After eight positions have been completed, the drift coefficients are calculated and printed.

A summary of the test results of the eight position tests using the main torquers is shown in table II. Table III contains the data obtained using the bias torquers. The data indicated by asterisks in the tables were not used in the calculation of the averages and standard deviations. The reason

TABLE I. – GYROFLEX GYRO EIGHT POSITION TESTS BIAS TORQUERS S/N-4778.

DATE	CRSX °/hr/mA	RXY °/hr	CRSY °/hr/mA	RYX °/hr	DXS °/hr/g	DYS °/hr/g	DXAY °/hr/g	DYAX °/hr/g	ANGLE Sec.	COMMENTS
2-19 *	35.5237	-.2471	35.7554	.9113			-.1845	.1567	-57.1	Analog Filter
2-20 *	35.3562	-.2565	35.5656	.8975			.1791	.1531	-56.4	On Y-Axis Over-
2-21 *	35.5317	-.2515	35.7555	.9080			-.1792	.1534	-77.9	Night Cooldowns
2-25	35.5302	-.2488	35.0596	.8999			-.1816	.1839	-36.8	No Filter,
2-26	35.5318	-.2474	35.057441	.9066			-.1839	.1842	-60.4	Cooldowns
2-27	35.5330	-.2498	35.0609	.9104			-.1760	.1829	-40.8	Only On
2-28	35.5364	-.2516	35.0639	.9030			-.1840	.1867	-49.2	Weekends
3-1	35.5353	-.2483	35.0650	.9138					-42	Four
3-11	35.5343	-.2421	35.0675	.9189			-.1839	.1869	-73	Position
3-12	35.5317	-.2476	35.0680	.9163			-.1909	.2046	-37	Test
Avg.	35.5332	-.2479	35.0631	.9098			.1834	.1882	-48.1	
1σ	.002	.0029	.004	.007			.0047	.0082	13.7	
N	7	7	7	7			6	6	7	

* These tests were not used in the average or standard deviation calculations

TABLE II. — GYROFLEX EIGHT POSITION TESTS MAIN TORQUERS S/N-4778

DATE	CRSX °/hr/mA	RXY °/hr	CRSY °/hr/mA	RYX °/hr	DXS °/hr/g	DYS °/hr/g	DXAY °/hr/g	DYAX °/hr/g	ANGLE Sec.
3-20	107.7118	¯.2616	107.5530	.9339			¯.18746	.1674	+429.7
3-20	107.7138	¯.2740	107.5465	.9142			¯.1821	.1708	+416
3-20	107.6958	¯.2533	107.5382	.9072			¯.1821	.1742	+480
3-21	107.7072	¯.2576	107.5031	.9083			¯.1824	.1654	+575
3-21	107.6911	¯.2642	107.5539	.9222			-2.625*	.16855	+418
3-21	107.6924	¯.2595	107.5366	.9179			¯.1816	.1700	+467
3-22	107.7548	¯.2674	107.5699	.9034			¯.1865	.1699	+294*
3-22	107.7204	¯.2681	107.5443	.9096			¯.1824	.1645	+407.8
3-31	107.6887	¯.2628	107.5312	.9090			¯.1839	.1673	+453
Avg.	107.7084	¯.2631	107.5418	.9139			.1835	.1686	+437.6
1σ	.021	.006	.018	.009			.0022	.0029	74.4
N	9	9	9	9			8	9	9

*This data is not used in the average or standard deviation calculations.

TABLE III. – GYROFLEX EIGHT POSITION TESTS BIAS TORQUERS S/N-4778

DATE	CRSX °/hr/mA	RXY °/hr	CRSY °/hr/mA	RYX °/hr	DXS °/hr/g	DYS °/hr/g	DXAY °/hr/g	DYAX °/hr/g	ANGLE Sec
3-25	35.5349	-.2568	35.0622	.9058			-.1878	+.1957	-70.04
3-25	35.5257	-.2567	35.0574	.9201			-.1847	+.1887	-.08
3-26	35.5272	-.2565	35.0649	.9111			-.1812	.1885	-39.7
3-26	35.5335	-.2554	35.0656	.9162			-.1854	.1894	-25.5
3-27	35.5299	-.2667	35.0610	.9209			-.1858	.1872	-43.2
3-27		-.2620		.9124			-.1856	.1861	+45.6
3-27	35.5312	-.2645	42.8035*	3.99*			-.1829	.2277*	+74938*
3-28	35.5307	-.2623	35.0642	.9075			-.1818	.1878	-44.3
3-28	35.5292	-.2572	35.0538	.9033			-.1853	.1910	+20.7
3-28		-.2594		.9085			-.1831	.1864	-75.5
4-1		-.2526		.9018			-.1839	.1885	-70.1
4-1	35.5345	-.2677	35.0683	.9013			-3.0656*	.1906	-11
4-2	35.5321	-.2620	35.0654	.9119			-.1830	.1873	-17.4
4-2	35.5341	-.2603	35.0649	.9088			-.1843	.1871	-77.3
4-3	35.5321	-.2484	35.0700	.9179			-.1861	.1905	+42.9
4-3	35.5337	-.2573	35.0616	.9115			-.1807	.1915	-41.4
4-3		-.2517		.9155			-.1833	.1872	-37.1
4-4		-.2571		.9111			-.1815	.1899	-19.9
4-4	35.5322	-.2511	35.0631	.9218			-.1882	.1868	-37.9

TABLE III. — GYROFLEX EIGHT POSITION TESTS BIAS TORQUERS S/N-4778 (Concluded).

DATE	CRSX °/hr/mA	RXY °/hr	CRSY °/hr/mA	RYX °/hr	DXS °/hr/g	DYS °/hr/g	DXAY °/hr/g	DYAX °/hr/g	ANGLE Sec.
4-5	35.5367	-.2603	35.0651	.9228			-.1848	.1880	-46.5
4-5	35.5318	-.2586	35.0590	.9195			-.1862	.1887	-98.9
Avg.	35.5312	-.2583	35.0631	.9119			-.1842	.1888	-32.3
1σ	.003	.0049	.0041	.0066			.0020	.0022	38.5
N	16	21	15	20			20	20	20

*This data is not used in the average or the standard deviation calculations.

for this is that, at times, the test table locks onto the wrong position, and therefore the data for that position is not usable.

A summary of the random drift tests performed using the digital filter is shown in table IV. The tests are all overnight runs (approximately 16-17 hours), and the filter bandwidth and table position are as indicated. The test procedure was to print the output of the filter once every 1,000 data samples (approximately once every 30 minutes).

3.3 FREQUENCY SENSITIVITY TEST

This test was performed with the Y-axis East-West, and the X-axis North. Gyro drift was measured at three different wheel excitation frequencies; 480 Hz which is the normal operating frequency, 500 Hz, and 460 Hz. The drift rate change versus wheel frequency was calculated from the data. The values were as follows:

X-axis -0.027°/hr/10 Hz

Y-axis 0.205°/hr/10 Hz

Both axes are within the specification of 0.4°/hr/10 Hz.

At the present time, a total of 2617.25 wheel hours have been accumulated at JSC on gyro serial number 4778.

TABLE IV. — GYROFLEX RANDOM DRIFT STANDARD DEVIATION — °/hr S/N-4778.

DATE	X-AXIS °/hr	Y-AXIS °/hr	TORQUER	COMMENT
3-18	.012	.004	Main	X-East .025 Hz Digital Filter Y-Up
3-19	.0035	.0079	Main	Y-East .003 Hz Digital Filter X-North
3-20	.0065	.0043	Main	X-Down, Y-east.003 Hz Digital Filter 0.1 Sec Sample Time
3-21	.0051	.0047	Main	X-Down .025 Hz Digital Filter Y-East
3-26	.0045	.0033	Bias	X-Down .025 Hz Digital Filter Y-East
3-27	.018	.0035	Bias	X-Down .025Hz Digital Filter Y-East
4-1	.0038	.0035	Bias	X-Down .025 Hz Digital Filter Y-East
4-2	.0029	.0021	Bias	X-Down .025Hz Digital Filter Y-East
4-3	.003	.0038	Bias	X-Down .025 Hz Digital Filter Y-East
4-4	.0067	.0077	Bias	X-Down .025Hz Digital Filter Y-East

4.0 CONCLUDING REMARKS

The day to day stability, and the repeatability of tests performed on the same day, indicates that the test setup is adequate for testing GYROFLEX gyros.

At the present time, gyro serial number 4800, which was obtained from MSFC, is being evaluated. Both gyros will be tested on the Precision Torque Measuring System (PTMS) to obtain data on the wheel run-up, and run-down, torque characteristics. Now that the table tilt axis readout problem has been corrected, several more multiposition tests will be performed on Gyro S/N-4778 to determine the DXS and DYS drift terms.

5.0 REFERENCES

1. Peckham, C.: GYROFLEX s/n-4778 Data Transmittal, LEC Memo No. GC-5409-136, February 12, 1974.

2. Gates, Robert L.: Trim-A Gyromonitor IMU Incorporating the GYROFLEX Gyro AIAA Paper No. 70-1012.

APPENDIX A

FREQUENCY RESPONSE OF A FINITE TIME INTEGRATOR

A

The transfer function of the H.P. 2401C Integrating Voltmeter can be represented by:

$$V_o(t) = \frac{1}{T} \int_o^T V_i(t)dt \qquad \text{(A-1)}$$

Where T is the integration period, $V_o(t)$ is the output voltage, $V_i(t)$ is the input voltage.

Taking the Fourier Transform of A-1,

$$\frac{V_o(\omega)}{V_i(\omega)} = \frac{\text{Sin } \omega T/2}{\omega T/2} e^{-j \omega T/2} \qquad \text{(A-2)}$$

Figure A-1 is a plot of the magnitude of A-2 for $T = 1$ sec., 10 sec., and 100 sec. The dotted line on the graph is the -3 dB level. The intersection of this line with the frequency response is the bandwidth of the voltmeter. Note that the frequency response curves in figure A-1 are the same as the frequency response of a zero order hold; therefore, the voltmeter can be represented as an A/D converter consisting of a sampler and a zero order hold.

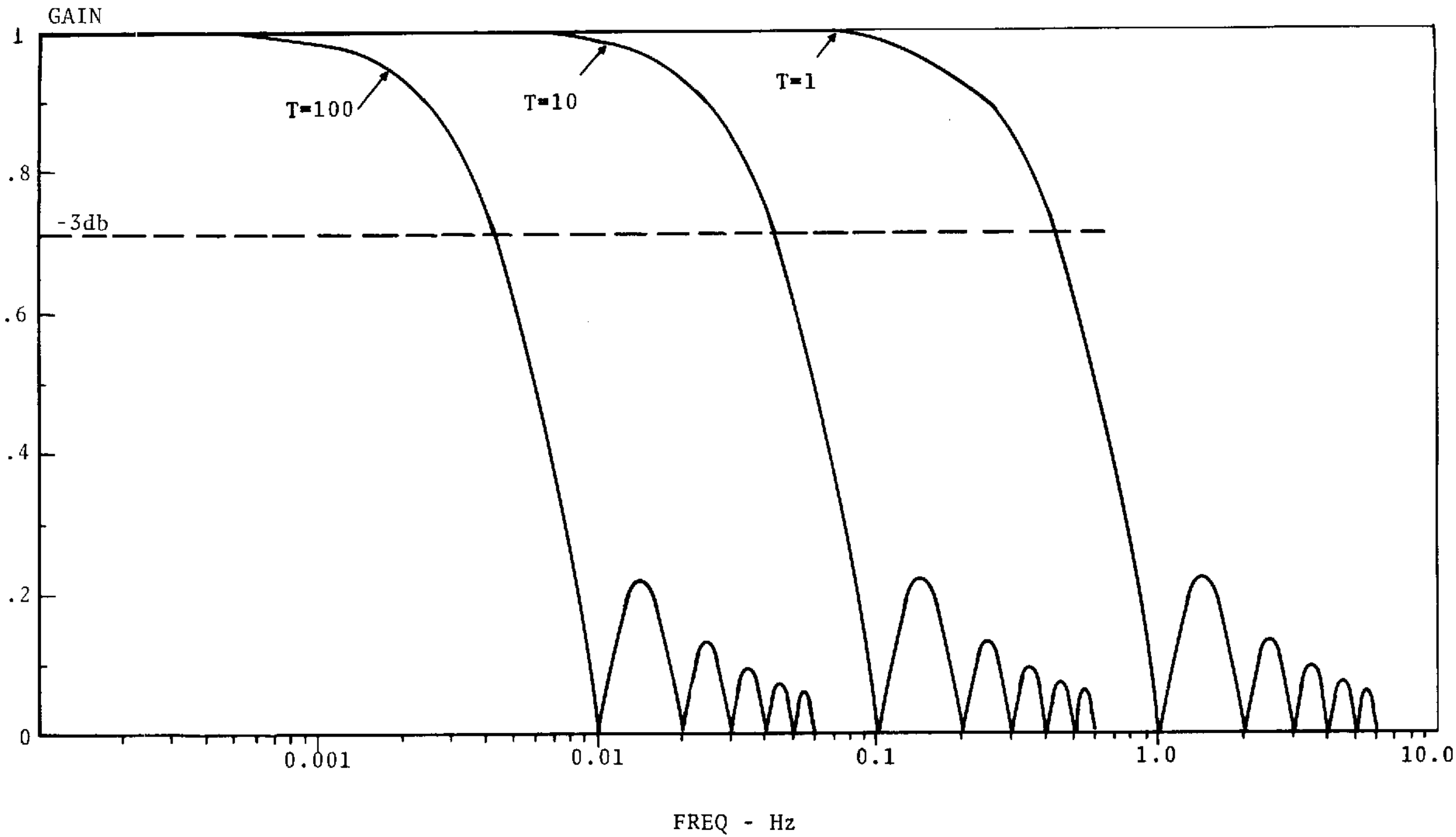


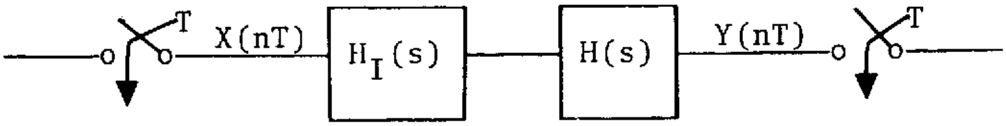
Figure A-1. – AP-2401 voltmeter frequency response.

APPENDIX B

DIGITAL FILTER DESIGN

B

The block diagram of the digital filter is:



Where $H(s)$ is the analog filter begin designed and $H_I(s)$ is the input approximator which is a zero order hold in this case. For one gyro, each axis is sampled once every two seconds. Therefore, $T = 2$. The filter being designed is a first order low pass with the following transfer function.

$$H(s) = \frac{a}{s + a}$$

with

$$a = 2\pi f_c$$

Therefore, the overall transfer function is

$$H_I(s)\ H(s) = \frac{1 - e^{-sT}}{s} - \frac{a}{s + a}$$

The z-transform of the above is:

$$\frac{Y(nT)}{X(nT)} = H(z)\ H_I(z) = \frac{(1 - e^{-aT})\ z^{-1}}{1 - e^{-aT}\ z^{-1}}$$

This equation can be written in the form of a difference equation as:

$$Y(nT) = (1 - e^{-aT})X[(n - 1)T] + e^{-aT}Y[(n - 1)T]$$

This equation requires only four storage locations in the calculator; two for the constants and two for the input and output values. For one gyro using the same filter time constant for each axis, six storage locations are required.

The frequency response of the filter with a cutoff frequency of 0.01 Hz is shown in figure B-1.

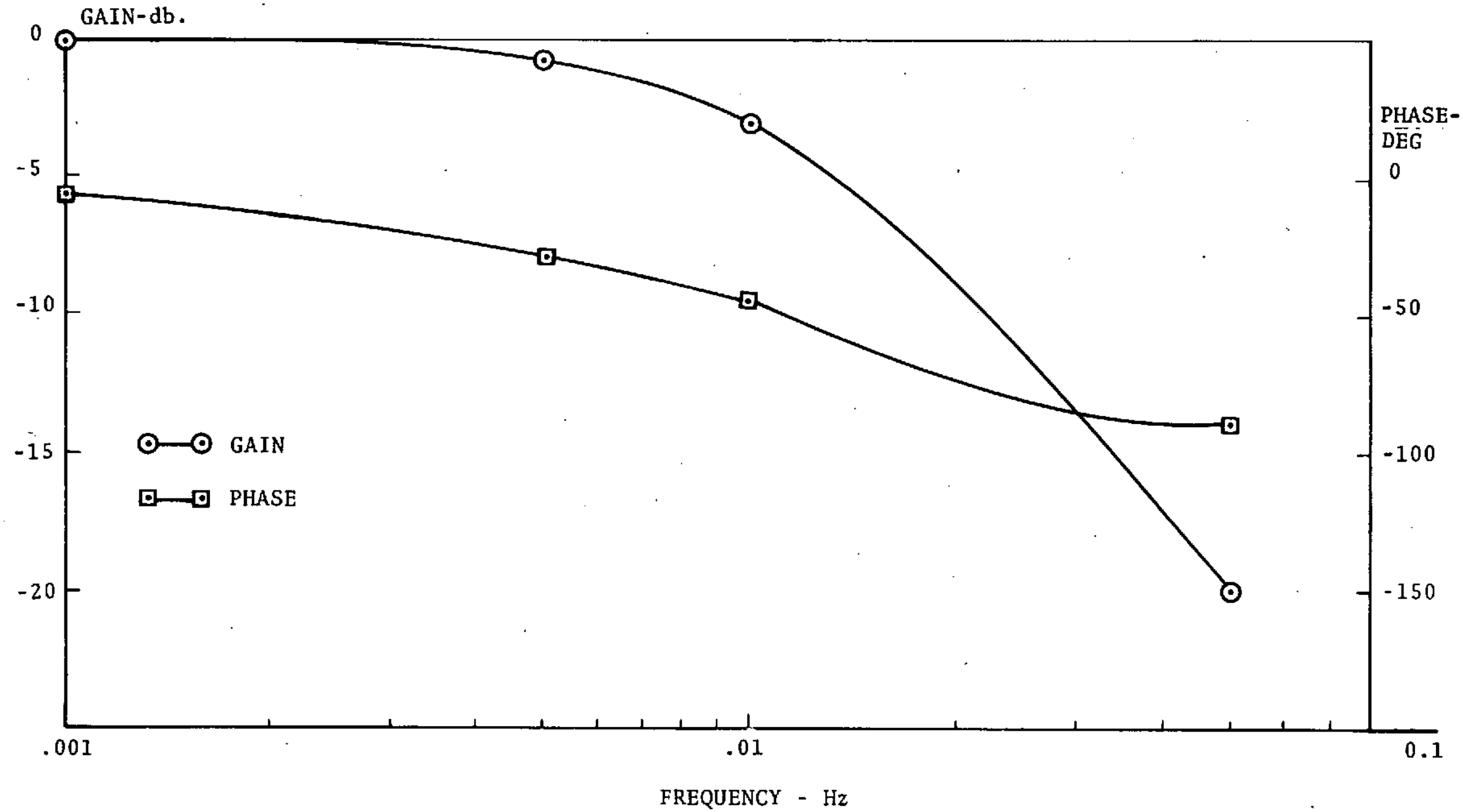


Figure B-1. – .01 Hz digital filter frequency response.

NASA-JSC