Angle Tracking Analysis and Test Development for the Integrated Stations

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An analysis and test development have been completed for the integrated tracking system. An antenna servo model was developed and its transfer function and gain constants are presented. The model was used to simulate the response of the antenna for the autotrack and program modes. These simulation results are compared with the data collected at the Pioneer site and the differences between the two modes are shown. Antenna response data for the integrated servo system are compared with the Echo site response data and DSIF servo specification curves. The servo specification curves are shown to be unrealistic for either the standard or integrated angle tracking systems.

I. Introduction

The integrated site tracking systems (DSSs 11, 42, and 61) have been analyzed and modeled. From the analysis, test software and procedures have been developed. The analysis and test design were done with two goals in mind. First, the test was used to evaluate the equipment just coming into service. Secondly, the same test will serve as a tool for regular maintenance and prepass countdown tests. In order to achieve these goals, several tasks were undertaken.

First, documentation was collected on the Angle Tracking System. This documentation was studied and from this the system was broken down into functional blocks. From these functional blocks, a model was developed, and simulations were conducted. Since the performance specifications for the antenna servo system were either nonexistent or vague, the model was used to establish realistic, definitive performance specifications.

An XDS 910 computer program was developed to monitor the response of the antenna servo system to a step input. This program was essentially a modification of the software that was written for the standard 26-m-diameter antenna sites (Ref. 1). The modified program is different from the original 26-m test program in that it does not command the antenna, and that it receives the antenna position from the high-speed data line instead of directly from the angle encoders. Except for these two differences, the sampling program is the same for both the standard DSIF sites and the integrated sites.

A secondary task was undertaken which complemented the previously mentioned efforts. The test program for the integrated site tracking system can output a paper tape that contains the antenna response to a step input as measured by the angle encoders. A program was written that writes the paper tape on a magnetic tape for processing by the UNIVAC 1108. The processing program has the same processing routines as the test program and also contains routines for plotting the various types of data. In this way angle servo data from the various sites can be processed and compared.

II. Angle Tracking Analysis and Model

A detailed angle tracking model was developed for the integrated sites. The model was developed under the assumption that the response of the angle tracking system was dominated by the servo electronics and inertia and friction of the antenna assembly. A functional block diagram of the servo system is shown in Fig. 1.

The isolation amplifier converts all input voltages to represent 10 volts/degree. This amplifier accepts input from the antenna position programmer or Magic "T" assembly of the antenna as well as manual commands. The isolation amplifier outputs to the position integrator.

The position integrator is a variable filter that determines how high a frequency will be allowed to affect the servo electronics. The frequency filtering is determined by the bandwidth selection switch located on the servo control console. This low-pass filter has as its cutoff frequencies 1.0, 0.5, 0.25, and 0.12 Hz. The position integrator outputs to the rate error junction which inputs to the rate integrator.

The rate integrator is the true integrator of the servo electronics. It is the location of the integrator, following the rate error junction, that makes the integrated servo electronics noticeably different from the standard DSIF servo electronics. The location of the integrator gives the integrated servo electronics more stability since the rate feedback loop will have better control over low-frequency poles. The output of the rate integrator is applied to the antenna through the servo valve, motor, and gear reducers.

The antenna characteristics block represents the most difficult part of the model. It was quickly determined that it would be too difficult to model the mechanical dynamics of the antenna in detail because of the complexity involved. Therefore, the mechanical characteristics model was developed with a pole that is determined by the antenna inertia to antenna friction ratio. A gain constant and zero were added, with the help of a root locus program. When this representation of the antenna dynamics was added to the model, the response then closely matched that of the actual antenna response. Figure 2 shows a detailed block diagram of the servo system and the *Appendix* gives the transfer functions and units of gain that were developed for the simulations.

III. Results From DSS 11

Tests were performed at DSS 11. The data from these tests were compared to the simulated data, data from DSS 12, and DSIF servo specifications. In addition a comparison was made between the servo modes at DSS 11. Figure 3 is a comparison of a DSIF step response servo specification (DOA-1146-DTL) to a standard and integrated station servo step response (DSS 12 and DSS 11, respectively). Table 1 is a comparison of several performance parameters for a standard and integrated station. It can be seen from Fig. 3 and Table 1 that, for approximately equal noise bandwidths, the integrated servo out performs the standard servo in all categories. This superior performance is due mainly to the fact that the integrator was moved inside the rate loop.

Figure 3 shows that although the integrated servo out performs the standard, it does not meet or out perform the DSIF response specification curve, with the exceptions of overshoot and settling time. The DSIF response specification curve represents a system that has much more gain than either the integrated or standard tracking systems have exhibited. Thus, the DSIF servo system response specifications are not realistic, and they should be changed so that station personnel will have realistic specifications to guide them in the operation and maintenance of the antenna servo systems.

The antenna was tested in both the autotrack and program modes. The autotrack uses the antenna's magic "T" and error channels in the receivers to determine the error signal for the servo electronics. Error signals in the program mode are determined through digital hardware in the Antenna Position Programmer (APP). This is accomplished by the APP by reading the angle encoders, subtracting this angle from a commanded angle and applying the difference, through D/A converters, to the servo electronics. It can be seen that there is a noticeable difference between the two modes (see Fig. 4). The simulations show (Figs. 5 and 6) that the autotrack or APP mode can be simulated by varying the gain of the servo electronics. This apparent difference in system gain is tentatively being attributed to a higher gain of the receiver.

IV. Summary

A model test software and test procedure have been developed for the integrated tracking stations. These are being used as acceptance tests as each of the integrated stations becomes operational. Later, when the stations become operational, the test procedure and program will be used to determine system performance and prepass readiness. In order to help with determination of realistic operating parameters, data will be collected from each of the integrated tracking stations and comparison made between the stations. There are plans to add angle jitter analysis and error coefficient calculations to the test program in the near future.

Reference

1. Rey, R. D., "Angle Tracking Analysis and Test Development," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. VI, pp. 170–187. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1971.

Table 1. Comparison of servo system step response for the integrated and standard stations[a]

DSS	BW setting, Hz	Gain setting	Overshoot, %	Settling time, s	Rise time, s	Delay time, s	Noise BW, Hz	−3-dB BW, Hz	Gain margin, dB	Phase margin, deg
11	0.12	0	22.35	41.03	9.00	7.68	0.04908	0.03689	−20.67	48.95
12	0.025	5	57.01	108.92	14.88	13.68	0.04175	0.01630	−7.77	35.81

[a]BW settings of 0.12 and 0.025 are equivalent bandwidth settings for these two different systems.

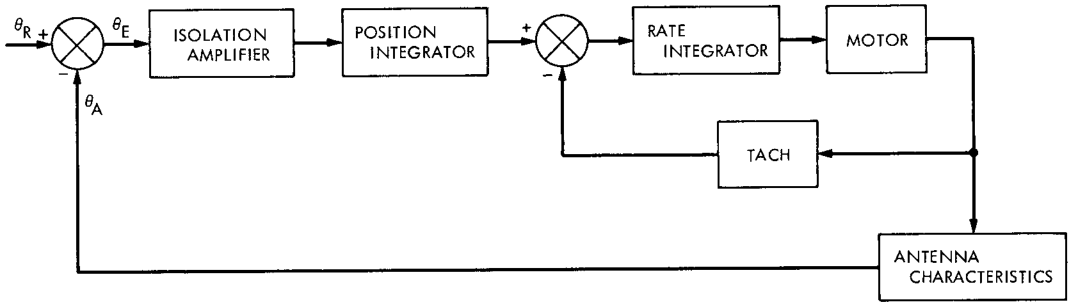


Fig. 1. Functional block diagram of the integrated servo system

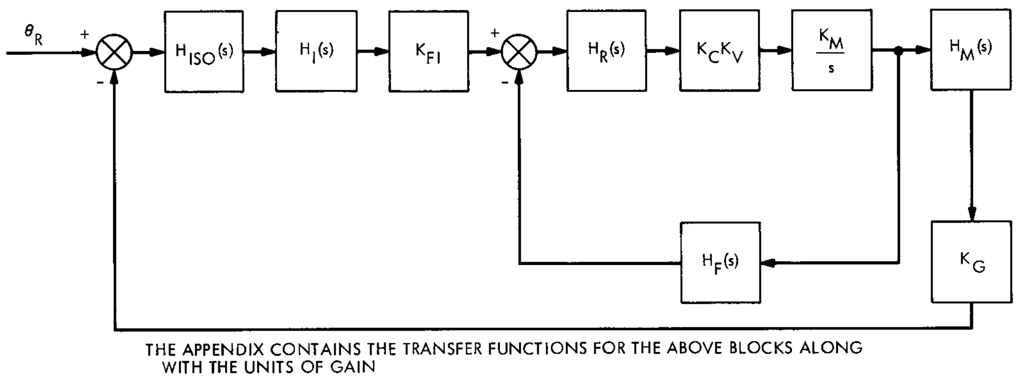


Fig. 2. Detailed block diagram for the integrated station servo system

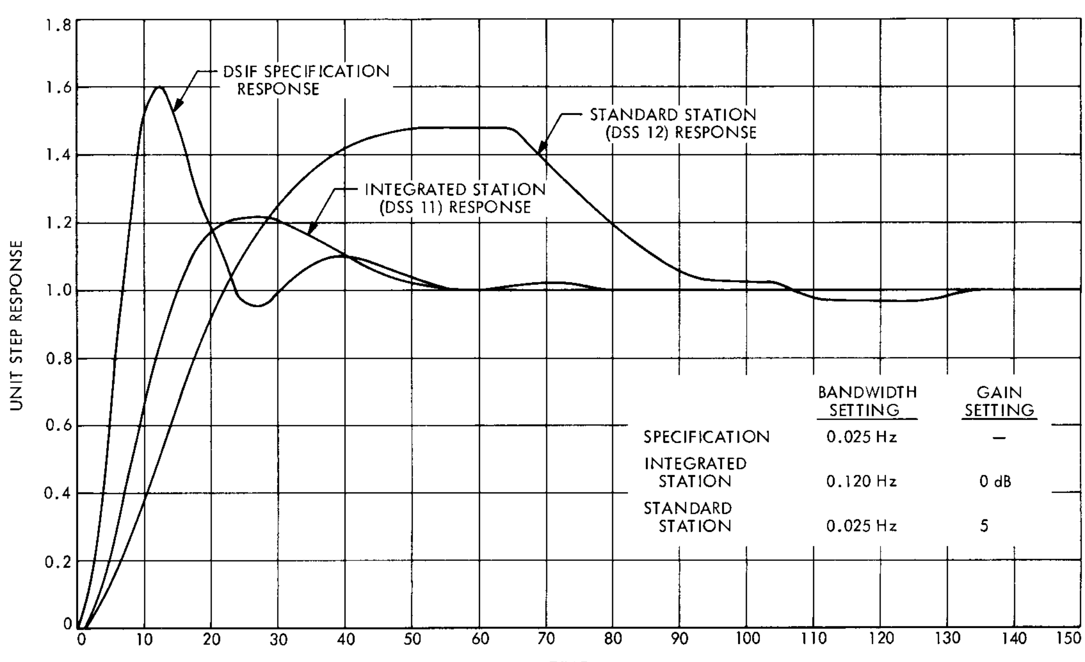


Fig. 3. Comparison of DSIF specification, standard station, and integrated station responses

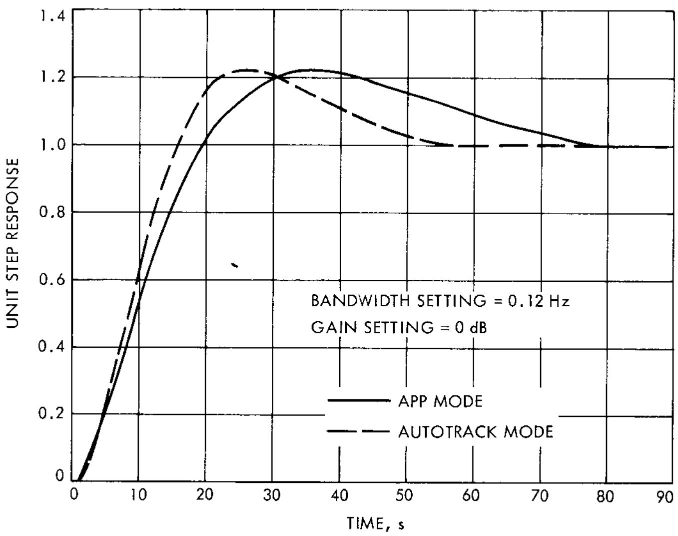


Fig. 4. Comparison of APP and autotrack modes for a step input

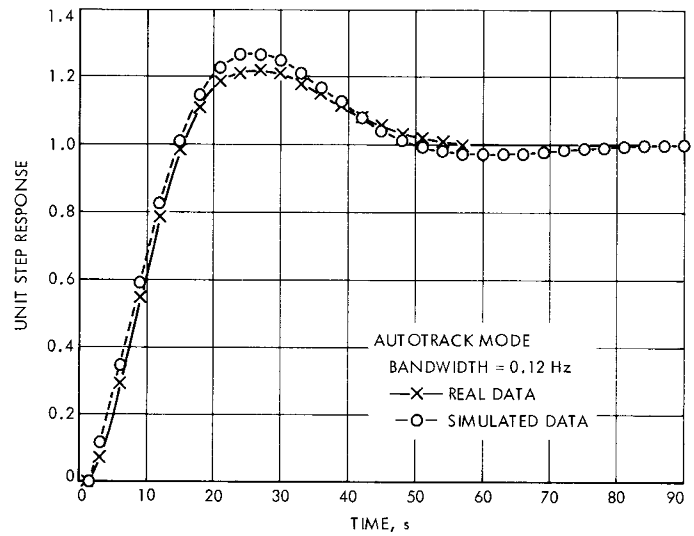


Fig. 5. Comparison of real and simulated data for autotrack mode

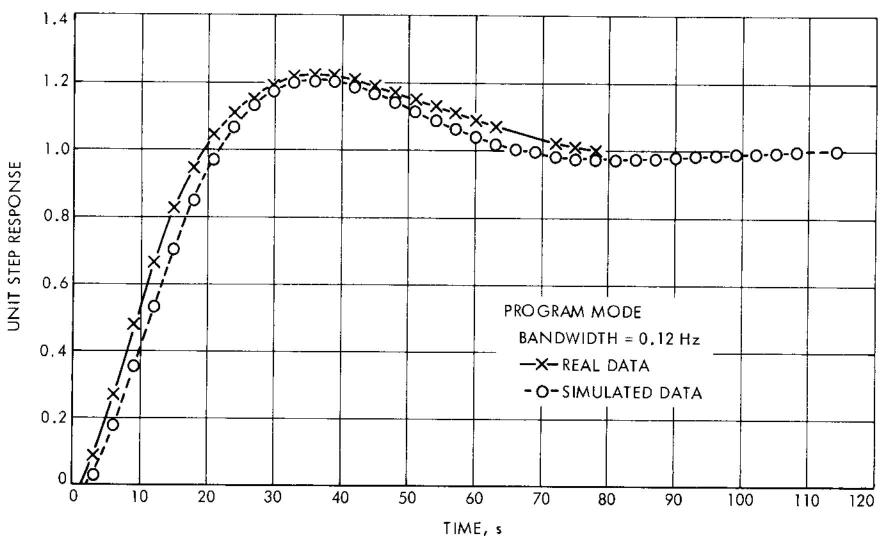


Fig. 6. Comparison of real and simulated data for program mode

Appendix

System Transfer Functions

This appendix contains circuits for the servo electronics, transfer functions for the tracking system, and values for the tracking system components. Figure A-1 is a simplified schematic of the servo electronics. The transfer functions for the servo electronics and antenna are listed below.

A. Isolation Amplifier

$$H_{ISO}(s) = \frac{A_2}{A_1} \cdot \frac{1 + sT_1}{1 + sT_2} K, \qquad \frac{\text{volts}}{\text{volt}}$$

where

$$A_1 = R_{IA8}$$

$$A_2 = \frac{R_{IA1} R_{IA13}}{R_{IA1} + R_{IA13}}$$

$$T_1 = R_{IA8} C_{IA3}$$

$$T_2 = \frac{R_{IA1} R_{IA13}}{R_{IA1} + R_{IA13}} (C_{IA1} + C_{IA2})$$

and K is the value of a voltage divider network which is controlled by the servo gain control (range: 0.5 to 0.95).

B. Position Integrator

The position integrator can be configured four ways, depending upon which bandwidth (BW) setting is selected (see Fig. A-1).

$$H_I(s) = \frac{A_I}{Z_I} \cdot \frac{1 + sT_{I2}}{1 + sT_{I3}}, \qquad \frac{\text{volts}}{\text{volt}}$$

(1) 0.12-Hz bandwidth setting

$$A_I = R_{I17} + R_{I13} + R_{I14}$$

$$Z_I = \frac{R_{I8}}{1 - \dfrac{R_{I7}}{R_{I7} + \dfrac{R_{I8} R_{I9}}{R_{I8} + R_{I9}}}}$$

$$T_{I2} = \frac{C_{I3} R_{I17} (R_{I13} + R_{I14})}{R_{I17} + R_{I13} + R_{I14}}$$

$$T_{I3} = R_{I17} (C_{I1} + C_{I2}) + (R_{I13} + R_{I14}) C_{I3} + (R_{I13} + R_{I14}) (C_{I1} + C_{I2})$$

(2) 0.25-Hz bandwidth setting

$$A_I = \frac{R_{I17}}{2}$$

$$Z_I = \frac{R_{I8}}{1 - \dfrac{R_{I7}}{R_{I7} + \dfrac{R_{I8} R_{I10}}{R_{I8} + R_{I10}}}}$$

$$T_{I2} = (R_{I13} + R_{I14}) C_{I3}$$

$$T_{I3} = \frac{R_{I17}}{2} (C_{I1} + C_{I2})$$

(3) 0.5-Hz bandwidth setting

$$A_I = \frac{R_{I17} R_{I18}}{R_{I17} + R_{I18}}$$

$$Z_I = \frac{R_{I8}}{1 - \dfrac{R_{I7}}{R_{I7} + \dfrac{R_{I8} R_{I11}}{R_{I8} + R_{I11}}}}$$

$$T_{I2} = \frac{R'_{I17} R'_{I13}}{R'_{I17} + R'_{I13}} C_{I3}$$

$$R'_{I17} = \frac{R_{I17} R_{I18}}{R_{I17} + R_{I17}}$$

$$R'_{I13} = R_{I13} + R_{I14}$$

$$T_{I3} = R'_{I17} (C_{I1} + C_{I2}) + R'_{I13} C_{I3} + R'_{I13} (C_{I1} + C_{I2})$$

(4) 1.0-Hz bandwidth setting

$$A_I = \frac{R_{I17} R_{I19}}{R_{I17} + R_{I19}} + R_{I13} + R_{I14}$$

$$Z_I = R_{I7} + R_{I8}$$

$$T_{I2} = \frac{R_{I30} R_{I31}}{R_{I30} + R_{I31}} C_{I3}$$

$$R_{I30} = \frac{R_{I17} R_{I19}}{R_{I17} + R_{I19}}$$

$$R_{I31} = R_{I13} + R_{I14}$$

$$T_{I3} = R_{I30} (C_{I1} + C_{I2}) + R_{I31} C_{I3} + R_{I31} (C_{I1} + C_{I2})$$

C. Rate Integrator

$$H_R(s) = K_R \frac{1}{s}\left(\frac{1 + sT_{R7}}{1 + sT_{R8}}\right), \qquad \frac{\text{volts}}{\text{volt}}$$

where

$$K_R = \frac{1}{B_R}$$

$$B_R = C_{R1} + C_{R3}$$

$$T_{R7} = R_{R19}C_{R1}$$

$$T_{R8} = \frac{C_{R3}C_{R1}}{C_{R1} + C_{R3}} R_{R19}$$

D. Mechanical Effects

This transfer function represents the effects of friction and inertia of the antenna structure.

$$H_M(s) = K_{MA}\frac{(1 + T_{M1}s)}{(1 + T_{M2}s)}, \qquad \frac{\text{degrees}}{\text{degree}}$$

where

T_{M1} = motor back pressure time constant

$$T_{M2} = \frac{\text{inertia of antenna}}{\text{friction of antenna}}$$

K_{MA} = hydraulic gain

E. Rate Feedback

$$H_F(s) = K_F K_T s$$

where

K_T = tachometer gain

$$K_F = \frac{1}{R_{F8} + R_{F15}}$$

F. Constant and Component Values

The values for the constants and components used in the model are listed below.

1. Isolation amplifier

$R_{IA1} = 511\ \text{k}\Omega$

$R_{IA8} = 511\ \text{k}\Omega$

$R_{IA13} = 5.6\ \text{M}\Omega$

$C_{IA1} = 0.068\ \mu\text{F}$

$C_{IA2} = 6800\ \text{pF}$

$C_{IA3} = 0.1\ \mu\text{F}$

2. Position integrator

a. 0.12-Hz bandwidth

$R_{I7} = 10\ \text{k}\Omega$

$R_{I8} = 10\ \text{k}\Omega$

$R_{I9} = 82.5\ \Omega$

$R_{I13} = 10\ \Omega$

$R_{I14} = 10\ \Omega$

$R_{I17} = 3.16\ \text{M}\Omega$

$C_{I1} = 0.01\ \mu\text{F}$

$C_{I2} = 0.1\ \mu\text{F}$

$C_{I3} = 10\ \mu\text{F}$

b. 0.25-Hz bandwidth

$R_{I7} = 10\ \text{k}\Omega$

$R_{I8} = 10\ \text{k}\Omega$

$R_{I10} = 0.348\ \Omega$

$R_{I13} = 10\ \Omega$

$R_{I14} = 10\ \Omega$

$R_{I17} = 3.16\ \text{M}\Omega$

$C_{I1} = 0.01\ \mu\text{F}$

$C_{I2} = 1\ \mu\text{F}$

$C_{I3} = 10\ \mu\text{F}$

c. 0.50-Hz bandwidth

$R_{I7} = 10\ \text{k}\Omega$

$R_{I8} = 10\ \text{k}\Omega$

$R_{I11} = 1620\ \Omega$

$R_{I13} = 10\ \Omega$

$R_{I14} = 10\ \Omega$

$R_{I17} = 3.16\ \text{M}\Omega$

$R_{I18} = 1.10\ \text{M}\Omega$

$C_{I1} = 0.01\ \mu\text{F}$

$C_{I2} = 1\ \mu\text{F}$

$C_{I3} = 10\ \mu\text{F}$

d. 1.0-Hz bandwidth

$$R_{I7} = 10\,\mathrm{k\Omega}$$
$$R_{I8} = 10\,\mathrm{k\Omega}$$
$$R_{I13} = 10\,\Omega$$
$$R_{I14} = 10\,\Omega$$
$$R_{I17} = 3.16\,\mathrm{M\Omega}$$
$$R_{I19} = 464\,\mathrm{k\Omega}$$
$$C_{I1} = 0.01\,\mu\mathrm{F}$$
$$C_{I2} = 0.1\,\mu\mathrm{F}$$
$$C_{I3} = 10\,\mu\mathrm{F}$$

3. *Rate integrator*

$$R_{R19} = 48.7\,\mathrm{k\Omega}$$
$$C_{R1} = 1\,\mu\mathrm{F}$$
$$C_{R3} = 0.15\,\mu\mathrm{F}$$

4. K_{FI} *constant*

$$K_{FI} = \frac{1}{R_{FI3} + R_{FI7}}$$

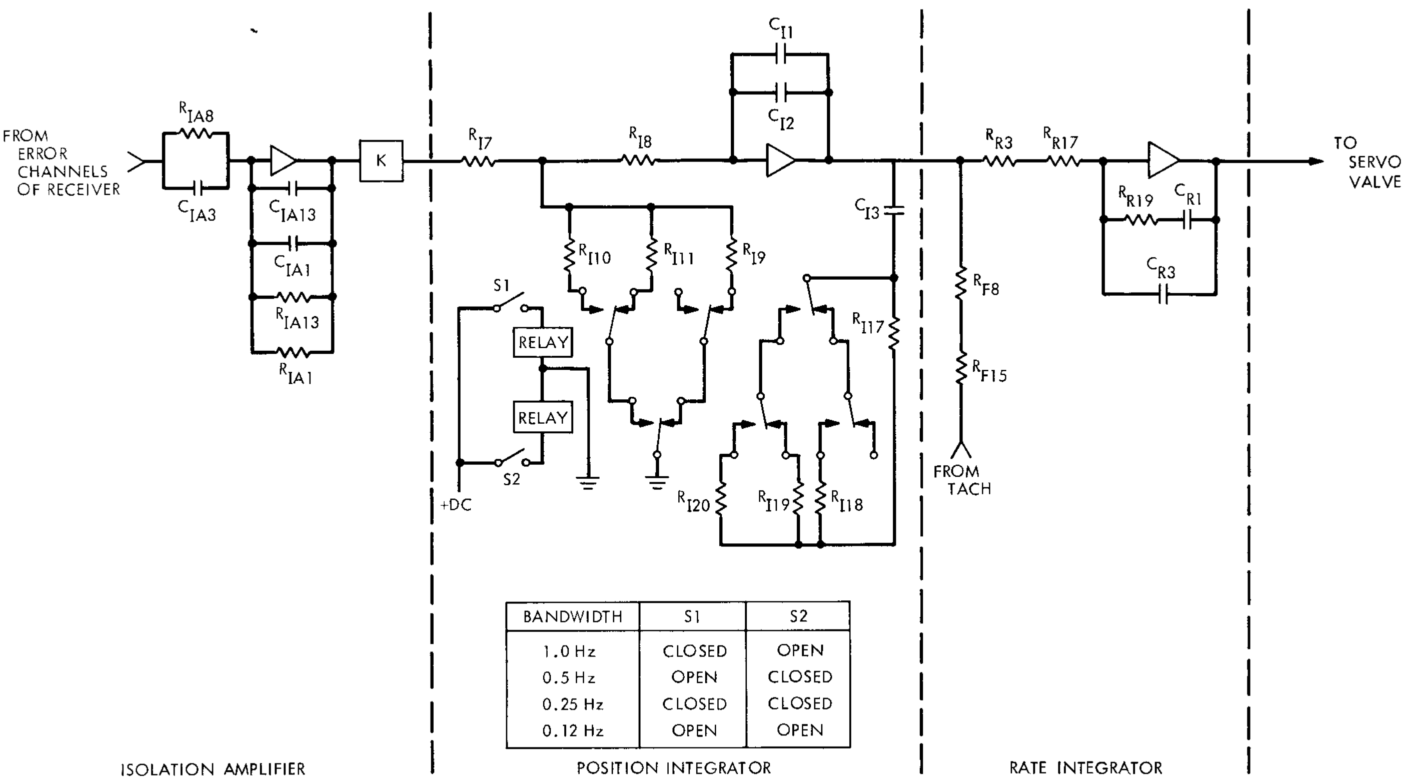
$$R_{FI3} = 28.7\,\mathrm{k\Omega}$$
$$R_{FI7} = 28.7\,\mathrm{k\Omega}$$

5. *Mechanical effects*

$$T_{M1} = 14 \text{ seconds}$$
$$T_{M2} = 42 \text{ seconds}$$
$$K_{MA} = 1.65 \text{ for APP mode}$$
$$K_{MA} = 2.3 \text{ for autotrack mode}$$

6. *Other constants*

$$K_C = 6.32 \times 10^{-3} \text{ amperes/volt}$$
$$K_V = 4055.8 \text{ cm}^3\text{/ampere-second}$$
$$K_M = 91.54\ \frac{\text{degrees/second}}{\text{cm}^3}$$
$$K_G = 2.43 \times 10^6\ \frac{\text{degrees}}{\text{degree}}$$
$$K_T = \frac{3.2 \text{ volts}}{1000 \text{ rpm}}$$



BANDWIDTH	S1	S2
1.0 Hz	CLOSED	OPEN
0.5 Hz	OPEN	CLOSED
0.25 Hz	CLOSED	CLOSED
0.12 Hz	OPEN	OPEN

Fig. A-1. Simplified schematic for the integrated servo electronics