ELECTRONIC DESIGN OF AN ELECTRONIC HIGH TORQUE-TO-INERTIA SERVOSYSTEM

Candidate system uses include missile guidance, surveillance, and tracking

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ADMINISTRATIVE INFORMATION

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Electronic design and development of a high torque-to-inertia servosystem for stabilizing a sensor system are described. The design philosophy leads to a low-cost/high-performance system. The stabilizing element developed is universal and has application for 1) missile guidance, 2) surveillance, and 3) tracking sensor systems. The servo design is based on math models and is used for electronic design implementation and evaluation.
CONTENTS

I INTRODUCTION ... page 1

II ELECTRICAL DESIGN ... 1
   A. Wiring Harness ... 1
   B. Control Panel ... 1
   C. Card Cage ... 15
      1. Compensation Card ... 15
      2. Demodulator Card ... 31
      3. MHD Driver Card ... 31
      4. Servoamplifier Card ... 31
      5. Current Drivers ... 47
   D. 10-inch Antenna Platform ... 47
   E. 5-inch Antenna Platform ... 58

III ELECTRONIC DESIGN ... 58
   A. Slave Loop ... 58
      1. Slave Command ... 63
      2. Feedback ... 64
      3. Compensation ... 65
   B. Track Loop ... 65
      1. Compensation ... 65
         a. Processor Filter ... 70
         b. Error/Rate Summer ... 70
         c. Compensation Filter ... 71
      2. Magnetohydrodynamic Rate Sensor (MHD) ... 71
      3. Demodulator ... 71
         a. 200-Hertz Bandpass Filter ... 75
         b. Phase Detectors/Filter ... 75
         c. Third-Order Filter ... 79
      4. Approximated MHD/Demodulator Transfer Function ... 79

IV MECHANICAL DRAWINGS ... 79

FIGURES

1. Servoelectronics system ... page 3
2. System block diagram ... 5
3. Wiring harness interconnections ... 7
4. Control panel ... 11
5. Control panel schematic ... 13
6. Card cage ... 17
7. Card cage wiring diagram ... 21
8. Compensation card ... 23
FIGURES (Continued)

9. Compensation card schematic ... page 27
10. Compensation card interconnection diagram ... 29
11. Demodulator card ... 33
12. Demodulator schematic ... 35
13. Demodulator interconnection diagram ... 37
14. MHD driver ... 39
15. MHD driver schematic ... 41
16. MHD driver interconnection diagram ... 44
17. Servoamplifier card ... 45
18. Servoamplifier schematic ... 48
19. Current drivers ... 51
20. Current driver servoamplifier simplified schematic, outer and inner gimbal ... 53
21. Current driver servoamplifier interconnections ... 54
22. 10-inch antenna platform ... 55
23. 10-inch platform wiring diagram ... 57
24. 5-inch antenna platform ... 59
25. 5-inch antenna platform wiring diagram ... 61
26. Slave loop block diagram ... 62
27. Slave loop compensation ... 62
28. Track loop block diagram ... 67
29. Track loop compensation ... 68
30. Magnetohydrodynamic rate sensor (MHD) ... 73
31. 200-Hz bandpass filter schematic ... 76
32. Phase detectors/filter schematic ... 77
33. Third-order filter schematic ... 80
34. Control panel outline and hinged lid (perspective) ... 83
35. Platform drawing sheet 1: bail ring mounting ... 85
36. Platform drawing sheet 2: base mount ... 87
37. Platform drawing sheet 3: bail ring and bearings ... 89
38. Platform drawing sheet 4: roller and spacer ... 91
39. Platform drawing sheet 5: inner motor mount ... 92
40. Platform drawing sheet 6: inner potentiometer mount ... 93
41. Platform drawing sheet 7: outer potentiometer mount ... 94

TABLES

1. Wiring harness parts list ... page 9
2. Control panel parts list ... 16
3. Card cage parts list ... 19
4. Compensation card parts list ... 25
5. 5-inch platform compensation card component changes ... 31
6. Demodulator parts list ... 37
7. MHD driver card parts list ... 43
8. Servoamplifier parts list ... 49
TABLES (Continued)

9. Current driver parts list (outer and inner) . . . page 53
10. 10-inch antenna platform parts list (electronics only) . . . 58
11. Slave loop compensation component values . . . 63
12. Slave compensation filter calculations . . . 66
13. Track loop compensation component values . . . 69
14. Track compensation filter calculations . . . 72
15. Demodulator transfer function and values . . . 75
16. 200-Hz bandpass filter component values . . . 76
17. 200-Hz bandpass filter calculations . . . 77
18. Phase detectors/filter component values . . . 78
19. Phase detectors/filter calculations . . . 78
20. Third-order filter component values . . . 80
21. Third-order filter calculations . . . 81
I. INTRODUCTION

This document provides data for the servoelectronics system used to drive an antenna platform for missile guidance applications. The servoelectronics system is illustrated in figure 1. A complete analysis of the system is provided in reference 1. It would benefit the reader to use that reference in conjunction with this document. The servoelectronics analysis was arrived at by using the given antenna platform mechanical and electrical characteristics (such as torque motor electrical characteristics, mechanical gearings, and expected inertia load conditions). The purpose of this document is to present the electrical and electronic design data required to complete the hardware for the servoelectronics loop. In addition, a limited set of mechanical drawings is included to complete the documentation.

The system is capable of driving two separate platforms: the 10-inch torque motor-driven antenna platform, which is the platform discussed in this document; and a 5-inch magnetic particle clutch motor-driven antenna platform designed by Hughes Aircraft Company. The necessary card change (servoamplifier card and current drivers) and component changes on the compensation card are pointed out in the appropriate sections.

The electronics was designed for laboratory use only, and certain shortcuts were taken (such as minimal packaging) in the design process to control cost and to meet a short schedule. Another design iteration is required to provide units suitable for flight test. Cost, weight, and size reduction will be addressed in a redesign.

II. ELECTRICAL DESIGN

The electrical design section provides the electrical interfaces and interconnections. The electrical design permits ready access to critical areas for testing and modification purposes and is easily set up to provide a good portable laboratory test bench. Interfaces with supporting equipment and system components are easily accomplished. Figure 2 illustrates system interfaces and connections.

A. WIRING HARNESS

The wiring harness diagram, as shown in figure 3, illustrates the interconnections between the control panel and the card cage and between the card cage and the antenna platform. It also illustrates signals coming from the video processor (not discussed in this document) and necessary power-supply connections. The cable between the control panel and the card cage was made 15 feet long so as to allow adequate separation between the operator and the antenna platform for rf interference suppression and testing purposes. The cable between the card cage and the platform is 2 feet long. Table 1 contains the parts list for the wiring harness.

B. CONTROL PANEL

The main function of the control panel, shown in figure 4, is to allow manual operation and monitoring of the servoelectronics system. The control panel schematic is illustrated in figure 5. Test jacks are provided to permit monitoring of pertinent signals. The flight programmer control panel switch is provided to transfer control from the control panel to the flight programmer (video processor signals).

Figure 3. Wiring harness interconnections.
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
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<td>CB-P1</td>
<td>1</td>
<td>PT06A-18-32P (SR)</td>
<td>Bendix</td>
<td>Connector</td>
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<td>MS3106R16-11S (C)</td>
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<td>Connector</td>
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Table 1. Wiring harness parts list.
Figure 4. Control panel.
Figure 5. Control panel schematic.
The control panel has several modes of operation. In the TEST mode, signals can be injected to drive the inner and outer gimbals. Two lights are provided to indicate that the input jacks for signal injection are activated for the inner and outer gimbals. When the TRACK SLAVE switch is in the SLAVE position, the TEST mode permits the injection of an inner and outer gimbals slave command to slow the antenna platform. If the TRACK SLAVE switch is in the TRACK position, the TEST mode permits the injection of an inner and outer gimbals rate signal to control the pointing of the antenna platform. When the system is in TRACK, the TRACK SLAVE light is activated.

In SLAVE mode, only slave commands can be given and the position potentiometers provide the voltage to slew and position the inner and outer gimbals.

In the TRACK mode, rate signals are provided by the guidance system inputs only. When in either TRACK or SLAVE mode, the TRACK SLAVE switch is overridden.

In the CAGE mode, the inner and outer gimbals are positioned to look forward or in a zero position.

The digital voltmeter will check the following voltages: +5 Vdc, +15 Vdc, and 28 Vdc. No power is applied to the servoelectronics until the power switch is on, which is indicated by a light. The torquer and gyro switches apply 28 Vdc to the current drivers and the MHD driver, respectively, as indicated by their respective lights. The control panel parts list is shown in table 2.

C. CARD CAGE

Figure 6 shows the card cage fully assembled. The card cage is the housing and interface wiring for the compensation card, demodulator card, MHD driver card, and the inner and outer gimbals current drivers. The card cage is wired to operate the 10-inch antenna platform (torque motor platform) as well as the Hughes Aircraft Company 5-inch antenna platform (magnetic particle clutch/motor platform). The cards are wire-wrapped to permit quick and easy assembly, modification, and addition of test points to the control panel. An extender card was fabricated to enable online testing. Table 3 shows the card cage parts list and figure 7 is the card cage wiring diagram. A bus system was incorporated with a central ground wheel to eliminate signal and grounding problems.

The card cage and its associated electronics can be significantly reduced in size and weight in a redesign to package for missile applications.

1. Compensation Card

Figure 8 shows the compensation card, which provides the necessary compensation required for the slave and track loops of the servo loop that will be discussed in the electronics design section. The compensation card is inserted into the first slot provided (nearest to connectors) in the card cage (X1). Figure 9 is the compensation card schematic and table 4 is the parts list. The compensation card interconnect diagram is shown in figure 10. The compensation card is made entirely from dual in-line integrated circuits and discrete components.

This is the only card that requires component changes to drive the 5-inch magnetic particle clutch/motor-driven antenna platform. Table 5 shows the necessary component changes.

The switches in figure 9 (U4 and U10) are drawn to represent TRACK mode. If a high input is placed on the TRACK/SLAVE input (P1-19), this activates the switches, places the card in the SLAVE mode, and discharges the capacitors of the integrators (U3 and U9).
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<th>Item</th>
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<th>Nomenclature</th>
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<td>Relay</td>
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<td>507-4758</td>
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<tr>
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Table 2. Control panel parts list.
Figure 6 - Card cage
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Table 3. Card cage parts list.
Figure 7. Card case wiring diagram.
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<td>U1, U2, U6, U7, U8, U12</td>
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<td>SN74747 Texas Instruments</td>
<td>Integrated circuit</td>
<td></td>
</tr>
<tr>
<td>U3, U9</td>
<td>2</td>
<td>LM208J National</td>
<td>Integrated circuit</td>
<td></td>
</tr>
<tr>
<td>U4, U10</td>
<td>2</td>
<td>DG201CJ Signetics</td>
<td>Integrated circuit</td>
<td></td>
</tr>
<tr>
<td>U5, U11</td>
<td>2</td>
<td>LM110D National</td>
<td>Integrated circuit</td>
<td></td>
</tr>
<tr>
<td>U13, U14</td>
<td>2</td>
<td>CD4011 RCA</td>
<td>Integrated circuit</td>
<td></td>
</tr>
<tr>
<td>U15</td>
<td>1</td>
<td>LM309DB National</td>
<td>Voltage regulator</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>8136-UG115 Augat</td>
<td>Wire wrap board</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Compensation card parts list.
Figure 10. Compensation card interconnection diagram
Table 5. 5-inch platform compensation card component changes.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number, Value</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4, C13</td>
<td>2</td>
<td>Red cap 4.4 µF</td>
<td>ERIE</td>
<td>Capacitor</td>
</tr>
<tr>
<td>C7</td>
<td>1</td>
<td>CK06 0.22 µF</td>
<td></td>
<td>Capacitor</td>
</tr>
<tr>
<td>C8</td>
<td>1</td>
<td>CK05 0.082 µF</td>
<td></td>
<td>Capacitor</td>
</tr>
<tr>
<td>C9</td>
<td>1</td>
<td>CK06 0.33 µF</td>
<td></td>
<td>Capacitor</td>
</tr>
<tr>
<td>R1, R30</td>
<td>2</td>
<td>RC07 5.1K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R2, R40, R68</td>
<td>3</td>
<td>RC07 2.4K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R5</td>
<td>1</td>
<td>RC07 3K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R10, R30, R48</td>
<td>3</td>
<td>RC07 24K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R11, R31, R49, R60</td>
<td>4</td>
<td>RC07 100K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R12, R13, R18, R33, R34</td>
<td>10</td>
<td>RC07 51K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R14, R35, R52</td>
<td>3</td>
<td>RC07 6.2K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R16, R19, R54, R57</td>
<td>4</td>
<td>RC07 200K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R26, R27</td>
<td>2</td>
<td>RC07 18K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R43</td>
<td>1</td>
<td>RC07 10K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R64, R65</td>
<td>2</td>
<td>RC07 20K</td>
<td></td>
<td>Resistor</td>
</tr>
</tbody>
</table>

2. Demodulator Card

The demodulator card is shown in figure 11. In the card's initial fabrication, dual in-line integrated circuits and discrete components were used. However, Honeywell now has a hybrid package available, as shown in figure 11. The unit is a quadrature demodulator. It provides the necessary signal conditioning for the MHD rate sensor in the feedback loop that will be discussed in the electronics section. The demodulator card is inserted into the second slot provided in the card cage (X2). Figure 12 is a schematic of the demodulator; figure 13 is the interconnection diagram; and table 6 is the parts list.

3. MHD Driver Card

The MHD driver card is shown in figure 14. (The MHD driver is the source of power for the MHD.) The MHD driver card provides two-phase, 400-hertz, 26-volt rms power to drive the MHD rotor. The driver is an integrated circuit servoamplifier fabricated by Inland Motors Inc. The GYRO switch on the control panel provides +28 Vdc to power this servoamplifier. Dual in-line integrated circuits and discrete components form the 400-hertz generator that drives the servoamplifier. The MHD driver card is inserted in the third slot provided in the card cage (X3). Figure 15 is a schematic drawing of the MHD driver, and table 7 is the parts list. Figure 16 is an interconnection diagram of the MHD driver.

4. Servoamplifier Card

The servoamplifier card is shown in figure 17. This card is only used with the 5-inch antenna platform. The current drivers (see next section) are not used for the 5-inch magnetic particle clutch/motor-driven antenna platform. The servoamplifier card is used to drive the magnetic particle clutches, power for which is provided by a 28-volt motor. This 28-volt
Figure 11. Demodulator card.
Figure 13. Demodulator interconnection diagram.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>1</td>
<td>EG1030AD06</td>
<td>Honeywell</td>
<td>Hybrid demodulator</td>
</tr>
<tr>
<td>XPC-1</td>
<td>1</td>
<td>4094</td>
<td>Augat</td>
<td>Vector board</td>
</tr>
</tbody>
</table>

Table 6. Demodulator parts list.
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number, Value</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1, C2, C3, C5, C6, C7</td>
<td>6</td>
<td>CK06 0.1 μF</td>
<td>Abbott</td>
<td>Capacitor</td>
</tr>
<tr>
<td>C4, C8, C9, C10, C11</td>
<td>5</td>
<td>CK06 1.0 μF</td>
<td>R-OHM Corp</td>
<td>Capacitor</td>
</tr>
<tr>
<td>R1</td>
<td>1</td>
<td>RC07 30K</td>
<td>Texas instrument</td>
<td>Resistor</td>
</tr>
<tr>
<td>R2, R3</td>
<td>2</td>
<td>RC07 51K</td>
<td>Inland</td>
<td>Resistor</td>
</tr>
<tr>
<td>R4</td>
<td>1</td>
<td>RC07 25K (select)</td>
<td>R-OHM Corp</td>
<td>Resistor</td>
</tr>
<tr>
<td>R5</td>
<td>1</td>
<td>RC07 200</td>
<td>Inland</td>
<td>Resistor</td>
</tr>
<tr>
<td>R6, R7</td>
<td>2</td>
<td>RC07 10K</td>
<td>R-OHM Corp</td>
<td>Resistor</td>
</tr>
<tr>
<td>R8</td>
<td>1</td>
<td>12W 5</td>
<td>Inland</td>
<td>Resistor</td>
</tr>
<tr>
<td>T1</td>
<td>1</td>
<td>6E55C1</td>
<td>Inland</td>
<td>Transformer</td>
</tr>
<tr>
<td>U1</td>
<td>1</td>
<td>XR-2206</td>
<td>Inland</td>
<td>IC, function gen</td>
</tr>
<tr>
<td>U2</td>
<td>1</td>
<td>74747</td>
<td>Texas instrument</td>
<td>IC, op amp</td>
</tr>
<tr>
<td>U3</td>
<td>1</td>
<td>EM1801</td>
<td>Inland</td>
<td>IC, servomtp</td>
</tr>
<tr>
<td>S1</td>
<td>1</td>
<td>SO1801</td>
<td>Inland</td>
<td>IC socket</td>
</tr>
</tbody>
</table>

Table 7. MHD driver card parts list.
power is controlled by the torque motor switch on the control panel. The electronic design for this card will not be discussed in the electronics section, since the main objective of this document is to discuss the 10-inch antenna platform. However, it is important to note that this card cage is universal for the two platforms, and that the necessary component changes for operation of the 5-inch antenna platform are pointed out in the former electrical design sections (the compensation card only). The servoamplifier card is inserted in the fourth slot of the card cage (X4). Figure 18 is a schematic of the servoamplifier card and Table 8 is the parts list.

5. Current Drivers

Figure 19 shows the inner and outer gimbal current drivers for the torque motors of the 10-inch antenna platform. The TORQUE switch on the control panel places +28 Vdc on the current drivers to activate them. The current drivers are mounted on a plate attached to the outside of the card cage. An extender card and cable are used to provide a wiring harness from the fifth slot of the card cage (X5) to the current drivers. Note that the current drivers are current-limited to protect the torque motors as well as the current drivers themselves. The current-limiting resistor \( R_x \) is determined by the equation:

\[
R_x = \frac{2}{I_{CL} - 0.4}
\]

where \( I_{CL} \) is the limiting current. The current drivers are integrated-circuit servoamplifiers fabricated by Inland. They are mounted by means of sockets and attached to heat sinks for easy replacement. Figure 20 is a simplified schematic; Table 9 is the parts list; and Figure 21 shows current driver interconnections.

D. 10-inch ANTENNA PLATFORM

Figure 22 shows the 10-inch antenna platform. The primary design features of the platform are the adaptability to other antennas, the large volume and weight capability, and the low-cost design. The modular construction technique of the platform allows adaptation to a variety of antennas without complete redesign. The platform is a ball-ring concept with a high torque-to-inertia design. The ball-ring concept allows large load volume on the gimbals. A roller suspension system is used to hold the ball ring. This concept keeps the costs of production down. Torque motors were used for the inner and outer gimbal drives to achieve a high torque-to-inertia ratio at a low cost. This high torque-to-inertia concept also reduces costs by eliminating the requirement of designing balanced loads. Conductive plastic potentiometers were used because of their superior durability. The Honeywell MHD rate sensor is used for track-loop stabilization. The MHD is a new-concept, subminiature, high-performance, two-axis rate sensor specifically designed for large-volume producibility. It has been qualified to environmental requirements of MIL-STD-810B for gyros installed in fixed-wing aircraft, helicopters, and missiles. It is ideally suited for tactical missile seeker head stabilization. Figure 23 is the platform wiring diagram and Table 10 is the parts list (which includes only the electronics). A limited set of drawings is provided below in the mechanical drawings section.

The antenna was designed and fabricated by AIL, Deer Park, Long Island, New York.
Figure 18. Servoamplifier schematic.
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number, Value</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, R2, R10, R11, R17, R18, R26, R27</td>
<td>8</td>
<td>49.9K 0.1W, 1%</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R3, R19</td>
<td>2</td>
<td>20.5K 0.1W, 1%</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R4, R12, R13, R20, R28, R29</td>
<td>6</td>
<td>12.4K 0.1W, 1%</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R5, R14, R21, R30</td>
<td>4</td>
<td>RC07 100</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R6, R15, R22, R31</td>
<td>4</td>
<td>RC07 2K</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R7, R16, R23, R32</td>
<td>4</td>
<td>RL65N5R00F 5.10W</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R8, R24</td>
<td>2</td>
<td>4.53K 0.1W, 1%</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R9, R25</td>
<td>2</td>
<td>24.9K 0.1W, 1%</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>C1, C2, C4, C5, C7, C8, C10, C11</td>
<td>8</td>
<td>CK05 560pF</td>
<td></td>
<td>Capacitor</td>
</tr>
<tr>
<td>C3, C6, C9, C12</td>
<td>4</td>
<td>CK05 0.01 F</td>
<td></td>
<td>Capacitor</td>
</tr>
<tr>
<td>C13, C14</td>
<td>2</td>
<td>CS13 22μF, 35V, 10%</td>
<td></td>
<td>Capacitor</td>
</tr>
<tr>
<td>CR1 through CR8</td>
<td>8</td>
<td>IN3600</td>
<td></td>
<td>Diode</td>
</tr>
<tr>
<td>Q1, Q3, Q5, Q7</td>
<td>4</td>
<td>2N1711</td>
<td></td>
<td>Transistor</td>
</tr>
<tr>
<td>Q2, Q4, Q6, Q8</td>
<td>4</td>
<td>2N3716</td>
<td></td>
<td>Transistor</td>
</tr>
<tr>
<td>H1 through H4</td>
<td>4</td>
<td>6105-B</td>
<td>Thermalloy</td>
<td>Heat sink</td>
</tr>
<tr>
<td>U1 through U4</td>
<td>4</td>
<td>LM108</td>
<td>Signetics</td>
<td>Integrated circuit</td>
</tr>
</tbody>
</table>

Table 8. Servoamplifier parts list.
Figure 20. Current driver servoamplifier simplified schematic: outer and inner gimbal.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number, Value</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, R2</td>
<td>4</td>
<td>1.2W 510</td>
<td></td>
<td>Resistor</td>
</tr>
<tr>
<td>R3</td>
<td>1</td>
<td>2W 0.18</td>
<td></td>
<td>Resistor, OG</td>
</tr>
<tr>
<td>R3</td>
<td>1</td>
<td>2W 1</td>
<td></td>
<td>Resistor, IG</td>
</tr>
<tr>
<td>HSI</td>
<td>2</td>
<td>HS1801</td>
<td>Inland</td>
<td>Heat sink</td>
</tr>
<tr>
<td>UI</td>
<td>2</td>
<td>EM1802</td>
<td>Inland</td>
<td>IC, servoamp</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>4094</td>
<td>Augat</td>
<td>*Vector board</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>SO1801</td>
<td>Inland</td>
<td>IC socket</td>
</tr>
</tbody>
</table>

*Vector board used as extender and cable connector.
NOTE: Parts list applies only to one current driver.

Table 9. Current driver parts list (outer and inner).
Figure 21. Current driver servoamplifier interconnections.
Figure 22 10-inch antenna platform
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>G-P1</td>
<td>1</td>
<td>PT02SF-20-39SY</td>
<td>Bendix</td>
<td>Connector</td>
</tr>
<tr>
<td>MHD</td>
<td>1</td>
<td>GG2500LC03</td>
<td>Honeywell</td>
<td>Rate sensor (MHD)</td>
</tr>
<tr>
<td>T1</td>
<td>1</td>
<td>DPH3320-A-17</td>
<td>Clifton</td>
<td>Torque motor</td>
</tr>
<tr>
<td>L2</td>
<td>1</td>
<td>DPH990B-251</td>
<td>Clifton</td>
<td>Torque motor</td>
</tr>
<tr>
<td>R1</td>
<td>1</td>
<td>3571S-1-502</td>
<td>Bourns</td>
<td>Potentiometer (5K)</td>
</tr>
<tr>
<td>R2</td>
<td>1</td>
<td>78SF1CS02</td>
<td>New England Instruments</td>
<td>Potentiometer (5K)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>F001-01-040</td>
<td>All</td>
<td>Antenna/processor</td>
</tr>
</tbody>
</table>

Table 10. 10-inch antenna platform parts list (electronics only).

E. 5-inch ANTENNA PLATFORM

Figure 24 shows the Hughes antenna platform, which is included here for documentation purposes only. The platform is a bail ring concept with magnetic particle clutch servos to drive each gimbal. Permanent magnet dc motors provide the mechanical power input to the clutches. The platform has inner and outer gimbals for positioning, and an MHD rate sensor for track loop feedback stabilization. Figure 25 is the platform wiring diagram.

III. ELECTRONIC DESIGN

The electronic design section illustrates the derivation of the compensation and feedback networks. (The compensation transfer functions are derived in reference 1.) This section also shows how to match the electronics to the above transfer functions. The torque motors, gear ratios, and inertial load factor are not covered in this section because these are considered fixed in determining the compensation transfer functions (see reference 1).

A. SLAVE LOOP

A slave loop is implemented about each gimbal by utilizing feedback from a gimbal-driven potentiometer. The slave servosystem has the function of pointing the antenna toward the target prior to activation of the target-tracking system. The slave loop commands are originated by an outside source in gimbal coordinates. Figure 26 illustrates the slave loop block diagram. The motor/amplifier/load is derived in reference 1 and is considered as given. The compensation required to close the slave loop is discussed in this section. Figure 27 is a simplified schematic of the slave loop compensation and table 11 presents component values. A boresight adjustment is located in the compensation card to permit zeroing the antenna platform at boresight.

58
Figure 34 - VHF antenna platform
Figure 25. 5-inch antenna platform wiring diagram.
Figure 26. Slave loop block diagram.

Figure 27. Slave loop compensation.
<table>
<thead>
<tr>
<th>Inner Outer Components</th>
<th>Inner Gimbals</th>
<th>Other Gimbals</th>
</tr>
</thead>
<tbody>
<tr>
<td>R64 R26</td>
<td>18K</td>
<td>30K</td>
</tr>
<tr>
<td>R65 R27</td>
<td>47K</td>
<td>30K</td>
</tr>
<tr>
<td>R66 R28</td>
<td>160K</td>
<td>160K</td>
</tr>
<tr>
<td>R67 R29</td>
<td>16K</td>
<td>16K</td>
</tr>
<tr>
<td>R68 R30</td>
<td>24K</td>
<td>6.8K</td>
</tr>
<tr>
<td>R69 R31</td>
<td>160K</td>
<td>82K</td>
</tr>
<tr>
<td>R70 R32</td>
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<td>R71 R33</td>
<td>82K</td>
<td>30K</td>
</tr>
<tr>
<td>R72 R34</td>
<td>82K</td>
<td>33K</td>
</tr>
<tr>
<td>R73 R35</td>
<td>6.2K</td>
<td>1.5K</td>
</tr>
<tr>
<td>R74 R36</td>
<td>10M</td>
<td>10M</td>
</tr>
<tr>
<td>R75 R37</td>
<td>50K pot</td>
<td>50K pot</td>
</tr>
<tr>
<td>C16 C7</td>
<td>0.15 μF</td>
<td>0.182 μF</td>
</tr>
<tr>
<td>C17 C8</td>
<td>0.082 μF</td>
<td>0.22 μF</td>
</tr>
<tr>
<td>C18 C9</td>
<td>0.33 μF</td>
<td>1.0 μF</td>
</tr>
</tbody>
</table>

Table 11. Slave loop compensation component values.

1. Slave Command

Slave command gain ($K_3^1$) was determined by assuming a signal input of range ±5 volts for ±45-degree movement of the inner and outer gimbals. Thus the inner and outer slow-position gain ($K_{SP}$) is calculated as follows:

\[ K_{SP} = \frac{10}{\frac{\pi}{2}} = 6.37 \text{ volts radian}. \]

Referring to figure 27, we can see that the slave command gain ($K_3^1$) is calculated as follows:

\[ K_3^1 = \frac{R_{28}}{R_{27}} = 4.10 \text{ volts/volt (outer gimbals)} \]
\[ K_3^1 = \frac{R_{66}}{R_{65}} = 3.40 \text{ volts/volt (inner gimbals)}. \]

The inner and outer gimbals gains differ because the gains in the respective slave loops differ. Total slave command gain is the product of the two gains (i.e., $K_{SP}K_3^1$).

63
2. Feedback

The outer gimbal feedback potentiometer is of the three-turn type. A 30-volt potential is placed across the potentiometer; thus the potentiometer gain ($K_p$) can be calculated as follows:

$$K_p = \frac{30}{6\pi} = 1.59 \text{ volts/radian (outer gimbal)}.$$  

The ratio ($N^1$) of the outer gimbal movement with respect to the potentiometer is 8.5:1.

The inner gimbal feedback potentiometer is of the single-turn type. A 30-volt potential is also placed across this potentiometer; thus the potentiometer gain ($K_p$) can be calculated as follows:

$$K_p = \frac{30}{2\pi} = 4.78 \text{ volts/radian (inner gimbal)}.$$  

The ratio ($N^1$) of the inner gimbal movement with respect to the potentiometer is 3.0:1.

Referring to figure 27, we can see that the feedback gain $K_F^1$ can be calculated as follows:

$$K_F^1 = \frac{R_{28}}{R_{26}} = 5.33 \text{ volts (outer gimbal)}$$  

$$K_F^1 = \frac{R_{66}}{R_{64}} = 8.89 \text{ volts (inner gimbal)}.$$  

Total feedback gain is the product of the three gains (i.e., $K_F^1 N^1 K_p$). For feedback gain in reference 1 ($K_F$), the following relationships apply:

$$K_F = \frac{K_F^1}{K_p^3} = 1.30 \text{ volts (outer gimbal)}$$  

$$K_F = \frac{K_F^1}{K_p^3} = 2.64 \text{ volts (inner gimbal)}.$$  

Note: The potentiometers used were of the high-precision, conductive plastic type because high feedback gain amplifies the crossover of the wirewound type.
3. Compensation

A lead-lag compensation network was necessary to provide the required stability. The transfer function for the slave loop compensation, per reference 1, is as follows:

\[
\frac{K_3^2(\tau_5 S + 1)(\tau_1^2 S + 1)}{(\tau_3 S + 1)(\tau_1^2 S + 1)(\tau_0 S + 1)}
\]

The calculations of the compensation gain \(K_3^2\) and the time constants \(\tau_5, \tau_1, \tau_3, \tau_1^2\), and \(\tau_0\) for both the inner and outer gimbals are shown in table 12. Note that for the compensation gain in reference 1 \(K_3^2\), the following relationships apply:

\[
K_3 = K_3^1 K_3^2 = 3.00 \text{ volts volt (outer gimbal)}
\]

\[
K_3 = K_3^1 K_3^3 = 3.49 \text{ volts volt (inner gimbal)}
\]

\[
\frac{K_3^2(\tau_5 S + 1)(\tau_1^2 S + 1)}{(\tau_3 S + 1)(\tau_1^2 S + 1)(\tau_0 S + 1)}
\]

B. TRACK LOOP

There are two loops involved in the tracking loop: the tracking loop itself and the stabilization loop. The tracking loop is closed by means of the reception of an emitting radar signal (via the antenna), which is processed to develop a line-of-sight rate \(\theta\) that is zeroed to allow automatic target tracking. The stabilization loop is provided as an inner loop in the tracking servosystem and is closed by means of the two-axis MHD rate sensor. This implementation causes the tracking loop error signals to be a measure of the inner and outer gimbal line-of-sight rates in inertially referenced coordinates. Figure 28 shows the track loop block diagram.

1. Compensation

Compensation consists of a processor filter, error rate summer, and compensation filter. Figure 29 is a simplified schematic of the compensation filter, and table 13 presents the component values. The error/rate summer has a balance adjust to obtain the proper balance between track error and rate feedback (stabilization). There is also a boresight adjust in the compensation filter to zero the track error output to the antenna platform. A switch around the integrator of the compensation filter is used to discharge the integrator when in slave mode. Otherwise, in switching from slave to track, the charged capacitor would cause an instant jump.
Outer Gimbal

\[ k_3 = \frac{R_{33} + R_{34}}{R_{31}} = 0.880 \text{ volt volt} \]

\[ \tau_1 = \frac{(R_{30} + R_{31})C_S}{1} = 0.0195 \text{ second} \]

\[ \tau_2 = \frac{R_{33} + R_{34}}{4} C_9 = 0.0195 \text{ second} \]

\[ \tau_3 = \frac{(R_{30})C_S}{1} = 0.0015 \text{ second} \]

\[ \tau_4 = \frac{(R_{35})C_9}{1} = 0.0015 \text{ second} \]

\[ \tau_5 = \frac{(R_{28})C_7}{1} = 0.029 \text{ second} \]

Inner Gimbal

\[ k_3 = \frac{R_{71} + R_{72}}{R_{70}} = 1.025 \text{ volts volt} \]

\[ \tau_1 = \frac{(R_{68} + R_{69})C_{17}}{1} = 0.0151 \text{ second} \]

\[ \tau_2 = \frac{R_{73} + \frac{R_{1} + R_{72}}{4}}{C_{18}} = 0.0156 \text{ second} \]

\[ \tau_3 = \frac{R_{68}C_{17}}{1} = 0.00197 \text{ second} \]

\[ \tau_4 = \frac{R_{73}C_{18}}{1} = 0.00205 \text{ second} \]

\[ \tau_5 = \frac{R_{66}C_{16}}{1} = 0.024 \text{ second} \]

Table 12: Slave compensation filter calculations.
Figure 58. Track loop block diagram
<table>
<thead>
<tr>
<th>Outer/Inner Components</th>
<th>Outer Gimbal</th>
<th>Inner Gimbal</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1/R39</td>
<td>3.3K</td>
<td>3.3K</td>
</tr>
<tr>
<td>R2/R40</td>
<td>24K</td>
<td>24K</td>
</tr>
<tr>
<td>R3/R41</td>
<td>3K</td>
<td>3K</td>
</tr>
<tr>
<td>R4/R42</td>
<td>3K</td>
<td>10K</td>
</tr>
<tr>
<td>R5/R43</td>
<td>1.1K</td>
<td>2.4K</td>
</tr>
<tr>
<td>R6/R44</td>
<td>2K</td>
<td>5.1K</td>
</tr>
<tr>
<td>R7/R45</td>
<td>2.2M</td>
<td>5.1M</td>
</tr>
<tr>
<td>R8/R46</td>
<td>10K</td>
<td>10K</td>
</tr>
<tr>
<td>R9/R47</td>
<td>50K pot</td>
<td>50K pot</td>
</tr>
<tr>
<td>R10/R48</td>
<td>12K</td>
<td>12K</td>
</tr>
<tr>
<td>R11/R49</td>
<td>110K</td>
<td>110K</td>
</tr>
<tr>
<td>R12/R50</td>
<td>56K</td>
<td>56K</td>
</tr>
<tr>
<td>R13/R51</td>
<td>56K</td>
<td>56K</td>
</tr>
<tr>
<td>R14/R52</td>
<td>3K</td>
<td>3K</td>
</tr>
<tr>
<td>R15/R53</td>
<td>56K</td>
<td>56K</td>
</tr>
<tr>
<td>R16/R54</td>
<td>91K</td>
<td>150K</td>
</tr>
<tr>
<td>R17/R55</td>
<td>68K</td>
<td>75K</td>
</tr>
<tr>
<td>R18/R56</td>
<td>30K</td>
<td>30K</td>
</tr>
<tr>
<td>R19/R57</td>
<td>270K</td>
<td>270K</td>
</tr>
<tr>
<td>R20/R58</td>
<td>100K</td>
<td>100K</td>
</tr>
<tr>
<td>R21/R59</td>
<td>50K pot</td>
<td>50K pot</td>
</tr>
<tr>
<td>R21/R59</td>
<td>50K pot</td>
<td>50K pot</td>
</tr>
<tr>
<td>R22/R60</td>
<td>10M</td>
<td>10M</td>
</tr>
<tr>
<td>R23/R61</td>
<td>470</td>
<td>470</td>
</tr>
<tr>
<td>R24/R62</td>
<td>51K</td>
<td>51K</td>
</tr>
<tr>
<td>R25/R63</td>
<td>10K</td>
<td>10K</td>
</tr>
<tr>
<td>C1/C10</td>
<td>1.0 µF</td>
<td>1.0 µF</td>
</tr>
<tr>
<td>C2/C11</td>
<td>0.082 µF</td>
<td>0.082 µF</td>
</tr>
<tr>
<td>C3/C13</td>
<td>3.3 µF</td>
<td>3.3 µF</td>
</tr>
<tr>
<td>C5/C14</td>
<td>1.0 µF</td>
<td>1.0 µF</td>
</tr>
<tr>
<td>C6/C15</td>
<td>100 pF</td>
<td>100 pF</td>
</tr>
</tbody>
</table>

Table 13. Track loop compensation component values.
a. PROCESSOR FILTER. The processor filter is used to smooth the signal output of the video processor. The transfer function to be obtained, per reference 1, is as follows:

\[ \frac{K_4K_5}{\tau_7S + 1} \]

The processor gain \( K_4 \) in both outer and inner gimbal drive is 7.0, as predetermined by design of the processor network (if processor). This means that the processor filter gain \( K_5 \) must be designed for 7.3 calculated as follows:

\[ K_5 = \frac{R_3}{R_1} = 7.3 \text{ volts/volt (outer gimbal)} \]

\[ K_4 = \frac{R_40}{R_39} = 7.3 \text{ volts/volt (inner gimbal).} \]

The processor filter time constant \( \tau_7 \) is calculated as follows:

\[ \tau_7 = R_2 \times C_1 = 0.024 \text{ second (outer gimbal)} \]

\[ \tau_7 = R_40 \times C_10 = 0.024 \text{ second (inner gimbal).} \]

b. ERROR/RATE SUMMER. The error/rate summer sums the track error and rate (stabilization) signals and balances them. To accomplish this, it was necessary to calculate the following gains.

Outer Gimbal.

\[ K_2^1 = \frac{R_8}{R_5} = 9.09 \text{ volts/volt} \]

\[ K_2^2 = \frac{R_8}{R_4} = 3.33 \text{ volts/volt.} \]

Inner Gimbal.

\[ K_2^1 = \frac{R_46}{R_43} = 4.17 \text{ volts/volt} \]

\[ K_2^2 = \frac{R_46}{R_42} = 1.00 \text{ volt/volt.} \]

\( K_2^1 \) is the rate gain (demodulator gain) and \( K_5^1 \) is the error gain (processor gain).
c. COMPENSATION FILTER. A lead-lag compensation network was necessary to provide the required stability. The transfer function for the track-loop compensation filter, per reference 1, is as follows:

\[
\frac{K_3(r_2S+1)(r_5S+1)}{S(r_2S+1)(r_5S+1)(r_3S+1)}
\]

The calculations of the compensation filter gain \(K_3\) and the time constants \(r_2, r_3, r_5, r_6\) for both the inner and outer gimbals are shown in table 14. The last stage of the compensation filter is an integration and translates to gain included in \(K_3\) [integrator gain = 1/R20C5 (outer gimbal) and 1/R58C14 (inner gimbal)].

2. Magnetohydrodynamic Rate Sensor (MHD)

A Minneapolis-Honeywell MHD two-axis rate sensor (GG2500) is used as the stable platform inertial reference. This single instrument closes both inner and outer gimbal stabilization loops. Figure 30 shows the MHD. This small, compact inertial rate measuring device makes it practical to fabricate small radar seekers.

The MHD rate sensor is an angular accelerometer with a liquid metal proof mass. Motion of the proof mass relative to the case is “magnetohydrodynamically” sensed to measure angular acceleration. The accelerometer case is rotated about an axis normal to the sense axis by a small hysteresis-type ac motor; this results in an ac output of the accelerometer where magnitude is proportional to the polar angular rate, and whose phase is a measure of the direction of the polar vector in the rotation plane. A reference generator is provided on the rotation axis whose output is a two-phase ac voltage synchronous with the accelerometer ac output. The two-phase reference generator outputs are used as switching reference voltages for two-phase detectors which convert the ac polar rate measurement into dc voltages which are proportional to the inner and outer gimbal components of the polar rate. The accelerometer output is a sinewave-modulated ac carrier frequency of 200 Hertz where the modulation contains the polar rate information. The gain of the MHD \(K_{MHD}\) is 0.8595 volt rms/radian/second.

3. Demodulator

Dual in-line integrated circuits and discrete components were used for the demodulator when it was first fabricated. Subsequently, Honeywell developed a hybrid package (1030AD06) which is now incorporated into the electronics. The demodulator has quadrature-switched phase detectors which extract quadrature components of the modulation to derive dc signals proportional to the inner and outer gimbal rates. The MHD reference generator provides the switching voltages for the two-phase detectors. The dc conversion requires a low-pass filter following the phase detectors to attenuate the carrier frequency ripple. This filter determines the maximum bandwidth achievable in any stabilization loop using this rate sensor. In this application, the filters limit the bandwidth to 20 Hertz. The transfer function and associated gains, time constants, and damping factors are shown in table 15. For purposes of displaying the derivation of these values, the demodulator is divided into three phases: 200-Hertz bandpass filter, phase detectors/filter, and third-order filter.
Outer Gimbal

\[
K_3 = \frac{(R_{12} + R_{13}) R_{19}}{R_{11} R_{16} R_{20} F_5} = 30.2 \text{ volts/volt}
\]

\[
\tau_2 = (R_{11} + R_{10}) C_2 = 0.0100 \text{ second}
\]

\[
\tau_2' = \frac{R_{12} + R_{13}}{4} + R_{14} C_3 = 0.0102 \text{ second}
\]

\[
\tau_3 = R_{10} C_2 = 0.000984 \text{ second}
\]

\[
\tau_3' = R_{14} C_3 = 0.000990 \text{ second}
\]

\[
\tau_5 = R_{18} C_4 = 0.0990 \text{ second}
\]

\[
\tau_6 = (R_{18} + R_{19}) C_4 = 0.990 \text{ second}
\]

Inner Gimbal

\[
K_3 = \frac{(R_{50} + R_{51}) R_{57}}{R_{49} R_{54} R_{58} C_{14}} = 18.3 \text{ volts/volt}
\]

\[
\tau_2 = (R_{49} + R_{48}) C_{11} = 0.0100 \text{ second}
\]

\[
\tau_2' = \frac{R_{50} + R_{51}}{4} + R_{52} C_{12} = 0.0102 \text{ second}
\]

\[
\tau_3 = R_{48} C_{11} = 0.000984 \text{ second}
\]

\[
\tau_3' = R_{52} C_{12} = 0.000990 \text{ second}
\]

\[
\tau_5 = R_{56} C_{13} = 0.0990 \text{ second}
\]

\[
\tau_6 = (R_{56} + R_{57}) C_{13} = 0.990 \text{ second}
\]

\[
\tau_6' = (R_{56} + R_{57}) C_{13} = 0.990 \text{ second}
\]

Table 14. Track compensation filter calculations.
Figure 30. Magnetohydrodynamic rate sensor (MHD)
\[
\frac{K_{MND}K_{D1}K_{D2}K_{D3}S}{(t_{4C}S+1)(t_{4A}S^2+2\delta_A t_{4A}S+1)(t_{4B}S^2+2\delta_B t_{4B}S+1)}
\]

where

\[
K_{MND} = 0.8503 \, V_{rms/\text{rad. s}} \text{ (MHD gain)}
\]

\[
K_{D1} = 1.11 \times 10^{-3} \, V_{rms/\text{Vrms}} \text{ (200-Hz bandpass filter gain)}
\]

\[
K_{D2} = 4 \, V_{\text{avg}}/V_{\text{rms}} \text{ (rectifier gain)}
\]

\[
K_{D3} = 1.00 \, V_{dc}/V_{\text{avg}} \text{ (third-order filter gain)}
\]

\[
t_{4C} = 0.00308 \text{ second (third-order filter time constant)}
\]

\[
t_{4B} = 0.00105 \text{ second (third-order filter time constant)}
\]

\[
t_{4D} = 0.000214 \text{ second (full-wave rectifier time constant)}
\]

\[
t_{4A} = 0.000760 \text{ second (200-Hz bandpass filter time constant)}
\]

\[
\delta_B = 0.053 \text{ (third-order filter damping factor)}
\]

\[
\delta_A = 1.00 \text{ (200-Hz bandpass filter damping factor)}
\]

Table 15: Demodulator transfer function and values.

### a. 200-Hertz Bandpass Filter

The 200-Hz bandpass filter is used to pass the 200-Hz signal received from the MHD and attenuate all other frequencies. Figure 31 is a simplified schematic taken from reference 2, which indicates how to derive its transfer function. The component values are shown in table 16: the transfer function and calculations of the gain \(K_{D1}\), the time constant \(t_{4A}\), and the damping factor \(\delta_A\) in table 17.

### b. Phase Detectors/Filter

The phase detectors produce the quadruplexing action necessary to decipher the incoming 200-Hz signal. A 400-Hz reference is generated by the MHD and is transformed to a 400-Hz square wave. This square wave is used to switch the phase detectors that separate the inner gimbal motion from the outer gimbal motion that results from the incoming 200-Hz signal. The two-phase detectors are tied in tandem. The filter following the phase detectors attenuates the switching ripple. A simplified schematic of the phase detectors/filter is shown in figure 32. The component values are shown in table 18. The transfer function and calculations of the gain \(K_{D2}\) and the time constant \(t_{4C}\) are shown in table 19.

---

\[ A_{V_o} = \frac{R_8 \cdot R_9}{R_9} \]

\[ \frac{V_o}{V_s} = \frac{A_{V_o} Z_3 Z_4}{Z_3 (Z_1 + Z_2 + Z_4) + Z_1 Z_2 + Z_1 Z_4 (1 - A_{V_o})} \]

\[ Z_1 = \frac{R_9}{C_7^5} \]

\[ Z_2 = R_6 \]

\[ Z_3 = \frac{R_7}{R \cdot C_8^3 + 1} \]

Figure 31. 200-Hz bandpass filter schematic.

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R5</td>
<td>162K</td>
</tr>
<tr>
<td>R6</td>
<td>51.1K</td>
</tr>
<tr>
<td>R7</td>
<td>316K</td>
</tr>
<tr>
<td>R8</td>
<td>21.5K</td>
</tr>
<tr>
<td>R9</td>
<td>46.4K</td>
</tr>
<tr>
<td>C7</td>
<td>0.01 \mu F</td>
</tr>
<tr>
<td>C8</td>
<td>4700 pF</td>
</tr>
<tr>
<td>C9</td>
<td>100 pF</td>
</tr>
</tbody>
</table>

Table 16. 200-Hz bandpass filter component values.
\[
\frac{K_{D1}}{j^2A + SB + 1}
\]

\[
K_{D1} = 1.11 \times 10^{-3} \frac{V_{rms}}{V_{rms}} = \frac{A_{40}R_6R_7C_7}{R_5 + R_6}
\]

\[
A = 5.77 \times 10^{-7} = \frac{R_5R_6R_3C_7C_8}{R_5 + R_6}
\]

\[
B = 1.52 \times 10^{-3} = R_5R_6R_7C_8 + R_6R_7C_8 + R_6R_7C_7 + (1 - A_{40})R_5R_7C_7
\]

Roots

\[
(t_{4A}S)^2 + 2b_A t_{4A}S + 1
\]

\[
t_{4A} = 0.00076 \text{ second}
\]

\[
b_A = 1.0
\]

Gain at 200 Hz = 0.73.

Table 17. 200-Hz bandpass filter calculations.

![Phase detectors/filter schematic](imageURL)

Figure 32. Phase detectors/filter schematic.
### Table 18. Phase detectors/filter component values.

<table>
<thead>
<tr>
<th>Outer Gimbals</th>
<th>Inner Gimbals</th>
</tr>
</thead>
<tbody>
<tr>
<td>R10 R23</td>
<td>6.34K</td>
</tr>
<tr>
<td>R11 R24</td>
<td>6.34K</td>
</tr>
<tr>
<td>R12 R25</td>
<td>65K (select)</td>
</tr>
<tr>
<td>R13 R26</td>
<td>10K</td>
</tr>
<tr>
<td>R14 R27</td>
<td>10K</td>
</tr>
<tr>
<td>R15 R28</td>
<td>39.2K (select)</td>
</tr>
<tr>
<td>R16 R29</td>
<td>6.34K</td>
</tr>
<tr>
<td>R17 R30</td>
<td>37.4K</td>
</tr>
<tr>
<td>R18 R31</td>
<td>56.2K</td>
</tr>
<tr>
<td>C10 C16</td>
<td>3300 pF</td>
</tr>
</tbody>
</table>

### Table 19. Phase detectors/filter calculations.

\[
K_{D2-} = \frac{R_{12}}{R_{10} + R_{11}} \quad 5.07 \frac{V_{\text{rms}}}{V_{\text{rms}}} \quad \text{negative half-cycle gain}
\]

\[
K_{D2+} = \frac{(R_{17} + R_{18})(R_{11} + R_{12})}{R_{11}(R_{15} + R_{16} + R_{17} + R_{18})} \quad 5.07 \frac{V_{\text{rms}}}{V_{\text{rms}}} \quad \text{positive half-cycle gain}
\]

\[
K_{D2} = K_{D2-} \times \frac{0.636}{0.707} \quad 4.56 \frac{V_{\text{avg}}}{V_{\text{rms}}}
\]

\[
\tau_{410} = R_{12}C_{10} = 0.000214 \text{ second}.
\]

\[
K_{D2} = \frac{R_{25}}{R_{23} + R_{24}} \quad 5.07 \frac{V_{\text{rms}}}{V_{\text{rms}}} \quad \text{negative half-cycle gain}
\]

\[
K_{D2+} = \frac{(R_{30} + R_{31})(R_{24} + R_{25})}{R_{24}(R_{28} + R_{29} + R_{30} + R_{31})} \quad 5.07 \frac{V_{\text{rms}}}{V_{\text{rms}}} \quad \text{positive half-cycle gain}
\]

\[
K_{D2} = D_{D2+} \times \frac{0.636}{0.707} \quad 4.56 \frac{V_{\text{avg}}}{V_{\text{rms}}}
\]

\[
\tau_{410} = R_{25}C_{16} = 0.000214 \text{ second}
\]
c. THIRD-ORDER FILTER. The third-order filter is a low-pass filter that follows the phase detector/filter used to attenuate the carrier frequency ripple. This filter determines the maximum bandwidth. Figure 33 is a simplified schematic of the third-order filter. The component values are shown in Table 20 and the transfer function and calculations (τ₉B and τ₆B) and damping factor (δB) in Table 21. The equation for the transfer function was obtained from reference 3.

4 APPROXIMATED MHD/DEMODULATOR TRANSFER FUNCTION

For ease of implementing on the computer, reference 1 used the following transfer function to approximate the MHD/demodulator circuits:

\[
\frac{K_{\text{MHD}}K_2}{(\tau_4 s + 1)^3}
\]

The same transfer function and the following data apply for both inner and outer gimbal electronics. The MHD gain (K_{\text{MHD}}) is 0.8595 volt rms/radian/second. The demodulator gain (K_s) is 3.33 volts dc volts rms. K_3 is equivalent to K_{D1}K_{P2}K_{D3} of the calculated transfer function. A time constant of 0.0015 second (τ₄) was calculated as an approximation of the MHD demodulator circuits.

IV. MECHANICAL DRAWINGS

It is recognized that the drawings in this section are not comprehensive, however, it is believed that they are complete enough to aid in analysis of the servo platform system. Figure 34 is an outline drawing of the control panel. The control panel is made of sheetmetal.

The last figures in this document are the mechanical drawings of the platform and the associated mountings to the platform. Figure 35 shows the mounting of the bail ring to the base. Figure 36 shows the base mount dimensions. Figure 37 shows the bail ring and bearings. Figure 38 shows the roller and spacer used to hold the bail ring. Figure 39 shows the inner motor mount. Figure 40 shows the inner potentiometer mount. Figure 41 shows the outer potentiometer mount.

---

Figure 33 Third-order filter schematic.

<table>
<thead>
<tr>
<th>Outer Inner Components</th>
<th>Outer Gainbal</th>
<th>Inner Gainbal</th>
</tr>
</thead>
<tbody>
<tr>
<td>R20 R33</td>
<td>100K</td>
<td>100K</td>
</tr>
<tr>
<td>R21 R34</td>
<td>100K</td>
<td>100K</td>
</tr>
<tr>
<td>R22 R35</td>
<td>100K</td>
<td>100K</td>
</tr>
<tr>
<td>C12 C18</td>
<td>0.022 µF</td>
<td>0.022 µF</td>
</tr>
<tr>
<td>C13 C19</td>
<td>0.047 µF</td>
<td>0.047 µF</td>
</tr>
<tr>
<td>C14 C20</td>
<td>3300 pF</td>
<td>3300 pF</td>
</tr>
</tbody>
</table>

Table 20 Third-order filter component values.
\[
\frac{K_{D3}}{S^3A + S^2B + SC + 1}
\]

<table>
<thead>
<tr>
<th>Inner Gimbal</th>
<th>Outer Gimbal</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_{A3} )</td>
<td>( C_{12}C_{14} )</td>
</tr>
<tr>
<td>( B )</td>
<td>( C_{12}C_{14} )</td>
</tr>
<tr>
<td>( C )</td>
<td>( C_{12}C_{14} )</td>
</tr>
</tbody>
</table>

\[
K_{A3} = C_{18}C_{19}C_{20}R_{33}R_{34}R_{35}
\]
\[
B = C_{18}C_{19}(R_{33} + R_{24}) + C_{18}C_{20}R_{33}(R_{34} + R_{35})
\]
\[
C = C_{18}R_{33} + C_{20}(R_{33} + R_{34} + R_{35})
\]

Solution

- \( A = 3.4122 \times 10^{-9} \)
- \( B = 1.452 \times 10^{-6} \)
- \( C = 3.19 \times 10^{-3} \)

Roots

\[
(\gamma_{41}^*S + 1)/(\gamma_{43}S^2 + 2\gamma_{48}B^\prime S + 1)
\]
\[
7.4C = 0.00308 \text{ second}
\]
\[
7.4B = 0.00108 \text{ second}
\]
\[
\gamma_{B} = 0.053 \text{ second}
\]

Table 21: Third-order filter calculations.
Figure 34. Control panel outline.
Control panel outline and hinged lid (perspective).
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<th>MAT'L</th>
<th>QTY</th>
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Figure 35. Platform drawing sheet 1: bail ring mounting.
ALL DIMENSIONS IN INCHES.

Figure 37.
Figure 37. Platform drawing sheet 7: ball ring and bearings.
Figure 38. Platform drawing sheet 4: roller and spacer.
Figure 93. Platform drawing sheet 5: inner motor mount.

ALL DIMENSIONS IN INCHES

TRANSFER MOUNTING HOLES FROM MOTOR

CLEARANCE HOLE AND CENTER BORE
FOR #8 SHECS TO DEPTH SHOWN

3.0 OF BAL RING

2.156 R

3.75 R

0.969 R

0.969 R

0.375

0.750

1.25

0.100

0.025
Figure 41. Platform drawing sheet 7: outer potentiometer mount.