Amplifier Board Design Specifications

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This document describes the layout and function of the PCB labeled RTC_AMP_04 REV002.

**Physical Description**

The amplifier board is a 4” by 4” printed circuit board (PCB). The thickness of this board is 0.062”. The amplifier board consists of six different layers. The top and bottom layers of this board are used for component placement and trace routing. The inner 4 layers consist of two voltage planes and two ground planes. These layers are used to provide power and ground to the various components loaded onto the board. There are 32 identical channels of electronics that are located on the top surface of the PCB. Each of these channels includes two different integrated circuit (IC) chips as well as 0603 (physical dimensions of 0.063” by 0.031”) surface mount resistors and capacitors. Also included on the PCB are 4 sets of test points, 2 sets of jumper pins, 5 connectors, and 5 mounting holes that are 0.125” diameter. There is also a center cutout that measures 0.71” by 0.71”. This cutout is located in the center of the board. The entire board was designed to have rotational symmetry. This symmetry allows the board to be rotated by 180 degrees. Figure 1 shows a diagram of the top side of the amplifier PCB.

![Figure 1: Top side layout of the amplifier PCB.](image-url)
**Functional Description**

The amplifier board serves as an interface between a spatial radiation sensor and a computer system. The purpose of this interface is to modify signals output by the radiation sensor into a binary signal that is usable by a FPGA based computer system. The radiation sensor is designed with 16 X and 16 Y channels. The 16 X channels are located on the front side of the sensor, and the 16 Y channels are located on the rear side of the sensor. These 32 outputs serve as the inputs into the amplifier board system through a connector on the amplifier board. The input signals are then passed through a series of op-amp circuits. Figure 2 displays this circuit chain.

![Figure 2](image_url)

*Figure 2: Schematic of the electronics implemented on the amplifier board.*

The schematic diagram in Figure 2 consists of 4 sections that when combined produce the desired pulse shaping necessary to construct a binary signal. These 4 sections are a coupling circuit, integrating circuit, inverting amplifier circuit, and a comparator circuit. The function of each of these subsections follows.

**Coupling circuit**

![Figure 3](image_url)

*Figure 3: Schematic diagram of the coupling circuit used in the amplifier board.*
The coupling section consists of two components. These components are a bias resistor and a coupling capacitor. A large resistance is used for the bias resistor, typically on the order of mega ohms. This resistor is used to make a connection to a large DC voltage that can be used to bias the radiation sensor. A bias voltage can be applied to the radiation sensor to increase the depletion with which will improve the collection of any charge created in the sensor by a radiation strike. On the amplifier board, the front side channels are connected to a two pin header that can be connected to a voltage bias pin. The rear side channels are connected to a two pin header that can be connected to the ground planes in the amplifier board.

The coupling capacitor in this circuit serves two purposes. The first is to AC couple the circuit so that any DC offset on the input signals is removed before the amplifier circuitry. The second purpose is to set the input time constant to the circuitry. The input time constant can be calculated as:

$$\tau = R_{\text{bias}} \times C_{\text{coupling}}$$

This time constant sets the threshold for the longest pulse width that can be input into the circuit. A pulse width longer then this maximum will be blocked by the coupling capacitor.

Integrator circuit-

![Integrator Circuit Diagram](image)

Figure 4: Schematic of the integrating circuit.

The op-amp used for this circuit is a LMV324. This device is powered by +3 V and -3 V. The output from the coupling circuit is input into the inverting input and the non-inverting input of the amplifier is grounded. A RC combination is connected in parallel between the output and the inverting input of the device. The integrating circuit works exactly as other integrators function. When a rising edge is seen at the input to the circuit, the circuit starts to integrate at a rate determined by the integrator time constant. This time constant is:

$$\tau_{\text{int}} = R_1 \times C_1$$

When a constant input is reached, the circuit stops integrating and the capacitor discharges based on the time constant formed by the integrating capacitor and the resistive combination of the integrating resistor and the output resistance of the amplifier. Finally, when a falling edge is seen at the input to the circuit, the circuit starts to negatively integrate at the same rate as before. Again, the capacitor discharges when a constant input is reached. This integration process
allows the input pulse to be stretched. This circuit also can apply some gain to the signal since the device is capable of integrating to either the positive or negative voltage rail depending on the shape of the input pulse.

Amplifier circuit-

![Amplifier Circuit Diagram]

Figure 5: Schematic of the amplifying circuit.

The op-amp used for this circuit is a LMV324 (datasheet available online). This device is powered with +3 V and -3 V. The output from the integrator is input into the inverting input of the device. The non-inverting input of the device is grounded. The purpose of this stage is to amplify the input signal. This amplification is achieved by implementing an inverting amplifier configuration. The gain of this circuit is:

\[
\frac{V_{out}}{V_{in}} = -\frac{R_3}{R_2}
\]

Comparator circuit-

![Comparator Circuit Diagram]

Figure 6: Schematic of the comparator circuit.

The op-amp used for this circuit is a LMH6601 (datasheet available online). This device is powered with +3 V and 0 V. The output of the amplifier circuit is input into the non-inverting input of this device. The inverting input of the device is connected to a tunable DC voltage that is used as the reference level. This final stage is used to produce the binary signal. The comparator circuit achieves this by outputting either the positive voltage rail (+3 V) or the negative voltage rail (0 V). If the input signal is at a voltage higher than the reference voltage, the output of the comparator is +3 V. If the input signal is at a voltage lower than the reference voltage, the output of the comparator is 0 V. Thus by
setting the reference level, the overall sensitivity can be tuned. This output signal is then passed to a pin header and can be output to a FPGA board.

**I/O Pins**

As mentioned before, there are 5 connectors on the amplifier board. Three of these connectors are for inputs into the board, and the other two connectors serve as the outputs. Two of the input are for powering the board and providing the bias and reference voltages. The other input connector is for the output signals from the radiation sensor. All of the connectors on the board have 0.100” between the pins. There are two different ways to determine pin 1 of the connector depending on its orientation. If the connector is oriented horizontally, then pin 1 is in the bottom row of pins and leftmost pin. If the connector is oriented vertically, then pin 1 is in the left row of pins and the topmost pin. If connectors have not been loaded on the amplifier board, then pin 1 is denoted by a square footprint while the rest of the pins have circles as footprints.

**Input from radiation sensor**

The connector that receives the input to the amplifier board is labeled CON1. This connector is a 2 by 17 connector. The radiation sensor package board is plugged into this connector. The pin out for this particular connector is seen in Figure 7.

![CON1 Pin out](image)

In Figure 7, GND denotes a grounded pin, R denotes a back side sensor channel, and F denotes a front side sensor channel. The square indicates pin 1 of the connector. The two center pins (17 and 18) are grounded to provide a reference level for the sensor signals.

**Input Power**

The amplifier board has two connectors that provide power to the board, CON2 and CON3. These two connectors have 180 degree rotational symmetry with respect to each other. Each connector carries 5 different voltages. These levels are a bias voltage, a reference voltage, a negative power voltage, a positive power voltage, and ground. Figures 8 and 9 show the pin out for both connectors.
In the above figures, the label GND indicates a grounded pin. The label V B indicates a bias voltage pin. This voltage is used to bias the sensor and increase the depletion width of this device. The label V R shows a reference voltage pin. This reference voltage is used to provide a level for the comparator stage that was described previously. Both the reference and bias voltage can be tuned to different levels in order to optimize the performance of the device. The final value for these voltages will be determined through testing of the amplifier board. The -3 V and +3 V pins indicate the voltages necessary to power the various circuits on the board. Each of these voltages is connected to a voltage plane contained within the PCB. Again, pin 1 is shown as a square.

Output pins to FPGA-

The amplifier board has two connectors that output signals to the FPGA computer system. These are CON4 and CON5. Each of these connectors is a 2 by 32 pin device. Figures 10 and 11 show the pin out for these connectors. Only the first 32 pins are shown in these figures. The other pins are left off because these pins do not carry signals of any importance on a single board. The extra signals allow for the board to be rotated by 180 degrees and stacked onto another amplifier board. These extra pins are for the outputs that would be achieved by a two board stack, making the total outputs 64.
Figure 10: Pin out for CON5 on the amplifier board.

Figure 11: Pin out for CON4 on the amplifier board.
In the above figures, the ground pins are labeled GND. Using the same notation as previously, the signals containing an R represent back side channels and the signals containing an F represent front side channels. As mentioned before, half of the pins on these connectors were omitted since no output signals are carried on these pins. The following table summarizes the values of the pins that were left off.

<table>
<thead>
<tr>
<th>Ground</th>
<th>CON5</th>
<th>CON4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pins 33, 35, 37, 39, 41, 43, 45, 47, 49, 51, 53, 55, 57, 59, 61, and 63</td>
<td>Pins 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, and 64</td>
<td></td>
</tr>
<tr>
<td>No signal</td>
<td>Pins 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, and 64</td>
<td>Pins 33, 35, 37, 39, 41, 43, 45, 47, 49, 51, 53, 55, 57, 59, 61, and 63</td>
</tr>
</tbody>
</table>

**Jumpers and Test Points**

**Jumpers**

The amplifier board has two jumpers labeled J1 and J2. Each of these jumpers is a two pin header on a 0.100” pitch. By placing a two pin jumper on J1, one side of the bias resistors for all of the back side channels (R1-R16) can be connected to ground. By placing a two pin jumper on J2, one side of the bias resistor for all of the front side channels (F1-F16) can be connected to the bias voltage pins in CON2 and CON3.

**Test Points**

The amplifier board is designed with 4 different test points. These points allow easy access to parts of the amplifier chain for 4 different channels. The test points are labeled T1, T2, T3, and T4. The following table shows the channels that these test points correspond to.

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Sensor Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>R1</td>
</tr>
<tr>
<td>T2</td>
<td>R16</td>
</tr>
<tr>
<td>T3</td>
<td>F1</td>
</tr>
<tr>
<td>T4</td>
<td>F15</td>
</tr>
</tbody>
</table>

Figure 12 displays one of the four test points.

![Figure 12: Schematic for one of the test points included on the amplifier board.](image)
In Figure 12, there are two pins labeled ‘I’ and ‘A’ respectively. The pin labeled ‘I’ is for testing the output of the integrating amplifier circuit. The pin labeled ‘A’ is for testing the output of the inverting amplifier circuit. These two points provide intermediate testing of the signal along the amplifier chain.

**Power Requirements**

The amplifier board requires three voltage levels to power the various chips. These voltages are +3.3 V, 0 V, and -3.3 V. Each of these ICs also draws a certain amount of current. The tables below show the current drawn for the desired operating voltages

<table>
<thead>
<tr>
<th></th>
<th>+3.3 Volts</th>
<th>-3.3 Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Nominal</td>
</tr>
<tr>
<td>( \text{I}_{cc} ) (A)</td>
<td>-</td>
<td>0.36(^1)</td>
</tr>
</tbody>
</table>

1. Calculated values from the information provided in the datasheet for the various op amps.
2. Measured value when power the amplifier board with the sensor connected.
Appendix A: Additional Op Amp Info

If more information is needed for the amplifiers used, the datasheets can be located at the following web pages. Requirements for the LMV324 are shown first and the information for the LMH6601 follows.

http://www.national.com/mpf/LM/LMV324.html#Overview

http://www.national.com/pf/LM/LMH6601.html#Overview

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Positive Supply Voltage</th>
<th>Negative Supply Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMV324</td>
<td>(Required Voltage)</td>
<td>(Required Voltage)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.7 V DC Supply Current</th>
<th>5.0 V DC Supply Current</th>
<th>Number of ICs</th>
</tr>
</thead>
<tbody>
<tr>
<td>(single chip)</td>
<td>(single chip)</td>
<td>(needed for amp board)</td>
</tr>
<tr>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>16</td>
</tr>
<tr>
<td>2.60E-04</td>
<td>4.10E-04</td>
<td></td>
</tr>
<tr>
<td>Max Amps</td>
<td>Max Amps</td>
<td></td>
</tr>
<tr>
<td>6.80E-04</td>
<td>1.16E-03</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.7 V Positive Supply Current</th>
<th>5.0 V Positive Supply Current</th>
<th>2.7 V Negative Supply Current</th>
<th>5.0 V Negative Supply Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>(all 16 chips)</td>
<td>(all 16 chips)</td>
<td>(all 16 chips)</td>
<td>(all 16 chips)</td>
</tr>
<tr>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>Typical Amps</td>
</tr>
<tr>
<td>4.16E-03</td>
<td>6.56E-03</td>
<td>4.16E-03</td>
<td>6.56E-03</td>
</tr>
<tr>
<td>Max Amps</td>
<td>Max Amps</td>
<td>Max Amps</td>
<td>Max Amps</td>
</tr>
<tr>
<td>1.09E-02</td>
<td>1.86E-02</td>
<td>1.09E-02</td>
<td>1.86E-02</td>
</tr>
</tbody>
</table>
Combining the above data produces the total voltage and current requirements for the amplifier board. These numbers are shown below.

### Voltage Requirements

<table>
<thead>
<tr>
<th>Voltage Requirements</th>
<th>Positive Supply Voltage</th>
<th>Negative Supply Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(total amp board)</td>
<td>(Required Voltage)</td>
<td>(Required Voltage)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

### Current Requirements

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Positive Supply Voltage</th>
<th>Negative Supply Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMH6601</td>
<td>(Required Voltage)</td>
<td>(Required Voltage)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.7 V DC Supply Current</th>
<th>5.0 V DC Supply Current</th>
<th>Number of ICs</th>
</tr>
</thead>
<tbody>
<tr>
<td>(single chip)</td>
<td>(single chip)</td>
<td>(needed for amp board)</td>
</tr>
<tr>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>32</td>
</tr>
<tr>
<td>9.00E-03</td>
<td>9.60E-03</td>
<td></td>
</tr>
<tr>
<td>Max Amps</td>
<td>Max Amps</td>
<td></td>
</tr>
<tr>
<td>1.06E-02</td>
<td>1.15E-02</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.7 V Positive Supply Current</th>
<th>5.0 V Positive Supply Current</th>
<th>2.7 V Negative Supply Current</th>
<th>5.0 V Negative Supply Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>(all 32 chips)</td>
<td>(all 32 chips)</td>
<td>(all 32 chips)</td>
<td>(all 32 chips)</td>
</tr>
<tr>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.88E-01</td>
<td>3.07E-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Amps</td>
<td>Max Amps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.39E-01</td>
<td>3.68E-01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.7 V Positive Current Required</th>
<th>2.7 V Negative Current Required</th>
<th>5.0 V Positive Current Required</th>
<th>5.0 V Negative Current Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>(total amp board)</td>
<td>(total amp board)</td>
<td>(total amp board)</td>
<td>(total amp board)</td>
</tr>
<tr>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>Typical Amps</td>
<td>Typical Amps</td>
</tr>
<tr>
<td>2.92E-01</td>
<td>4.16E-03</td>
<td>3.14E-01</td>
<td>6.56E-03</td>
</tr>
<tr>
<td>Max Amps</td>
<td>Max Amps</td>
<td>Max Amps</td>
<td>Max Amps</td>
</tr>
<tr>
<td>3.50E-01</td>
<td>1.09E-02</td>
<td>3.87E-01</td>
<td>1.86E-02</td>
</tr>
</tbody>
</table>