Mercury PFPD Electronics Circuit Description
Revision: 1
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1. Applicability

This document applies to Mercury PFPD schematic 03-925069-00, Revision C1.

2. Power supplies and grounds

There are four grounds serving the PFPD electronics circuitry. Ground 1 is the return for the +5V digital supply. It is connected directly to Ground 4, the unregulated +24V return, at the card edge connector on the Mother board. The analog return is Ground 2, which provides a low-noise return for the ±15V and +5.25V supplies. Ground 3 is the reference for analog signal distribution, which carries almost no DC current. All of the grounds must be tied together externally for the board to function properly.

Three RC filters remove noise from the analog power supplies. These consist of R464 with C47, R47 with C48, and R48 with C49.

3. Digital circuits

U11 decodes bus address information to access buffered shift register U10, latch U12 and buffer U14, as well as a dual DAC. The latch holds all of the digital control signals for the board, while the buffer transmits the board identification number and status data to the bus.

Commands and data for the on-board microcontroller (U9, an 87C751) are transferred from the bus through shift register U10. When a byte is directly latched into the register, flip-flop U7 is simultaneously set. Its output (pin 5) tells the microcontroller that a byte is available. The microcontroller then pulses U10-13 low to transfer the latched data into the shift register, followed by 8 pulses to U10-11 to shift the data out through U10-9. When all of the data bits have been read, the microcontroller pulses U7-1 low, clearing the latch to inform the CPU that the buffer is available for another byte.

Most of the outputs of the 87C751 control analog functions, which may be disturbed by noise on the digital control lines. VR2 regulates the +5V power for U9, keeping the noise from the system +5V supply off of the microcontroller's outputs.

The reset signal for the microcontroller comes from latch U12. Software must reset U9 with a positive pulse lasting at least one microsecond before it will execute its program.

4. Electrometer

AR2 (pins 1-3) converts the small current from the photomultiplier tube into a voltage. On the most sensitive range ("Range 10"), both switch sections 1 and 2 (pins 2-3 and 6-7) of U3 are open, leaving R21 as the only feedback resistor. The effective feedback resistance is reduced on ranges 9 and 8 by closing switch section 1 or 2, respectively, placing either R19 or R20 in parallel with R21, for feedback resistances of 2M or 198k. These resistances produce nominal full-scale output voltage (10mV at AR1-1) at currents of $5x10^{-10}$, $5x10^{-9}$, and $5x10^{-8}$ on the three ranges, which are 5 times higher than the currents implied by the Range settings.

The range setting is directly controlled by the microcontroller (U9), remaining static only when the user selects Range 10. On the less sensitive ranges, AR2 is set to the most sensitive range while waiting to detect the start of a flame pulse, changing to the selected range setting only during the integration time. Since the microcontroller samples the user range selection only once during each flame pulse cycle, the setting at AR2 will not reflect changes in the method until the next pulse occurs.

Capacitor C19 sets the time constant of the electrometer to 100µs on Range 10. This is about 1000 times faster than the standard FPD electrometer, in order to follow the rapid changes in current during the flame pulses. Since the noise is low on the less sensitive ranges, no extra capacitors are used to set the time constant on these ranges, and the time constant falls to 10µs and 1µs on Ranges 9 and 8, respectively.

A switchable current source is provided at the electrometer input to test entire signal path. As long as latch output U12-12 remains low, switch U8 (pins 6-8) is turned on. This holds Q1 off, disconnecting the diagnostic current from the electrometer input. Turning off U8 allows the emitter of Q1 to drop to -600mV, placing 9.4V across R29 and injecting 470nA into the input.

5. Gated Integrator

The output of the electrometer is fed to the integrator, AR2 (pins 5-7), through a set of resistors and analog switches. Between pulses, section 4 of U4 (pins 14-15) is open, while section 1 of U4 (pins 2-3) is closed. This keeps C22 discharged and holds the output of AR2 (pin 7) near ground. When the desired integration time begins, the shunt switch across C22 is opened, and section 4 of U4 is closed. A current proportional to the output voltage of the electrometer then flows into C22 through the resistors connected between AR2-1 and U4-14. The integrator output ramps in a negative direction until U4 (pins 14-15) is opened again. The current then stops flowing, and the integrator output remains constant.

Optimum dynamic range exists when a voltage of +10V at the electrometer output results in a peak integrator output voltage of -10V at the end of the integration time. Since the integration time varies with the mode selection, the resistance between the electrometer output and the integrator input must vary in direct proportion to the integration time, in order to keep the peak integrator output voltage constant. As the microcontroller adjusts the integration time, it also turns on the appropriate analog switches, shunting some combination of resistors R22-R25, R31, and R32, to leave a net resistance which is proportional to the integration time. Since the integration time is much shorter in "SWEEP" mode than in normal operation, a dedicated resistor (R30) is switched in for this mode, with all other integrator gain-setting analog switches open.

6. Sampler and Filter

At the end of the integration period, switch U5 (pins 14-15) is turned on for 500µs, charging C24 to the output voltage of the integrator. The integrator can then be reset without affecting the detector output. The high input impedance of AR3 (a unity-gain buffer) at pin 3 isolates C24 from the input of the following filter, but leakage currents of a few picoamps may still exist. The sawtooth waveform produced by the leakage is not visible at the detector output at normal pulse rates. If no pulses are detected for one second, the microcontroller initiates a new cycle of integration and sampling anyway, preventing the sampler from slowly drifting off into saturation.

A filter consisting of AR3 (pins 5-7) and its associated resistors and capacitors smooths the steps coming from the sampler. It is a two-pole filter, having repeated real poles, with a bandwidth of 0.9Hz. The DC gain of the filter is -1, to compensate for the inversion which takes place in the integrator. R26 and C25 prevent glitches due to switching of the system ADC multiplexer from disturbing AR3.

7. Trigger Comparator

The ouput of the electrometer (AR2-1) connects to the inverting input of the trigger comparator, U6. Between pulses, the electrometer output voltage is lower than the threshold voltage at the noninverting input, and the open-collector output of U6 is pulled high by R43. When the electrometer voltage rises above the threshold voltage, the comparator output goes low, generating an interrupt to the microcontroller and starting the timing period. R42 provides about 15mV of hysteresis to prevent oscillations during the relatively slow variations of the electrometer output voltage.

The desired trigger voltage at the noninverting input of U6 is set by section A of dual DAC U13. AR4 (pins 1-3), together with R40 and R41, inverts the +10V reference voltage, applying -10V to the reference input of U13. The DAC output (at AR4-7) is then 10 * N / 256, where the DAC setting *N* varies between 0 and 255. R35 and R36 divide the DAC output by about 4, giving a trigger voltage range at U6-2 of 0 to 2.55V. Since the comparator is fast enough to respond to narrow noise glitches, C30 is placed inside the electrometer shield to remove digital noise. R34 prevents C30 from slowing down the hysteresis feedback excessively.

Triggering always occurs at 10nA input current in the normal operating modes, since the electrometer is always set to the most sensitive range while waiting for a trigger pulse. If a lower DC level is applied to the electrometer input, the comparator output will remain high, and the microcontroller will initiate integration cycles once per second. At higher DC input levels, the comparator is constantly in the triggered state. The microcontroller then starts a new cycle as soon as the 70ms holdoff period from the previous cycle expires, producing 14 cycles per second. This faster rate makes viewing waveforms on an oscilloscope much easier and speeds the reaction of the output voltage to operator actions.

8. Igniter Supply

The igniter power supply provides a regulated current of 3.2ADC to a load of about 0.5 to 0.7 Ohms. The +24VDC system supply voltage is stepped down through an LT1074 switching regulator (U2), connected in the buck topology. The regulator operates at 100kHz, connecting and disconnecting the +24V input with its output (pin4). When pin 4 is switched to +24V, the current in L1 rises. When the switch is opened, the voltage at pin 4 drops rapidly to -0.5V, and the inductor current, which had been flowing through VR4, flows through CR9. C13 smooths the output voltage as the current in L1 rises and falls.

Load current flows through R14, creating a voltage drop of 0.32V at 3.2A. The difference between this voltage and the voltage set by R17 and R18 is amplified in AR1 and applied to the PWM comparator input of U2. The duty cycle of the regulator shifts in the appropiate direction to force the two voltages to be the same. R16 and C18 set the bandwidth of the feedback loop to prevent oscillations. The error amplifier in U2 is not used, since it requires an input voltage of +2.2V, which is much too large for this application. C17 keeps high-frequency noise out of the error amplifier input, so that it does not interfere with the external amplifier control.

The igniter power supply is turned on and off with a signal from latch U12-19. This signal is inverted by U7 (pins 8-13), which is a flip-flop connected as an inverter. (The inversion is required to turn the supplies off when latch U12 is reset by the SYSENAB signal.) When the control signal from U7-9 is high, diode CR10 is turned on. Pin 6 of AR1 is pulled well above pin 5, forcing the output of AR1 to ground and lowering the output current close to zero.

U11 (pins 9-15) decodes two signals from latch U12 (pins 15-16), to select which one of three diagnostic voltages is applied to the Detector Miscellaneous input of the system ADC. Selecting the Y2\ output of U11 (pin 10 low) turns on analog switch U8 (pins 9-11). The voltage at the top of R14, which is equal to the igniter current (in amps) divided by 10, is applied to the ADC multiplexer input. R39 limits current through U8 if there is a short at the multiplexer input, preventing destruction of the switch and pcb traces. Selecting the Y1\ output of U11 (pin 11 low) applies the voltage on the high side of the igniter, divided by 11 through R37 and R38, to the ADC input. The division is necessary, because the igniter voltage will rise to the full +24VDC supply voltage when the igniter is disconnected.

9. High Voltage Supply (sheet 2)

The high voltage power supply is a balanced inverter which is adjustable from -300 to -900 Volts. A TL494 switching regulator controller (U1) furnishes the reference voltage, two error amplifiers, a pulse-width modulator, and the power switching transistors on a single chip.

One error amplifier regulates the high voltage output, which is summed with the output of a DAC (U13, section B) through R7 and R8, and applied to the inverting input of the amplifier (U1-2). Since the noninverting input (U1-1) is held at ground, the inverting input must also remain at zero volts, forcing the high voltage output at J2 to vary from 0 to -900 VDC as the DAC output voltage varies from 0 to +10VDC. Feedback from the amplifier output (U1-3) through R4 and C2 determines the regulator loop characteristics and maintains stable operation. Capacitor C4 reduces coupling of output switching noise and nearby digital signals into the amplifier input.

If the detector's photomultiplier tube is exposed to ambient light with high voltage applied, excessive anode current will flow. Damage is prevented under such conditions by shutting down the high voltage supply whenever the detector output signal exceeds ten to twelve volts. Under normal signal conditions, the noninverting input of the second error amplifier (U1-16) is held negative through R11. CR7 prevents the input from dropping below -300mV, which would cause the device to malfunction. When the signal voltage rises above +10V, current through R10 pulls U1-16 positive. The error amplifier output (U1-3) also rises, with a gain of three (determined by R3 and R9), thus reducing the supply voltage. Note that the outputs of both error amplifiers appear at U1-3. Since they share a common pull-down resistor, the amplifier whose output is more positive controls the composite output terminal.

Pulse-width modulation at a 20kHz rate (set by R1 and C3) controls the supply output voltage. The ends of the primary winding of T1 are alternately connected to ground through R2 and R6 by the switching transistors in U1. The resistors limit the primary current, allowing pulse-width control of the output voltage and protecting the switching transistors if the supply is shorted. Diodes CR1 and CR2 prevent the ends of the primary from dropping below ground, which also clamps the positive excursions at +30V, due to the coupling between the halves of the winding. VR1, C1, and C9 provide a stable, low-impedance source of +15V to the switching supply.

The control signal which turns on the igniter supply (U7-9) also enables the high voltage supply. When this signal is low, the dead-time control input of U1 (pin 4) is pulled low through R13. This sets the dead time, when neither switching transistor is turned on, to its minimum value of 3%. When the control signal is high, the DT pin (U1-4) is raised above 3.5V through CR8, setting the dead time to 100% and shutting down the supply. C5 pulls U1-4 up when the supply is turned on, creating a soft start, as the dead-time control voltage is slowly pulled down through R13.

Transformer T1 has a turns ratio of about 29:1 from the secondary to one half of the primary. The peak secondary voltage of about 275V maximum is quadrupled by the network consisting of CR3-6 and C6-8 and C11. R5 and C10 attenuate the 20kHz ripple and introduce a maximum drop of 75V under normal loading.

Since pin 2 of U1 is at a virtual ground, R12 and R7 divide the high voltage output by a factor of about 2700. This creates the HV_SENSE signal, which is routed through analog switch U8 (pins 2-3) to the ADC for diagnostics. AR4 (pins 12-14) is a unity-gain buffer which isolates the supply from the glitches created by switching of the system ADC input multiplexer.

<u>Revision History</u>

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