Title: Safety Board Overcurrent & Overspeed Comparator New Negative Supply Modification
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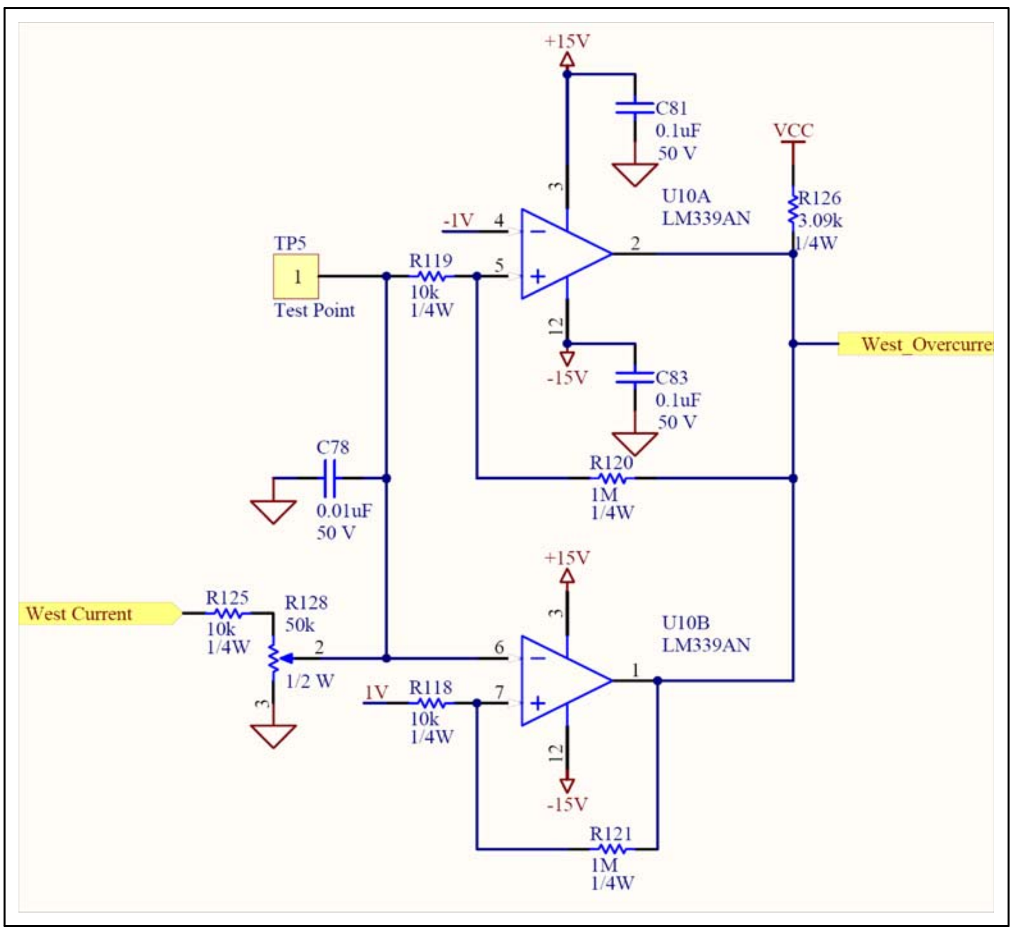
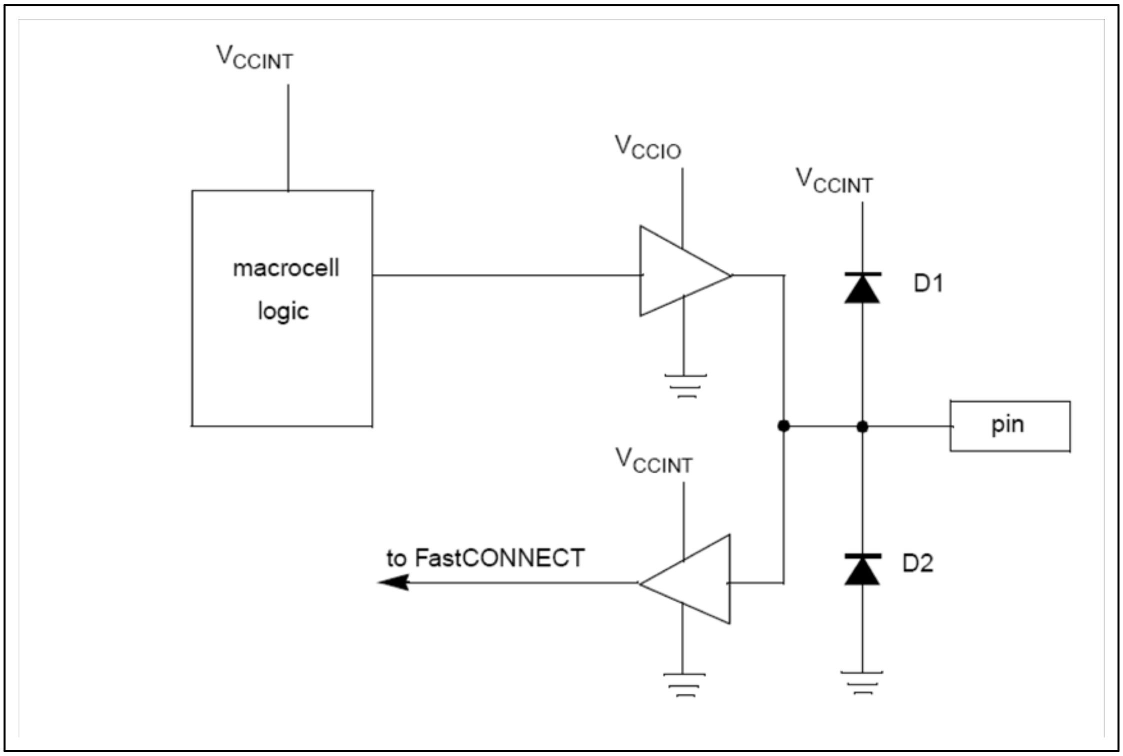
Description: The comparators on the safety board use +/-15V due to the positive and negative currents and velocities that they compare. This is perfectly fine. However, this means that the open collecter transistor output pull down value will be approximately -15V. The current design has this connected DIRECTLY to the CPLD which only accepts an absolute maximum value of -0.5V. Since -15V is larger in magnitude than the -0.5V, the protection diodes in the CPLD clamp the voltage to approximately -0.7V (thus the -0.5V maximum spec). The current is limited by only the comparator short circuit current of 20 mA. This stresses the CPLD since its clamp diode must dissipate the power (diode drop x 20mA). In the actual TCS system, the comparator only pulls down the output during an error condition (overcurrent and overspeed). Once detected, the TCS system disables motion, thereby removing the error condition. In the lab system, however, the overcurrent condition is simulated by pots, with the error condition being present until the tester adjusts the pot back to a normal current value. The CPLD may be able to withstand the stresses due to the short duration of error conditions and it may or may not survive in the lab. Regardless, exceeding the manufacturer's rating is usually not advisable.

This analysis has two goals for the modification:
1) Remove the overstress condition.
2) Modify the existing boards with the least amount of work possible.

Meeting both of these goals will not lead to an ideal solution, however, an acceptable one that is better than the current state should be possible. The solution for this problem is to replace the -15V supply on the comaparator with a -0.7 volt supply and reduce the trip points to about +/-0.50 V. This allows operation of the circuit as is designed presently. The output, when pulled down, will include the VCE drop of the output transistor, reducing the voltage level from the -0.7V supply to something within the CPLD minimum voltage rating.



Saftey Board comparator circuit.



Internal schematic/diagram of the CPLD at the input pin. Notice D2.

Directions

Fill in yellow highlighted regions.

Values of importance are highlighted in aqua.

Unit coversions

arcsec := 60·60·deg

Variables / Constraints / Design Parameters

Ref_pos_V := 0.44V	**+0.44V refernce voltage.**
Ref_neg_V := −0.44V	**-0.44V refernce voltage.**
VCC := 5V	**VCC is nominally +5V.**
negative_supply := −15V	**Negative supply voltage.**
LM339_quiescent_I_typ := 1mA	**LM339 IC total supply current w/ all output high impedance.**
LM339_quiescent_I_max := 2.5mA	**LM339 IC total supply current w/ all output high impedance.**
LM339_output_sat_V_typ := 250mV	**LM339 output saturation voltage @ Isink < 4mA.**
num_of_comparator_ICs := 5	**Numer of LM339 ICs used in Safety Board design.**
CPLD_min_input := −0.5V	**Minimum CPLD input voltage level.**

$R121 := 1M\Omega$ **Value of this resistor.**

$R118 := 10k\Omega$ **Value of this resistor.**

$R126 := 3.09k\Omega$ **Value of this resistor.**
$R120 := 1M\Omega$ **Value of this resistor.**
$R119 := 10k\Omega$ **Value of this resistor.**
$R125 := 10k\Omega$ **Value of this resistor.**
$R128 := 50k\Omega$ **Value of this resistor.**

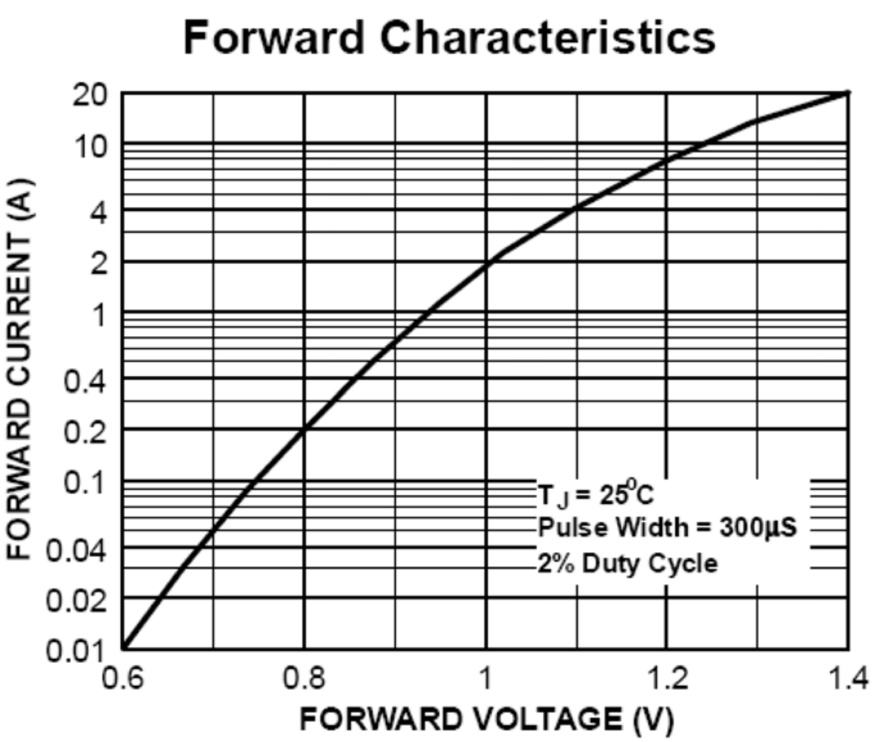
$Amp\_scale\_factor := 11.66 \frac{A}{V}$ **NC307 amplifier current telemetry scale factor.**

$Speed\_scale\_factor := -596.8310658 \frac{\frac{arcsec}{s}}{V}$ **Speed scale factor on Safety Board (after average circuit).**

$Desired\_overspeed := 2200 \frac{arcsec}{s}$ **Desired overspeed.**

$Desired\_overcurrent := 35A$ **Desired overcurrent.**

$V\_drop\_1N4005 := 0.65V$ **Forward voltage drop of 1N4005 @ 25C, 40mA.**



Forward voltage drop of 1N4005.

"Power Supply" Analysis section

First design the "power supply" section. Since the current draw is low, a resistor/diode combination will work in place of an actual power supply.

The current draw of all the comparators with no outputs pulling down:

$$supply\_I\_total := LM339\_quiescent\_I\_max \cdot num\_of\_comparator\_ICs$$

$$supply\_I\_total = 12.5 \cdot mA$$

Likely only one error will occur, but's let's assume all nine possible errors trip:

$$comparator\_pull\_down\_I\_total := 9 \cdot \frac{(VCC - V\_drop\_1N4005)}{R126}$$

$$comparator\_pull\_down\_I\_total = 0.013\ A$$

Assume a very conservative number combing both of the above numbers:

$$supply\_current\_required := supply\_I\_total + comparator\_pull\_down\_I\_total$$

$$supply\_current\_required = 0.025\ A$$

Calculate the current limit resistor and power rating:

$$supply\_resistance := \frac{(negative\_supply - V\_drop\_1N4005)}{-supply\_current\_required}$$

$$supply\_resistance = 621.774\ \Omega$$

Select a standard resistance value that is close to the resistance calculated:

$$supply\_res\_actual := 680\Omega$$

Actual current:

$$actual\_suppl\_current := \frac{|negative\_supply|}{supply\_res\_actual}$$

$$actual\_suppl\_current = 22.059 \cdot mA$$

Power rating:

$$resistor\_power\_rating := \frac{negative\_supply^2}{supply\_res\_actual}$$

$$resistor\_power\_rating = 0.331\ W$$

The diode power rating is:

$$diode\_power\_rating := V\_drop\_1N4005 \cdot actual\_suppl\_current$$

$$diode\_power\_rating = 14.338 \cdot mW$$

The logic low input voltage for the CPLD from the comparator is:

$$min\_voltage\_input\_CPLD := LM339\_output\_sat\_V\_typ - V\_drop\_1N4005$$

$$min\_voltage\_input\_CPLD = -0.4\,V$$

The minimum voltage must be greater than (more positive):

$$CPLD\_min\_input = -0.5\,V$$

Comparator Analysis section - OVERCURRENT

Determine the trip points of the comparators which includes hysteresis.

$Pullup\_output\_V := 5V$ **Assume pullup will be 5V, which it will be very close to.**

Guess value

$$Vtrip\_pos := 0.5V$$

Given

$$\frac{-(Pullup\_output\_V - Vtrip\_pos)}{R120 + R119} - \frac{(Pullup\_output\_V - Vtrip\_pos)}{R121} + \frac{(VCC - Pullup\_output\_V)}{R126} = 0$$

$$Ref\_pos\_V + \left[\frac{R118}{(R118 + R121)}\right]\cdot(Pullup\_output\_V - Ref\_pos\_V) = Vtrip\_pos$$

$$Vtrip\_pos := Find(Vtrip\_pos) = 0.485\,V$$

Guess value

$$Vtrip\_neg := -0.5V$$

Given

$$\frac{-(Pullup\_output\_V - Ref\_pos\_V)}{R121 + R118} - \frac{(Pullup\_output\_V - Ref\_neg\_V)}{R120} + \frac{(VCC - Pullup\_output\_V)}{R126} = 0$$

$$Vtrip\_neg + \left(\frac{R119}{R119 + R120}\right)\cdot(Pullup\_output\_V - Vtrip\_neg) = Ref\_neg\_V$$

$$Vtrip\_neg := Find(Vtrip\_neg) = -0.494\,V$$

Ideally, the bottom of the resistor divider to meet the overcurrent goal in the negative direction would be:

$$R\_bot\_guess := 15k\Omega$$

Given

$$\frac{-Desired\_overcurrent}{Amp\_scale\_factor} = Vtrip\_neg + (R125 + R128 - R\_bot\_guess)\cdot\left[\frac{(Vtrip\_neg)}{R\_bot\_guess} - \frac{(Ref\_neg\_V - Vtrip\_neg)}{R119}\right]$$

$R\_bot := Find(R\_bot\_guess) = 10.849 \cdot k\Omega$

The telemetry voltage that would trip the comparators would be:

$$Vin\_neg := Vtrip\_neg + (R125 + R128 - R\_bot) \cdot \left[\frac{(Vtrip\_neg)}{R\_bot} - \frac{(Ref\_neg\_V - Vtrip\_neg)}{R119} \right]$$

$Vin\_neg = -3.002\ V$

$Vin\_neg \cdot Amp\_scale\_factor = -35\ A$

$$Vin\_pos := Vtrip\_pos + (R125 + R128 - R\_bot) \cdot \left[\frac{(Vtrip\_pos)}{R\_bot} - \frac{(VCC - Vtrip\_pos)}{R120 + R119} \right]$$

$Vin\_pos = 2.463\ V$

$Vin\_pos \cdot Amp\_scale\_factor = 28.724\ A$

$Trip\_point\_difference := |Vin\_neg| - |Vin\_pos| = 0.538\ V$

$Trip\_point\_difference \cdot Amp\_scale\_factor = 6.276\ A$

In terms of percent error from the opposite polarity trip point:

$$percent\_error := 1 - \left(\left| \frac{Vin\_neg}{Vin\_pos} \right| \right) = -21.85 \cdot \%$$

The current that would have to be provided by the telemetry signal would be:

$$Vin\_neg\_current := \frac{(Vin\_neg - Vtrip\_neg)}{R125 + R128 - R\_bot} = -0.051 \cdot mA$$

$$Vin\_pos\_current := \frac{(Vin\_pos - Vtrip\_pos)}{R125 + R128 - R\_bot} = 0.04 \cdot mA$$

Comparator Analysis section - OVERCURRENT * OVERSPEED

HOWEVER the negative and postive absolute values are not equal. In the case of the currents, it won't matter. For the overspeed, they should be close. Let's recalculate the values using new R125 and R128 resistor values for the overcurrent circuits. The overcurrent will be calculated, but won't be implemented.

$R125\_mod := 1k\Omega$ $R128\_mod := 1k\Omega$

Ideally, the bottom of the resistor divider to meet the overcurrent goal in the negative direction would be:

$R\_bot\_mod\_guess := 1k\Omega$

Given

$$\frac{-Desired\_overcurrent}{Amp\_scale\_factor} = Vtrip\_neg + (R125\_mod + R128\_mod - R\_bot\_mod\_guess)\cdot\left[\frac{(Vtrip\_neg)}{R\_bot\_mod\_guess} - \frac{(Ref\_neg\_V - Vtrip\_neg)}{R119}\right]$$

$R\_bot\_mod := Find(R\_bot\_mod\_guess) = 330.411\cdot\Omega$

The telemetry voltage that would trip the comparators would be:

$$Vin\_neg := Vtrip\_neg + (R125\_mod + R128\_mod - R\_bot\_mod)\cdot\left[\frac{(Vtrip\_neg)}{R\_bot\_mod} - \frac{(Ref\_neg\_V - Vtrip\_neg)}{R119}\right]$$

$Vin\_neg = -3.002\ V$

$Vin\_neg\cdot Amp\_scale\_factor = -35\ A$

$$Vin\_pos := Vtrip\_pos + (R125\_mod + R128\_mod - R\_bot\_mod)\cdot\left[\frac{(Vtrip\_pos)}{R\_bot\_mod} - \frac{(VCC - Vtrip\_pos)}{R120 + R119}\right]$$

$Vin\_pos = 2.929\ V$

$Vin\_pos\cdot Amp\_scale\_factor = 34.154\ A$

$Trip\_point\_difference := |Vin\_neg| - |Vin\_pos| = 0.073\ V$

$Trip\_point\_difference\cdot Amp\_scale\_factor = 0.846\ A$

In terms of percent error from the opposite polarity trip point:

$$percent\_error := 1 - \left(\left|\frac{Vin\_neg}{Vin\_pos}\right|\right) = -2.477\cdot\%$$

The current that would have to be provided by the telemetry signal would be:

$$Vin\_neg\_current := \frac{(Vin\_neg - Vtrip\_neg)}{R125\_mod + R128\_mod - R\_bot\_mod} = -1.502\cdot mA$$

$$Vin\_pos\_current := \frac{(Vin\_pos - Vtrip\_pos)}{R125\_mod + R128\_mod - R\_bot\_mod} = 1.464\cdot mA$$

Now for the overspeed circuits:

$R125\_OS := 1k\Omega$ $R128\_OS := 1k\Omega$

Ideally, the bottom of the resistor divider to meet the overcurrent goal in the negative direction would be:

$R\_bot\_OS\_guess := 1k\Omega$

Given

$$\frac{Desired\_overspeed}{Speed\_scale\_factor} = Vtrip\_neg + (R125\_OS + R128\_OS - R\_bot\_OS\_guess)\cdot\left[\frac{(Vtrip\_neg)}{R\_bot\_OS\_guess} - \frac{(Ref\_neg\_V - Vtrip\_neg)}{R119}\right]$$

$R\_bot\_OS := Find(R\_bot\_OS\_guess) = 268.935\ \Omega$

The telemetry voltage that would trip the comparators would be:

$$Vin\_neg\_OS := Vtrip\_neg + (R125\_OS + R128\_OS - R\_bot\_OS)\cdot\left[\frac{(Vtrip\_neg)}{R\_bot\_OS} - \frac{(Ref\_neg\_V - Vtrip\_neg)}{R119}\right]$$

$Vin\_neg\_OS = -3.686\ V$

$$Vin\_neg\_OS\cdot Speed\_scale\_factor = 2.2\times 10^{3}\cdot\frac{arcsec}{s}$$

$$Vin\_pos\_OS := Vtrip\_pos + (R125\_OS + R128\_OS - R\_bot\_OS)\cdot\left[\frac{(Vtrip\_pos)}{R\_bot\_OS} - \frac{(VCC - Vtrip\_pos)}{R120 + R119}\right]$$

$Vin\_pos\_OS = 3.6\ V$

$$Vin\_pos\_OS\cdot Speed\_scale\_factor = -2.149\times 10^{3}\cdot\frac{arcsec}{s}$$

$$Trip\_point\_difference\_OS := |Vin\_neg\_OS| - |Vin\_pos\_OS| = 0.086\ V$$

$$Trip\_point\_difference\_OS\cdot Speed\_scale\_factor = -51.301\cdot\frac{arcsec}{s}$$

In terms of percent error from the opposite polarity trip point:

$$percent\_error\_OS := 1 - \left(\left|\frac{Vin\_neg\_OS}{Vin\_pos\_OS}\right|\right) = -2.388\cdot\%$$

The current that would have to be provided by the telemetry signal (op-amps on Safety Board) would be:

$$Vin\_neg\_current\_OS := \frac{(Vin\_neg\_OS - Vtrip\_neg)}{R125\_OS + R128\_OS - R\_bot\_OS} = -1.844\cdot mA$$

$$Vin\_pos\_current\_OS := \frac{(Vin\_pos\_OS - Vtrip\_pos)}{R125\_OS + R128\_OS - R\_bot\_OS} = 1.799\cdot mA$$