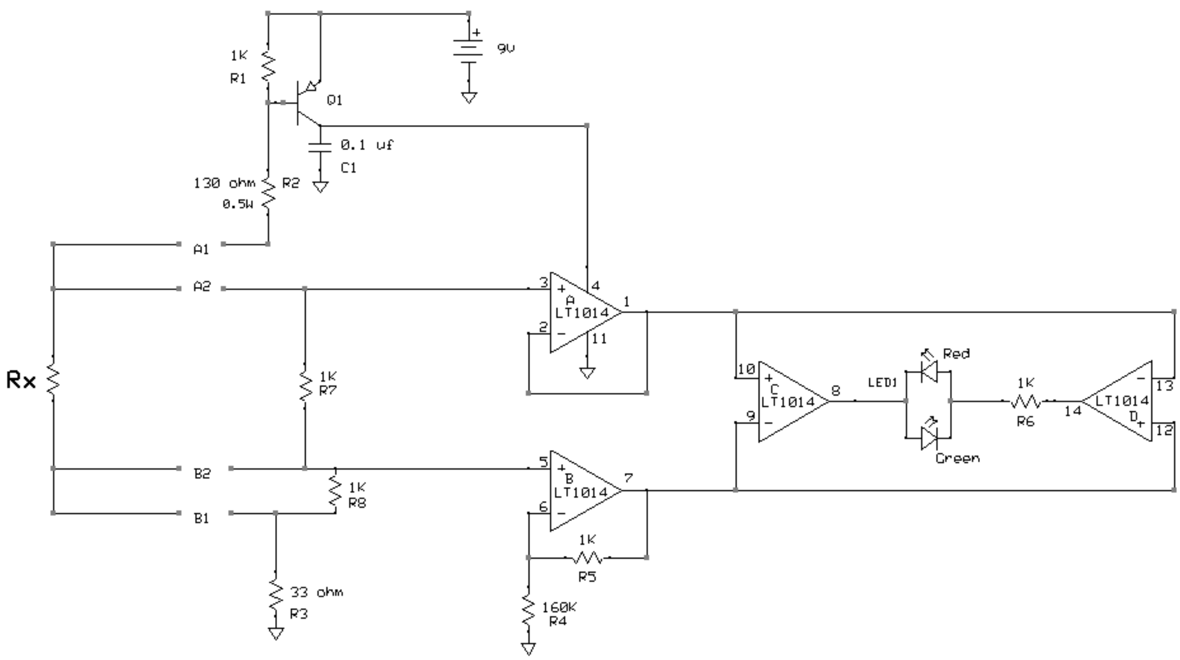
Lathe Electronic Edge Finder Model 1.5, version 0.1

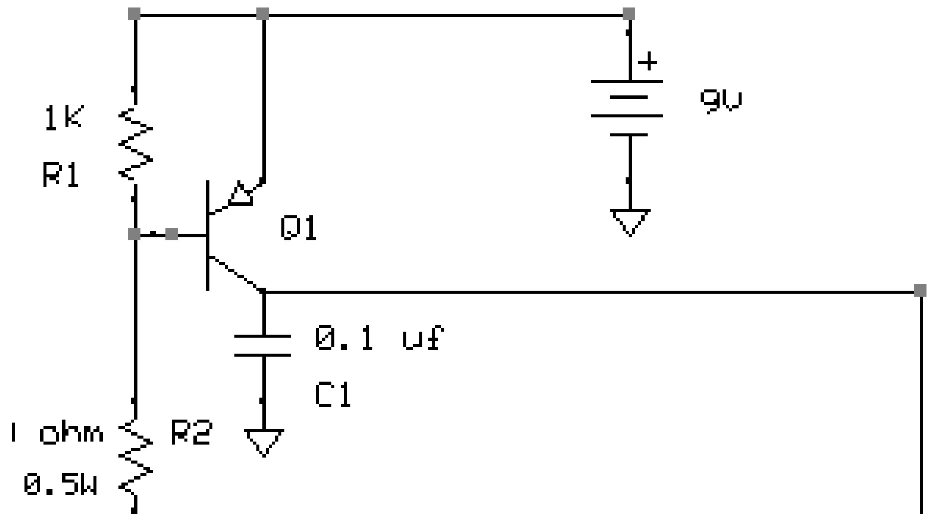
By R. G. Sparber



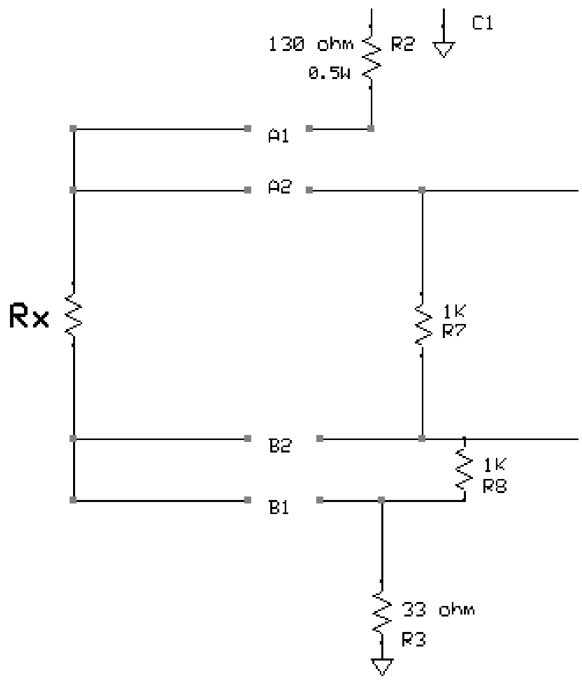
The LEEF Model 1.5 is almost identical to the Model 1 except for sensitivity. The Model 1 has an average threshold of 2.06 ohms. The Model 1.5 has an average threshold of 0.2 ohms. This increase in sensitivity comes at a cost. While the Model 1 uses less than 10 mA for its test current, the Model 1.5 uses less than 55 mA. There is a lot of shop experience with edge finders passing around 10 mA through the machine's bearings with no ill effects. There is also experience with currents greater than 1000 mA passing through bearings causing damage. The further we get away from 10 mA and the closer we get to 1000 mA, the more risk the operator takes. No scientific data has been found to assess the risk of a 55 mA test current.

Overview of Circuit

The circuit has automatic power control. When the test probes are connected to the machine, the circuit turns on. When the probes are disconnected, the circuit powers down.



This function is performed by having the test current pass through R2. This causes Q1 to be driven deep into saturation. Q1's collector is then pulled up to near 9V which feeds the quad op amp.



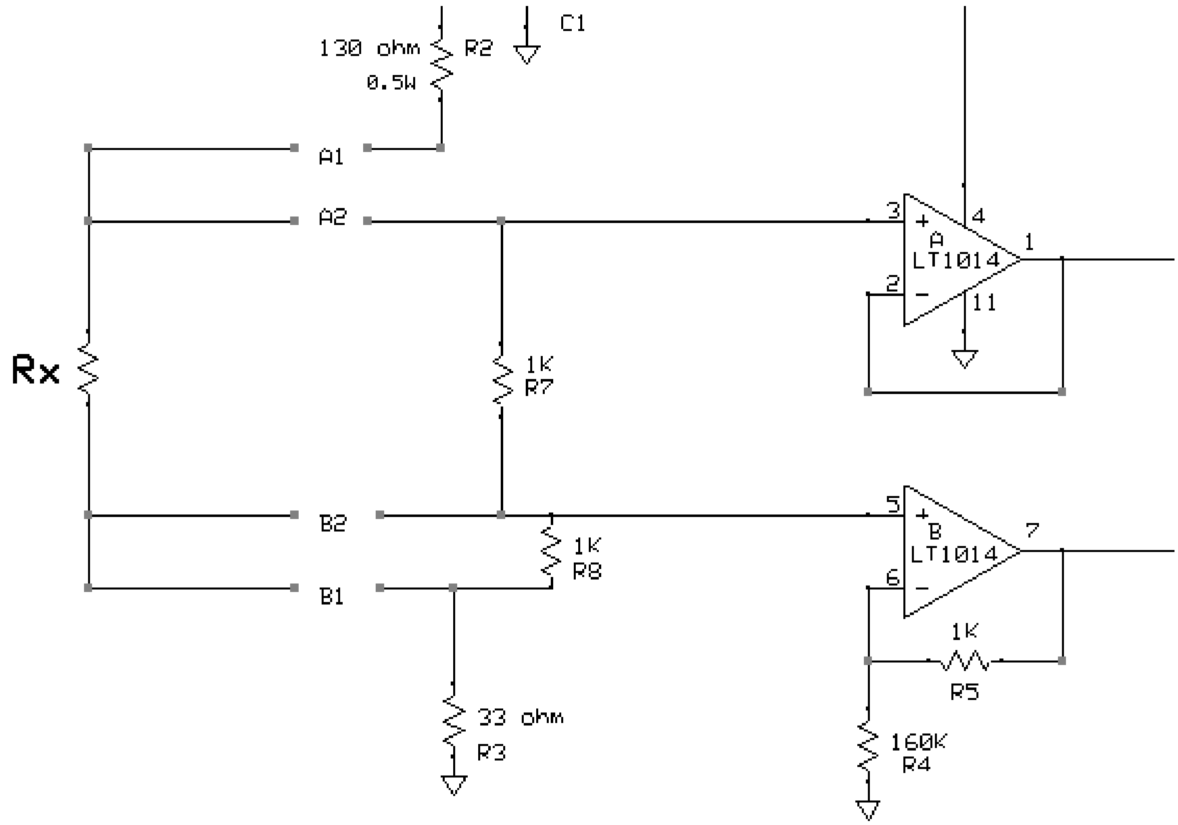
The test current passing through R2 feeds into the unknown resistance, R_x via probe A1. The current then flows out of R_x via probe B1, into R3, and returns to ground.

Not shown in the scematic is that there is unknown contact resistance is these probes. This resistance can be almost as large as R_x so has the potential of creating a large error. What makes this resistance troublesome is that the voltage across R_x can be about the same as the voltage across contact A1 and/or B1.

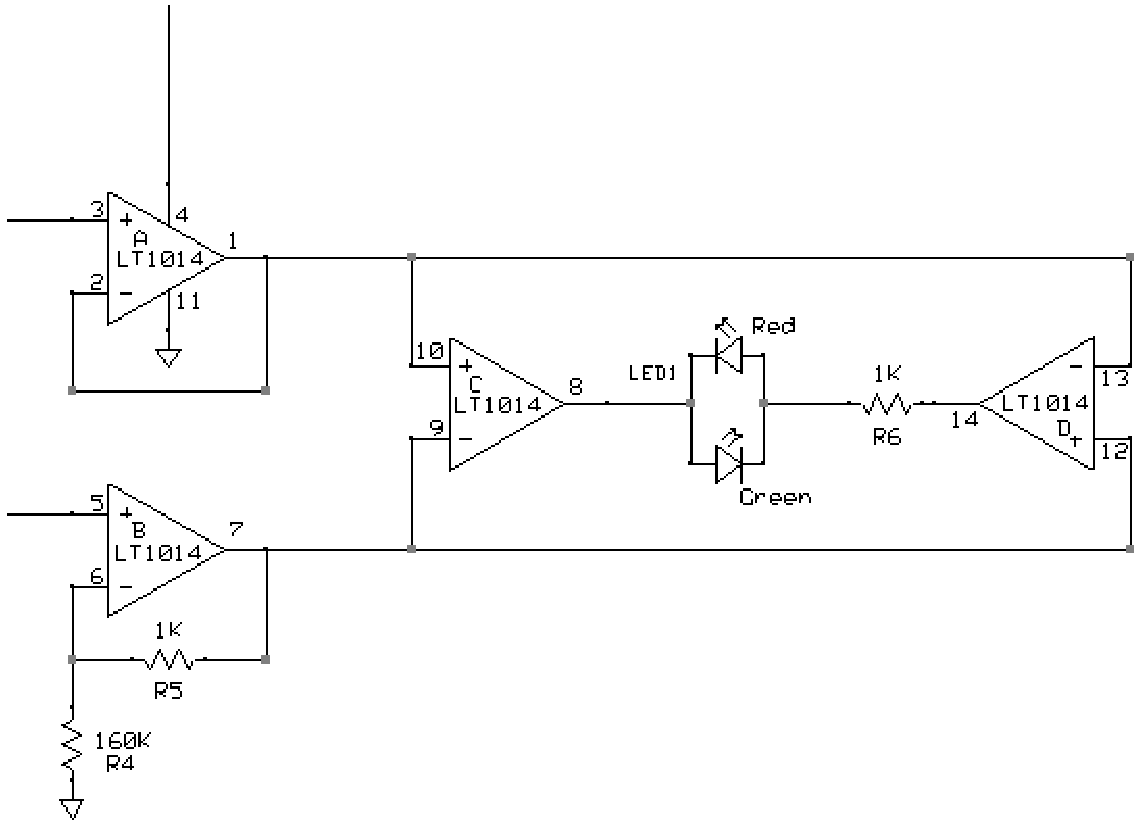
We solve this problem by having a second set of probes, A2 and B2. These probes would have similar contact resistance but carry almost no current[2]. We therefore do not genarate much voltage across A2 or B2. While our test current flowing through A1 and B1 is around 50 mA, our current through A2 and B2 is around 30 nA which is 1 million times smaller.

R_7 and R_8 provide paths to ground for stray static electricity current that could damage the op amps. They have minimal effect on accuracy.

[2] This is called a Kelvin connection.



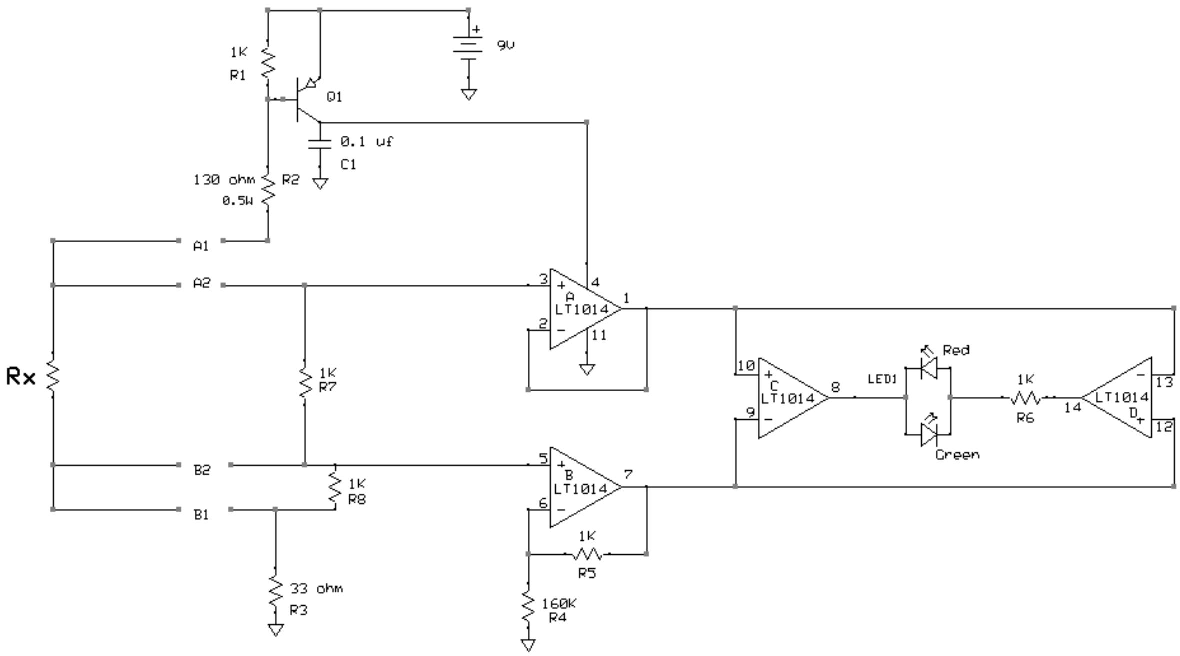
Op amps A and B measure the voltage across R_x . When R_x equals the threshold, the voltage at pin 1 equals the voltage at pin 7. Below this threshold, the touchdown LED is red. Above this threshold it is green.



When R_x is above the threshold, the voltage on pin 1 is greater than the voltage on pin 7. This causes op amp C to drive pin 8 to near 8V while causing op amp D to drive pin 14 to near 0 volts. Current then flows from pin 8 to pin 14 causing the green LED to light.

When R_x is below the threshold, the voltage on pin 1 is less than the voltage on pin 7. This causes op amp C to drive pin 8 to near 0 volts while causing op amp D to drive pin 14 to near 8V. Current then flows from pin 14 to pin 8 causing the red LED to light.

Detailed Circuit Analysis



I_x is the current through R_x

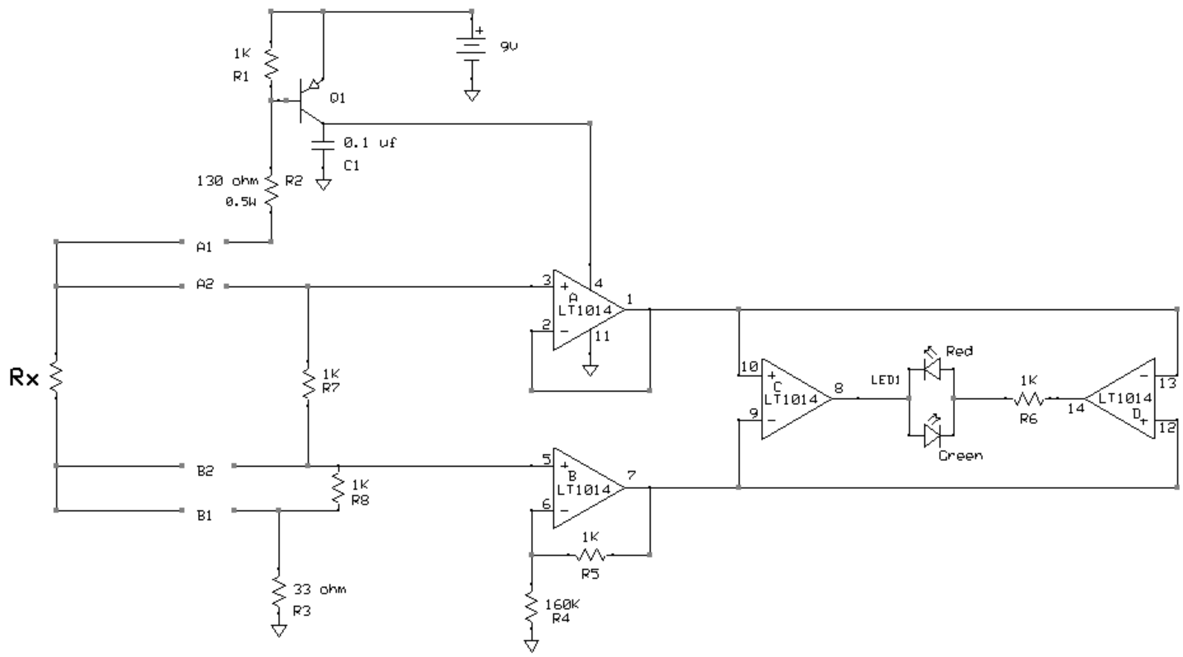
$$I_x = \frac{(V_{battery} - V_{EBsat1})}{R_2 + R_x + R_3} \qquad (1)$$

$$I_x = \frac{(9V - 0.75V)}{130 + R_x + 33}$$

But since R_x is much less than 133+33 ohms, we can ignore it and say that

$$I_x \cong \frac{(9V - 0.75V)}{133 + 33}$$

$$I_x \cong 50\ mA \qquad (2)$$



V_5 is the voltage at pin 5 with respect to ground.

$$V_5 = R_3 \times I_x \qquad (3)$$

This assumes that the input bias current flowing out of pin 5 is small. For the LT1014 it is equal to or less than 30 nA which is much less than I_x of 50 mA so it is a reasonable assumption.

$$V_3 = \{V_5\} + R_x I_x \qquad (4)$$

This ignores the input bias current flowing out of pin 3.

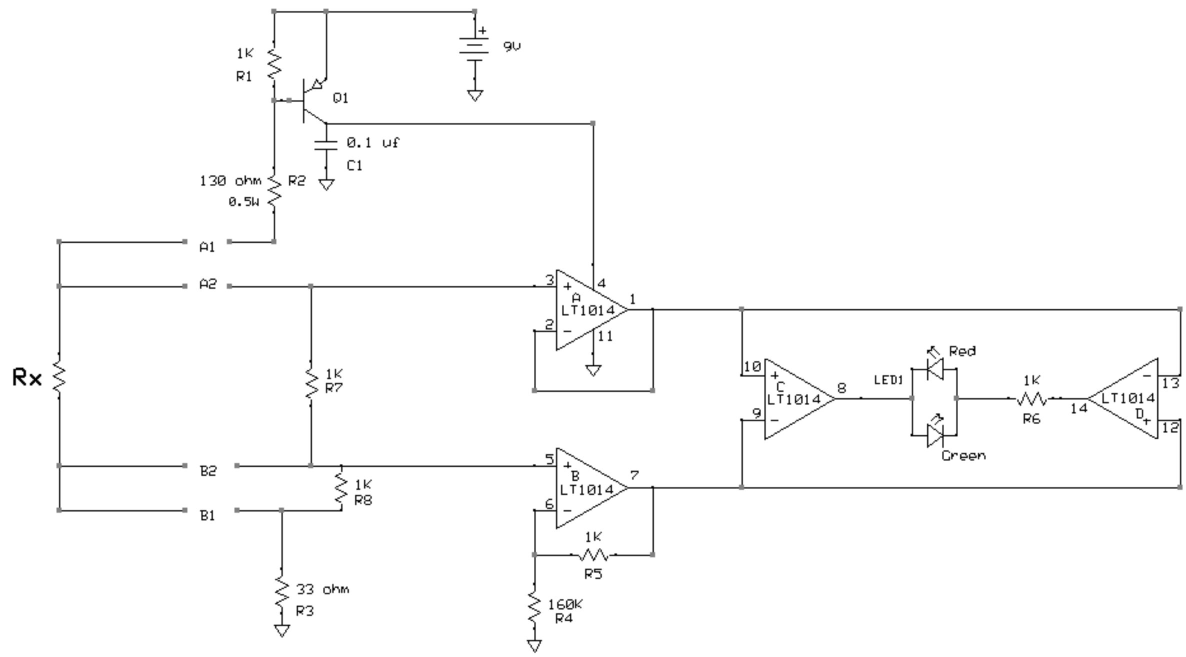
Putting (3) into (4) we get

$$V_3 = \{R_3 \times I_x\} + R_x I_x$$

or

$$V_3 = (R_3 + R_x) \times I_x \qquad (5)$$

We now have the input voltages to op amps A and B defined.
Next we will look at the output of op amps A and B.

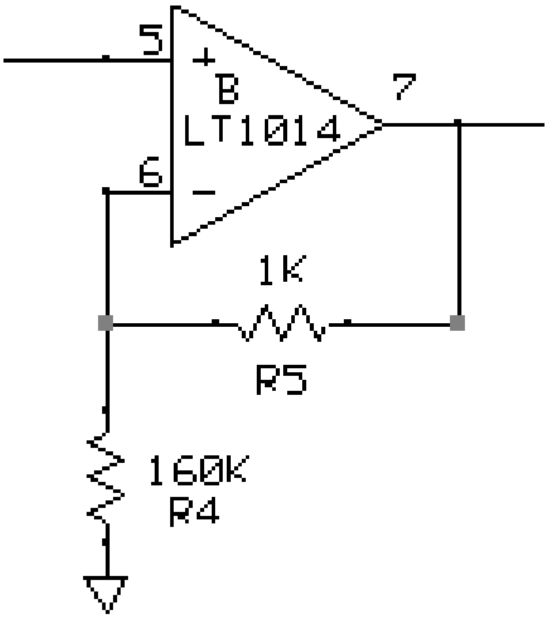


First consider op amp A in the ideal case. This op amp is configured for unity gain. The output voltage equals about 10^5 times the input voltage. This means that the input voltage is 10^{-5} times the output voltage. So for any output voltage, the input is extremely tiny. We can therefore say that V_3 approximately equals V_2. But pin 2 is tied to pin 1 so the output voltage essentially equals the input.

Inside the op amp we have an input offset voltage, V_{osA}. The input offset voltage can be modeled by putting a voltage source in series with pin 3. We then get

$$V_1 = V_3 + V_{osA} \qquad (6)$$

For the LT1014, V_{os} can be as large as ± 0.3 mV.



Next look at op amp B in the ideal case. The voltage on pin 5 essentially equals the voltage on pin 6.

$$V_6 = V_5$$

Furthermore, the current flowing out of pin 6 is zero in this ideal case.

Note that the voltage across R_4 is V_6. So I can say

$$I_{R4} = \frac{V_6}{R_4}$$

But this current can only flow through R_5. We can then say that the voltage across R_5 equals I_{R4} times R_5. The left end of R_5 is tied to pin 6 which we know is at the voltage V_6. Putting this all together we can say that

$$V_7 = V_{R5} + V_6$$

$$V_7 = R_5 I_{R4} + V_6$$

$$V_7 = R_5 \frac{V_6}{R_4} + V_6$$

$$V_7 = \left(1 + \frac{R_5}{R_4}\right)(V_6)$$

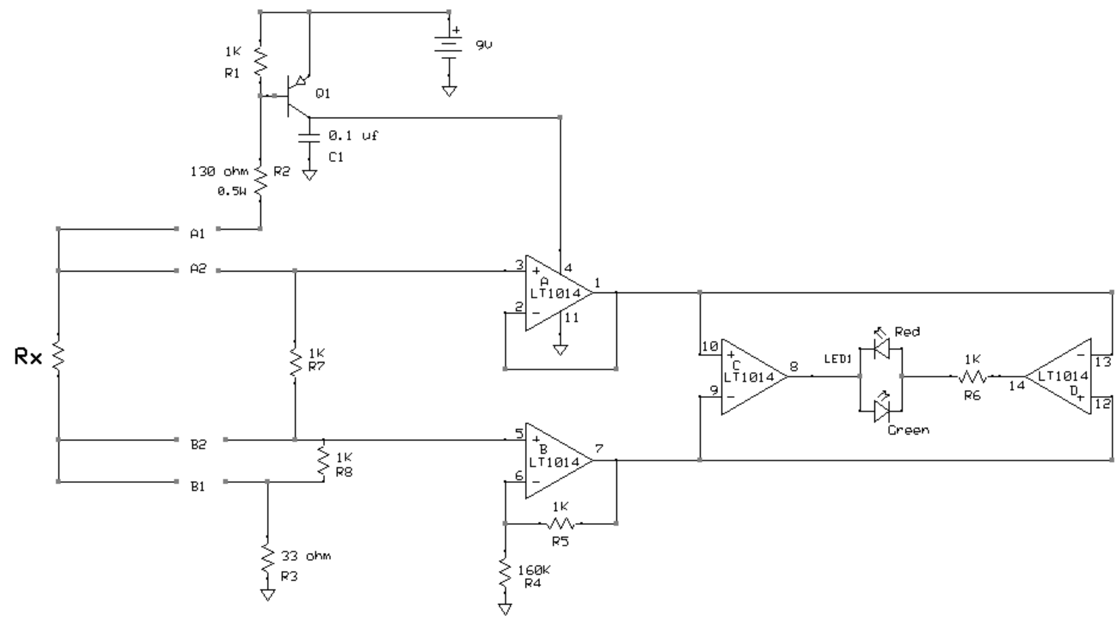
Since V_6 equals V_5 we can write

$$V_7 = \left(1 + \frac{R_5}{R_4}\right)(V_5)$$

Next consider the effect of input offset voltage, V_{osB}. It can be put in series with pin 5 so modifies V_5

$$V_7 = \left(1 + \frac{R_5}{R_4}\right)(V_5 + V_{osB}) \quad (7)$$

I am ignoring the input bias current out of pin 6 here. Given an R_5 of 1K and a maximum input bias current of 30 nA, this causes an error of 30 µV which is much less than the maximum input offset voltage. If it was a problem, I would put a 1K in series with pin 5. That would cancel the effects of input bias current. It would not address input offset current but that is smaller.



Op amp C swings between maximum and minimum output voltage. This is around 8V. The typical gain of the op amp is 10^5. This means that a change of $\frac{8V}{10^5}$ = 80µV is all that is needed to swing the output over its maximum range. This is small enough to ignore. So we can say that the output of op amp C changes when the input equals about zero. But wait, we must include it's input offset voltage. So we end up with the state change somewhere within the input offset voltage tolerance of V_{osC}. It is a maximum of ±0.3 mV at room temperature. Op amp D's inputs are tied to the same nodes as op amp C. When a voltage is applied to these inputs such that one op amp changes state, the other one will either change at the same time or have already changed state. It all depends on their input offset voltages. So I can limit my analysis to just the state change of op amp C.

$$V_{osC} = \{V_{10}\} - \{V_9\} \qquad (8)$$

But V_{10} is the same as V_1 and V_9 is the same as V_7 so we can say

$$V_{osC} = \{V_1\} - \{V_7\}$$

We know that

$$V_1 = V_3 + V_{osA} \qquad (6)$$

and

$$V_7 = \left(1 + \frac{R_5}{R_4}\right)(V_5 + V_{osB}) \qquad (7)$$

Plug them to get

$$V_{osC} = \{V_3 + V_{osA}\} - \{\left(1 + \frac{R_5}{R_4}\right)(V_5 + V_{osB})\} \qquad (9)$$

We know

$$V_3 = (R_3 + R_x) \times I_x \qquad (5)$$

And also

$$V_5 = R_3 \times I_x \qquad (3)$$

Plug them into

$$V_{osC} = \{[V_3] + V_{osA}\} - \{\left(1 + \frac{R_5}{R_4}\right)([V_5] + V_{osB})\} \qquad (9)$$

And get

$$V_{osC} = \{[(R_3 + R_x) \times I_x] + V_{osA}\} - \{\left(1 + \frac{R_5}{R_4}\right)([R_3 \times I_x] + V_{osB})]$$

Then do a bit of algebra.

$$V_{osC} = [\left(R_3 + R_x - R_3 - \frac{R_5 R_3}{R_4}\right) \times I_x] + [V_{osA} - [\left(1 + \frac{R_5}{R_4}\right)(V_{osB})]$$

$$V_{osC} = [\left(R_x - \frac{R_5 R_3}{R_4}\right) \times I_x] + [V_{osA} - [\left(1 + \frac{R_5}{R_4}\right)(V_{osB})] \qquad (10)$$

Note that $\left(1 + \frac{R_5}{R_4}\right) = 1.03$ multiplies V_{osB}. I can change it to 1 with minimal effect on the accuracy of the equation.

$$V_{osC} = [\left(R_x - \frac{R_5 R_3}{R_4}\right) \times I_x] + [V_{osA} - V_{osB}]$$

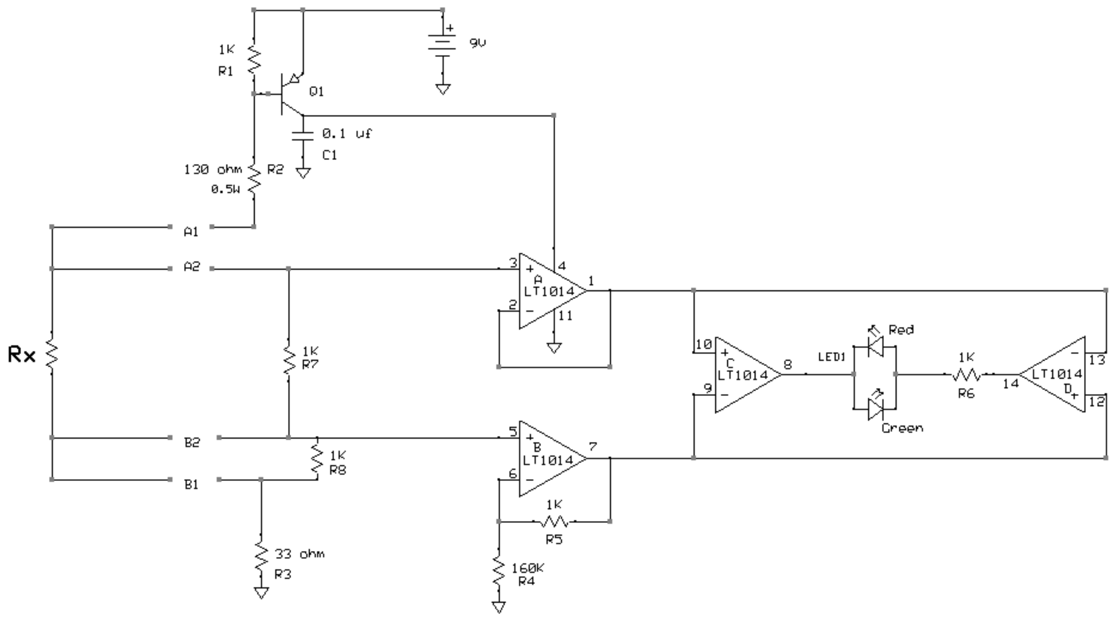
Solving for R_x we get

$$R_x = \frac{R_5 R_3}{R_4} + \frac{V_{osA} - V_{osB} - V_{osC}}{I_x}$$

All of these offset voltage are some value ranging between negative to positive so I can ignore their signs and just say

$$R_x = \frac{R_5 R_3}{R_4} + \frac{V_{osA} + V_{osB} + V_{osC}}{I_x} \qquad (11)$$

Where R_x is the threshold where op amp C changes state.



If the total input offset voltage is zero, we get

$$R_x = \frac{R_5 R_3}{R_4} \qquad (12)$$

Plugging in what we know yields

$$R_x = \frac{1K \times 33\ ohms}{160K}$$

$$R_x = 0.206 \text{ ohms}$$

But we really can't ignore the input offset voltages. If we go for absolute worst case, then we get

$$R_x = \frac{R_5 R_3}{R_4} + \frac{V_{osA}+V_{osB}+V_{osC}}{I_x} \qquad (11)$$

$$R_x = 0.206\ ohms \pm \frac{0.3\ mV+0.3\ mV+0.3\ mV}{50\ mA}$$

$$R_x = 0.206\ ohms \pm 0.02\ ohms$$

Actual variation in the threshold should be less than this ±10% tolerance.

Extending this Idea

What if we accept a worst case error of ±10% for the threshold but want to make the circuit more sensitive. We see that a test current of 50 mA lets us have a threshold of 0.2 ohms.

Keeping the voltage across R_x the same, we can halve the threshold if we double the test current. So we would have an R_x equal to 0.103 ohms. The test current would be 100 mA which means the tolerance on this threshold would be 0.01 ohms. We retain our error of ±10%.

In order to raise the test current to 100 mA, we would need to use equations 1:

$$I_x = \frac{(V_{battery} - V_{EBsat1})}{R_2 + R_x + R_3} \qquad (1)$$

Again ignoring the effect of R_x because it is much smaller than $R_2 + R_3$,

$$100\ mA \cong \frac{(9V - 0.75V)}{R_2 + R_3}$$

$$R_2 + R_3 \cong \frac{(8.25V)}{100\ mA}$$

$$R_2 + R_3 \cong 82.5\ ohms$$

One design choice would be to set R_2 equal to 56 ohms and R_3 equal to 27 ohms. R_2 would dissipate about 0.56 watts so should be a 1 watt resistor. R_3 dissipates about 0.27 watts so should be a ½ watt resistor. It would also be a good idea to lower R_1 so Q1 doesn't have such a large base drive. Assuming a V_{be} of 0.75V, an R_1 of 27 ohms would mean it would pass 28 mA. That pulls about 22 mA out the base of Q1. This is a safe level of base current. R1 only dissipates 21 mW so can be an 1/8 watt resistor.

Having a threshold of 0.103 ohms ±10% is attractive but that 100 mA test current pushes us deeper into the unknown with respect to damaging bearings. This is why I developed the Model 2 which has a threshold of 0.01 ohms and a test current of less than 25 mA:

http://rick.sparber.org/LEEF_Model_2.pdf

I welcome your comments and questions.

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