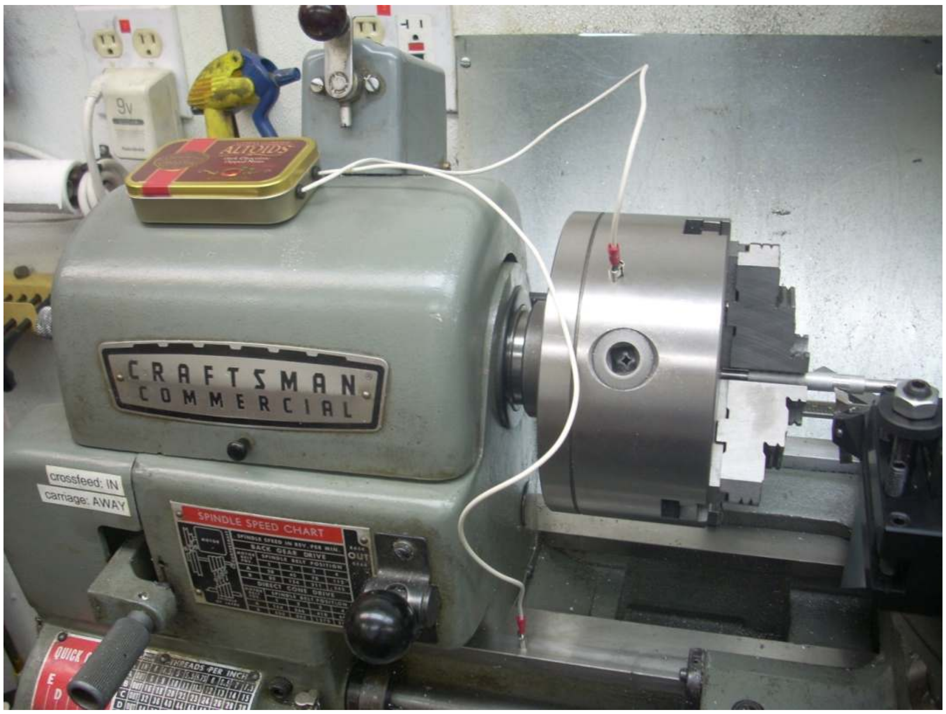
Lathe Electronic Edge Finder, Model 1, version 0.1, document version 2.2

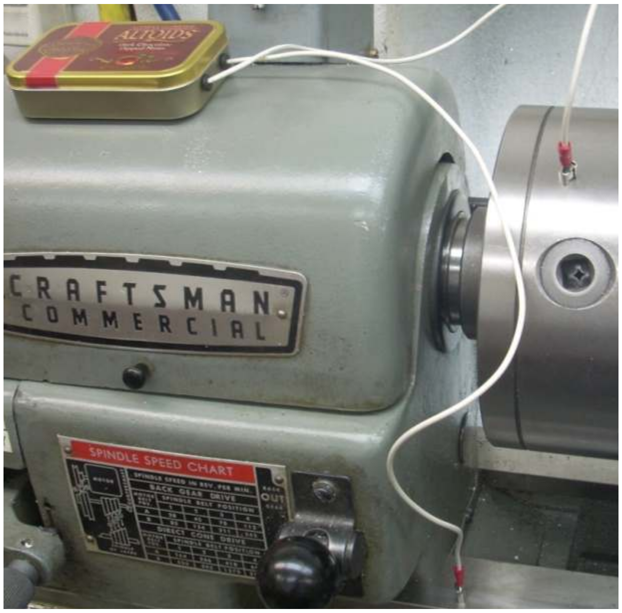
By R. G. Sparber



Have you ever needed to set a High Speed Steel cutter so it just touches the work piece? Every time I do it, the cutter digs in a little bit and I find myself taking off a few thou where I thought I was just touching the surface. This is particularly difficult when trying to use a boring bar deep inside a hole.

The solution is to use a Lathe Electronic Edge Finder (LEEF).

The device presented here is simply an Electronic Edge Finder but with two unique features. This first feature detects the difference between the low electrical resistance between all parts of the lathe and the extremely low resistance at the point where the cutter first contacts the work piece.



The second feature is the ease of use. Although there is electronics inside that Altoids® box, there is no power switch. Whenever I must deal with a power switch, it ends up being left in the "on" position and the battery goes dead. With this edge finder, power is on only when the wires are connected to the machine. And while power is on, there is a faint but rather annoying sound to remind me that the battery is being discharged.

Another design feature aimed at ease of use are the clips that connect the wires to the machine. They are magnets[2]. You just toss the end of the wire onto the bare, metallic surface and a good connection is made.

I have done my best to make the ***using*** of this gadget easy. This has meant that the building phase may be difficult for some. Inside the Altoids box is an integrated circuit, a transistor, and a handful of resistors plus a piezoelectric beeper. All parts can be bought at Radio Shack®.

For those with minimal background in electronics, I have drawn the circuit in picture form. This will be followed by a description for those with more knowledge of electronics.

Here is a video of the edge finder being used on my lathe.

http://www.youtube.com/watch?v=r4CLX7tR8Vk&list=UUQowQlSfFxybveyBDVOHXxw&index=5&feature=plcp

[2] This is standard practice on welding cable ground clamps.

Before starting to build the edge finder, it would be prudent to verify that it will work on your lathe. You will need an ohm meter able to measure down to 0.5 ohms.

Start by putting both probes on the spindle. Record the resistance reading. Then put one probe on the spindle and the other on the ways of your lathe. Subtract the first reading from the second. If the result is greater than 2 ohms, this LEEF will work. If you see less than 2 ohms, try turning the spindle a little. On my lathe the resistance varies between less than 2 ohms and 40 ohms as I turn the spindle by hand by a few degrees. Sometimes I must turn the spindle a little in order to use the LEEF.

If you consistently have a spindle bearing resistance less than 2 ohms, then the LEEF, Model 2 may work for you. It can handle resistances down to 0.01 ohms. For details see

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

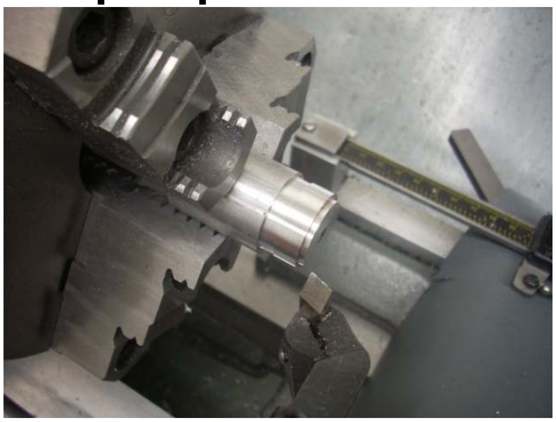
Although intended for use on the lathe, the LEEF does work on the mill too. A video of this device being used on my mill can be seeing at:

http://www.youtube.com/watch?v=QPi83uIxRM0&feature=youtu.be

and

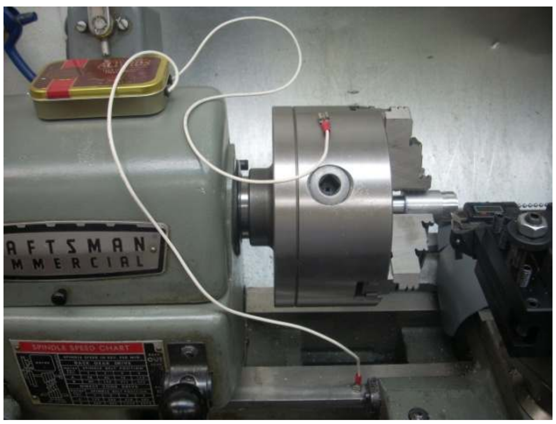
http://www.youtube.com/watch?v=NJFS7EC6PIA&feature=channel&list=UL

Shop Experience

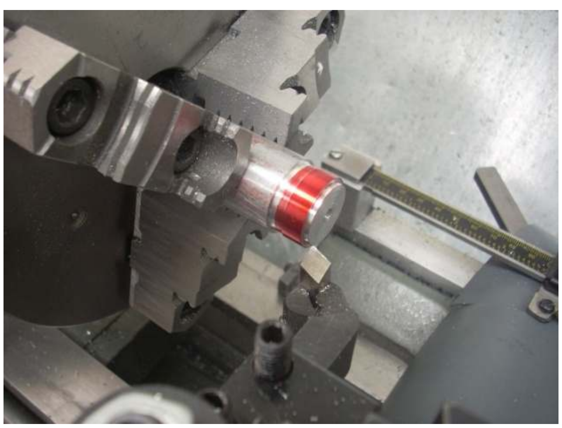


How well can I return the tip of my cutter to a reference surface?

First I chucked up some round stock and turned it true. Then I cleaned the OD and cutter with alcohol to remove all oil and swarf.

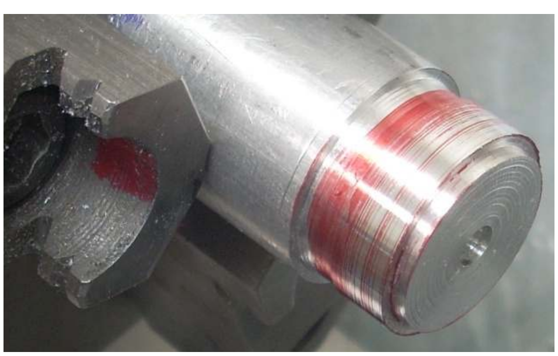


I connected the detector between my 3 jaw chuck and the ways and slowly fed in the cutter until I heard the loud beep. The longitudinal dial was then zeroed. I fed in again and made a small adjustment to the zero point.



I backed out the cutter and coated the surface with dye.

Then I started the lathe, fed in until I reached zero, and took a single pass.



To my amazement, I had removed some but not all of the dye. Now ***that*** is a precise reestablishment of zero.

Physical Design

The edge finder consists of a small metal box with two wires sticking out of it.

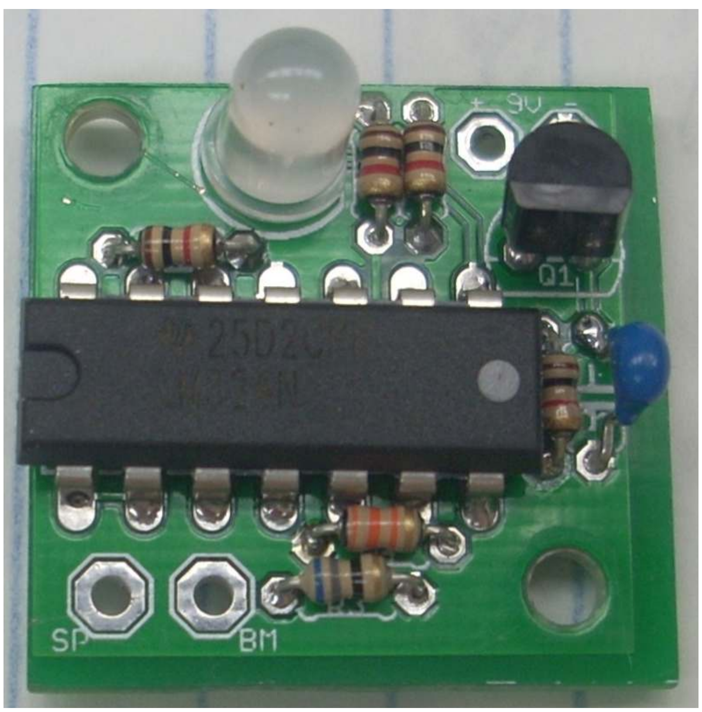
Open up the box and you find a 9V battery and a piezoelectric beeper. These beepers are so loud that no effort was made to cut a hole for the sound to get out. The green foam holds the circuit board in place.

Under the foam is a circuit board with a small handful of parts in it[3]. Having all of this room made fabrication easier. All connections were made by directly soldering leads together.

A sheet of rubber was placed under the circuit board to prevent shorts between circuit connections and the metal box.

[3] Diode D1 is not shown in this picture. It was added later.

This is a computer rendered picture of the first prototype circuit board developed by Mark Cason. Mark's daughter will offer both a kit and a finished/tested product for sale. This board is about 1" square. This version uses a red/green LED rather than a Super Bright LED, a red LED, and a piezoelectric beeper.



This is my first assembled finished version which uses a commercially made circuit board.

When not in use, the wires wrap around the box. Magnets at the ends of the wires stick to the box. The red tape prevents them from shorting together and turning on the device.

Here is a close up view of one lug being modified to accept a magnet.

The curled clips are straightened.

A neodymium magnet[4] 1/8" x ¼" x ¼" fits nicely. I formed the sides over the top and bent up the front a little.

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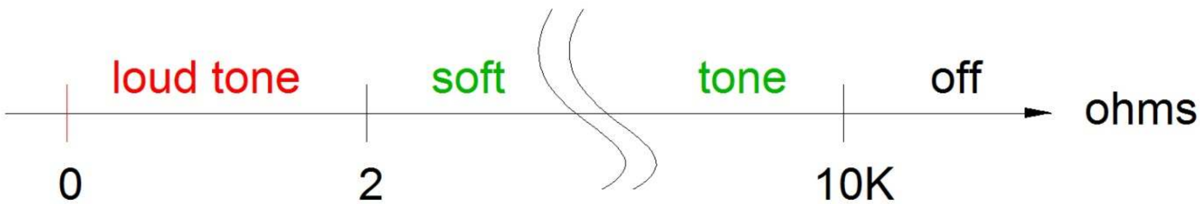
[4] See http://www.kjmagnetics.com/proddetail.asp?prod=B442-N50

Electrical Design Overview

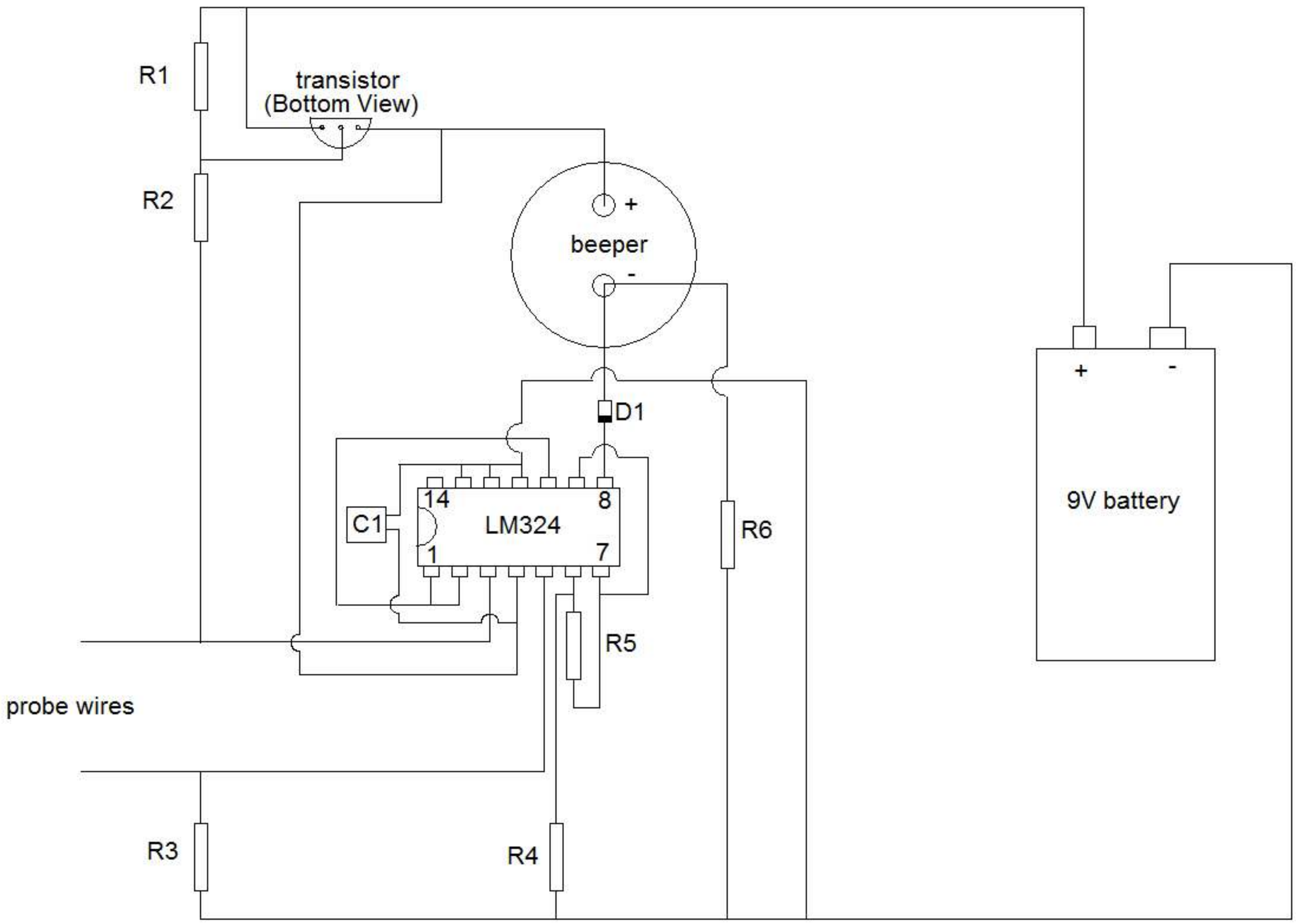
The edge finder is just a glorified continuity checker. What makes it special is its ability to detect when the resistance across it's probes is less than 2 ohms. Most continuity checkers alarm at many hundreds of ohms.



The circuit works by comparing the unknown resistance to a known resistance. This comparison is not dependent on battery voltage. If the unknown resistance is less than 2 ohms, the piezoelectric beeper generates a loud tone. If the resistance is greater than 2 ohms but less than about 10K, there is a soft tone. Above about 10K, the circuit turns off.

Pictorial Assembly View

For those uncomfortable reading schematics, here is a pictorial wiring view. All parts can be bought at Radio Shack (except the Altoids candy box).



name	value	tolerance	color bands
R1	1K	5%	brown/black/red/gold
R2	1K	5%	brown/black/red/ gold
R3	68	5%	blue/gray/black/ gold
R4	33K	5%	orange/orange/orange/gold
R5	1K	5%	brown/black/red/gold
R6	10K	5%	brown/black/orange/gold

C1 is a 0.1 uF bypass capacitor

Transistor: any low voltage general purpose PNP

Diode (D1): any low power/low voltage general purpose diode

Integrated circuit: LM324 (quad op-amp)

Beeper: any piezoelectric beeper able to run on 8V DC

9V battery: nothing special

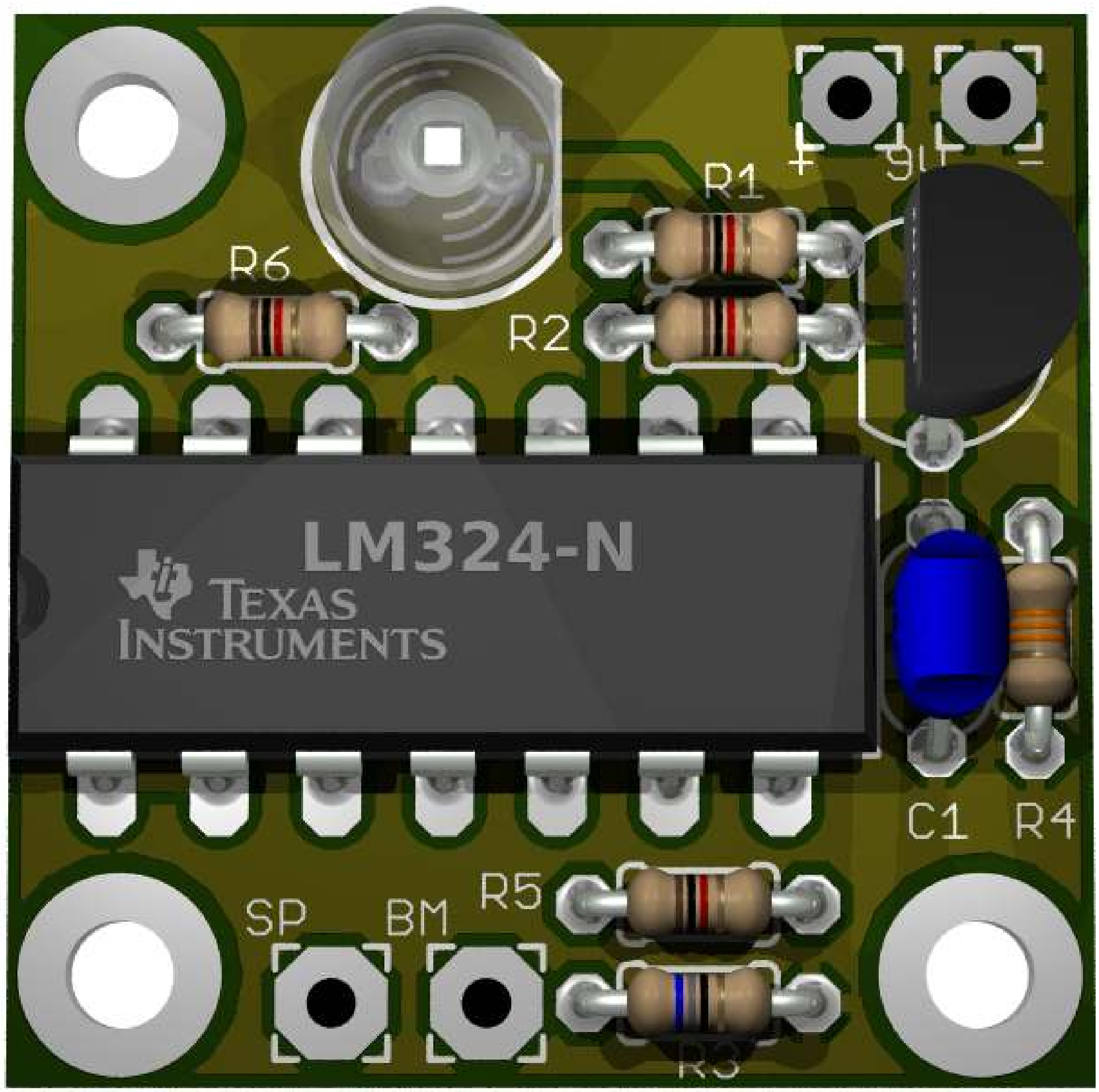
Keep all wires connecting to the integrated circuit as short as possible.

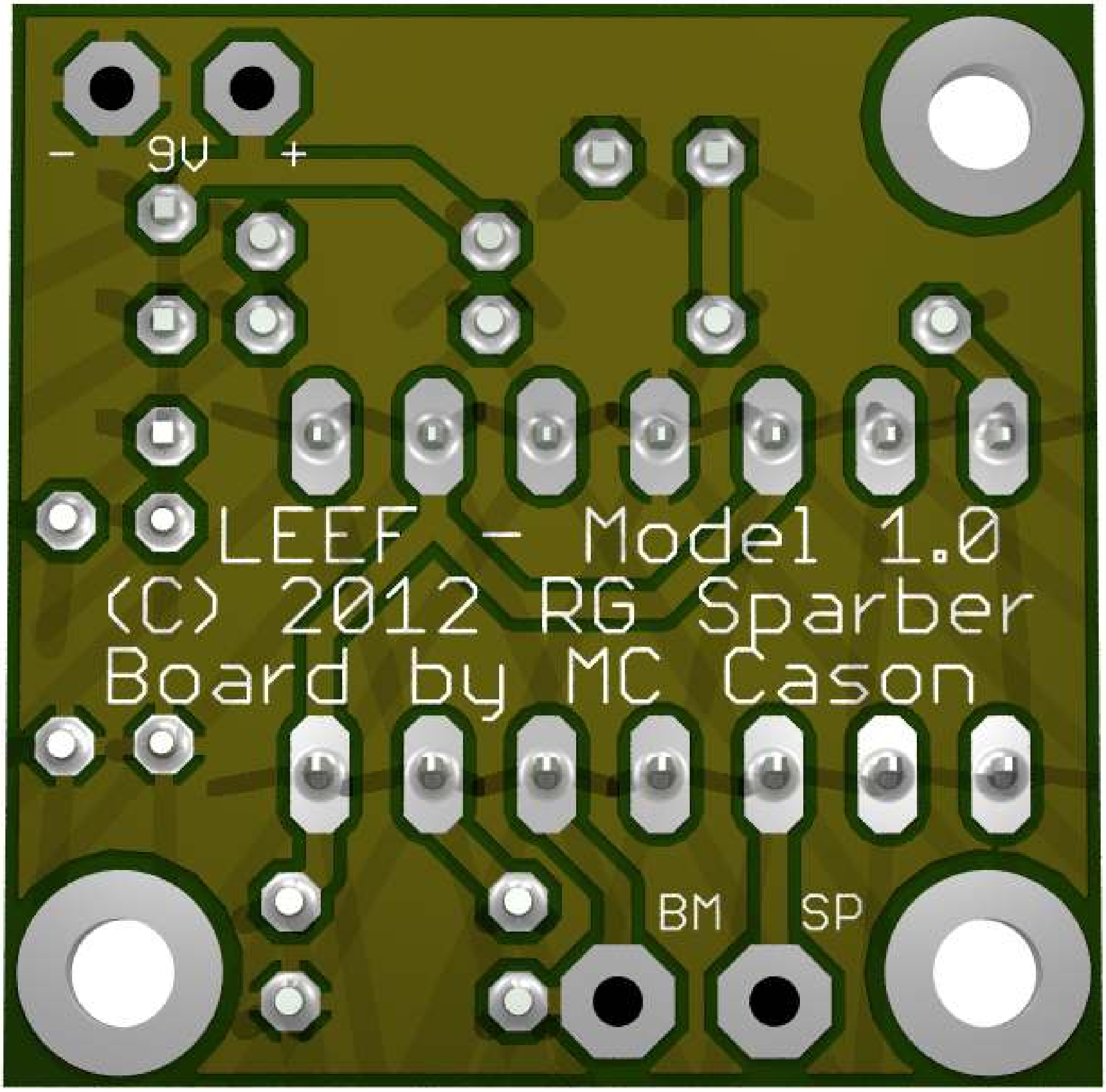
Note that the solid color band printed on the body of the diode indicates the wire that connects to pin 8 of the integrated circuit.

The value of R6 can be changed to adjust the "power on" warning tone's volume.

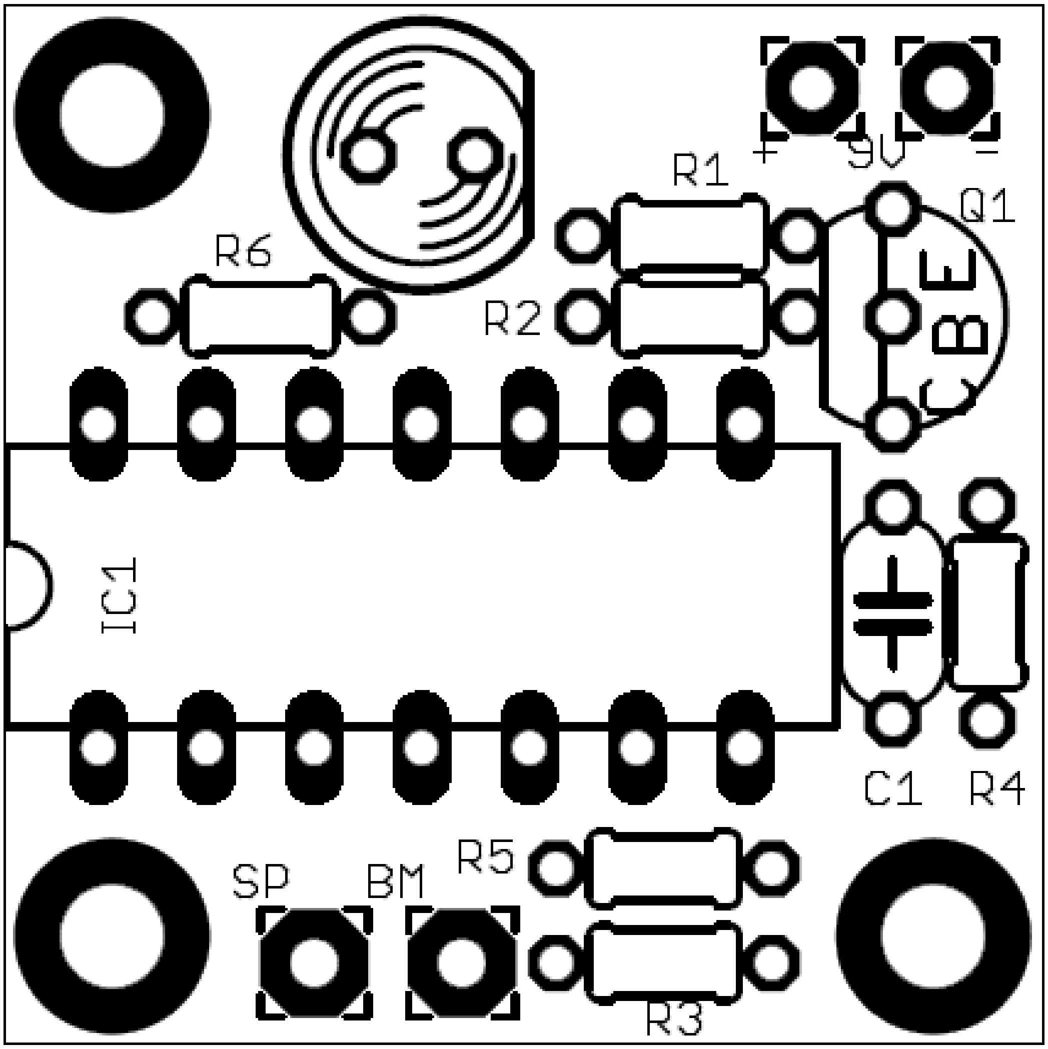
Circuit Board Layout

Mark Cason did a masterful job of laying out this board and documenting it. It is for the circuit version that uses a single red/green LED and no piezoelectric beeper. Note that this layout is not the same as the prototype shown previously.

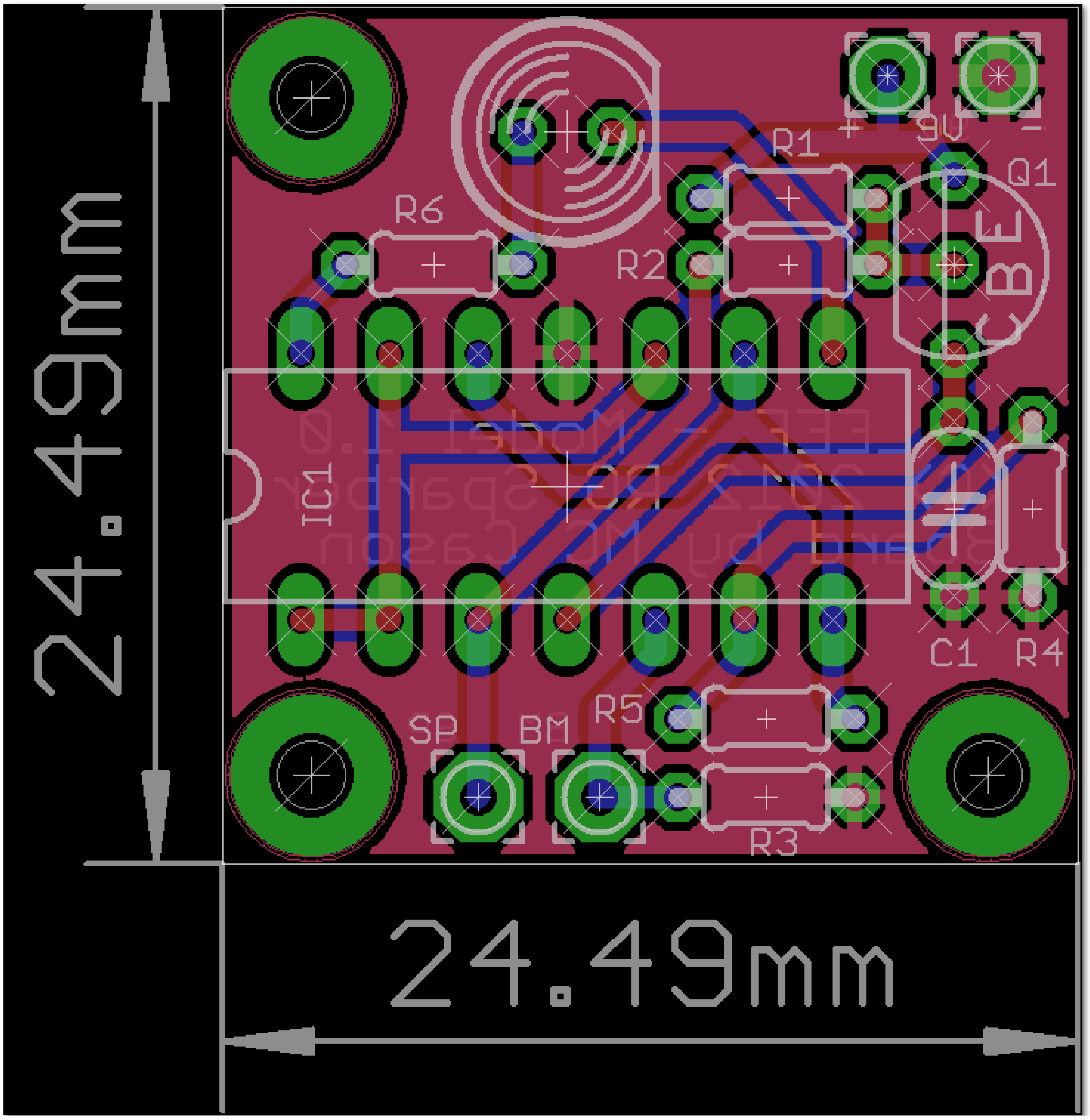




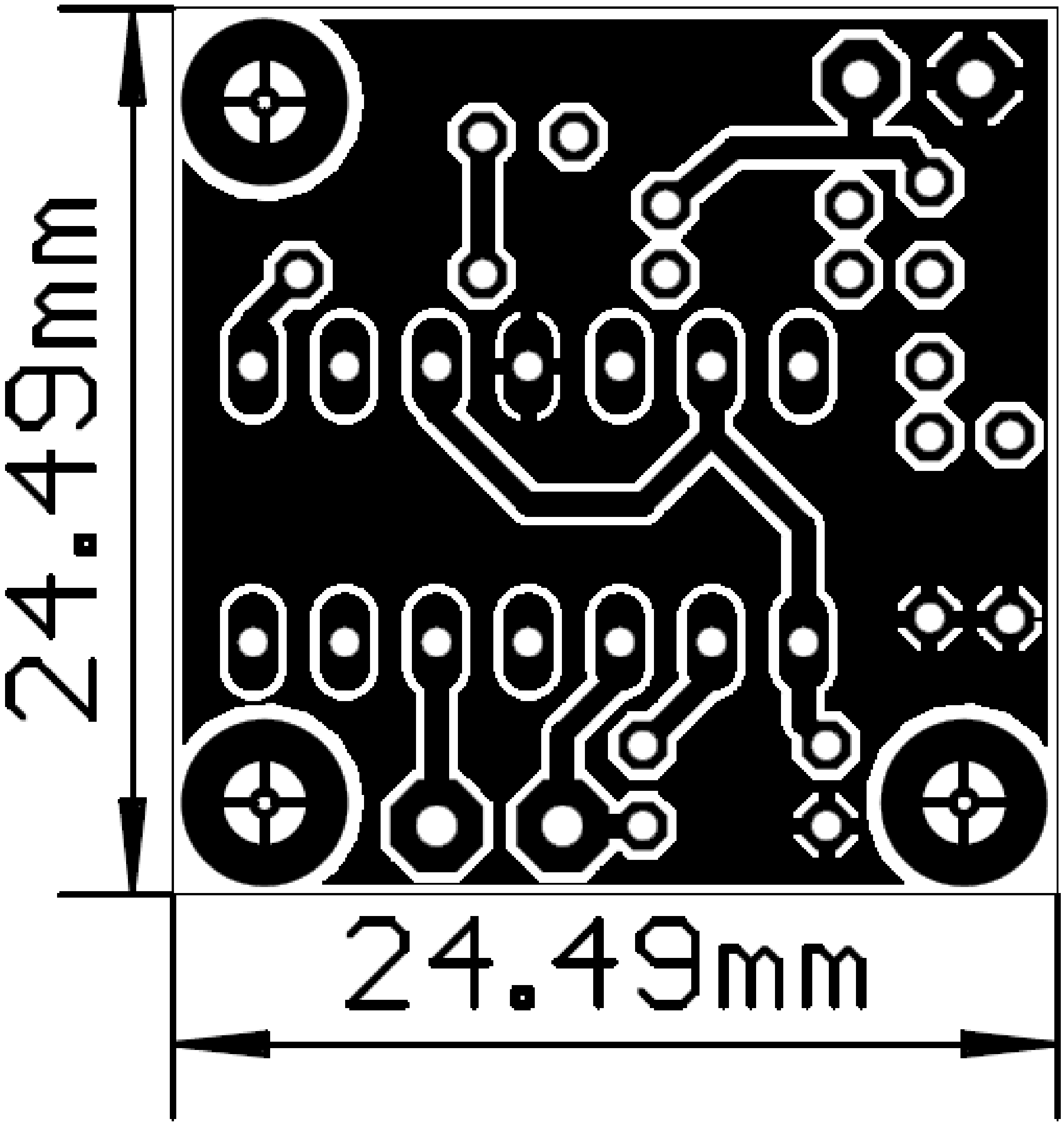
Yup, still a computer simulation. Sure looks real to me.



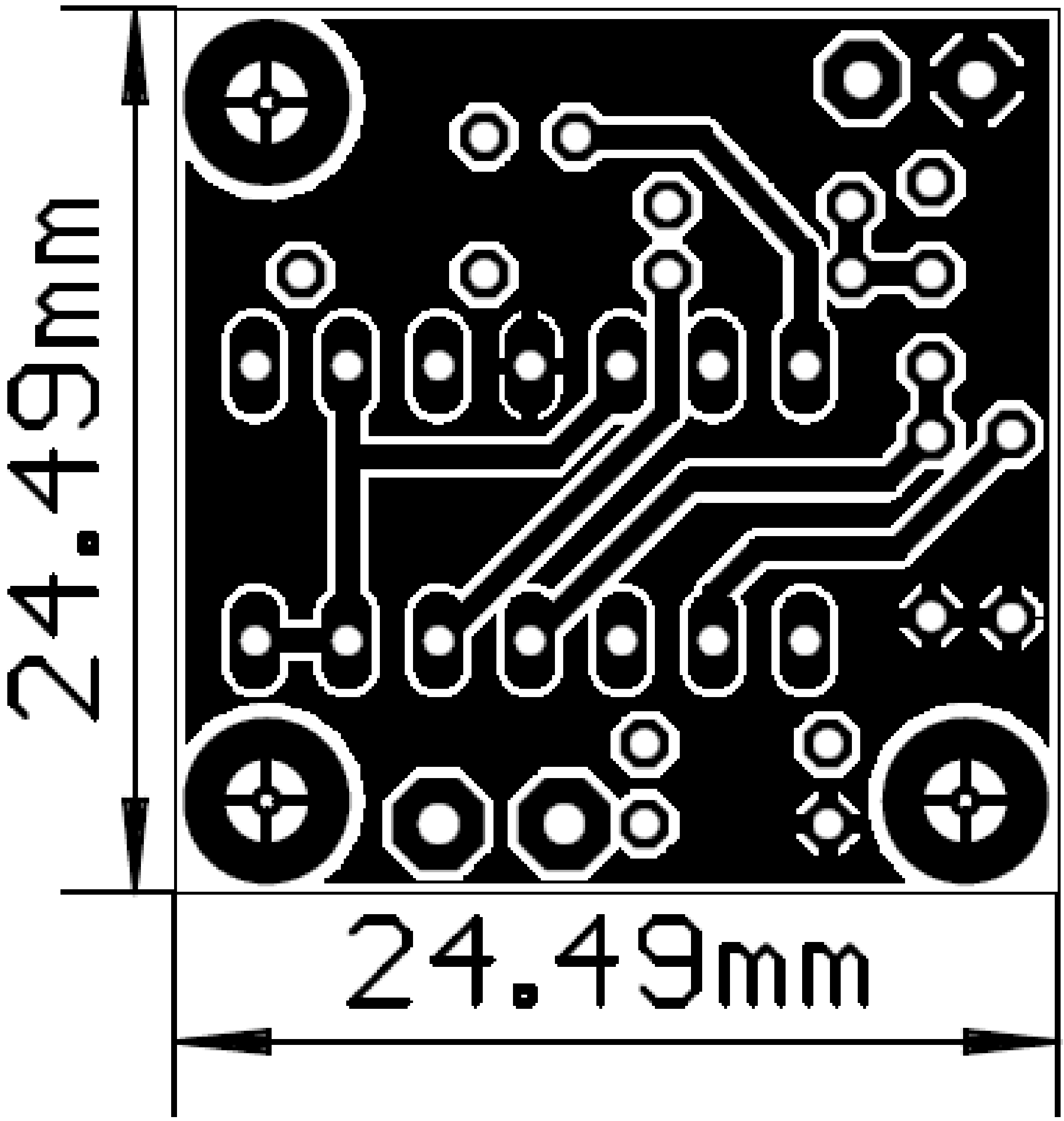
Parts placement drawing suitable for printing.



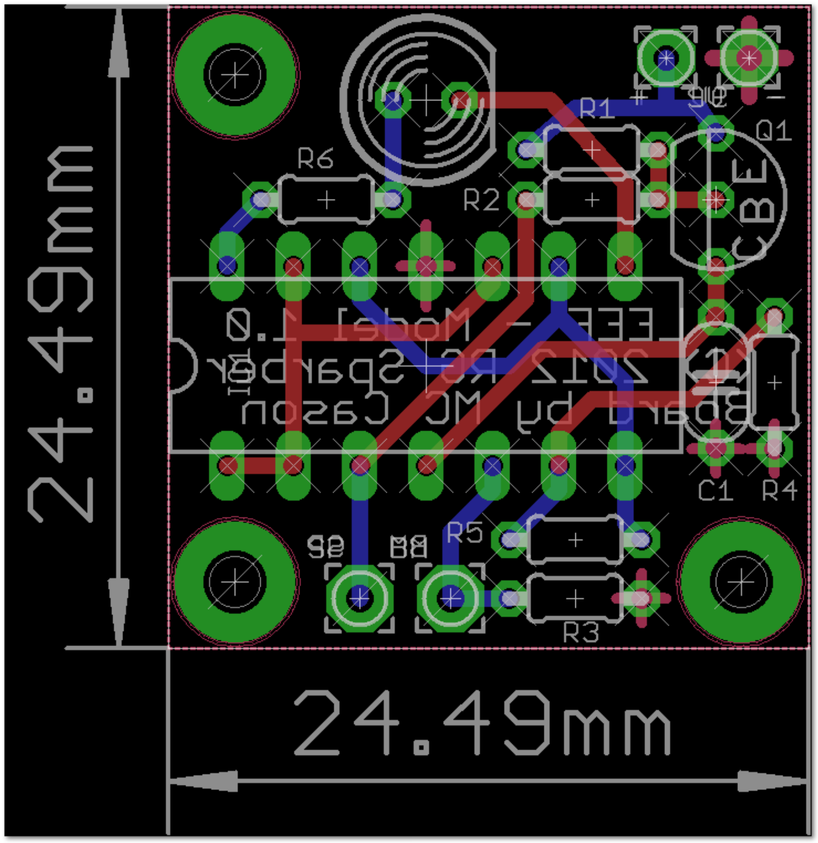
This is a top view and includes traces, ground plane, and silk screen.



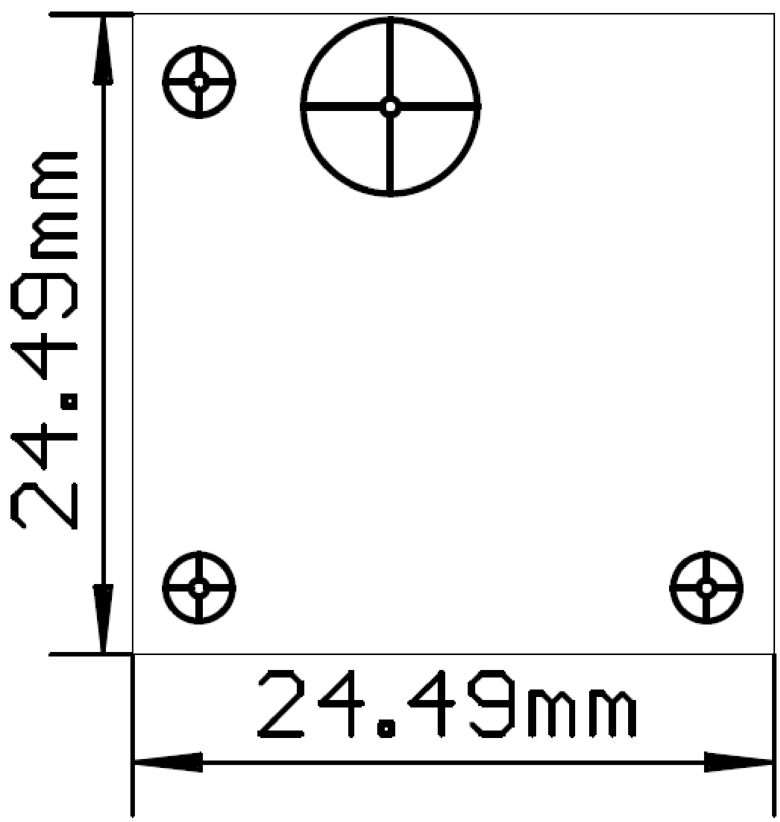
This is the bottom mask.



This is the top mask mirrored.



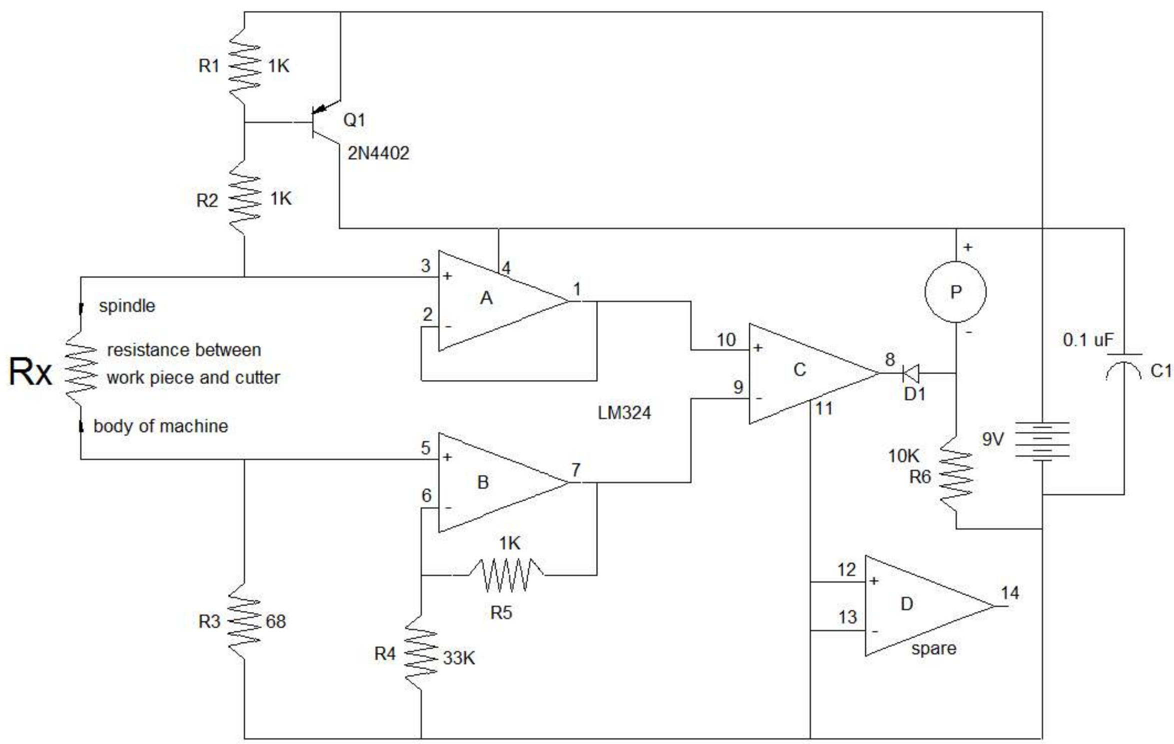
This is a top X-ray view without ground plane.



This is a template that can be used to drill the mounting and LED clearance holes.

Scale all masks and the template to 24.49 mm on a side. I do this by first printing the artwork at 100%. Then use a digital caliper set to metric to measure the width. Divide 24.49 mm by this measurement and multiply by 100%. Then round to the nearest integer to get the needed zoom percentage. For example, if you measured 29.4 mm, then change the zoom to $\frac{24.49\ mm}{29.4mm} \times 100\%$ = 83.3%. My zoom should be set to 83%. Print and recheck.

Detailed Circuit Description

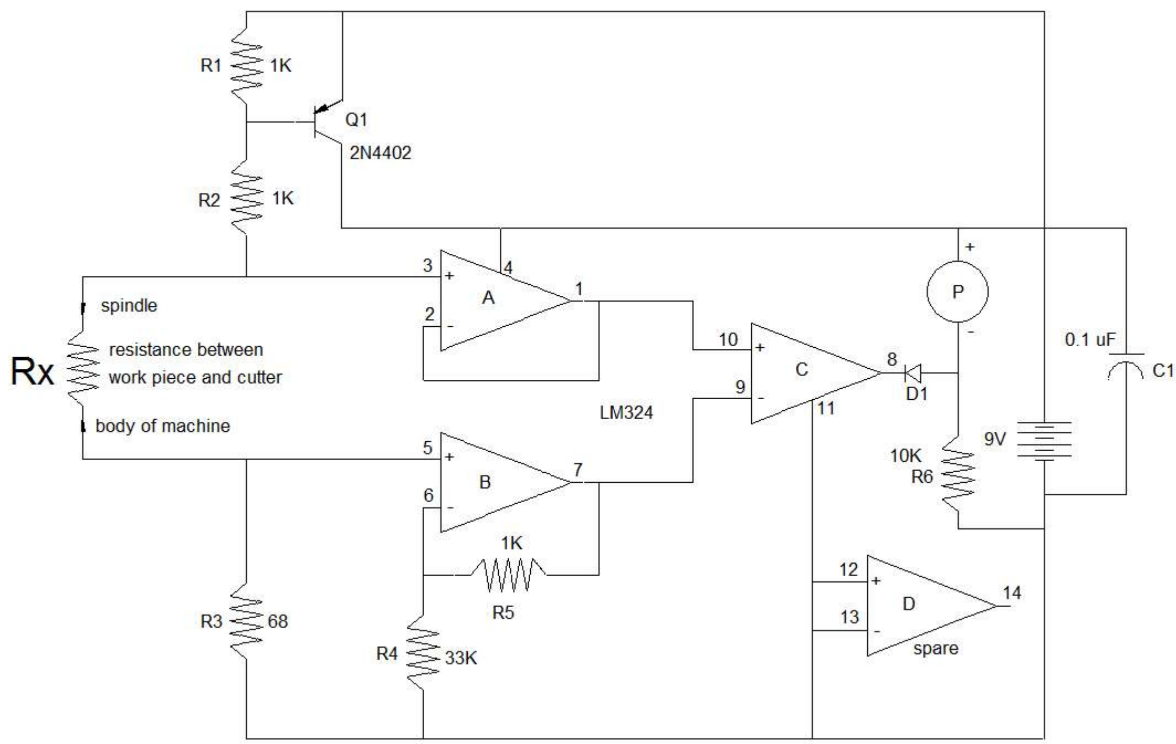


Lines that "T" connect. Lines that cross do not connect.

The circuit changes state when Rx is at 2.1 ohms. Above 2.1 ohms but less than about 10K, the voltage at pin 3 with respect to pin 5 (called V_{3-5}) is higher than V_{7-11}. V_{3-5} is equal to V_{1-5}.

With V_{10-9} is positive, op-amp C will have an output voltage near V_{4-11}which is close to the full battery voltage. Diode D1 is back biased and a small current flows through the piezoelectric beeper and R6. A low volume tone is generated to warn the user that power is being used.

Below 2.1 ohms, V_{1-5} is less than V_{7-5}. This causes V_{8-11} to be near zero. D1 turns on and close to the full battery voltage is applied to the beeper. It generates a very loud tone to indicate touch-down of the cutter.



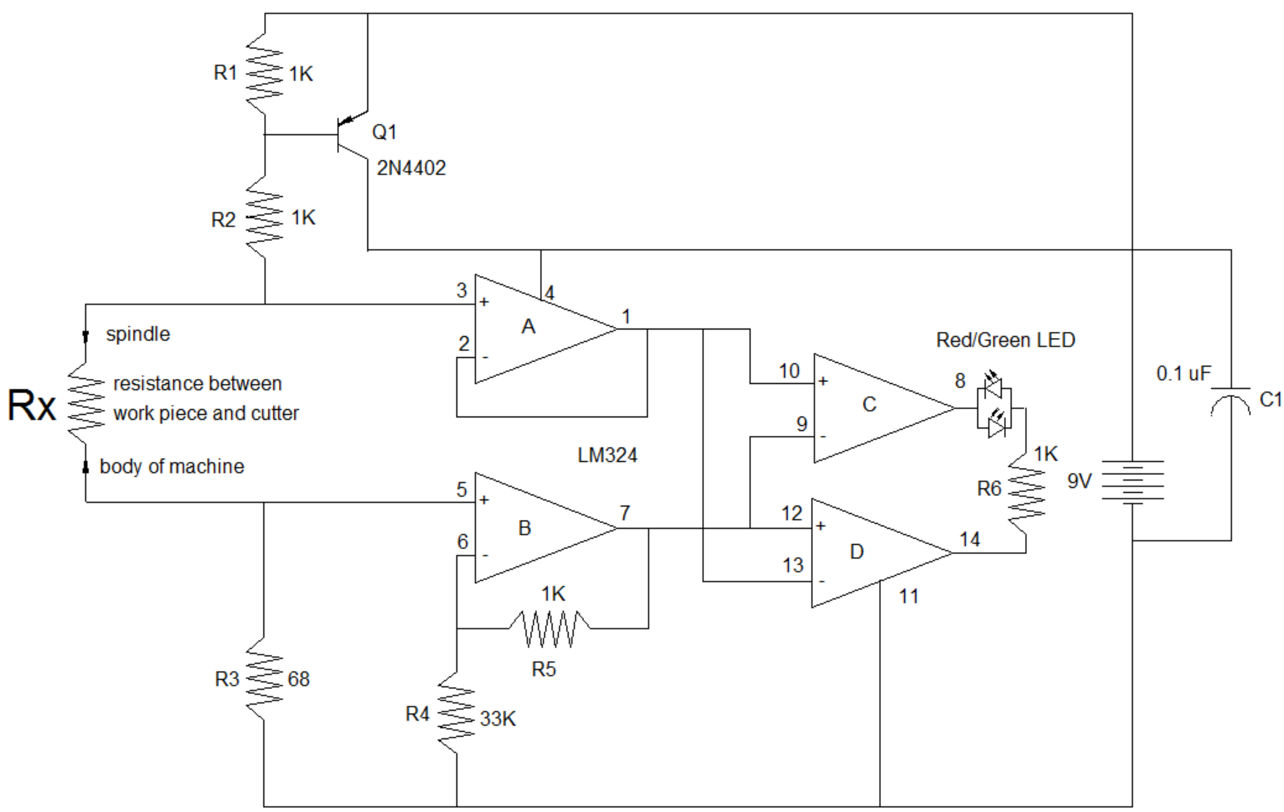
Op amp B measures the test current times R3. It then generates a small reference voltage which is applied to pin 9. The voltage applied to pin 10 is a function of both Rx and the test current. Op amp C compares two voltages that are both functions of the test current. In this way the test current's value drops out of the equation and the circuit is only comparing resistances.

When Rx is greater than about 10K, transistor Q1 turns off and removes power from the integrated circuit and beeper. When the probes see an open circuit, the battery current goes to zero.

C1 should be connected to pins 4 and 11 with the shortest possible lead length.

See page 9 for the parts list.

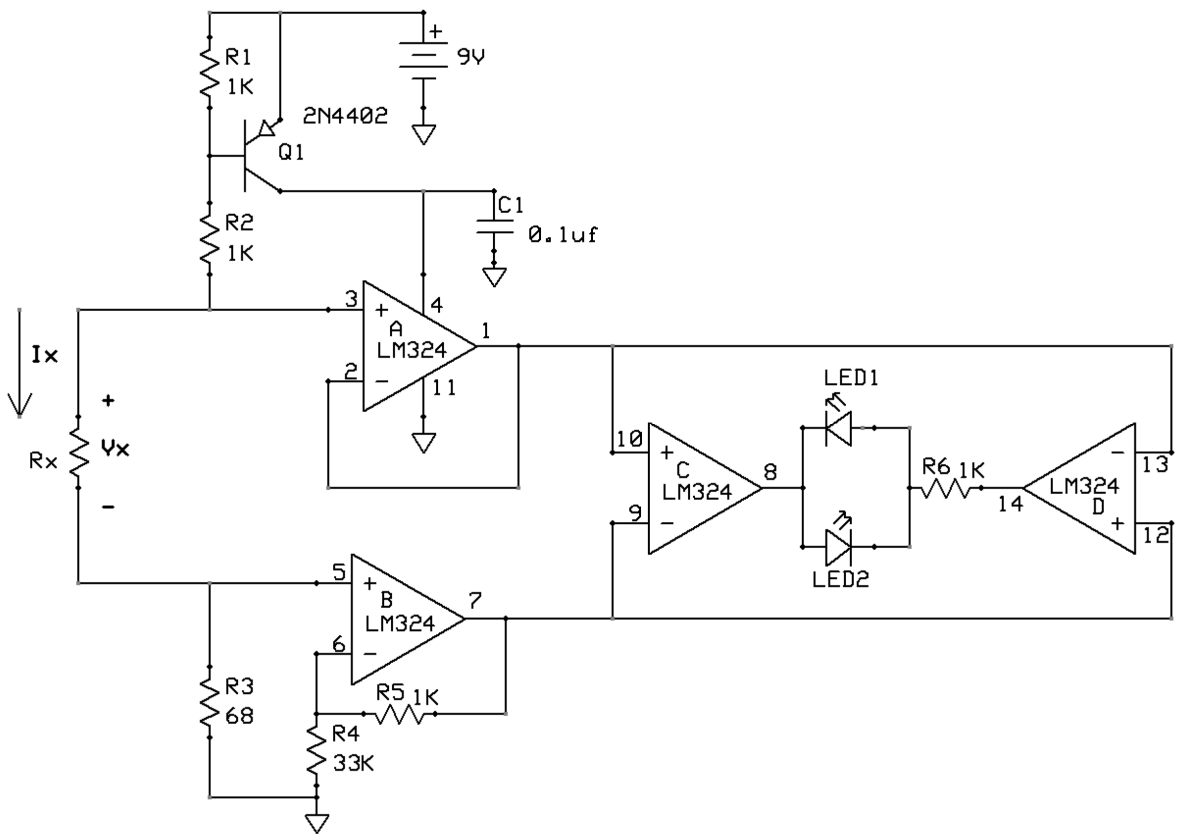
A variation on the design is to replace the piezoelectric beeper with a red/green LED. This lowers cost and makes the LEEF more compact.



These LEDs could be positioned to shine on the feed dial making it easy to both monitor the dial's position and the circuit's state. In fact, the "body of machine" probe could be integrated with the LEDs so only two cables exit the device.

When $V_{1\text{-}7}$ is positive, pin 8 rises to near 8V and pin 14 falls to near 0V. That turns on one of the two LEDs. When $V_{1\text{-}7}$ is negative, the polarity across the LED reverses and the other LED turns on. In this way you get a power on visual indication plus a touch-down indication, all in one LED package.

Detailed Circuit Analysis



I_x is the current through R_x

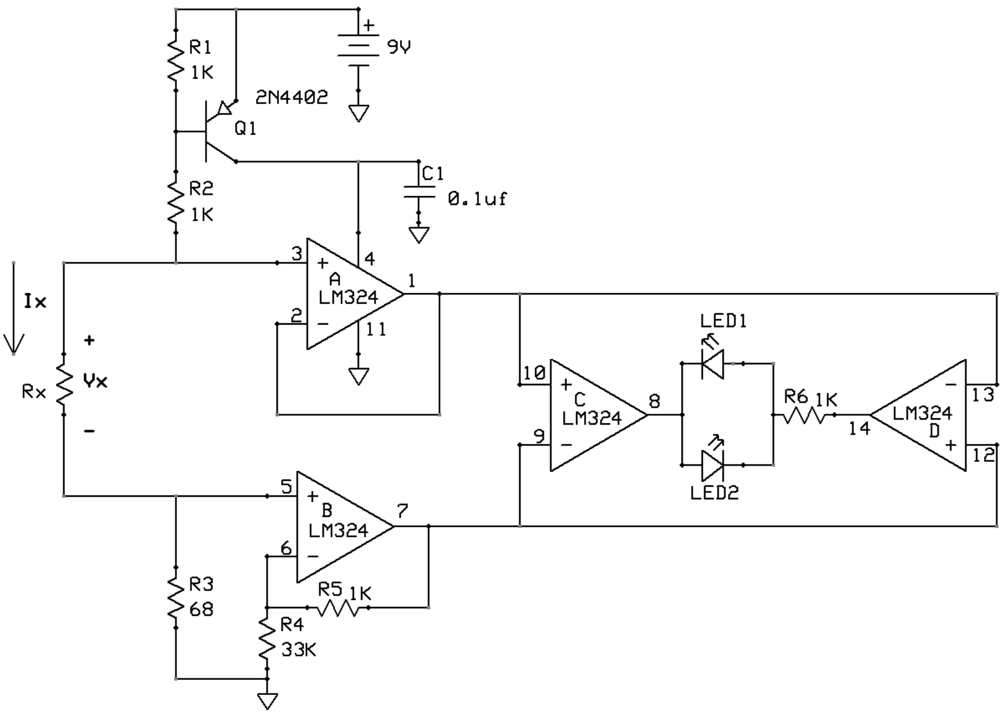
$$I_x = \frac{(V_{battery} - V_{EBsat1})}{R_2 + R_x + R_3} \quad (1)$$

$$I_x = \frac{(9V - 0.75V)}{1K + R_x + 68}$$

But since R_x is much less than 1K, we can ignore it and say that

$$I_x \cong \frac{(9V - 0.75V)}{1K + 68}$$

$$I_x \cong 7.7\ mA \quad (2)$$



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

$V_5 = R_3 \times I_x$ (3)

This assumes that the input bias current flowing out of pin 5 is small. For the LM324 it is equal to or less than 0.25 µA which is much less than I_x of 7.7 mA so it is a reasonable assumption.

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

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

Putting (3) into (4) we get

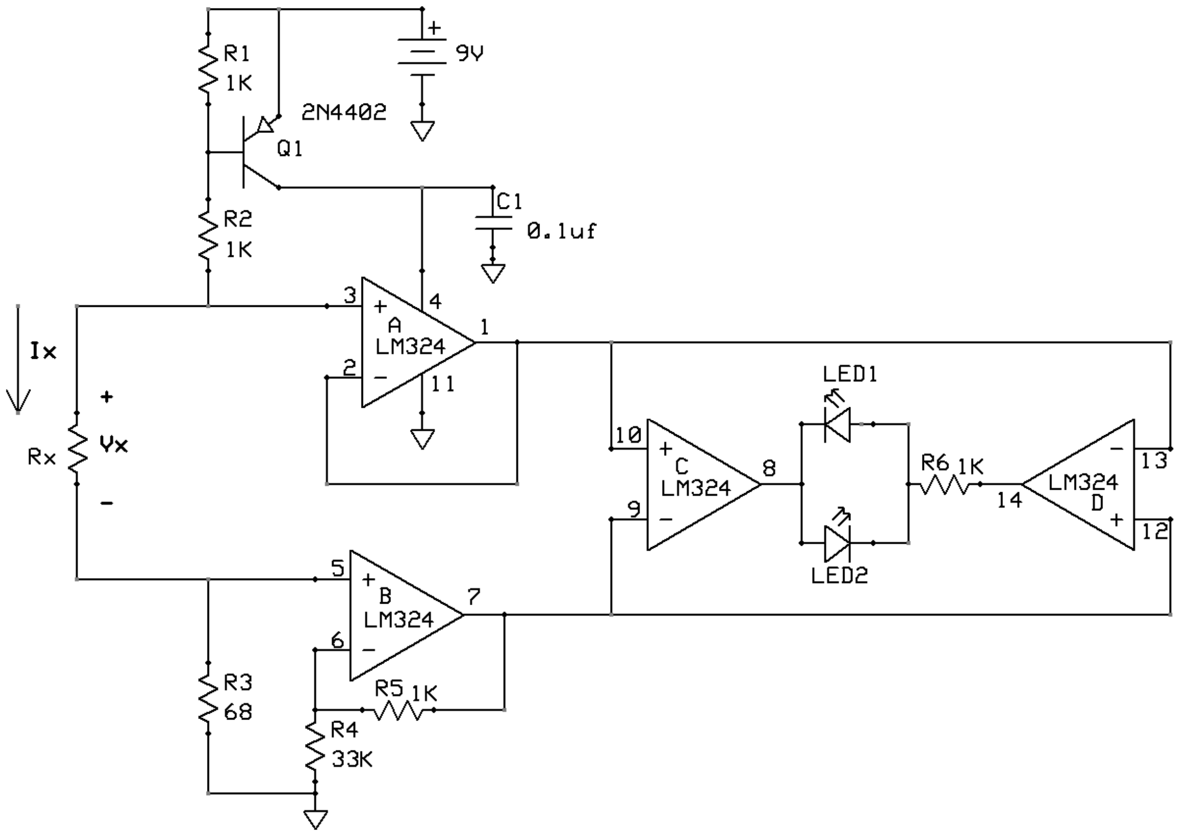
$V_3 = \{R_3 \times I_x\} + R_x I_x$

or

$V_3 = (R_3 + R_x) \times I_x$ (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.

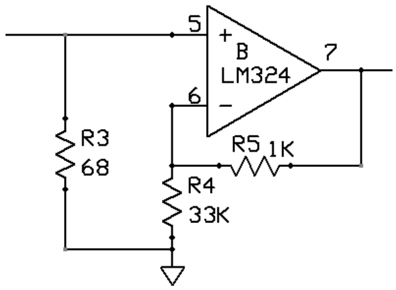


First consider op amp A in the ideal case. This op amp is configured for unity gain. The output voltage equals about 10^5 times the input voltage. This means that the input voltage is 10^{-5} times the output voltage. So for any output voltage, the input is extremely tiny. We can therefore say that V_3 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 LM324, V_{os} can be as large as ± 7 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

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

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

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

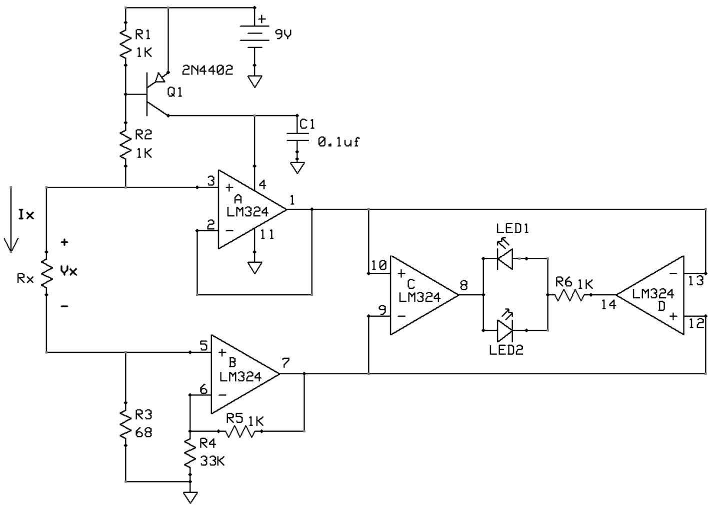
$$V_7 = \left(1 + \frac{R_5}{R_4}\right)(V_6)$$

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 0.25µA, this causes an error of 0.25 mV 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 typically ±3 mV with a maximum of ±7 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

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

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

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

And get

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

Then do a bit of algebra.

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

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

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.

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

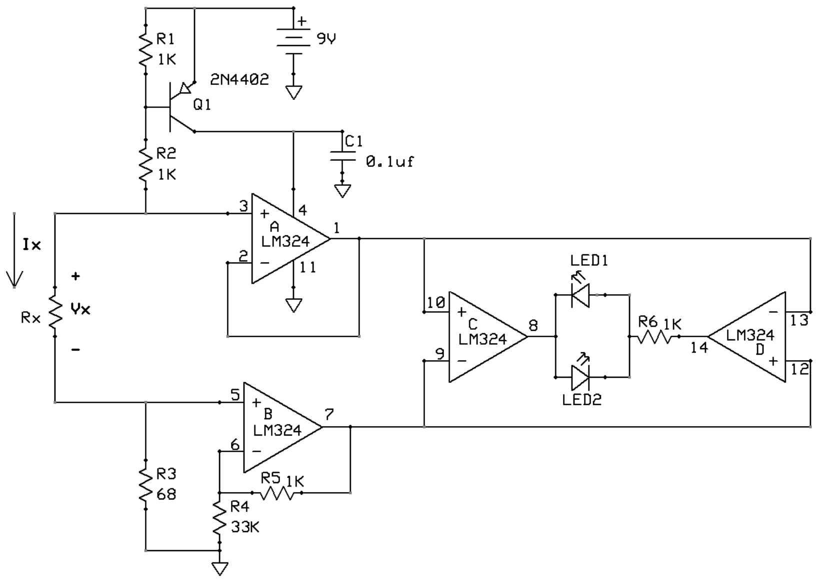
Solving for R_x we get

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

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

$$R_x = \frac{1K \times 68\ ohms}{33K}$$

$$R_x = 2.06 \text{ ohms}$$

But we really can't ignore the input offset voltages. The problem is coming up with a reasonable worst case. If we go for absolute worst case, then we get

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

$$R_x = 2.06\ ohms \pm \frac{7\ mV + 7\ mV + 7\ mV}{7.7\ mA}$$

$$R_x = 2.06\ ohms \pm 2.72\ ohms$$

This says that the minimum R_x is a negative resistor. That won't work. But this is also an absolute worst case so is rather unrealistic.

We can use all typical values. This is still absolute worst case with respect to polarity since each offset has been chosen to maximize the variation.

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

$$R_x = 2.06\ ohms \pm \frac{3\ mV+3\ mV+3\ mV}{7.7\ mA}$$

$$R_x = 2.06\ ohms \pm 1.17\ ohms$$

Well, that is better. The threshold is still very sloppy but the circuit will detect touchdown.

The requirement is that the touchdown resistance must be no larger than 0.6 ohms. If we set minimum R_x equal to 0.8 ohms, then we will always detect touchdown. This turns (11) on its head:

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

$$0.8\ ohms = 2.06\ ohms + \frac{V_{osA}+V_{osB}+V_{osC}}{7.7\ mA} \qquad (11)$$

-9.7 mV = $V_{osA} + V_{osB} + V_{osC}$

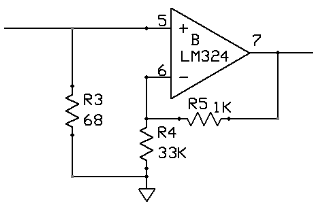
So as long as the sum of the three offsets is no more negative than -9.7 mV, I will be able to detect touchdown.

In the prototype I measured an input offset voltage of 1.6 mV. Assume that as my typical value and take the worst case polarities. This yields

$$R_x = \ 2.06\ ohms\ \pm \frac{1.6\ mV + 1.6\ mV + 1.6\ mV}{7.7\ mA}$$

$$R_x = \ 2.06\ ohms\ \pm 0.62\ ohms$$

So here is where engineering judgment comes in. If this was going into high volume production, I would abandon the LM324 and go with the LT1014 which has a maximum input offset voltage of ±0.3 mV at room temperature. It would give us an absolute worst case threshold variation of ± 0.12 ohms.



But the LT costs about $4 and LM costs about 25¢. So for a one-off hobby version, I would stay with the LM and test the threshold. If too low, modify R3 accordingly.

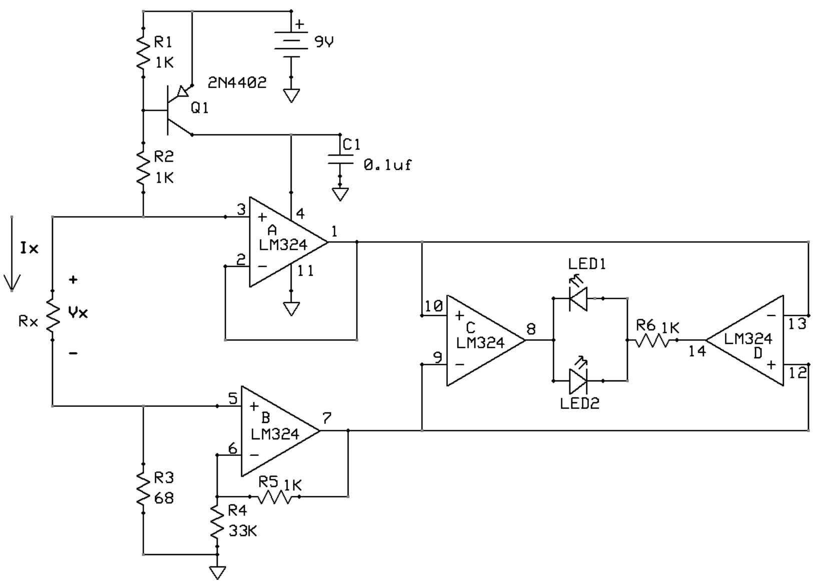
An alternative is to raise I_x. That too will lower the variation. In the LEEF model 2 this current is 20 mA.

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

$$R_x = \ 2.06\ ohms\ \pm \frac{7\ mV + 7\ mV + 7\ mV}{20\ mA}$$

$$R_x = \ 2.06\ ohms\ \pm 1.05\ ohms$$

So that keeps us out of trouble too.



In order to set I_x to 20 mA, we can use

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

$$20\ mA \cong \frac{(9V - 0.75V)}{R_2}$$

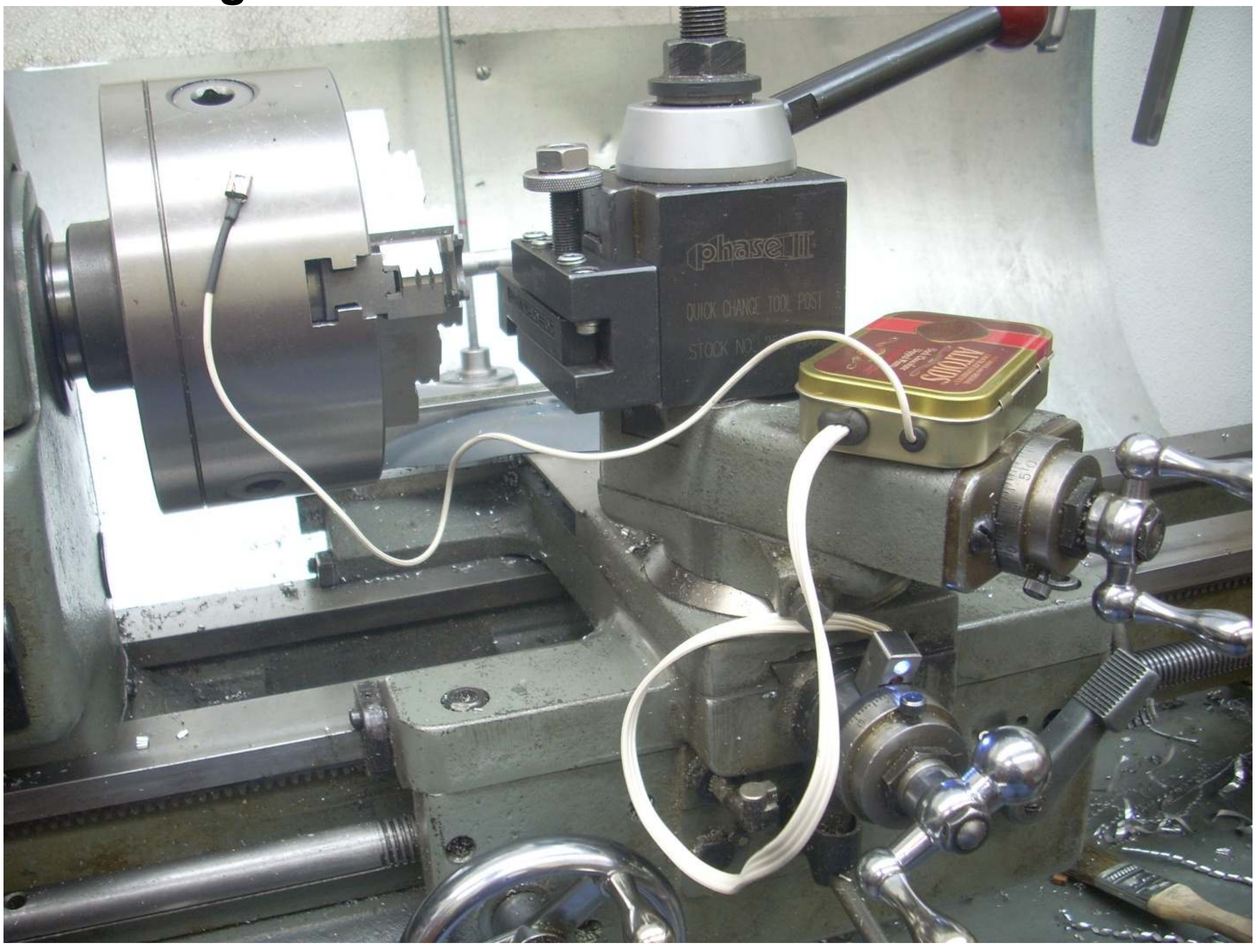
$$R_2 \cong \frac{(9V - 0.75V)}{20\ mA}$$

$$R_2 \cong \frac{(9V - 0.75V)}{20\ mA}$$

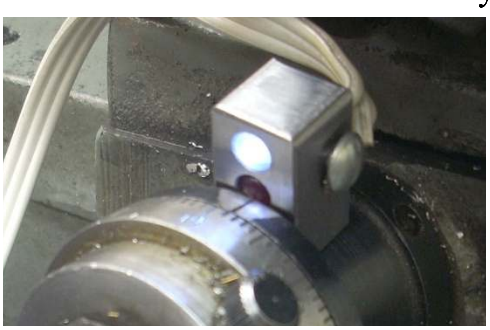
$R_2 \cong 413\ ohms$ so use the standard value of 390 ohms.

So you see that there are many options here if the threshold, R_x, is too low.

First Design Revision



I have moved the two LEDs from inside the box into one of the magnetic clips. Now the LEDs can shine directly onto the dial.



Before I reach touch-down of the cutter, my dial is illuminated with a Super Bright LED.

Once the cutter touches down, my Super Bright LED goes dark and my red LED comes on. Both LEDs go dark when they are removed from the lathe and placed back on the box.

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Thanks to Jay B. and Mike Marshall of the Atlas_Craftsman Yahoo group for supplying me resistance data on their machines.

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I welcome your comments and questions.

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