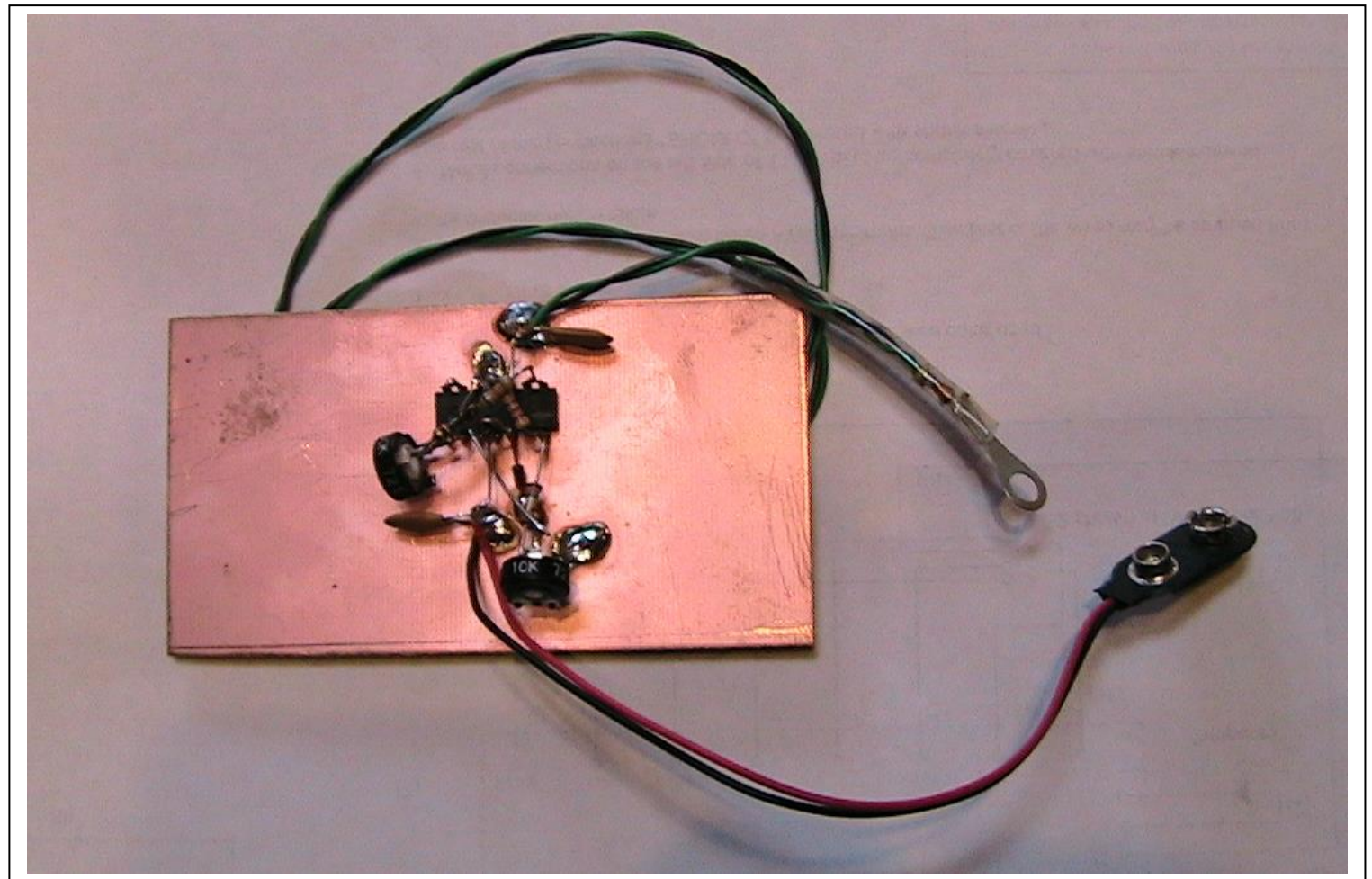


Lab 10

Integrated Circuits Power Amplifier

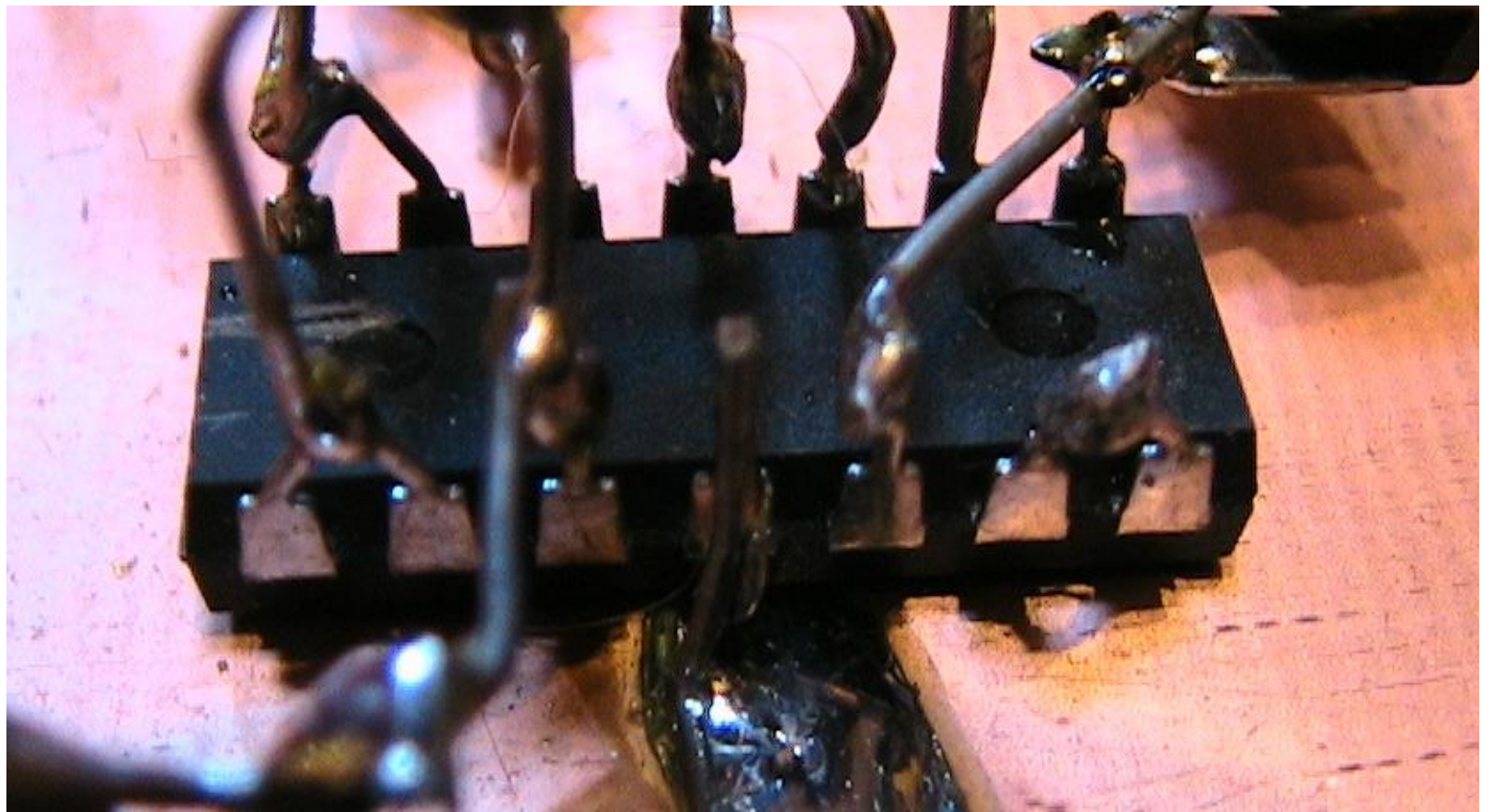
Tonight's lab will introduce you to two concepts in electronics. Operational amplifier power amplification and "dead-bug" construction.

Let's talk about dead-bug construction first. Here is a project I did for the magazine showing how to make a digital thermometer using a digital voltmeter and (guess what) a diode as a temperature sensor. Hey, if the technology hands you lemons, make lemonade. Anyway, the article (see the last pages of this lab) used an LM324 and "dead bug" construction.



Here is a close-up of the 14 pin LM324 integrated circuit. Note that the "legs" or terminals of the package are sticking straight up into the air, resembling a cockroach that had an overdose of Old Rammycackle for dinner. In other words, a dead bug.

What are the advantages of this form of construction? For one thing, it is cheap and easy to do. I can go from schematic to finished circuit in far less time than it takes to do it on a proto-board. Two, it is relatively



simple to simply solder parts directly to the scrap PC board material and have them remain fairly well in place. Three, it is fairly easy to desolder the circuit if I've made an error or want to change the circuit.

Let's get to building the amplifier. Cut yourself a piece of pc board material about 4" square. Trim off any rough edges that the shear left on the board with a file. (It won't hurt the circuit to leave them on, but you may cut yourself on the sharp edges.)

Here is the data sheet for the little LM386 chip that we are going to use, followed by the schematic of the amplifier we are going to build for ourselves. The step-by-step instructions begin on page 6.

LM386

Low Voltage Audio Power Amplifier

General Description

The LM386 is a power amplifier designed for use in low voltage consumer applications. The gain is internally set to 20 to keep external part count low, but the addition of an external resistor and capacitor between pins 1 and 8 will increase the gain to any value from 20 to 200.

The inputs are ground referenced while the output automatically biases to one-half the supply voltage. The quiescent power drain is only 24 milliwatts when operating from a 6 volt supply, making the LM386 ideal for battery operation.

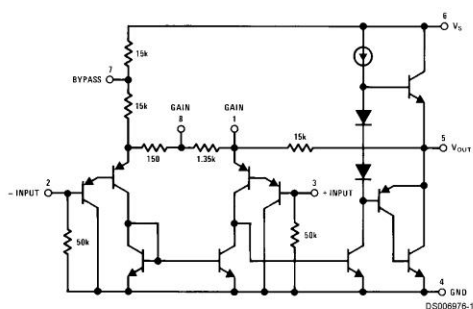
Features

- Battery operation
- Minimum external parts
- Wide supply voltage range: 4V–12V or 5V–18V
- Low quiescent current drain: 4mA
- Voltage gains from 20 to 200
- Ground referenced input
- Self-centering output quiescent voltage
- Low distortion: 0.2% ($A_V = 20$, $V_S = 6V$, $R_L = 8\Omega$, $P_O = 125mW$, $f = 1kHz$)
- Available in 8 pin MSOP package

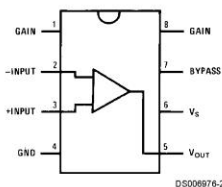
Applications

- AM-FM radio amplifiers
- Portable tape player amplifiers
- Intercoms
- TV sound systems
- Line drivers
- Ultrasonic drivers
- Small servo drivers
- Power converters

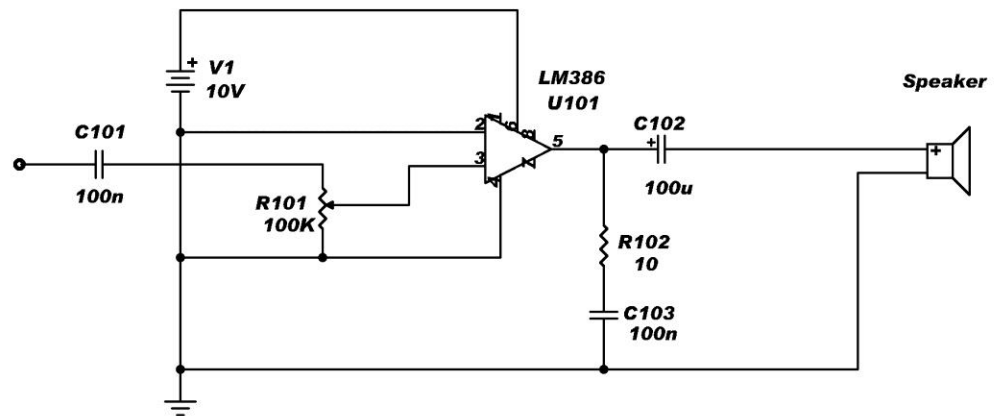
Equivalent Schematic and Connection Diagrams



Small Outline,
Molded Mini Small Outline,
and Dual-In-Line Packages



Top View
Order Number LM386M-1,
LM386MM-1, LM386N-1,
LM386N-3 or LM386N-4
See NS Package Number
M08A, MUA08A or N08E



Simple Audio Amplifier		
Rev	ID	
A	CIE-01	
Date: 11 Nov 09		Page: 1 of 1

Step By Step Instructions:

1. Cut a short (1/2") bare wire from one end of the 10 Ω (brown-black-black-gold resistor. Bend the wire into an L shape with equal legs on the L.
2. Identify pin 1 on the LM386 integrated circuit. On the BOTTOM of the IC scratch a line or mark to identify pin 1 when the IC is upside down.
3. Place the IC near the center of the pc board material that you cut into a square. Turn the heat control on your soldering iron all the way up and solder the wire L to the pc board near pin 4 of the IC. Solder the wire so that the free end of the wire is vertical. See first page of data sheet to identify pin 4 of the IC.
4. Solder the free end of the wire to pin 4 of the IC.
5. The battery clip has two wires, black and red. Bend the wire end of the red wire into a U hook and place the U around pin 6 of the IC. Crimp the U closed with longnose pliers and solder the red wire to pin 6. Be careful not to make a solder bridge between pin 6 and pins 5 or 7. Do not put the battery into the clip yet.
6. Solder the black battery clip wire near the edge of the pc board.
7. Cut the 10 Ω (brown-black-black-gold) resistor wires to about 1/4 " long each. Bend both ends into a U shape and crimp one end to pin 5 of the IC, then solder using as little solder as possible ("tack solder"). Save the cutoff leads.
8. Cut both leads of a 100 nanofarad (may be marked 0.1 microfarad or .1 μ f) to 1/4". Bend one lead into a U shape, crimp it into the free end of the 10 Ω resistor (crimp both U hooks together) and solder.
9. Bend the other end of the 100 nanofarad capacitor so it lies flat on the pc board and solder it to the pc board.
10. Cut the (+) lead of the 100 microfarad electrolytic capacitor to about 1". Bend a U hook at the end and crimp-solder it to pin 5 of the IC. Hot glue the capacitor to the board making sure that none of the case of the capacitor is touching the board. Cut the remaining (-) lead of the capacitor to about 1/2" and leave it free-floating straight up from the board.
11. Look at the back (black plastic) of the volume control 100k Ω potentiometer and note that it has three terminals ("pins"). Call them left, center, and right.
12. Solder one of the cutoff resistor wire leads to the center pin (using the U-hook method). Solder the other end of the wire to pin 3 of the IC in such a manner that the left pin of the control is touching the pc board.

13. Solder the left pin of the control to the pc board.
14. Cut both ends of the remaining 100 nanofarad capacitor to $\frac{1}{4}$ ". Bend a U-hook into both ends. Solder one end into the right pin of the volume control. Leave the other end free-floating for the time being.
15. Have the instructor or lab assistant look at your work before installing the 9 volt battery.
16. Connect a speaker using alligator clipleads, one end to the pc board and the other end to the free lead of the 100 μ f capacitor. The speaker MAY have a (+) sign on it or not. If it does, the (+) sign goes to the capacitor.
17. Use the trainer function generator by setting the frequency to 1000 Hz. (1 kHz.) and the output level to 100 millivolts peak-to-peak. Use the digital oscilloscope to set the level (have the instructor or lab tech show you how to set a level and a frequency using the 'scope).
18. Use the volume control to set the output across the speaker to 1 volt peak-to-peak.
19. Now, using the oscilloscope to measure the output across the speaker, and without touching the input level control(s), lower the frequency until the output has dropped to 700 millivolts (70% of 1 volt). Record that frequency here _____
20. Similarly, return the frequency to 1 kHz. and note that the output has returned to one volt. Increase the frequency until the output has dropped to 700 millivolts. Record that frequency here _____.
21. What you have just done is a bandwidth test of this amplifier. When you buy a piece of sound equipment it will say something like "Frequency response flat from 30 Hz. to 30 kHz.). Your amplifier is "flat" between the two frequencies you recorded above.
22. Remove the oscilloscope and trainer function generator from the circuit.
23. (If the computers are so equipped in the classroom). Connect the "shell" or longest pin out the back of a 3mm stereo connector to the pc board using a long alligator cliplead. Connect either of the two short pins to the free lead of the 100 nanofarad capacitor (input). Plug the stereo connector into the CDROM on the computer and insert a music CD into the CDROM player. You should hear the music in the speaker.
24. Briefly remove the alligator cliplead from one short pin and put it on the other short pin. You should hear at least a minor change in the sound. What you are listening to are the left and right channels of the music on the CD coming out those two pins.

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AERO 'LECTRICS



BY JIM WEIR

How **hot** are we?

Some time ago, I needed a way of remotely reading the temperature of an engine baffle while the aircraft was in flight. Obviously, I couldn't climb out to read a surface-mount thermometer, nor could I aim one of those neat little infrared thermometers at the baffle while in flight. The device that I'm about to describe is an inexpensive remote-sensing digital thermometer.

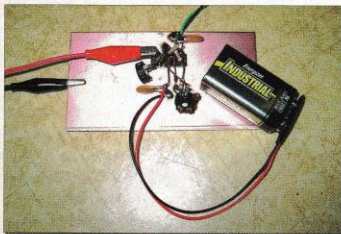
But more than just an article about a thermometer design, I'm going to take you step by step through my thought process for each component I used in the design. Not that I expect you to become an avid circuit designer, but you might find something of interest in knowing that there is a mathematically precise reason for every value chosen in any electronic design.

Let's Get Started, Then

First, we have to think about what temperatures we want to sense. Sensing freezing to boiling water is one problem; sensing freezing alcohol (-40°F) to exhaust gas temperature (1500°F) is another problem altogether. In this case, I determined that the temperature would never exceed 200°F , so the problem resolved itself to picking a sensor that would be accurate, repeatable and cheap. In general, engineers say that when it comes to accurate, repeatable and cheap, you can have...any two. However, in this case, we find that an ordinary silicon diode is an accurate, repeatable and cheap temperature sensor. As a matter of fact, in your home computer, you probably have a built-in thermometer that lets you see the temperature of your CPU, your motherboard and your fans. The sensor? An ordinary silicon diode, less than one cent apiece.

But is it linear? Is the relationship between temperature and diode voltage a straight line? Yep, straight as an arrow. Between the diode voltage at the freezing point of water (32°F or 0°C) and the boiling point of water (212°F or 100°C), the line is a perfect 2 millivolts per degree C or 1.1 millivolts per degree F. Now we have our first data for

design, the forward diode voltage at freezing is 665 millivolts; at boiling that same diode voltage is 465 millivolts, a range of 200 millivolts from one end to the other.



Here's the circuitry for this month's project.

Jim Weir began acquiring Aero 'Lectrics expertise in 1959, fixing Narco Superboms in exchange for flight hours. A commercial pilot, CFI and A&P/LA, Jim has owned and restored four single-engine Cessnas. These days, he runs RST Engineering and teaches electronics at Sierra College. Ask him questions at rec.aviation.homebuilt or visit his site at www.rst-engr.com/kitplanes.

Photos: Jim Weir

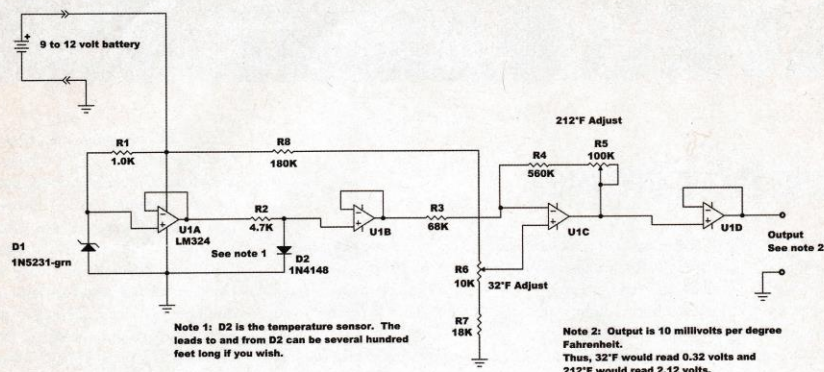
Now that we know the front end, all we have to do is specify what sort of readout we want and let the design translate the "goesinta" to the "goesouta." My choice of digital readouts when I'm doing something cheap and I only need three digits of resolution is one of the many digital voltmeters on the market. The one shown (Harbor Freight #30756) goes on special every couple of months for \$2.99. If that isn't cheap enough, I can't help you much.

How do I want the readout? I want 32° to read 32 on the meter. I want 212° to read 212 on the meter. If that is my desired outcome, then if I want to run the circuit from a 9-volt transistor radio battery or from 12-volts ship's power, then my output can't exceed 9 volts. The output will then read 0.32 volts at freezing and 2.12 volts at boiling. Now we have another data set. The difference between boiling and freezing on the meter is 1.8 volts. If my input is 0.200 volts and my output is 1.8 volts, then the gain of the in-between circuit has to be $1.8 / 0.200 = 9.0$. No problem.

Somehow we have to have a standard—a constant voltage that we can expect to stay reasonably stable with changes in ambient temperature, changing battery voltage and other environmental considerations. Generally, a *zener diode* is chosen to give us a stable voltage over these varying conditions. A zener diode is run in what is called *reverse breakdown*, where we intentionally exceed the reverse voltage limit on the diode and cause it to conduct current at the *zener voltage*. We've learned over the years how to manufacture zeners that will break down at precisely the voltage we want, so the problem resolves itself to picking the zener diode voltage that will be best for us.

Here's a Little Secret...

Now a little secret that a lot of good engineers don't know—the "zener" effect is actually two different mecha-



nisms going on in that little diode. One of those mechanisms has what is called a *positive temperature coefficient*, and the other mechanism has a *negative temperature coefficient*. That is, the zener voltage varies over temperature as a function of which of these mechanisms is more predominant. Here's the secret—those two mechanisms cancel each other out almost perfectly at zener voltages between 5 and 6 volts, so a zener chosen between these two limits has practically zero temperature drift. I'll pick a 5-volt zener for a couple of reasons, not the least of which is that I can buy one at The Shack if necessary. Thus, D1 is a 5-volt zener. I've given you one popular diode number, but any 5-volt zener will work as well.

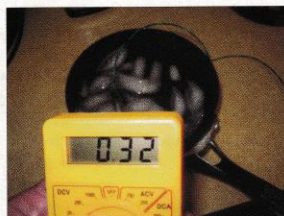
How much current to run through the zener for best performance? I'd really like to run about 10-20 milliamperes for best operation over varying battery voltages, but in order to get best battery life if I'm running on a transistor radio battery, I'll run about half of that. A 1.0 K Ω resistor (R1) will let between 4 mA (9-volt battery) and 7 mA (12-volt ship's power) keep the zener alive and regulating.

One thing we do *not* want to do is to suck any of that current away from the zener. An op-amp (U1A) connected as a voltage follower will draw less than 1 microampere (μ A), which will introduce an error of less than 0.01% in the reference voltage. The op-amp has one and only one purpose in life—it wants to keep the (+) non-inverting input as close to the (-) inverting input as is electrically possible. If we put the 5-volt zener voltage at the (+) input, then the output will do whatever it has to keep the (-) input at 5 volts also. If we tie them electrically together, the output will "follow" whatever voltage we put on the (+) input, and will exercise the huge

close to the center of its linear range, I'm going to flow 1 milliampere of current through the diode. A 4.7K Ω resistor will flow a milliamp through D2.

Again, I really don't want to disrupt the voltage-temperature current flow curve, so I'll use another section of our four-section op-amp. U1B is another very high impedance input voltage follower. The output of U1B is exactly the same voltage-temperature curve as we discussed earlier (the straight line).

Now that we've got the sensor voltage at the output of U1B, we can start the amplification process. If you will recall, we need a gain of 9.0 to amplify the sensor voltage to read properly on the digital voltmeter. The gain of U1C is given as the ratio of the feedback resistors (R4+R5) to the input resistor (R3). I want to be able to exactly adjust the output to read correctly on the meter, so I'll need some sort



Did you get everything right? With the probe in a pot of ice water, you should get a reading like this.

potential voltage gain of the device (300,000:1) to make this happen.

So, with the output voltage of U1A at 5 volts, how do I forward bias our little temperature-variable voltage? I actually have a lot of leeway in making the decision as to how much current to flow through the diode, so to put the diode reasonably

of an adjustment in the feedback path.

Because I've got 100K Ω potentiometers in stock, that forced the choice of R5, which then forced the choice of R4 to 560K Ω , which in turn forced the choice of R3 to 68K. Now we have to do an "offset" to bring up the bottom end of the scale so that the bottom end reads correctly. While I could have done this with two resistors, the choice of three resistors

makes the setting of R6 (a 10K Ω potentiometer) a lot easier. Since we have a gain of roughly 9 in the upper feedback network, we'll need a *loss* of 9 in this network. Choosing R8 (180K Ω) and R9 (18K Ω) gives us this intended loss.

So as to not upset this carefully constructed offset amplifier, we'll use the spare section of the LM324 op-amp as U1D, another voltage follower out to the digital voltmeter.

Some Notes

Fastening the sensor (D2) to the surface to be measured is often a problem. Soldering D2 with a very short lead on the diode onto a solder lug lets us bolt the sensor directly to the surface for best thermal contact.

You can have a couple of hundred feet of wire of nearly any gauge you want between the circuit board and the sensor D2.

Calibration? A bowl full of ice cubes half filled with water is going to be 32°F after about a half hour of cool-down. A spaghetti pot half full of water on the stove is going to be 212°F, less about 1°F for each thousand feet you are above sea level. Set the freezing adjust first, then the boiling adjust. You may have to go back and forth a couple of times if you want accuracy to a degree or so. You may want to let the diode come to room temperature between boiling and freezing so as not to crack the glass on the diode.

The whole circuit sucks about 6 mA from a 9-volt battery, giving a battery life of about 100 hours. That's a whole lot of measurements.

Coming Up?

I've been asked to do an automatic shut-off switch for nonessential items that will automatically drop those items offline if the aircraft charging system fails and lets the battery droop. I've also been asked to show how to run all those alarm inputs plus the comm audio into an intercom that has a single audio input. And there are, as always, a few other goodies in the back of my mind. ✈



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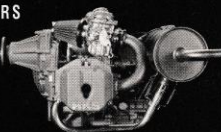
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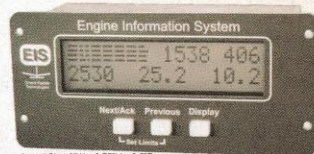
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