Java Power

Building a Thermoelectric Mug

Be the envy of your colleagues with this über-nerd coffee mug that generates power from heat using the same energy converters that are used on deep space probes! Equipping a mug with thermoelectric energy converters and heatsinks will allow you to drive a small motor or other electrical device. You can even claim to be environmentally responsible by extracting useful work out of heat that would otherwise just go to waste.

Deep space probes like Cassini or Voyager are too far from the sun to use solar cells. They derive their energy instead from RTGs (Radioisotope Thermoelectric Generators), which are basically armored canisters holding plutonium dioxide fuel, which stays hot due to radioactive decay. Because these generators must work reliably for decades in space with no intervention for adjustment or lubrication, NASA needed a no-moving-parts way of generating electricity, instead of some kind of piston engine. The answer is thermoelectric converters — semiconductor junction devices that generate a current as heat flows through them. Although they are not very efficient, they are robust and reliable.

Thermoelectric devices were once rather exotic and difficult to obtain, but the performance of modern microprocessors is such that they produce enormous amounts of heat, which must be removed efficiently to prevent overheating of the chip. So, little thermoelectric plates have become widely available. Here, I will show how you can use these in reverse to generate electrical power.

Thermoelectric Devices

The thermoelectric effect is the generation of an electrical current at the junctions of two dissimilar materials (originally metals, but the effect is larger for certain semiconductors like silicon-germanium and lead telluride) if the junctions are at different temperatures. It is quite a small effect — only a few microvolts per degree Centigrade. The effect is reversible — if the temperatures of the two junctions are switched, the voltage reverses. It is also reversible in that if a current is supplied to the junctions, one will become cold and the other warm — heat is being transported by the electrical current.

The thermoelectric cooling modules we'll use in this project are an array of around 100 pairs of p-n junctions, wired in series. They are sandwiched between two thin ceramic plates to make it easy to mount them with good thermal contact to a heatsink. This also allows the device to be cooled. Typically, these are supplied with a few amps of current at 12-15 V and they can transport several tens of watts of heat. Note that the heatsink and fan on a typical CPU installation must reject not only the heat transported from the CPU by the cooling plate, but also the additional heat produced by the plate — that 12 V, times several amps, is another
several tens of watts of heat.

In this project, we'll supply heat to the converter and draw a current from it. When heat is flowing through the converter (which will have an efficiency of typically 1% if the temperature difference across it is about 30 °C), negative charge appears at the heatsink side (the "cold end") of the converter in the N-type legs. Note that an effective heatsink is crucial — it is no use making the whole converter hot: one side must be hot and the other cold.

**Improving Performance**

Thermal conduction is like electrical conduction — the flow of heat is like a current and temperature is like voltage. The thermal circuit is a chain of resistances from the high voltage (the hot liquid) to "ground" — the cool air. If the thermal resistance is low, then the "current" or heat flow will be highest.

One of the resistances in the circuit is the thermal converter itself. Ideally, this is the largest resistance in the circuit, so that most of the power is dissipated in the converter and not in useless resistances elsewhere.

So, the other resistances (thickness divided by thermal conductivity) should be minimized — this means a thin-walled mug made of a thermally-conducting material like metal. Similarly, the heatsink should be effective. The better the heatsink, the cooler it will be and, thus, the temperature difference across the converter will be maximized.

Poor contacts between surfaces can introduce very high thermal resistances — unless surfaces are ground exceptionally flat and perfectly aligned, a lot of airgaps fill the contact area with contact being made only through little bumps in the surfaces. The way to minimize these resistances and the temperature drops they cause is to use a thermal grease or heatsink compound that fills these little gaps with a relatively conductive material.

The voltage produced by the converter is proportional to the temperature across it — this is, after all, the way thermocouples are used as temperature sensors. The current produced by the converter is proportional to the heat flow through it. The heat flow through the converter is proportional to the temperature difference across it. So, the power produced by the converter (current times voltage) is, therefore, proportional to the square of the temperature difference. This is why it is vital to maximize the temperature difference by hot liquid, conductive mug and contacts, and a good heatsink.

To extract the most electrical power from the converter, it is important to choose the load impedance carefully.

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**Resources**

Thermoelectric Cooling Modules can now be found in many electronic parts stores and catalogs. One manufacturer/vendor is Magalan Technology, Inc. ([www.leadingtechnologysales.com](http://www.leadingtechnologysales.com)).

I used several of their ICE-IT TEC 1-127055 cooling modules (40 x 40 x 3.8 mm, rated max 15.4 V at 5.2 A for cooling).

Another manufacturer is TE Technology ([www.tetech.com](http://www.tetech.com)) with a wide range of modules ($100.00 minimum order). I have also used their TM-TB-127-1.4-1.05(P) modules (40 x 40 x 3.8 mm, rated 15.7V 8.6 A). TE Tech's website also has a lot of technical papers you can download.
gives a high (short circuit) current, but a tiny voltage. Somewhere in between, there is an optimum impedance (usually just a few Ω) that sucks a decent current out of the converter without letting the voltage drop too far. For these kinds of converters, the short circuit current can be rather high, so you more or less want as low an impedance as possible.

**Constructing Your Mug**

One difficulty is that a mug is cylindrical, whereas the converter is flat. One possibility is to find or make a square or hexagonal mug — or perhaps bash some flat surfaces onto a tin mug. Another approach is to make some adapter pieces to help mate the converter to the mug; if you’re ambitious, you could machine these out of metal. My quick-and-dirty approach is to wad up aluminum foil, which acts as a fairly conductive — but moldable — material.

You could make the construction of the mug as robust as you like — using machined parts or glue. On the other hand, if — like me — you just want to try it for awhile before using the converters in another project, you could strap the converters on to the mug using some steel or bare copper wire, twisting the wire tight on the mug handle to hold everything in place.

I found that, with 40 mm heatsinks and a steel mug with flat sides, I could typically get about 0.3 volts and several tens of milliamps out of each converter. To get higher voltages, the simplest approach is to mount more than one converter (in thermal parallel, but electrical series). I used five — about as many as there was room for on a large mug — to get about 1.5 V. If someone can come up with a circuit that can multiply DC voltages of a few hundred millivolts up to several volts, it would make these converters much easier to use! Note that thermoelectric devices are like solar cells or batteries — they have a polarity, which depends not only on their internal wiring, but also the direction that heat is flowing through them. So make sure that you wire them correctly to add their voltages!

So, what can you drive with this sort of power? An LED works pretty well — 20 mA is certainly enough, but you’ll need to make sure you have enough voltage from the converters to exceed the forward voltage drop of the diode. Some LEDs can have forward voltage drops of 2 V or more, but some that are as low as 1.4 V will work better. Some small DC electric motors will run on a volt or less, but you’ll need to make sure it runs smoothly enough at low current. Motors sold in solar power kits may work well; one I use was ripped from an old CD player. I glued a small balsa wood propeller onto it to make it very
obvious when the motor was spinning. My mug, with five converters on it, ran this motor for about 24 minutes before the voltage dropped too low.

**Some Closing Thoughts**

Be careful! Hot liquids can cause nasty burns. Remember also that the cooling fins may be hot, so don't jab them into your face if you drink from the mug. Also, if you hammer an enameled steel mug to make flat surfaces for attaching the converters, beware of the enamel spalling (glass flakes).

Of course, if you want to explore or demonstrate the performance of thermoelectric converters, you needn't use an actual mug. You could attach the converter to a die-cast aluminum box and use that as a receptacle for hot water. A limiting performance factor in the mug is the "cold end" temperature afforded by the heatsink. You can get much higher performance from the converter if you sandwich it between two boxes: one with hot water and the other with cold water — or better yet, ice.

Don't be tempted to go too far with pushing power out of your converters. If temperatures exceed 100°C significantly, the semiconductors can degrade and the solder that bonds the junctions can melt — a eutectic bismuth/tin solder that melts at only 138°C is widely used to make thermoelectric modules!

This is a somewhat expensive project, given its rather frivolous nature. New thermoelectric modules sell for about $20.00 apiece, so there is about $100.00 of converters in the five-converter mug. You might want to experiment first with a single converter. However, as these devices become ubiquitous in CPUs, they may start appearing in surplus outlets and become available at lower prices. You might be able to salvage some from old PCs. **NV**