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Smartphones—Experiments with an External Thermistor Circuit

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This contribution adds a further example to illustrate how to use the headphone port of a smartphone to receive data from an external circuit, in this case, a simple, adaptable homemade example for temperature measurement.[1]

Temperature is routinely measured by a thermistor in a simple circuit. Figures 1(a) and 1(b) show such a circuit that can be controlled by an iPod, iPad, or iPhone app. Many physics students are familiar with the usual setup for this circuit where a dc current is fed to the circuit and the voltage across the thermistor is monitored.[2] A change in temperature changes the resistance of the thermistor, which can be recorded as a dc voltage change (such as by an Apple II).

Thermistor resistance, *R*, is exponentially related to temperature by the equation $R = Ae^{\frac{B}{T}}$, where *A* and *B* are constants. Taking a natural log of both sides gives the linear equation $\ln R = \ln A + \frac{B}{T}$. The constants are determined by calibrating with a few known temperatures.

To repeat this measurement using the headphone port on an iPhone or iPod requires just a little more work. Designed for audio, the headphone port filters dc current inputs and outputs. However, a sine wave with frequency ranging up to 20 kHz can be output by a phone app from the headphone port to serve as input to the temperature circuit. The amplitude of the returning sine wave output is determined by the resistance of the thermistor. Only the amplitude of the sine wave varies in the circuit, not the frequency. The iPod returns V/V_0 in decibels (dB), where *V* is the voltage measured between ring three (the microphone input) and the tip of the headphone jack [see Fig. 1(b)] and V_0 is an internal reference voltage. The output *dB* reading is proportional to $\ln R$ since $R = V/i$. The amplitude of the circuit output is measured through the headphone microphone jack as a decibel (dB) reading by our phone app.[3] Plotting *dB* for several independently measured temperatures and fitting the plot to a straight line gives the constants *A* and *B* (which contain the constant reference voltage V_0 and constant current *I*). With the constants *A* and *B*, determined from the plot (Fig. 2), the circuit is calibrated to measure other temperatures. To reduce noise due to sampling errors, a software low pass filter is applied to the peak decibel reading of the returning sine wave as measured over a short period of time. Programmed with the equation, the app can measure temperature changes, then email or plot results (Fig. 3). The headphone volume control serves to calibrate for individual circuit differences.

Surprisingly, the thermistor is very sensitive to small temperature changes (air currents, for example). Encasing the thermistor in something with a little thermal inertia (for

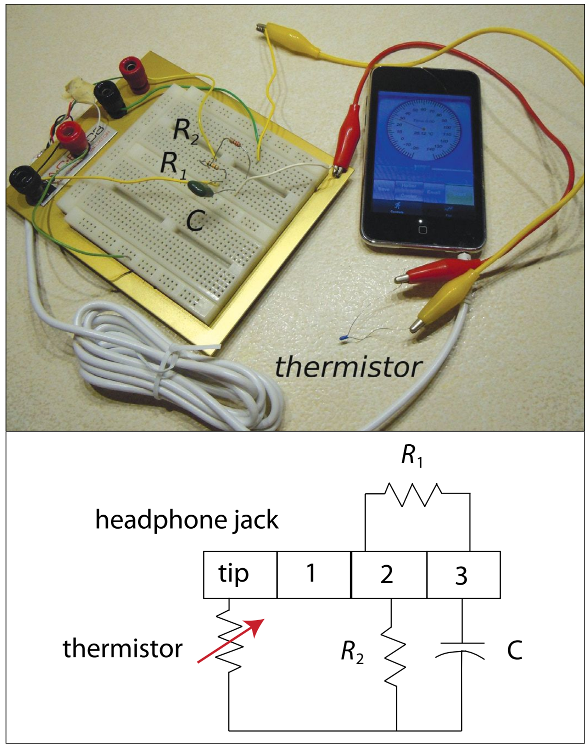

Fig. 1. (a) Measuring temperature using an external circuit and and iPod. (b) Circuit diagram for Fig. 1 (a). R_1 = 10 kΩ, R_2 = 220 Ω, and C = 0.1 μF. The headphone jack is a standard four-pole jack.

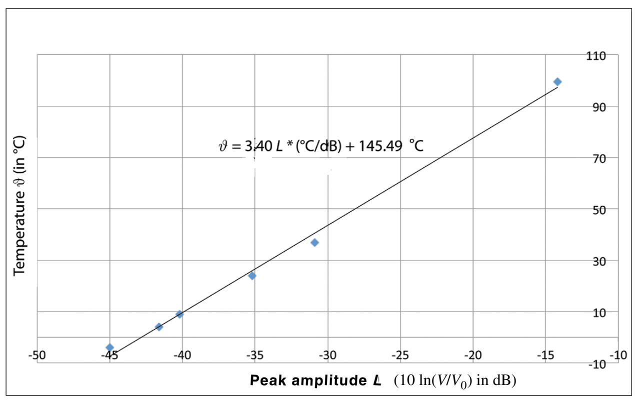

Fig. 2. As explained in the text, the iPhone returns V/V_0 in decibels, dB, which is proportional to ln *R*. The plot is of temperature (in °C) versus peak amplitude *L* from the thermistor in dB taken for temperatures, respectively, in the freezer compartment of a refrigerator, in ice water, in the refrigerator, in an air-conditioned room, outside during the day, and in boiling water.

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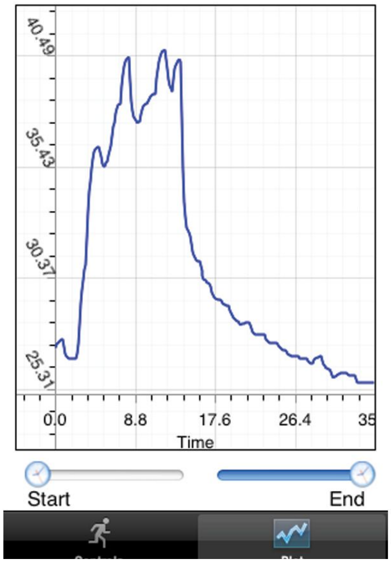

Fig. 3. The thermistor app plotting temperature changes over time.

example, the shell of a plastic ink pen) adds some stability to the measurements.

Other measurements

The same thermistor circuit [Figs. 1(a) and (b)] and app can also be used with other measurement devices that produce similar resistance change characteristics. For example, ambient light levels can be measured by replacing the thermistor with a light-activated photo resistor. As another example, some water sensors act as variable resistors that are sensitive to humidity. Strain gauges used in force probes and elsewhere change resistance when subjected to stress. Some types of pressure gauges signal pressure by a changing resistance. Basically, the circuit and app turns a phone into a measurement tool that can be used for a wide range of experiments with a variety of sensors.[4]

Although the above examples are for an iPhone, iPad, or iPod, the concepts are not limited to these particular mobile devices as any smartphone or programmable device with a headphone could, with appropriate programming, use the same circuit. Data collection with mobile devices offers a vast potential for science experiments and is at the same beginning stage that computer data collection was when the Apple II with a game port was introduced some 30 years ago. As early computers opened a whole range of scientific experiments to a wider audience and inspired a new generation of scientists, we feel smartphones and other mobile devices offer comparable possibilities.

References

1. For other examples, see K. Forinash, and R. Wisman, "Smartphones as portable oscilloscopes for physics labs," *Phys. Teach.* **50**, 242–243 (April 2012).
2. See, for example, John W. Snider and Joseph Priest, *Electronics for Physics Experiments: Using the Apple II Computer/Book with Disk* (Addison-Wesley, Reading, 1989).
3. K. Forinash and R. Wisman, "Mobile Science – Temperature," Apple App Store (itunes.apple.com/us/app/mobile-science-temperature/id467423322?mt=8; temporary web addresss). Source code is available to modify for sensors that do not have an exponential response.
4. A list of sensors and how they function can be found at www.sensorland.com/ (temporary web address).