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Smartphones as portable oscilloscopes for physics labs

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Given that today's smartphones are mobile and have more computing power and means to measure the external world than early PCs, they may also revolutionize data collection, both in structured physics laboratory settings and in less predictable situations, outside the classroom. Several examples using the internal sensors available in a smartphone were presented in an earlier paper in this column.[1,2] But data collection is not limited only to the phone's internal sensors since most also have a headphone port for connecting an external microphone and speakers. This port can be used to connect to external equipment in much the same way as the game port on the early Apple II was used in school labs. Below is an illustration using the headphone port to receive data from an external circuit: Smartphones as a portable oscilloscope using commercially available hardware and applications.

Plugging an oscilloscope probe, offered by the German company HMB-TEC,[3] into the headphone port and downloading software available from several sources,[4] turns an iPhone or iPod into an oscilloscope. Figure 1 shows the probe and SignalScope software in action (several other apps perform similar functions, including AudioScope and oScope).

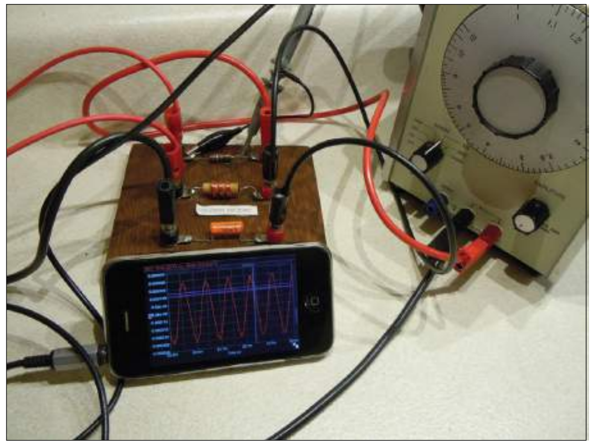

Fig. 1. iPhone as oscilloscope using the SignalScope app. The oscilloscope probe is plugged into the iPhone headphone port and connected across a resistor in a series L-R-C circuit driven by a sine wave. The circuit elements are a 1000-Ω resistor, a 25-mH inductor, and a 0.1-ΩF capacitor.

The use of the headphone port does impose limitations on oscilloscope measurements. Although the audio hardware in most mobile devices is designed for sample rates as high as 44.1 kHz, the audio port frequency response range for earlier iPhones is between 100 Hz and 8 kHz. The iPhone 3G and later models have a fairly flat frequency response between 10 Hz and about 20 kHz, and can accept up to a 5-V signal (although lower voltages are recommended). A further limitation of using an iPhone as an oscilloscope is that, unlike an oscilloscope that allows dc and low frequencies to be measured, the iPhone uses ac coupling to connect to the microphone. This means that low frequencies are filtered, which will distort a square wave signal somewhat. However we found that sine waves up to at least 12,000 Hz are accurately represented without distortion on an iPhone 3GS.

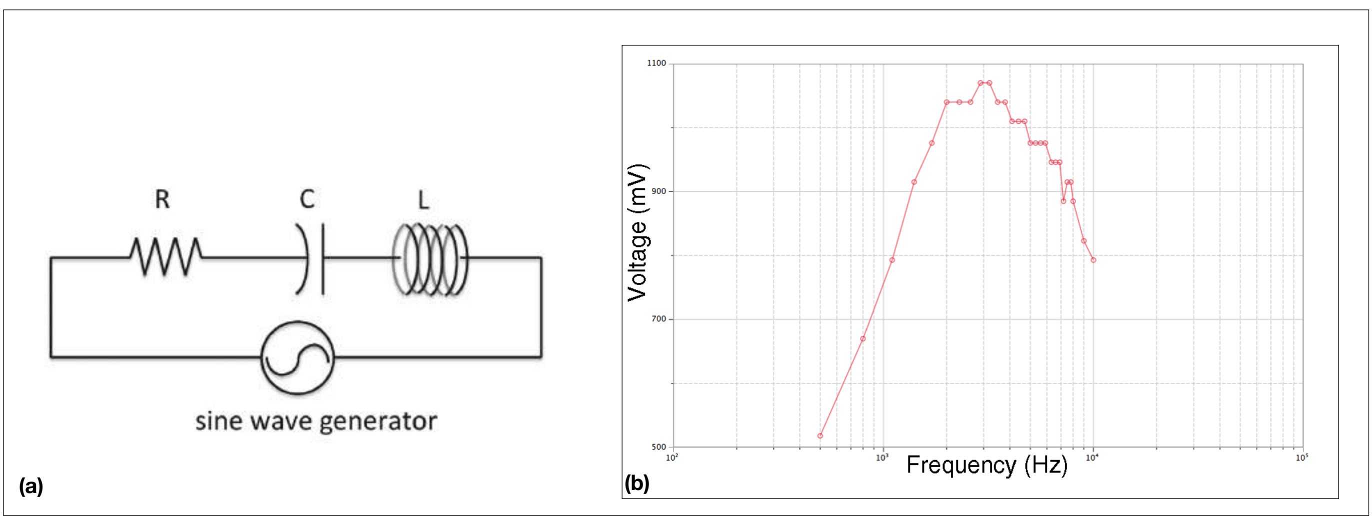

Fig. 2. (a) Circuit diagram for Fig. 1. The oscilloscope probes are placed across the resistor. (b) Voltage versus frequency taken from SignalScope on the iPhone across the resistor of an LRC circuit driven by a sine wave at different frequencies. Resonance occurs at 3200 Hz.

As a trial experiment we used the iPhone and oscilloscope app to determine the resonance frequency of a standard series combination of an inductor, resistor, and capacitor (LRC). The circuit (Fig. 2) has a 25-mH inductor, a 1000-Ω resistor, and a 0.1-μF capacitor in series driven by a sine wave generator. Figure 3 shows a graph of the amplitude of the signal, measured by the iPhone, across the resistor as a function of frequency. The resonance frequency

$$\left(f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} \right)$$

is about 3200 Hz. SignalScope is actually a bit easier to use than an oscilloscope because there are cross hairs that can be used to pick out a data point, the value of which appears on the screen.

SignalScope can be calibrated to an external source (for example a set voltage) and set to appropriate units (since the port was designed to work with a microphone, the default vertical scale unit is the pascal). The time scale can be set between 0.1 ms and 500 ms by a two-finger pinch-to-expand command; the amplitude scale is adjusted similarly. Screenshots can be saved as pictures and a trigger mode captures transient voltages. A real-time fast Fourier transform option has several choices of windowing, averaging, and frequency resolution (Fig. 3). The vertical axis can be logarithmic or decibel. A SignalScope Pro version adds the options of saving raw data in spreadsheet format (for later analysis), a signal generator, sound level meter, and other useful features. This software is also available for the iPad.

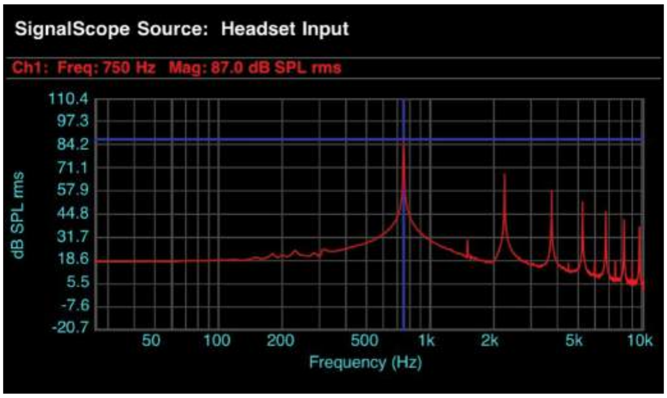

Fig. 3. SignalScope app screenshot of the fast Fourier transform (FFT) of a triangle wave of 750 Hz from a wave generator.

References

1. J. Kuhn and P. Vogt, "Diffraction experiments with infrared remote controls," *Phys. Teach.* **50**, 118–119 (Feb. 2012).
2. P. Vogt and J. Kuhn, "Analyzing free fall with a smartphone acceleration sensor," *Phys. Teach.* **50**, 144–145 (March 2012).
3. HMB-TEC; hmb-tec.de/iPhoneApps/iPhone_Apps.html. The company lists a number of other external probes (temperature, IR probe, laser pointer, etc.) as available, but many of the items listed are not actually for sale yet.
4) We tested SignalScope (www.faberacoustical.com/products/iphone/signalscope_pro/), AudioScope (www.hensleyindustriesllc.com/iphone/audioscope/audioscope.html), and oScope (itunes.apple.com/us/app/oscope/id344345859?mt=8).