Demo Abstract: Hijacking Power and Bandwidth from the Mobile Phone's Audio Interface

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1 Introduction

The mobile phone is the most pervasive personal communications and computing platform ever created and yet, among its various analog interfaces, only one is open, standardized, and widely accessible: the headset port. In this demo, we augmente the mobile phone with a range of phone-powered peripherals. We show that the mobile phone headset port can be used to efficiently power external peripherals and communicate with them, enabling many new phone-centric applications. But, why use the headset port at all? One reason is that it is an open, simple, and ubiquitous interface with documented electrical and mechanical specifications. Perhaps even more important, the headset interface is backward- and forward-compatible with most mobile phones in use today.

This project poses several engineering and research challenges. The output from the audio jack is a low voltage signal, often even lower than typical transistor threshold voltages. To be useful, it must be converted to a higher voltage using energy harvesting and voltage boosting circuits that can operate with input AC voltages in the 200 mV level. Due to the limited voltage headroom, simple rectification is difficult without substantial power losses. It may also require maximum power point tracking. Matching the harvesting circuit's cost, complexity, and conversion efficiency with the ideal audio waveform also presents an iterative co-design problem.

For this demo, we designed a circuit to harvest power from the audio port. We find that the headset can deliver approximately 15.8 mW per channel from the iPhone's headset port. We demonstrate a circuit that can harvest energy from a single channel and an audio signal that when played on the phone can maximize the output power from the harvesting circuit. We also demonstrate that a pair of (coded) audio signals can be generated by the phone processor and transmitted to both the energy harvesting circuit (power) and a microcontroller (signal) and where the signal can be decoded by the microcontroller. Conversely, we show that the microcontroller can also generate a coded signal that can be read by the mobile phone's microphone input and decoded by the phone to present a stream of digital data. Finally, integrating all of the various pieces, we present a simple oscilloscope application that runs partly on the mobile phone and partly on an external microcontroller powered using the mobile phone's right audio channel. The two processors communicate using the left audio channel (phone to microcontroller) and microphone (microcontroller to phone).

SenSys'10, November 3–5, 2010, Zurich, Switzerland.
ACM 978-1-4503-0344-6/10/11

2 System Overview

2.1 Energy Harvesting

Our first design goal is to harvest energy from the headset jack of a mobile phone, convert it into a more usable form, and achieve high conversion efficiency in the process. To sidestep the two basic engineering challenges – low-supply voltage and need for rectification – we use a step-up microtransformer, followed by FET-based rectification, followed by (parallel) blocking Schottky diode(s), followed by filter capacitors, as shown in Figure 1. One key element of the design, the microtransformer, leverages a recently introduced device for flyback and step-up for energy harvesting applications. These new transformers are small (6 mm x 6 mm x 3.5 mm), have high coupling coefficients ($>$ 0.95), and are available in a range of turns ratios [1]. We use a 1:20 ratio.

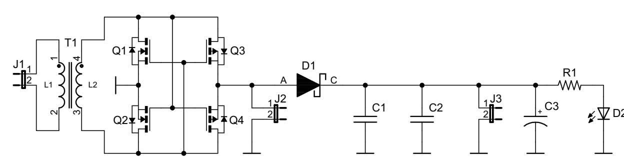

Figure 1. The energy harvesting circuit. A 1:20 microtransformer boosts the input voltage. A FET bridge efficiently rectifies the AC signal to DC. Parallel Schottky diodes provide low-loss blocking to prevent the output filter capacitor from discharging through the FET bridge. An (optional) LED with current-limiting resistor provides a visual power indicator.

The stepped-voltage is passed through a FET bridge for rectification. Since the stepped-up voltage is substantially higher than the FET threshold voltage, the FETs are in conduction and offer marginal loss. Another benefit to stepping-up the voltage is a reduction in current flow through the blocking diode, and therefore a reduction in forward voltage drop. However, since the diode is an exponential device, this unfortunately does not result in a substantial decrease in the forward voltage drop, but it does eliminate the voltage drop from a second diode in the rectifier. And, since the diode forward voltage drop is a small fraction of the rectified voltage, this design incurs a small inefficiency compared to direct rectification of the low-voltage signal.

Matching the load and source impedances is critical to achieving maximum power transfer from audio jack to energy harvester. In our design we set the output frequency to 22 kHz to match the impedance of transformer to the iPhone's audio output port impedance of 3.6 Ω.

2.2 Data Communication

Our developed platform demonstrates bi-directional communications between the mobile phone and a peripheral microcontroller. The requirements for this communication channel are: (i) it must operate in the audio frequency range, and (ii) it must be easy to implement on a microcontroller. A speciallized communication chip is not possible as most integrated circuits that provide modulation and demodulation functionality are not low power, drawing tens of milliwatts. Thus, the second requirement is necessary as we need to implement both the modulator and demodulator inside a microcontroller.

Given these two requirements, we use Manchester encoded low-voltage RS-232 signaling at 8.82 kbaud to create a virtual universal asynchronous receiver/transmitter (UART) abstraction over the audio serial bit stream. Since the UART protocol adds a start, stop, and optional parity bit to every byte, the effective data rate is $\sim$ 800 bytes/sec.

The Manchester encoding is necessary to balance the number of 0 and 1's in the UART data stream. As the audio channel is AC coupled, it cannot sustain a constant voltage. Thus, a long sequence of 0's or 1's in the UART data would inevitably lead to problems, as the line would droop back to the common level.

3 Demonstration

In this demo we will show that the various pieces of the system – energy transfer, data input, and data output – can all be combined into a single, integrated, and fully-functional application. For that purpose, we designed a prototype handheld oscilloscope, as shown in Figure 2. This system illustrates a canonical handheld instrument that uses the phone's display for visualization, and the microcontroller's ADC to measure an external signal.

At the heart of this system is the application running on the phone. It generates a 22 kHz tone on the right audio channel to power the microcontroller using the energy harvesting circuit. The left audio channel sends a Manchester encoded data stream to the microcontroller. The phone's microphone input receives a Manchester encoded data stream from the microcontroller.

One of the motivations for harvesting energy, rather than directly powering a peripheral with an external battery, is to reduce the form factor. While the prototype is large due to the use of a development kit and protoboard, the active components used can be integrated onto a much smaller circuit board. For the demonstration, we developped an integrated version of the prototype depicted in Figure 3. This second prototype fits on a PCB of 1.0" x 1.0". Even this PCB is still large, as the used microcontroller provides many features not used in the application.

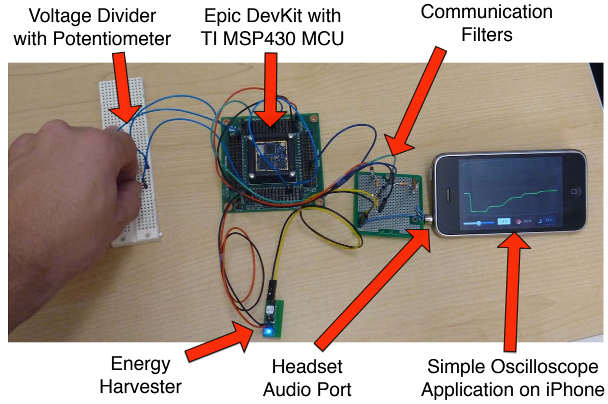

Figure 2. Prototype phone-centric oscilloscope application in full operation. The system consists of four distinct subsystems which are all shown working together: (i) iPhone; (ii) communication filters; (iii) energy harvester; (iv) microcontroller with potentiometer simulating a resistive sensor. The blue LED, located at the bottom of the energy harvester, is turned on and clearly visible in this figure.

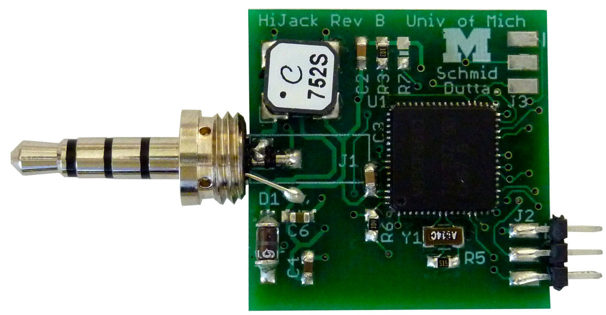

Figure 3. Integrated prototype. The PCB is a mere 1.0" x 1.0" and exposes two analog inputs, several digital IOs, and either a SPI, I^{2}C, or UART, depending on the microcontroller configuration and sensor requirements.

Battery-free, plug-and-play operation is one reason that USB has been a popular and effective interface on traditional computers, and increasingly on high-end smartphones as well. Although many vendors offer proprietary interfaces (e.g. the iPhone docking connector), the vast majority of mobile phones do not offer a standardized power and analog data interface. In this demo we show that it is possible to augment the ubiquitous headset jack with exactly this functionality.

4 References

[1] http://www.coilcraft.com/lpr6235.cfm.