Hijacking Power and Bandwidth from the Mobile Phone’s Audio Interface

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ABSTRACT
We endow the digital mobile phone with an analog interface that can parasitically power external peripherals and transfer data to and from them using the existing headset interface. Our design delivers 7.4 mW at 3.5 V to a load and offers a bidirectional communications channel at a data rate of 8.82 kbps. We will demonstrate a simple oscilloscope application using this new functionality. Our HiJack adapter allows ubiquitous access to a plethora of sensors not available before on a cellphone platform.

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 augment 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, as Figure 1 shows. Perhaps even more important, the headset interface is backward- and forward-compatible with most mobile phones in use today, so the mobile phone could form the basis for many health and communications applications in developing regions.

The motivation for such mobile phone peripherals comes from several quarters. First, the emergence of mobile phone accessories like the Square Card Reader [1] suggest that simple peripherals that can leverage the headset port have commercial appeal. Second, researchers focused on developing regions have a need for low-power vital signs devices that could directly interface to a mobile phone and be powered from it. Third, leading academics have argued for reformulating introductory computer science curriculums around the mobile phone. With this demo we show how many important electrical engineering concerns like power, communications, and embedded systems can also be explored in this context. This proposal seeks to enable additional devices like the Square Card Reader, provide a basis for new phone peripherals, and enable greater student engagement by allowing EECS students to tinker with their phones.

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. Using the audio output to deliver power and data functionality requires exploring several design tradeoffs and concerns.

For this demo, we designed a circuit to harvest power from the audio port. We find that the headset can deliver approximately 7.4 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).
2. 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 2. 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. We use a 1:20 ratio.

![UART Manchester Encoding](image)

Figure 2: 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 high-efficiency power transfer from a power supply to its load. In this case, the impedance offered by the microtransformer’s primary winding should be matched to the iPhone’s audio output port’s impedance of 3.6 Ω. The transformer’s datasheet states that the primary DC resistance is 200 mΩ and primary inductance is 25 μH, which we verified empirically. Since the transformer’s DC resistance is small compared to the power supply’s output impedance, we focus on the transformer’s impedance. The impedance, \( X_L \), offered by an inductor is

\[
X_L = j\omega L = j2\pi f L.
\]

Rearranging to solve for \( f \), the desired excitation frequency, gives

\[
f = \frac{X_L}{(2\pi L)}.
\]

Substituting our measured impedance and inductance values gives

\[
f = \frac{3.6 \Omega}{(2\pi \times 25\mu H)} = 22.9 \text{ kHz}.
\]

The target excitation frequency sits just at the edge of what the iPhone is capable of producing. Fortunately, however, we have complete control over the excitation frequency within the audio band, so we can generate a 22 kHz waveform which will achieve near optimal power transfer to the energy harvester circuit.

3. DATA COMMUNICATIONS

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. The second requirement is necessary as we need to implement both the modulator and demodulator functions inside of a microcontroller since most other integrated circuits that provide a modulation and demodulation functionality are not sufficiently low power, drawing tens of milliwatts.

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 ~800 bytes/sec.

The Manchester encoding is necessary to balance the number of 0’s 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.

4. APPLICATIONS

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 3. 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.
The user interface provides visual feedback to the user of the voltage measured using the microcontroller’s ADC input. Figure 6 shows a screenshot close-up of the application running on an iPhone. The graph displays a historic view of measured data, while the text box shows the last received measurement. The data are transmitted from the microcontroller at regular sample intervals. A slider allows the user to change the sampling rate from about 1/10 to 800 Hz, the limit given the 8.82 kbps UART speed. The slider setting is sent over the left channel to the microcontroller, which decodes the signal and changes its sample rate accordingly.

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 example, the two largest components – a transformer and a TI MSP430F1611 microcontroller – measure a mere 6 mm x 6 mm and 9 mm x 9 mm, respectively. For the demonstration, we developed an integrated version of the prototype depicted in Figure 5. 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.

We are working on identifying a minimum set of peripherals, allowing us to choose a newer TI MSP430 (<36 mm²) to incorporate all the components on a circuit board of about 1.0” x 0.20” size. This is small enough to carry in a pocket along with a phone, allowing any electrical engineering student to carry an oscilloscope or multimeter at all times. Or it would allow the addition of many types of sensors, be it ozone, gas, or even medical (like EKG or blood oxygen) to any phone that has a headset connector and provides rudimentary programming capabilities.

5. CONCLUSION

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.

With the basics of powering external devices and communicating with them now in place, it will soon be possible to plug a small circuit board into almost any existing mobile phone, power an external sensor (e.g. EKG, PulseOx, etc.), bias it with a voltage, read its analog output back, perform some sophisticated filtering, and present an instant result. In short, a parasitically-powered analog expansion interface for the mobile phone will enable many new applications that are either impossible or infeasible with today’s technology. The mobile phone has already become the personal computer. Tomorrow it could become the oscilloscope, volt-ohmmeter, and digital stethoscope as well. We will demonstrate a small, but important, step toward enabling that future.

6. REFERENCES