A Compact, Wireless, Self-Powered Pushbutton Controller

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Abstract. We describe a compact piezoelectric pushbutton and associated minimal circuitry that is able to wirelessly transmit a digital ID code to the immediate region (e.g., 50-100 foot radius) upon a single button push, without the need of batteries or other energy sources. Such devices have the potential of enabling controls and interfaces to be introduced into interactive environments without requiring any wiring, optical/acoustic lines of sight, or batteries.

1) Introduction

As copious interactive devices are built into the smart environments of tomorrow, a major issue will be how they are controlled. Although remote acoustic and optical sensing will increasingly open voice and vision channels as the requisite processing and algorithms improve, there will still be a need for deliberate tactile gesture, which is at the moment provided by hardwired interfaces or various kinds of remote controls. Both of these solutions can often have drawbacks - e.g., wiring is expensive and inflexible, while remote controls need batteries that require periodic replacement. A potential solution to some of these difficulties would be the development of a wireless controller that is able to transmit its function code without needing to be wired or powered, drawing its energy directly from the controlling gesture.

Indeed, one of the earliest remote controls worked in this way. The Zenith "Space Command"[1], introduced for televisions in 1956, housed 4 aluminum rods tuned to different ultrasonic frequencies spaced between 35 and 45 kHz. When a button was hit, it struck the corresponding rod, producing an ultrasonic pulse that was decoded at the TV, which then performed the appropriate function. Although ultrasonic communication has its share of difficulty (e.g., interference and false signals from clanking metal, annoyance to dogs, etc.), it persevered in TV remote controls for roughly 25 years before giving way to the active IR devices in common use today. Both ultrasound and infrared communication require a direct or reflected line-of-sight, however, which can limit their utility in many scenarios. Wireless RF controllers, such as automotive keyless entry buttons, avoid this problem, since radio waves in their frequency bands pass freely through people and nonmetallic objects. Although their current drain is fairly modest, they still require batteries, which occasionally (and often at inopportune times) need replacement.

Various developers and researchers have worked on harnessing the energy exerted when pushing buttons to eliminate or reduce the need for batteries in the attached devices. One example is a scheme proposed for tapping the excess energy exerted when typing on a laptop[2] by building little magnetic generators around each key. Related projects have designed self-powered transmitters that send an RF pulse when a door is opened[3] or a piezoelectric crystal is struck[4]. Another example, closer to the theme of this article, can be found in a young child's toy from Japan called the "Pipi"[5]. This is a simple batteryless remote control with one button; when pushed, it launches an impulse into a small piezoelectric element, which produces a spark that drives a Hertzian resonator, creating an RF signal that is detected by a battery-powered companion receiver (placed up to a few feet away), which then beeps like a pager. Although these projects demonstrate passively-powered RF communication, the transmissions are largely uncoded, hence don't easily allow for multiple buttons or any control complexity.

At the MIT Media Lab, we developed a pair of sneakers with flexible piezoelectric structures placed under the insole to generate power as the user walked. We first presented this system to the Wearable Computing community in 1998[6]. As the piezoelectric materials were bent and compressed, energy was innocuously extracted and stored, allowing a 12-bit digital ID code to be wirelessly transmitted from the shoe across a large room after every 3-5 steps[7]. The work presented in this paper evolved from this system. By using a rigid piezoceramic element in a spring-loaded striker instead of the flexible elements used in the shoe and introducing a transformer matched to the piezoelectric's characteristics, we have produced a device that provides ample power to transmit a robust digital ID code across the entire floor of a building with only a single push.

2) Technical Design

A piezoelectric conversion mechanism is employed in the switch due to its low weight, small size, minimal complexity, and minimal cost. To obtain the highest efficiency of mechanical-to-electrical energy conversion, the piezoelectric element must be operated at its mechanical resonance. To do this, the element is impacted for a very short duration and then released, allowing it to self-oscillate at its resonant frequency. Since piezoelectrics produce high voltages at low currents, and standard electronic circuitry requires low voltages at high currents, a step down transformer is used to couple the two and better match impedances. The inductance of the transformer [L] and the capacitance of the piezoelectric element [C] form a resonant circuit - the transformer thus must be selected appropriately for this "LC" electrical resonance to equal the element's mechanical resonance for optimum energy transfer. After passing through the transformer, the electrical energy is rectified, stored in a capacitor, and regulated down to the required voltage (3V) of the RF circuitry.

Figure 1 shows the circuit diagram. A 4.4 μF tank capacitor integrates the charge transferred from a button strike. This, in-turn, powers a MAX666 low-dropout linear regulator, which provides a stable (although very inefficient) +3 volts supply until the tank capacitor's charge is drained. When the MAX666 is activated, the HT12E digital ID encoder is enabled, producing a repeating 12-bit serial ID broadcast via the On-Off-Keyed (OOK) transmitter module.

The key components of this device are shown at left in Figure 2. The leftmost device is the piezoelectric button, the core of a Scripto “Aim 'N Flame” lighter with the spring action modified to deliver a softer strike. This button is 35mm long and 7mm in diameter, has a deflection of 3.5mm at a maximum force of 15N, and a total activation energy of 30mJ with a mechanical resonance near 50 kHz and a capacitance of 18 pf. At right is the transformer, an amorphous-core device manufactured for electronic flash applications with a 90:1 turns ratio that transforms a peak of a few thousand volts at the piezo element to 30 volts at the tank capacitor. The piezo-transformer ensemble operates at 7% mechanical-to-electrical efficiency, delivering 2 mJ of energy per push. This translates to the order of 0.5 mJ at 3 Volts after the linear regulator.

The ID code is generated with the Holtek HT-12E encoder that produces eight bits of ID and four bits of data. The transmitter is the RFM HX1003 that runs at 418MHz, consumes 7.5 mW, and can transmit up to 50 feet. The receiving base station requires four successful receipts of the twelve-bit code before a complete transfer is registered.

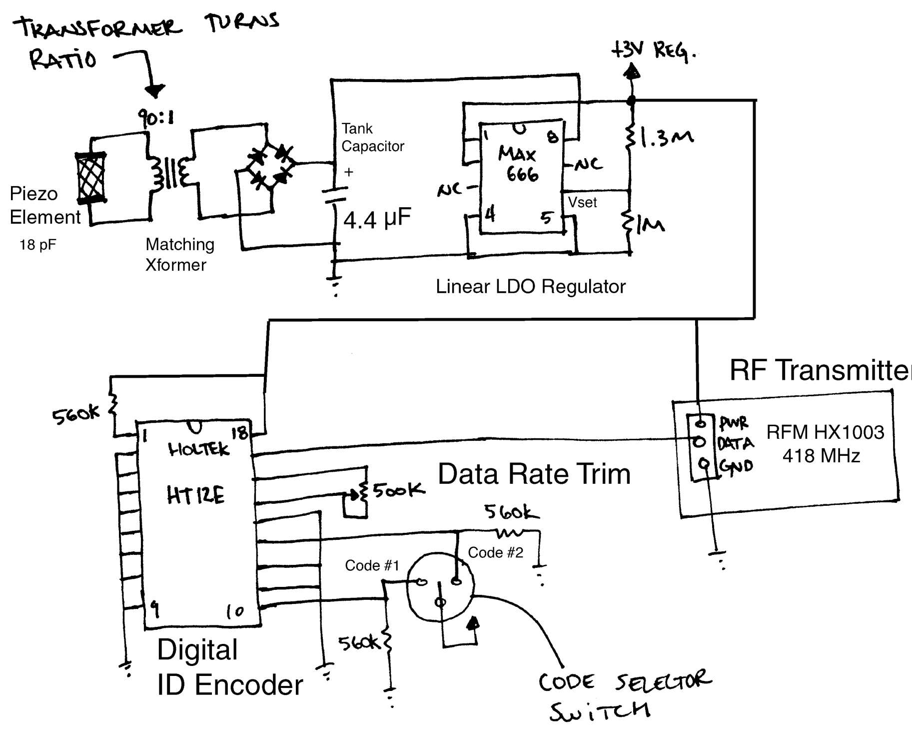

Fig. 1. Schematic diagram of self-powered pushbutton electronics

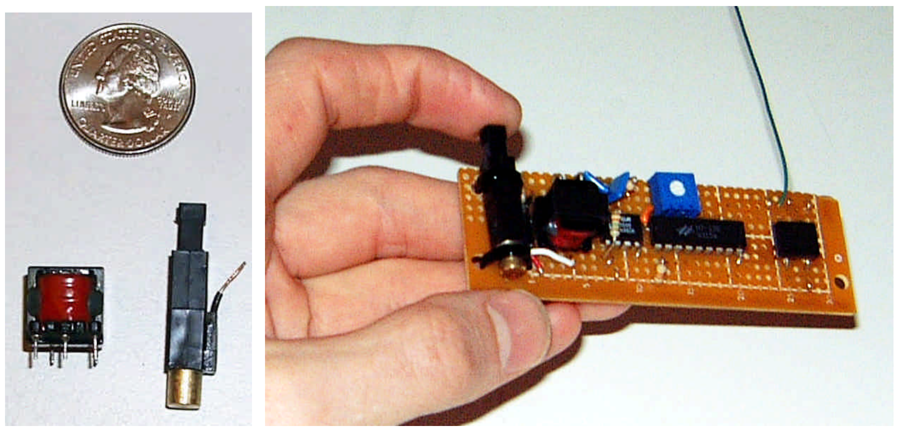

Fig. 2. Critical components (left – not including US quarter) and operational prototype board (right) for self-powered wireless ID pushbutton transmitter of Fig. 1

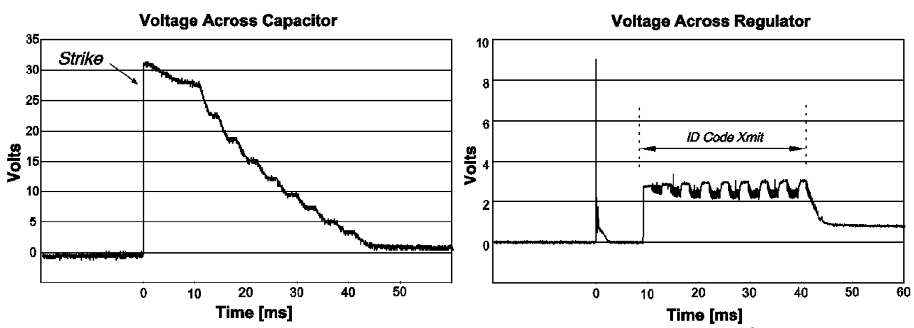

Fig. 3: Voltage across tank capacitor and regulator output voltage vs. time for a single press

The required time for successful completion of transmission is 20ms. Since the energy drain of the transmitter dominates over the remainder of the circuit, the total energy consumption is approximately 7.5mW for 20ms, totaling 150μJ. As outlined above, our button produces ample power for this application. As seen in Figure 3, at roughly 10 ms after the strike, the regulator becomes active, providing power to the transmitter and encoder circuitry for at least 30 ms (the ripple is due to the cyclic load of the OOK code, and the spike is a transient coupled in from the strike).

Our prototype circuit board for the pushbutton transmitter, containing all needed components, is shown at right in Figure 2. Note that the size of this prototype is much larger than needed, as through-hole components were used here for simple assembly. With surface-mount packages and more advanced assembly techniques, the circuit size should be very compact, dominated by the components of Figure 2 (left), which weigh about 8 grams. Production expense is likewise small, falling well under $5. per unit. The wire leading up to the top-right of the photo acts as a 1/4-wave whip antenna for the transmitter, and the trimpot is provided for adjusting the ID data rate in tests - it's not needed in practice.

In the course of developing this device, we explored variations on the components. The efficiency of the transformer is limited by flux leakage and core saturation when the primary current peaks. We accordingly tried a much larger transformer (with over 50 times greater mass), which gave us a somewhat better efficiency of 8.3% after being matched to the piezo element. We then used a larger piezoelectric element in this system (from the sparker of a gas grill igniter) - together with the larger transformer and appropriate matching, we obtained 20 mJ at 3 Volts with 13% efficiency. As the small components of Figure 2 were amply adequate for powering our system (and are much more conducive to packing onto a miniature circuit board), we were thankfully able to avoid using these larger devices in this application.

3) Conclusions and Discussion

This study has proven that a compact, wireless, self-powered, ID-transmitting pushbutton can indeed be built. The performance of our design, however, has considerable room for improvement. A prime candidate here is redesigning the transformer to reduce leakage and saturation while optimally matching the piezoelectric element. Likewise, the piezoelectric element and striker mechanism could be designed more appropriately and efficiently. One potential issue with hard strikes on rigid piezoceramics is the formation of microcracks in the piezoelectric material, which gradually degrade the generator's performance. Although we have softened the impact that our striker produces, long-term survival testing is necessary to guarantee stable performance. Other techniques can also be applied to better stimulate the piezoelectric generator, such as passive hydraulics driven at the element's resonant frequency[8].

The linear regulator used to produce 3 Volts is likewise very inefficient here with such a large voltage drop across it. A high-frequency, fast startup switching regulator, as developed in [7], would increase the efficiency of the regulation stage considerably.

In real-world applications, having one piezoelectric element and transformer per button may be inefficient. Other forms of this interface can be explored that perhaps integrate multiple passive pushbuttons or other input interfaces with a single piezoelectric striker, allowing a single piezoelectric generator to specify several degrees of freedom.

Additionally, our current device is transmit-only, hence is unable to verify the receipt of data transmission. The current prototype, however, is able to generate significantly more power than needed for simple ID transmission, especially over a shorter distance. Possibilities can then be explored for more robust operation, e.g., transmitting a more fault-tolerant digital code or first powering a low-power receiver that is able to select a band with minimal interference upon which to transmit the ID code.

4) Acknowledgements

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5) References

1) Webb, P. and Suggitt, M., **Gadgets and Necessities - An Encyclopedia of Household Innovations**," ABC-CLIO, Santa Barbara, CA., 2000, pp. 237-238.

2) Crisan, A., *Typing Power*, US Patent No. 5,911,529, June 15, 1999.

3) Johnson, P.M., MacKenzie, R.W., and Reeves, J.R., *Transmitter Circuit*, US Patent No. 3,796,958, March 12, 1974.

4) Mitchell, J.P., *Piezoelectric Pulse Amplifier*, US Patent No. 3,548,314, December 15, 1970.

5) The Pipi "Kodomo No Omocha" toy from Tomy corporation, Japan, 1998.

6) Kymisis, J., Kendall, C., Paradiso, J., Gershenfeld, N., "Parasitic Power Harvesting in Shoes," *Proc. of the Second IEEE International Conference on Wearable Computing, (ISWC)*, IEEE Computer Society Press, pp. 132-139, October 1998.

7) Shenck, N. and Paradiso, J., "Energy-Scavenging with Shoe-Mounted Piezoelectrics," *IEEE Micro*, Vol. 21, No. 3, May-June 2001, pp. 30-42.

8) J.F. Antaki et al., "A Gait Powered Autologous Battery Charging System for Artificial Organs," *Proc. of the 1995 American Society of Artificial Internal Organs Conf.*, Lippincott Williams & Wilkins, Philadelphia, 1995, pp. M588-M595.