Wi-Pie: Energy Harvesting in Mobile Electronic Devices

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Abstract—A recent study puts the number of mobile phones in use around the world at an astonishing 5 billion and these numbers are growing rapidly. This places the increase in energy consumption of mobile phones in the world at an alarming level. Wi-Pie or Wireless-Piezoelectric technique combines RF energy scavenging and piezoelectric energy harvesting technologies to provide an alternative method of powering mobile electronic devices. By placing piezoelectric crystals beneath the keypad of a mobile phone, we intend to generate a small voltage with every key press which could be stored in a secondary storage device like a capacitor. The charge accumulated in the device can then be transferred to the primary storage or the battery so that the use of external chargers can be minimized. Additional power management circuitry is used to intercept the known and the unknown sources of ambient RF radiations. The received RF power is converted to DC and conditioned before it's delivered to the load. Although the RF energy levels are low, a combination of the harvesting and scavenging techniques will provide a significant source of power

Keywords—* *energy harvesting; piezoelectric; mobile electronics; RF scavenging;

I. INTRODUCTION

The International Telecommunication Union (ITU) estimated that by the end of 2010 there would be 5.3 billion mobile cellular subscriptions worldwide, including 940 million subscriptions to 3G services. [3] The number of mobiles phones today is estimated to be as many as the cellular subscriptions and it is expected to grow at a rapid pace. With the growth of technology and the advent of next generation wireless standards the reach of mobile communication is expected to grow over 90% in the coming years. This brings the total number of mobile handsets in use around the world to a huge number and hence, the energy consumed by them increases beyond a reasonable amount. This puts a greater toll on the power generation plants, leading to increased usage of depleting resources. As the world is moving towards an energy crisis, finding an alternate method to power these mobile electronic devices is the need of the hour. Batteries used in these devices are prone to frequent replacement due to their short lifetime and are a threat to the environment if disposed improperly.

Therefore, building an environment friendly powering system that could harvest energy during normal operation of these devices, like key pressing, may provide a solution to the above stated challenges. This paper presents a theoretical approach towards identifying ways in which energy could be harvested from such normal operations. Some of the potential advantages of this system may include prevention of mobile phones going dry on remote locations, ability to charge the device during power failure, minimizing the use of external chargers thereby reducing e-waste and eventually making these devices battery-free.

II. CONCEPT FUNDAMENTALS

The concept of harvesting energy from ambient sources is not new. It has been around since the invention of piezoelectric materials. Research in this field thus far has shown that usable energy can be obtained from piezoelectric materials with simple electronic circuitry. These circuits may be embedded in a mobile phone such that every key-press during texting and regular mobile use can be converted into electrical energy. Our solution is to place piezoelectric crystals beneath the keys of a mobile phone, thereby harvesting the energy generated from the pressure.

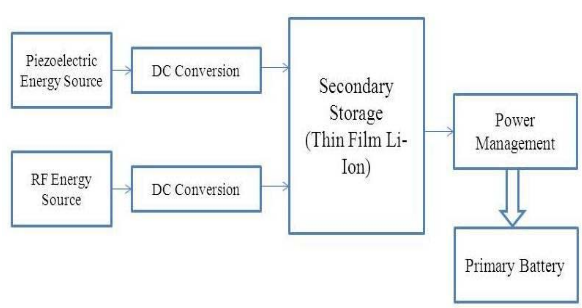

Fig. 1 Proposed energy harvesting model

The world at present communicates at an astonishing pace where the total number of SMS sent between 2007 and 2010 stands at a staggering 6.1 trillion. In other words, close to 200,000 text messages are sent every second. Taking these statistics into consideration, this technique provides a great scope for improvement especially in the energy harvesting field.

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Additional power circuitry could also be included to harvest the known and the unknown RF energy in the environment. By using power conditioning circuitry, the received radio energy can be converted to DC and supplied to the battery. Since the technology is in its inception, the power generated would be low and thus has to be combined with other harvesting sources in order to provide a seamless energy source.

III. PIEZOELECTRIC HARVESTING MODEL

One of the significant advancements in this field so far is using piezoelectric materials to harvest energy and accumulate them in secondary storage until a sufficient level is reached. Research has been done in identifying the suitable material that could be used as piezoelectric transducers and some of the materials are MFC, PZT and Quick Pack. Study shows that each of these materials has different dielectric and thermal properties. Different materials that could be used as piezoelectric generators were identified and their ability to transform vibration source into electrical energy has been studied in [1]. Foremost research has been done in proving that a capacitor can be used as a secondary storage in energy harvesting applications [2]. Since then all the energy harvesting models have used single capacitors as secondary storage devices. But using a single capacitor was not sufficient enough to drive an electronic device. It requires an efficient interface circuit that could convert the rectified energy and store it in a capacitor. However, this concept is limited to implementing in small wireless sensors or for wearable medical appliances. Not much has been done so far in identifying ways in which this can be implemented in mobile phones or other electronic devices that operates on more power. It is therefore important that the limitations of using a capacitor has to be overcome in order to successfully model the energy harvesting system required for this purpose.

The piezoelectric transducer under consideration here is a standard PSI-5A4E single layer disk (.0075" thick) piezo ceramic sheet from Piezo Systems Inc. This PZT material under consideration is a .125" (3.2mm) diameter disc and is suitable for placing beneath the keys of a mobile phone. This material is chosen because of its high motion to volt sensitivity in the order of 390 x 10^{-12} meter/volt (d33) and -190 x10^{-12} meter/volt (d31). It also exhibits a high 'g' constant in the range of 24.0 x 10^{-3} volt-meter/newton. Since the direction of force under consideration here is parallel to the polarization axis we will take in to account only the longitudinal d33 and g33 coefficients. A pair of nickel electrodes would be bonded to the ceramic for electrical contact and it exhibits extremely low current leakage and low magnetic permeability suitable for low power energy harvesting applications.

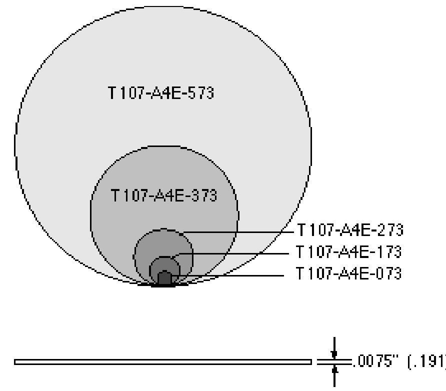

Fig. 2 Dimension of T107-A4E-073 piezo ceramic sheet

The charge accumulated by the piezoelectric material, taking longitudinal effect into consideration, is independent on the size and shape of the material. Therefore using several small piezoelectric crystals placed beneath the keys of a mobile phone and connected electrically in parallel would be an appropriate design for this energy harvesting model.

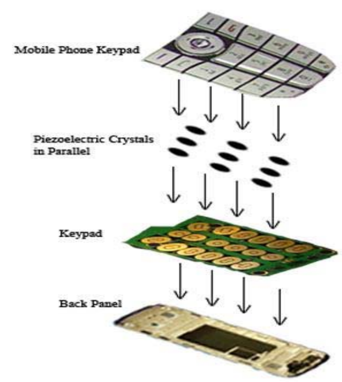

Fig. 3 Layers in the Piezoelectric Model Phone

The resulting charge is

$$C_x = d_{xx} F_x n,$$

where d_{xx} is the piezoelectric coefficient for a charge in x-direction released by forces applied along x- direction (in pC/N). F_x is the applied Force in x- direction and n corresponds to the number of stacked elements.

A comparison between a capacitor and a thin film battery for their choice as the secondary storage device is essential for this research. Capacitors are limited by their inability to provide continuous source of power essential for driving electronic devices. They exhibit sharp bursts of charge and discharge thereby making the use of a voltage regulator mandatory.

They are limited by their voltage level and their unstable discharge makes them highly unsuitable for use in commercial devices. The existing prototypes use the capacitor as the secondary storage device. The capacitor tends to charge during an input from the piezoelectric, and discharge when there is no input. But in the application of the harvester circuit, we prefer the secondary storage device to charge using the trickle voltage from the key-press and discharge only at the time of full charge. Hence the capacitor cannot be used to store the trickle charge as it discharges once the key is released. So, a better alternative to this problem would be using rechargeable batteries especially thin film or battery cells.

We modified the existing piezoelectric harvesting circuit to include the thin film battery as a secondary storage device which can charge using the trickle voltage and discharge at a constant DC of 5V to charge the primary battery. Protection circuits could be employed on both the secondary and primary batteries to prevent overcharging and other conditions. Since both the primary and secondary are Lithium batteries, we discuss a common protection circuit. These thin film batteries have the capability to last longer as they can be recharged with the harvested energy over and over. But, this requires an efficient low loss interface circuit that could effectively transfer the energy to the battery. The ideal choice for the secondary battery is a Li-ion thin film battery with high charge density.

IV. RF ENERGY HARVESTING MODEL

Signals transmitted by TV antennas, mobile phone antennas and towers are electromagnetic radiation in the radio frequency spectrum. This radiation is not direction specific and is transmitted in all directions. Hence, a large portion of this radiation is wasted as stray energy in the environment. However, this radiation can be captured using power generating circuits with a suitable antenna and can be converted to useable DC voltage, providing an alternate source of power.

A device may be embedded with a microstrip size printed dipole antenna and additional power conditioning circuitry, such that the energy in the GSM-900, GSM-1800 and WLAN frequencies may be uniformly captured. The power output obtained from such a harvester varies with the distance from the source of the radiation. Power densities from $0.1mW/m^2$ to $1.0mW/m^2$ can be obtained at distances of 25m to 100m [4] and this can be increased by a factor of up to 3 by using an array of these antennas. During heavy mobile traffic, the power generated can be significant enough to provide enough DC energy to charge the mobile phone itself.

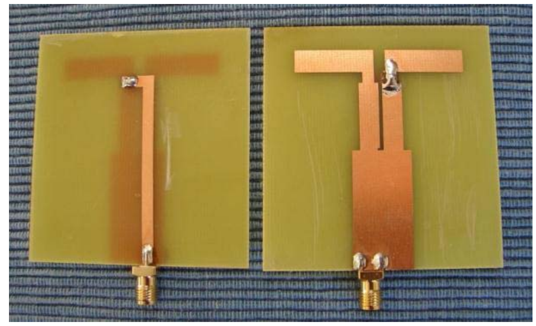

Fig. 4 A model of the printed dipole antenna from [4]

The conditioning circuit may utilize a floating gate transistor at the output of the patch dipole antenna in order to convert the obtained RF energy into useable DC power. In the case of a mobile phone, a higher power may be required for the purpose of charging. A capacitor can be linked to the drain of the transistor and an additional transistor may also be used in order to generate that required power. [5]

We observe that the energy transmitted by a mobile phone is not completely utilized and is present as stray radiation in the vicinity of the phone. In the proposed model, the RF scavenging technique discussed earlier can be implemented in a mobile phone so that the wasted energy from the mobile phone‘s transmitting antenna can be used effectively for charging the device itself. This acts as an efficient fold-back mechanism. In addition to this mechanism, ambient RF energy from mobile towers and other mobile phones can also be harvested so that a greater DC voltage may be accumulated, making the charging process faster. With the increase in the number of mobile phones and other wireless devices coming into use, the amount of stray radiation that can be converted to useful energy will make RF harvesting truly realizable.

V. CONCLUSION

The idea of integrating piezoelectric energy harvesting and RF energy harvesting techniques and implementing them in mobile phones will open new avenues in energy conservation. From the size perspective this model might not seem feasible for a mobile phone. But, with the advancement of MEMS technology and micro-sensor applications this could be developed in to an efficient control and interface circuit model to improve the power harvested from ambient vibrations. The reducing size of all devices will make this model implementable in all commercial mobile electronic devices. This model efficiently utilizes currently developing energy harvesting technologies to reduce day to day energy consumption.

By developing an advanced energy harvesting circuitry that could improve the power generated from vibration sources, the number of times a mobile phone needs to be charged can be reduced. This will also minimize the use of external chargers thereby reducing the necessity to replace them often.

From the environment perspective, this model could also reduce the amount of e-waste that accumulates every year in the form of disposed battery chargers and batteries. The efficient integration of the two discussed energy harvesting techniques with respect to the use of thin film batteries as secondary storage might eventually make the portable electronics devices independent of a primary source and thus has the potential to make them entirely battery-free.

Therefore, by reducing the average energy consumption and by minimizing e-waste this model addresses the issues of energy and environmental crisis at the same time. A practical realization of this model in commercial electronic devices will pave the way for developing piezoelectric technology for the benefit of humanity.

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