Advances In Power Sources For Wireless Sensor Nodes

E.M. Yeatman
Department of Electrical & Electronic Engineering, Imperial College London, SW7 2BT, U.K.

Abstract – Wireless sensor nodes may have power requirements as low as microwatts, and while batteries suitable for such applications may have lifetimes in years, inexhaustible supplies which scavenge energy provide an interesting alternative. This paper reviews the approaches to powering micro-sensor nodes.

Key words – wireless sensors, micro-power generator, power scavenging, MEMS

I. INTRODUCTION

Increasing miniaturization and cost reduction of sensors, circuits and wireless communication components is creating new possibilities for networks of untethered sensors, in wearable and other applications. However, untethering requires not only wireless networking of nodes, but wireless powering. Batteries are the main solution at present, but unless they can provide very long lifetime while not dominating the size (or cost) of the nodes, battery replacement will be a significant deterrent to widespread adoption of these technologies. As an alternative, therefore, sources which scavenge energy from the environment are very attractive. In this paper we review current developments in micro-power sources, including batteries and other finite energy sources, and energy scavenging.

II. POWER REQUIREMENTS

For wearable applications, sensor nodes will usually be monitoring environmental conditions or biological functions. The data requirements of many such sensors will be modest, since both the resolution and the required update rate are low. Some examples [1] are summarized in Table I.

Table I. Body sensor data rate requirements.

Code	Signal	Depth	Rate	Data Rate
PA11	Heart rate	8 bits	10 / min.	80 bits/min.
PA12	Blood pressure	16 bits	1 / min.	32 bits/min.
PA13	Temperature	16 bits	1 / min.	16 bits/min.
PA14	Blood oxygen	16 bits	1 / min.	16 bits/min.

It is clear that these data rates are negligible (around 1 bit/s or less), which implies both a very low clock rate on the circuit, and low transmission power for the wireless uplink. It can be shown [2] that data transmission at up to 1 kbit/s, over the distances expected between body network sensors (up to 1 m), can be provided with sub-microwatt power levels. The remaining power usage is for the sensors themselves, and the conditioning electronics. Both temperature and pressure measurement can be done by measuring the voltage drop of a current through a resistor. The power needs only to be sufficient to overcome thermal noise ($\approx 10^{-20}$W/Hz at room temperature), and so can be negligible. Thus for the very low bandwidths of the application (as low as 1 Hz), the sensor elements themselves need not have significant power consumption.

Finally, the interface or signal conditioning electronics will cause some power loading. The most straightforward requirement will be for A-D conversion; ADC's have been reported with power consumption levels of 1 μW [3], and since this is at sample rates (4 kS/s) above our requirements, significantly sub-microwatt levels should be achievable. Thus, total power levels as low as 1 μW may be sufficient for realistic sensor nodes.

III. EXHAUSTIBLE SOURCES

As stated, batteries are currently used for powering most wireless devices. Where the power requirements are modest, primary (i.e. non-rechargeable) batteries are usually chosen, for their higher energy densities, lower leakage rates and low (initial) cost. For sensor node applications, battery lifetimes of at least a year are desirable, corresponding to 32 J per μW average power. Lithium based primary batteries provide 1400 – 3600 J/cc [4], so in principle a lifetime of several years is achievable for a battery well below 1 cc. Thus, although the finite lifetime remains a disadvantage, and other issues such as operating temperature range may reduce their practicality, primary batteries remain a very attractive source for sensor nodes.

Exhaustible sources using fuel are also under investigation for small portable electronics, although mainly for higher power levels. The motivation is the very high specific energy of hydrocarbon fuels, e.g. 17.6 kJ/cc for methanol [5]. Converting this energy to electrical form in the conventional way, i.e. using a heat engine, is difficult on a micro-scale because of the need to maintain large temperature differences. However, micro-engineered heat engines for this purpose are being investigated, e.g. [6]. Fuel cells, however, are an attractive alternative, as they require much lower temperatures and have no moving parts. A popular variant for miniaturisation is the direct methanol fuel cell [7]. In these devices, the methanol reacts electrochemically with water at the anode, producing free electrons and protons, the latter being oxidised to water at the cathode after passing through a polymer membrane. Power levels reported were as high as 47 mW/cm^2.

IV. POWER SCAVENGING

We can move away from finite energy sources by scavenging from the variety of energy sources in the node's environment, i.e.: motion and vibration, air flow, temperature differences, ambient electromagnetic fields, and light and infra-red radiation. In the latter case, solar cells provide an excellent solution. This is a relatively mature technology, inexpensive and highly compatible with electronics, and the available power levels can be up to mW per cm^2. However, the drawback is that the sensor must be in a well lit location, correctly oriented and free from obstructions. This creates severe limitations for a personal application.

Gathering radio frequency radiation suffers much less from these geometric limitations. In the VHF and UHF bands [8], for which miniature antennas can operate with reasonable efficiency, field strengths are from $\approx 10^{-2}$ to 10^3 V/m. We can approximate the power density crudely as E^2/Z_0, where $Z_0 = 377\ \Omega$ is the impedance of free space. For 10 or 1 V/m, for example, this gives 26 or 0.26 $\mu W/cm^2$. A few V/m thus probably represents the minimum radiation level needed for successful energy scavenging. However, even typical urban environments do not show these levels except in special areas such as in the vicinity of cellular base stations [8]. This suggests that radio frequency scavenging is an approach with limited applicability. Scavenging thermal energy depends on the presence of temperature differences, e.g. between the surface of the body and the ambient. The power available is modest; a microengineered device reported below 1 $\mu W/cm^2$ for a ΔT of 10K [9]. The use of air flow is promising for higher power levels, although with correspondingly higher device size; a microengineered axial flow turbine with a radius of 6 mm has been reported producing 1 mW for an air flow of 30 l/min [10].

Scavenging power from vibration or body motion is a promising approach, pursued by a number of research groups. We have pioneered a device specifically designed for wearable or implantable applications, where the motion frequencies are low and so resonant devices are unsuitable [11]. The so-called Coulomb-force parametric generator moves in a start-stop fashion at the acceleration peaks, and prototypes generating 2 μJ/cycle have been reported [12].

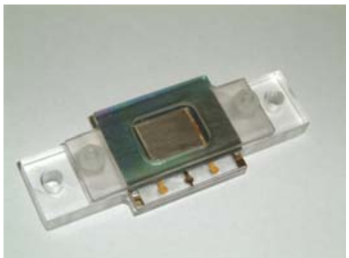

Figure 1. Prototype of vibration-powered electrostatic generator. Moving plate is $\approx 1\ cm^2$.

V. CONCLUSIONS

Batteries continue to be the leading power source for sensor nodes; however, a variety of energy scavenging approaches are being developed which should free wireless micro-sensors from the need for finite energy supplies.

VI. REFERENCES

1. T. Balomenos, “User Requirement Analysis and Specifications of Health Status Analysis and Hazard Avoidance Artefacts”, DC FET project ORESTEIA, Deliverable D02, 2001.
2. D. Yates & A. Holmes, “Micro Power Radio Module”, DC FET project ORESTEIA, Deliverable ND3.2, 2003.
3. Sauerbrey J., Schmitt-Landsiedel D. & Thewes R., “A 0.5-V 1-μW successive approximation ADC”, IEEE J. Solid-State Circuits 38(7), 1261- 1265, 2003.
4. Brodd R.J., Bullock K.R., Leising R.A., Middaugh R..L, Miller J.R., Takeuchi E., “Batteries, 1977 to 2002”, J. Electrochemical Society 151 (3): K1-K11, 2004.
5. S. Roundy, D. Steingart, L. Frechette, P. Wright, and J. Rabaey, “Power Sources for Wireless Sensor Networks”, Lect. Notes Comput. Sci. 2920,1-17, 2004.
6. Whalen S., Thompson M., Bahr D., Richards C. & Richards R., “Design, fabrication and testing of the P-3 micro heat engine”, Sens. & Actuators A-Physical 104 (3): 290-298, 2003.
7. Yen T.J., Fang N., Zhang X., Lu G.Q. & Wang C.Y., “A micro methanol fuel cell operating at near room temperature”, Appl. Phys. Lett. 83 (19): 4056-4058, 2003.
8. Mantiply E.D., Pohl K.R., Poppell S.W. & Murphy J.A., “Summary of measured radiofrequency electric and magnetic fields (10 kHz to 30 GHz) in the general and work environment”, Bioelectromagnetics 18 (8): 563-577, 1997.
9. M. Strasser, R. Aigner, M. Franosch and G. Wachutka , “Miniaturized thermoelectric generators based on poly-Si and poly-SiGe surface micromachining”, Sensors & Actuators A: 97-98, 535-542, 2002.
10. Holmes A.S., Hong G., Pullen K.R., Buffard K.R., “Axial-flow microturbine with electromagnetic generator: design, CFD simulation and prototype demonstration”, Proc. MEMS 2004, Maastricht, 25-29 Jan 2004, 568-571.
11. P. D. Mitcheson, T. C. Green, E. M. Yeatman and A. S. Holmes, “Architectures for Vibration-Driven Micro-Power Generators”, IEEE/ASME J. Microelectromech. Syst., in press.
12. P. Miao, A. S. Holmes, E. M. Yeatman and T. C. Green, "Micro-Machined Variable Capacitors for Power Generation", Proc. Electrostatics '03, Edinburgh, UK, March 2003.