The Human Body as an Energy Source

New technologies for generating energy

Thijs Beckers

'Save energy!' is a much-heard slogan these days, with rising oil prices and the greenhouse effect always in the news. Research has taken place in the Holst Centre for some time on the development of 'energy scavengers', energy converters that use body heat. These can only generate small amounts of power, but there are no waste products.

Figure 1. The prototype of the pulse oximeter is already small enough to be worn as a wristwatch.

These days a lot of thermal energy is lost to the environment. The giant cooling towers next to power stations are a clear example, with their billowing steam clouds. New developments are taking place on a much smaller scale to utilise this 'waste heat' and convert it into electricity.

EVERLASTING ENERGY

Electronic devices need electrical energy to operate. For portable devices batteries have predominantly been used, but this could be about to change...
At the Holst Centre development is taking place of 'Energy Scavengers', also called 'Energy Harvesters'. These ingenious technological devices make use of piezo-electric, electrostatic, electromagnetic or thermal energy to generate a voltage. The latter form of energy is of particular interest. There are many heat sources that lose (and therefore waste) thermal energy to their surroundings. Just think of the heat generated by industrial machines, cars, ovens, etc. Another source of thermal energy is the human body.

MUSIC OF THE FUTURE?

For mobile applications it would of course be great if we could make use of an existing heat source such as the human body. We could then listen endlessly to our iPod or MP3 player and our mobile phone would never have to be connected to a mains charger again...
But we haven't come that far yet. The current technology still requires too much power to work off just our body heat (unless you convert all of the body heat, which isn't very practical). The Holst Centre has already developed a prototype of a blood gas data logger (**Figure 1**). This is a completely autonomous system, which takes its power from the heat coming from the wrist of the volunteer.
The underlying technique in this sy-

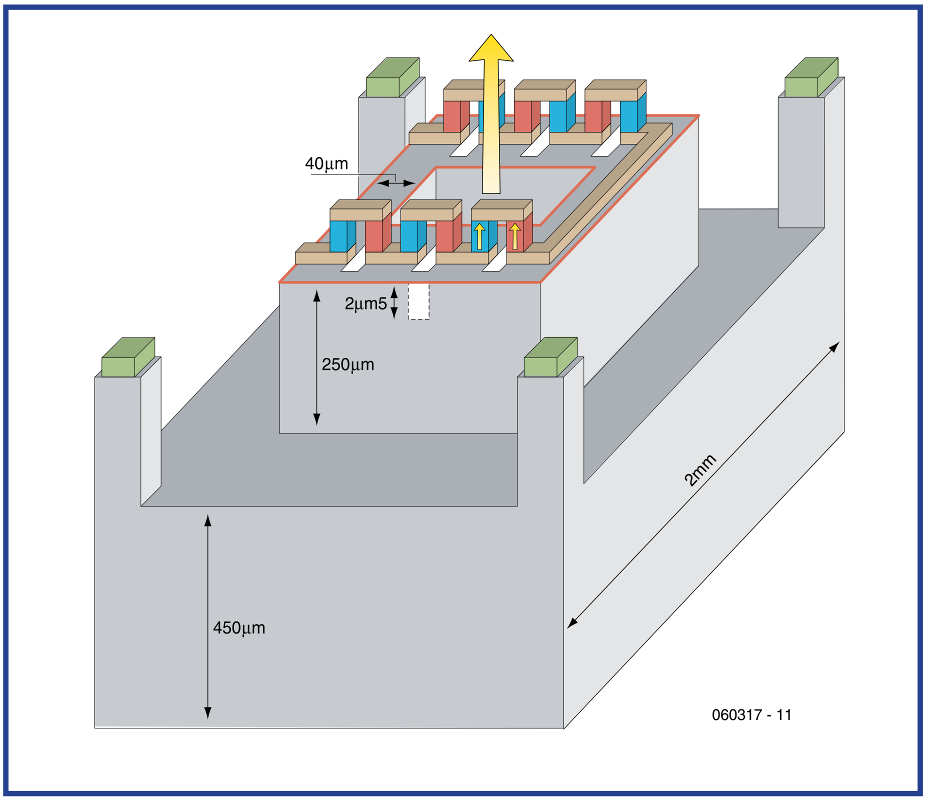

Figure 2. Structure of thermopiles in silicon. The heat flow (yellow arrows) creates a voltage across the thermal elements. The series connection increases the voltage to a useable level.

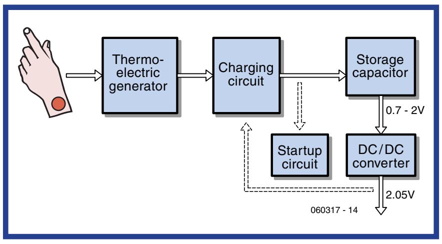

Figure 3. Block diagram of a thermo-electric supply. The energy extracted by the energy scavenger needs further processing before it becomes useable.

stem isn't new however. It makes use of the so-called Seebeck-effect (see inset). What is new is the way in which the thermal energy from the heat source is converted...

TECHNOLOGY

So-called thermopiles can now be constructed using silicon (see **Figure 2**). These thermopiles consist of thermocouples, which generate a small voltage when there is a temperature difference across the thermocouple junction. When a large number of thermocouples is connected in series a useable voltage is generated. This voltage is calculated using the formula $Uo = m \cdot \alpha \cdot \Delta T$, where m is the number of thermocouples, α the Seebeck coefficient and ΔT the temperature difference between the two metals of the thermocouple.
In practice each thermocouple generates about 1 mV. To obtain a useful voltage (between 1 and 10 V) we therefore need at least a thousand of them. Such a large number isn't a problem since the thermal elements are built on silicon.
Figure 3 shows the block diagram of a thermo-electric power supply. At an ambient temperature of 22°C the human body releases about 10 mW/cm^2 of heat energy (measured near an artery). Depending on the conditions, the thermo-electric generator can generate between approximately 100 to 200μW. The charger circuit stores this energy in a battery or capacitor. This is then used to supply the circuit with power. The maximum power transfer occurs when the load resistance is the same as the internal resistance of the thermopiles. The energy scavenger in the blood gas data logger supplies between 100 and 600 μW, depending on the conditions. As the ambient temperature rises, the power output decreases. At about 36° there is no temperature difference between the skin and the surroundings so no energy can be generated (see **Figure 4**). Should the temperature rise even further, the element will start to produce a voltage again. However, it now works 'in the opposite direction' in that the skin is now warmed up by the element rather than cooled. This heat is then released elsewhere by the body.

THERMAL RESISTANCE

The power output of the thermal element is greatly influenced by the total thermal resistance. This consists of

Holst Centre

The Holst Centre (www.holstcentre.com) is a joint imitative of IMEC and TNO. It is an independent Research & Development institute that develops new technologies for autonomous wireless transducers and systems-in-foil. Research into energy scavenging techniques is carried out within IMEC-NL. An important hallmark of this institute is the interaction and collaboration with industrial and academic institutions. This overlap means that the Holst Centre can adapt their scientific strategies to the industrial requirements. Investments provided by the government and several companies have significantly increased the chances of a successful outcome of the research. The combined knowledge along with the new developments gives the contributing parties a head start in the market, something they couldn't have achieved without this level of co-operation.

Seebeck-effect

The Seebeck effect was discovered in 1821 and is named after its inventor Thomas Johann Seebeck. It is the direct conversion of a temperature difference at the junction of two different metals or semiconductors into an electrical potential. It is actually the opposite of the well-known Peltier effect, where an electrical current is converted into a temperature difference. In fact these two processes are the same, with the energy conversion happening in opposite directions. For this reason they are collectively called the Peltier-Seebeck or thermo-electric effect.

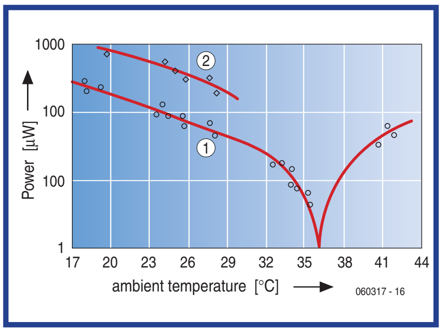

Figure 4. Power output of the thermopiles. Graph 1 is of a seated person; graph 2 is of a running person. The difference is caused mainly by the cooling capacity of the heatsink.

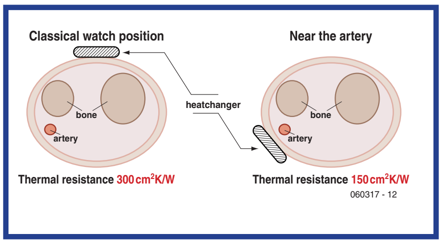

Figure 5. Thermal resistance of the body. The best place for the heat exchanger is clearly near an artery.

the thermal resistance of the body, the thermo-electric generator and the surrounding air.

Several studies have been made of the thermal resistance of the human body. The optimum thermal transfer is achieved when the thermal element is placed over an artery (see **Figure 5**). The thermal resistance is then about 150 cm^{2}K/W. The resistance of the heat exchanger is in the region of several hundred cm^{2}K/W.

The thermal resistance of the air depends very much on the surrounding air movement. For a person sitting down this was 500 cm^{2}K/W with the heatsink used. The same heatsink had a resistance of 'only' 200 cm^{2}K/W when this person was walking (refer to Figure 4).

During these tests it was also found that heavy exercise by the test subjects didn't result in any extra energy being generated. The body is so efficient in dissipating excess heat that the skin temperature doesn't rise significantly and hence there won't be an increase in the energy extracted.

The head is generally the warmest part of the body. It is therefore from here that you can get the best return when converting body heat into electrical energy. The only disadvantage is that it doesn't look very appealing (see **Figure 6**).

'ENERGY-FREE' MEASUREMENTS

The device designed at the Holst Centre, the wireless pulse oximeter sensor (see Figure 1), uses these newly developed technologies. The signals from a blood gas and hart rate sensor (of the type also used in hospitals) are connected to a sort of wristwatch. This strap contains all of the electronics as well as the power supply. The block diagram in **Figure 7** shows how the pulse oximeter is constructed. The heat exchanger is placed above the artery, which indirectly supplies the electronics with the required energy. All the analogue and digital signal processing is carried out on-board. A radio transmitter is used to send the data to (for example) a PC, so that the information can be displayed in real-time and, if necessary, an alarm can be raised when the data goes outside a certain range.

OLD AND NEW TOGETHER

The theories behind these devices aren't exactly new. The technology has existed for quite some time, but was much too bulky for portable applications. Because of this, the Holst Centre concentrates its research mainly on the miniaturisation of the technology. They are now researching the production of a thermopile using silicon. This means that the energy collectors can be manufactured on silicon wafers, similar to microprocessors, which provides a big cost saving. The tiny dimensions of the elements mean that you can connect enough of them in series to produce a useable voltage.

This isn't exactly a new idea, as can be seen from the Seiko Thermic Watch [1,2]. This watch makes use of the same effect that the pulse oximeter uses. The dimensions of the thermopile are much greater, since it is constructed using discrete elements. It

Figure 6. This many scavengers seems a bit over the top...

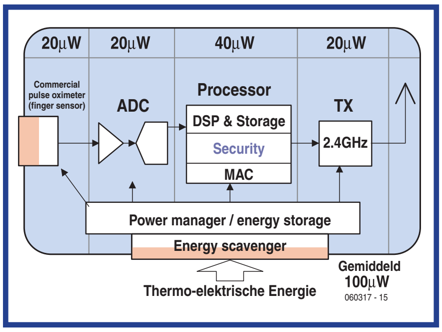

Figure 7. The internal structure of the wireless pulse oximeter is directed at making the size and energy consumption as small as possible.

also converts much less energy into an electrical output.

Other products that use ambient energy sources are of course solar cells (see **Figure 8**). A less well-known, but no less interesting, application are the light switches made by EnOcean (see **Figure 9**). Pressing the switch genera-

tes enough power to energise a small transmitter, which activates a remote relay [3].
There are many other devices that make use of 'human energy': wind-up radios and telephone chargers, and torches that first have to be shaken to charge them up. But most of these are nowhere near as ingenious as the modern technologies.

ENERGY EVERYWHERE

Energy scavengers are the future. They operate wirelessly and have uses in numerous applications. Just think of alarm systems, industrial applications where the heat from machines can be used, medical applications, such as the wireless pulse oximeter described earlier, which can also be connected to a GSM, making remote readings from greater distances possible. Other uses are in domotics, where many sensors can be used without having to install cables, gaming (the controller doesn't require batteries and won't run out of power in the middle of that all-important game), wireless keyboards and mice, and so on.
Another area where these devices will have a future is in the automotive industry. In America it is compulsory for new cars to continuously monitor their tyre pressure. Realistically, this can only be implemented using wireless technology, which is an area that energy scavengers excel in (see the May 2005 issue of Elektor electronics, 'Sense Organs for Vehicles').
The technology can also be used as an alternative to RFID, which is a passive system. With energy scavengers it is possible to actively monitor what happens to a product. As an example, you could tell if a deep freeze product has been defrosted. The temperature can be continuously logged via a sensor, so you can tell at a later date exactly what happened to the product. In combination with a paper display you could even tell directly what the shelf life of the product was.

Thermocouples

A thermocouple consists of two wires made from different metals or alloys that have been joined together, preferably welded. When a temperature difference occurs across the junction a potential difference is created, which is proportional to the temperature difference. The potential difference is in the order of 6 to 60 microvolt per °C (µV/°C).

Figure 8. The Camel fridge. This is a good example of an alternative energy source. (photo Naps Systems Oy)

Figure 9. A light switch made by EnOcean. This wireless switch converts the energy used in pressing the switch into electrical energy, which powers a transmitter that activates a remote relay.

ELECTRONICS UNLIMITED

The amount of electronics used in our day-to-day lives is increasing all the time. Just think of the car, coffee machine, electric toothbrush, etc. Many new solutions are invented to provide all these electronic devices with power. The thermopiles from the Holst Centre are just the tip of the (technological) iceberg, which will grow to new heights despite the greenhouse effect...

(060317)

With thanks to Ruud Vullers, senior researcher Holst Centre, for his assistance.

Weblinks:

[1] www.roachman.com/thermic
[2] www.natureinterface.com/e/ni03/P045-049
[3] www.enocean.com