Institution: University of Bedfordshire

Unit of Assessment: 11- Computer Science and Informatics

Title of case study: Powering Electronic Devices from Ambient Radio Signals

1. Summary of the impact

We have developed an energy harvesting technology that extracts energy from ambient radio signals which is used to power or charge low power electronic devices. The key impact from this work is raising the public, media and business awareness and interest in our technology. This has included a BBC Technology clip featuring our technology, several national and local radio interviews and coverage on numerous websites and newspapers around the world. Although this technology has not yet been commercialised (a target application is powering smart meters), it has already had a significant impact and reach in public and commercial debate and an enhancement in the public understanding of science.

2. Underpinning research

Professor Ben Allen (Professor of Computer Science and Head of Centre for Wireless Research)
Dr Tahmina Ajmal (Lecturer in Engineering)
Dr Vladimir Dyo (Senior Lecturer in Computer Networking)
Mr David Jazani (Senior Lecturer in Construction)
All affiliated to the Centre for Wireless Research, Institute for Applicable Computing, University of Bedfordshire

Sept 2010 – to date

<u>Background to the problem addressed</u>

With the UK government launching its 'Green Deal' in 2010, 142 million smart meters are set to be installed in UK properties by 2020. Current smart meter designs require batteries to power them, which need replacing every few years. If smart meters could operate autonomously, we estimate that in the UK alone this would reduce the related operational costs of utility companies by up to £170M/year.

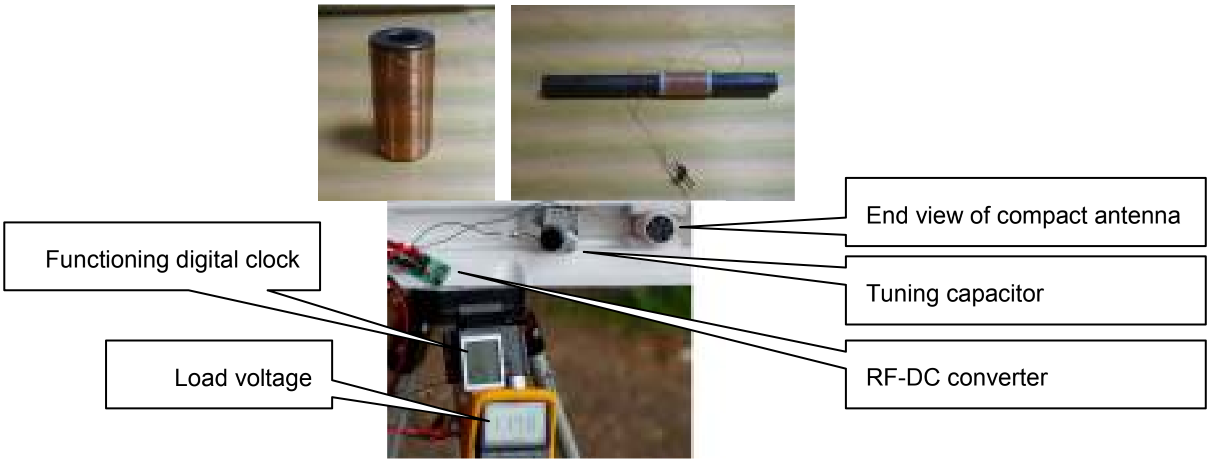
<u>Approach</u>

We have been developing a means of powering smart meters or other low-power electronic devices such that batteries will not be required. Our device harvests energy from ambient radio signals and, to the best of our knowledge, is the only UK-based example. Our aim is to have our energy harvesting technology as an integral part of smart meters deployed across the UK and beyond.

We have been researching an eco-friendly method for powering electronic devices, such as smart meters, clocks or wireless sensor nodes, by means of converting ambient radio frequency (RF) energy into direct current (DC) which is used to power or charge the device. Compared with conventional batteries, our device is more eco-friendly due to its having a significantly reduced environmental footprint than that associated with manufacturing and disposing of conventional batteries. The complete system may be retro-fitted into existing battery holders and comprises a compact transducer, such as a small ferrite rod antenna, and an integrated converter. We decided to harvest energy from medium-wave broadcast transmissions because of the good geographical coverage associated with these frequencies, the available signal power and the number and disposition of the transmitters [3.1, 3.2]. The harvesting apparatus is self-contained, and may have a topology akin to that of a standard battery e.g., AA, C or D, such as those shown in the figure below. It may, alternatively, be a different size and shape but provide a means of connection directly to the standard battery holder of the user device and hence fitted as a direct battery replacement to suitable devices. We have derived a model for determining the performance of the device [3.1] which has enabled us to optimise the design to maximise the output power, whilst minimising the device cost and form factor [3.3]. The figure below shows two example implementations for different form factor requirements.

Harvesting energy from ambient radio signals is an emerging field, but our findings differ from other attempts elsewhere, since we have focussed on different transmitted frequencies, considered different applications, targeted a direct battery replacement and considered the importance of integrating biodegradable packaging around the device.

We have demonstrated that, provided there is an adequate amount of energy in the ambient radio signals at the reception site, we can convert this energy into direct current to power or charge low-power electronic devices [3.1-3.3]. Our initial results show that a device of size 58cm x 4.5cm can operate a digital clock up to 10 km from a 150 kW transmitter. Further design optimisation activities have enabled us to demonstrate an increase in the conversion efficiency of the antenna, and hence significantly reduce its length to less than 10cm whilst retaining performance. The images below show two such examples, one with form factor of a D-cell (top-left) and the other with form factor of two AA-cells (top-right). The bottom image shows our device operating during field trials and producing 1.2V and powering a digital clock. D.C. Power levels of up to 0.5mW for distances from 2.4-14.4km have been achieved, which compares well with modelled results [3.2].



Examples of our compact antennas
Top-left: D-cell size, Top-right: 2 x AA size, Bottom: Functioning device

3. References to the research

3.1 T Ajmal, D Jazani, B Allen, "Design of a Compact RF Energy Harvester for Wireless Sensor Networks", IET Wireless Sensor Systems 2012, June 2012, London (4 citations, 125 downloads from IEEE Xplore checked Oct '13, 8 downloads / month) tv.theiet.org/technology/communications/14062.cfm

This paper presents our analytical model and design concept. Key design parameters are explored and conclusions drawn in terms of their impact.

3.2 B Allen, T Ajmal, V Dyo, D Jazani, "Harvesting Energy from Ambient Radio Signals: a load of hot air?", Loughborough Antennas and Propagation Conference, Nov. 2012, Loughborough, key-note paper, (74 IEEE Xplore, checked Oct '13, 7 downloads / month) tv.theiet.org/technology/communications/15434.cfm

This paper presents our RF energy harvesting concept and analytical model. Additional design factors such as effective permeability are introduced and explored.

3.3 V Dyo, T Ajmal, B Allen, D Jazani, I Ivanov, "Design of ferrite rod antenna for harvesting energy from Medium Wave broadcast signals", IET Journal of Engineering, Dec 2013

digital-library.theiet.org/content/journals/joe/

This paper details our RF energy harvesting concept, extends our analytical model to include rod permeability and self-resonant frequency, and develops a means of optimisation of the antenna which we use to determine key design parameters. We use field trial results to validate our work.

4. Details of the impact

Our activities relating to RF energy harvesting stemmed from the need to enable sensors and low power electronic devices to operate autonomously, i.e., without interrupting operation whilst refreshing batteries, powering devices in hard-to-access locations or reducing the cost associated with refreshing batteries for a large number of devices. As such, RF energy harvesting is an emerging field that has received unprecedented profile in terms of research outputs and media profile in the last 12 months and after our initial work was publicised in 2011. Thus the business arena surrounding RF energy harvesting technology is still developing, yet despite this our work has so far produced two patents, received a significant media profile, attracted potential investors and even inspired school children to consider novel sources of energy as alternatives to batteries.

i. We have undertaken performance modelling of our device, which includes optimising our design for maximum performance and minimum material costs, as detailed in references 3.2 and 3.3. This resulted in our initial patent filing, which the Patent Office examiners have examined and have not raised major concerns relating to our claims (filing number 1116273.2 September 2011) [5.1].

ii. With our patent filed, in October 2011 we presented our findings at a public seminar hosted by the University of Bedfordshire. This attracted a University press release which triggered considerable international media attention on BBC local and national radio, BBC television, local and international newspapers and worldwide internet coverage, including articles in the USA, Canada, India and New Zealand (sample listed in section 5). The reach of the impact is estimated to be 2.4 million people, with an indicative value (* method below) of £27k [5.6]. The consequence of the extensive media coverage has been a large number of enquiries from potential investors including EnOcean, Roke Manor Research, Elster Metering, Honeywell, Shell, Axis Electronics, Arquiva, Cambridge Design partnership and J-Mac [5.2], [5.4]. Discussions are on-going with several of them. A tangible impact resulting from our discussions was the establishment of a technical innovation competition with private sector backing from Axis Electronics (which ran in 2012/13 and is anticipated to run again in 2013/14). The competition engaged university students and staff, and invited entries demonstrating an innovative electronics-related design. The prize, won by a team of 2nd year undergraduate engineering students for their mobile phone detection device, was a tour of Axis Electronics state-of-the-art factory, possible internship and the possibility for their innovation to be commercialised. The winning entry featured on the University website. Consequently, Axis Electronics made substantive contribution to the Departments' Employer Engagement Panel [5.3]. Potential commercial opportunity in terms of funding a technology spin-off venture also arose. This led to the team giving an invited presentation to technology companies in the Milton Keynes area and the conception of an 'Innovation Den' at the University of Bedfordshire and in partnership with BizTech – the technology business forum in Milton Keynes.

** Estimated using a media monitoring platform called Precise. The platform calculated the value and reach of the item. Value refers to the space the item fills in terms of advertising space, and calculating the cost if we had paid for the item space, so showing money saved. The reach is the circulation of the magazines or newspapers, so the platform calculates how many people read the publication and how many would see the article. The financial value is achieved by comparing this with the equivalent spend required on conventional advertising for the same reach.*

iii. In July/August 2012 we had a concept demonstrator constructed and tested by AND Technology Research Ltd who reported that our concept is sound and also indicated areas where we can optimise our design further [5.4]. We are currently working on improving the design of our demonstrator, raising enough investment to fund a product prototype and conduct detailed market analysis. Through these activities we have presented our ideas to several potential collaborators who have recognised the value of what we have done to date, and have provided positive feedback on our devices, both in terms of technical and market potential [5.2], [5.3].

iv. Our technology has been presented to more than 120 primary, secondary school and college students from the Bedfordshire and Buckinghamshire region, including at Drayton Parslow Village School where the activity was followed up by the class installing a science table for pupils to freely explore and dismantle electronic equipment [5.5]. The objective of the activity was to raise awareness of environmental and operational limitations of batteries and present alternatives, including harvesting energy from radio waves. Feedback from all of these activities was very positive, with some secondary pupils considering studying electronics at university, and primary school pupils feeling challenged that devices such as electronic toys and torches can be power or charged by radio transmissions.

v. As a consequence of the work to date, a second patent relating to RF energy harvesting has been filed by the University of Bedfordshire (filing number 1305083.6, March 2013) [5.1]. A research student, I Ivanov, is working on further developments (and has made great progress in terms of successfully demonstrating a more advanced experimental device as reported on [3.3]). Discussions are on-going with the National Radio Centre at Bletchley Park with a view to installing an interactive demonstrator available to visitors.

5. Sources to corroborate the impact

5.1 Associate, D Young & Co
Patent attorney managing our patent filings.

5.2 Director of Cambridge Design Partnership
Collaborator for funding application.

5.3 CEO, Axis Electronics
Sponsored a University electronics competition as a result of his interest in our technology for potential investment.

5.4 CEO, AND Technology Research Ltd
AND Technology Research undertook a technical review and design activity of an early prototype.

5.5 Teacher, Drayton Parslow Village School, Bucks
Hosted a ‘show and tell’ of our work to reception class primary school children

5.6 The following are examples of media items.
The top 5 have been selected from a list of more than 20 items.

System to 'eliminate' batteries, 11/02/2012, BBC News (web)
www.bbc.co.uk/news/uk-england-beds-bucks-herts-16869064
Reach of 1,801,585

Breakthrough in radio wave energy, 22/02/2012, BBC Look East television news and web
www.bbc.co.uk/news/uk-england-beds-bucks-herts-17128356
(also featured on BBC technology website)
Reach 412,000

New system to 'eliminate' batteries, 12/02/2012, Sify (web)
www.sify.com/news/new-system-could-eventually-eliminate-batteries-news-international-mcmmknfhbeb.html
Reach 91,061

University trio unveil an electric revolution, 16/02/2012, Bedford Times & Citizen (print and web)
www.bedfordtoday.co.uk/news/business/local-business/university_trio_unveil_an_electric_revolution_1_3536154
Reach 55,683

Power’s in the air, 28/02/2012, Know It New Zealand (blog)
knowit.co.nz/2012/03/27-february-to-02-march-2012-tech-universe-digest
Reach 44,880