Institution: Loughborough University

Unit of Assessment: B13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Significant commercialisation with international impact underpinned by substantial antenna-related research.

1. Summary of the impact (indicative maximum 100 words)

This case study describes how spin-out company, Antrum Ltd (founded in 2001) realises the commercial potential of Loughborough University's extensive antenna research. Antrum has been consistently profitable typically turning over between £150K - £300K. Examples of how research projects, through industrial partnership, have evolved to commercial products illustrate the success of Antrum's business model and the effectiveness of the partnership between the University and its spin out company. The Case Study describes how the University's wireless communications research, between 1998 – 2011, consistently challenged accepted antenna design to meet demand for products that are more efficient, robust, smaller and commercially viable.

2. Underpinning research (indicative maximum 500 words)

Prof. Vardaxoglou established the broad-based *Wireless Communications Research Group* (WiCR) at Loughborough University (LU) in 1988 incorporating the specialist Centre for Mobile Communications Research (CMCR) in 1998. Its labs, staff and facilities are important components of the School of Electronic, Electrical and Systems Engineering. The School is internationally and nationally leading in communications engineering as evidenced by external value assessments. Prof. Vardaxoglou (Professor at LU from 1988 to date) leads the WiCR with key contributions from researchers: Mr. Rob Seager (Lecturer at LU from 1982 to date), Dr. Panagamuwa (Research Associate at LU 2004 to 2007, now Lecturer 2007 to date) and Dr. Alford Chauraya (Research Associate at LU from 2003 to date).

The WiCR researches topics applicable to innovative wireless communications technology, focused primarily on antennas, microwave and mm-wave engineering, and metamaterial structures though extending to all modern communication systems and their supporting processes. With innovation at its centre, the WiCR collaborates with several internationally leading companies – Orange, British Aerospace, Marconi, Sarantel, European Space Agency and world-leading universities – Ohio State University, Michigan State University, Aalto University (Finland) and the University of Sienna. WiCR's activities are characterised by strong industrial collaboration with support from EPSRC and EU sponsors. The team are supported by advanced test and measurement facilities including a 15m x 5m x 5m tapered anechoic chamber optimised for cylindrical near-field measurements from 400 MHz to 18GHz.

From the outset, WiCR's work was characterised by innovation and sensitivity to commercial imperatives – improving the effectiveness, aesthetics, and value for money of antennas. An early achievement, in collaboration with Sarantel Ltd, was the development of low Specific Absorption Rate (SAR) antennas as safer alternatives for mobile phone users and GSM, GPS and SATCOMMS applications (see papers **3.1-3.3** below). WiCR is pioneering research in metamaterials in microstrip planar high gain antennas for point-to-point links and cylindrical patch array antennas for base-station applications. Enhancing the feeding sub-system improves bandwidth capability and efficiency whilst reducing manufacturing complexity. The work benefits from international collaboration on the analysis and synthesis of electromagnetic metamaterials with specific electric and magnetic properties. This includes applications of magnetic metamaterials to the radiation performance of small antennas. It is the foundation for many analysis methods used in the field and is published widely. (see papers **3.4 -3.6** below)

WiCR have had research breakthroughs on novel planar metamaterials and were the first to publish completely planar artificial magnetic conductor surfaces that are simultaneously electromagnetic band gap structures for surface wave suppression.

WiCR has designed a high-gain multiband horn antenna for point-to-point links for a UK mobile phone service provider. Designed to reduce the required number of radio link antennas on an antenna farm, they also reduce costs and negative impact on the aesthetic environment.

The Group have numerical analysis and advanced corroborative model results to demonstrate the advantages of introducing higher permeability to dielectric materials to improve the radiative efficiency of small antennas. Implementation of cost-effective materials is being investigated for material application to low-SAR devices.

3. References to the research (indicative maximum of six references)
The six examples selected have all appeared in influential publications with a proven global impact.

3.1 Leisten, O., Vardaxoglou, J.C., Schmid, T., Rosenberger, B., Agboraw, E., Kuster, N. and Nicolaidis, G., "Miniature Dielectric-Loaded Personal Telephone Antennas with Low User Exposure", *Electronic Letters*, 34(17), 20th August 1998, pp 1628-1629, ISSN: 0013-5194. DOI: 10.1049/el:19981197

3.2 James, J.R. and Vardaxoglou, J.C., "Investigation of Properties of Electrical-Small Spherical Ceramic Antennas", *Electronics Letters*, 38(20), September 2002, pp 1160-1162, ISSN 0013 5194. DOI: 10.1049/el:20020818

3.3 Leisten, O., Vardaxoglou, J.C., McEvoy, P., Seager, R.D. and Wingfield, A., "Miniaturised Dielectrically-Loaded Quadrifilar Antenna for Global Positioning System (GPS)", *Electronics Letters*, 37(22), 25th October 2001, 1321-1322, ISSN 00135194. DOI: 10.1049/el:20010906

3.4 Lee, Y.L.R., Chauraya, A., Lockyer, D.S. and Vardaxoglou, J.C., "Dipole and Tripole Metallodielectric Photonic Bandgap (MPBG) Structures for Microwave Filter and Antenna Applications", *IEE Proceedings - Optoelectronics*, 147(6), December 2000, pp 396-401, ISSN: 1350 2433. DOI:10.1049/ip-opt:20000892

3.5 Feresidis, A. and Vardaxoglou, J.C., "High Gain Planar Antenna using Optimised Partially Reflective Surfaces", *IEE Proceedings - Microwaves, Antennas and Propagation*, 148(6), 1st December 2001, 345-350, ISSN 13502417. DOI: 10.1049/ip-map:20010828

3.6 de Maagt, Peter, Gonzalo, Ramon, Vardaxoglou, J.C. and Baracco, Jean-Marc, "Electromagnetic Bandgap Antennas and Components for Microwave and (Sub)millimeter Wave Applications", *IEEE Transactions on Antennas and Propagation*, 51(10), 1st October 2003, 2667-2677, ISSN 0018926X. DOI: 10.1109/TAP.2003.817566

Research Grants which provided the expertise and environment
From 1998 to 2003, Sarantel Group Plc (parent company of Sarantel Ltd) invested £1,000,000 in the development, modelling and automatic tuning process for manufacture of dielectric-loaded quadrifilar helix GPS antennas. The scale of this investment reflects the confidence the company had not only in the expertise of the Group but also the commercial potential of the technology. Grants 1 - 3 also relate to the Sarantel collaboration:

1. EPSRC GR/R42580, "Metalodielectric photonic band gap filter structures for low absorption multiband mobile telephones" £105,849, Feb 2002 – Aug 2004, PI: Y Vardaxoglou
2. EPSRC GR/R94596, "New theoretical and experimental models of the definitive low SAR antenna" £192,108, June 2003 – Sept 2005, PI: Y Vardaxoglou
3. EPSRC EP/E006213/1, "Enhancing Networks and Wireless Research at Loughborough University's Communications Research Group - A Case for Platform Grant Support" £537,146 was a broad ranging grant with implications for both the work with Sarantel and the work with Philex, June 2007 – Nov 2010, PI: D Parish
4. EPSRC J13042 KTP/Antrum Ltd: USB DTV tuner aerial research and development, May 2011, 1 year. £56,000, PI: Y Vardaxoglou
5. EPSRC EP/C510607 "Meta-antennas: highly-directive planar antennas for wireless LAN & fixed broadband systems" £104,007, April 2005 – Dec 2007, PI: Y Vardaxoglou

4. Details of the impact (indicative maximum 750 words)
WiCR works closely with industry to share knowledge and understand the commercial imperatives

of the sector. In 2005, it organised the first Loughborough Antennas & Propagation Conference to foster collaborative knowledge transfer and extend the reach of its work. This significant annual showcase is a truly global event and attracts c.250 international delegates from research, industry and governments (**5.1**). In 2012, over 200 papers were submitted. It has been described as *"a premier workshop in the world"* and as providing *"the 'right' atmosphere for the 'meeting of minds in a unique way that other workshops are now trying to emulate" by* Raj Mittra, Director, Electromagnetic Communication Lab, Pennsylvania State University and as *having "significant and enduring value to the antenna research and design community not only in the UK, but also Europe and the world as a whole"* by Prof Leo Kempel, Michigan State University.

In 2001, as an outlet for the commercial potential of WiCR's research, Antrum Ltd span out of the University with Prof. Vardaxoglou as Technical Director and the University as a shareholder. Antrum trades successfully, with several major clients such as ESA, Orange, BSkyB, Sarantel and Philex and a consistently buoyant turnover of c. £150K pa (**5.2**). Working closely with WiCR, Antrum refines research outcomes into designs and specialist devices for applications in aerospace and defence, smart commercial and industrial communications, medical and automotive markets.

WiCR and Antrum have maintained a connection with Sarantel (**5.3**) (designers of high-performance miniature antennas for portable wireless applications) over several years. A significant project designed and interrogated the functioning of a novel antenna for GPS applications (research papers 3.1 – 3.3 above). Once the antenna's design and operation was fully understood, the research developed innovative techniques to control its manufacture. The collaborators developed the dielectric-loaded quadrifilar helical antenna, which Sarantel markets as *PowerHelix* technology. The research built-up an understanding of how the quadrifilar helical antenna has little interaction with its close environment – a highly desirable feature for mobile equipment antennas. *PowerHelix* has a right-hand circular polarisation generating a cardioid-shaped reception pattern above the antenna. The active part of the antenna is isolated from the handset case and has a very small near-field region making it less susceptible to close body proximity or other absorbing material than conventional designs.

Much of the Sarantel research aimed to understand how complex devices, such as these antennas, might be simulated using commercial software, as a cost effective, practical option for both for research and industrial applications (for example, see **5.4**). This knowledge is retained within WiCR and has informed subsequent research projects.

Significantly Sarantel were able to refine their manufacturing processes and to produce six antenna variants targeted at a range of customers worldwide. Sarantel gained a competitive advantage in the sector. The technology is now utilised in the following:

1. AutoSeis HDR1C autonomous seismic node.
2. Mobile solutions AG in a GPS telephone.
3. Algodue Elettronica in their Geopoint portable GPS tracker.
4. Tom Tom's Navigator 6 Bluetooth Receiver
5. Hewlett Packard's iPAQ rx5000 series travel companion
6. HyOn in their personal multimedia player
7. Locosys in several products
8. Benefon TWIG Discovery Smartphone
9. ST Electronics in their ruggedised PDAs
10. Hummingbird GPS fish finder from Johnson Outdoors (USA)

In a competitive market, this enhanced product line was crucial to Sarantel's success. The company expanded to Japan – exporting British technology based on British research. They currently employ c. 43 people and had a six-month turnover, as at 31/03/2011, of £1.03m.

To give a second significant example of the transformation of research into commercial reality, the

potential of novel outdoor VHF antennas made using metamaterials was explored in a PhD project (Nerijus Riauka, 2007 – 2010) which drew upon several areas of research (papers 3.4 – 3.6 above) to arrive at 'the Blade' novel antenna. Several innovative research steps met the specific demands of digital TV which were posed by the industrial collaborator Philex Ltd (UK) (**5.5**). The technology's potential was recognised early and IP protection secured by Antrum with the University's co-operation (UK Patent Application: 1212340.2, EC Design Registration: 2074567) (**5.6**). An EPSRC KTA award (2010-2011), allowed WiRC and Antrum to develop the *Blade* further improving both its functionality and aesthetic appeal. A license has been signed with Philex and the Blade antenna is currently in production with advanced negotiations nearing conclusion with major retailers both in the UK and US (**5.7**).

5. Sources to corroborate the impact (indicative maximum of 10 references)

The following sources can be made available at request from Loughborough University

5.1 Link to The Institution of Engineering and Technology Website promoting the annual Loughborough Antenna and Propagation Conference from 2005 – 2012. http://www.theiet.org/communities/antennas/lapc/
5.2 Development Director, Antrum Ltd, antruminfo@antrum.co.uk - To verify Antrum's role in the commercialisation of research originating from WiCR
5.3 Letter from Chief Technology Officer and founder of Sarantel Group PLC
5.4 Press release on collaboration http://www.realwire.com/releases/garmin-chooses-sarantel-technology-to-drive-development-of-next-generation-handheld-gps-devices
5.5 Press Release from Philex Electronics UK Ltd
5.6 UK patent application - Application No.: 1212340.2 (date: 11/7/2012) and International (PCT) Patent Application No. PCT/GB2013/051762 (date 3/7/2013 (priority date 11/7/2012)) , Antrum Ltd, Title: Antennas, Inventor: Yiannis Vardaxoglou
5.7 European Community Design Application No. : 2074567-001, Antrum Limited, Title: Indoor Antenna, Inventor: Yiannis Vardaxoglou