Institution: University of Liverpool

Unit of Assessment: 13 - Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Radio Frequency (RF) Engineering for Applications

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

In this case study, two specific examples of impact are reported. One is cost-effective and high-performance ***smart antennas*** for the offender tagging system and marine navigation system for Guidance Navigation Ltd (Guidance). This collaboration has resulted in new and leading products and also helped the company to win a range of contracts. The other example is the development of a novel ***intelligent drilling system*** for Zetica Ltd. This system can detect deeply buried unexploded ordinance and other objects. It has given Zetica a unique new product to significantly improve operational safety and win business worldwide.

2. Underpinning research (indicative maximum 500 words)

Context: RF engineering is based on the use of radio waves or electromagnetic waves to solve engineering problems. It is an essential part of modern wireless systems, such as mobile telephones and radar.

Research: Antennas are essential for any RF system. A good antenna can significantly improve the system performance without increasing the cost and energy consumption. Huang has developed novel antenna designs. The scope of his innovative designs are reviewed in his book [3.1], international conference proceedings [3.2] and journal papers [3.3]. Since 2001, he has conducted extensive research into antennas for radio positioning and tracking applications using an antenna diversity technique [3.2]. This technique normally uses at least two separated antennas, with different polarisations, to improve the quality of the received signal (i.e. enhanced signal-to-noise ratio), which is extremely important for communications and positioning systems in multipath (e.g. indoor) environments. However, this technique cannot be easily applied in all applications due to constraints such as space, especially for portable devices. Special designs and original ideas are therefore required. A comprehensive study of antenna diversity has been undertaken at Liverpool, with funding from the EPSRC and industry. Novel designs have been proposed, including one which uses the same radiator but different feeding ports to realise the diversity [3.3]. This solution is not only cost-effective, but also space-efficient. This underpinning innovation was later implemented by Guidance.

Another important research project conducted in the RF engineering group at Liverpool from 2005 addressed the problem of detecting unexploded ordnance below the surface (including bombs dropped during WWII). Conventional practice uses ground penetrating radar (GPR). This method is good for detecting shallow objects, but the challenge was how to detect and identify deeply-buried ones. A novel technique of using a borehole magnetometer with a wireless link was developed by Huang and colleagues at Liverpool [3.4-3.6]. This approach, which included both hardware and complex data interpretation software, was based on a full-wave electromagnetic model. The advantage of this approach is that nearby unexploded ordnance can be accurately located and identified at the same time as drilling the boreholes used for pre-construction ground surveys [3.4–3.6].

Key dates: The work with Guidance began with an EPSRC research grant (GR/S12845/01 from 2003 to 2005 for £128k) where antenna diversity was investigated.

Key researchers: Professor Y. Huang (Lecturer 1995, Senior Lecturer 2000, Reader 2007, Professor 2011); Dr X. Zhu (Lecturer 2004, and Senior Lecturer 2009), and Dr W. Al-Nuaimy (Lecturer 2000).

3. References to the research (indicative maximum of six references)

3.1 Y. Huang and K. Boyle, *Antennas – from theory to practice,* John Wiley & Sons, ISBN: 9780470510285, 378 pages, Aug. 2008.

3.2 Y. Huang, S. C. Su, and J. Hodgskiss, "Base Station Diversity Investigation of Mobile Radio at 450 MHz", *Proc of IEEE APS & URSI*, vol. 2, pp. 314-318, San Antonia, USA, June 2002, ISBN: 0-77803-73308102.

3.3 H. Chattha, Y. Huang, S. Boyes and X. Zhu, "Polarization and Pattern Diversity Based Dual-Feed Planar Inverted-F Antenna", *IEEE Trans on Antennas and Propagation*, vol. 60, pp. 1532-1540, 2012. http://dx.doi.org/10.1109/TAP.2011.2180308

3.4 Q. Zhang, Y. Huang and W. Al-Nuaimy, "UXO Location and Identification Using Borehole Magnetometery," *IEE Proc. Science, Measurement and Technology*, vol. 153, no.1, pp. 22-30, Jan. 2006;http://dx.doi.org/10.1049/ip-smt:20050027

3.5 Q. Zhang, W. Al-Nuaimy and Y. Huang, "Detection of deeply buried UXO using CPT magnetrometer", *IEEE Trans on Geoscience and Remote Sensing*, vol. 45, no. 2, pp. 410-417, Feb. 2007; http://dx.doi.org/10.1109/TGRS.2006.886178

3.6 Q. Zhang, W. Al-Nuaimy and Y. Huang, "Interpretation of borehole magnetometer data for the detection and characterisation of unexploded bombs", *Journal of Applied Geophysics*, vol. 61, no. 3 pp. 206-216, March 2007; http://dx.doi.org/10.1016/j.jappgeo.2006.05.004

Research grants awarded which underpin the impact:

5/03 – 10/05 Y. Huang*, "A new method for characterising antenna diversity systems",* £128,000, EPSRC (GR/S12845/01).

12/07- 12/09 Y. Huang and X. Zhu, "*A Novel RF Positioning System for Multipath Environments*". £262,452, Knowledge Transfer Partnership (KTP) with Guidance Ltd, funded by DTI/Research Councils (Ref. KTP006498).

2/08 – 7/10 W. Al-Nuaimy and Y. Huang, "*Development of a New MagAuger System for Sub-surface Unexploded Ordnance Detection"*. £217,220, Knowledge Transfer Partnership (KTP) with Zetica Ltd, funded by DTI/Research Councils (Ref. KTP006540).

4. Details of the impact (indicative maximum 750 words)

The original research work from 2003 onwards has helped UK companies to introduce new products and improve both their competitiveness and productivity. Two specific beneficiaries are: Guidance and Zetica.

The work with Guidance Navigation Ltd began with an EPSRC research grant (GR/S12845/01) which then lead to a KTP award (KTP006498 from 2007 to 2009 for £262,452). Guidance is a leading developer and supplier of sophisticated navigation and position measurement systems. When Guidance began to work with Liverpool in 2005, the company employed about 30 people. Now the company has expanded to three groups working in navigation, monitoring and microwaves with over 120 employees. The company has benefited greatly from two innovative solutions from the research described above: one was a smart and cost-effective diversity antenna system for their offender tagging system, which has significantly improved the system reliability and operational range. The other one was a specially designed reflector antenna which could produce a narrow horizontal beam but a broad vertical beam for marine guidance and navigation.

Guidance has provided electronic tagging systems for use in offender monitoring since 2000. However, there was a serious problem with the system: the RF communication link between the tag and the receiver was not reliable and sometimes caused false alarms, potentially disastrous since offenders might be falsely accused of breaching their home curfew terms. Huang and colleagues identified that the unreliable radio link was mainly caused by the unoptimised antenna. A cost-effective polarisation diversity antenna system based on our original work [3.1, 3.2], was developed and implemented by Liverpool, has significantly improved the system performance. As a result security of offenders has increased, the public policy relating to offender management has improved and Guidance has outperformed its competitors and won new contracts. For example, in the UK its market share has gone up from 20% (2005) to over 70% (2010); and it has also helped

the company to win contracts overseas (e.g. the USA and France). In addition, in 2006 the company won the Queen's Innovation Award for this product. In 2011, Guidance Monitoring division was bought by G4S (a global security company) for over £10m due to the outstanding performance and profitability of the well developed tagging system [5.1].

Around 2005, Guidance was developing a new product, "RadaScan", a microwave-based range and bearing measuring system for the marine and offshore dynamic positioning market. One of the main challenges was the antenna which should be small (< 0.5 m x 0.5 m) and have a narrow radiation beam-width (< 2 degrees) in the horizontal plane, but a broad one (> 15 degrees) in the vertical plane. Guidance approached Liverpool where an in-depth study was conducted and an innovative antenna was successfully designed using the Liverpool research, developed and implemented by Guidance: ***"All the major specifications were achieved. This product was a great success and has now become the best selling product for Guidance Navigation Ltd and generated the major income stream for the Company The company size has grown from about 40 people in 2005 to more than 100 people in 2012"*** The income stream generated was ***"…about £6m in 2011"*** [5.1].

Collaboration with Zetica Ltd has been going on for over 10 years. A feasibility study for unexploded ordinance started in 2005 which resulted in a KTP award in Feb. 2008 (KTP006540 for £217,220) for 2.5 years to develop this idea into a product. Zetica is a UK leader in environmental geophysics with a reputation for cost effective surveys. Redevelopment of previous used land is a key element of national planning policy. When a construction project starts, it normally begins with a survey to ensure the safety and suitability for the project. Common practice is to drill many holes to identify subsurface features. However, this process was slow and sometimes dangerous due to occasional unexploded subsurface ordnance (UXO), e.g. from WWII. This can be a significant problem for development for dense urban areas (e.g. London), where bombing was of high frequency. The research work on intelligent drilling systems at Liverpool [3.4-3.5] provided an excellent solution to this problem. The system comprises a new magnetometer and wireless communication unit, enabling the ground information near the borehole to be obtained. The unexploded subsurface ordnance can be located and identified with greatly improved efficiency and personnel safety. ***"This unique product has enabled Zetica to provide far more economic and flexible service".*** Liverpool's expertise in antennas: ***"…has enabled [Zetica] to explore new business opportunities around the world… related services are now a significant part of the company's portfolio"*** [5.2].

The impact achieved has arisen directly from the underpinning research undertaken solely at Liverpool. Our contribution has not only directly helped the companies to produce new products, improve performance and win contracts, but an additional benefit is that both the working environment and company personnel safety have been improved.

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

5.1 The Product Director at Guidance Navigation Ltd (now G4S) has provided a letter of support to corroborate the use of improved antenna systems for offender monitoring.

5.2 The Managing Director from Zetica Ltd has provided a letter of support to corroborate that the product has enabled Zetica to "*provide more economic and flexible services*."

Websites:

(i) Further evidence to corroborate impact via G4S website

(ii) http://www.guidance.eu.com/ provides evidence to corroborate impact via Guidance Navigation Ltd
http://marine.guidance.eu.com/ui/content/content.aspx?ID=282.

(iii) http://www.zetica.com/ provides further evidence to corroborate impact via Zetica.

(iv) Use of Liverpool research listed at http://www.zetica.com/publications/index.htm provides further evidence to corroborate impact via Zetica.

(v) Article by Zetica in leading professional publication noting new detection techniques http://www.zetica.com/downloads/demystifying-uxo-detection.pdf provides further evidence to corroborate impact via Zetica.