Institution: QUEEN MARY UNIVERSITY OF LONDON (QM)

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

Title of case study: Ultra wideband (UWB) antennas and propagation

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

State-of-the-art radio systems require antennas that are a) able to cover an ultra-wide range of operating frequency bands, and b) compact and yet robust enough to be mounted in settings that range from satellites to the human body. Our pioneering work in this area has led to the significant contributions to the UK Ofcom Spectrum Framework Review and the developments of new products and business opportunities, new technologies for assessing the EM emission on the mobile handset and for smart meter deployment, and wearable antennas deployed in the battlefield to reduce the load and smart communications for dismounted soldiers.

2. Underpinning research (indicative maximum 500 words)

Traditional UWB antennas are bulky in size, which limits their applications. Built on the group's extensive expertise and experience in antenna engineering, Xiaodong Chen (Professor, Reader at that time) and his team consisting of Jiangxin Liang (PhD student, Sept. 2003 – Mar. 2006), Choo Chiau (Research assistant, Mar. 2005 – June. 2007), Pengcheng Li (academic visitor from Beijing Institute of Telemetry, Sept. 2004 – Feb. 2006), Lu Guo (PhD student, 2004-2008) and Clive Parini (Professor, Head of Group) proposed a printed version of the UWB monopole for the first time, in which the ground plane is printed on the substrate. Previously, planar UWB monopoles were all realized with a perpendicular ground plane. Furthermore, the QMUL group identified the operating mechanism of planar UWB antennas as the combination of overlapping multiple resonances and travelling waves [1]. This technical breakthrough has resulted in an explosion of research work on the printed version of UWB antennas worldwide. Chen was invited to contribute to a book chapter [2] and as a co-author to a book [3] on the subject. A variety of compact UWB antennas were developed in the group for various applications funded by the UK government and industry. The principles of UWB antennas were further exploited for designing broadband couplers for deployment in ultra wideband power line communications under a DTI/EPSRC Technology Programme project (Chen: EP/D033950/1).

The concept of UWB antennas as a compact wideband array for airborne remote sensing was successfully developed by Parini & Chen via an industrial funded PhD student (Sheng Wang 2006 – 2009) from Selex Galileo Ltd [I3]. A one year post doctorial follow on programme of work was supported by Selex-Galileo to develop a novel experimental calibration technique for a 1024 element phased array for airborne military applications. No publication of this prototype's performance was permitted for security reasons.

The group was the first to apply UWB technology for body area networks in collaboration with University of Birmingham, which led to a book on the topic of body-centric communications [4] and several book chapter contributions. Work was supported by three EPSRC research grants (> £2m) both jointly held with Birmingham (2003–2013: GR/S03812/01, EP/E030270/1 & EP/I009019/1). The research has attracted early-stage researchers attending three EU supported doctoral schools held at Queen Mary (www.antennasvce.org/Community/Education/Courses/Locations, European School of Antennas). The work [5,6] was the first in the area of UWB for body-centric networks and is considered to be one of the most cited papers on UWB antennas effects on the human body propagation channel. The subsequent research activities in this field led to the design and evaluation of UWB antennas coupled with tunable electronic circuitry to be used in smart and

cooperative personal and body area networks (Alomainy First grant EPSRC: EP/H048154/1). The group has recently secured a TSB grant for 12 months (Alomainy: TS/L000237/1) to further investigate the research challenges behind UWB localisation of human hands and translate it into potential commercial applications.

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

1. J. Liang, C.C. Chiau, X. Chen and C.G. Parini, 'Study of a Printed Circular Disc Monopole Antenna for UWB Systems', *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 11, 2005, pp. 3500-3504. (Citation from Google: >500)

2. X. Chen, Chapter 8: Theory of UWB Antenna Elements, 'Ultra Wideband: Antennas and Propagation for Communications, Radar and Imaging', Wiley, 2006.

3. D. Valderas, C. Ling, J. Sancho, D. Puente, X. Chen, 'Ultrawideband Antennas: Design and Applications', Imperial College Press, 2010.

4. P. S. Hall, Y. Hao (editor) "Antennas and Propagation for Body-Centric Wireless Networks"- 2006, (Google Citation > 400)

5. Q. Abbasi, A. Sani, A. Alomainy and Y. Hao 'On-body radio channel characterization and system-level modeling for multiband OFDM ultra-wideband body-centric wireless network', *IEEE Transactions on Microwave Theory and Techniques*, Vol. 58, no. 12, pp. 3485-3492, December 2010. (Citation from Google: 13)

6. A. Alomainy, A. Sani, A. Rahman, J. Santas and Y. Hao, 'Transient Characteristics of Wearable Antennas and Radio Propagation Channels for Ultra Wideband Body-Centric Wireless Communications', *IEEE Transactions on Antennas & Propagation*, Special Issue on Body-Centric Wireless Networks, Vol. 57, Issue 4, Part 1, April 2009, pp. 875-884. (Citation from Google: 69)

Grants:
EPSRC grant: *Gigabit Powerline Communications*, (Chen: EP/D033950/1)
EPSRC grant: *Wearable Antennas for Body-Centric Wireless Networks* (Hao, EP/E030270/1)
EPSRC grant: *iRFSim for BSNs -Imaging based subject-specific RF simulation environment for wearable and implantable wireless Body Sensor Networks* (Hao, EP/E057624/1)
EPSRC grant: PATRICIAN: New Paradigms for Body Centric Wireless Communications at MM Wavelengths (Hao,EP/I009019/1)
EPSRC grant: *Smart Antenna Systems for Cooperative Low-Power Wireless Personal and Body Area Networks* (Alomainy, EP/H048154/1);

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

The underpinning research has generated several impacts on 1) public services, 2) the environment, and 3) the economy.

1) Impact on public services

The UK government made £17bn through the auction of 3G radio spectrum bands making it vital for it to monitor interference over this wide frequency band. The group, teamed with **MASS Ltd**, developed an Automatic Interference Monitoring System for Ofcom to examine the increasingly congested EM spectrum over 40 sites across the country during 2005–2007. This work has constituted a major contribution to the Ofcom Spectrum Framework Review Report published in April, 2008 [I6]. This technology enables Ofcom to monitor/regulate the 3G radio bands for better mobile communication services.

2**) Impact on the environment**

With the integration of multiple functions on mobile phone handsets, the EM emission from different components has caused interference to the radio channels, which burdens wireless networks, causing excess power consumption. **Sony-Ericsson**, have funded the group to develop wideband test equipment for detecting EM interference on mobile terminals since 2007 [I1]. This work has led to a patent application (EU Patent Application No: 08100712.2,). In 2008, **Innovation China-UK** funded the group to commercialise the developed technology in collaboration with Beijing University of Posts and Telecommunications, China. Two specialist test units were built and sold (one to Sony-Ericsson and the other to Wavetown Communications Ltd, China). The developed products enable the mobile handset manufacturers to assess their mobile phones and make sure the products are in 'green' operation.

3) Impact on economy (new products, business opportunities and licence)

3.1) Data communication over power-lines usually operates at low data rate due to the narrow carrier signal bandwidth. In the latest Pan-European drive for efficient use of the energy, a high data rate communication technology is required to realise the concept of smart power grid/metering in every household. The group teamed with **Artimi Ltd.** and subsequently **SiConnect Ltd.** and **COE Plc.** developing very high data rate powerline communication technology supported by DTI/ESPRC technology programme project (EP/D033950/1) in 2006. The technology developed with SiConnect was purchased by POEM Technologies Co Ltd, China in 2008 for exploitation in Chinese market. In addition, the technology is being evaluated in a separate project funded by DECC (Department of Energy & Climate Change) and supported by EoN as a method to connect smart electrical appliances to the UK smart meter deployment rollout to reduce peak electricity load on the UK power distribution network [I2].

3.2) Modern air-borne phased array radar systems require a compact broadband antenna array. With the funding from **Selex-Galileo (UK)** [I3], this work successfully exploited strong mutual coupling to construct a wide scanning planar phased array antenna with bandwidth of 4.5GHz - 18GHz and scan angle up to 60°. It used novel electromagnetic analysis techniques combined with statistical and neural network methods to predict performance in a time frame suitable for industrial design. A 32 x 32 element fully active phased array based on this work was built by Selex-Galileo for the UK MoD. In a statement of support for this work [I3] the Selex project leader stated: '*The impact from this work has lead to Selex being able to develop new products with improved performance in the area of high performance / high value military airborne radar, ESM and very wide bandwidth airborne RF systems.'*

3.3) A key component in broadband wireless communication systems is the broadband antenna covering all the required frequency bands. The group has helped **Jaybeam Ltd** (UK) in optimising a broadband base station antenna product (via EPSRC Knowledge Transfer Account scheme with Lu Guo, 2008-2009). Jaybeam Ltd was lately bought by Amphenol Antenna Solutions [I7].

3.4) A satellite employs many antennas for radio control and data link. QM has signed a license with SSBV Space & Ground Systems Ltd (formerly Satellite Services Ltd) to commercialise a compact broadband antenna for multiple functions on a small satellite under QM Innovations Ltd funding. The prototypes of the antenna will be deployed on the satellite TechDemoSat-1 for the demonstration of UK Innovative Space Technologies, the project being led by Surrey Satellite Technology Ltd with a total funding of £3.5m from the UK government and industry [I8].

3.5) Body-centric wireless communications has abundant applications in personal healthcare, smart home, personal entertainment and identification systems, space exploration and military. The group has applied UWB radio technology to body centric communications and they have been awarded with generous funding from Dstl on developing textile antennas for wideband

communications in battlefields [I4] and NPL on developing the measurement standard for the next generation of wearable antennas [I5].

3.6) UWB antenna technology is being used (via the Antenna groups EPSRC £1m Platform Grant "Antennas for Healthcare and Imaging" funding) to develop miniature body mounted pulse radar based motion tracking system (operating in the 6-10 GHz band) with 10mm position accuracy for sports medicine applications. This work bringing together the QM *Centre for Sports and Exercise Medicine* and the Antenna Group, along with SME collaborators *Mediwise Ltd* and *Shadow Robot Company Ltd*. A significant competitive advantage over existing systems is that our system is wireless, will be more robust and does not need the "studio" environment that optical systems require. Activities through the platform grant and first grant (Alomainy: EP/H048154/1) has initiated collaboration with Shadow Robot Company [I9], an SME based in London, on providing accurate localisation systems using UWB technologies for limbs and joints mimicking in the robotic industry. The research team at QM and Shadow Robot were successful in securing a TSB grant for 12 months (Aug. 2013) (Alomainy: TS/L000237/1) to further investigate the research challenges behind UWB localisation of human hands and translate it into potential commercial applications. It aims to develop a new design of control system, based around a "base station" that uses UWB signals to locate antennas precisely within the unit. The proposed system has exciting applications in a range of robotic applications including, for example, the performance industry by being able to mimic a person's limb movements to manupulate "set" changes and in medical systems as precise surgery robotic.

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

I1. "Expert" Terminal Antennas, Sony Mobile Ltd., Factual statement provided re QM developed wideband test equipment for detecting EM interference on mobile terminals.

I2. Principal Engineer, Department of Energy and Climate Change. Factual statement provided re QM UWB powerline technology and its trails re the UK smart meter deployment.

I3. Leader Antenna Engineer, Selex Galileo Ltd. Factual statement provided re Selex funded research at QM into Wide-Band Dual Polarised Array Antennas, and its subsequent deployment.

I4: Principal Engineer, Dstl. Factual statement provided re DSTL funded research for the development of textile antennas for wideband communications in the battlefield.

I5. Senior Research Scientist, National Physical Laboratory. Factual statement provided re NPL collaboration on accurate measurements related to body-worn antennas and implantable devices primarily aimed for healthcare and medical technologies.
www.sciencedaily.com/releases/2009/09/090908103638.htm

I6. Ofcom: Progress on key spectrum initiatives – a review and update of the Spectrum Framework Review and SFR:IP, 3 April, 2008. for pdf document search:
"stakeholders.ofcom.org.uk/binaries/consultations/sfrip/annexes/sfrprogress.pdf"

I7. Amphenol Antenna Solutions: www.amphenol-antennas.com

I8. BBC news report: www.bbc.co.uk/news/science-environment-1156051

I9. Shadow Robot Company: www.shadowrobot.com