Institution: The University of Leeds

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

a. Context

This submission is based on research carried out in the School of Electronic and Electrical Engineering, which was ranked top in its UoA in RAE 2008. The School is successful in creating non-academic impact from all areas of its research, including:

- Technology transfer to industry through research collaboration, consultancy, licensing of innovations, and industrially-targeted dissemination activities;
- Creation of new businesses through university spin-outs and joint ventures;
- Informing policy of Government departments and other public bodies through collaboration, consultancy, and dissemination activities;
- Increasing public awareness of the benefits of engineering research through dissemination of research highlights through the media, and participation in public lectures/events.

Primary beneficiaries of our research include the electronics and opto-electronics sectors, major telecommunications companies, medical diagnostic and instrumentation manufacturers, and UK Government organizations.

b. Approach to impact

The School exploits formal Faculty/University processes established to identify and develop impact, including the expertise of specialized business development managers (BDMs) employed to work closely with researchers to identify the potential impact of their research, find/build strategic partnerships to define research challenges, and undertake early development of exploitation opportunities. A School Industrial Advisory Board comprising twelve leaders from our target sectors meets annually to discuss and advise on research needs, and we also draw on our seven Visiting Professors who have expertise encompassing national SMEs through to large multi-national organizations. Subsequent support is delivered through the central University Commercialization Services, which focuses on formal IP protection/management, market scoping, due diligence and creating detailed exploitation plans, and later stage commercialisation through licencing (via subsidiary company, University of Leeds IP Ltd) or through spin-out (via partnership with IP Group PLC). The Commercialization team includes experienced case managers, dedicated patent and contracts administrators, and a corporate solicitor. A budget covers filing of UK/PCT patent applications, management of search reports and patent office actions, as well as proof-of-market/concept funding to provide market validation and help achieve commercially relevant technical milestones.

Our end-users comprise long-standing industrial collaborators (e.g. Agilent, from the mid-1980s), personal contacts developed through former colleagues/students, relationships identified and engendered through university scoping, and by direct approaches from industry/end-users, *inter alia*.

The creation of impact, and our approach to interacting with non-academic end-users of our research, is facilitated through a number of mechanisms that depend upon the nature of the activity and its position in the research and innovation cycle:

1. For our **challenge-led research**, engagement with industry and other potential beneficiaries is in place prior to the start of the research process to co-define the research, provide end-user pull, and to ensure that well-informed decisions are made during the programme. For our work at highest technology readiness, the end-users are typically long-standing collaborators who commit resources including studentships and expertise. The research is collaborative, and often embedded in the company with staff secondments. Examples of this approach are exemplified by **two case studies** in this submission, namely: development of radio frequency filters with Radio Design (originating from Filtronic PLC, itself a School spin-out), and the development of high frequency measurement techniques with Agilent Technologies. Our challenge-led research at lower readiness is also usually co-defined and part-funded by end-users, but primarily supported through UK/EU research council funding. As exemplified though by our **third case study**, in which challenge-led research for industrial process monitoring enabled a technology to aid the visually impaired, it is important to be agile to ensure unforeseen opportunities are not missed. Selected other examples in this period demonstrating the nature of the relationships with end-users, and the approaches taken to follow through to generate impact or identify potential impact, include:

Optical Communication Systems and Networks Long-standing collaborators BT, Avago (through

EPSRC 'TINA' EP/D076676 and 'HIPNET' EP/E001696) and Ericsson ('VESEL' EP/E007198) approached us in 2008 to address the full energy requirements of communications networks. To capture the entire network implication we used university BDM support to approach Oclaro (component manufacture), Cisco (routing), and BBC (content), leading to Programme Grant EP/H040536 (2010–2015) pursuing carbon-free networks. In parallel, Alcatel-Lucent Bell Labs invited us to lead research on core networks in the GreenTouch consortium, comprising 54 companies/universities. This led to EP/K016873 (2013–2015) with Alcatel and BT, and a record energy efficiency improvement in the core network (64-fold; GreenTouch White paper, June 2013), now adopted by vendors including Alcatel-Lucent and Huawei and operators including France Telecom and Alcatel-Lucent (thierry.klein@alcatel-lucent.com). Furthermore, through a visiting fellowship to BT in 2012 using university HEIF funding, BT invited us to design energy efficient networking for access in the TV 'white spaces', with demonstrators now in Ipswich and the Isle of Bute (louise.krug@bt.com). We also designed a caching scheme to reduce the BBC iPlayer carbon footprint, which is currently being demonstrated (chris.chambers@rd.bbc.co.uk). Finally, working with Manchester and Doncaster-Sheffield airports (tim.walmsley@manairport.co.uk) and funded through EP/H003398, we introduced communication systems to improve airport surface access, reducing their carbon footprint, building on our 'TINA' Heathrow designs (stephen_challis@baa.com).

Instrumentation and Ultrasonics Discussions at a TSB workshop in 2011 with SME Speir Hunter (paul.jarram@speirhunter.com) led to a project sponsored by National Grid (peter.b.martin@nationalgrid.com), GL Services (peter.nolan@gl-group.com) and Speir Hunter to develop portable embedded instrumentation to detect pipeline defects in the oil/gas industry; in total >£1M has been invested in Leeds by industrial collaborators. Our patented technology (e.g. WO2013/128212 and WO2013/128210; priority 02/03/2012) is now exploited globally by National Grid (UK), Shell (USA & Canada), Enbridge (Canada), Total (France), Gasunie (Netherlands & Germany), Sinopec (China & Malaysia) and Petrochina (China), *inter alia*. In parallel, we were approached in 2012 by Sellafield (geoff.x.randall@sellafieldsites.com) and MMI Engineering (dburt@mmiengineering.com) to assess ultrasonic techniques for flow characterization. Following University/EPSRC 'Bridging the Gaps' support, a £1.2M TSB bid was funded (TS/K004476/1) in 2013. Furthermore, through participation in a BP-organised workshop, we received industrial funding for the detection of sand corrosion in pipework (michael.power@uk.bp.com).

2. The translation of **discovery-led research** to end-users requires an agile approach to identify potential opportunities and beneficiaries, many of which will not have been apparent at the outset, followed by proof-of-principle/concept projects to engage with end-users and align to their needs, or to position the technology for spin-out. Examples of approaches taken in this period include:

Terahertz Electronics and Photonics Discovery-led research on free-space terahertz (THz) spectroscopy positioned us for successful bid to EPSRC's Technologies for Crime Prevention & Detection call (GR/S63045, 2004–2007), which introduced us to government end-users, including HMGCC (Dr H Cummins), HM Customs & Excise (later HMRC; Dr J Whyte), PSDB (later HOSDB, then CAST; Dr R Lacey, Dr M Hogbin), and DSTL (Dr G Shilstone). The end-users helped direct the research, and provided drugs-of-abuse/explosive samples, two PhD studentships (including Burnett, now an EPSRC PDRA Fellow), and a two-year PDRA position (Dean, now an EPSRC Career Acceleration Fellow). Research outputs/reports informed HM Government on THz technology, and led to further funding through the UK Explosives & Weapons Detection Innovative Research Call with HOSDB (£428,017, 2009–2012, matthew.hogbin@homeoffice.gsi.gov.uk) to develop THz QCL-based scanning imagers, and the US Defense Threat Reduction Agency ($256k, 2013).

Bio-Nanoelectronics Discovery-led research on molecular-scale electronics developed a technique to coat <50-nm-separated electrodes with different molecules (WO2004/033724, priority 10/10/2002, granted in Europe, Japan, US). Exploiting this, a new collaboration with the MRC Cancer Research Centre, Cambridge, and the Leeds Institute of Molecular Medicine, led to the development of a label-free electronic diagnostic platform for multiplexed protein sensing (WO2008/032066, priority 16/09/2006, now under examination in the EU/US). A £497k CCLRC (later STFC) programme with Rutherford Appleton Laboratory (e.huq@rl.ac.uk) (2008–2011) helped develop the technology further. An approach by Swiss Precision Diagnostics in 2009 (Dr K Zak, former Chief Technology Officer) led to two company-funded studies (£36k), and Faculty BDM support then led to: EPSRC Follow-on funding (EP/I500928) with SME Avacta (ed.quinn@avacta.com); an NIHR i4i programme (NIHR II-FS-0109-11095); an RDA ('Yorkshire

Forward') Proof of Commercial Concept Fund award (2009); and, a company-funded study by P&G (£31k, morand.kl@pg.com) in 2011. A BBSRC CASE award, together with £80k, from Abbott Diagnostics (BB/G018065, 2009–2013) was brokered by a former PhD student (sophie.laurenson @abbott.com). Together with £200k IKC funding (EP/G032483) and funding from Wellcome/EPSRC (WT088908/Z/09/Z), these activities positioned our technology to address clinical diagnostic end-user requirements, and our diagnostic platform is being appraised by IP Group (cassie.doherty@ipgroupplc.com) for spin-out in 2014.

The School increases public awareness of its research, and engineering research in general, by dissemination of research highlights through print, radio and TV media (facilitated by Faculty/University Communication units), and by participation in public and school lectures/events both locally e.g. the annual Leeds Festival of Science (www.leeds.ac.uk/festivalofscience) and nationally. One example of particularly high exposure in this period, with resulting public interest internationally, centred on the extensive BBC TV coverage of our UltraCane (see Case Study 3).

Researchers are rewarded/recognized for developing impact through promotion/salary increments, and the University has a policy to ensure researchers and their Schools benefit from successful IP exploitation. Promotion to Chair is possible for sustained strategic leadership of EKT activity.

c. Strategy and plans

The School has a long-standing proven track record in pursuing and enabling impact with reach and significance from all of its research, both challenge- and discovery-led, as discussed and evidenced above and in the case studies. This will continue to be achieved through:

- Regular reviewing of School/Institute research activity and refocusing in the light of international developments, research funder priorities, and end-user requirements;
- Focusing of School investment (in personnel, infrastructure, support) on our research areas of international excellence, and which have critical mass, or are growing critical mass (see REF5);
- Disseminating research outputs (in high impact factor journals, at conferences, to alumni, and via the University press office) to inform academic/non-academic end-users as widely as possible;
- Proactively engaging with our existing industrial end-users to identify new commercialization opportunities, and identifying potential new end-users assisted by university/BDM scoping.

Since late-2011 the University has been growing a new process to achieving impact based around 14 sector-specific 'innovation hubs', exploiting HEIF, Impact Acceleration Account, and other funding to employ specialized BDMs, and provide proof-of-market/concept funding, *inter alia.* The approach connects external market demand with our recognized research and innovation strengths, providing clear pathways for external stakeholders to access University capabilities. The School is a beneficiary of two hubs in particular: Digital Technologies (www.digital.leeds.ac.uk, which is led by the School (EHL)), and Medical Technologies (www.medical-technologies.co.uk).

Aligning with our research vision set out in REF5, over the next period our impact priorities include:

- Pull-through of quantum cascade laser and our other free-space/guided-wave THz technology into engineered systems, including compact imaging/spectroscopy apparatus, with particular exploitation for security and environmental applications, and pursue commercial licensing/spin-out;
- Translation of our energy efficient optical networks through close engagement with end-users addressing the entire network, and through the GreenTouch consortium. The commercial exploitation of microwave components/systems will continue with our long-standing industrial partners;
- Translation of our electronic diagnostic platform and microbubble technologies through commercial licensing/university spin-out. Proof-of-market/concept funding will be pursued to support our less-developed technologies including electronic cell organization/selection devices.

d. Relationship to case studies

Case Studies 1 and 2 are based on our long-standing expertise in microwave/millimetre wave design. They demonstrate the value of early engagement with industry (here long-standing collaborators) to co-define the research, collaborate, provide end-user pull, and to ensure that well-informed decisions are made during the programme. Case Study 3 is based on our long-standing expertise in ultrasonics and instrumentation. Although the underpinning research was challenge-led and, with industrial end-users, targeted industrial process monitoring, it demonstrates that maintaining an agile approach, as required in translating discovery-led research, allows unforeseen opportunities to be developed. In this case, the resulting ultrasonic mobility aid for the visually impaired led to economic, health and societal impact of substantial reach and significance.