Institution: THE UNIVERSITY OF MANCHESTER

Unit of Assessment: UoA13b Electrical and Electronic Engineering

a. Context

The Unit of Assessment is based on one of the largest electrical and electronic engineering schools in the UK, and has a long tradition of working closely with industrial and commercial bodies. The University's origins can be traced to 1824 when Manchester industrialists established the Mechanics' Institute to help their workers learn the basics of science. This School was the first to study Electrical Engineering as an independent academic subject, with the first Chair appointed in1905. Today, many of the academic staff are recruited from industry and are well equipped to bridge the academic-industrial divide.

Main non-academic user groups, beneficiaries, or audiences for the Unit's research
External beneficiaries of the Unit's research include commercial, manufacturing, utility, research, and service organisations, ranging from network power distribution, future radio-astronomy science (e.g. the Square Kilometre Array radio telescope) to nanotechnology spin-out companies. To enable trust and openness in research and data sharing, the Unit has several formal long-term relationships with external partners, including National Grid, EDF, Electricity North West, National Instruments, Rolls Royce, and Syngenta. Other beneficiaries of the Unit's research include government policy makers, the Health Service, and non-profit organisations.

Main types of impact relevant to the Unit's research and relation to research groups
The research benefits the economy principally through industry. The impact includes new power technologies and materials (Power Conversion and Electrical Energy and Power Systems Research Groups, EEPS), devices ranging from nano-electronic (Microelectronics and Nanostructures Research Group) to pylon design (EEPS), network modelling tools (Microwave and Communication Systems Research Group, MCS), process control (Control Systems Research Group, CS), and signal processing software (Sensing, Imaging and Signal Processing Research Group, SISP). The research also has impacts on health, the environment, and public policy. These include imaging work with local hospitals (SISP), environmentally friendly transformer design (EEPS), and, through the Unit's e-Agri Research Theme, an invited contribution to Sir John Beddington's Sustainable Agri-Food panel (Westminster, June 2011), and related initiatives (e.g. TSB and DEFRA funding panel membership; also Gates Foundation 2013). In addition, staff have generated IPR (230 invention disclosures, and 18 patents granted in the review period), leading to licenses, spin-outs, and staff company directorships (7).

b. Approach to impact

Staff interaction with beneficiaries to develop research impact; evidence of nature of interactions; and other mechanisms to support impact
Developing impact is central to the Unit's research strategy and is characterised by five strands:

- Larger-scale research contracts in which those impacted are directly engaged
- Smaller-scale focused projects e.g. PhD studentships, UG projects, sabbaticals, consultancies
- Specific knowledge-transfer activities, such as KTAs, proof-of-principle funding, and spin-outs
- Developing standards and public-guidance documents
- Public engagement with the broader community

Structures in the School, Faculty, and University to support these activities are exemplified below.

Larger-scale research contracts in which those impacted are directly engaged
Senior academics manage strategic research partnerships with external organisations, acting as an initial point of contact to allow all the School's academics opportunity to interact with strategic partners. Their role is recognised in the School's workload allocation model. At present the School has research partnership managers for Syngenta (managed by Grieve), National Grid (Cotton), Rolls-Royce (Smith), Electricity North West (Milanovic), Siemens (Barnes), and MoD (Lanzon). The rail sector is also being targeted. Commercial framework agreements for long-term collaboration have been developed with National Grid, Rolls Royce, National Instruments, Syngenta, Rapiscan Systems, and Electricity North West. Many of the 89 industrially funded research projects, valued at nearly £14m, have resulted from long-term strategic partnerships. These provide a natural path to develop industrial and commercial impact, sometimes by technology transfer (e.g. power system

utilities to the aerospace sector). While continuing to seek new partners and challenges, the Unit, supported by University resources such as the University of Manchester Innovation Group (UMI^3) and Business Engagement team, encourages all academics to contribute to existing partnerships.

Smaller-scale focused projects such PhD studentships, UG projects, sabbaticals, consultancies
Interaction outside academia is encouraged through e.g. studentships and Knowledge Transfer (KT) schemes, and, more directly, consultancy. Examples include power distribution (Terzija, Crossley, Ochoa), wind farms and radar (Brown), lightning protection (Cotton), distributed sensors (Green), advanced RF measurements (Sloan), electromagnetic detection (Peyton), and sub-sea pipeline inspection (Gaydecki). Industrial interaction can also take many forms, e.g. in one Electrical Energy and Power Systems project, six PhD students and postdoctoral researchers subsequently joined Alstom and National Grid. A deeper relationship with industry has been aided by secondments within companies; e.g. Cotton and Barnes have spent extended periods with the National Grid and Sloan with Aligent (USA). Exploitation of sabbaticals is described in REF5.

Specific knowledge-transfer activities, such as KTAs, proof-of-principle funding, and spin-outs
Interaction at higher technology-readiness levels includes KTAs, licensing, and spinouts. In the period, the School has had 230 invention disclosures, and 18 patents granted. There have been two spinouts, namely, Cable Sense and Arago Technology. Cable Sense raised £1.6m and employs 7 people. Another 2006 spin-out Nano ePrint raised most of its £1.3m VC funding in the period. Four licenses have been granted, Lennox's Acoustek to Perceptive Engineering Ltd, Rowland's Microshocks Harness to Parmenter and Petrie Ltd and to Total Access Ltd, and van Silfhout's Beam Position Monitor to FMB Oxford Ltd (now in synchrotron sources in the USA, France, Australia, Japan, and UK). Selected examples of this IP are reflected in the Impact Case Studies. Important support and leadership has been provided by University of Manchester Intellectual Property (UMIP) and Innovation Group (UMI^3). From the University's EPSRC KT Account, the School has had 13 Concept and Feasibility Projects, 1 KT Fellow, 17 Exploitation Secondments, 2 Exploration Secondments, 3 KT Partnerships, and 4 KT Challenge Awards. The total value of these and company contributions exceeds £3.4m (companies as diverse as the Midlands NHS trust, Genesis Oil and Gas, and Manchester Airport). A co-managed Energy Innovation Fund of £1m was created by a partnership involving National Grid, Scottish and Southern Energy Power Distribution, the University of Manchester Intellectual Property (UMIP), and the UMIP Premier Fund. Managed by MTI Partners, the aim is to identify and develop novel research and technologies for commercialisation and use by the distribution and transmission industry. Crucially, it allows researchers to identify exploitation opportunities in these markets and gain a year of funding to develop proof of principle.

Developing standards and public-guidance documents
Staff chaired or participated in the standardisation work of international organisations such as CIGRE. As examples, Milanovic is convenor of CIGRE WG C4.605 and of CIGRE/CIRED JWG C4.1.12 and Terzija of CIGRE WGB5.14; Z Wang is an expert member of CIGRE D1.01.16 and CIGRE A2.35, and UK Representative and Deputy Convenor of CIGRE A2/C4.39.

Public engagement with the broader community
The Unit's staff enthusiastically support outreach activity through STEM initiatives, science fairs, and events at the Manchester Museum of Science and Industry (MOSI). Examples include stands dedicated to electrical and electronic engineering at MOSI and elsewhere as part of Manchester Science Festival Week; "Meet the Electrical Power Engineers", a Saturday event of hands-on activities at MOSI for school-age children; National Science and Engineering Week (stand visited by 731 children from 38 different schools); the Manchester Big Bang Fair, and a tutorial week and workshop for students on a STEM Leadership course (the School itself has 7 approved Ambassadors). In 2013, an open day celebrating a 10-year partnership with National Grid drew 121 visitors from 60 companies. Staff use local and national conduits to promote their research activities, including media interviews (e.g. Cotton, http://news.bbc.co.uk/1/hi/7413828.stm) and public lectures (e.g. Gaydecki's several-dozen lectures on digital signal processing to adult education centres, schools, and science festivals in the period).

Evidence of the Unit's flexible and agile approach to opportunities
All interactions of the Unit with external organisations give opportunities to seek potential exploitation and impact. The School encourages its alumni and close collaborators to help identify

opportunities, and to use its teaching links as a basis for building relationships. For example, links with SMEs, especially those local to Manchester, are encouraged by carrying out test work, for e.g. International Transformers in the HV lab, and feasibility tests for SMEs local to the University's Dalton Cumbrian Facility. The School encourages links through its taught courses by establishing scholarships, summer placements, UG courses with a year in industry, and industrially linked fourth-year and MSc dissertation projects and partnership in the Electronics Skills Foundation (http://www.ukesf.org/scholarship-scheme).The School is also part of the Power Academy, in which a group of 13 engineering companies have sponsored 32 UG students in the review period. It is similarly part of the PhD sponsorship programme, the Power Networks Research Academy with 19 engineering companies. This provides students and supervisors day-to-day contact with engineers in a wide variety of industrial environments, helping to indentify research opportunities as they occur, and facilitating support in both directions.

A different example of flexibility in action is in relation to staff acting as non-executive directors (Song of Nano ePrint; Oakley of DMIST Research Ltd; Peyton of Cable Sense; Cotton and Rowland of Arago). Other examples include the use of University's EPSRC KT Account and the co-managed Energy Innovation Fund detailed earlier.

Evidence of follow-through from these activities to identify resulting impacts
Impact is reviewed at Research Group level. Each year each Group is expected to generate an internal research impact statement, assessed by the School Research Committee. The purpose is to focus ideas and to identify potential avenues for impact and opportunities that previously may not have been considered. At an individual level, the impact of all academics' work is assessed and discussed at the annual Performance and Development Review (PDR).

Supporting and enabling staff to achieve impact, and reward and recognition
The School promotes staff participation in professional bodies by formally crediting this work in its load-allocation model. As examples, Forsyth is a member of the Aerospace and Defence KTN's National Advisory Committee on power systems; Grieve was in a similar position in the Electronics Sensors and Photonics KTN; Missous is Board Member of the EKTN; Rowland was for two years President of the IEEE Dielectrics and Electrical Insulation Society and is now on the IEEE Technical Activity Board Strategic Planning Committee. As noted earlier, the Unit has several participants in the standardisation committees of international organisations.

The School supports staff in the registration of IP, and the Faculty holds regular IP-awareness courses. The University policy is to reward such activity, giving the academic a generous share of the benefits from IP ownership or spin-out companies (see earlier). The University's promotion process recognises Knowledge and Technology Transfer as one of four criteria (with research, teaching, and service or leadership). Two recent professorial promotions were strongly influenced in this way. Impact is also important in the staff PDR. Since 2009, the University's annual Research Profiling Exercise has asked academic staff to identify the social and economic impact of their research as part of their research portfolio.

Use of institutional facilities, expertise or resources in undertaking these activities
The University Business Engagement Team links the School to large external organisations such as Siemens and EDF. The University of Manchester Innovation Group (UMI^3) provides expertise on intellectual property commercialisation and incubation to the Unit's researchers, and manages the UMIP Premier Fund, at £32m the largest seed fund in Europe dedicated to one university. The Premier Fund has invested £2.4m in proof-of-principle projects and spins-outs from the School in the review period. A good example is the spin-out Arago Technology, which has received funding from the Premier Fund, National Grid, and SSE, totalling £2.8m. The company was presented with the Power & Energy Award and highly commended in the Emerging Technologies Category at the IET Innovation awards ceremony in 2012, and the Existing Performance Improvement prize at the Energy Innovation Awards 2010. Other examples of UMI^3's support of impact are given elsewhere.

c. Strategy and plans

The Unit embraces the challenge of applying technology to major areas of societal concern, engaging with the needs of commercial, manufacturing, utility, service, and non-profit organisations, government policy makers, and the Health Service through its cross-disciplinary

Research Themes and discipline-specific pathways. As detailed in REF5, future strategy will be informed by the establishment of a new Engineering campus, co-locating the School with other engineering disciplines. The University has an explicit goal to be ranked among the top three universities in the UK for exploitation of research, and to offer the most generous rewards to staff for income from IP. The Unit has for many years established strategies for impact based on its core strengths, in turn reflected in its Research Group structure. It is acknowledged that some academics are better placed to create impact than others, and the School therefore does not set uniform targets for all academics. Each individual is, however, expected to generate a personal impact plan, and increased impact is a collective target for Research Groups. The Faculty target of increasing invention disclosures by 10% p.a. has also been adopted. Specific strategies and plans to build on and extend existing good practice are as follows:

1. *Encouraging and identifying impact contributions at PDRs and promotions*. As discussed in the previous section, encouraging potential impact as part of personal development is particularly important in influencing less-established staff and embedding impact in the Unit's culture.

2*. Supporting commercialisation, licensing, and spin-out activities.* The School formally recognises the time required to set up spin-out companies and attend standards bodies by allowing for them in the academic load-allocation model.

3*. Regularly updating web pages and media releases*. Using the web and media to illustrate success helps attract new interest. The School uses Faculty PR functions to publicize technical breakthroughs and awards, and its web site, restructured in July 2013, is continuously updated.

4*. Involving industrial partners and alumni*. The School's alumni database is being strengthened to enable better world-wide engagement. For example, Paul Strzelecki (formerly European VP at Motorola) has been appointed Visiting Professor. There is also increased interaction with the industrial Advisory Group, with meetings being held at the same time as 4th-year UG project presentations and the annual 2nd-year PhD poster day, improving access and dialogue.

5. *Encouraging staff at all levels to strengthen and renew existing framework agreements*. All staff are encouraged to exploit the long-term commercial relationships the School has with major companies (Section b). Thus, in the review period, Rolls Royce and National Grid renewed agreements, and EDF, Electricity North West, and Rapiscan Systems signed new agreements.

6. *Identifying research partnership managers in discussions with key industries*. In this period, partnership managers have been put in place, as described in Section b, providing an easier path for staff to industrial funds and exploitation of ideas. Each manager now has targets associated with his or her industrial partner. Partnerships are reviewed periodically, and change with time.

7. *Encouraging staff to undertake consultancy.* Clear guidelines are in place, and staff are encouraged to use consultancy and contract laboratory work as a method of relationship building. This has been very successful in recent years as outlined in REF5. In the review period, 139 consultancies have gone through University accounts.

d. Relationship to case studies

The Unit's case studies have been chosen to illustrate successful but different approaches to generating impact. *Synchronised Protection of Electrical Power Transmission Networks* illustrates the benefit of long-term managed partnerships with both utilities and industry, enabling a deeper relationship across the whole of the National Grid. *Application of Environmentally Friendly and Fire-Safe Transformer Liquids has* an alternative approach in which materials for high-voltage hardware have been taken to implementation through active participation in professional bodies (CIGRE). *Application of Advanced Control Techniques to the Process Industries* illustrates how direct financial support from the University's Technology Fund led to a spin-out company in which the School's flexible allocation of time and facilities allowed academics to make the transition to commercial exploitation. *Molecular Beam Epitaxy Applied to Quantum Devices for Industrial Applications* shows EPSRC-funded activity transformed into commercial activity through specialist School labs, direct University support (UMIP), and a KTP. *Signal Wizard Systems: Intuitive DSP* illustrates how flexible easy-to-use techniques developed in response to user need allowed penetration into a wide range of markets. *Power System Asset Management* shows how technology exploited in power system utilities has then been developed for the aerospace sector.