Institution: University of Manchester

Unit of Assessment: UoA13b Electrical and Electronic Engineering

a. Overview

This Unit of Assessment covers 52 members of staff in the School of Electrical and Electronic Engineering, one of nine schools in the Faculty of Engineering and Physical Sciences. The School is one of the largest electrical and electronic engineering schools in the UK and the most popular recruiter of international students. Its research is supported through distinct organisational structures based on Research Groups, with particular disciplinary expertise, and Research Themes, which facilitate cross-disciplinary interaction between Research Groups, other Schools, Research Institutes in the University, and external organisations. The Research Groups cover Electrical Energy and Power Systems; Power Conversion; Control Systems; Sensing, Imaging and Signal Processing; Microwave and Communication Systems; and Microelectronics and Nanostructures. The Research Themes are in Electronics in Agriculture (e-Agri), Energy, and Autonomous Systems.

Major achievements in this review period include the following:

- New research awards of £41m, more than double the total in RAE 2008.
- 40% increase in outputs published in the "top 20% journals" compared with RAE 2008, and more than 90 outputs with citations in the top 5% of the field, including Halsall's Science article on the hydrogenation of graphene, with over 1000 citations.
- 230 invention disclosures, 18 patents granted, 2 spin-outs, and five licences.
- Prizes including an R&D 100 Award for X-ray beam measurement (2013) and two IET Innovation awards for spinouts Pipeline Engineering (2010) and Arago Technology (2012).
- Lead role of the Unit in the £20m Dalton Cumbrian Facility and contribution to the University's successful bid for the £64m BP International Centre for Advanced Materials.
- Major international conferences hosted by the Unit including the 2011 IEEE Innovative Smart Grid Technologies Conference, the 2013 IEEE Systems, Man and Cybernetics Conference, and the 2008 UKACC International Conference on Control.

b. Research strategy

Vision and Strategic Goals

The School's overarching vision is to be world leading in all its research, teaching, and knowledge-transfer activities. The strategic research aims for the School and for the Unit are to maintain the strength of its core disciplines through its Research Groups while promoting interdisciplinary research through its cross-cutting Research Themes. This approach, combined with the scale of the School, enables the Unit's impact on commercial, manufacturing, utility, service, and non-profit organisations, government policy makers, and the National Health Service.

Over-Arching Strategy and Achievements

Strategic Planning. The development of the vision and research strategy of the Unit takes place in the context of the University's Strategic Plan. That plan aims specifically to value and invest strategically in research excellence, to broaden funding sources, to give parity of esteem to translational research, and provide world-leading postgraduate research. A key performance indicator (KPI) for the University's research is the Shanghai Jiao Tong "Academic Ranking of World Universities". In engineering, its position has improved from 44th in 2007 to 37th in 2013.

Both the strategy and resultant operational plans for the Unit are developed by the School's Research Committee, led by the Director of Research, supported by the School Leadership Team, Heads of Research Groups, and Research Theme Leaders. There is a separate subcommittee on future research development, chaired by the School's Director of External Affairs, taking, in turn, input from the whole School research community. The quality of strategic planning has progressed in the review period. In 2008-9, annual plans were defined in relation to the University's Research Strategy and in 2009-10 quantitative KPIs were introduced and have since been central to planning and tracking progress. By way of example, since 2010, the number of publications in the top 20%

of journals (e.g. Science, PNAS, and the top IEEE Transactions journals) has increased by 40%; the PGR:staff ratio including all academics has increased from 2.8 to 3.3; and the number of PhDs completed within 48 months has increased from 62% to 76%. Improvements in other measures are reviewed in the designated sections.

Engagement with Users of Research. In setting its research agenda, the Unit works closely with users of research, seeking opportunities for both academic and non-academic impact. This involves engagement with international, national, and local industry, with standards organisations, and with professional organisations and institutes. There is an active Industrial Advisory Group with representatives from 13 companies including Rolls-Royce, National Instruments, Selex Gallileo, E.ON UK, EA Technology, National Grid, Jaguar Land Rover, IBM UK, Centrica plc, Sellafield Ltd, PBSI Group Ltd, Agilent, and Cummins. Where the opportunity for a more strategic relationship is identified, a senior academic works with the organisation to establish an understanding of its needs and the support required, develops an account plan, optimizes bid quality, and facilitates interaction on behalf of staff either within or across Research Groups or through one of the Research Themes. This approach has led to managed strategic relationships with organisations as diverse as Rolls-Royce, Electricity North West, National Grid, Rapiscan Systems, Agilent, Siemens, Syngenta, and BP. Examples of the success of this strategy are the establishment of the Syngenta University Innovation Centre for research into electronics for agriculture and technology for food processing; the expansion of the National Grid Power Systems Research Centre; the Agilent Technologies Millimetre Wave Laboratory; and the Rolls-Royce University Technology Centre in Electrical Systems for Extreme Environments.

Research Groups and Themes: Strategic Aims and Achievements in the Period

Electrical Energy and Power Systems Research Group (EEPS), led by Crossley, focuses on future networks, with research into the design and operation of power-system plant, transmission networks, and smart low-carbon distribution networks, and the development of HVDC expertise. Achievements, facilitated by one of the best academic experimental facilities in the UK, include award-winning spin-out company Arago Technology; contributing to the design of Europe's first ester-filled 90MVA green transformer; development of a new approach to wide-area protection using GPS; integration within the European Monitoring System of the first GB-based phasor measurement system; and a new method for optimal accommodation of distributed generation.

Power Conversion Research Group (PC), led by Forsyth, focuses on advanced electrical machines and power electronic converters using the latest devices and materials, including superconductors to provide more efficient and effective electrical power conversion and control for transport and renewable energy generation, transmission, and distribution. Achievements, underpinned by advances in power converter and superconductor technologies, include demonstrating an efficient and compact silicon carbide converter for electric vehicle power trains (Prodrive commercialization); developing a magnesium diboride superconducting fault current limiter (under commercial evaluation); invention of DC circuit-breaking concepts (2 patents); and contributing to the world transmission grid operator trade body position paper on DC transmission (VLPGO).

Control Systems Research Group (CS), led by Heath, focuses on the development and implementation of control design methods, as well as process monitoring and diagnostics, with applications in oil and gas, pulp and paper, pharmaceuticals, automotive, aerospace, and nuclear industries. Achievements include pioneering work in negative imaginary systems and robustness analysis of non-square systems, now standard tools in nano-positioning force-feedback control for atomic force microscopy, and a novel structure in constrained distributed control (stabilising the storage beam at the Diamond Light Source synchrotron). It has an expanding role in autonomous systems and in smart grids (with EEPS and PC), where achievements include the design and commissioning of a control system for waste-water treatment with spin-out company Perceptive Engineering and successful implementation of pipeline monitoring by acoustic reflectometry.

Sensing, Imaging and Signal Processing Research Group (SISP), led by Ozanyan, focuses on exploiting its broad expertise to address multidisciplinary measurement and signal-analysis problems in chemical, mechanical, electrical, security, and biological systems, and the building of sensor systems for users in academia, industry and healthcare. One achievement with strong

societal and research significance is Peyton's development of a novel technology for the accelerated detection of landmines (Peyton is a member of the Scientific & Users Advisory Panel of the charity "Find a Better Way" founded by Sir Bobby Charlton). Other achievements include the measurement of focused X-ray beams (R&D100 technology prize, used in 5 synchrotron radiation sources), and electrical capacitance tomography (ECT) imaging of particle density in fluidised bed dryers, with applications in the pharmaceutical and food and energy processes industries.

Microwave and Communication Systems Research Group (MCS), led by Sloan, focuses on multidisciplinary approaches to problems in highly mobile communications, cognitive radio, millimetre-wave and terahertz technologies, and RF and microwave components and systems for industrial applications. Achievements include radio interference management algorithms for future LTE networks (being evaluated by BT and other telecommunications companies); development of system-critical components for the Square Kilometre Array radio telescope; MMIC chip design for use in ultra-broadband instrumentation systems (DC - 110GHz), currently being tested and evaluated for commercial use; and wireless and aquatic sensor systems for industrial processes with particular emphasis on deployment to monitor nuclear waste in storage.

Microelectronics and Nanostructures Research Group (MN), led by Hamilton, focuses on developing new electronic materials and advanced material structures for novel devices and circuits, with research ranging from atomic-scale measurement and simulation to circuit design and implementation with applications in ultra-high-speed devices for space research. A significant achievement was the demonstration (Halsall) of successful hydrogenation in converting graphene into graphane, a 2-D solid with enhanced electronic functionality, in the work that led to the award of the Nobel prize to Geim and Novoselov in 2010. Also, the demonstration that nanoscale energy transfer from metallic nanoparticles into alumina enhances X-ray detection has potential application in spatially resolved dose monitoring during radiotherapy for cancer, currently being evaluated by the Christie Hospital.

Energy Research Theme, led by Cotton, who is also Director of University-wide Manchester Energy, has the strategic aim to respond to the challenge of low-carbon energy supply by coordinating expertise in power systems and energy conversion, sensors, control systems and communications. Achievements include strategic research partnerships with National Grid and Electricity North West and a partnership with the Association of Greater Manchester Authorities to support the transition to a low-carbon future through joint work in areas including the electrification of heat. A multi-centre project is supporting the development of advanced energy-storage systems including those based on graphene technology.

Electronics in Agriculture Research Theme, e-Agri, led by Grieve, has the strategic aim of informing the electronics community of the needs of modern agronomy and food science to enable engineering of new systems and "e"-devices for reducing waste, increasing yields, and improving nutrition. Achievements include the establishment of the Syngenta University Innovation Centre; contribution to the Sustainable Agri-Food panel (Westminster, June 2011); and, with Syngenta and the BBSRC Rothamsted Research Centre, the first-ever successful demonstration, in 2013, of a viable wireless sensor for fungal pathogens including *Sclerotinia sclerotiorum*, the most economically significant monocyclic crop disease in Northern Europe.

Autonomous Systems Research Theme, led by Lanzon, has the strategic aim of developing innovative scientific methods that lead to technologies requiring minimal human intervention. Research partnerships have been established with BAE Systems, National Nuclear Laboratory, North West Aerospace Alliance, Rolls-Royce, and Roke Manor Research. Achievements include intelligent agent-based energy-management and autonomous mission re-planning, developed through participation in the Integrated Electrical Power Networks Evaluation Facility, and autonomous robots being developed for nuclear decommissioning applications through the £20m Dalton Cumbrian Facility, which is now a National Nuclear User Facility.

Future Strategic Aims

The research agenda of the Unit will continue to be based on discipline-specific Research Groups and cross-disciplinary Research Themes. The structure of the Research Groups will, however, be

reviewed in the coming 12 months to ensure continued development of core expertise in the appropriate disciplines. The three Research Themes will be augmented with a fourth targeted on the rail transport sector (led by Kopsidas). The development of new technologies has generated more cross-group initiatives (including exchange of personnel) and the new Manchester Engineering Campus Development will be used to foster such changes and improve physical infrastructure and efficiency. The Unit will continue to develop international relationships including the BRIC countries, and expand European collaboration and funding, a key goal in the next period.

c. People

The 2013 staff survey showed the University is a good place to work. Of the 78% of responses from the School's academics, 92% said that the University is a good place to work, 90% feel proud to work at the University, and 100% agree with the University goal to support world-leading research. The corresponding responses from research staff were stronger still, at 100% for all three questions. The survey places the University highest of the 28 HEIs surveyed by Capita.

i. Staffing strategy and staff development

The aim of the Unit has been to recruit internationally leading staff and those who have the potential to become the best. Staff engaged in the selection process are formally trained in selection and recruitment and in equality and diversity to ensure the best candidates are recruited. Recruitment is strategically focused on the development of the Research Themes, but with the balance of the Research Groups and teaching capability also in mind. In all appointment and promotion decisions, the aim is (1) to recognise and reward excellence; (2) to maintain or develop critical mass in key areas; and (3) to open interfaces between existing areas of strength. In the review period, 12 new academic staff were recruited.

Relationship to research strategy and physical infrastructure

Staff development is achieved through the six Research Groups. Five are located in the Sackville Street Building and one, Electrical Energy and Power Systems (EEPS), is in the nearby Ferranti building, which houses the High Voltage Laboratory. The role of the Research Group leaders is "to develop and recruit outstanding staff in research and teaching & learning, facilitate visits by internationally leading researchers, develop staff to lead major projects, develop facilities and manage space, provide ownership of PGT courses, facilitate high-quality output, and increase visibility of activities". Appointments and promotions are managed at School and Faculty level to ensure they are truly strategic. The Research Themes define that focus, and each appointment has a rigorous plan and justification before approval. For example, Carrasco Gomez is in Control, but developing applications in EEPS; Mancarella is in EEPS and is working on future energy networks crossing into electrical and gas supply industries; and Casson and Wright in Sensing, Imaging and Signal Processing were recruited to strengthen links with medical instrumentation. All but one appointment in the period has been at Lecturer or Senior Lecturer level to give sustainability to the skill sets available. The posts included one new position (Yin) entirely funded by Mettler Toledo Safeline Ltd.

International staff appointments, international recruitment and visiting scholars

Reflecting its research outlook and desire to recruit the best candidates, the School is a truly international community. For example, 58% of its academics and 62% of research staff originate from outside the UK, and over 70% of its research students are from outside Europe. In the review period academics have been recruited originating from Peru (Ochoa), Italy (Mancarella), China (Liu, Yin), Montenegro (Durovic), Romania (Stancu), Poland (Majewski), Spain (Carrasco Gomez), and Greece (Kopsidas).

To foster new collaborations and share best practice, there is an active visiting scholar programme. Nearly 200 academics held visiting positions during the period. Visitors came at all levels, MSc and PhD students, postdoctoral researchers, academics, and scientists, and from all over the world. For example, Dr M Ishii, National Institute for Materials Science (Tskuba) visited Hamilton for 18 months; Prof Y Han President North University of China and Prof H Bian from Huazhong University of Science and Technology, China, visited Yang for 3 and 13 months, respectively; Dr J Bray from

the Royal Military College of Canada visited Sloan for one year; Dr J Black and Dr P Hopewell from the Rolls-Royce Strategic Research Centre visited H McCann and Forsyth, aided by 2-year Royal Society Industry Fellowships.

Equality and diversity

The Unit is committed to the advancement of equality in employment and staff career development. The School has an Equality and Diversity strategy including applying for the Athena SWAN award by April 2014. Equality data monitoring and action planning is embedded into the annual performance reviews, which monitor recruitment, staff profile, and promotion patterns. Fifty-five of its staff have undertaken equality and diversity training in the period. These data are reviewed by its Equality and Diversity Committee, chaired by the Head of School.

Women in Science, Engineering and Technology, formed in 2005, is a network for female academic, research and technical staff and students in the EPS Faculty. Led by George, it is funded by the Faculty and encourages women to enter and develop careers in science, engineering, and technology. In the period, the number of female academic staff has increased by 1 to 8%, a number the School is working to increase. The proportion of female support staff is unchanged at 39%. The University is one of a few institutions that is part of the Equality Challenge Unit's Black and Minority Ethnic Systemic Change Pilot and is undertaking initiatives in relation to recruitment and mentoring. Ethnic diversity is being maintained, with 42% White British, 19% Other White, and 37% BME.

Career development: Applicable to all staff

To review individual career development and planning, the University implements a Performance and Development Review (PDR) scheme for all staff, which includes a written preparation document, a one-to-one discussion, and an agreed written conclusion. All staff, including researchers, independent of experience, have an annual PDR. Should consistent difficulties be identified, the Head of School intervenes to help identify support needs or other action. Several staff have benefited in this way. Academics who are also line managers are trained in conducting PDRs of all staff they are responsible for.

A comprehensive programme of training activities is provided by the EPS Faculty Researcher Development team, which is directed at post-doc, early-career, and established academics. It includes over 70 training events each year, web resources, e-bulletins, a detailed Research Staff Handbook, and funding for researcher-led initiatives and support communities of researchers. The programme has five over-arching categories: Research & Enterprise, Communication, Career Management, Leadership & Management, and Teaching & Learning. An annual Research Staff Conference provides up-to-date information and networking opportunities for staff from across the University. During the review period, UoA staff participated over 1300 times in training courses. The University also runs a training programme called 'Headstart' which aims to enable middle and senior academic and administrative staff to develop the leadership skills and qualities required to operate at senior levels within Higher Education. In the period 6 staff undertook the programme.

Career development: Specific to early career researchers

New staff are allocated a senior member of staff to act as a mentor during their probationary period and beyond. The post of Mentor is distinct from that of line-manager and the two ensure a positive support network. The mentor system is confidential, facilitatory, and focussed on the development and needs of the mentee. The system is overseen by an experienced Senior Mentor, currently Peyton. New staff are given initial funding to help with research start-up costs and attendance at conferences, with additional support made available for travel to liaise with potential funding bodies and research collaborators. New staff are also given strategic consideration in the award of doctoral studentships.

All new academic staff participate in the University's New Academics Programme, involving about 50 contact hours over an 18-month period, and a range of associated mentoring and development activities. The research components deal with grantsmanship, managing a research portfolio, publication strategy, and postgraduate recruitment and supervision. It also covers IPR, collaborating with industry, and public engagement. The School has its own induction process

detailed in the EEE Staff Handbook, managed by the Head of School Administration.

Two award-winning initiatives provide further support. The website "An Academic Career", developed by the University of Manchester Careers Service, gives a comprehensive guide to working in higher education, and won the Times Higher Education 2011 Award for Outstanding Support for Early Career Researchers. The award-winning Manchester Gold programme, available to any staff member, supports the development of a mentoring culture. Staff are matched to more experienced colleagues, who act as their career mentor over a nine-month period. There are currently two such mentoring partnerships in place.

Concordat to support the career development of researchers

The University of Manchester has developed an Implementation Plan to ensure full support for the Concordat, in recognition receiving the HR Excellence in Research Award from the European Commission. With the aid of the Careers Research Online Survey 2011, the University incorporated the views of research staff into the Plan, especially through improved research staff representation on University committees. In addition, Faculty-specific Research Staff Handbooks have also been distributed, ensuring that all researchers are aware of the support available. The School is helping to pilot the development of a web-based PDR system for Research Staff, a system that will be extended to all staff during the next review period.

Sabbaticals

Sabbatical leave is encouraged to enable staff to concentrate on research. All sabbaticals have clear plans and deliverables associated with them before approval, and staff use the opportunity to make visits to universities, research institutes, and commercial organisations. For example, Mutale visited Copperbelt Energy in Zambia for research on integration of grid-connected PV in a developing country; Missous visited the University of Modena in Italy for research on high-speed devices; Lanzon visited the Università Politecnica delle Marche in Italy for work on UAV control; and Halsall spent time at the University of Santa Barbara using their facilities for THz radiation generation. To ensure staff can pursue opportunities presented by spin-out companies, their time can, by agreement, be bought-out (e.g. arrangements for Peyton for CableSense and Rowland for Arago). This enables temporary back-filling of posts.

Promotions

Promotions boards are held annually except for the Professoriate, whose boards are held every other year. Promotions Master Classes are held annually to support all staff in their applications. These classes describe the promotion route, the role of the Promotion Committees, tips for CVs, case studies, and the option of one-to-one guidance. All staff on promotion boards are trained in equality and diversity. During the review period there were 42 academic promotions.

Personal research fellowships won in an open competition

Applications for fellowships are encouraged, aided by the Faculty, which provides support and training. In the review period the following were awarded: Royal Society Industrial Fellowship (Wu), Royal Academy of Engineering/EPSRC Fellow (Huda El Mubarek), Royal Academy of Engineering Fellowship (Migliorato), 2 EPSRC Fellowships (Majewski, Migliorato), Visiting Researcher Fellow at Agilent Technologies (Sloan), and Alexander von Humboldt Foundation Fellow (Terzija).

ii. Research students

The development of the next generation of researchers is central to the Unit's mission. The drive is to improve quality, consistency, and personalisation of supervision. The PhD and EngD programmes have a maximum duration of four years to submission of the thesis. MPhil programmes have a one-year research period followed by a one-year submission period.

Approaches to recruitment

The Director of Postgraduate Studies and Recruitment Office manage publicity and student recruitment. The aim is to attract the highest quality candidates by advertising in www.findaphd.com, www.jobs.ac.uk, 'Prospects' publications and website, and on the School's own website. The School contributes to the University's Postgraduate Prospectus and takes part in the University Postgraduate Open Day each November. The University International office attends

many overseas education events, aiding recruitment of high-quality students. All applications are made online and are vetted to ensure that applicants meet the minimum requirement of a 2:1 UK honours degree (or equivalent) before they are circulated to academic staff. Applicants with a 2:2 UK honours degree can be offered an MPhil study option. Before an offer is made, the potential student is interviewed by two members of staff (one being the proposed supervisor), who are trained in selection, interviewing, and equality and diversity.

Support mechanisms

A Research-Council-funded Doctoral Training Grant enables about seven fully funded studentships to be offered each year to Home and EU students. Industrial support enables typically three of these to be converted to industrial CASE awards. Students are also funded through the School's membership of the Power Networks Research Academy (EPSRC, Central Networks, EA Technology UK Power Networks, SSE, Scottish Power, and National Grid). Two full scholarships to graduating international students are also funded each year. Many research students are recruited from the School's six taught Masters courses, which have about 190 students each year. Students are encouraged to apply for the University's President's Doctoral Scholarships, Alumni Awards, and the Faculty Dean's awards, and about four students win funding via these routes each year, one of the highest rates in the Faculty. A CDT in Power Networks has recently been awarded (EPSRC and industrial funding, November 2013) that will provide support for 66 PhD students over 5 annual cohorts. The Unit is also significantly involved in two other CDTs recently awarded to the University. The continuing strategy is nevertheless to maintain both traditional and CDT sources of student support.

As students consider their next steps they are able to use the University's award-winning Careers Service which employers have regularly rated as the best in the UK. Help and advice is offered on careers and job-hunting, as well as opportunities to develop the skills that employers look for.

Training and progress monitoring

Each research student has a supervisory team consisting of a main supervisor, a co-supervisor, and an advisor. The supervisors are responsible for technical supervision and progress, whereas the advisor provides an independent link to the School**.** Compulsory training for doctoral students includes an introduction to research, H&S, research methods, and academic malpractice awareness. Recommended and optional training courses cover subjects such as academic writing, viva preparation, production of conference posters, presentation skills, research methods, IP, and writing lay summaries.

A highlight of the year is the Postgraduate Research Poster display, compulsory for 2nd-year postgraduates. This event is attended by the Industrial Advisory Group (Section b), and allows all staff and students to appreciate the breadth of research. It also prepares students for international conferences, which they are expected to attend before graduating.

In the review period, a compulsory online progression monitoring system, eProg, was introduced. This records attendance at formal monthly meetings and provides each student with clear milestones for their degree, along with evidence of training and quarterly progress reports. Progression from first to second year depends on a written report and oral examination by two examiners, as does progression from second to third year.

d. Income, infrastructure and facilities

Income and research funding portfolio

The aim has been to increase funding to a sustainable level with a balance from Research Councils, Government, and industry. Overall new awards have increased from £17m in 2002-07 to £41m in 2008-13. The mix of funding sources and diversity of collaborators is now one of the Unit's strengths, which it plans to maintain. As an illustration, although income from the Research Councils has increased from RAE 2008 (for staff returned) to REF by over £11M, it has dropped from 56% to 48% of income, as industrial funding has increased to 31% and UK government funding to 13%.

The Unit's six Research Groups are all highly research active, exemplified by the range and level

of direct funding received in the review period, namely:

- 80 industrial or commercial projects with a total of approximately £15 million. Funding comes from, among others, National Grid, E.ON UK, ENW, Syngenta, Rolls Royce, Ferranti Technologies, SP Power Systems, Pipeline Engineering, SSE, BP, Pilkington, GE Aviation Systems, MoD, Subsea Integrity Group, UK Power Networks, EDF, Power Systems Services, Tesco Stores, Siemens, New & Renewable Energy Centre, Mettler Toledo Safeline, British Energy, Agilent Technologies, Pfizer, Feliong Trading, Alstom Grid, and Tata Steel.
- 24 EU projects with total funding £5.5m, including 8 Framework VI projects, 12 Framework VII projects (including small, large and combination), 3 Clean Sky, and 1 Coal & Steel.
- Commercial framework agreements to strengthen partnerships and technology transfer in both directions (National Grid, Rolls Royce, National Instruments, Syngenta, Rapiscan Systems, Electricity North West).

Another of the Unit's successful strategies to improve efficiency and research power is to move to larger collaborative projects. For example, it took a lead role in the £20m Dalton Cumbrian Facility; it contributed to the University's successful bid for the £64m BP International Centre for Advance Materials; Power Conversion has been invited to join the core team for the National Power Electronics Centre (other institutions being Bristol, Imperial, Newcastle, Nottingham and Warwick) and the core team for the recent EPSRC bid to renew the Research Centre for Non-Destructive Evaluation (RCNDE with Imperial, Bristol, Nottingham, Warwick, and Strathclyde). Strong support is given to such initiatives, e.g. Hamilton was temporarily relieved of Research Group Leadership to write a major bid in 2013.

A breakdown of industrial sources reveals that over half the industrial income is from companies which have entered into long-term strategic commercial and technical agreements, creating a stable income stream as planned. Although research in power systems is the larger part of the industrial funding, work in electronics for agriculture, industrial control systems, and sensing all have substantial funding, in line with the strategy of facilitating technology transfer.

Provision and operation of specialist infrastructure and facilities

Three unique large-scale facilities support the Unit's research output, underpinning relationships with industrial partners and feeding into its research themes:

- The National Grid Power Systems Research Laboratories are unique in Britain. They include the National Grid High Voltage Labs, the largest in the UK, with 2,000 kV impulse, 800 kV AC and 600 kV DC test-sets. Excellent relations with the utilities led to a coastal 400 kV outdoor test facility being built for a project and a new Protection, Communications and Control Lab, resulting in world-class facilities for wide-area monitoring of electrical networks.
- The Intelligent Electrical Power Networks Evaluation Facility (IEPNEF) was established at Manchester by a £1m investment from Rolls-Royce and the MoD under the Systems Engineering for Autonomous Systems Defence Technology Centre. IEPNEF provides a unique capability to examine more-electric aircraft power systems. In the 100 kW facility, hardware-in-the-loop techniques are used to provide an aero-engine emulator that drives real generator hardware supplying a four-bus reconfigurable network.
- The Microelectronics & Nanostructures Fabrication facility is a state-of-the-art 6" wafer Molecular Beam Epitaxy facility, allowing materials growth, characterisation, device and integrated circuit fabrication and testing. This equipment is used in industrial collaborations including with e2v in the design and manufacture of Gunn diodes for car radars for BMW and Audi, ultra-high-precision linear encoders with Renishaw PLC, LT-GaAs materials with Teraview for THz imaging, and ultra-low-noise amplifiers for the Square Kilometre Array.

Investments (both current and planned) in infrastructure and facilities

The Unit is based in the Sackville Street Building and the Ferranti Building, both on the University campus. Since 2008 much of the space has been refurbished, aiming to develop contiguous space in Sackville Street for each Research Group, and improving the dedicated mechanical and electrical workshops. The School has 3,800 m^2 of research laboratories and 11,000 m^2 space in

total (including teaching space). In addition to infrastructure investment reported elsewhere, £1.1m was spent on research infrastructure (including equipment and related estates improvement).

In the next few years the School will move to a new purpose-built facility as part of the University's Estates Masterplan, with the Manchester Engineering Campus Development accounting for £250m of the £700m to be spent on phase 1 before 2018. The move of all the Engineering Schools to a single site will enable the Unit to strengthen research output by deepening its relationship with other disciplines and sharing infrastructure.

Administrative and technical support services have been radically reorganised in the period. Benefits include the co-location of research administration and finance staff in the Sackville Street Building and robust cover for sickness and holidays. Best practice is being identified across the Faculty. A new Research Support Manager post has been created and four Research Support Officers added to improve bidding and project management. Research Support Services now has seven staff across this School and one other, compared with two for the School in RAE 2008.

Consultancies and professional services

Individual academics are encouraged to carry out a managed amount of personal consultancy to both exploit their expertise and transfer technology, but also to develop further research funding. All such work is approved by the Head of School to ensure it is within acceptable bounds. In the period 139 consultancies have taken place through the University accounts with a value of £525k.

The Unit's laboratories carry out commercial testing on a limited scale to support and foster relationships with local industries. This allows staff insight into the challenges facing the industrial community, and for industry the opportunity to better understand the Unit's capabilities. For example, the HV lab has a long tradition of testing for International Transformers, and some limited testing for strategic partners such as National Grid is also performed under commercial contracts.

e. Collaboration or contribution to the discipline or research base

Support for and exemplars of research collaborations

In line with the drive for larger projects and long-term research partnerships with industry, there is strong encouragement of research collaborations. Support for this activity is provided by a sabbatical policy which aims to have 10% of academic staff on sabbatical each year, subject to suitable individual research plans. Both inward and outward academic visits are encouraged, as are secondment and recruitment opportunities. The Unit is consequently active in large national and international collaborations, many of which it leads. Examples follow:

- The Square Kilometre Array, a £6.5m STFC grant with Oxford and Cambridge Universities.
- The UKRC SuperGen program, which has led to activity such as Flexnet and Amperes, led by the Unit. It is a member of the RCUK HubNet, which leads coordination in energy networks, and part of the EPSRC Energy Networks Grand Challenges—Transformation of the Top and Tail (Project Manager) (£4.1m) and the Autonomic Power Systems (£3.5m) project in partnership with Universities of Strathclyde, Cambridge, Durham, Sussex, and Imperial; Accenture, Agilent Technologies UK, E.On, IBM UK Labs, KEMA, Mott MacDonald, National Grid, PB Power, Scottish and Southern Energy, examining future network management..
- Multiple FP7 projects (e.g., ROOTHZ, RealiseGrid, PEGASE, SuSTAINABLE, ADDRESS), totalling more than £3.4m since 2008, with Universities of Salamanca, Chalmers, Lille, NTUA (Athens), Porto, Liege, Berlin, Seville, Camillas, Duisburg-Essen, and others.
- Solar Energy research, a collaboration with the National Renewable Energy Laboratory (Colorado) and the Fraunhofer Institute for Solar Energy (Freiburg).

The University is a member of N8, which allows more opportunities to share or access facilities both within the University and across N8. In addition, each Research Group maintains a list of key strategic collaborators and ensures these are managed in a constructive manner as a whole (for example publicizing additional research opportunities).

Support for and exemplars of interdisciplinary research

The University has developed Institutes to cut across disciplines and the Unit is an active participant, for example, members of the Microwave and Communication Systems and the Sensing, Imaging and Signal Processing Groups work in the Photon Science Institute, and staff will be fully involved in the new £61M, 7600 m^2 National Graphene Institute, through which they will continue to collaborate with the Schools of Physics, Chemistry, Materials, and Chemical Engineering and Analytical Science. As another recent example, the University has won the competition for the BP International Centre for Advanced Materials, which involves an investment of $100m from BP over the next 10 years. This is a multidisciplinary centre with Manchester acting as the hub and the University of Cambridge, the University of Illinois at Urbana-Champaign, and Imperial College as spokes.

Developing interdisciplinary research is part of the Unit's strategy (Section b). Examples include:

- The £20m Dalton Cumbrian Facility is a collaboration with the Schools of Chemistry, Materials, CEAS and MACE to establish research groups to tackle radiation chemistry and engineering decommissioning, the latter led by the School with 25% of the DCF budget.
- Silicon Compatible GaN Power Electronics programme with the Universities of Glasgow (lead), Sheffield, Bristol, Nottingham, Liverpool and Cambridge is a £6m EPSRC grant, with over half a million awarded to the School.
- Photonics and Electronics for Medical and Healthcare was a feature of an EPSRC Platform Grant with over £800k awarded to the School, and led to a collaborative programme with other schools and the NHS (Christie Hospital), University of Cambridge, and RISO labs (Denmark).
- A £700k project involving the School of Materials (Lyon, corrosion) and the School of Mechanical Aerospace and Civil Engineering (Dupere, acoustics) is developing models of conductor behaviour for the National Grid.
- A EUR 1m project (led by Wu) is one of the partners in a EUR 12m EU project on flexible robotic systems for automated packaging of food products, which involves Marks & Spencer.

Impact of research collaborations with research users on research activities and strategy

The Industrial Advisory Group is used to provide a direct method for industrial collaborators to feed into the Unit's research strategy. Likewise, research partnerships (Section b) have a central role in influencing research activity, income, and impact. The major experimental facilities available to the Unit (Section d) are also strategically underpinned by these collaborations. An example of the success of this strategy is in the application of electromagnetic inspection and imaging technologies to the process, security, and biomedical fields.

A major impact of research collaboration on strategy has come from the global agri-science business, Syngenta, selecting the School as partner for next-generation sensors and informatics technologies. This was Syngenta's first University Innovation Centre and it invested £1.5m. The resulting research laboratory infrastructure and commercial opportunities enabled the Electronics in Agriculture (e-Agri) Research Theme to be launched, which has since attracted over £5m in research funding from other agri-food companies and public funds. The e-Agri Theme has positioned itself among a group of 20 leading SME and academic partners consulted by the UK Government and EU Commission on future engineering for sustainable agriculture and food.

The Unit has a strategy of leveraging the facilities and expertise of other organisational units in the University. This approach also fosters collaborations and access to world-class facilities, e.g. the support offered by the Photon Science Institute (MN and SISP Research Groups), the School of Materials (SISP and EEPS Research Groups use of X-ray and materials characterisation facilities), research hospitals (SISP), and the Diamond Light Source (EEPS and SISP).

To enhance collaborative research impact, staff can take up formal collaborative positions; for example, J. Mutale has moved to the Brooks World Poverty Institute half-time to work with colleagues from other faculties there; Lennox works partly in the Dalton Nuclear Institute; and Cotton is Director of the multidisciplinary Energy Theme for the University.

Leadership in the academic community

Major awards and prizes
Recognition for notable contributions to the research base has been through the following: IET Measurement in Action Award (2010, Lennox), 2 Energy Innovation Awards Existing Performance Improvement Prize (2010, Cotton and Rowland) and 2 Energy Innovation Awards, 5 IET Innovation Awards (Oakland, Gaydecki, Wu, Rowland, Lennox); Service Award from Society for Imaging Science and Technology (2013, Foster); shortlisting for Science & Technology Woman of the Future award (2010, George); SET and Global Graphical System Design Awards (2013, project students); and EAWE Excellent Young Wind Doctor Award (2011), EPSRC UK ICT Pioneers 2012 prize in the category of "Connected World" (2012), EPSRC Doctoral Prize Fellowship (2013), and Elsevier Doctoral Thesis award (2013) (PhD students).

External leadership roles
Adding to 35 Fellows of learned societies, Yang and Milanovic were elected FIEEE and Missous FREng. Rowland was a member of IEEE Technical Activities Board, Strategic Planning Committee, and served two terms as President of the IEEE Dielectric and Electrical Insulation Society. Hamilton was a member of Council of IoP, also of Audit and Risk Committee and Group Coordination Committee, and Chair of the Nanoscale Physics and Technology Group. Foster and Halsall were members of the IoP Fellowship Committee. Mutale was on the IEEE President's Ad Hoc Committee on IEEE African Activities Development. Peyton was secretary of the International Society for Industrial Process Tomography. Ozanyan was on the UK Sensors and Instrumentation Leadership Committee set up by ESP KTN to advise the TSB. Brown was a council member of the Engineering Professors Council and of the IET Antennas and Propagation Steering Group. Ozanyan, Milanovic, Yang, Crossley were IEEE Distinguished Lecturers giving presentations world-wide (e.g. Stanford, Rio de Janeiro, Tsinghua, Tohoku, Berkeley, Sofia, Buenos Aires, Sao Paulo, Auckland, Tianjin). Staff were part of UK F&C Office missions on Smart Grids (Asia 2011, 2012) and on Sensors (New Zealand 2012). Halsall sat on an NSF panel in an advisory role to the US government (Washington, 2009). Staff chaired or participated in many CIGRE working groups (Crossley, Z Wang, Terzija, Ochoa, Milanovic).

External advisory boards
Brown, Halsall, Missous, Peyton, and Sloan served on EPSRC prioritization panels, and 20 staff were members of the EPSRC Review College. Lennox, H Wang, and Rezazadeh served on EU Review panels. Milanovic was a member of the Electrical Power and Control Systems Advisory Board of Rolls-Royce plc, and of the prioritization panel of the French National Research Agency, review colleges for research agencies of Denmark, Greece, The Netherlands, Italy, Serbia, Chile; Wu of the Executive Committee of the IET RF & Microwave Professional Network; Brown of the Advisory Committee of the Sector Skills Council for Science, Engineering and Manufacturing Technologies; Rezazadeh of the Board of Directors of Gallium Arsenide and Other Compound Semiconductor Devices Association; Missous of the Board of Directors of the Electronic Technology Network; and George of the international Academic Advisory Board for National Instruments.

Journal editorial boards
Three academics are editors-in-chief (Ozanyan: IEEE Sensors Journal; Smith: IET Electrical Systems in Transportation; Foster: Vision Research, Elsevier). In all, 42 staff served on editorial boards, including IEEE Trans. Automatic Control, IEEE Trans. Dielectrics & Electrical Insulation, IEEE Trans. Power Delivery, IEEE Trans. Measurement & Instrumentation, IEEE Trans. Neural Networks, IET J Control Theory and Applications, IET Electrical Systems in Transportation, IET Electric Power Applications, and Measurement Science and Technology.

International conference organisation, invited lectures, and conference and other chairs
Conferences hosted include the 2008 UKACC International Conference on Control; the 2011 IEEE Conference on Innovative Smart Grid Technologies, and the 2013 IEEE Systems, Man and Cybernetics Conference. Elsewhere, staff gave over 100 keynote or invited lectures at international conferences, and served as 16 conference or programme chairs and 46 session or topical chairs.