Instrumentation 2003

CCLRC

Contents

The Council for the Central Laboratory of the Research Councils (CCLRC) is an independent, non-departmental public body of the Office of Science and Technology, which itself is part of the Department of Trade and Industry. CCLRC owns and operates the Rutherford Appleton Laboratory in Oxfordshire, the Daresbury Laboratory in Cheshire and the Chilbolton Facility in Hampshire.

Compiled and edited by Tim Nicholls, Mike Kenward, Mike Johnson, June Preston and Clare Wadley

Designed by Ampersand Design Ltd, Abingdon

Produced by CCLRC Presentation Services Group

RAL-TR-2003-005

Welcome to **Instrumentation 2003**, an introduction to the work of CCLRC's Instrumentation Department.

Detectors and their data acquisition systems are the 'eyes' through which the physical and biological sciences observe and measure the world. Modern detectors allow us to capture the spectrum of ultraviolet light transmitted by a protein as it unfolds, to image the X-ray emissions from our Sun, to detect the subtle pattern of neutrons diffracted from a high temperature superconductor, or to visualise the short-lived particles produced in a high-energy particle physics experiment.

CCLRC's facilities and programmes demand access to leading-edge instrumentation of many types, from novel detectors, to microelectronics and complete data acquisition systems. Instrumentation Department staff play a key role in providing this access. They work closely with staff in CCLRC's science departments and with university colleagues.

We also believe that we have an important role in encouraging the advances in science that can come about through the transfer of instrumentation technologies from one discipline to another. We are actively seeking links to other centres, both within the UK and overseas, to explore where our technology can bring significant improvements to new areas of science.

Instrumentation 2003 illustrates the new techniques we are developing to deliver CCLRC's future scientific programme; I hope it also conveys the excitement and enthusiasm our engineers and scientists bring to their work.

Mike Johnson, Director Instrumentation

Introduction

CCLRC's Instrumentation Department currently employs around 130 staff. Their central mission is to design and build world-leading instrumentation for the facilities and programmes within CCLRC. Instrumentation Department staff are therefore involved in all of CCLRC's large in-house facilities – the ISIS neutron source, the Synchrotron Radiation Source, and the Central Laser Facility – developing new instruments and providing support for existing systems.

Instrumentation Department (ID) staff also play a major role in the UK's participation in CERN, the European particle physics laboratory in Geneva, and at other international laboratories, through the design and construction of the large experiments. ID staff also support CCLRC's activities in space science and earth observation.

The department employs staff with a wide range of skills, from applied physicists, with particular expertise in radiation detectors of all types, through specialists in microelectronics design, to experts in electronics systems and software controls. The department also runs Europe's largest electronics design software support activity (within EUROPRACTICE) for academic users of Electronics Design Automation (EDA) software.

The technical facilities within the department enable ID to design a variety of electronic systems from custom integrated circuits to board-level systems, to assemble high precision detector systems under clean-room conditions, and to test detectors and electronic systems.

Detectors, and the sophisticated data acquisition electronics that enable data capture, lie at the heart of much physics-based experimental science. Maintaining a leading position in such science demands continual improvements in these technologies. Our work is assisted in this regard through CCLRC's **Centre *for* Instrumentation.** The **C*f*I** funds research and development into the new instrument technologies needed for tomorrow's science. ID staff play a major role in delivering the **C*f*I**'s programme, and in maintaining the skills base that CCLRC will need in the future.

The many engineering projects that ID undertakes – typically the department has around 70 projects underway at any one time – need careful management. This is achieved through CCLRC's project management system and the department's full certification under the ISO9001 quality assurance scheme.

Hybrid pixel sensors

X-rays are an essential tool in many scientific applications. CCLRC develops world-class X-ray imaging detectors for applications including astronomy, medical imaging and the study of condensed matter, such as proteins and catalysts, using synchrotron radiation.

Researchers want ever higher performance from X-ray detectors. In addition to forming images with the entire X-ray spectrum from below 1 keV up to 150 keV, there is a need to increase total detection rates to 10^{12} photons per second. There is also a need to detect the energy (colour) of each photon to give increased contrast and diagnostic power.

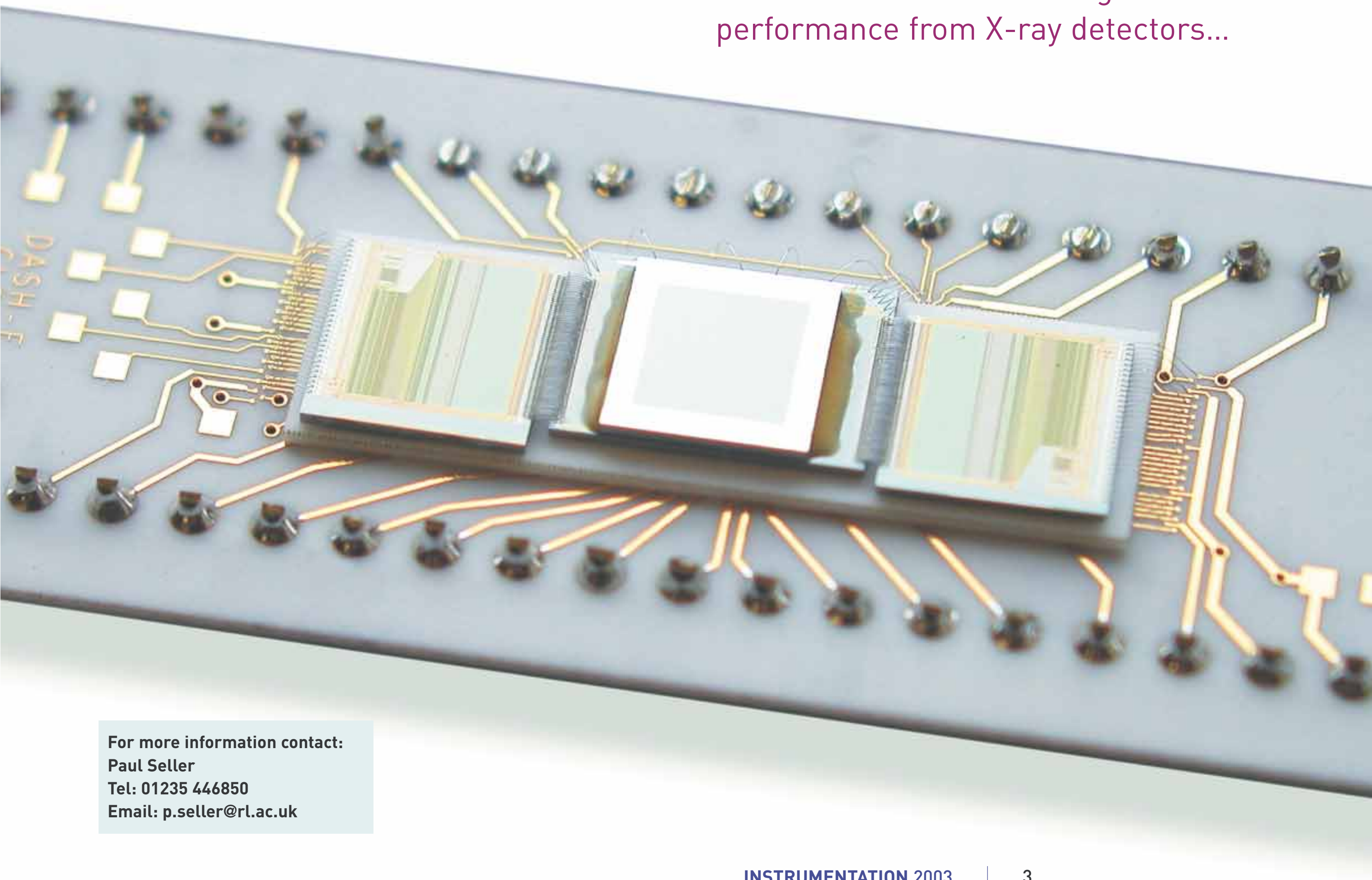
As part of the development of new instrumentation technologies, CCLRC is taking advantage of the versatility of hybrid semiconductor sensors. Instrumentation Department has developed a silicon-based energy-resolving detector with an array of 16x16 pixels, each 300 micrometres square. The array is bonded onto a microelectronics readout circuit that simultaneously captures the X-ray image and the energy of each photon.

To extend the range above 20 keV a cadmium zinc telluride semiconductor detector has also been bonded to the electronics. This allows the device to take energy spectra up to 150 keV.

CCLRC has also built and tested modules of a photon-counting silicon detector for protein crystal diffraction. The modules have a uniform pixel size of 150 by 150 micrometres over a silicon detector of 448 by 64 pixels. Several modules have been built and tested and have successfully delivered images from X-ray sources.

A silicon X-ray detector.

...researchers want ever higher performance from X-ray detectors...

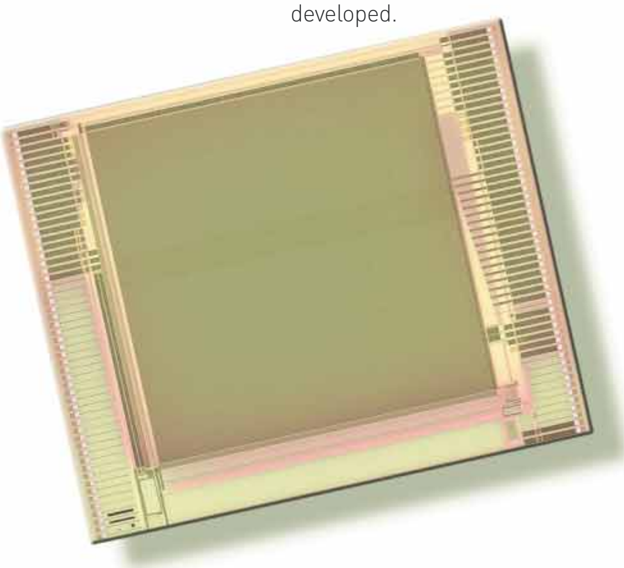


For more information contact:
Paul Seller
Tel: 01235 446850
Email: p.seller@rl.ac.uk

Active pixel sensors

A new generation of smart sensors will improve the performance of earth observation experiments and could ultimately help to restore sight in the blind.

Instrumentation Department (ID) is developing world-leading Monolithic Active Pixel Sensors (MAPS) for scientific applications. Advanced microelectronic technologies are used to produce Complementary Metal-Oxide Semiconductor (CMOS) integrated circuits that combine a sensor array with processing capability. A series of prototype devices are being developed.



The 512x512 active pixel sensor.

One will have 12 million pixels, one of the world's largest sensors. Others will deliver world-beating resolution and readout speed.

These types of sensor will be used for observing Earth from space with 1-metre resolution and for investigation of the Sun at extreme ultraviolet wavelengths. ID is applying the same techniques to the detection of charged particles in high-energy physics and in biomedical applications, where a sensor implanted on the retina could help with certain types of blindness.

Instruments that are to journey into space have to meet special requirements. As well as being light and reliable – they are beyond the reach of a service engineer – instruments on spacecraft must make as small a drain as possible on the precious on-board power supply. They must also survive the harsh environment, with its steady stream of radiation.

The CCLRC team met these challenges with leading-edge design tools, designing 'right first time' a full camera integrated on to a single CMOS chip. This sensor, specifically designed for a star tracker, consists of an array of 512x512 pixels.

...one will have 12 million pixels, one of the world's largest sensors...

Each pixel integrates a photodiode and a simple amplifier. The signals from each pixel in a row are simultaneously amplified and converted into a 10-bit binary word. The readout and control of the chip are fully digital, making it easier to develop the imaging system.

For more information contact:
Renato Turchetta
Tel: 01235 446633
Email: r.turchetta@rl.ac.uk

Gas microstrip detectors

Instrumentation Department (ID) has played a significant role in the development of several gas detector technologies for high performance applications. In addition to designing state of the art multi-wire gas chambers, ID is developing Gas Microstrip Detectors (GMSDs) for high counting rate applications.

GMSDs, which have their origin in neutron scattering applications, are robust devices whose small dimensions can allow them to collect data more quickly than the larger multi-wire gas chambers. ID's development programme will bring benefits to applications such as low energy X-ray spectroscopy, small and wide angle X-ray scattering, neutron scattering and electron detection.

A GMSD contains a set of microscopic metal strips etched on a thin insulating substrate. Incoming charged particles or photons create ionisation in the gas volume, which is then amplified by an applied electric field and collected on the microstrips.

An attraction of GMSDs is that their manufacture exploits standard photolithographic techniques used by the electronics industry.

By careful optimisation, it has been possible to increase the detector gain beyond that previously achieved by as much

Sub-micron R&D

For nearly half a century, the relentless demand for higher performance has driven the semiconductor industry to integrate increasing numbers of ever smaller features into microelectronic devices. This technological scaling presents both opportunities and challenges to Instrumentation Department.

For more information contact:
Marcus French
Tel: 01235 446484
Email: m.j.french@rl.ac.uk

Smaller features bring greater possibilities for embedding functionality, leading to more powerful and compact instruments. But working with increasing integration at smaller dimensions is challenging and requires complex design tools. The specialist expertise of Instrumentation Department (ID) in this area allows the research community to benefit from the advances in microelectronic technology.

In line with the electronics industry, ID is moving from 0.25 micrometre technology for designs and will soon switch to 0.13 micrometre or below. This puts immense pressure on the design of ASIC systems.

As features shrink in ICs, interconnections between active components play an increasing role in defining the speed of logic circuits. This makes it vital to achieve correct signal timing in designs, and necessitates modelling designs of new ICs in three dimensions, adding to the complexity of the design process.

Power supply is another issue that requires detailed modelling at smaller dimensions. There is a complex interplay between feature size and operating voltage. Smaller features need lower supply voltages, which means that power distribution and modelling become important in the design process.

Analogue systems also suffer when designers have to reduce voltages to accommodate smaller features. It is necessary to devise new architectures that can maintain the voltage required for a circuit to function.

Unlike digital systems, where reducing the voltage lowers power levels, for analogue circuits the total power often remains constant. This requires larger currents, putting further strain on the device's power distribution. Add the increasing cost of fabrication and larger wafer sizes, and it becomes ever more important to achieve 'right first time' design. With this in mind Instrumentation Department is two years into a project, funded by the Particle Physics and Astronomy Research Council, to help to enhance its capability in these new technologies and to develop prototypes of key electronic structures.

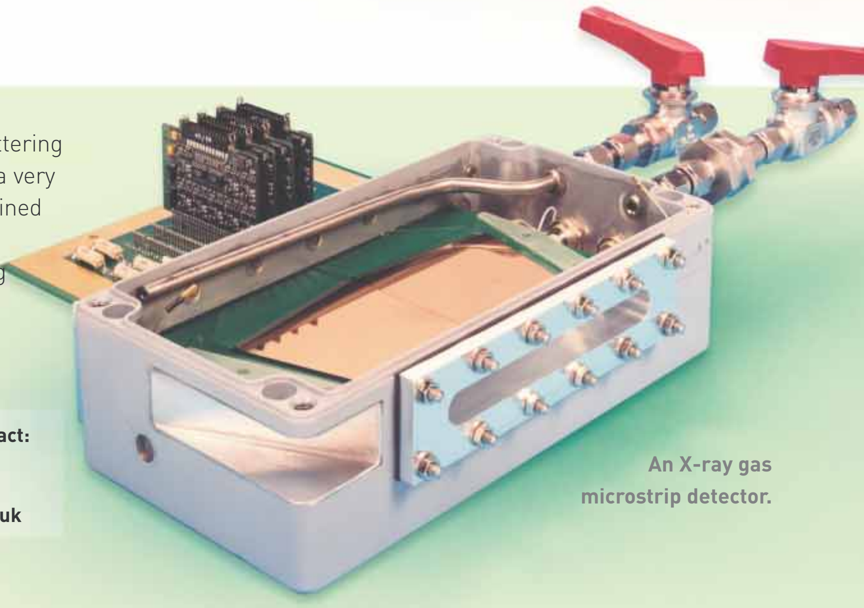
> ...Instrumentation Department's specialist expertise in this area allows the research community to benefit from the advances in microelectronic technology...

as 1000, producing an excellent signal to noise ratio. This extends the useful response of detectors not only into the soft X-rays region below 1 keV, but beyond, to allow detection of single electrons.

ID has developed several prototype systems, including a detector for X-ray magnetic circular dichroism. The department has also developed a prototype system for wide angle X-ray scattering experiments, delivering a very high counting rate combined with position sensitivity.

ID is also collaborating with scientists from ISIS to develop GMSDs for neutron applications.

For more information contact:
Dominic Duxbury
Tel: 01235 445136
Email: d.m.duxbury@rl.ac.uk



An X-ray gas microstrip detector.

Integrating technologies

The increasing power of new accelerators and detectors puts extra demands on the instrument systems that capture and analyse the resulting flow of data. For example, new target stations on ISIS and the new diamond synchrotron at RAL will support new generations of instruments, each of which will generate more data from more detector channels.

At the same time as the output of data from instruments increases, researchers will expect seamless integration of experimental control systems, data acquisition, real-time processing power and 'e-Science' technology.

...ID is exploiting a number of key technologies to meet these growing demands...

Instrumentation Department is exploiting a number of key technologies to meet these growing demands. Developments in microelectronics allow us to integrate digitising electronics and high-speed serial data links with analogue circuits. The department also benefits from advanced approaches to the design of custom electronics.

For example, the increasing capability of Field Programmable Gate Arrays (FPGAs), allow us to implement more functionality in each device. With their ability for reconfiguration under software control, FPGAs also open the door to greater flexibility in the design and operation of systems. Sophisticated design tools allow us to flexibly place functionality in hardware, firmware or software, modelling and simulating different options before building the system.

Industry standard bus systems developed for computing, such as PCI, offer speeds in excess of 100 Mbyte per second in a variety of configurations. Adopting these in systems greatly simplifies interfacing custom electronics to computers for processing and storage of data.

An example of ID applying these new design tools and techniques is a general purpose data acquisition building block, which takes the form of a PCI card that plugs into a standard PC or processor module.

The card has two sections, with a standard back end holding two large FPGAs, 256 Mbytes of memory and a PCI interface. There are two interchangeable front end sections; one design with eight 53 MHz 12 bit ADCs and another with 68 bi-directional differential channels.

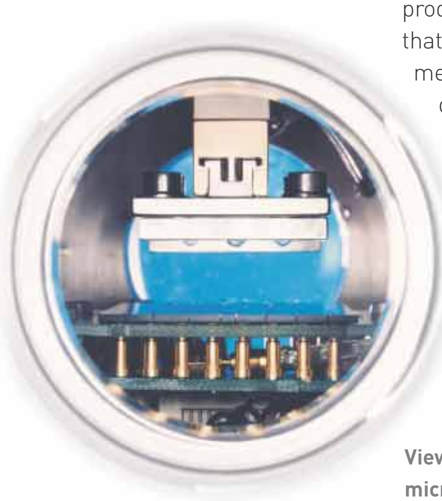
These high performance modules are already in use in a number of projects, including the RAPID 2 detector system for the SRS, data acquisition studies for ISIS, and a number of detector development projects for synchrotron radiation and particle physics. Their adaptability makes them potential solutions for a number of future data acquisition systems while reuse of the original design minimises costs.

High performance data acquisition cards under test.

For more information contact:
Steve Quinton
Tel: 01235 445534
Email: s.p.h.quinton@rl.ac.uk

DEXAFS – A depth profiling X-ray detector

Extended X-ray Absorption Fine Structure (EXAFS) spectroscopy is offering new diagnostic capabilities thanks to work in Instrumentation Department (ID) to develop advanced detector systems. EXAFS is a well-established technique that involves the analysis of X-ray absorption to probe the structure and electronic properties of matter.



View of the depth-profiling gas microstrip instrument.

In collaboration with teams in the UK and Germany, ID has produced a detector system that adds the ability to measure electrons from different depths within a sample. This added capability allows researchers to conduct simultaneous EXAFS studies of both the surface and bulk material of a sample.

The new detector system exploits the capabilities of a Gas Micro-Strip Detector (GMSD) developed by the department. Containing both detector and sample in the same experimental environment, it allows EXAFS studies at ambient temperature and pressure.

The ability to operate at elevated temperatures has been added, which will allow researchers to study catalysis reactions as they happen.

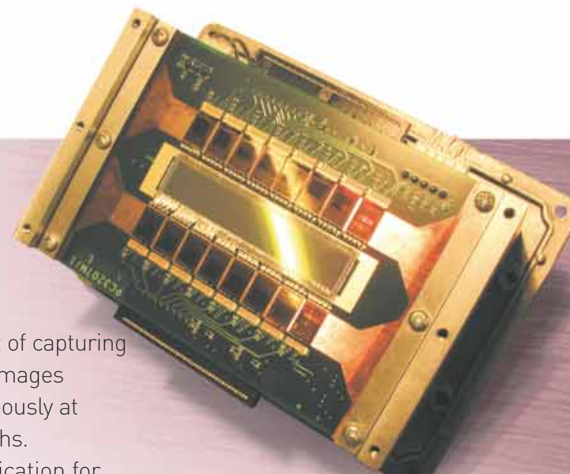
The department also developed the readout system for the new instrument. This consists of charge preamplifiers and shapers mounted locally to the detector. The signals are then transmitted to a multi-parameter data collecting system that can handle counting rates of over 500 kHz without introducing significant non-linearities.

The output from this system is a large collection of pulse-height spectra, one for each point in the EXAFS scan. Software developed by the collaboration takes these spectra and generates EXAFS scans at various depths within the sample.

For more information contact:
John Lipp
Tel: 01235 445316
Email: j.lipp@rl.ac.uk

DIFFEX – Colour X-ray imaging

In many areas of science using X-ray techniques, researchers would like to produce images at different wavelengths or energies. This 'colour imaging' is particularly challenging when also trying to detect X-rays at the high rates necessary for some experiments.



The DIFFEX detector assembly.

Using leading-edge technologies in solid-state detectors and microelectronics, Instrumentation Department is addressing both of these challenges with the DIFFEX project.

DIFFEX is a silicon detector with 1024 microstrips and 1024 independent readout channels. The readout is implemented on 16 64-channel microelectronic devices, which sense and amplify the charge created in a strip by the absorption of an X-ray. The size of the signal depends on the energy of the incident X-ray.

The readout circuits, all operating in parallel, convert the signal into a digital value, which is used to increment one of 16 counters, depending on the energy. Different counters detect and store split events, where two silicon strips share the charge. Each channel is therefore equivalent to a multi-channel analyser, with the whole readout system integrated into an area of only a few square millimetres.

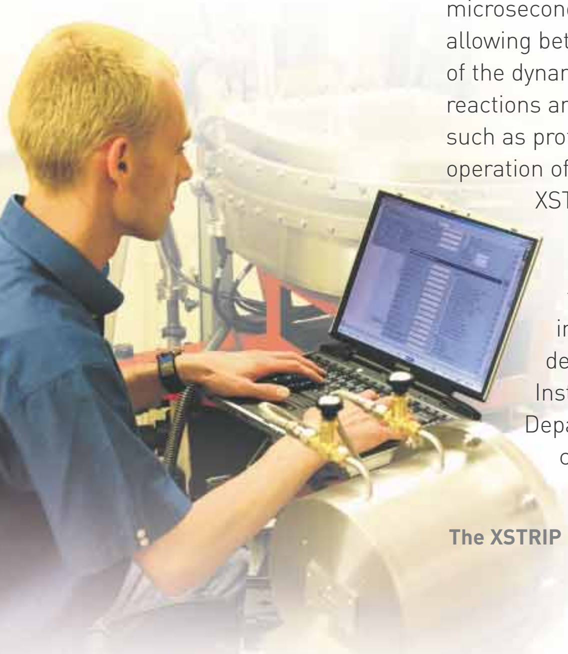
The final product of capturing data is a set of 16 images obtained simultaneously at different wavelengths.

The driving application for DIFFEX is the detection of powder diffraction patterns in a lab-based system or at a synchrotron. Because of the fast, massively parallel, multi-channel operation, DIFFEX will open new perspectives for time-resolved experiments. Its advanced architecture also paves the way towards full 'colour', two-dimensional X-ray imaging.

For more information contact:
Renato Turchetta
Tel: 01235 446633
Email: r.turchetta@rl.ac.uk

XSTRIP – A high resolution X-ray detector

A new instrument developed by CCLRC in collaboration with Cambridge and Southampton universities dramatically enhances the power of X-ray studies of dynamic processes.



The XSTRIP detector system extends the scope of energy-dispersive EXAFS down to microsecond timescales, allowing better understanding of the dynamics of chemical reactions and phase changes, such as protein folding or the operation of catalysts.

XSTRIP combines silicon microstrip technology with fast low-noise integrated circuits, developed by Instrumentation Department (ID), to capture data.

The XSTRIP detector is fabricated from 500-micrometre thick high-resistivity silicon. The strip contains 1024 diodes arranged in a linear array. These diodes are individually bonded to fast, low noise integrated circuits able to read out data at 100 kHz rates. The result is an instrument that can make high-speed precision measurements of structural changes.

In the project, funded by Engineering and Physical Sciences Research Council, ID also designed the data acquisition system around commercial off-the-shelf components using standard PC architecture. This not only reduced the time and cost of development, but also allowed significant flexibility in the data processing architecture.

The XSTRIP system is up to 50 times faster than previous detector systems. The improved linearity of the read-out electronics also improves the data quality.

Early experience with the detector has demonstrated such high performance that there is already interest in further XSTRIP systems from other synchrotron facilities around the world.

For more information contact:
Jon Headspith
Tel: 01925 603624
Email: j.headspith@dl.ac.uk

The XSTRIP instrument in use at the Synchrotron Radiation Source.

RAPID 2 – High-speed X-ray detection

The demand for new instrumentation is often an opportunity for Instrumentation Department (ID) to introduce new techniques and technologies. This was important in the case of the development of RAPID 2, a second-generation detector system for the SRS at the CCLRC Daresbury Laboratory.

The RAPID 2 instrument was developed by CCLRC for use on the SRS, under an EPSRC grant held by Birkbeck College. Its aim is to investigate the structure of materials, primarily in powdered form, as a function of changing pressure, temperature, pH, humidity or presence of corrosive atmospheres. It will provide high-resolution, time-resolved studies of reacting materials with unprecedented speed and accuracy.

The RAPID 2 instrument is required to deliver a high count rate of up to 10 MHz while simultaneously detecting X-rays scattered from the sample at wide angles (WAXS) and small angles (SAXS). This entails two detectors connected to the same data acquisition system.

In designing this second generation of readout electronics for RAPID 2, ID took the opportunity to make use of the latest technologies to develop a more integrated system that consumes less power, while operating at the same speed, than the earlier systems. This allowed a higher density of components on the purpose-built PCBs, leading to significant cost reductions, higher data rate capability and increased reliability.

ID designed and built the complete RAPID 2 system, including the wire plane gas detectors and electronics. The WAXS detector consists of 512 10-micrometre diameter wires, spaced 0.75mm apart. This high tolerance device is assembled with the wires under tension and requires a significant level of both design and assembly skill to ensure a correctly working detector. The efficient layout and large number of signal connections to the readout system electronics also posed a challenge, requiring ID to design custom crates to house the large PCBs.

RAPID 2 was successfully installed and commissioned on a new, high-brightness beamline at the SRS during 2002. Early results demonstrate the huge potential of this instrument.

For more information contact:
William Helsby
Tel: 01925 603250
Email: w.i.helsby@dl.ac.uk

SR detector support

Over 40 detector systems are installed or available on experimental stations at the SRS at the CCLRC Daresbury Laboratory. Instrumentation Department (ID) staff are a focus for detector issues with customers and have to respond quickly to diagnose and repair faults. Our objective is to maximise data quality and minimise lost beam time, since the loss of detector systems, and consequently the experimental station, is costly.

Improvements in synchrotron-based research can only be achieved by ensuring that detector technology improves to match the enhancements in sources and beam optics. Staff working on detector development work closely with support scientists so that new systems are integrated smoothly and efficiently into experimental stations.

The same close collaboration is also important in the introduction of new systems that come to the SRS from universities and other organisations.

ID staff provide essential support for SRS detectors.

A further task for ID is to support the acquisition and use of equipment or technology developed within CCLRC by other organisations and facilities. The availability of this support can be vital in situations where customers do not have in-house expertise.

For more information contact:
David Bogg
Tel: 01925 603705
Email: d.bogg@dl.ac.uk

The RAPID2 instrument being commissioned on an SRS beamline.

Silicon beam monitors

High precision synchrotron-based measurements rely on accurate monitoring of the intensity and position of the X-ray beam. Instrumentation Department is developing and evaluating beam monitor systems based on silicon diode detectors.

The motivation for using silicon is to develop solid-state replacements for the current generation of gas chamber systems. Silicon is more efficient at detecting X-rays than the argon commonly used in gas detectors, requiring less sensitive signal amplification. The homogeneity of silicon also makes it easier to characterise the energy loss in the detector. These properties hold the promise of more sensitive detectors with higher resolution.

The higher density of silicon delivers a 150-fold reduction in the stopping distance for X-rays. This makes it possible to build more compact devices and place silicon diode detectors where there is insufficient room for an ion chamber. Silicon detectors are also simpler to operate and more stable, with a more accurate response, than gas devices.

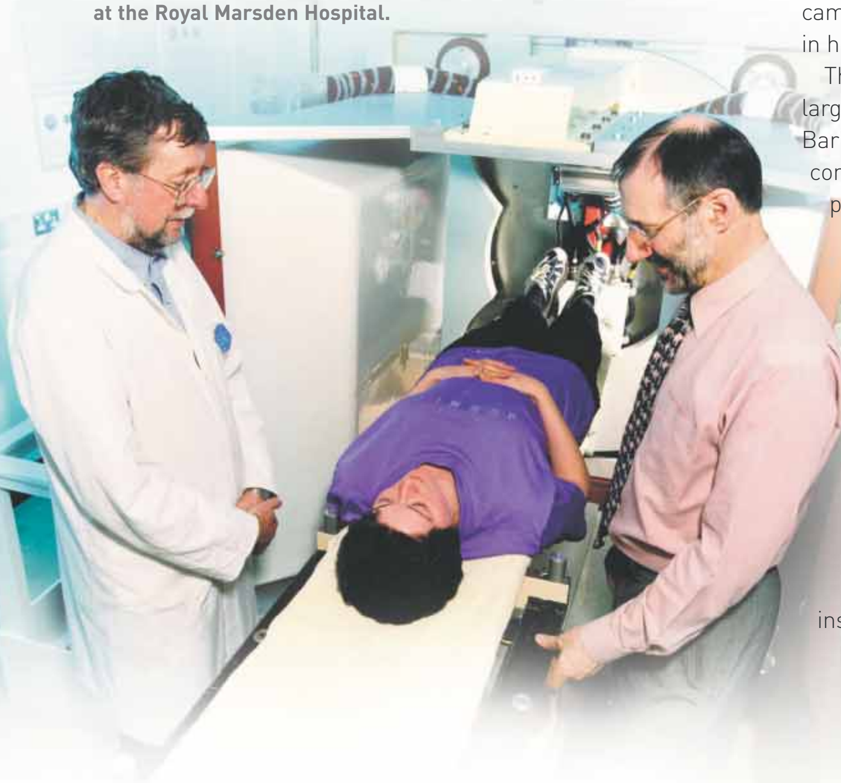
ID has evaluated different types of silicon structure, size and mode of operation, demonstrating good flux linearity with better efficiency and stability than the current versions of gas-based beam monitor detectors.

For more information contact:
Guiseppe Salvini
g.salvini@dl.ac.uk

PETRRA - An advanced PET camera for medicine

Positron Emission Tomography (PET) is a powerful medical imaging technique. Images produced using PET show the metabolic function of organs and tissues. The technique delivers significant benefits in the diagnosis of diseases such as cancers, brain malfunction and heart disease.

The PETRRA camera installed at the Royal Marsden Hospital.



The novel positron camera, PETRRA, has been developed in a project including CCLRC and the Royal Marsden Hospital. A joint venture company, PETRRA Ltd has been formed and the camera has entered a significant new phase in its development with the start of patient trials. The aim is to build PETRRA cameras commercially for use in hospitals around the world.

The camera is based on large-area gas detectors. Barium fluoride scintillators convert the gamma rays produced by positrons in the patient into ultraviolet photons that are detected in the gas. The instrument provides the biggest active volume of any positron camera built to date. It is ideally suited to finding secondary tumours in cancer patients who need a whole-body scan. The camera has been installed in the scanning suite at the Royal Marsden Hospital at Sutton, Surrey. Tests conducted using 'phantoms', which simulate real patients and have well understood imaging characteristics, demonstrate that the camera can image small tumours anywhere in the body.

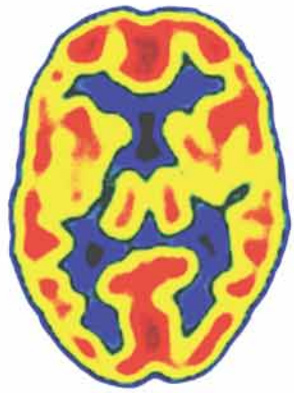


Image of a brain phantom obtained with PETRRA.

For more information contact:
Richard Stephenson
Tel: 01235 445336
Email: r.stephenson@rl.ac.uk

Understanding how proteins fold

Research on the human genome has thrown the spotlight on the way in which proteins 'fold' and arrange themselves in cells. How a protein folds determines how it functions in the body. Instrumentation Department (ID) is helping to develop instruments that improve the precision and speed of protein folding studies.

ID is working on new approaches to the study of circular dichroism (CD), a powerful technique in determining the secondary structure and three-dimensional shape of proteins. CD relies on the fact that large biological molecules, such as proteins or DNA, are composed of optically active elements. They show a preference in the absorption of light depending on its state of circular polarisation, its 'handedness'.

Protein molecules will preferentially absorb left- or right-handed circularly polarised light, depending on their structure. By measuring the difference in absorption between left- and right-polarised light information about the shape of a protein can be obtained. Such experiments are an increasing part of the work of the Synchrotron Radiation Source at the Daresbury Laboratory.

The department is working on a novel instrument system,

Improving medical X-ray images

In the century since the discovery of X-rays by Roentgen, the basic technique for obtaining images has remained largely unchanged. Medical X-ray imaging is usually based on the contrast between those X-rays that passed through an object and those that were absorbed.

In addition to some of the X-rays being absorbed by a material, others are scattered from electrons within the atoms. In traditional X-ray imaging, the scattered rays are not considered to contain any useful information about the object; they decrease the contrast of the image by 'fogging' the X-ray film.

Researchers who use the SRS for diffraction studies know that scattered X-rays carry detailed information about the structure of the object through which they pass. Instrumentation Department (ID) is working with various academic institutes to detect and use scattered X-rays from biological tissues.

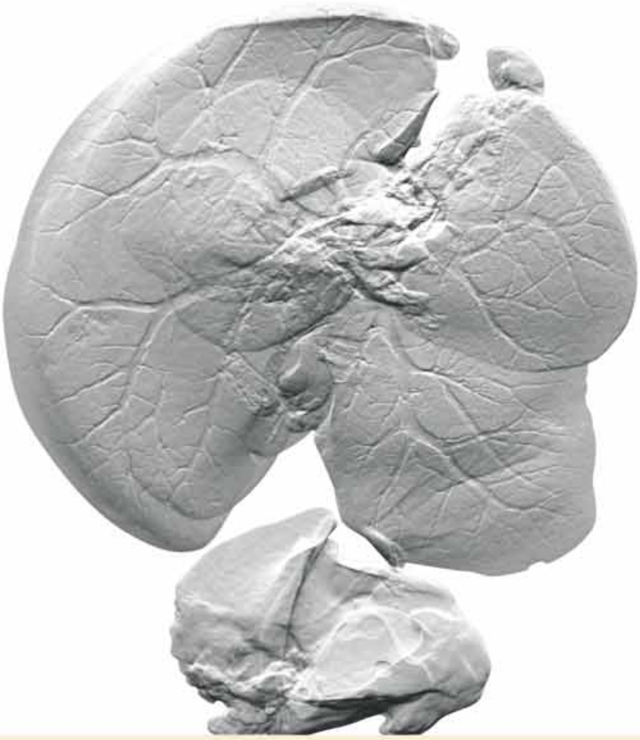
By studying scattering in different angular regimes, it is possible to gather different types of information about the structure of an object. X-rays scattered at large angles in highly ordered materials provide information on how each atom is arranged in a crystal lattice. X-rays scattered at small angles arise from refraction at density interfaces within the object.

Selecting only the small-angle scattering can produce images that highlight these interfaces. This is achieved by placing a silicon crystal, known as an analyser, between the object and the detector. This only reflects photons in a certain range of angles. Thus an image is formed on the detector from only the scattered X-rays.

ID's expertise in X-ray beam line control and detector technology has contributed to an instrument capable of producing very high quality images of biological samples. The beauty of this system is that the scattered X-rays deposit no energy in the object, so a high contrast image can be produced with a smaller dose than by conventional methods.

For more information contact:
Chris Hall
Tel: 01925 603886
Email: c.j.hall@dl.ac.uk

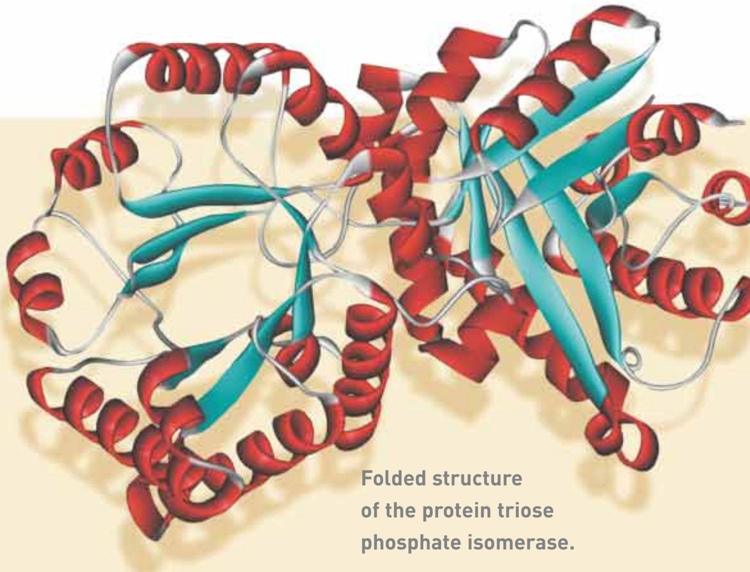
Image of a mouse liver using small-angle scattered X-rays.



based on a linear silicon detector array that will perform a CD measurement at multiple wavelengths simultaneously. Such a system will revolutionise the study of CD, opening the way for high-throughput experiments and dynamic studies with unprecedented accuracy.

A first CD spectrum has been produced at the SRS, with a silicon detector array and electronics designed in house. ID is now developing a detector capable of detecting photons below 200 nm, the present limit with silicon photodiodes, while retaining a linear array format.

For more information contact:
Spyros Manolopoulos
Tel: 01235 445028
Email: s.manolopoulos@rl.ac.uk



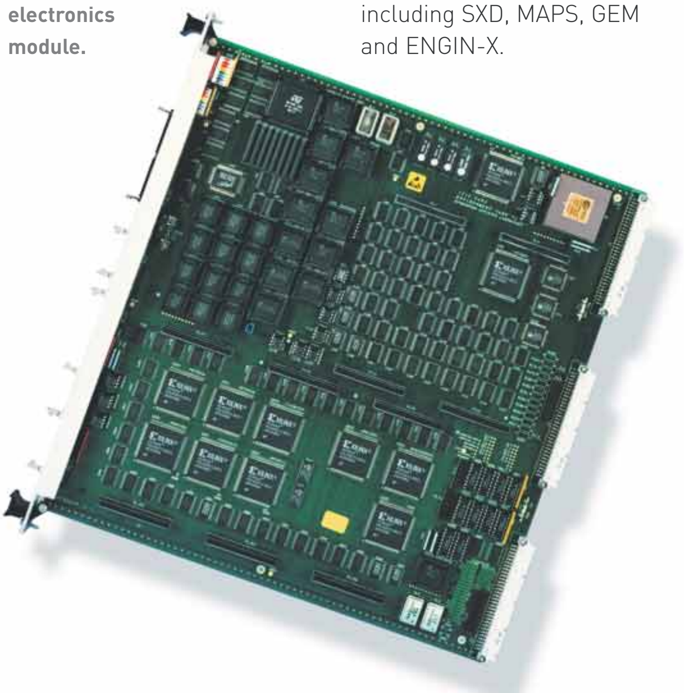
Folded structure of the protein triose phosphate isomerase.

Data acquisition electronics

With 19 major instruments, and researchers eager to capture ever more information from each instrument, ISIS places constant demands on data acquisition electronics (DAE). The DAE systems are the essential link between the neutron detectors and the computers that collect, store and enable scientists to analyse their data.

In recent years, Instrumentation Department (ID) has helped ISIS to achieve a massive increase in data capture capability through the design and implementation of the DAE-II system – an important development for a number of ISIS instruments, including SXD, MAPS, GEM and ENGIN-X.

An ISIS DAE electronics module.



DAE-II is a replacement for the original system, DAE-I, which is still in operation. First introduced in 1984, DAE-I has undergone substantial development and now incorporates new operational features. The system now has many more modules for detector input as detector arrays have grown. Significant changes have also been made to the computer interface.

ID continues to support DAE-I but the recent introduction of DAE-II has enabled an increase in the number of detectors in each instrument. Whereas early DAE-I systems were required to capture data from fewer than 100 detectors, today's instruments may have more than 10,000 channels.

As part of the move to DAE-II, ID has developed a PC interface. In previous systems the interface was to ageing Alpha machines running VMS. Based on a commercial card, the new interface allows a tenfold improvement in data transfer rates to 10 Mbytes per second, with the prospect of higher rates in the future. The new interface also benefits from the processing power available in modern PCs.

The first ISIS instrument to have data acquisition controlled by a PC is ENGIN-X, a new system optimised for engineering measurements.

...ID has helped ISIS to achieve a massive increase in data capture capability through the design and implementation of the DAE-II system...

Resistive wire detector electronics

The department has been a key player in the design and construction of detector and data acquisition electronics for the resistive wire detector array in the Alignment Facility (ALF) for ISIS. ALF allows researchers to align crystal samples before analysing them in the main ISIS instruments. This reduces the need for valuable beam time for alignment.

ALF includes an array of 24 metre-long tubes filled with ^{3}He. The tubes are arranged as a pixellated array. The electronics detect the position of a neutron passing through the detector by comparing the charge of electrical signals produced at each end of a wire running the length of each tube.

The detector electronics, designed and built by ID, comes in two parts, a low impedance front-end amplifier board and a 16-channel ADC board to calculate the position of each event. The electronics will also be used to evaluate trials of an experimental 3-metre long ^{3}He tube for the MERLIN instrument.

Scintillating detectors

Instrumentation Department (ID) plays a significant role in the development of electronics for detector systems at ISIS. Here the department brings to bear its skills in microelectronics design and the integration of many channels of readout into a single system.

The GEM detector array at ISIS.

One area of work where ID has contributed is in the development of electronics for detectors based on scintillators and photomultiplier tubes (PMTs). For example, ID has been involved in the installation of GEM, the General Materials Diffractometer, recently constructed at ISIS. When fully commissioned, this major instrument will include electronics to read out more than 400 detector channels.

...Instrumentation Department plays a significant role in the development of electronics for detector systems at ISIS...

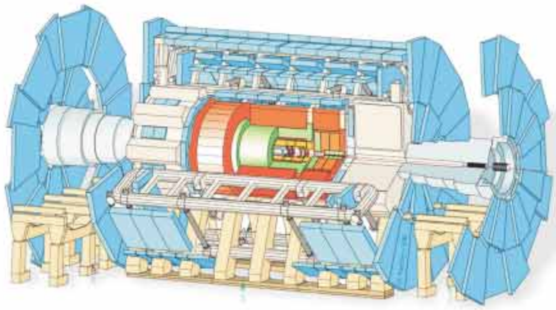
ID has devised electronics that can accommodate different designs of modules for scintillator detectors. This proved valuable in the upgrade of SXD-II, the Single Crystal Diffractometer, where the requirement was for the installation of two-dimensional pixel array modules as opposed to the one-dimensional linear arrays of the GEM modules. Thanks to this design, it was necessary to change only a few component values on the printed circuit boards, saving time and money in producing a very large detector array with more than 350 PMT channels.

For more information contact:
Julian Norris
Tel: 01235 445807
Email: j.norris@rl.ac.uk

David Allen
Tel: 01235 446454
Email: d.b.allen@rl.ac.uk

ATLAS level one trigger system

Instrumentation Department (ID) is contributing to the design and construction of instrumentation for the experiments being built for the Large Hadron Collider (LHC) at CERN. Due to start operation in 2007, the LHC will investigate the fundamental properties of matter. ATLAS (A Toroidal LHC Apparatus), is one of the two large general purpose detectors at the LHC.



Schematic view of the ATLAS detector.

Courtesy CERN

The ATLAS detector will produce an unprecedented flood of data. Of the billions of particle interactions that occur every second, only a small fraction contain data useful for analysis. The experiments rely on several levels of sophisticated processing to successively reduce the data volume by selecting only interesting events.

Engineers from ID are designing and building 'trigger' systems to make these decisions. One such system searches for patterns in the energy deposited in the detector by particles produced in the collisions. The trigger will discard approximately 999 events for every one that contains useful data.

While the system is deciding which events to record, memory buffers hold detector data. The high cost of these memories means they must be kept to a minimum. As a result, the system has less than a microsecond to process the data and to decide whether to record or reject an event.

Recent developments in the performance of Field Programmable Gate Arrays (FPGAs) allow us to deliver a highly integrated system that can also be re-programmed in situ. It will therefore be possible to implement improved or alternative trigger algorithms during the lifetime of the experiment. This leads to a more flexible and future-proof design than one based around traditional Application Specific Integrated Circuits (ASICs).

For more information contact:
Viraj Perera
Tel: 01235 445692
Email: v.j.o.perera@rl.ac.uk

CMS tracker readout

The Compact Muon Solenoid (CMS) experiment is one of the massive next-generation particle detectors under construction for the LHC at CERN. A major component of CMS is a large, cylindrical silicon micro-strip detector. This system will record the trajectories of the huge numbers of particles emanating from each collision. Instrumentation Department (ID) is developing two important elements of the electronics for data acquisition on the silicon detector.

Courtesy CERN

The CMS detector is currently being built at CERN.

The APV25 read-out device and the Front-End Driver (FED) module will provide the large-scale electronics system required to read out the enormous data volumes generated by the 10 million channels in the silicon tracker. Together, the APV25s and FEDs will form a reliable, robust and cost-effective readout system.

The APV25 is a custom ASIC (Application Specific Integrated Circuit), designed 'right first time' by Instrumentation Department in a 0.25 micrometre process technology that is naturally resistant to the intense radiation environment experienced within the detector. Some 80,000 of these devices will amplify the signals generated in the silicon by 40 million collisions per second and store them in analogue form.

After the detector trigger system has selected events of interest, the stored information is processed and transmitted over optical fibres to the FEDs. These digitise the signals, perform hit-detection and suppress empty channels, reducing the data to a more manageable level. This is then passed on to the CMS central data acquisition system for further processing and storage.

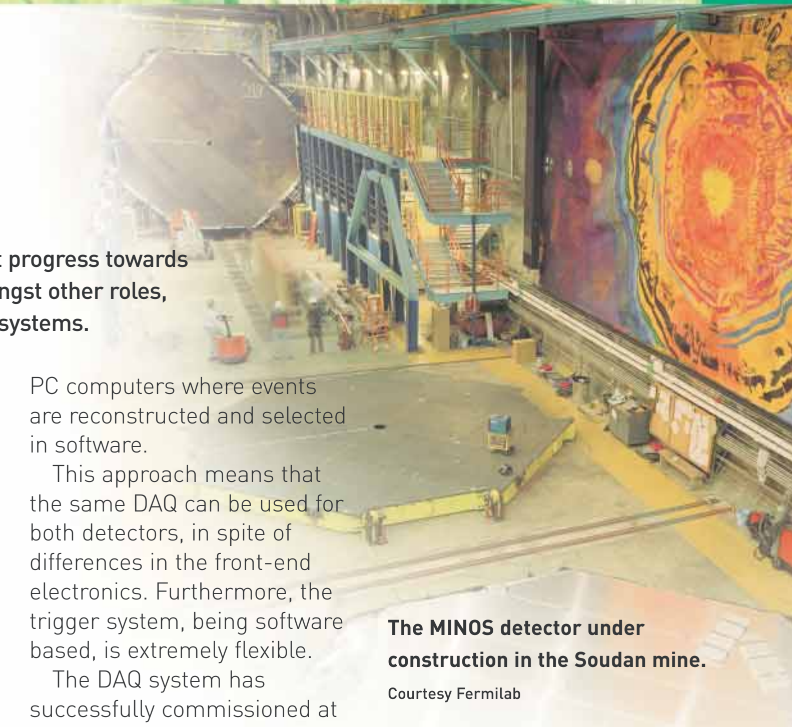
The 450 FEDs required by the CMS silicon tracker process data using algorithms implemented in many large Field-Programme Gate Arrays (FPGAs). The latest generation of FPGAs, with up to two million logic gates each, are well suited to this task. The re-programmability of these devices also provides a high degree of flexibility in the design of the processing algorithms.

Initial design and prototyping of the FED took place during 2002. The production of 500 modules for the final system will be completed during 2005.

For more information contact:
John Coughlan
Tel: 01235 446474
Email: j.a.coughlan@rl.ac.uk

MINOS – A long baseline neutrino experiment

Engineers and scientists from CCLRC have made significant progress towards the full operation of the MINOS neutrino experiment. Amongst other roles, CCLRC has prime responsibility for the data acquisition (DAQ) systems.



The MINOS detector under construction in the Soudan mine.

Courtesy Fermilab

MINOS is an international experiment designed to study the properties of neutrinos, in particular to determine if they have mass. The experiment consists of two huge detectors; one at the Fermilab accelerator laboratory in Chicago and the other 700 metres below ground in an iron mine located at Soudan, Minnesota.

MINOS will look for changes in a beam of neutrinos created at Fermilab and fired through 730 km of the Earth's crust to Soudan. By comparing the composition of the beam at Fermilab in the Near Detector with that observed at Soudan in the Far Detector, it is possible to infer the properties of the neutrino.

Instrumentation Department's design for the DAQ was, rather than a traditional approach of custom-built readout and trigger electronics, to employ commercial processor units that capture data continuously from the front-end electronics. High-speed links transfer this data to an array of standard PC computers where events are reconstructed and selected in software.

This approach means that the same DAQ can be used for both detectors, in spite of differences in the front-end electronics. Furthermore, the trigger system, being software based, is extremely flexible.

The DAQ system has successfully commissioned at the Far Detector and is now in routine use. A prototype system is presently also in use for development of the Near Detector electronics.

For more information contact:
Saeed Madani
Tel: 01235 446439
Email: s.madani@rl.ac.uk

MUSCAT – Understanding muon scattering

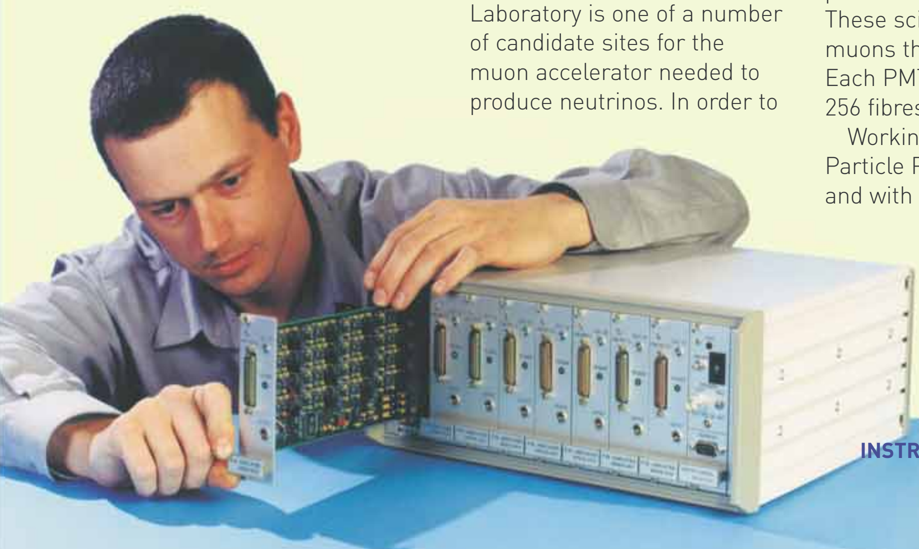
Instrumentation Department (ID) tapped into its expertise in particle detectors to provide important electronics for the MUSCAT muon scattering experiment. MUSCAT, due for installation in 2003 on a beam line at the TRIUMF laboratory in Vancouver, Canada, is part of a global research programme to develop a neutrino factory.

High energy physicists are keen to study neutrinos and plan to create them through the decay of muons. CCLRC Rutherford Appleton Laboratory is one of a number of candidate sites for the muon accelerator needed to produce neutrinos. In order to make this approach viable an improved understanding of the scattering of muons in matter is required.

MUSCAT uses a large vacuum vessel equipped with a variety of tracking and detection apparatus. It has a series of optical fibre scintillators that feed light created by the passage of muons through them into photomultiplier tubes (PMTs). These scintillators track the muons through the detector. Each PMT gathers light from 256 fibres.

Working with CCLRC's Particle Physics Department and with researchers at CERN and TRIUMF, ID combined an understanding of physics with its ability to design compact, efficient electronics for the data readout system.

The MUSCAT readout system consists of 24 16-channel amplifier cards. The readout system simultaneously reads signals generated from 24 PMTs and then feeds data into a computer system. To keep costs down, ID designed a system that minimised the number of components required while maintaining a good signal to noise ratio and dynamic range.

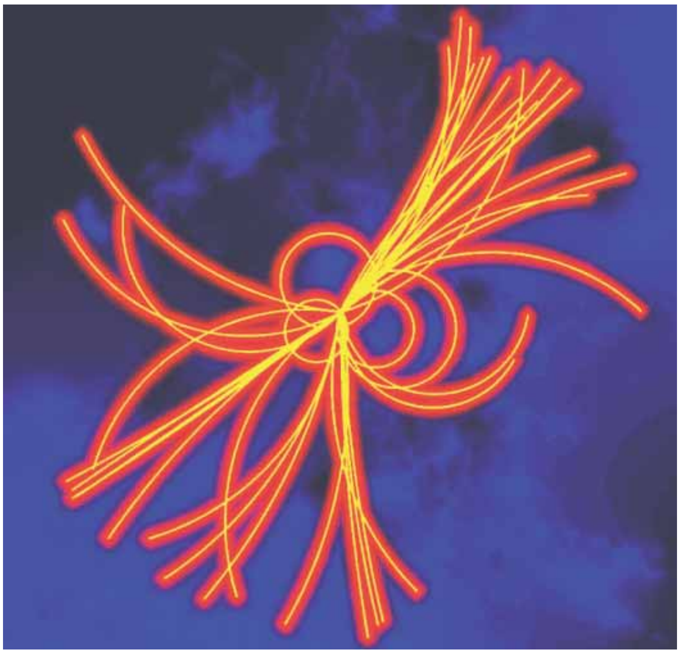


Electronics for the MUSCAT experiment.

For more information contact:
Roger Barlow
Tel: 01235 446470
Email: r.barlow@rl.ac.uk

LCFI – An R&D programme for linear collider detectors

The huge scale, complexity and cost of advanced accelerators requires the high energy particle physics community to undertake long-term planning, research and development. Even prior to construction of the LHC, groundwork is being done for the next big facility. This is likely to take the form of a linear accelerator, up to 30 km in length, which will collide electrons and positrons at unprecedented energies.



Computer simulation of a particle collision in a linear collider detector.

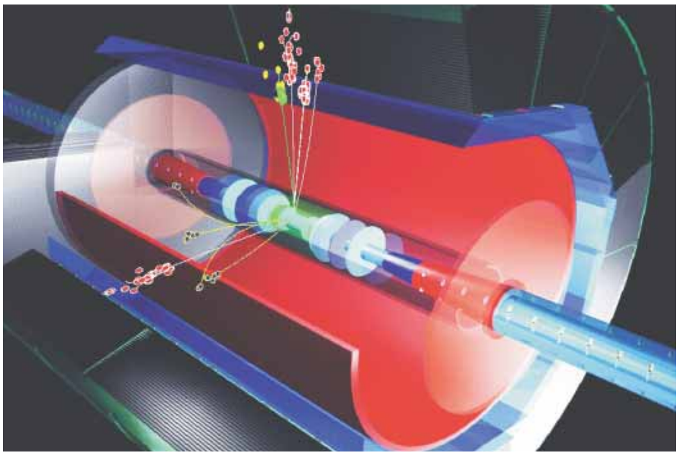
Courtesy DESY Hamburg

Detectors at the linear collider will be required to make high precision measurements of the short-lived, heavy 'flavours' of quarks. This requires a high-resolution detector, in close proximity to the collision beams, which can accurately reconstruct vertices in tracks emanating from the decay of heavy quarks. An existing approach is to encircle the collision point with detector arrays based on silicon Charge-Coupled Devices (CCDs).

The Linear Collider Flavour Identification (LCFI) collaboration, which includes CCLRC, is an R&D programme with the goal of proving the viability of a CCD-based vertex detector for the linear collider. This will require a CCD with very low power dissipation capable of tolerating a high radiation environment. It must also operate at frequencies several orders of magnitude higher than existing designs.

LCFI is evaluating a number of potential CCD designs. ID is closely involved in the development of a high speed 'column-parallel' readout system for CCDs and has also designed and constructed a test system to power, control and read out a range of devices. Interfaced to a computer, this system provides a comprehensive and flexible framework in which to perform the tests.

...The Linear Collider Flavour Identification (LCFI) collaboration, which includes CCLRC, is an R&D programme with the goal of proving the viability of a CCD-based vertex detector for the linear collider...



A conceptual design for a linear collider detector.

Courtesy DESY Hamburg

For more information contact:
Stephen Burge
Tel: 01235 445528
Email: s.r.burge@rl.ac.uk

GERB 3 – Measuring the Earth's radiation budget

The MSG-1 satellite, launched into orbit in August 2002, is the first of a new generation of weather satellites. EUMETSAT's Meteosat Second Generation (MSG) satellites will allow meteorologists to provide far more accurate European weather forecasts. MSG-1, the first of three similar satellites planned so far, carries instruments developed and designed by a collaboration that includes CCRLC.

Artist's impression of an MSG satellite in orbit.
Courtesy ESA – D. Ducros

CCLRC provided overall management of the GERB (Geostationary Earth Radiation Budget) instrument on MSG-1. The instrument is designed to make accurate measurements of the Earth's radiation budget from geostationary orbit. A linear array of 256 detectors forms images of the Earth every 2.5 minutes.

The spacecraft rotates continuously at 50 revolutions per minute, so a descan mechanism ensures that the instrument mirror stays pointing in the right direction. Designing this system was particularly challenging since GERB is mounted on the edge of the satellite and is subjected to forces 18 times greater than gravity on Earth.

Instrumentation Department designed the control system for the descan mechanism of the GERB-3 instrument, which will be flown on the third satellite, MSG-3. A novel design was adopted, which provides better control, and hence clearer images, than that used for the earlier GERB instruments.

The system is implemented using modern vector control techniques resulting in an innovative, precision mirror pointing system. Vibration and thermal tests of the instrument, designed to simulate the harsh environment encountered during flight, have demonstrated that the control system meets the demanding requirements.

The instrument, completed in 2002, is due for launch on MSG-3 in about seven years. The vector control system is the first known application of the technique for a space instrument, and has potential for use in many aerospace applications.

For more information contact:
Alec Hardie
Tel: 01235 445826
Email: a.l.hardie@rl.ac.uk

Antenna control

Under contract to CCLRC's Space Science and Technology Department, Instrumentation Department (ID) has implemented a complete upgrade of the control systems for the antenna used at RAL to communicate with satellites. The upgrade was needed so that the antenna can, in future, operate in the X-band, at frequencies of around 8.5 GHz. This fourfold increase in communications frequency over previous operations requires high precision positioning of the antenna.

The upgrade was also necessary because the age of the original equipment made it increasingly difficult to maintain.

The antenna is now back in daily service, receiving data from the Advanced Composition Explorer (ACE) spacecraft under contract to the US National Oceanic and Atmospheric Administration (NOAA). ACE is located in space about 1.5 million kilometres from Earth and investigates the solar wind and high energy particles coming from elsewhere in the galaxy.

Delivering near-real-time data through a network of ground stations including RAL, ACE can provide short-term warnings of solar activity likely to disrupt power grids and communications on Earth.

The original equipment, some 20 years old and housed in a nearby building, has been replaced with a system in a weatherproof cabinet at the antenna's pedestal. The new cabinet complements one containing the servo amplifiers, installed in 1999 when the drive motors and associated power amplifiers were upgraded.

The project involved designing interfaces between a PC and the existing antenna structure, together with the installation and commissioning of the new equipment. This had to work with new control software developed by an external company. The new interfaces allow remote control and monitoring of the antenna, via the Internet if necessary.

For more information contact:
Adrian O'Hea
Tel: 01235 445369
Email: a.r.o'hea@rl.ac.uk

The RAL antenna tracking a satellite.

Electronics production and testing

Successful development and production of advanced electronic systems depends on first class layout and manufacture of printed circuit boards (PCBs), evaluation of custom devices and detailed testing of assembled products. Instrumentation Department (ID) provides a complete service for electronics production and testing.

ID is able to perform detailed tests of semiconductor devices prior to integration. Sophisticated device testing equipment allows automated tests to be performed, based on data derived during design and simulation.

The department produces boards for a wide range of instrument systems. The process involves converting a schematic design into the PCB layout, then managing the procurement of components and the external manufacture of the boards. ID also undertakes rigorous testing of the completed boards and provides long-term support during their operational life, which can be 15 years or more.

Production of state of the art PCBs requires access to the latest design tools. The department makes widespread use of a range of leading design software packages used throughout the electronics industry.

The trend towards increasingly high-density packaging of electronic devices, and the move to put ever larger numbers of components on each board, has led to increasingly complex PCBs; these may have up to 6,000 components with a total of 25,000 connections running over 14 layers. Such demands require PCB designers to be aware of the current capabilities of the PCB manufacturers. For that reason the department maintains close contact with manufacture and assembly companies.

PCBs of this complexity require rigorous testing, at both component and board levels. Automated testing is becoming increasingly important. The output files from the PCB layout, coupled with the use of appropriate design techniques throughout the development process, enable the use of advanced testing methodologies. These include automatic JTAG chain tests, which can verify the interconnection and correct operation of components.

Functional and system-level testing of assembled boards is also undertaken. These tests make extensive use of high performance test equipment and bespoke testing software produced in house using tools such as LabView.

Sophisticated equipment allows automated testing of semiconductor devices.

For more information contact:
Viraj Perera
Tel: 01235 445692
Email: v.j.o.perera@rl.ac.uk

Integrating semiconductor detectors

Instrumentation Department provides state of the art resources to support the research community. CCLRC, universities throughout the UK and international bodies benefit from access to a large detector integration facility at RAL, operated by the department.

This facility is used for the precision assembly and testing of semiconductor detectors, which play an increasingly important role in scientific instrumentation. A Class 10,000 clean room complex at RAL provides sophisticated metrology and alignment equipment and a wire-bonding capability.

...the facility has established a global reputation in wire bonding, using ultrasound to make wire connections between detectors and electronics with micrometre precision...

Semiconductor technology has made increasing inroads into detectors since its early adoption in astronomy. More recently, semiconductor detectors have changed the way in which particle physicists track collisions. To do this, detectors have to be constructed with minimal mass and designed to withstand the severe radiation environment created by accelerators. These detectors are often inaccessible after installation and may need to survive without any opportunity for servicing for ten years or more.

These stringent requirements demand production techniques far beyond those used in the electronics industry. For example, the facility has established a global reputation in wire bonding, using ultrasound to make wire connections between detectors and electronics with micrometre precision.

The largest current project in this area is the construction of around 600 silicon detector modules for the ATLAS inner tracking detector, which is due to be installed at the Large Hadron Collider (LHC) at CERN in 2005. On the horizon, the facility expects to provide similar services for the diamond synchrotron radiation source.

The department's expertise in wire bonding contributed to several projects described elsewhere in this review, including XSTRIP, GERB and DIFFEX. The facility is also involved in the development of nanotechnology in the UK, including work on field emitter arrays for the Nanotechnology Research Centre at the University of Birmingham.

For more information contact:
Richard Apsimon
Tel: 01235 446153
Email: r.j.apsimon@rl.ac.uk

Wire bonding a semiconductor detector module.

Advanced design tools

Instrumentation Department not only deploys the latest design tools and techniques in its own electronics design activities, but also helps the academic community across Europe to gain access to them. Through its EUROPRACTICE Software Service, the department's Microelectronics Support Centre (MSC) supplies leading-edge, industry standard software tools and flows for the design and verification of electronic, microelectronic and Micro Electrical Mechanical Systems (MEMS).

The centre consists primarily of application engineers supporting the highly complex design tools and flows for its external customers.

The tools provided by the MSC, at significantly reduced cost, are expensive commercial packages typically used only by the largest multinational companies. The scheme is funded largely through user fees, with additional strategic funding through the Information Society Technologies (IST) programme of the European Commission.

The EUROPRACTICE Software Service has over 560 customers in 39 countries, with an installed base of over 26,000 licences and an annual turnover of over €3 million.

The customers for this service are universities and academic research laboratories within the European Union, along with countries close to Europe, including the newly affiliated states and countries with traditionally close links to Europe. The centre also provides additional dedicated support for the UK research community funded by the Engineering and Physical Sciences Research Council.

For more information contact:
John McLean
Tel: 01235 445276
Email: j.a.mclean@rl.ac.uk

...the EUROPRACTICE Software Service has over 560 customers in 39 countries, with an installed base of over 26,000 licences and an annual turnover of over €3 million...

The Microelectronics Support Centre provides access to highly complex design tools.

Contacts

Instrumentation Department Office
Tel: 01235 445566
Fax: 01235 445753
Email: instrumentation@rl.ac.uk
Web: http://www.ins.clrc.ac.uk

Director of Instrumentation
Dr Mike Johnson
Tel: 01235 445418
Fax: 01235 445840
Email: m.w.johnson@rl.ac.uk

General Enquiries
Tel: 01235 445533
Email: enquiries@cclrc.ac.uk
Web: http://www.cclrc.ac.uk

CCLRC Rutherford Appleton Laboratory
Chilton
Didcot
Oxfordshire
OX11 0QX

CCLRC Daresbury Laboratory
Keckwick Lane
Daresbury
Warrington
Cheshire
WA4 4AD

CCLRC