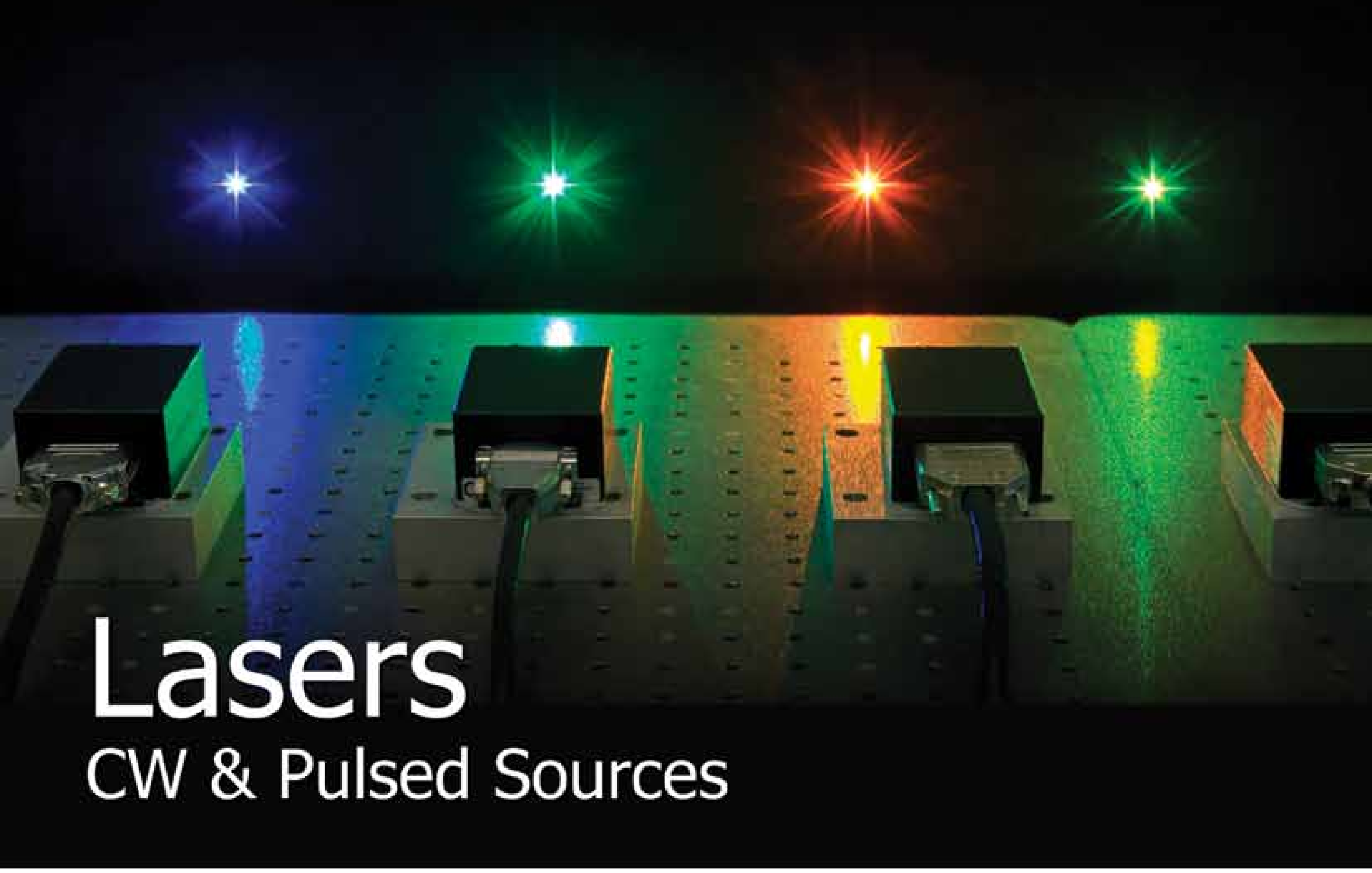
Australian Physics

Volume 50, Number 4, Jul–Aug 2013

PRECISION NOISE MEASUREMENT

LIFE AS A PETROPHYSICIST

AUSTRALIAN SENIOR PHYSICS CURRICULUM



Lasers
CW & Pulsed Sources

DPSS

Low noise CW DPSS lasers
ns pulsed DPSS lasers
Sub-ns DPSS lasers
ps DPSS lasers
Light engines

Diode Lasers

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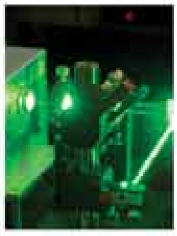
High performance fixed wavelength
High power NIR diode lasers
Frequency stabilised laser
Fibre coupled versions



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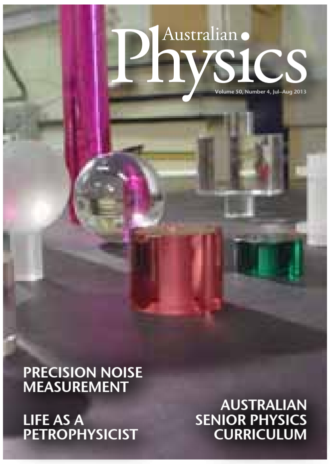

Cover

Assorted dielectric crystal whispering gallery mode resonators. Crystalline resonators exhibit extremely high Q-values and form the heart of low phase noise oscillators and high frequency stability systems. See article p114.

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Australian Physics

A Publication of the Australian Institute of Physics

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Published six times a year.

Print Post approved PP 224960 / 00008
ISSN 1837-5375

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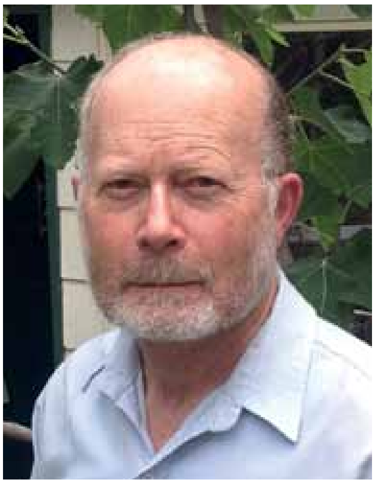
EDITORIAL

Something for everyone



In this issue we have three very different articles. Eugene Ivanov and Michael Tobar, from the University of Western Australia, describe their work on precision electromagnetic measurements and the generation of low noise microwave signals for which they were awarded the AIP's 2012 Alan Walsh Medal for Service to Industry. Of particular interest is that outcomes from this work, which had its origins in the quest to detect gravitational waves, include ten separate patented inventions that were licenced to a WA-based company.

Jane Turner, a petrophysicist at Woodside, gives an account of her career journey from an undergraduate degree with majors in physics and mathematics at UWA, via a position as rock physicist, to her present position at Woodside Energy in WA. While Jane acknowledges that she had little knowledge of geology at the beginning she believes her background in maths and physics gave her "a massive advantage in the oil industry'. Jane's experience serves as an example of the valuable expertise and capability that a physics training can bring to multidiscipline teams in industry.

We have from time to time published articles of this genre: an account of the career progression of a physics graduate working in what could be described as a non-traditional career for a physicist. I am keen to publish more articles of this kind, so expressions of interest would be greatly appreciated.

The third article, by physics teacher Neil Champion, explains the structure of the Australian Senior Physics Curriculum released in November 2012. Neil's article covers many aspects of the curriculum: content, pedagogical goals, and assessment principles.

We conclude the issue with obituaries of the four former CSIRO physicists, Tony Farmer, John Dunlop, Gerry Haddad, and Don Price who tragically died in a helicopter crash earlier this year. These obituaries remind us of the significant contributions these four physicists made to physics and its applications via their careers with CSIRO.

Aware of something worthy of an item in *News & Comment*? Items submitted for possible inclusion in this section would be gratefully received. Proposed items should include an appropriate image, and be sent to the editor.

Brian James

PRESIDENT'S COLUMN

We live in interesting times

We have all watched in amazement at the political developments at the national level over the last few weeks. Not only has there been change at the prime-ministerial level, but Kim Carr is now back as Minister for Innovation, Industry, Science and Research, and with responsibility for Tertiary Education.

In this context, and with the upcoming Federal Election in mind, *Science and Technology Australia* (of which AIP is a part) participated strongly in a joint statement on 17th June to all of the political parties on *"Invest in Research and Translation: Stand up for Australia's Future"*. Together with the two Academies, the Group of Eight, Universities Australia, the CRC Association and the Association of Australian Medical Research Institutes, this joint effort was fronted by Prof Brian Schmidt. It features a call to all politicians on 6 fundamental principles: (1) Investing strategically and sustainably; (2) Building our research workforce – getting and keeping the best; (3) Building a productive system and getting the most out of it; (4) Being among and working with the world's best; (5) Bringing industry and academia together; and (6) Expanding industry research:

Investing strategically and sustainably.
Governments must support planned, stable and appropriate investment in research over the long term, which is essential if we are to tackle large, complex problems and opportunities facing Australia. This will yield better results and ensure the best use of every dollar spent.

Building our research workforce – getting and keeping the best.
To ensure we attract and retain the best researchers we must offer appropriate conditions. Many of the nation's world class researchers are stuck in a cycle of one- to three-year grants for their salaries and research materials. This career uncertainty means many leave research or leave Australia to seek a stable future. The nation is the loser every time uncertainty impedes discovery, prevents planning and inhibits fruitful partnerships.

Building a productive system and getting the most out of it.
Governments must set a stable and sustainable funding framework for infrastructure (buildings, equipment and the technical experts to keep them operating), especially for national facilities without which critical work cannot continue or even begin. This must be backed with resources that keep valuable facilities running once they are built. A central research infrastructure investment framework, such as National Research Investment Plan (NRIP), is essential.

Being among and working with the world's best.
Global collaboration is more necessary than ever with the rise of international research, commerce, communication and other systems that transform our lives and opportunities. Our best researchers must be able to work with the best globally, building on the credibility Australian researchers already have across a wide array of disciplines. This will require a strategic investment that can facilitate international engagement at a government to government level, as well as support for collaboration on specific research projects.

Bringing industry and academia together.
When industry and researchers work together effectively we innovate and multiply our strengths. We must ensure there are clear and reliable policy incentives that facilitate deep and sustained collaboration between industry, public sector, university and research institutes. This not only ensures that the benefits from basic research are translated into practice in Australia, but also harnesses national talent and creates knowledge, opportunity and new jobs.

Expanding industry research.
Governments need to create an environment which encourages industry to invest more in research and which makes Australia an attractive place for international companies to undertake research. Improving industrial productivity has become critical to ensuring strong growth and innovation underpinned by research and development and investment plays a key part in meeting this objective.

I would urge all of our members to contact their local candidates for the upcoming Federal election, and discuss the issues related to science, and physics in particular, with them.

And finally I would like to congratulate former AIP President Tony Thomas on his success in attracting the 2016 International Nuclear Physics Conference to Adelaide, the first time it will have been held in Australia.

Rob Robinson

Bragg Gold Medal for 2013

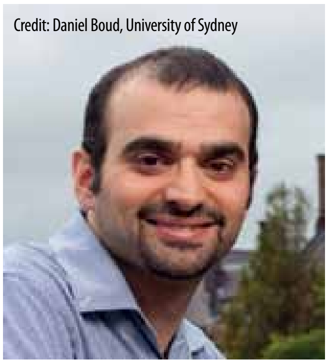
The AIP's 2013 Bragg Gold Medal for Excellence in Physics has been awarded to Dr Martin Fuechsle from the University of New South Wales for his PhD thesis titled *Precision Few-Electron Silicon Quantum Dots*. His research at the Centre for Quantum Computation and Communication Technology focused on the realisation of atomically precise dopant-based quantum nanostructures in silicon using a scanning tunneling microscope.

The Bragg Gold Medal recognises the student who is judged to have completed the most outstanding PhD thesis in physics at an Australian university in the past year.

New Fellows elected to Academy

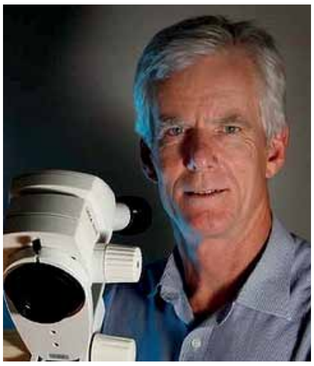
New fellows of the Australian Academy of Science include three physicists: Professor Bryan Gaensler (ARC Centre of Excellence for All-sky Astrophysics, University of Sydney), Professor Geoffrey Taylor (ARC Centre of Excellence For Particle Physics at the Terascale, University of Melbourne) and Professor Andrew White (ARC Centre of Excellence for Engineered Quantum Systems; ARC Centre of Excellence for Quantum Computation and Communication Technology, University of Queensland).

Bryan Gaensler has made fundamental contributions to our understanding of the Universe through his outstanding research on high-energy astrophysics, cosmic magnetic fields and the structure of our Galaxy. His pioneering studies have delivered a unique view on the brightest explosion in history, provided the standard framework for relativistic outflows from neutron stars, revealed the distribution of magnetic fields throughout the Universe, and revised our estimates of the thickness of the Milky Way.



Credit: Daniel Boud, University of Sydney

Australian physicists, led by Geoffrey Taylor, made important contributions to the recent discovery of the Higgs Boson. Right from the initial idea, he has played a major role in the design and construction of the advanced detectors for the proposed Large Hadron Collider at CERN.



The inner tracking component at the heart of the ATLAS detector, designed and built in Melbourne under Taylor's direction is one of the many independent scientific and technical advances which led to the successful outcome at CERN. his work on ATLAS is just a part of his distinguished career in Experimental Particle Physics going back several decades.

Credit: Australian Academy of Science

We are at the beginning of a second quantum revolution, where technology harnesses not just one but all the features of quantum mechanics—most notably, entanglement. These quantum technologies can achieve tasks that are otherwise impossible. Andrew White is a world leader in quantum technology, making significant contributions through his research in the fields of quantum information science and quantum optics. Notable achievements include the development of quantum tomography, a technique for complete and precise measurement of quantum states and processes—now the standard tool for evaluating systems—and the first unambiguous demonstration of a quantum-logic gate operation, setting the standard for all competing realisations.

Women in Physics lectureship 2013

Professor Elisabetta Barberio, from the University of Melbourne, has been selected to present the 2013 Women in Physics lecture tour. Prof Barberio currently leads the ATLAS analysis effort at the ARC Centre of Excellence for Particle Physics at the Terascale. In 2012, her group had an important role in the discovery of the Higgs-like particle at the Large Hadron Collider that has recently been confirmed as the Higgs boson. Elisabetta has a strong record of presenting her work to popular audiences, and chairs the committee that oversees the public outreach programs run

by the School of Physics at the University of Melbourne. The tour is being coordinated by Elizabeth Chelkowska, who can be contacted at Elizabeth.Chelkowska@environment.tas.gov.au.

Prior to joining the University of Melbourne in 2004, Prof Barberio was a staff researcher at CERN. She played a crucial role in data analysis for the OPAL experiment at the Large Electron Positron Collider; and in the design and construction of the ATLAS experiment at the Large Hadron Collider (LHC). Since 2009, Prof Barberio has chaired the Australian Nuclear and Particle Physics group of the Australian Institute of Physics.

Branch News

ACT

The April 2013 branch meeting of the ACT Branch, held on the UNSW Canberra campus, was joint with the Australian Acoustical Society and featured a presentation by Stephen Barrass on Digital Fabrication of Acoustic Sonification

Stephen Barrass is an Associate Professor of Digital Design and Media Arts in the Faculty of Arts and Design at the University of Canberra. His PhD thesis on Auditory Information Design (ANU) is among the most influential works in data sonification. His contributions to the field include design patterns, psychoacoustic methods, acoustic sonifications and the open source Mozzi sonification synthesiser. He pioneered interactive sonifications for oil and gas exploration and automobile engineering in the Cyberstage Virtual Reality Theatre. In his talk Stephen discussed the applications of acoustic sonification with a particular emphasis on physics and acoustics and embedded sensor sonification on microprocessors. He explored the idea of acoustic sonification through a series of experiments that map a head-related transfer function (HRTF) dataset measured from a Kemar dummy onto the shape of a bell constructed in three-dimensional CAD software and then digitally fabricated in stainless steel. The tones produced from the left and right HRTF bells are compared against each other and with a null bell. The pitch and timbre of the left and right bells are perceptibly different from each other, and from the null. The spectra of these bells have a double harmonic series that distinguishes them from the null. These results suggest that the HRTF bells could be used to compare and classify HRTF datasets. This conclusion supports the hypothesis that acoustic sonifications could provide useful information about a general range of datasets.

The interested reader is referred to Stephen's website: **http://stephenbarrass.com/**

NSW

On Tuesday 14 May 2013, the Australian Institute of Physics and the Australian Nuclear Science and Association (ANSTO) held its joint meeting of the year at the ANSTO discovery centre in Lucas Heights and featured Dr Joseph Bevitt on his topic of "The Chemistry of the Nucleus".

Dr Joseph Bevitt is the Scientific Coordinator and head of the Bragg Institutes User Office. He is responsible for the management of the User Office, the proposal process through which researchers can access the OPAL neutron scattering facilities, outreach and promotion activities.

In this highly interactive presentation, Dr Joseph Bevitt discussed many exciting uses and characteristics of nuclear radiation and fascination of the Nucleus as he engaged the audience in a number of interactive experiments: "The Scintillation Counter", "The Radioactive Cosmic Banana", and "Spotting a fake"! From radiological techniques used to determine ground-water consumption, to fraud detection in art and the use of neutrons in developing communications technologies, the 'Chemistry of the Nucleus' presentation explored the science behind nuclear reactions and processes and how it is utilised in Australia.

Precision Noise Measurements and Oscillator Frequency Stabilization

E. N. Ivanov and M. E.Tobar[1]

ARC Center of Excellence of Engineered Quantum Systems
School of Physics, University of Western Australia, Perth, WA 6009

This work summarizes recent advances in two closely related research fields: precision electromagnetic measurements and generation of low noise microwave signals. The progress achieved in those fields over the past decade was largely associated with the applications of microwave circuit interferometry - a powerful measurement technique born out of the quest to detect gravitational waves.

1. INTRODUCTION

The concept of interferometric measurements at microwave frequencies was first suggested in the 50's [1], but it took almost 40 years before its high potential was fully realised [2]. This realisation was largely assisted by arrival of the High Electron Mobility Transistor (HEMT) amplifiers with excellent noise performance. In the late 90's, the synergy of microwave interferometry and low-noise amplification enabled the first "real-time" noise measurements with spectral resolution approaching the thermal noise limit. This development brought about experimental evidence of intrinsic fluctuations in the microwave components, which had been earlier considered to be "noise free". The further progress in the resolution of spectral measurements went well beyond the thermal noise limit [3, 4]. This was achieved due to the more efficient use of signal power. The idea was similar to that of the "power recycling" suggested by Drever [5] to enhance sensitivity of laser interferometers, which consisted in prolonging the interaction of the useful signal with the test sample in order to coherently accumulate its *non-thermal* fluctuations and, therefore, reduce relative contribution of the thermal noise to the overall noise floor of the measurement system.

The principles of microwave circuit interferometry were also behind the breakthrough in the field of frequency-stabilised microwave oscillators, which resulted in almost a thousandfold improvement in their phase noise performance relative to the previous state-of-the-art [6, 7]. The ultra-low phase noise oscillators with Interferometric Signal Processing (ISP) were incorporated into advanced Doppler radars enhancing their ability to see the "stealth" planes and the warheads of ballistic missiles. In addition to military applications, low-phase noise microwave oscillators are expected to play an important role in a range of physical experiments, such as studying the quantum behaviour of macroscopic objects. The prospects include observation of the zero-point motion of a mechanical mode, quantum non-demolition measurements and generation of entangled states between macroscopic objects and microwave photons [8].

"...low-phase noise microwave oscillators are expected to play an important role in a range of physical experiments, such as studying the quantum behaviour of macroscopic objects."

The methods of advanced noise measurements devised at the University of Western Australia (UWA) were essential for understanding the nature of the excess phase noise in optical frequency synthesis [9]. This noise was associated with demodulation of femtosecond light pulses and seriously degraded fidelity of frequency transfer from the optical to the microwave domain. The origin of this excess noise was ultimately linked to the beam-pointing fluctuations of the femtosecond lasers and power broadening of the demodulated light pulses in photodetectors [10, 11]. Unravelling the "mystery" of the excess noise paved the way for generation of spectrally pure microwave signals from the optical sources [12, 13].

Overall, the UWA research team patented ten separate inventions related to the microwave circuit interferometry. They were licensed to West Australian company, Poseidon Scientific Instruments (PSI) Pty. Ltd, which, for more than a decade, remained the manufacturer of the

[1] The AIP's Alan Walsh Medal for Service to Industry for 2012 was awarded to Laureate Fellow Michael Tobar and Winthrop Professor Eugene Ivanov of the University of Western Australia for their work on precision electromagnetic measurement, described in this article.

lowest phase noise microwave oscillators having generated more than 30 million dollars of net income. Last year Raytheon acquired PSI, along with the rights to the oscillator noise suppression technology, in order to “enhance its defence capabilities”.

“Overall, the UWA research team patented ten separate inventions related to the microwave circuit interferometry.“

2. PRECISION NOISE MEASUREMENTS

Fig. 1 shows a schematic diagram of a high-resolution noise measurement system. It represents a microwave equivalent of an optical Michelson interferometer in which the Hybrid Coupler (HC) acts as a beam splitter/combiner. One arm of the interferometer contains a variable broadband load; another - a distributed resonator formed by the Device Under Test (DUT), a phase-shifter with a variable delay ϕ and a directional coupler with directivity ε. These two parameters (ϕ and ε) determine the resonant frequency and the coupling of the distributed resonator, respectively. By varying them one can maximize the signal power absorbed in the distributed resonator, which, in turn, will maximize sensitivity of the measurement system to any type of *non-thermal* fluctuations of the DUT.

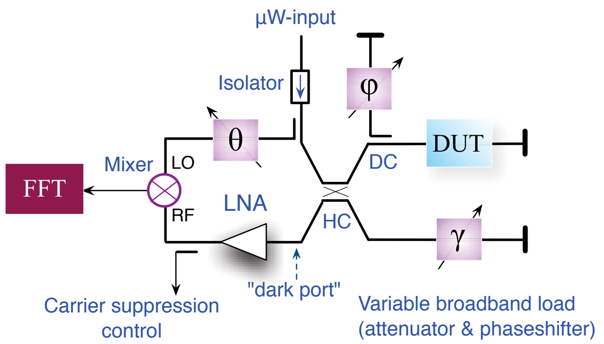


Fig. 1. Interferometric noise measurement system with distributed resonator (FFT- Fast Fourier Transform spectrum analyzer)

The destructive interference between the signals reflected from the interferometer arms suppresses carrier of the combined signal while preserving the noise modulation sidebands originating from the *non-thermal* fluctuations of the DUT. The noise modulation sidebands are amplified and converted into voltage at the output of the microwave readout system consisting of a Low Noise Amplifier (LNA), a mixer and a reference phase-shifter. Depending on the value of the reference phase shift θ (see Fig. 1), voltage fluctuations at the output of the microwave readout system vary synchronously with either phase or amplitude fluctuations of the DUT. This means that one can measure both phase and amplitude fluctuations of the DUT with equal accuracy. The latter, when expressed in the units of phase noise power spectral density, is given by [3]:

$$S_{\varphi}^{n/f} = 16 S_{TH}\left(1+\frac{T_{amp}+T_{mix}/K_{amp}}{T_0}\right)\alpha(1-\alpha)^2 \quad (1)$$

where α is the DUT insertion loss, T_{amp} and T_{mix} are the effective noise temperatures of the LNA and mixer, respectively, T_o is the ambient temperature, K_{amp} is the gain of the LNA and S_{TH} is the thermal noise limit: $S_{TH} = k_B T_0/(P_{inc}\alpha)$, where k_B is the Boltzmann constant and P_{inc} is the power of a useful incident on the DUT. If power at the interferometer “dark port” is less than -40 dBm (0.1 μW), the LNA operates in a small-signal regime with the lowest effective noise temperature, which for the typical room temperature HEMT amplifier is close to 50 K [2].

Clearly, the resolution of spectral measurements can exceed the thermal noise limit, i.e. $S_{\varphi}^{n/f} < S_{TH}$, provided that LNA gain is sufficiently high, so that $T_{mix}/K_{amp} < T_{amp}$, and DUT insertion loss is low (α). This prediction was confirmed experimentally in [3], where we described a 9 GHz micro-strip prototype of the noise measurement system in Fig. 1. Its phase noise floor at $F > 1$ kHz was measured to be -203 dBc/Hz at P_{inc}=250 mW, which was 3 dB below the thermal noise limit.

Replacing the micro-strip components with the waveguide ones reduces the distributed loss in interferometer arms allowing for an extended interaction between the signal and test sample in the distributed resonator. It also eliminates sources of technical fluctuations from the interferometer, as some micro-strip components tend to exhibit an excess noise when exposed to high signal power. In [5], we investigated noise properties of a waveguide-based noise measurement system with the Magic Tee acting as a power divider/combiner. An inductive diaphragm was placed in one arm of the Magic Tee to create a distributed resonator. By adjusting the aperture of the diaphragm and its distance from the symmetry plane of the Magic Tee we maximized the phase sensitivity of the instrument. The highest value of phase sensitivity measured was close to 1400 V/rad. This was a factor of 4 higher relative to the conventional interferometer without distributed resonator.

Trace 1 in Fig. 2 shows the Single Side Band (SSB) phase noise spectrum of the measurement system in [5].

The broad peaks in the noise spectrum are of vibration and acoustic origin. The $1/F$-background is due to fluctuations of ambient temperature upsetting interferometer balance, since no precautions were taken to thermally insulate the measurement system. At $F > 5$ kHz the environmental disturbances no longer affect the measurement system and its noise floor flattens at -213 dBc/Hz. This is almost 10 dB below the thermal noise limit (dash line in Fig.2). Trace 2 in Fig. 2 shows the phase noise spectrum measured with the LNA input terminated with 50 Ω load. Even though there is no signal at the input of LNA, the noise spectrum is of $1/F$-type at Fourier frequencies below 100 Hz. This is due to technical fluctuations induced in the mixer by a strong signal at its LO port (see Fig. 1). This technical noise can be, in principle, removed by transferring noise measurements to some intermediate frequency at which spectral density of technical fluctuations falls below the thermal noise background [14].

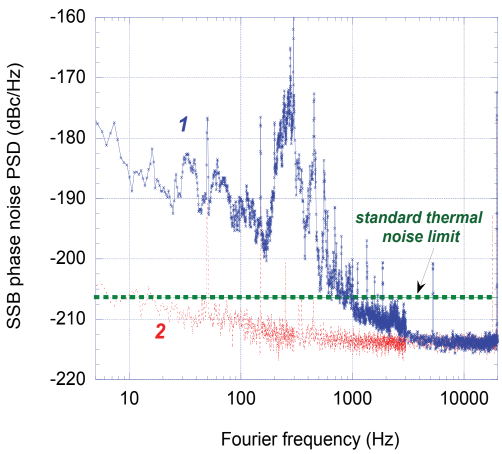


Fig. 2. Phase noise floors of a 9 GHz measurement system: noise floor of the entire system (1); noise floor due to fluctuations in the electronics of the microwave readout (2).

Surpassing the thermal noise limit requires a careful attention to technical noise sources. First, the carrier at the "dark port" of the interferometer must be strongly suppressed to avoid saturation of the LNA and associated with it flicker noise. Secondly, the signal of the microwave pump source has to be band-pass filtered to remove the higher order harmonics from its spectrum. Such harmonics are not attenuated when the interferometer is balanced and saturate the LNA. Thirdly, one has to deal with the sensitivity of the measurement system to pump oscillator frequency noise due to the relatively high dispersion of the distributed resonator. For this reason, the measurements in [5] were performed with a composite source consisting of a high power amplifier capable of generating a few watts of microwave power driven by the low-phase noise microwave oscillator described in the next section.

3. GENERATION OF LOW-PHASE NOISE MICROWAVES

Any resonator in reflection acts as a narrow-band absorber. When coupling to the resonator tends to critical, power of the reflected signal decreases simplifying detection of the noise modulation sidebands. This was an original idea behind the use of critically coupled resonators for oscillator phase noise reduction [15]. It proved to be impractical. The experiments by JPL group [16] showed that cavity coupling could not be adjusted accurately enough to achieve high levels of carrier suppression required for effective noise reduction. The introduction of the Interferometric Signal Processing (ISP) solved this problem, resulting in immediate 25dB improvement in oscillator phase noise performance relative to the previous state-of-the-art [6].

Fig. 3 shows a schematic diagram of a frequency stabilised microwave oscillator with the ISP. A high-Q Sapphire Loaded Cavity (SLC) resonator is used both as a band-pass filter of the loop oscillator and a dispersive element of a frequency discriminator. The Voltage Controlled Phase-shifter (VCP) in the loop oscillator changes frequency of oscillations by varying phase delay around the microwave loop. The frequency discriminator and the VCP act, respectively, as a sensor and an actuator of a frequency control system, which locks oscillator frequency to the selected resonant mode of the resonator. Provided that the gain of the frequency control system is sufficiently high, spectral purity of the generated signal depends on *two types of noise mechanisms.* First, close to the carrier ($F < 10$ Hz), oscillator phase noise is governed by fluctuations of the SLC resonant frequency. These fluctuations vary synchronously with fluctuations of ambient temperature and dissipated microwave power. They are of primary importance to the secondary frequency standards, such as cryogenic sapphire oscillators [17].

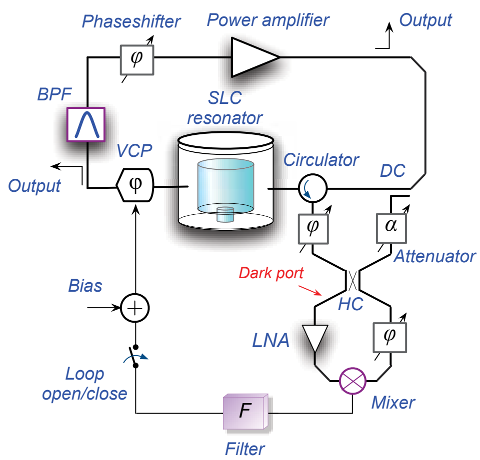


Fig. 3. Schematic diagram of a low-phase noise microwave oscillator with interferometric signal processing

The effect of these fluctuations in the Doppler range of Fourier frequencies (F > 100 Hz) is negligible, as compared to that due to the technical fluctuations in the electronics of the frequency discriminator, which is the main noise mechanism responsible for fast excursion of oscillator frequency from the SLC resonance.

Strong carrier suppression and the high-gain amplification of the residual noise are the key conditions allowing an effective reduction of oscillator fast frequency fluctuations. Provided that these two conditions are met, one can improve the oscillator phase noise performance by elevating the level of microwave power dissipated in the resonator. Following this approach we built two high power 9 GHz oscillators with the phase noise power spectral density -157 dBc/Hz at the Fourier frequency F = 1 kHz [7]. These oscillators are still the lowest phase noise microwave signal sources in the Doppler range of Fourier frequencies (F > 100 Hz). Their phase noise performance is three orders of magnitude better relative to what can be achieved without the use of the interferometric signal processing.

A new generation of extremely low phase noise oscillators can be created based on the SLC resonators cooled to liquid nitrogen temperature. This is because the SLC resonator Q-factor increases by more than 2 orders of magnitude when cooled from 300 K to 77 K. Considering the thermal noise limited frequency discriminator, such an increase in the Q-factor would result in 4 orders of magnitude reduction in spectral density of phase fluctuations (although, only at Fourier frequencies within the bandwidth of the cryogenic resonator).

"Their phase noise performance is three orders of magnitude better relative to what can be achieved without the use of the interferometric signal processing."

Also, classical microwave oscillators may face a strong competition from various types of photonic devices capable of generating low-phase noise signals both at microwave and optical frequencies. For example, advances in optical frequency comb technology have already enabled synthesis of microwave signals with spectral purity rivalling that of the best cryogenic sapphire oscillators [9-11, 17]. The optical frequency comb technology, however, is not well suited to suppression of *fast* phase fluctuations of the optically synthesized microwave signals: phase noise spectra of such signals at Fourier frequencies above tens of Hz are dominated by the laser shot noise. This is due to the low power-handling capacity of the ultra-fast photo-detectors used for signal extraction. Yet, the situation changes rapidly: band-pass filtering of the unwanted spectral components of the optical comb proved to be an effective technique for improving the spectral purity of the optically synthesized microwave signals [12, 13].

"It was possible to maintain the phase synchronous operation of a cryogenic oscillator for many hours with phase deviations less than a few milliradians."

Another approach to generation of the low-phase noise microwaves may be related to frequency locking of a microwave oscillator to a free-spectral range of a high-finesse optical cavity. This could be accomplished by up-converting the microwave signal to the optical domain either via phase or intensity modulation of a CW laser. As the linewidth of the optical resonances remains constant over tens of THz, this would permit generation of microwave signals with the phase noise independent on carrier frequency. Furthermore, considering the rapid progress in the development of ultra-fast optical modulators and photodetectors, one can envisage photonic oscillators with superior phase noise performance at frequencies reaching into the millimetre-wave range.

4. TOOLS FOR PRECISION NOISE MEASUREMENTS

4.1. Phase Synchronisation Systems

Accurate measurements of phase fluctuations of high-performance oscillators is a challenging task involving construction of two almost identical oscillators, one of which ("slave") must be frequency tunable, so it could be phase-referenced to the fixed frequency "master". Furthermore, the technique used for frequency tuning must not degrade the phase noise of the "slave" oscillator, while enabling its tight phase synchronization with respect to the "master". Meeting the latter requirement ensures that residual phase variations between two oscillators are sufficiently small to permit operation of a phase detector in a small-signal regime with the highest possible spectral resolution.

In [18], we described a technique for high precision phase synchronization of a microwave oscillator based on the SLC resonator cooled to 77K. The coarse (and slow) frequency tuning of such oscillator was carried out by

varying temperature of the metal shield surrounding the sapphire crystal, while the fine (and fast) frequency tuning was performed by varying microwave power dissipated in the sapphire. Two feedback control systems were needed for oscillator phase synchronization. The digital frequency control system stabilised the SLC temperature with the resolution of a fraction of μK. The analogue phase-locked loop controlled the phase of oscillations by altering level of microwave power dissipated in the SLC resonator. It was possible to maintain the phase synchronous operation of a cryogenic oscillator for many hours with phase deviations less than a few milliradians.

4.2. Sources of Pure Modulated Signals

It is often necessary to perform accurate measurements of weak fluctuations in the presence of high intensity ones. Situations such as this arise when characterizing the noise properties of the frequency-stabilized microwave oscillators or when dealing with optical frequency dividers, which extract microwave signals from the stable lasers. In both cases, spectral density of phase fluctuations is two-three orders of magnitude less than that of the amplitude fluctuations. Under such conditions, to ensure correct measurements of the weak phase fluctuations the measurement apparatus must be immune to amplitude fluctuations of the analysed signal. Making the measurement system insensitive to amplitude fluctuations of the incident signal requires a source of a pure amplitude-modulated (AM) signal.

On the other hand, a source of a pure phase-modulated (PM) signal is a key component of Pound-Drever-Hall reflected-sideband technique widely used for oscillator frequency stabilisation both in the microwave and optical domain [19, 20]. This technique relies on phase modulation of a signal incident on the resonator and synchronous demodulation of the reflected response. It enables accurate determination of the resonant frequency regardless of phase delay variations in the path between the resonator and the source of PM-signal. However, if a spurious AM-modulation is present in the spectrum of the incident signal, this offsets the resonant frequency from its true value causing a frequency error. In addition, random variations of the AM-modulation index induce fluctuations of oscillator frequency. The effect of AM-modulation on oscillator frequency stability was evaluated in [21]

$$\sigma_y(\tau) = \sigma_m(\tau)\frac{1-\beta^2}{4\beta Q\varphi} \qquad (2)$$

where $\sigma_y(\tau)$ is the Allan deviation [22] of oscillator fractional frequency fluctuations, $\sigma_m(\tau)$ is the Allan deviation of AM-index fluctuations, τ is the integration time, ϕ is the index of PM-modulation of the incident signal, parameters Q and β are the Q-factor and coupling coefficient of the resonator, respectively.

As follows from (2), fluctuations of AM-modulation index must be sufficiently small ($\sigma_m << 1$) to avoid the need for setting coupling coefficient β too close to unity (which is a challenging task at low cryogenic temperatures). In [21], we described PM-modulator for which the σm was measured to satisfy the following fit: $\sigma_m(\tau) \sim 5\times10^{-8}/\sqrt{\tau}$. Substituting this expression in (2), along with $Q = 5\times10^8$ (which is a typical Q-factor of the SLC resonator at 5-7 K), $\phi = 0.1$ rad and $\beta = 0.8$ we obtained $\sigma_y(\tau) < 10^{-16}/\sqrt{\tau}$. This value of oscillator frequency stability is at least 4 times better than the current state-of-the-art.

Finally, we'd like to remark that generation of pure PM-signals is largely assisted by the existence of a device – an amplitude detector, which is immune to phase variations of the incident signal. One can't rely on similar approach when envisaging an ideal amplitude modulator, as all phase detectors are sensitive to power. That is where microwave interferometry, once again, "comes to the rescue" [21].

CONCLUSION

Throughout our research we:

- Demonstrated the possibility of "real time" noise measurements with spectral resolution beyond the standard thermal noise limit. This was achieved by combining the principles of microwave circuit interferometry with the efficient use of signal power and by paying close attention to technical noise sources influencing the measurement process. The high spectral resolution of interferometric devices makes them suitable for study of noise phenomena in various components and materials at microwave frequencies, as well as for precision tests of the fundamental physics;
- Improved phase noise performance of microwave signal sources by almost three orders of magnitude relative to the previous state-of-the-art. The high-power microwave oscillators with the Interferometric Signal Processing remain the lowest phase noise sources in the microwave domain in the Doppler range of offset frequencies;
- Developed a number of research tools required for precision electromagnetic measurements including a system for phase synchronization of a cryogenic sapphire oscillator and source of a pure phase-modulated microwave signal.

Acknowledgement

Authors gratefully acknowledge the 15 years of continuing support of the Australian Research Council and the collaborative research between the UWA and Poseidon Scientific Instruments.

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A journey from physics student to petrophysicist

Jane Turner

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In this article Jane Turner describes her progression from a BSc at the University of Western Australia, with majors in physics and mathematics, to her current position as a petrophysicist with Woodside Energy, a position that involves analysing log and well data to estimate a reservoir's porosity, permeability, hydrocarbon saturation and net to gross. Jane notes that studying physics taught her how to learn, plan and solve problems: skills that made transitioning to a complex, very technical work place, such as the oil and gas industry, smooth and a lot of fun.

I started out my physics career as a commercial pilot, and I admit it was mostly random luck that drove my career. Becoming more and more focused on aviation theory, I decided to study for a degree. I started at the University of Western Australia, studying a Bachelor of Science with majors in physics and pure mathematics. From the start I really enjoyed the physics courses; I thought the ideas were exciting and I liked the atmosphere, there were experiments going on all the time and people discussing interesting things over coffee.

During second year I was given the opportunity of a summer scholarship with the School of Physics and I chose to do a project on seismic noise at the Australian International Gravitational Observatory (AIGO), near Gingin. Essentially the project involved burying geophones, using signal processing software, turning power off randomly and a compactor that simulated road noise. The test sites for the compactor were up to 5 km from the laboratory. Naturally, this experiment was conducted in December and 40°C temperatures.

"I was given the opportunity of a summer scholarship …. and I chose to do a project on seismic noise at the Australian International Gravitational Observatory…"

I was lucky to have a laboratory assistant who understood the need to stand very still every ten minutes for calibration purposes and who could actually lift the compactor, since I couldn't manage it on my own! Analysing the noise spectrum was a lot of fun detective work. It involved things like spotting a hammer dropped on the building slab, noise from air conditioning units and the signal from the 2004 Boxing Day earthquake, which rang the Earth like a bell for months afterward. My supervisors and I wrote a paper on my findings: my first journal article was published in *Review of Scientific Instruments* the following year and I was hooked.

When my supervisors offered me the opportunity to do an Honours project I accepted. I hadn't planned on further study, but I'd had so much fun doing my summer project that the offer was irresistible. It was during Honours that I really focused on my career. I started with the obvious issue - pilots mostly work in the country and I was a frappe and city kind of person. I didn't like the heat, some days I didn't even like the outdoors. I loved physics,

The author on a geomechanics field trip in Boltana, Spain (the Pyrenees) about to go white water rafting with my team.

so what were my options? Was it possible to actually get a job doing physics without a doctorate?

The top 5 Google suggestions for physics jobs were: the defence department, the Meteorological Bureau, the Australian Bureau of Statistics, investment banking and the oil industry. I looked into all the options and was on the verge of accepting an offer when I successfully interviewed with Shell, and they found me a position within their organisation. The position was as a rock physicist (geophysicist) in the United Kingdom.

When I decided to take the job with Shell, I wasn't completely certain what being a rock physicist involved. Europe was a big draw card and Shell kept explaining that they would train me, which was very comforting. It never really occurred to me that I had started my dream career; I assumed these sorts of things didn't just fall in your lap. It turns out I was wrong about that and luckily, in the right place at the right time, studying the right subjects.

The Shell and Woodside training programs are exceptional. My training has never really finished. I have travelled to 13 countries and really got to know the Netherlands, Scotland and Houston before returning to Australia. It is exciting, fascinating and the people are fantastic. I learn something new and exciting several times a day, and even as a new graduate, I had the opportunity to work on real problems and make decisions using my findings. My role came to involve 4D seismic, quantitative interpretation , geomechanics and petrophysics.

"I learn something new and exciting several times a day, and … I had the opportunity to work on real problems and make decisions using my findings."

Toward the end of 2007 I joined Woodside Energy, back in my home town of Perth. Woodside is Australia's largest independent oil and gas company, and the country's largest oil and gas operator. With assets in Australia such as the North West Shelf, Pluto, Browse, the Exmouth Basin and the Sunrise field in the Timor Sea, there's a diverse range of projects at different stages to work on. There are also international assets such as deep water production in the Gulf of Mexico, the Leviathan gas field in offshore Israel and acreage in the USA, Brazil, Peru, Myanmar, the Republic of Korea and the Canary Islands. It's an exciting place to work.

The author on board the Atwood Eagle drilling rig for a logging job during the Pluto campaign.

4D seismic is simply seismic images of the reservoirs at different time periods, sort of ultrasound images of the subsurface. These are the 'before' and 'after' pictures that show you saturation and pressure changes (where the gas, water and oil are). These can help you figure out what's happening under the ground. QI is quantitative interpretation and all about wireline logs and rock properties – basic elastic and inelastic moduli. Some of my work involves building geomechanical models in 4D to see how stress changes around salt diapirs as we produce from reservoirs on the flanks. These sorts of things can tell you where and even when, you need to drill new wells.

Other days my job has involved estimating the maximum seafloor subsidence to see if a platform design is appropriate and designing a monitoring program for reservoir compaction. Other things I work on are more geophysics related, things like modelling log responses, or pore fluid fill. Geophysics for me involves seismic attributes like frequency, noise, semblance and property modelling. The software is always great and I have done a lot of work on clusters and neural networks. It is exciting discovering things and working with scientific people.

I also work with laboratories, on experiments that I design or run to get information on things like rock properties. Don't think that once you leave university and join the oil and gas industry that you never have to organise or write up an experiment again! I usually have one running

in the background, or communicate results or requests most days. Experiments are a big part of the job in many of the roles I have held.

Unlike almost every other geo-anything in the oil industry, I had very little knowledge of geology when I began work; I have always been an odd geophysicist! Having a maths and physics background is a massive advantage in the oil industry; I can translate what the geologists want into quantifiable, measurable data and vice versa. Most subsurface teams in the industry are multidisciplinary. This means they have a combination of different specialists such as reservoir engineers, geologists, geophysicists, petrophysicists, subsurface analysts, managers and drilling and completions experts. These people all speak slightly different specialist languages and like many similar teams, communication is the key. Being able to explain what you are working on and challenges you face, helps the team problem solve together.

"Having a maths and physics background is a massive advantage in the oil industry; I can translate what the geologists want into quantifiable, measurable data and vice versa."

Being a petrophysicist involved most of the skills I already had from university and industry, analysing, modelling and simulation. It's basically problem solving in a detective kind of way. The industry has great funding for training and technology, so there are always new and exciting things to try. Also, the oil industry in Perth is generally short staffed due to the large number of mining companies and comparatively small number of engineering/physics/mathematics graduates. Staffing is very competitive and most companies offer flexible environments and competitive packages.

During this period I also had the opportunity to become involved in logging operations. This means designing logging programs, monitoring them in real time and making evaluations on the results, as well as associated decisions based on your analysis. It's an intense job, which often involves a bit of overtime, but it's also extremely exciting and I was given time off afterward. It was challenging, but there's a sense of pride when you realise your work can help determine if a well is a success or not.

Much of the work I do involves data acquisition; essentially designing an experiment the way you do at university. I choose tools and parameters based on well objectives, and then write instructions. I monitor data collection and interpret it as I go; usually this involves investigating analogues, analysing trends, finding correlations and checking for 'busts' in my conclusions. There is also an element of

Several members of the Woodside petrophysics team in 2011, with the author second from the right.

academia in my work: I sometimes write journal articles on technical topics within the industry or present at conferences.

Dealing with uncertainty is also a very important part of a petrophysicist's job. We need to communicate how sure we are of our results and what, realistically, we think of in terms of probable outcomes. You need to know what you don't know, and figure out if it's worth knowing for sure or if it's the kind of uncertainty you can live with. If you had all the time and money in the world, would a more accurate answer make a difference to your final decision? It's a little scary to realise that sometimes, the answer is no.

Education is also a large part of my role, both in terms of teaching and learning. I have been involved in teaching graduates and other juniors and I really enjoy it. It really tests how well you understand concepts and occasionally those first few left field questions as someone gets their mind around something can be genius. Also, graduates these days are far better with software and can often give me a hand with my (very mediocre!) programming skills. It's odd, considering the amount of training I've done, but it's the advice and lessons I received from my technical mentors that makes me good at my job and which I value most.

"…but it's the advice and lessons I received from my technical mentors that makes me good at my job and which I value most."

Woodside also sponsored me to do my Graduate Certificate in Oil and Gas Business Administration at UWA in 2009/10. It was excellent to get a feel for the history of the industry, the financial side, particularly the oil pricing and OPEC and management in general. It's not the sort of subjects I'd ever managed to study and it certainly helped me to put my role into context. Further study, not just training, but MBAs and Masters are often available in the industry. Woodside promotes learning and actually encourages people to learn more, even outside of their initial area of expertise.

Networking is also critical in my role. I've been lucky enough to work in many different branches of the company and some mornings it's not about what you know, but who you know to ask! It's important to have people you can call on for queries and assistance. You just need to be able to explain what you need or what you're working on without the jargon.

There are also a lot of more formal arrangements to help people network and get the most out of their jobs and careers. Things like technical mentors and the graduate buddy program make it easy to meet people and get information or advice outside of your immediate team. Organisations such as the Woodside Young Professionals and the Women of Woodside also regularly organise networking events and are a great way to meet people when you join or want to get to know people from completely different parts of the company.

To date my career has been exiting, challenging and fun and I have high expectations for the future. The oil and gas industry is a welcoming and exciting place for physicists with great communication skills, be they graduates or experienced people from other fields of study or employment. It offers a wealth of subjects, projects, roles, new technology, exciting technical analysis work and the opportunity for further study. I'd definitely recommend the oil and gas industry; it turned out to be my dream career!

AUTHOR BIO

Jane Turner holds a Bachelor of Science with honours in physics and majors in pure mathematics and physics from the University of Western Australia. Following an Honours thesis on seismic noise at the Australian International Gravitational Observatory she was offered a position with Shell Exploration and Production Europe as a geomechanicist and then as a geophysicist. She has worked on 4D finite element models for wellbore design and stability, as well as 4D seismic and log data to establish rock properties and fluid fill in oil and gas reservoirs. Jane joined Woodside Energy in Perth doing similar roles before becoming a petrophysicist, her current position involving analysis of log and well data to estimate a reservoir's porosity, permeability, hydrocarbon saturation and net to gross.

Australian Senior Physics Curriculum: Overview and Opportunities

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The Australian Senior Physics Curriculum is a highly defensible curriculum on several grounds. It covers the physics canon in a sensible narrative structure. It follows ACARA's F-10 Science curriculum directly. It maintains the impetus of that curriculum's insistence that science education is more than fact transmission. It ensures that students engage with the way physics is conducted and experienced in the world. Finally, it guarantees that students will achieve rigorous standards based on the study of real and appropriately challenging physics that increases in complexity as students mature.

Introduction

The Australian Senior Physics Curriculum was published quietly in November last year.[1] It was the product of a difficult gestation that began disastrously with a flawed and then abandoned version. Physics teachers, physics teacher educators and physicists from around Australia were scathing in their criticism of that attempt. This version was built from the ground up with more reputable specifications, advisors and writing support.

This national senior curriculum is likely to form the basis for each State and Territory's senior physics curriculum but will be variously interpreted in every jurisdiction's vernacular as they develop courses of study. In ACARA's words:

The senior secondary Australian Curriculum for each subject should not, … be read as a course of study. Rather, it is presented as content and achievement standards for integration into state and territory courses.[2]

The curriculum is divided into four semester units. In Unit 1, students investigate data associated with thermal, nuclear and electrical physics. They use a particle model to explain these phenomena. They move on to use observation and data as they describe and explain motion and wave behaviour in Unit 2. They develop field ideas through gravitational and electromagnetic phenomena in Unit 3. Finally, they build on their knowledge from these units as they explore relativity, quantum physics and the Standard Model of particle physics. Examples in context were subsequently published as support material for each sub-unit.

Achievement standards are specified for each year of study. They are organised into two broad categories: physics concepts, models and applications, and physics inquiry skills.

The Australian Senior Physics Curriculum " is presented as content and achievement standards for integration into state and territory courses."

Design features of the curriculum

The Australian Senior Physics Curriculum has been designed to ensure an appropriate selection from the accepted physics canon. The canon is more than a set of facts for transmission; hence the embedding of specific methodological issues in the curriculum. Content and method are carried via a narrative structure that embraces the reflexive interplay between observation, data and explanation, building complexity on simpler ideas encountered earlier in the curriculum. Finally, the design ensures continuity with the F-10 Australian Science curriculum through the use of the three equal strand structure – science understanding, science as a human endeavour and science inquiry skills.[3]

Canonical

The major components of a modern physics curriculum have been carefully selected for inclusion in the Australian Senior Physics curriculum. This guarantees coverage of all important physics topics – the canon of physics.

Unit 1: Thermal, nuclear and electrical physics.

Heating processes includes: simple, kinetic particle model; temperature, thermal equilibrium, energy conservation and work; heat, latent heat, heat capacity, and efficiency.

Ionising radiation and nuclear reactions includes: the nuclear atom, nuclear force (qualitative); natural and artificial radioactivity and half-life; fission, fusion and mass defect.

Electrical circuits includes: charge, current, potential difference, resistance, power; conservation rules, and equivalent circuits.

Unit 2: Linear motion and waves

Linear motion and force includes: uniformly accelerated horizontal and vertical motion; energy and momentum, collisions (elastic/inelastic); equivalence of graphical, geometrical and algebraic representations.

Waves includes: speed, frequency and wavelength; resonance; intensity; Snell's Law, and image formation in mirrors and lenses.

Unit 3: Gravity and electromagnetism

Gravity and motion includes projectiles; circular motion; Universal gravitation.

Electromagnetism includes electrostatic force; electric field and potential difference; magnetic field and force; magnetic flux; transformers.

Unit 4: Revolutions in modern physics

Special relativity includes time dilation; length contraction; relativistic correction for momentum; mass-energy equivalence.

Quantum theory includes: photon energy, photoelectric effect, blackbody radiation, de Broglie wavelength; atomic electron resonance and spectroscopy. (Young's double-slit experiment is referred to, but a quantitative analysis of path difference and fringe separation is not specified).

The Standard Model includes quarks, leptons, gauge bosons; fundamental forces; particle interactions, conservation laws, symmetry; particle accelerators; big bang theory, force and matter.

Table 1: Unit structure in the Australian Senior Physics Curriculum

Unit	Topic
1	Heating processes Ionising radiation and nuclear reactions Electrical circuits
2	Linear motion Waves
3	Gravity and motion Electromagnetism
4	Special relativity Quantum theory Standard model

Methodological

Throughout the curriculum, a conversation about the nature of physics as a discipline is apparent. Physics is more than a set of facts about what happens. Important as this is, the 'facts' are contestable, they can arise independently of particular theory but they are also discovered during the interrogation of a theory. Theories themselves are contestable explanatory tools.

There is an emphasis on the idea of model, which is used as a generic term for various levels of representations of reality, if we are allowed to beg the question about reality. Models are central to science because scientists use them to describe, explain, relate and predict phenomena. Models can be expressed in a range of ways – via words (with language that is commonly metaphorical), images (actual or imagined), mathematics (numerical, algebraic, geometric, graphical), or physical constructions (including some machines). Models help scientists to frame physical laws and theories, and these laws and theories are also models of the world. Models are not static – as scientific understanding of concepts or physical data or phenomena evolves, so too do the models scientists use to describe, explain, relate and predict these. That is, physics proceeds via the reflexive interplay of theory and evidence.

Narrative structure

Physics is presented as a discipline that is primarily concerned with observation, organisation and explanation. The particle model of matter at different scales is introduced in Unit 1 and returns in Unit 4, but with a different focus and meaning. The separation of space and time

in Unit 2 and Unit 3 is reconciled through space-time in Unit 4. Forces, initially separated artificially into contact and non-contact forces, are explained later using field models (Unit 3) and the Standard Model (Unit 4). Observations about energy transfers are explained in particle and wave form. Particle and wave explanations are shown to be models that explain different observations about the interactions of matter and electromagnetism. In this respect, the omission of a quantitative analysis of path differences and fringe separation in Young's double-slit experiment is indefensible. How is it possible to account for the wavelike properties of light, or indeed the wavelike properties of matter, if students are not required, as part of the narrative, to examine quantitatively this most significant of experiments?

The structure of the curriculum provides for ideas to be repeated, but with increasing complexity and applicability. Figure 1 shows the spiral nature of the curriculum. It is coded to show the extent of the Year 11 and then Year 12 components of the curriculum. Starting from a simple particle model (centre) and a relatively naïve view of the world students are drawn in to a more complex understanding of matter, space, time and energy and the nature of evidence-based scientific explanations of phenomena.

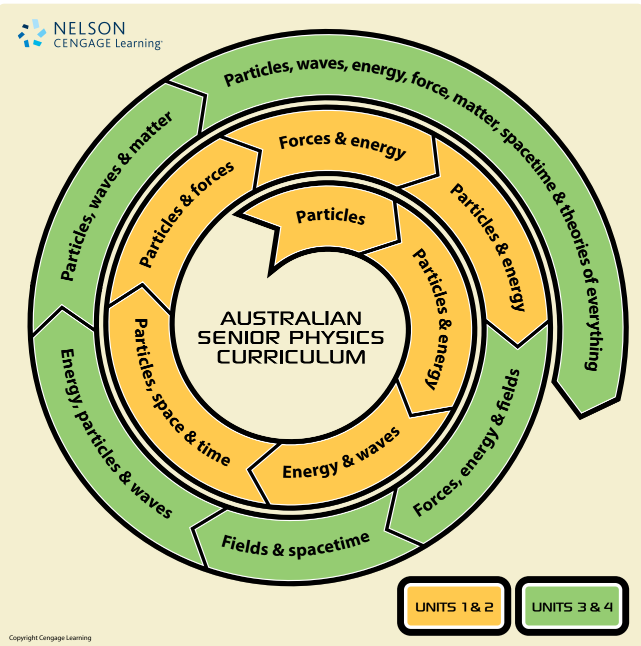

Figure 1: Spiral nature of the Australian Senior Physics Curriculum.

Continuity

The Australian Senior Physics Curriculum has been designed to ensure continuity with ACARA's F-10 Science Curriculum. Most State curricula have not treated this important design feature seriously, with serious effects on the way students experience the vibrancy of senior sciences. If students are to remain engaged and standards are to improve, senior sciences should not start over as though students were *tabulae rasae* on which to write facts that are disembodied from communal and methodological issues at discipline and societal levels.

This curriculum is constructed so that junior and middle years' science teachers will need to ensure their students are ready for a senior curriculum that continuously and consciously builds on previous ways of knowing. For example, the Year 7 Science understanding curriculum introduces the effect of unbalanced forces on motion. Taught well, students should be able to identify the agent and the receiver of a push or pull. By Year 10, they should be able to use this embedded idea to sort out Newton's laws of motion in terms of external effects by agents on receivers and their quantitative effects on net forces, hence, accelerations. The particle model of matter, and energy and change, are other key ideas that develop through Years 8-10 and appear in increasing complexity during the senior years. Each of these topics includes Science inquiry skills and are understood to have implications for the discipline of physics as it relates to societal needs, such as heating and cooling or vehicle safety.

Continuity is also evident in the mathematical requirements expected of senior physics students. They must be competent in all Year 10 mathematical work. That puts pressure on Year 10 teachers to ensure that all students are competent in mathematics. In the senior years, students will need to include inverse-square relationships as well as graphical analysis skills such as drawing and explaining the meaning of the line of best fit. Students should be able to plot raw data, predict a relationship and test this using graphical analysis techniques. It is to be hoped that somewhere along the way they have also built good skills in scientific notation, estimation and proportionality relationships.

Equivalent strands

The Senior Physics Curriculum continues the three-strand structure of the F-10 curriculum. There is no reputable

argument to supplant the consistent evidence about best practice in science education around the world. ACARA, through its briefing papers, has embraced the huge body of evidence contained in the Goodrum Report (2001)[4], a distillation of thirty or more years of consistent evidence that showed, and I am convinced still shows, that students fare best when they are immersed in an holistic science education. Such an enterprise makes explicit the basis for claims to truth as well as the nature of, and criteria by which, change is authorised. The three strands, Science understanding, Science as a human endeavour and Science inquiry skills are treated as equals for this purpose.[5]

Science understanding includes: data as the key to evidence; key concepts, models and theories; and strengths and limitations of models, concepts and theories to explain phenomena

Science as a human endeavour includes: construction of evidence-based explanations; assessment and review of explanations in the light of new evidence and the capacity to predict new evidence; collaboration, peer review, and globalised cooperation; social, economic, ethical and cultural factors that influence and are influenced by applications of science.

" … students fare best when they are immersed in an holistic science education … . Science understanding, Science as a human endeavour and Science inquiry skills are treated as equals for this purpose."

Science inquiry skills includes: active engagement in research questions and processes of investigation; appropriate data representation and analysis, including error, uncertainty and limitations of data (the use of 'percentage error' in Units 1 and 2 is unfortunate because it reinforces an erroneous idea that some experimentally determined values are absolute, without uncertainty); forming hypotheses and making conclusions; evaluating scientific and media text; communicating effectively for purpose and audience.

Already, teachers and students in Australian schools are embracing this construction of the curriculum. Systems have established standards consistent with the Australian F-10 curriculum.[6] Textbooks and related e-books have been published and are being used throughout Australia.[7]

Examples in context

'Examples in context' were added to the November 2012 version of the Australian Senior Physics curriculum in March 2013. They were designed as possible contexts, which could be used to teach the Science as a human endeavour strand in a Unit, along with the related concepts from the Science understanding strand. They are not meant to be definitive, though it is possible that some systems might convert some or all into assessable curriculum statements.

In Unit 1, the examples in context include: heating processes (energy security and sustainability – emerging energy sources; energy balance of earth; development of thermodynamics); ionising radiation and nuclear reactions (radioisotopes and radiometric dating; harnessing nuclear power; nuclear fusion in stars); electrical circuits (electrical energy in the home; powering the digital age; electrical lighting).

Unit 2 comprises: linear motion and force (road safety and technology; sports science; developments and limitations of Newton's laws); waves (monitoring earthquakes and tsunamis; noise pollution and acoustic design; development of the wave theory of light).

Unit 3 comprises: gravity and motion (forensic science – projectiles; artificial satellites; developing understanding of planetary motion); electromagnetism (medical imaging; the Square Kilometre Array; superconductivity).

Finally, in Unit 4, the examples in context include: special relativity (development of the special theory of relativity; ring laser gyroscopes and navigation; nuclear reactors); quantum theory (development of the quantum model; black body radiation and the greenhouse effect). The Standard Model (evidence for the Higgs boson particle; particle accelerators; the Big Bang theory).

There is a speculative flavour to many of these suggestions. They are not always sufficiently connected to the Science understanding strand to be used as rich contexts for all or even most of the specified learnings in a unit. They frequently demonstrate a profound ignorance of current knowledge and methodological issues that would provide an appropriately modern, subtle and balanced way to approach societal issues and the history of science.

Achievement standards

What then of assessment? Rubrics for the *Achievement standards* are provided, for Year 11 and Year 12, in two categories: Physics concepts, models and applications and Physics inquiry skills. Each describes the expectation of performance in five categories, from higher order taxonomical categories to basic categories. They require students to demonstrate performance within the specified units and sub-units of a year-long curriculum. Achievement standards for Physics concepts, models and applications are matched to both the Science understanding and Science as a human endeavour strands. Achievement standards for Physics inquiry skills are matched only to the Science inquiry skills strand.

Conclusion

The Australian Senior Physics Curriculum, published in November 2012 was supplemented in March 2013 by Examples in context. It brings the use of the three strands - Science understanding, Science as a human endeavour and Science inquiry skills - from F-10 up to Year 12. The curriculum coherently introduces students to the canon of physics in a sensible narrative structure that ensures students pay attention to substantive methodological issues. It is appropriately structured to ensure higher standard physics is studied as students build on their previous knowledge, first from F-10 Science, and then within the Unit structure.

Despite one inexplicable omission (quantitative analysis of Young's double slit experiment) and one measurement error (percentage error) this is a reputable, and essential, response to long-established knowledge about the kind of science curriculum that actually engages students. The curriculum will effectively educate students in the physics canon, related methodological issues and the ways in which physics is conducted in, and connects with, society. Assessment standards will ensure that successful senior secondary physics students are well-educated.

References

[1] ACARA, Senior Secondary Curriculum, Physics, at **http://www.australiancurriculum.edu.au/SeniorSecondary/Science/Physics/RationaleAims**

[2] ACARA, Senior Secondary Curriculum, Physics, at **http://www.australiancurriculum.edu.au/SeniorSecondary/Science/Physics/**Overview-of-the-senior-secondary-Australian-Curriculum

[3] ACARA, F-10 Science curriculum, at **http://www.australiancurriculum.edu.au/Science/Rationale**

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[5] Goodrum, Denis, Amelia Druhan and Joanna Abbs, *The Status and Quality of Year 11 and 12 Science in Australian Schools*, Report to the Australian Academy of Sciences, 2011, Recommendation 1, "…all the three strands of Science Understanding, Science as a Human Endeavour and Science Inquiry Skills need to be adequately covered in the content." **http://www.science.org.au/reports/documents/Year1112-Report-Final.pdf**

[6] **http://ausvels.vcaa.vic.edu.au/Science/Overview/Rationale-and-Aims**

[7] For example, *Nelson iScience for the Australian Curriculum*, series 7-10, Nelson Cengage, South Melbourne, 2012, available in print and digital form, **http://www.nelsonsecondary.com.au/2/524/12/science_.pm** ,various authors including Neil Champion.

AUTHOR BIO

Neil Champion BSc(Hons) DipEd MScEd was directly involved in writing the Australian Senior Physics Curriculum. He is an experienced secondary physics teacher at Buckley Park College in Victoria and has held numerous school leadership positions in State and Independent schools, including Principal. Neil has taught university level Physics and Physics Teaching Method for pre-service teachers. As VCAA Science Manager, he was responsible for the development and implementation of world first senior secondary curriculum in photonics and synchrotron physics. For over 20 years, Neil has published school science texts for VCE Physics, IB Middle Years Program and 7-10 Australian Science Curriculum.

'Charged charmonium' confounds particle physicists

Physicists working independently at two different particle-physics labs have found tantalizing evidence for a new and mysterious hadron. Dubbed Zc(3900), the particle seems to be a "charged charmonium" and is made from quarks assembled in a way that has possibly never been seen before. Further studies of Zc(3900) could provide important new information about the strong force that glues together quarks in hadrons.

Charmonia, which are heavy mesons, contain a charm and anti-charm quark. Because they are a composite particle, they can exist in a number of different energy states – the most famous being the first excited state called the J/ψ particle. Discovered in 1974, the J/ψ particle made physicists realize for the first time that quarks are real. Although physicists have learned much about quarks over the past four decades, current theories are still not good enough to predict which of the many possible combinations of quarks will form stable mesons.

Zc(3900) was spotted independently by physicists on the BESIII experiment in Beijing and the Belle experiment in Tsukuba, Japan. Both teams focused on the mysterious Y(4260) particle, which was discovered in 2005 at the BaBar experiment in the US. Y(4260) is perhaps the most puzzling of the "XYZ" particles, which have been produced over the past decade at BaBar, Belle, BESIII and elsewhere.

Although they are believed to be combinations of quarks, the XYZ particles have so far defied explanation. One possible explanation is that Y(4260) is part of a new family of "hybrid charmonium" particles in which the gluons that mediate the strong force exist in excited states. Alternatively, Y(4260) could contain four quarks rather than just two (a tetraquark structure) – and could even resemble a "molecule" made of two mesons bound together. To gain a better understanding of Y(4260), the BESIII and Belle teams therefore created large numbers of them by colliding electrons and positrons together. While the Y(4260) is so short-lived that it cannot be detected directly, its signature turns up in the energy spectrum of pions and J/ψ particles produced in the collision.

Four quarks: is Zc(3900) a charged tetraquark?

But both teams found more than they bargained for – evidence of an unexpected particle Zc(3900) with a mass around 3.9 GeV/c2. This new particle is even more mysterious than Y(4260) because it appears to decay to an electrically charged pion plus an electrically neutral J/ψ. This means that Zc(3900) must carry electric charge, therefore not simply comprising charm and anti-charm quarks.

One explanation for this behaviour is that the new charged particle is a molecule comprising two D mesons that are somehow bound together – something that is predicted by some models of how quarks interact. Another, more tantalizing possibility, is that Zc(3900) is a tetraquark comprising a charm/anti-charm pair plus an up quark and an anti-down quark. If the latter proves to be true, the number of possible hadrons allowed by nature could be much greater than physicists had thought – and by studying these new particles, important new insights into low-energy quark interactions could be gleaned.
[*Phys. Rev. Lett.* **110**, 252001 and 252002 (2013)]

Do dark-matter discs envelop galaxies?

A new type of dark matter that could strongly interact with regular matter to form large discs that would overlap galaxies like our own has been postulated by a group of researchers in the US. There is believed to be at least four times as much dark matter in the universe as there is ordinary matter. But despite its great abundance, dark matter is generally thought to very weakly interact with conventional matter, causing it to form amorphous halos around galaxies that contrast with the richly structured galactic discs themselves. The new research suggests this view may be oversimplified, arguing that a substantial minority of dark matter might in fact interact strongly, and could be detected in cosmic-ray observations.

Much evidence has been accumulated to support the existence of dark matter, which, unlike normal matter, does not give off or absorb electromagnetic radiation. For example, the greater-than-expected rotational speeds of stars in the outer-lying regions of galaxies suggest that those galaxies contain more mass than can be accounted for simply by adding up all of the light. However, scientists still do not know what dark matter actually is. They

Is the Milky Way cloaked in dark matter?

do know that much of dark matter interacts weakly with other matter and with itself. Among theorists' leading candidates for dark matter are so-called weakly interacting massive particles (WIMPs) and axions, which rarely collide with one another. The existence of these particles is also suggested from work in other areas of physics – WIMPs being predicted by some forms of supersymmetry, while axions might explain why strong interactions obey charge–parity symmetry.

In the latest work, Lisa Randall and colleagues at Harvard University argue that such weakly interacting particles might not tell us the whole story. By considering the characteristics of the dark matter surrounding our own Milky Way galaxy, the researchers calculate that as much as 5% of that dark matter might not be weakly interacting. They also point out that this "double-disc dark matter" (DDDM), as they call it, would probably dissipate energy while retaining angular momentum from its motion about the galactic centre, causing it to form a thin disc just as ordinary galactic matter does. They work out that the dark and visible discs would have about the same mass, which would imply that the densities of DDDM and normal matter in the universe would be roughly equal. The dark disc might be detectable in the near future. Evidence for its existence could come from the gravitational effect it has on the motion of the billion Milky Way stars that the European Space Agency's upcoming Gaia mission will study. [*Phys. Rev. Lett.* **110**, 211302 (2013)]

How to hear the shape of a room

Can you obtain the dimensions of a darkened room by clapping your hands and listening to the echoes? Bats, dolphins and some other animals navigate using echoes and some blind humans have trained themselves to do this. Now engineers in Switzerland and the US have worked out a way to calculate the dimensions of a room using a single loudspeaker and four arbitrarily placed microphones. They believe this could find applications in building design, audio forensics and much more.

In theory it should be possible to hear the shape of a room by producing a sound and measuring the time taken for the echoes to arrive at particular points. But doing this in practice is not easy. Now researchers at the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland and Harvard University in the US have developed an algorithm that uses sound to work out the dimensions of any room with flat, protrusion-free walls. The system uses a single loudspeaker to create sound and four microphones placed anywhere in the room to capture the echoes. They tested their algorithm by calculating the dimensions of a lecture theatre at EPFL and comparing the results of their

Sounding out Lausanne Cathedral

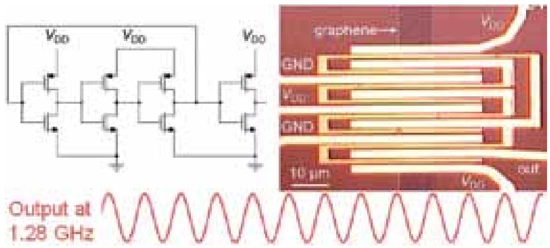
echo calculations with the actual values. They found the two were remarkably close: the 7.08 m distance between two walls, for example, was calculated as 7.01 m – a discrepancy of less than 1%.

The researchers foresee a variety of possible applications for their technology. Most obviously, it could be used by architects and sound engineers designing a building in which echoes are important, such as a concert hall, to ensure that the room has the desired acoustics. They decided to find out how well their algorithm would perform when the requirement that the walls be flat and protrusion-free was not satisfied by placing their set-up in the portal of Lausanne Cathedral, which has a domed ceiling and numerous protrusions such as pillars and large statues. Even here, their system calculated the distances between flat surfaces accurately. [PNAS doi: 10.1073/pnas.1221464110 (2013)]

Graphene circuit breaks the gigahertz barrier

Researchers in the US and Italy have made the first integrated graphene digital circuits that function at gigahertz frequencies. The circuits are ring oscillators and the work could be an important step towards realizing all-graphene

microwave circuits, says the team. Graphene is a 2D sheet of carbon just one atom thick and it – along with similar 2D materials such as carbon nanotubes and molybdenite – shows great promise for future electronics. This is because electronic devices smaller than 10 nm could be made using these 2D materials – at least in principle. Be-



low the 10 nm length scale, devices based on conventional silicon are expected to be too small to function properly and therefore graphene and similar materials offer a route to making ever-smaller electronic devices.

One major challenge facing those developing such 2D devices is speed. Modern silicon processors operate at microwave (gigahertz) frequencies, as do communications chips in devices such as mobile phones. Therefore, any practical 2D device would have to run just as fast. Until now, however, the fastest 2D device – a carbon-nanotube ring oscillator – operates at a lethargic 50 MHz. Now, a team led by Roman Sordan of the Politecnico di Milano and Eric Pop of the University of Illinois says it has made the first integrated graphene oscillators – with the added bonus that the devices operate at 1.28 GHz. The graphene ring oscillators also appear to be less sensitive to fluctuations in the supply voltage compared with both conventional silicon CMOS devices and earlier oscillators made from the 2D materials.

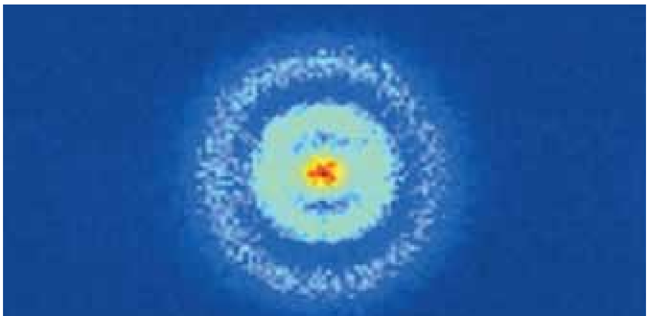
In addition to being used to generate clock pulses in microprocessors, oscillators are also one of the main building blocks of analogue electronics. Microwave electronics, for example, are based on voltage amplifiers, oscillators and mixers. "Graphene amplifiers and mixers have already been demonstrated, so the oscillators we made represent the final 'missing' component for making all-graphene microwave circuits," Sordan says.

And that is not all. The team has also fabricated stand-alone graphene frequency mixers from its ring oscillators. Previous graphene mixers were not stand-alone because they required external oscillators to function. [*ACS Nano*, **10**.1021/nn401933v (2013)]

'Quantum microscope' peers into the hydrogen atom

The first direct observation of the orbital structure of an excited hydrogen atom has been made by an international team of researchers. The observation was made using a newly developed "quantum microscope", which uses photoionization microscopy to visualize the structure directly. The team's demonstration proves that "photoionization microscopy", which was first proposed more than 30 years ago, can be experimentally realized and can serve as a tool to explore the subtleties of quantum mechanics.

The wavefunction is a central tenet of quantum theory – put simply, it contains the maximum knowledge that is available about the state of a quantum system. More specifically, the wavefunction is the solution to the Schrödinger equation. The square of the wavefunction describes the probability of where exactly a particle might be located at a given time. Although it features prominently in quantum theory, directly measuring or observing the wavefunction is no easy task, as any direct observation destroys the wavefunction before it can be fully observed.



What lies within the H atom?

In the past, "Rydberg wavepacket" experiments have tried to observe the wavefunction using ultrafast laser pulses. In these experiments, the atoms are in a superposition of their highly excited "Rydberg states". These experiments show that the periodic electron orbitals around nuclei are described by coherent superpositions of quantum-mechanical stationary states. The wavefunction of each of these states is a standing wave with a nodal pattern (a "node" is where there is zero probability of finding an electron) that reflects the quantum numbers of the state. While previous experiments have attempted to capture the elusive wavefunction or the nodal patterns, the methods used were not successful. Direct observation of the nodal structure of a single atom being most difficult to achieve. [*Phys. Rev. Lett.* **110**, 213001 (2013)]

Physicists rethink celebrated Kelvin wake pattern for ships

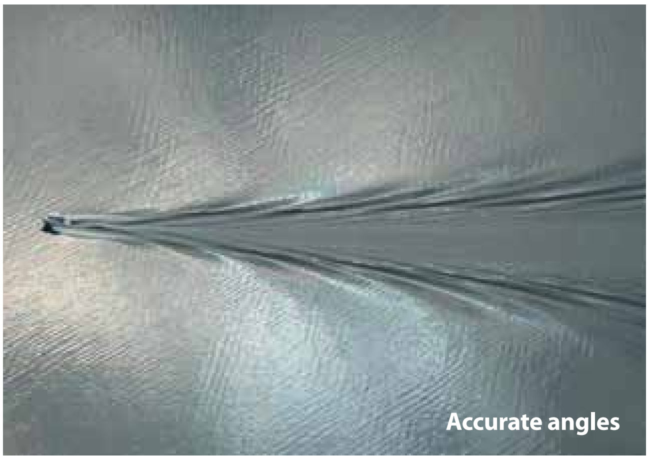
Lord Kelvin may have been an accomplished sailor, but he might have missed a trick when he famously described the phenomenon of wakes fanning out at a constant angle of

19.47°, no matter the speed of the vessel. That is the claim of two French physicists, who have used satellite images and mathematical modelling to study narrower wakes associated with fast-moving boats.

Kelvin's prediction is rooted in two key properties of gravity waves on the water surface: first, that those with large wavelengths travel faster than those with short wavelengths; and second, that the group velocity of a deep-water wave is exactly half its phase velocity. As a boat moves through calm water, it excites waves over a range of wavelengths, with the longest speeding away faster than the shortest and then dissipating. Constructive interference between the slower, shorter waves causes a pair of shock waves to form in a distinctive V-shape that emanates from the boat.

Kelvin showed that the angle that each arm of the V makes with the centre line is 19.47°, irrespective of how fast the boat is travelling.

Marc Rabaud of University of Paris-Sud in Orsay and colleague Frédéric Moisy noticed that the photographs they used to illustrate Kelvin wakes to fluid-mechanics students were at odds with the theory they were trying to teach. They analysed images from Google Earth, using measurements of boats' hull lengths and wake angles, as well as calculations of their velocities, to help them build a new mathematical model to describe narrow wakes. What the researchers found was that at higher speeds, boats produce a smaller spectrum of wavelengths that tends towards the length of the boat itself. According to the duo, a boat cannot produce wavelengths longer than its hull, so as soon as the wake hits a limiting speed governed by this length, its waves all travel with equal speed through the water, much like sound waves through air. At this point, like the Mach cone associated with supersonic jets, the angle of the wake is suddenly governed solely by the speed of the boat – the faster it goes, the more its wake stretches and narrows. [*Phys. Rev. Lett.* **110**, 214503 (2013)]



Accurate angles

Conferences 2013-14

20–21 September 2013
STANSW Annual Conference 2013. Inquiry Science: Bedding down the NSW Syllabus. UNSW, Sydney, NSW
http://www.stansw.asn.au

29 September-3 October 2013
4th World Conference on Science and Technology Education (WorldSTE2013). Sarawak Malaysia
http://worldste2013.org/

11 October 2013
Nuclear Science and Engineering in Australia (ANA2013)
Sydney Mechanical School of Arts, Sydney, NSW
http://www.nuclearaustralia.org.au/ANA2013%20Conf%20Brochure.pdf

13-16 October 2013
Australasian Radiation Protection Society (ARPS) Conference. Cairns, Qld
http://www.arps.org.au/?q=content/conferences

15–17 October 2013
Healthy, Wealthy and Safe: Metrology Society of Australia 12th Biennial National Conference
MGSM Executive Conference Centre, Macquarie Park, Sydney
http://metrology.asn.au/conferences.html

17–19 October 2013
Looking to the Future: International Research in a Changing World – Humboldt Colloquium. Sydney, NSW
http://www.humboldt-foundation.de/web/dates-humboldt-colloquia.html

3-7 November 2013
Engineering and Physical Sciences in Medicine conference, EPSM 2013. Perth, WA
http://www.promaco.com.au/events/EPSM/#.UeJ_8VPArYM

24-27 November 2013
37th Annual Conference of the Australian Society for Biophysics
RMIT City campus, Melbourne, VIC
http://www.biophysics.org.au/Meetings/2013/

8-11 December 2013
ANZ Conference on Optics & Photonics. Fremantle, WA
http://2013anzcop.com/

2-6 February 2014
23rd Australian Conference on Microscopy and Microanalysis (ACMM23) and the International Conference on Nanoscience and Nanotechnology (ICONN 2014). Adelaide, SA
http://www.aomevents.com/ACMMICONN

21-26 September 2014
Joint International Conference on Hyperfine Interactions and Symposium on Nuclear Quadrupole Interactions 2014, Academy of Sciences, Canberra
http://www.hfinqi.consec.com.au/

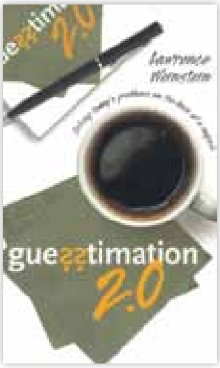
7-11 December 2014
21st Australian Institute of Physics Congress. ANU, Canberra, ACT

BOOK REVIEWS

Guesstimation 2.0: Solving today's problems on the back of a napkin.

by Lawrence Weinstein and Patricia Edwards.
Princeton University Press, 2012, 378 pages
ISBN: 069115080X

Reviewed by John Daicopoulos, James Cook University



It's no secret that at some point during a job interview for Google the candidate will be required to answer a Fermi question of the nature "how many dust grains would fit on the head of a pin?" Apparently, Google management is interested in a candidate's ability to illustrate their reasoning skills in finding an accurate, if imprecise, answer to a problem posed on the spot. The mental skills necessary to work out the answer are difficult to practise, let alone exhibit during a high pressure interview.

Guesstimation 2.0: Solving today's problems on the back of a napkin, by Lawrence Weinstein is the second book containing a series of Fermi questions written expressly for prospective Google applicants...well not exactly, it's a well written manual full of examples to solving perplexingly fuzzy problems. The first book was published in 2008 and co-authored with John A. Adam, which makes one wonder why this book, published in 2012, was necessary. The answer is in the variety and depth of the examples provided.

Weinstein begins with a very instructional, albeit short, "How to..." section making the case for estimation and asking the reader to "Dare to be imprecise." I found it helpful to re-read this section occasionally. The remaining eight chapters detail a variety of topics from Recycling, Heavenly Bodies (astronomy), Materials, and even Radiation. I discovered the chapter on The Five Senses to be the most fascinating especially as it provided a few useful problems for use in my wave optics subject as, what size of telescope aperture is needed to see an Earth-like planet. The chapters on Energy conservation had little interest for me, however, there was a segment called To Pee or Not to Pee that was worth a gander.

Readers of The Physics Teacher, the journal of the American Association of Physics Teachers, will be familiar with many of the pieces contained in this round of Guesstimation as Weinstein has been writing a regular column in it for years called Fermi Questions, strangely enough. Those short guesstimation segments are well suited for a journal of that type, the longer articles can be easily separated by shorter fragments of fun reading.

Depending on your reading style Guesstimation 2.0 can be full of delightfully punctuated snippets of information or, infuriatingly difficult to read; however, that fragmented style of presentation makes it very easy to set it down returning to pick it up later, or reading it out of order in a manner that suits your interests, which was my preferred style.

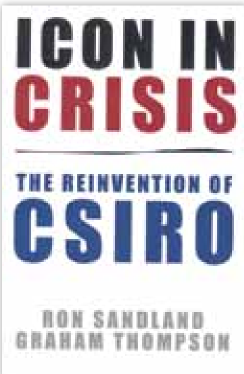
Some of the problems addressed are US-centric requiring an almost encyclopedic depth of knowledge and assumed detail in order to solve; there is an expected comfort with mathematics and a familiarity for physics throughout that parts may be a bit too weighty for the general reader outside of North America, for physicists that will not pose a problem. On another pleasant note, Weinstein argues for and uses the metric system throughout the problems posed, I for one am happy with that.

Lawrence Weinstein has assembled a hefty collection of imprecise problems that are begging for resolution, if only to illustrate the reasoning behind the resolution. And therein lies the impetus for Google's focus on using them: problems are difficult to solve only when we have not faced them before. Tackling ambiguous problems with reason and clarity is a worthy character trait for any employee.

Icon In Crisis: The Reinvention Of Csiro

by Ron Sandland and Graham Thompson.
New South Publishing, Sydney 2012, 357pages
ISBN 978-174-2233-39-0 (paperback)

Reviewed by Fred Pribac, Richmond, TAS 7025



At the turn of the century, despite an 80 year record of outstanding research achievement, CSIRO was experiencing the first rumblings of real trouble in its relationship to government. Up to this point, a long line of distinguished and capable CEOs had presided over an organisation of immense popularity and mythic stature which had always been strongly supported by federal government. However, the output from CSIROs disparate Research Divisions was increasingly being criticized as too insular, too theoretical and insufficiently focussed on Australia's practical and economic needs. Management at CSIRO had, broadly speaking, been more directed to scientific

excellence than to corporate modernity and client needs.

In 2001, CSIRO received a rude snub from government when it failed to gain additional funding under the new Backing Australia's Ability innovation program (worth $2.9 billion over five years). It seems that this situation really scared CSIRO's upper management tiers. It was into this atmosphere of trepidation that Dr Geoff Garret was appointed as the head of CSIRO. Dr Garret was noted for recently implementing modern corporate management practises in South Africa's sister CSIR. With his appointment there was a conscious phase shift in CSIRO's relationships with government.

This book relates the implementation, successes and tribulations of the subsequent decade of managerial transitions that swept through CSIRO.

Both of the authors of the book were intimately involved in effecting the managerial changes that the book explores. They purport to have written an account that can be read on several levels: as the history of an important scientific initiative, as an in depth study of a major change initiative within a complex organisation of highly intelligent and creative individuals or as an examination of the impact of different leadership styles at different levels of CSIRO. Although clearly written, such an ambitious aim does not produce a book that is meant for light reading.

On the one hand the reader is afforded a fascinating interior glimpse of the deliberations and machinations of CSIROs strategic corporate thinkers but on the other hand, because of the intimate involvement of the authors, the reader is left wondering if the material has truly been treated objectively.

As a former rank and file employee of CSIRO, I found myself trying to read between the lines at least as much as I was reading the actual lines. I also found myself marvelling over and over again at the shear amount of angst, tenacity, and additional complexity that the pursuit of the transition to matrix management, flagships, BHAGs and the various other acronyms mentioned in the book has required. This has been not just a painful affair but also a protracted and ongoing one. As well as the transition successes, the authors have been relatively unflinching in reporting the problems and collateral damage. Here and there, there are some minor resorts to rhetoric that typically are slanted away from sympathy for more negative viewpoints.

CSIRO has not managed its own reinvention without significant public criticism. The authors have explicitly given coverage to some of these, however, I am not convinced that they have given a sufficient account in this regard. I also would have liked a greater exploration of some of the, sometimes withering, public criticisms from industry, science and economic commentators around perceptions of the effects of increased politicization of CSIRO.

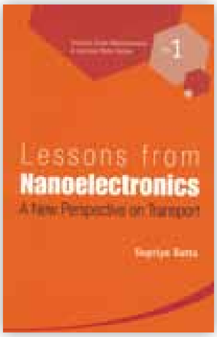
The style of writing, for me, sits a little uncomfortably between opinion piece and technical report. In the most uncharitable interpretation; it could even be viewed as a protracted and overly optimistic advertorial piece for CSIRO. However, for students of research management and those interested in either the history or future well-being of CSIRO, I recommend this book as an unprecedented, well written and cogently argued resource from a front line perspective.

Lessons from Nanoelectronics: A New Perspective on Transport

By Supriyo Datta

World Scientific Publishing Co. Singapore, 2012, 473 pages,
ISBN: 978-981-4335-29-4 (softcover)

Reviewed by Mukunda Das, Theoretical Physics, The Australian National University, Canberra



Supriyo Datta is well known as a researcher in the nanoscience community. The book under review contains several items mainly from the author's earlier texts. At the outset I wish to say that the presentation in the book makes interesting reading for novices, where several ideas are inventively explained. However, there are many serious points of concern, which I outline below.

Unlike a superconductor, a normal material always has finite resistance, arising out of elastic and inelastic scattering of electrons; the former from defects (impurities, surfaces) and the latter from phonons. Resistance is an inherent electrical property that directly represents the amount of energy dissipated from the driver to the environment, via the device. As all elastic scattering conserves energy, it is dissipation-free. Therefore, the physics of dissipation enters through the inelastic scattering alone. The argument that only elastic conductors dissipate energy is difficult to swallow. Proposals for conduction totally without inelasticity is an extreme instance of Occam's razor as amplified by Einstein: a physical explanation should indeed be as simple as possible, but not simpler.

Regarding 'A new Ohm's law', the resistivity parameter ρ characterising a conductor carries within itself the

combined effects of elastic and dissipative scattering. In its novel and imaginative form (eq. 1.4), the elastic mean-free path appears once again in the new Ohm's law; that appears redundant. This finding thus looks more like a law of unintended consequences, since elasticity should be incorporated precisely once – and for all – within the 'old' Ohm's law expression for ρ, no matter whether the device is classical or nanoscopic.

For meso-systems the source-drain contacts, and their interfaces conjoined to the system, play a pivotal role in the conduction process. Although there are verbose descriptions, there is little show of any explicitly physical account. The chemical potential is an equilibrium property of a material, which is a global constant. The electro-chemical potential has the additional local contribution from the internal electrostatic screening at the interface. In view of this, the local electro-chemical potential cannot, in principle, be constant as implied throughout the text.

For microscopic transport with a small applied field, the Kubo formula gives a formally exact expression of conductivity, but its actual structure in practice comes from explicit knowledge of elastic and inelastic scatterings, of which the latter is truly a many-body concern, not reducible to any kind of single-carrier scenario. Unfortunately, the simplifications presented here undermine the power of Kubo by a complete absence of its essential many-body reasoning. For problems of nano-transport, the author claims that "much of the physics does not involve the quantum aspect and can be understood within a semi-classical picture". It is a flawed argument since atoms, far less their quasi-molecular congregations, cannot be understood classically.

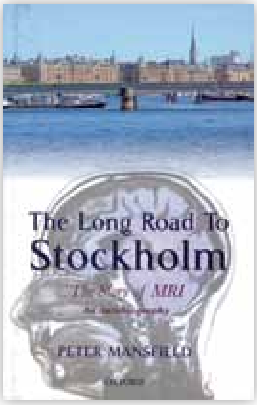
Related conceptual difficulties involve the appeal to two different Fermi functions for a non-equilibrium system driven by external potentials. The Fermi function used in the book is not the solution to a classical Boltzmann transport equation (BTE), rather from a quantum BTE as was correctly done by Uehling and Uhlenbeck. There are many other such points which are brushed under the carpet.

Regarding references, many seminal papers and text books are ignored. As one example, *Transport in Nanostructures* by Ferry and Goodnick is a good text that must be worth mentioning in any up-to-date survey. Although the present book is written cleverly, I do have some reservations for recommending it to students of science or engineering, at least those who care about the foundational underpinnings of nanoelectronics.

The Long Road to Stockholm: The Story of MRI – An Autobiography

by Peter Mansfield
Published by Oxford University Press, Oxford, 2013. 241 pages.
ISBN 13: 978-0199664542

Review by : Rebecca Ryan (PhD student, School of Physics, University of Melbourne)



Sir Peter Mansfield received a Nobel Prize for Physiology and Medicine in 2003, jointly, with Peter Lauterbur, for his contribution to the development of MRI (Magnetic Resonance Imaging). The first half of Mansfield's story is the tale of how he rose to academic success despite the adversity of childhood circumstances. The second half of the book progresses through the technical milestones of Mansfield's career and his work in the development of MRI.

Aged 11, not knowing what an exam was, and having had many disruptions to schooling due to movement in and out of London during World War II, Mansfield performed badly on a Grammar School entrance test. He was hence afforded only a limited schooling experience up until age 15. He describes an early interest in technical pursuits during this time – starting with a fascination for printing presses, making toy soldiers to sell and the creation of fireworks. Upon telling his career advisor at school that he was interested in becoming a scientist, he was told that he did not have the qualifications and should try something less ambitious! So he went to work full time at a printing press at the age of 16.

Despite setbacks to the start to his adult life, Mansfield found his way back into science and gained a PhD in Physics at the age of 26. There is no mention of any great struggle or desperation about following a passion for science: he simply set about the task of enrolling in night school to gain university entrance and the rest is history.

Mansfield takes pain to mention in great detail every person he worked with along the way in his career - mentors, students, post docs, research associates- affording many pages to descriptions of their projects, input of ideas and findings. This would not be complete without describing incidents with opponents - one of these being John Waugh who published a paper on multi-pulse MRI - an idea Mansfield had already worked on and had published four years earlier. A short chapter titled 'An-

tagonisms to MRI' also provides an account of Mansfield's dealings with Raymond Damadian (who very publicly denounced Mansfield and his right to the prize in 2003).

Upon reflection, these anecdotes, rather than having the effect of heightening a sense of dishonesty in some of his adversaries - instead remind us of the difficulty of keeping abreast of research in the era of printed journals. Several letters and descriptions of correspondence (pre-internet age) regarding collaborations on projects are provided in the book - these take place over many months! Mansfield himself recalls having to wait to get back to his university (University of Nottingham) library to check the findings in a paper that someone referred him to at a conference; he was only able to do so almost a week after it was mentioned to him.

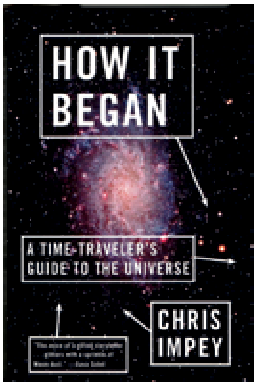
Mansfield's matter-of-fact tone throughout the story of his rise from a working-class background to Nobel laureate limits the possibility of inspiration. The tale of his early years (half the book) does make for some fascinating reading - the memories of air-raid sirens at the outbreak of World War II and the evacuation from London (as was mandated for children at the time). Counter-balancing this - the story of 'the road' of events leading to winning the Nobel Prize lacks fervour and feeling. The reader is however left with broad insight into the scope of a successful research career and the span of time taken to develop MRI as we know it today.

How It Began-A Time Traveler's Guide To The Universe

By Chris Impey.
WW Norton and Company, NY and London, 2013, 434 pages
ISBN 978-0-393-34386-1 (paperback)

Reviewed by John Macfarlane, Trevallyn, Tasmania.

Chris Impey, an Edinburgh graduate with many years' experience as a practising astronomer and now based at the University of Tucson, Arizona, has a rare and precious gift for turning abstruse concepts into readable, or even



poetic, language. *How It Began* is his latest in a series of popular science texts (*How It Ends, The Living Cosmos*...,etc.) which takes the reader on a thought-journey from Chapter 1 "Separated at Birth" through 15 Chapters ending with "Multiverse". On the way we are introduced to just about every subject that we ever wanted to know about the past and present status of astrophysics, cosmology and the evolution of life. Throughout the book, there are frequent notes (collected in a 52-page-long appendix) where complex or unfamiliar topics are further explained. In fact, in some respects I found the notes made almost more compelling reading than the main text!.

There is also a comprehensive index covering all sections of the text where for example, the concepts of dark energy, inflation, multiverse, dark matter, are dealt with, while still acknowledging that gaping holes still exist in our present understanding. More mainstream physics terms including white noise, quantum fluctuations, and the Planck scale, are also clearly, if briefly, discussed.

All this detail obviously makes for a lengthy text, and parts of the narrative are almost too auto-biographical in style, where Impey recounts his personal thoughts and experiences on trips to observatories in places as far apart as Hawaii, Chile, and Siding Spring. The breadth of his erudition is evident, for instance, in the opening paragraphs of Chapter 11 "Big Bang" where he digresses into a discussion of the Dreamtime, citing scholarly works on Aboriginal history. Many other sections may be, for some readers, excessively long-winded, digressing into such fascinating topics as ancient Greek cosmology and mythology. Throughout the text, there are many diagrams and photographs, most of which cry out to be carefully studied, but suffer from poor quality reproduction- a consequence perhaps of low-cost printing.

In summary, this is one of the most readable pop-science books I have seen, despite its sometimes annoying wordiness. Mathematical concepts are conveyed in near-poetic language but with almost a complete lack of equations. In total, the book probably meets one of the author's stated aims which is to "humanize the universe", while on the way, providing a truly cosmic overview of *How It Began.*

Tony Farmer

1944 - 2013

Tony Farmer was with the CSIRO for 40 years and in that time improved the world in many quiet ways, from the small – making better hip replacements – to the large – destroying ozone-depleting chemicals.

He was also a manager who could look beyond the immediate concerns of his research groups and take a wider divisional and organisational view. The referees for his application for a position at the CSIRO, as well as noting his talents as a researcher, emphasised his adaptability, his warm personality , his good sense and good humour, and his unselfish assistance of colleagues.

Anthony John Douglas Farmer was born in Adelaide on September 5, 1944, the son of Doug and Nancy Farmer. After schooling at Adelaide Technical High, he took a bachelor of science with honours from Adelaide University, then a PhD in physics in 1970. He then spent three years as a postdoctoral researcher at York University in Toronto and a year at the University of Newcastle.

Farmer started with the CSIRO in 1973 as a research scientist with the department of physics. His research had already been in spectroscopy at very short wavelengths and his initial project with the CSIRO was the development of a new method to make precise measurements of the spectral characteristics of light sources and detectors. He also collaborated with the US National Bureau of Standards on a successful project that eventually improved the accuracy of silicon photodiodes.

From 1981, Farmer was involved in a new research area, thermal plasmas. With Gerry Haddad, he published a series of benchmark papers on temperature measurements of electric arcs. Initially the measurements used spectroscopic techniques, which made use of the light emitted by the arc.

After that, to avoid some of the problems, Farmer and Haddad pioneered the use of laser scattering – a more accurate approach, but one that presented extreme experimental difficulties , as the strength of the scattered signal was minuscule compared with the intense arc radiation. It was a tribute to Farmer's skill and persistence that this work was successful.

He led many industrial projects in arc physics in the 1990s, two of which were outstanding successes. One was the development of a process to coat artificial hip joints with hydroxyapatite (artificial bone) using plasma spraying, for Portland Square Pty Ltd. The second, with the CSIRO's division of manufacturing technology and SRL Plasma, was on the development of the PLASCON waste treatment process to allow the destruction of ozone-depleting substances.

Twelve PLASCON plants, most of which are still operating, have been constructed around the world. For this work, Farmer was awarded, together with two CSIRO colleagues, the 2008 Alan Walsh Medal for Service to Industry by the Australian Institute of Physics.

Farmer was promoted to senior principal research scientist (level 8) in 1998. In 2000, he took on the leadership of the sub-surface radar project. This team made significant advances in the understanding of the interaction of electromagnetic waves and the geophysical environment, and they developed borehole electromagnetic probes for geophysical measurements while drilling in coalmines . The team also developed SiroPulse, a sub-surface radar system designed for security countermeasures applications, which received wide acceptance within Australia, New Zealand and US government agencies.

In 2005, Farmer became a theme leader in the industrial physics division , and from 2008 was deputy chief of operations at CSIRO's materials science and engineering division . He retired in 2010, but continued as an honorary fellow, working in particular in the area of high power ultrasonic processing.

Away from science, Farmer's interests were varied. After acquiring an unruly labrador when he first moved to Sydney, he joined Hornsby Dog Training Club, and held many positions on the committee. He excelled at sports, particularly tennis and squash. He was a passionate supporter of the Swans, regularly attended theatre, ballet and symphony concerts, and was deeply involved with his family.

Tony Farmer is survived by his wife, Paquita (nee Ifould), daughters Jenni and Cathie, sons-in-law Ross and John, grandchildren Beth, Annie, Zach and Charlotte, mother Nancy and sisters Sue and Robyn.

- Tony Murphy

This obituary was previously published in the Sydney Morning Herald, 6 June 2013.

John Dunlop

1946 - 2013

John Dunlop was a solidstate physicist, with a particular interest in metal physics and the magnetic properties of hard magnetic materials.

He joined the CSIRO in 1976 as a research scientist with the National Measurement Laboratory and over the years worked in CSIRO Applied Physics, CSIRO Telecommunications and Industrial Physics (CTIP) and CSIRO Materials Science and Engineering (CMSE). In 1987, he was promoted to principal research scientist.

In his early years at the CSIRO, Dunlop's research focused on the magnetic properties of transition metal alloys and glassy metals. With the latter he developed techniques for their fabrication, which involved rapid solidification from the molten phase.

However, the greater part of his career was devoted to the study of rare-earth permanent magnets and their application in devices, in particular electric machines. He was part of the team that developed a pilot plant for the production of the rare-earth magnet neodymium-iron-boron , which was an extremely successful project and resulted in the formation of a spin-out company, Australian Magnet Technology.

John Burton Dunlop was born in Wigan, England on August 27, 1946, to Dorothy and Herbert Dunlop. As a child, he would search the bookshelves whenever he was taken visiting, and read quietly. He never seemed to forget anything he read and in later years was a Trivial Pursuit champion.

After Wigan grammar school he did a bachelor of science (physics) with honours, followed by a PhD in physics (1972) at Imperial College London. He was a research fellow at the University of Sheffield and a Royal Society European program fellow at the University of Genoa, Italy. In 1969 he married Wendy, with whom he had three sons, but they divorced. Dunlop was always keen to see his science applied. This was achieved many times with projects conducted through SEMCAM (the Sydney Electrical Machines, Controls and Applied Magnetics) consortium, and with industrial partners.

He and his team members were credited with the discovery of the so-called fifth family of permanent magnets, the 3:29 alloys. He also contributed to the development of novel methods for producing titanium-based alloys.

Dunlop was also very active in the Australian solid-state physics community. His efforts, with close colleagues, led to the establishment in 1977 of the Australian Institute of Physics' solid state physics meeting – usually referred to simply as the Wagga conference. Every year this brings together solid-state physicists from Australia and overseas in an informal gathering.

Earlier this year, Dunlop attended the 36th meeting, including the ritual lunch at the Goulburn workers club. He was also on the beam advisory group for the Australian Nuclear Science and Technology Organisation's newly developed research reactor, Opal.

Dunlop was actively involved in social activities at CSIRO such as the children's Christmas party when his sons were young. Later, he led a bushwalking group and lunchtime exercise classes. In retirement he participated in a regular gathering of CSIRO scientists. He was a dedicated father and football enthusiast who was involved in his sons' soccer teams as coach and a strict but impartial umpire. Good sportsmanship was more important than which team won the game.

Dunlop was not comfortable seeking rewards for himself, preferring to perform useful work for his colleagues and collaborators, and for Australian companies. He was highly respected for his deep scientific knowledge, his cheerful willingness to help and give advice to other researchers, and his friendly and generous nature. Dunlop retired from the CSIRO in 2008, although he often returned to help with research and development problems.

He and his partner of 15 years, Vivian Cateaux, began exploring the country in their off-road trailer (aka the space shuttle) and he had recently been researching how to build a house that required no heating or cooling, had tripleglazed windows and ducted air to keep the house at a constant temperature and to eliminate dust.

John Dunlop is survived by Vivian, sons Simon, Jonathan and Andrew, granddaughter Isabella and brother Peter.

- Stephen Collocott

This obituary was previously published in the Sydney Morning Herald, 5 June 2013

Gerry Haddad

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Nearly 20 years after physicist **Gerry Haddad** published his last scientific paper, his work is still cited by researchers, a testament to the quality of his work. He was also a deeply practical man who could not only design experiments but also design, build and debug the equipment needed.

Gerald Neil Haddad was born in Mount Gambier on September 17, 1941 the eldest of three children to Claude Haddad, a teacher, and his wife, Lorna. Gerry was always a bright student but Claude never let him get too big for his boots. Test results of 100 per cent were never good enough when the writing was untidy.

Gerry went to Nuriootpa High School until 1957, then received a bursary to attend Adelaide High for his final year. He matriculated in 1959 then took a bachelor of science with honours from Adelaide University, then a PhD in physical sciences (1968).

He then worked at the University of Adelaide, Culham Laboratory in Britain, the University of Nebraska and the University of Oklahoma, then as a research fellow at the ANU. His expertise was in ultraviolet and plasma spectroscopy , and fundamental atomic processes in plasmas.

Haddad started with the CSIRO in 1982 as a senior research scientist with the Division of Applied Physics at Lindfield. He was an outstanding experimentalist, with a real talent for the engineering and technical development of new systems. Less than a year after starting at the CSIRO, his group leader described him as being "the best experimentalist I have ever worked with".

Haddad led a number of projects in the gas discharge field, ranging from fundamental studies of interactions of electrons with molecules through spectroscopic measurements of welding arcs to the design of high-power arc plasma reactors for mineral processing for Australian companies, including a facility for the dissociation of zircon sands to produce zirconia for ICI.

The success of his work contributed strongly to the rapid development of the CSIRO plasma group's global reputation. The landmark papers of Haddad and Tony Farmer on the temperature measurements of electric arcs, which are cited in leading textbooks on arc welding, showed that the approximate properties of welding arcs can be predicted theoretically assuming " local thermal equilibrium" .

This made the development of sophisticated computer codes for the prediction of weld properties possible for almost any industrial configuration, and these have been adopted worldwide by companies and universities. Haddad earned rapid promotion as a scientist, reaching senior principal research scientist (level 8) in 1989.

In 1988, Haddad decided to pursue a career in research management and took a position as program manager in plasmas, thin films and thermometry in the Division of Applied Physics. Nevertheless, for many years he remained strongly involved in the research and development of the plasma group, often taking the opportunity to " get his hands dirty' ' in the lab. The plasma researchers who followed remained indebted to him for the experimental facilities he had developed.

Haddad's success as a research manager and leader echoed that of his research career. Following the formation of CSIRO Telecommunications and Industrial Physics, he was appointed as a portfolio manager in 1996, deputy chief in 1999 and chief in 2003. He was also chief of CSIRO Industrial Physics (CIP) from its formation in 2004 until he retired in 2007. After retiring he took a position at Standards Australia and was there until his second retirement in 2012.

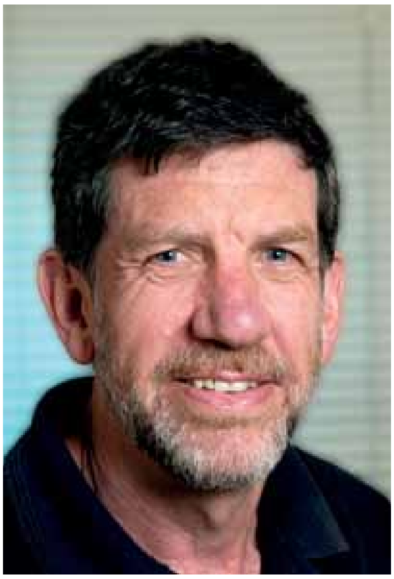
As well as science, Haddad loved making stuff. He particularly loved working with wood and made much of the furniture and fittings for his house, as well as garden paving, patios, decking, fencing, garden beds, and bridges over the creek. It was fitting that his retirement present from the CSIRO was a lathe.

As a young man, Haddad tried many sports and was particularly good at water-skiing . He and his partner, Jacqui de Battista, had recently started travelling the country in their motor home.

Gerry Haddad is survived by Jacqui, who was communications manager of CSIRO Industrial Physics, sons Andy and Sean, stepchildren Jamie, Becky and Bridget, mother Lorna and sister Pam.

- Tony Murphy and Jacqui de Battista

This obituary was previously published in the Sydney Morning Herald, 7 June 2013.



Don Price

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Don Price was a passionate scientist who applied his love of physics to solving many and varied practical problems. He lived by the mantra, " There is physics in everything." He joined the CSIRO in 1982 as a research scientist with the Division of Applied Physics in Lindfield . His father, Sir Robert Price, worked at CSIRO for many years as an organic chemist, ending up as chairman of the scientific organisation from 1970 to 1977. Together they had almost 70 years of CSIRO service.

Don Price's work on modelling the behaviour of ultrasonic waves in composite materials led to the development of instrumentation for the non-destructive testing of aerospace structures. Modern aeroplanes are no longer just made of riveted metal, but rather materials such as carbon fibres glued together, and Price worked out how to test the joins ultrasonically without destroying them. He performed outstanding research in this area in collaboration with Boeing for many years.

Donald Carruthers Price was born in Dumfries, Scotland on May 25, 1945, only son of Jerry Robert Price and his wife, Joyce, also a research scientist and later chairman of the World Association of Girl Guides and Girl Scouts. Jerry went to England, from Australia, when he won a scholarship to Oxford. When war broke out, Joyce took the last civilian flying boat out of Australia to marry him. They then stayed on to help with the war effort.

After the war, they returned to Australia and settled in Melbourne. Don went to Caulfield North Central School, where he was already showing a number of his traits – virtually always late, a love of sport (he later ran many marathons, with a best time of two hours, 36 minutes), thoughtfulness , kindness and generosity – then to Melbourne Boys High School. He went on to Monash University, where he did his PhD in 1970 on the magnetic properties of materials.

Before joining the CSIRO, he worked in Canada, Britain, the ANU and the Royal Military College Duntroon. He then worked on the detection of breast cancer using ultrasound at the Queensland Institute of Technology.

On joining the CSIRO, he expanded his research in ultrasonics to include measurement techniques and materials properties. He went on to become discipline leader for acoustics and ultrasonics, and held other leadership positions. He was promoted to senior principal research scientist in 1993.

Price was instrumental in the development of a collaboration with NASA that resulted in the Ageless Aerospace Vehicle (AAV) project, for which he was project leader. The project focused on intelligent active sensing systems for structural health management in aerospace vehicles, though the principles had much broader applicability.

Price also led the tube eccentricity measurement project, which developed an online system to measure the wall thickness and eccentricity of extruded copper tube using high frequency ultrasound . The system was installed in the production line at the MM Kembla Tube and Fittings mill, where it is used to sort tubes for subsequent processing, and continues to provide valuable results.

Beyond science, Price contributed greatly to the division. As a member of the management teams of CSIRO Telecommunication and Industrial Physics and CSIRO Industrial Physics, he was instrumental in setting research directions , and increasing the awareness of the division's science achievements in the broader community . He played a major role in internal divisional review processes , and in managing the division's contribution to external reviews of its science.

He was responsible for co-ordinating and leading the work of various research teams, and managed and developed valuable external collaborations. He was also a great mentor to students, regularly hosting students from Australia and overseas, and was very active in the Australian physics community.

Price was quietly spoken, with a wry sense of humour. He was never comfortable with self-promotion , preferring the quality of his work to speak for itself. Following his retirement in 2009, Price continued with CMSE as an honorary fellow.

Don Price is survived by his wife, Diane (nee Symonds, married 1970), children Catherine and Ben, grandson Nicholas and sister Margaret and Elizabeth.

- ***Stephen Collocott and John Lowke***

This obituary was previously published in the Sydney Morning Herald, 10 June 2013.

PRODUCT NEWS

COHERENT
New Intensified Camera

Princeton Instruments has launched a unique emICCD technology, available exclusively in their PI-MAX®4 camera platform. For the first time ever, one camera combines the advantages of image intensifiers (subnanosecond exposure times) and the benefits of emCCDs (linear gain and high quantum efficiency) to provide single-photon sensitivity and fully quantitative performance.

For more than three decades, Princeton Instruments ICCD cameras have been the industry standard for time-resolved imaging and spectroscopy applications. The recently introduced PI-MAX4 series of cameras, offers advanced capabilities such as <500 picosecond gating, very high repetition rates, RF modulation, and complete control via the LightField® software platform with an oscilloscope-like user interface.

Traditional intensified cameras, the workhorses of ultrashort, time-resolved applications, are limited by nonlinearity due to microchannel plate (MCP) saturation as well as an inability to distinguish single photons. Alternatively, emCCD cameras, which have become the main tools for low-light applications, lack ultrashort gating capabilities. By combining these two key technologies for the first time, Princeton has created unique emICCD cameras that are free of the aforementioned limitations, allowing researchers in combustion, ultra-low-light imaging, quantum optics, and time-resolved imaging and spectroscopy to design experiments hitherto not possible.

Introducing New Signal Generators from Stanford

The SG380 Series RF Signal Generators use a unique, innovative architecture (Rational Approximation Frequency Synthesis) to deliver ultra-high frequency resolution (1μHz), excellent phase noise, and versatile modulation capabilities (AM, FM, ØM, pulse modulation and sweeps) at a fraction of the cost of competing designs. The standard models produce sine waves from DC to 2.025 GHz (SG382), 4.05 GHz (SG384) and 6.075 GHz (SG386).

Three new SG390 RF Signal Generators, with carrier frequencies from DC to 2.025 GHz, 4.050 GHz and 6.075GHz, support both analog and vector modulation. The instruments utilise a new RF synthesis technique which provides spur free outputs with low phase noise (−116dBc/Hz at 1GHz) and extraordinary frequency resolution (1μHz at any frequency). Both analog modulation and vector baseband generators are included as standard features.

Ultrafast Fibre Lasers from Calmar

Coherent Scientific now offers the Calmar range of ultrafast fibre lasers, to complement our existing range of Ti:sapphire ultrafast oscillators and amplifiers.

Calmar fibre lasers generate clean optical pulses less than 100 fs, with repetition rates from kHz to 640 GHz, average power up to 10 W, and single pulse energies up to 20μJ. Fibre lasers are available at several wavelengths from 532 nm to 1600 nm.

All Calmar products are exceptionally compact and easy to use, requiring no alignment or other maintenance. Applications include amplifier seeding, optical communications, non-linear optics, biomedicine and materials processing and more.

For further information please contact Coherent Scientific at sales@coherent.com.au

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QExtra - Quantum Efficiency Enhancing CCD Technology from HORIBA

- Pulse width < 80 ps
- Average power (@40 MHz) >1 mW
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- Collimated output or single mode fibre coupled

The ps pulsed laser diode heads of the LDH-FA series are based on a Master Oscillator Fibre Amplifier (MOFA) concept with optional frequency conversion. The master oscillator generates infrared picosecond pulses with variable repetition rates up to 80 MHz. The output of this seed

laser is directly connected to a single or double stage fibre amplifier, which boosts the output from the

seed laser by several dB while maintaining the other characteristics of the seed laser beam like e.g. the emission wavelength, polarisation and the short pulse width.

The high pulse energies of the amplified infrared lasers permit an efficient wavelength conversion using, for example, single pass Second Harmonic Generation (SHG) or Fourth Harmonic Generation (FHG). In this way, it is for the first time possible to generate picosecond pulses at 266, 531 or 766 nm with adjustable repetition rates up to 80 MHz and final pulse widths below 100 ps (FWHM).

Horiba Fluorescence - FluoroCube Extreme

In the FluoroCube Extreme, Horiba have seamlessly combined their fluorometers with the high intensity and broad wavelength range of a supercontinuum laser. So why go extreme?

- Lifetime: Allows you to choose any excitation wavelength.
- It's like having infinite Deltadiodes!

Features:

- Select any excitation wavelength from 430 nm to over 2 μm for lifetime measurements. Wavelengths below 430 nm can still be addressed using our existing DeltaDiodes or NanoLEDS.
- Select pulsing frequency from 2 - 10 MHz (using required pulse picker)
- Complete optical, mechanical and software integration:
- Adapter for use with excitation monochromator
- Complete delay and signaling integration for synchronization
- Control of wavelength, and pulse frequency directly from DataStation Software, in addition to monitoring the laser power.

Aerotech PlanarDL Two Axis, Mechanical Bearing, Linear-Motor Stage

AEROTECH® *Dedicated to the Science of Motion*

- Integrated, low-profile, XY, linear-motor stage
- Excellent geometric performance (straightness to ±0.4 μm; flatness to ±1 μm)
- Anti-creep, precision crossed-roller bearings
- Large selection – nine models in travel and accuracy

The PlanarDL XY design allows for unparalleled planar geometric performance in applications where straightness and flatness of motion are critical. High-precision anti-creep crossed-roller bearings, precision-machined surfaces and Aerotech linear motors driving through the axes' center-of-stiffness result in a positioning stage with exceptional geometric tolerances.

Noncontact Direct-Drive Technology

Only noncontact, direct-drive technology offers high-speed and accurate positioning coupled with maintenance-free operation and long service life. At the heart of the PlanarDL is Aerotech's proprietary direct-drive technology. This drive technology allows for unmatched performance compared to other competitive screw-based and linear motor designs.

The PlanarDL-200XY and -300XY stages are both available with one or two motors per axis, allowing optimization of each individual axis for the specific application and process. Regardless of the number of motors selected, the resulting drive force acts through the centers of friction and stiffness resulting in superior geometric performance and accuracy.

Extreme Positioning Performance

The PlanarDL is available in three positioning performance options. Relying upon decades of experience in system-level design including not only positioning mechanics, but also software and electronics, Aerotech has developed advanced technologies to push the envelope of precision. High-performance -PLUS and -ULTRA options are available to enable accuracies and straightness values down to ±400 nm and orthogonality down to 1 arc second.

For more information please contact Lastek at sales@lastek.com.au

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WARSASH SCIENTIFIC
6-axis Hexapod for loads up to 20kg

Warsash Scientific is pleased to announce the release of the H-820.D12 Hexapod from PI (Physik Instrumente). The H-820 Hexapod has been specifically designed from the ground up with the performance characteristics of all its components perfectly tuned and selected for cost-efficiency, allowing the new Hexapod to be offered at a favorable price.

The H-820 also convinces by its performance: It pro-

vides travel ranges of up to 100 mm in X and Y direction and 50 mm in the Z axis as well as rotational angles up to 60°. Thanks to the specially developed brushless torque motors, a load capacity of 20 kg and velocities of up to 20 mm/s can be achieved. The H-820 system also includes a powerful digital controller commanded via Ethernet. All target positions are conveniently given in Cartesian coordinates.

Its price and performance make the H-820 particularly appealing for applications in industrial automation and manufacturing, or for research, e.g. in biotechnology.

Why Parallel Kinematics?

The Hexapod is driven by six high-resolution actuators, all connected directly to the same moving platform. This parallel-kinematic structure combines high system stiffness with a large clear aperture.

Because of the low mass of the moving platform, positioning operations can be performed with far lower settling times than with stacked multi-axis systems. In those systems, runout and guiding errors, that have an impact on the dynamic properties of the individual axes, as well as friction and inertia of moving cables, all accumulate to limit the system's accuracy and repeatability – problems which do not affect parallel-kinematic systems like the Hexapod.

Well-known for the high quality of its products, PI (Physik Instrumente) is the global leader in piezo nanopositioning and Hexapod systems. PI's product range is available from Warsash Scientific in Australia and New Zealand, a long-time distributor, and reliable technology partner and consultant.

Measure 1000x Faster

Warsash Scientific is pleased to announce the release of the UHF-BOX Boxcar Averager from Zurich Instruments. The UHF-BOX is the latest option for the technology leading UHFLI lock-in amplifier. With the UHF-BOX Boxcar Averager Zurich Instruments now extends its signal processing know-how to boxcar techniques and offers customers the fastest commercially available boxcar averager.

Until now, scientists using pulsed laser sources to make time-resolved measurements have been limited by the performance of conventional analogue boxcar averagers or have been forced into compromises using modulation techniques, lock-in amplifiers or expensive application specific instrumentation.

UHF-BOX provides a fully digital boxcar averager with unprecedented bandwidth and dead time specifications. Users can now measure at repetition rates up to 450 MHz directly, over 1000x greater than the previously available measurement rate, with a 600 MHz input bandwidth and all without the need for additional modulation devices and the compromises they require. There's now no need to miss a single pulse of information.

Available as an option for the 600 MHz UHFLI lock-in amplifier, with UHF-BOX two boxcar units are provided as well as two peak form analysers (PFA), enabling instantaneous signal pulse shape visualisation. The UHFLI is already equipped with an integrated toolset for time and frequency domain signal analysis - an oscilloscope, a frequency response analyser and an FFT spectrum analyser – so once again Zurich Instruments is addressing its core product philosophy of reducing laboratory setup complexity.

The introduction of the UHF-BOX broadens Zurich Instruments' support to the pulsed laser community, enabling faster and more sophisticated measurements than ever before. Baseline free measurements, multi-channel operation and fully differential laser path measurements are all possible.

According to Dr. Flavio Heer, CTO of Zurich Instruments: "The introduction of the UHF-BOX Boxcar Averager option for our 600 MHz UHFLI lock-in amplifier means that, thanks to the <2ns dead time, laser scientists will be able to make measurements up to a thousand times faster than previously because no pulse will be missed. They'll benefit from an improved signal to noise ratio, compared to using a lock-in alone, as all signal harmonics will be captured. And we've learnt from our customers that having a convenient way of determining the boxcar parameters would be a great help with getting results quickly, and that's what we've provided with the PFA. The UHFLI with UHF-BOX option is a fully digital instrument with unprecedented performance, along with a wide range of instrument types and tools all within a single device."

Zurich Instruments makes lock-in amplifiers, phase-locked loops and impedance spectroscopes that have revolutionized instrumentation in the high-frequency (HF) and ultra-high frequency (UHF) ranges by combining frequency-domain tools and time-domain tools within each product. This reduces the complexity of laboratory setups, removes sources of problems and provides new measurement approaches that support the progress of Research.

For images and more information, contact Warsash Scientific on +61 2 9319 0122 or sales@warsash.com.au.

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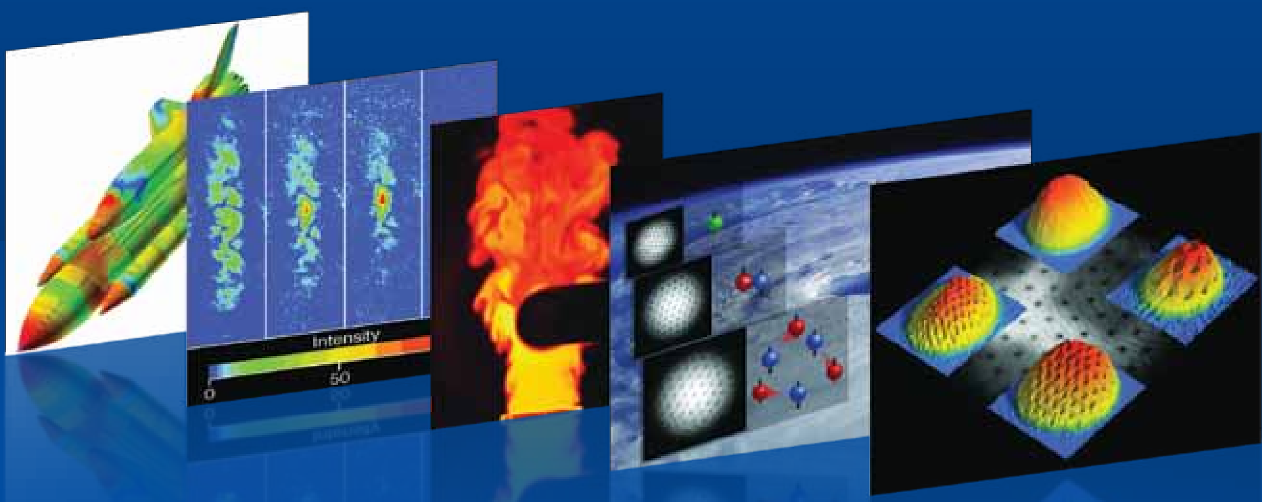

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