A legacy for lasers

Ronald Drever may be most famous for co-founding the LIGO project and his gravitational-wave research, but his contributions to laser stabilization have had broad impact on the photonics community.

The sad news that Ronald Drever, a Scottish physicist and a pioneer of gravitational-wave detection, passed away on 7 March, aged 85, has found the pages of many newspapers and science websites around the globe in recent weeks. Much coverage has focused, understandably, on Drever's role in co-founding the Laser Interferometer Gravitational-Wave Observatory (LIGO) project (www.ligo.org) in the US, which last year, following a series of improvements in sensitivity, reported the first detection of gravitational waves — an incredible feat that brought worldwide acclaim.

However, what perhaps hasn't been widely acknowledged is just how important one of the innovations that Drever helped invent has become to laser science in general. The innovation in question is the so-called Pound–Drever–Hall (PDH) laser stabilization scheme, whereby the emission frequency of a laser is locked with great precision and robustness to a resonance of an optical Fabry–Perot cavity. The PDH stabilization approach not only played an essential role in the development of highly sensitive interferometric gravitational-wave detectors, but also became an important and widely used tool for ultrafine atomic spectroscopy, optical frequency standards and quantum optics, where experiments demand stable lasers with narrow linewidth.

Drever first started his research into gravitational-wave detection at the University of Glasgow in the 1970s, where he established a research group on the topic and concentrated on designing, building and stabilizing large optical interferometers with Jim Hough, who is still at Glasgow and became director of its Institute for Gravitational Research for a number of years. Drever then moved to Caltech in the US in the early 1980s and teamed up with Kip Thorne at Caltech and Rai Weiss at the Massachusetts Institute of Technology, and the trio founded the LIGO project that features two independent, giant L-shaped interferometers in Hanford and Livingston with 4-km-long arms.

The PDH scheme was first documented in the journal *Applied Physics B* in 1983 in a paper entitled 'Laser phase and frequency stabilization using an optical resonator', written by Drever, Hough and others from Glasgow and John Hall and Frank Kowalski at the National Bureau of Standards and the University of Colorado[1]. The approach relies on capturing and analysing the reflection from an optical Fabry–Perot cavity of a laser beam that has been phase modulated by a radio-frequency signal. The resulting phase measurement gives information on the relative position of the laser frequency with respect to the cavity resonance and thus provides an error signal that can be fed back to the laser control circuitry to stabilize the laser. The technique is used around the world in many optics labs and the paper has been cited over 2,000 times, according to the Thomson Reuters' Web of Science.

Ron Drever in his lab. Courtesy of J. Hough.

Interestingly, on this original paper, Pound is not named as an author. However, the story is that Drever had the inspiration to try and make an optical analogue of a phase-based stabilization scheme that Robert Pound, a Harvard physicist, had developed in the 1940s to stabilize the frequency of microwaves[2], and that is why Pound's name is synonymous with the technique.

"Drever worked with Pound for a year in the 1950s and that is probably where the idea came from," explained Hough, who was an author on the 1983 paper and remembers writing much of it. "Pound was not on the original paper but he was acknowledged."

Drever then reached out to John (commonly called Jan) Hall at Colorado who had a reputation of being an expert experimentalist in high-resolution spectroscopy to make his idea a reality. Hall later went on to receive a share of the 2005 Nobel Prize in Physics for his work on spectroscopy optical frequency combs. "Jan Hall and Drever had great respect for each other," said Hough.

The original experiments described in the 1983 paper report the locking of a dye laser and a gas laser to a stable optical cavity and achieving a linewidth of the order of 100 Hz. Today, refinements of the scheme and improvements in cavities mean that linewidths on the order of 60 mHz are possible[3].

Jun Ye at Colorado worked with Hall before his retirement and also Drever at Caltech. He has spent much of his career using the PDH scheme ever since he first encountered it as a student in the 1990s. "The PDH scheme has incredible robustness and really has emerged as the dominant locking mechanism," he commented. "Today, all these years later, we are still using it to try and make ultrastable lasers with linewidths of just a few millihertz."

Importantly, compared with other stabilization schemes, the PDH scheme is fast, and as it is based on phase it is largely immune to intensity fluctuations and is very robust. As a result, it is highly effective, and this combined with its relative simplicity and inexpense to implement means that it has become a very popular technique.

Sylvain Gigan, a researcher from Laboratoire Kastler Brossel in Paris, France, says he recalls spending much of his time during his PhD on quantum optics staring at the error signal from the PDH scheme. "The PDH technique was a very elegant and robust way to get such an error signal, in a very clean way. There were also other techniques that were more exotic, but in my honest opinion, the PDH technique definitely was, by far, the most reliable," he told *Nature Photonics*. "To me, this technique, while probably considered minor in the career of Drever, is one of the most beautiful examples of optical analog signal processing, and definitely one of the best examples of the many subtle tricks that made laser history." ❐

References

1. Drever, R. W. P. *et al. Appl. Phys. B* **31,** 97–105 (1983).
2. Pound, R. V. *Rev. Sci. Instrum.* **17,** 490–505 (1946).
3. Kessler, T. *et al. Nat. Photon.* **6,** 687–692 (2012).