EMRP – ENG61 Future Grid
WP1 - Optical current sensor

2016-08-31

SP Technical Research Institute of Sweden

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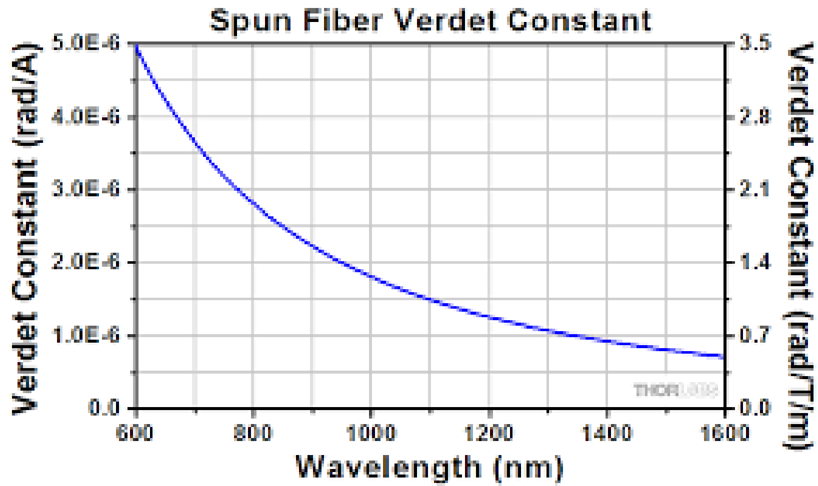
Work on the optical current sensor

- Targets and strategy
- System designs
  - Interferometry detection – Renishaw / Arteche
  - Phase detection – Profotech / ABB / etc.
    - Free space propagation
    - All fibre version
- Fibre development – University of Southampton and LNE
  - New materials
  - Reference measurments at LNE
- Programming API
- Theoretical support

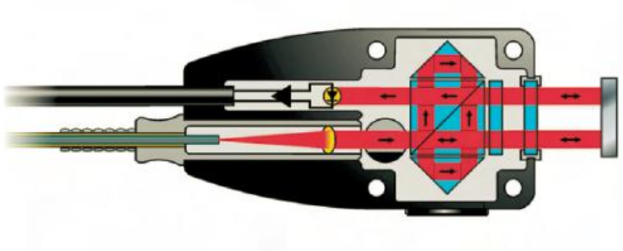
Targets and strategy

- Targets
  - 1 – 10 kA dynamic range.
  - 100 ppm measurement uncertainty
- Strategy
  - Selection of system working principle
    - Interferometric, Sagnac and Reflective mode studied
  - 633 nm instead of 1300 nm – 4 x higher response
  - Tb doped fibres – higher response
  - HiBi Spun fibre – avoid effects of birefringence



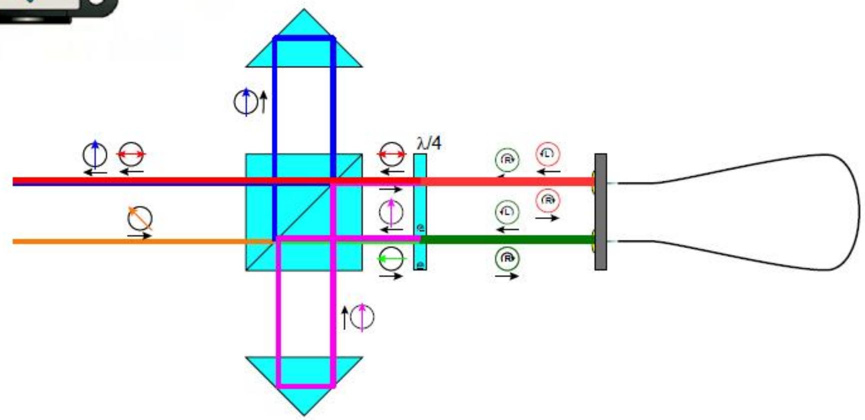
System designs

- System overview – Interferometric (Renishaw)



4 Layers available

Polarization is shown in the direction of propagation,
using a coloured arrow (linearly polarized)
or a coloured ring (circularly polarized)
Black arrow shows direction of propagation



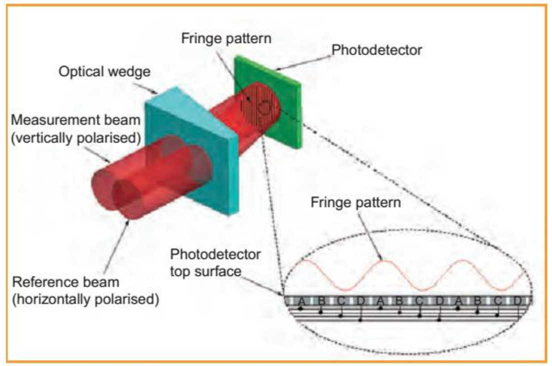
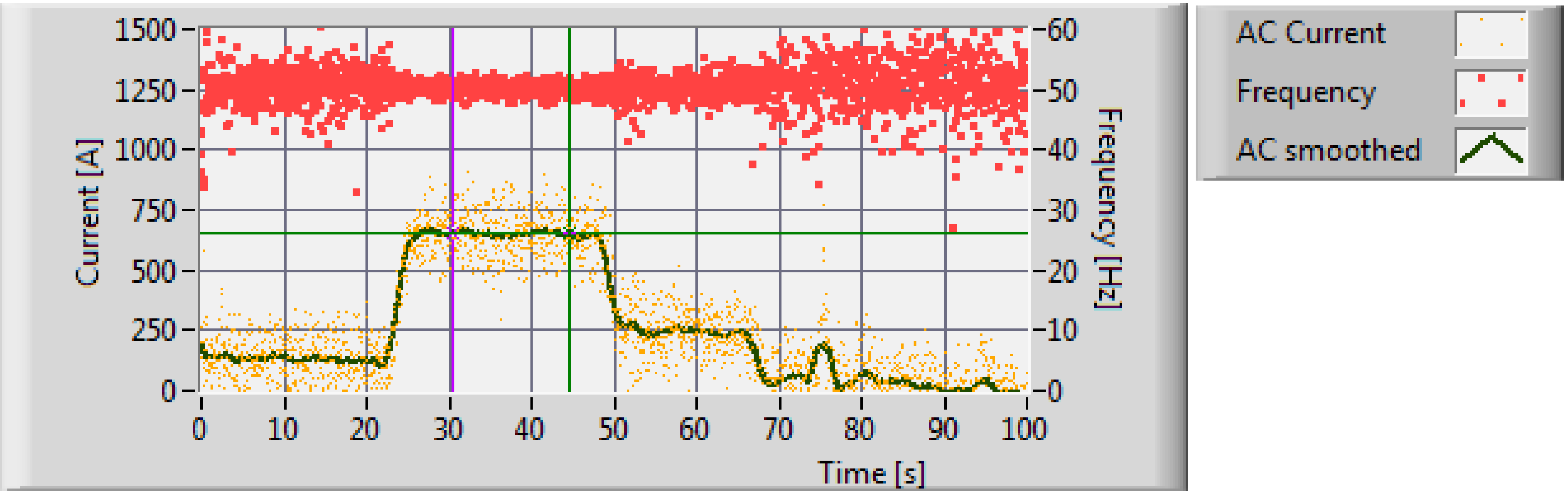


Figure 4: optical wedge and interference patterns

System designs

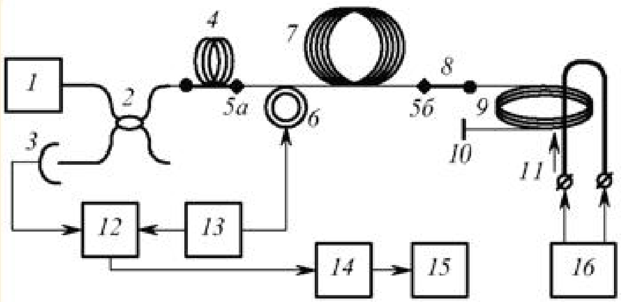
- Results – Interferometric (Renishaw)



System design

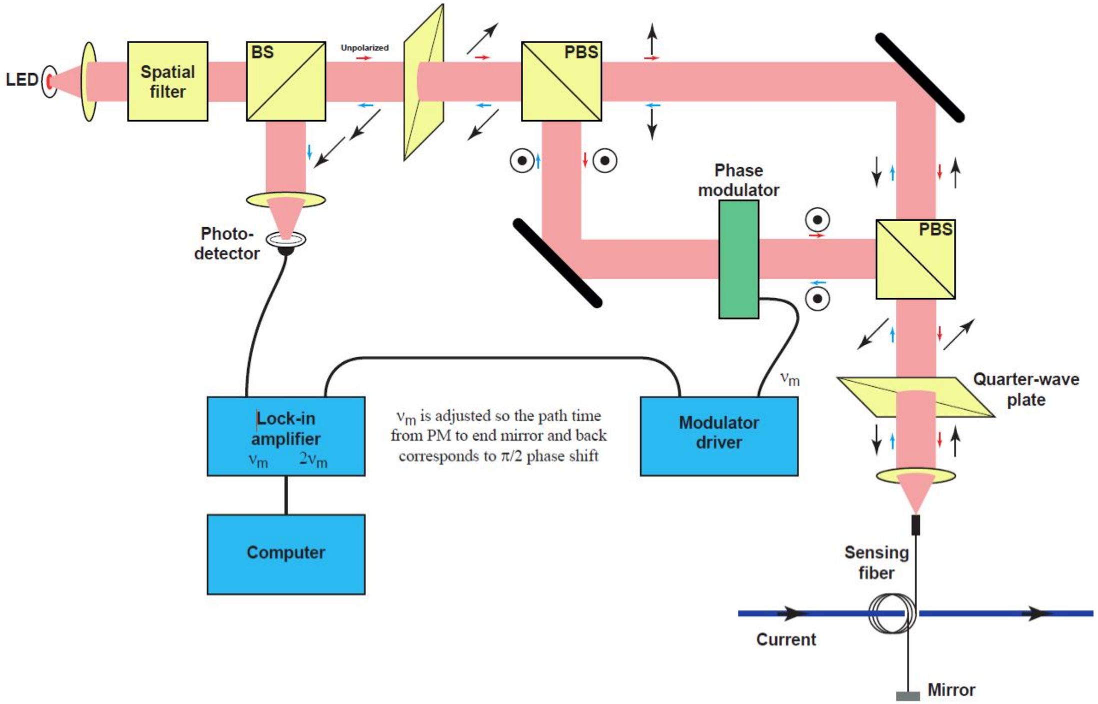
- System overview – reflective mode (Profotech)

- Components
  - 1: Wide-band light source
  - 2: Coupler
  - 4: Polarizer
  - 5a and b: 45° splices
  - 6: Birefringence modulator
  - 7: Delay
  - 8: Quarter-wave plate
  - 9. Sensing fiber
  - 10: Mirror
- Operates in reflection
  - 3: Photodetector
  - 12–15: Read-out electronics
- 16: Current source



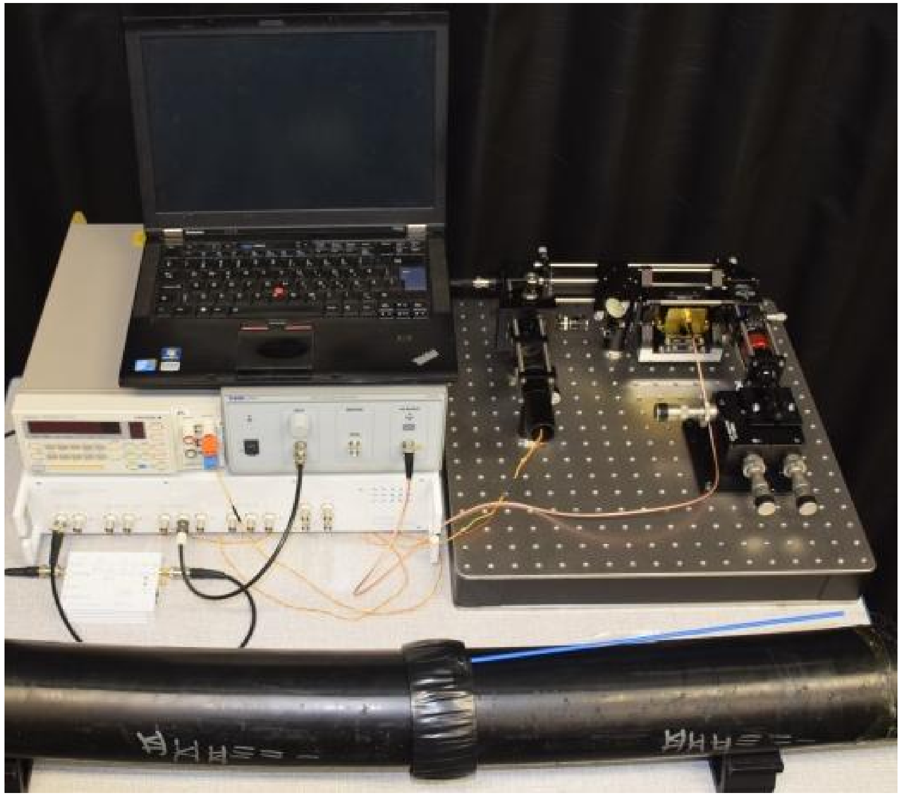
System design

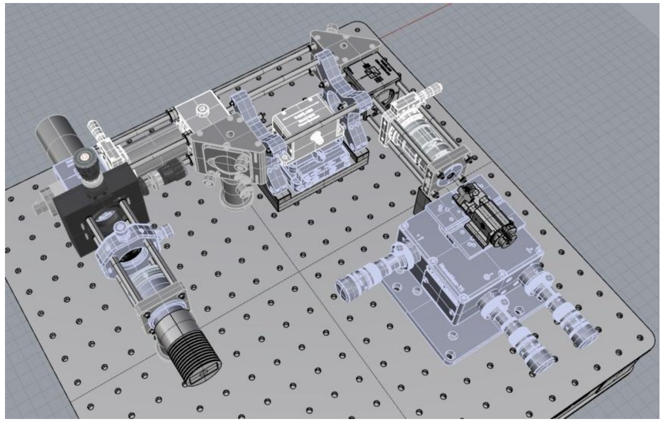
- System overview – open air design



Sensor systems

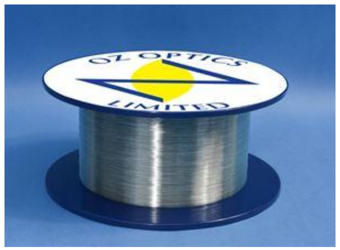
- Free space propagating version





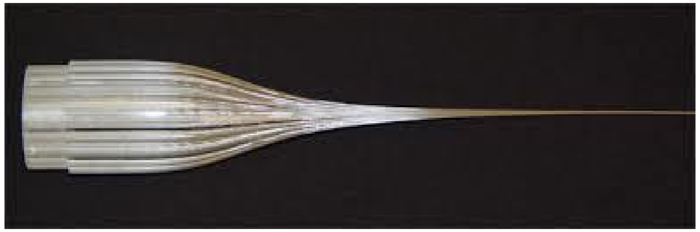
Sensor systems

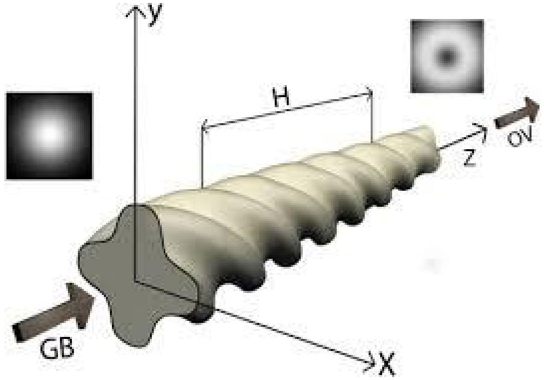
- All fibre version
- Fibre welding – Fujikura available at SP
- Components
  - EOM
  - 50/50 Splitter
  - Splicing – Fujikura
  - PM fibre
  - Sensing fibre – Southampton
  - End mirror coating



Fibre development - University of Southampton

- Tb doping of materials
  - Tb-doped Al_2O_3-P_2O_5-SiO_2, Tb-doped Al_2O_3-SiO_2 and P_2O_5-SiO_2
- Manufacturing of preforms
- Spinning of fibres – pitch 3 – 7 mm
  - HiBi fibres for optimum performance to counter birefringence induced by bending.
- Characterization at LNE





Programming API - LabVIEW

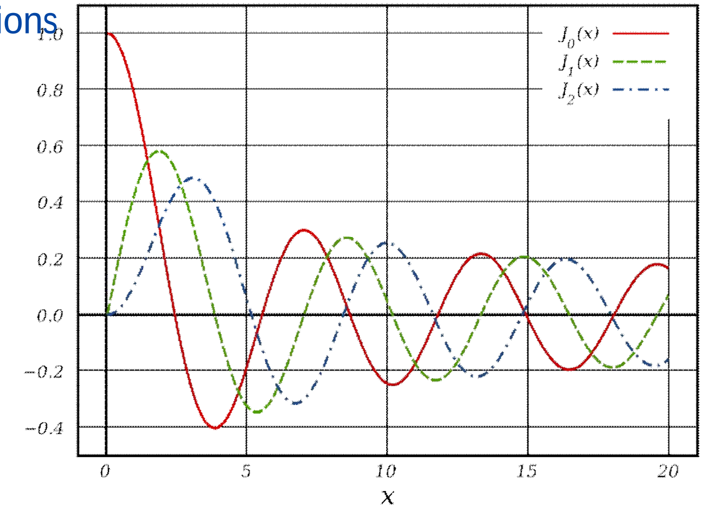
- Started with electrical signals for testing of principles of the lock-in amplifier
- Functions of the amplifier mapped
- Works with two simultaneous carrier waves and modulations
- Synchronization to AC signals still to solve.
- Hanning-compensation of unsynchronized sampling works. Amplitude error ca 0,015 %.
- API and method of calibration

Theoretical dissemination – Chalmers

- Output signal is detected with a lock-in amplifier
- Make a Fourier series expansion to second order – Bessel functions
- Three different scale factors for the different overtones
  - We want two of them

    $J_1(4A_m \sin(\omega_0 \Delta t)) = J_2(4A_m \sin(\omega_0 \Delta t))$
  - One of them should ideally be zero

    $J_2(4A_m \cos(\omega_0 \Delta t)) = 0$
  - This can be achieved!



- We choose the amplitude (A_m) and the frequency (ω_0)
- Numerical example:
  - Length of the sensor fibre: 10 m
  - Phase modulation frequency should be 0.75 MHz
  - Phase modulation amplitude should be 1.44 rad

Theoretical dissemination – Chalmers

- We set up the output signal according to

$$r(t) = P_{\cos(2\omega_0\ t)} + iP_{\sin(\omega_0\ t)}(t)$$

- In the ideal case we have

$$r(t) \propto \cos(4\theta_f) + i\sin(4\theta_f) = \exp(i4\theta_f) = (\exp(i2\theta_f))^2$$

- In the general case we assume

$$\theta_f \propto r(t)$$

- A complete signal characterization…
  - From fibre design parameters
- Via u and v in the Jones matrix
  - To the Faraday angle
- Via the detected Fourier components

…which is nice!

Output Signal Visualization
Faraday Effect in Spun HiBi