Polarization-sensitive plug-in optical module for a Fourier-domain optical coherence tomography system

Manuel J. Marques, Sylvain Rivet, Adrian Bradu
and Adrian Podoleanu

Applied Optics Group, School of Physical Sciences, University of Kent,
Canterbury CT2 7NH, United Kingdom

AOG Applied Optics Group @ University of Kent

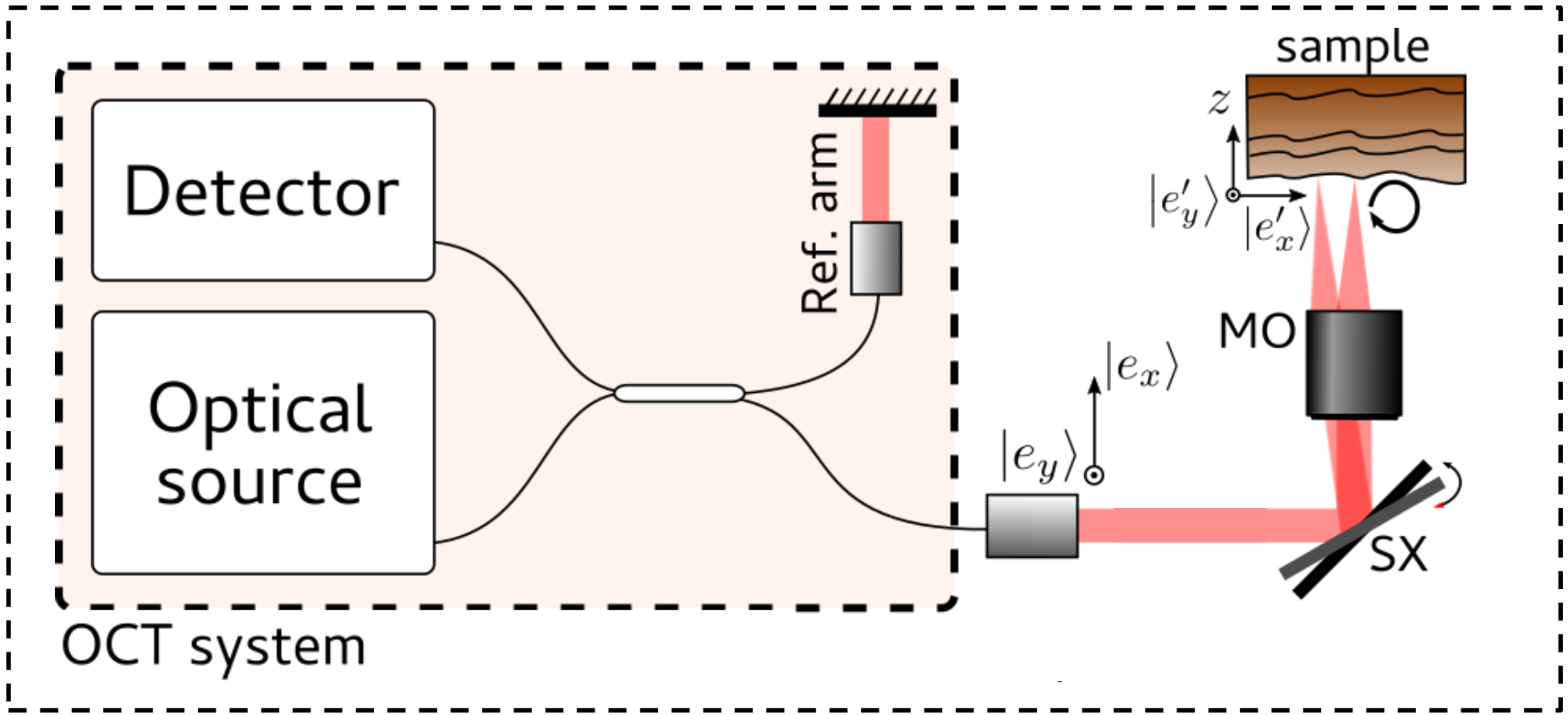
University of Kent

Motivation

- OCT: image translucent (@NIR) structures, resolution ~ 1-10 μm, few mm penetration.
- Functional extension: **P**olarisation-**S**ensitive OCT (PS-OCT).
- With PS-OCT we can study the retardance and axis orientation of samples. Potential applications include:
  - Measuring the density of the retinal nerve fibre layer;
  - Assessing burned tissue in dermatology;
  - Characterisation of polymers (NDT).

PS-OCT systems: can one add the functionality to an *existing* OCT system?

(as in… a plug-in module?)



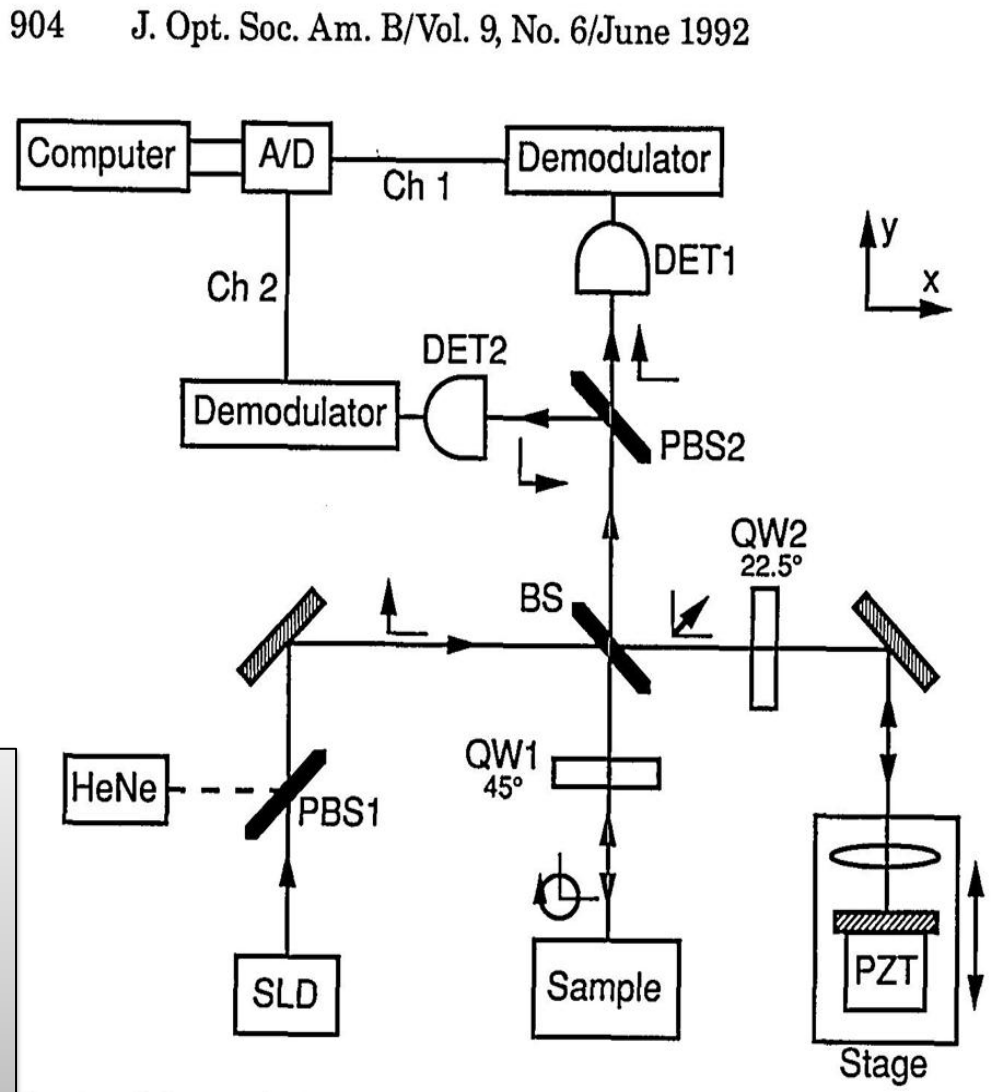
PS-OCT systems

First publication: Hee *et al.* (1992)

- Sample illumination with **circularly polarised light**.
- **Bulk** optics implementation.
- 2 orthogonal states are interrogated w/ **2 PDs**.

Since then:

- **Fibre**-based OCT systems;
- Interferometer interrogated in **frequency-domain**.

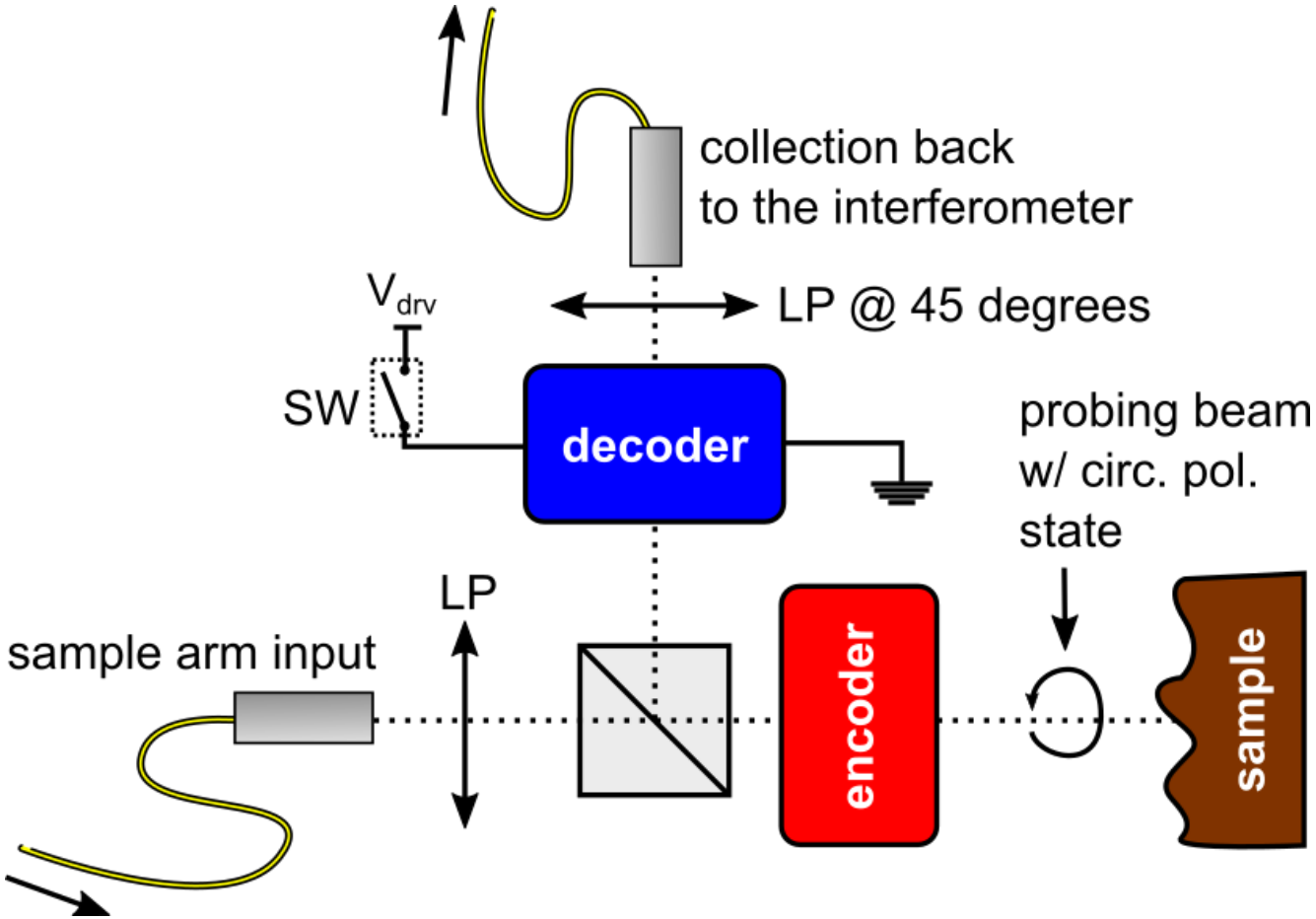


Challenges:

- Fibre-based PS-OCT systems introduce additional complications!
  - External factors (temperature, stress) affect the birefringence of SMFs;
  - Polarisation-maintaining fibres help but introduce PMD (ghosting of images).
- Spectral-domain detection:
  - Complexity is increased (eg. two spectrometers required).
- Module must be able to be installed on any OCT system with minimal modifications required!

Our first solution…

(Version 1.0)



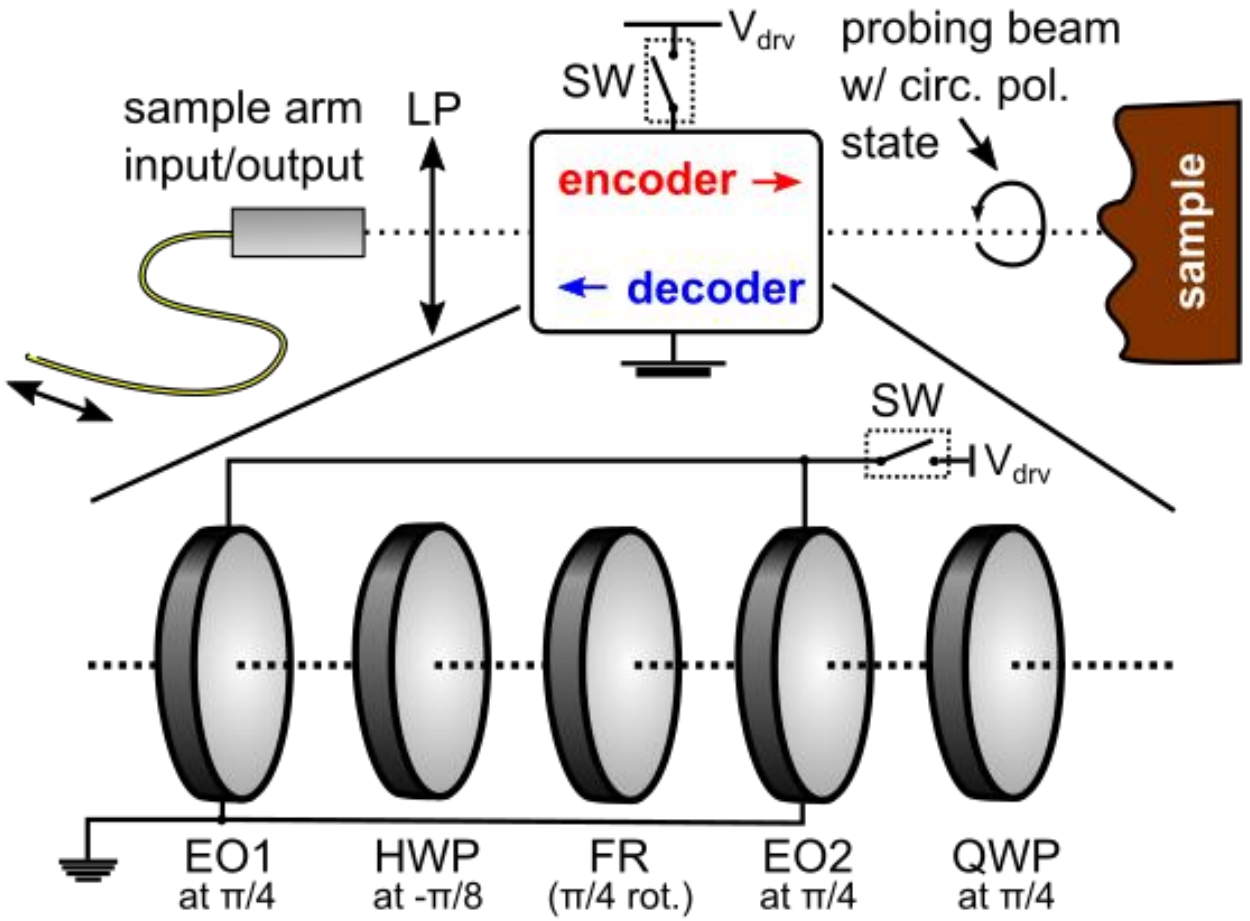
Marques *et al.*, *Opt. Lett.* **40**(16), 2015.
(and presented @ PW, BiOS 9697-55)

…*sequentially* measures the 2 orthogonal states *before* power is collected back to the interferometer.
(only **1 detector** required!)

With some limitations, however:

- Switchable decoder was **too slow** to ensure *in-vivo* imaging!
- 2 propagating paths (encoding/decoding) had to be ***spatially* separated**.

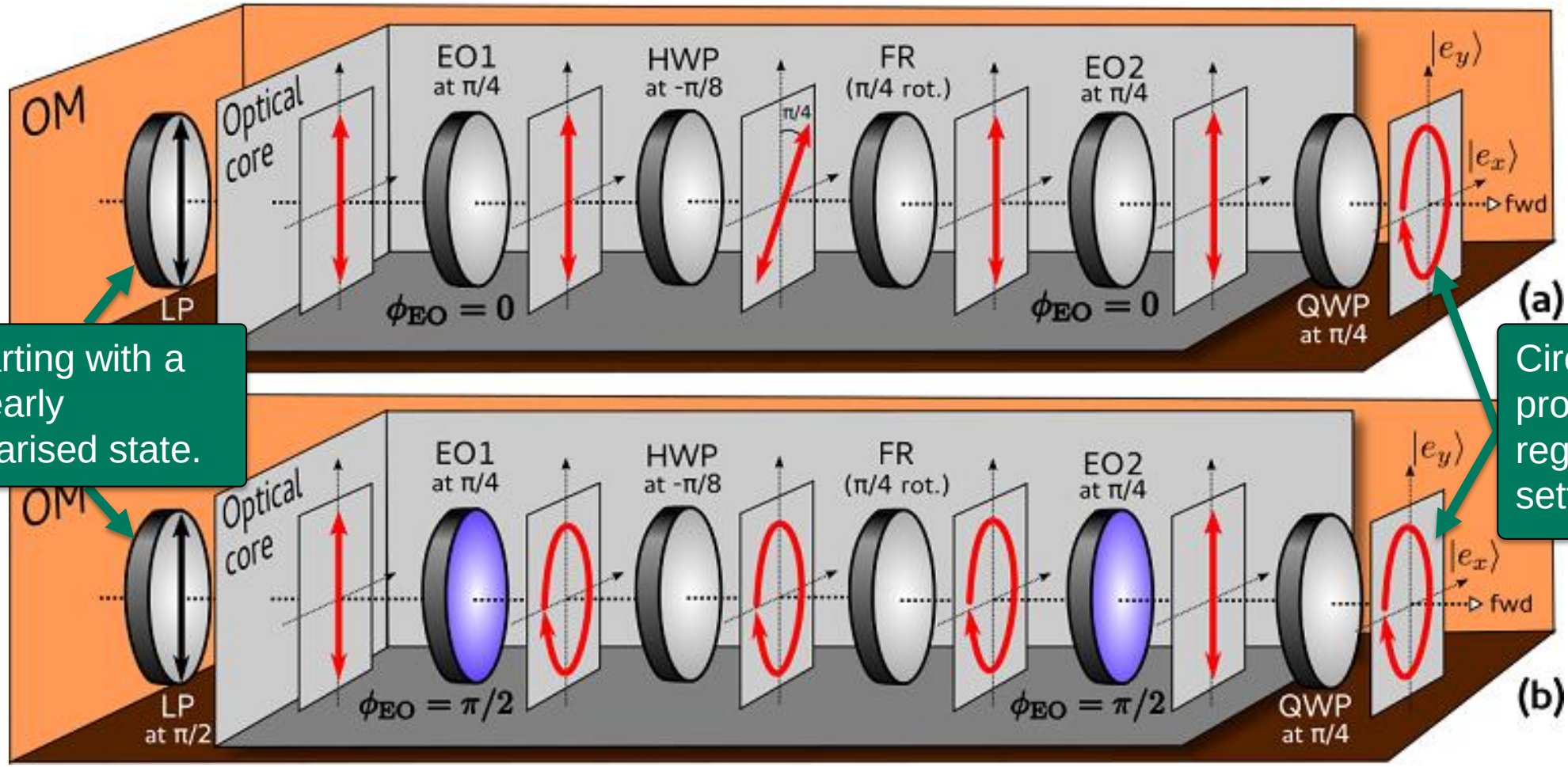
Version 2.0: in-line configuration
(concept)



- **Rotating element** - a combination of 2 EO modulators; (switching times < ms achievable)
- **Non-reciprocal design:** Faraday rotator ensures encoding and decoding path can be through the same elements (no need for spatial separation).

Rivet *et al.*, *J. Opt.* **18**(6), 2016.

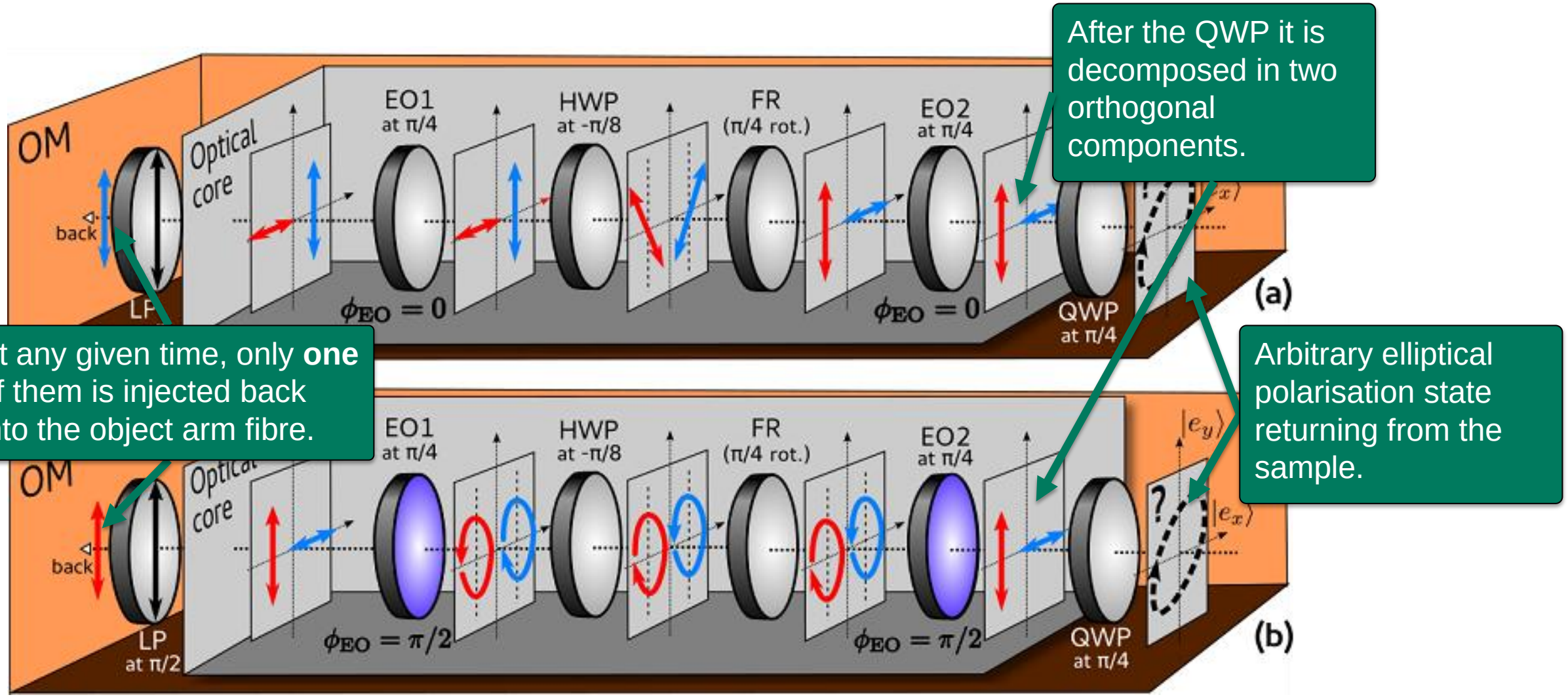
Principle of operation: forward propagation



Starting with a linearly polarised state.

Circularly polarised probing beam, regardless of the setting of ϕ_{EO}.

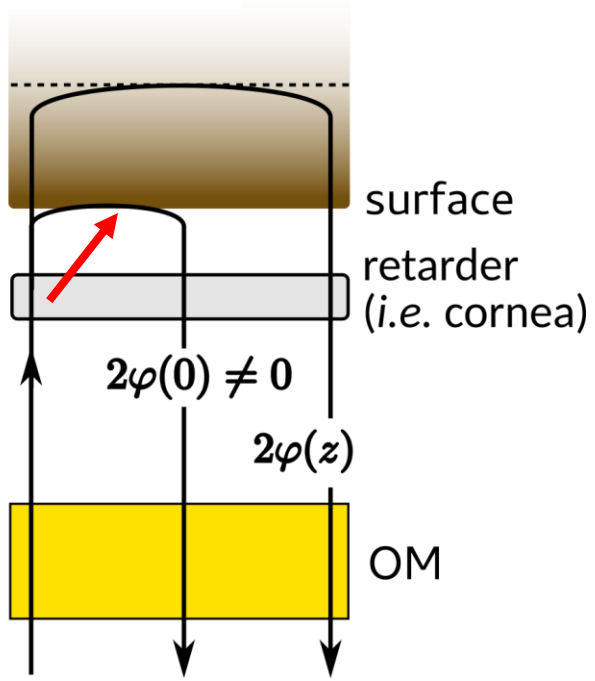
Principle of operation: backward propagation



Full polarization characterization is now possible! (but with some caveats for the measurement of θ…)

Three options:

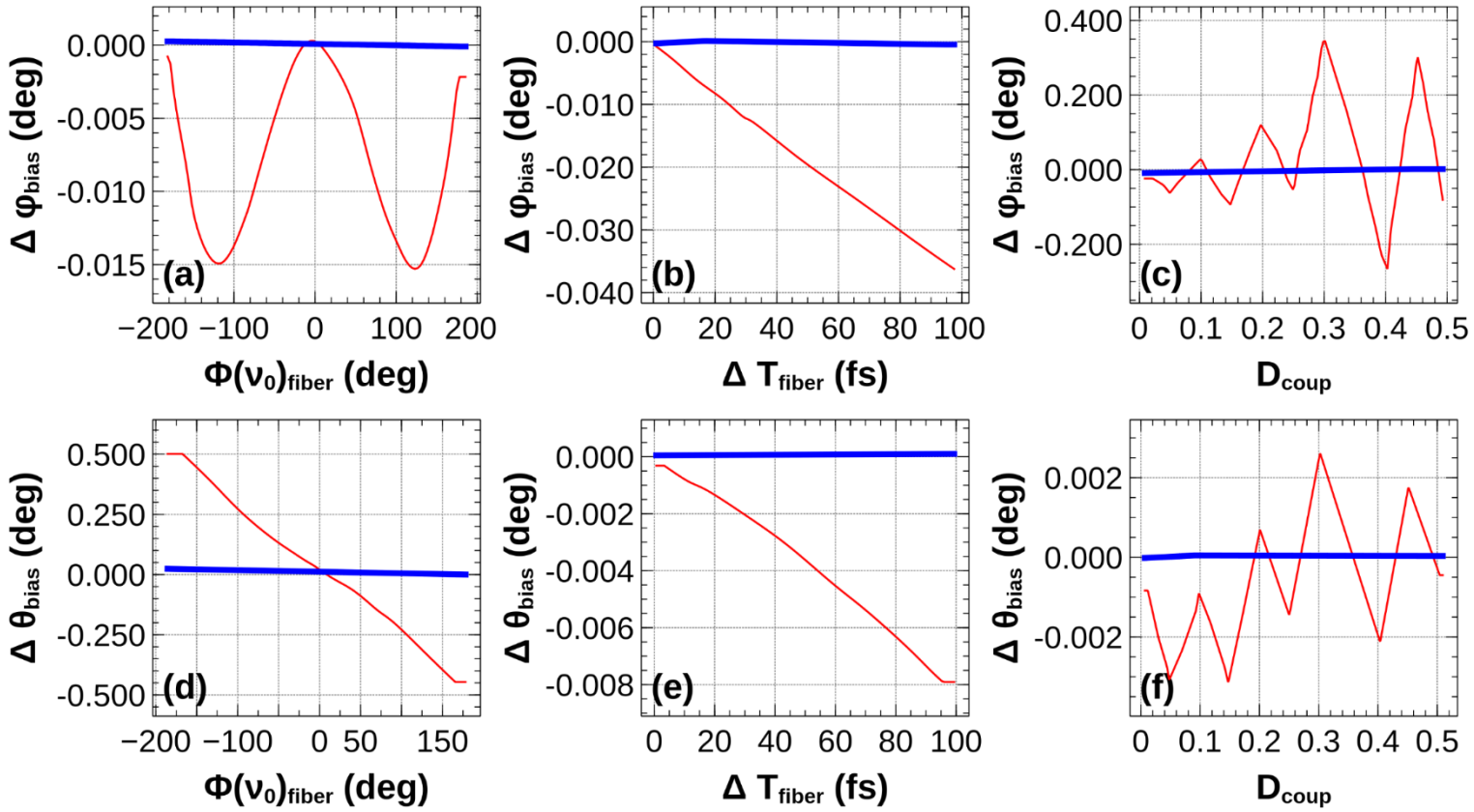
- Fast switching time: phase extraction from the OCT signal.
  (phase doesn't change between the two measurements)
- Slow switching time: use the first surface of the sample as a reference!
- But what if the "measured retardance" on the first surface is zero?



Measurement errors

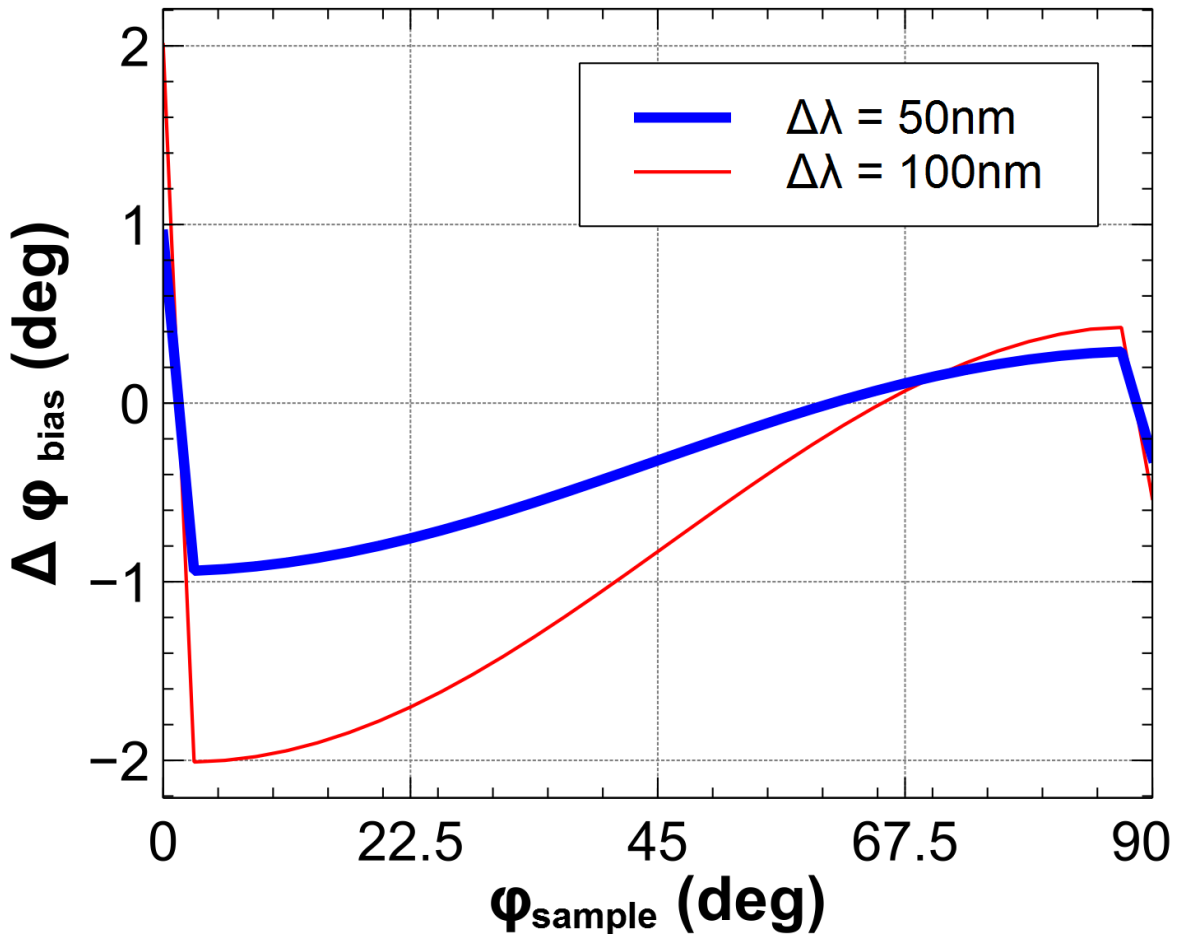
Rivet *et al.*, *J. Opt.* **18**(6), 2016.

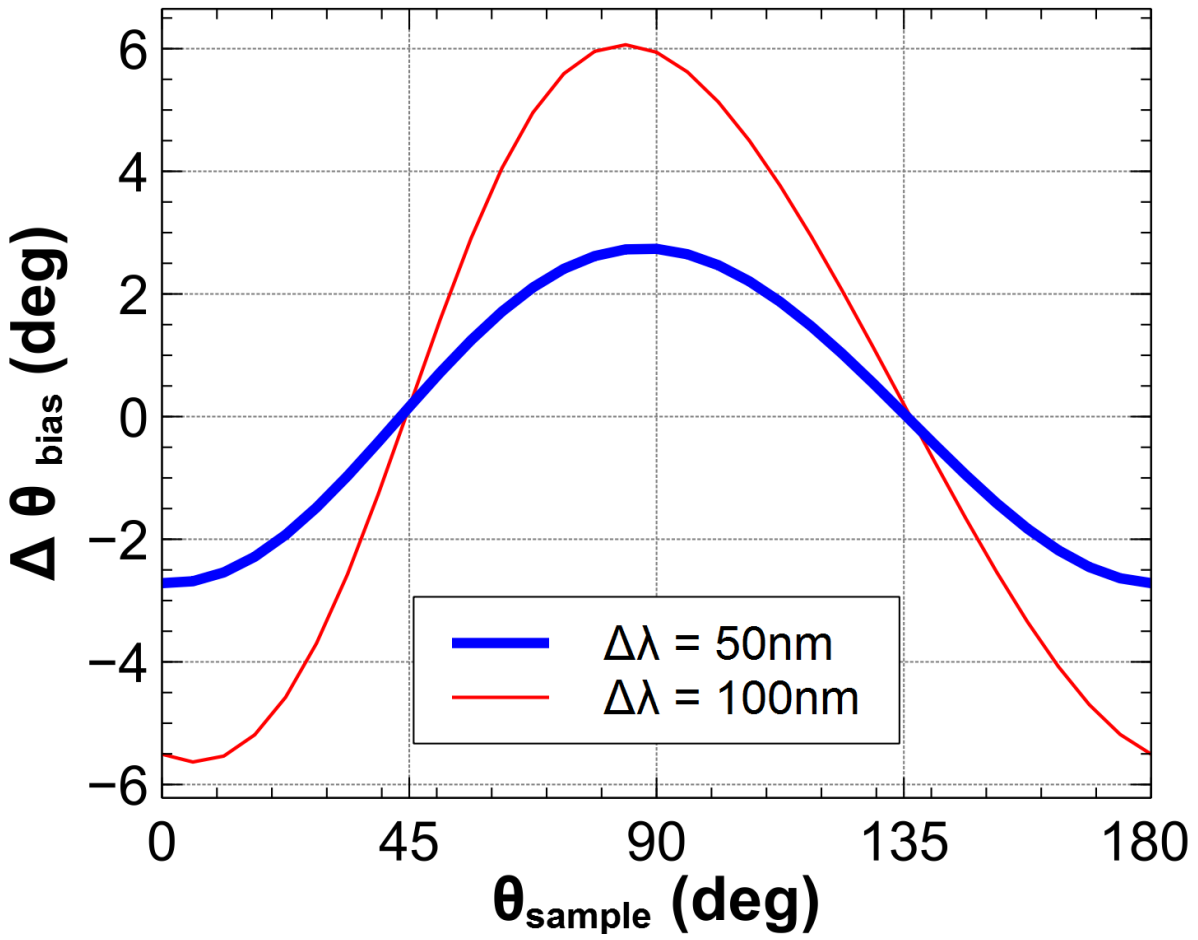
- Switching time *must* be shorter than the period of:
  - The random phase variation in the interferometer (for the measurement of θ);
  - The variation in the fibre disturbances.
- However… these errors are *<u>miniscule</u>* in comparison with those stemming from the **chromatic response** of the elements!



Chromatic response

Rivet *et al.*, *J. Opt.* **18**(6), 2016.





To conclude…

- Measurement errors within the module:
  - can come from fluctuations in the fibre properties;
  - but stem mostly from the chromatic response of the polarization elements (this is the case with every PSOCT system!!).
- Measurement procedure is still sequential!
- Version 2.0 of our polarization sensitive module is a *significant* improvement over version 1.0:
  - **Inline design** (true "*plug-in*" module);
  - Switchable decoder with a high switching rate: **complete** polarization characterization, and **no bottleneck** introduced in the speed of the OCT system!

Than

AOG (a

Firefox — 2nd Canterbury Conference on OCT (emphasis on broadband optical sources) | Save the date! - Mozilla Firefox

2nd Canterbury Conference on OCT...

2ccoct.aogkent.uk

Search

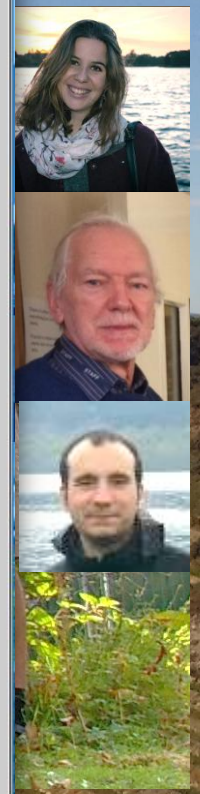
2nd Canterbury Conference on OCT (emphasis on broadband optical sources)

Save the date!

Home

Date: **6th – 8th of September 2017**
Venue: **University of Kent, Canterbury (United Kingdom)**

Chairs:
Adrian Podoleanu, University of Kent, Canterbury, United Kingdom
Ole Bang, Technical University of Denmark, Copenhagen, Denmark



erc

Douro Valley (near Pinhão), Portugal – September 2016