Numerical analysis of a swift, high resolution wavelength monitor designed as a Generic Lightwave Integrated Chip (GLIC)

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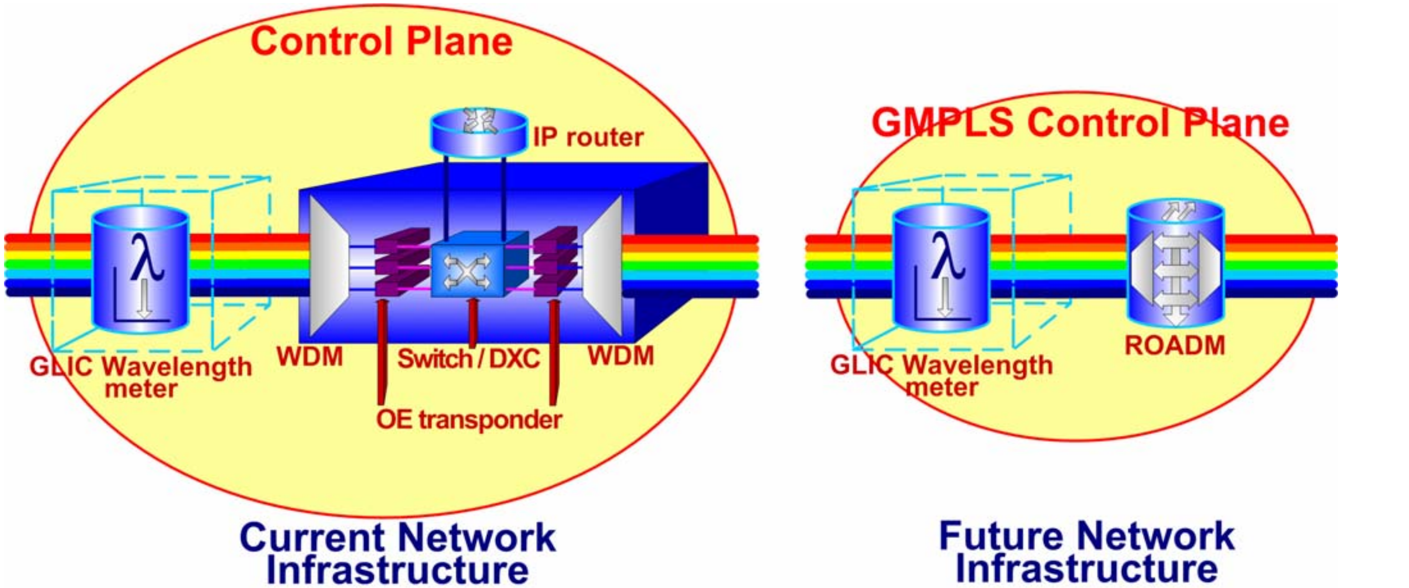
Principles of the GLIC wavemeter

- Can determine wavelengths with 2 – 5pm resolution
- Sub – microsecond response time
- Adaptable to a number of applications
  - Communications
  - Biophotonics
  - Sensing

GLIC in Communications Networks

- Compatible with present and future network configurations
  - Critical component for network monitoring in WDM-PON (WDMA) rollout



Description of the device

- Fabricated in SiO_2 on a Silicon substrate
  - Easily incorporated into PLC based systems
- Consists of a 4 channel PLC
  - Has mutually offset dual Fabry – Perot etalons on 2 channels
  - 3rd channel contains a linear dielectric filter
  - 4th channel is for throughput and reference

Schematic Layout of GLIC wavemeter

Theory governing the device

- Initial tunable Micro Electro Mechanical System (MEMS) filter
  - serves as a coarse channel pre – selector
- Linear filter
  - generates a crude Look Up Table (LUT)
- Use in – quadrature response of the FP arms
  - normalised
  - wavelength is determined using Free Spectral Range (FSR) data

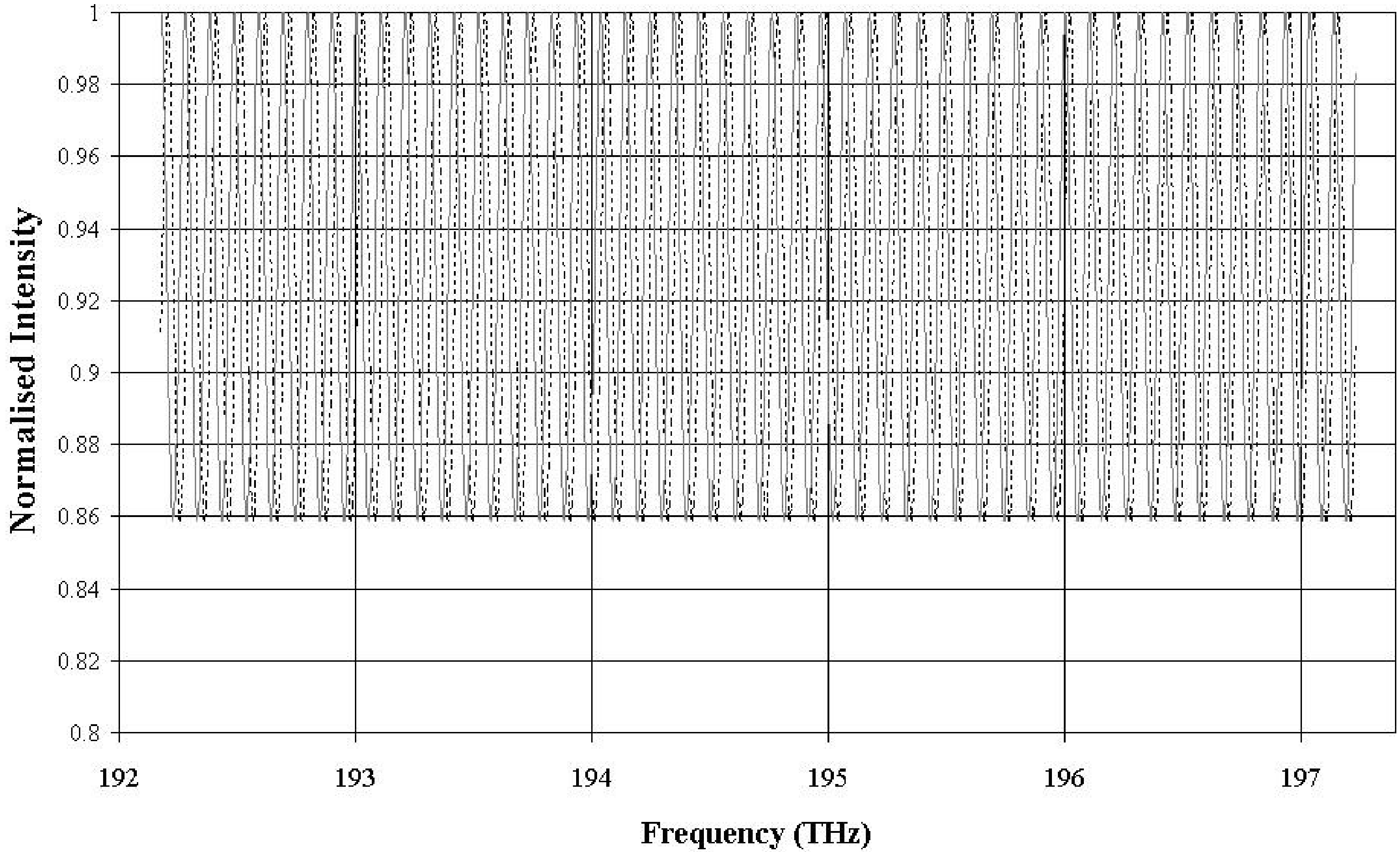
Necessity for Quadrature

- Host of devices may be used as to determine wavelength
  - Linear Dielectric Filters (LDF)
  - Fabry – Perot Interferometers (FPI)
- Standalone versions do not realise high resolution
  - Staircase effect in LDF
  - Resolving power of FPI diminishes as spectrum of interest increases

Realising Quadrature

- Reflections from the mirror faces create a multiple beam interference pattern
- Establish a suitable offset so as to advance one FSR by ¼ wavelength
  - Arbitrarily selected 100 GHz (25 GHz)
- Ensure no swap over of FSR's occur in the region of interest
  - FSR's remain within ±4 GHz of the 25 GHz required for quadrature

Plot of Quadrature over the entire C Band



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Determining the cavity shift

- Condition for maximum to occur in the interference pattern: $m\lambda = 2\,n\,d\,\mathrm{Cos}(\theta)$
- The FSR in terms of frequency is: $(\nu)_{FSR} = \dfrac{c}{2nd}$
- Selecting the desired order of Interference and the spectrum of interest permits the etalon lengths to be evaluated
- Dual cavity systems augment the resolving power
  - Maxima exist when those of the intermediate longer etalon coincide with those of the shorter air trenches
  - Range may be increased without an overlapping of orders

Important parameters for the design

- Require a Low finesse
  - R air – glass interface ≈ 4%
  - A sinusoidal type Airy function response
  - Elongation permits use of approximately linear section of FSR to resolve the wavelength

$$F = \frac{\pi\sqrt{R}}{1-R}$$

- High Visibility preferred
  - More resolving power in the vertical plane
  - Sharpens the fringes into delta – like functions
    - Requires a finesse – visibility tradeoff

$$\boldsymbol{V} = \frac{\mathbf{2}\boldsymbol{R}}{\mathbf{1}+\boldsymbol{R}^2}$$

Addressing losses

- Losses at facets do not affect the visibility and finesse relationships
  - Will affect intensity of the throughput pattern
- Optimise trench thickness
  - Cavities longer than 20μm suffer severe losses (>2dB per trench)
- Prevent thermal losses

$$\frac{\partial(nd)}{\partial T} = \left(n\alpha + \frac{\partial(n)}{\partial T}\right)d$$

  - $\partial n/\partial T \approx 0.00001$ /°C
  - Heat entire device to a homogeneous temperature of 60 °C to avoid thermal transients affecting quadrature

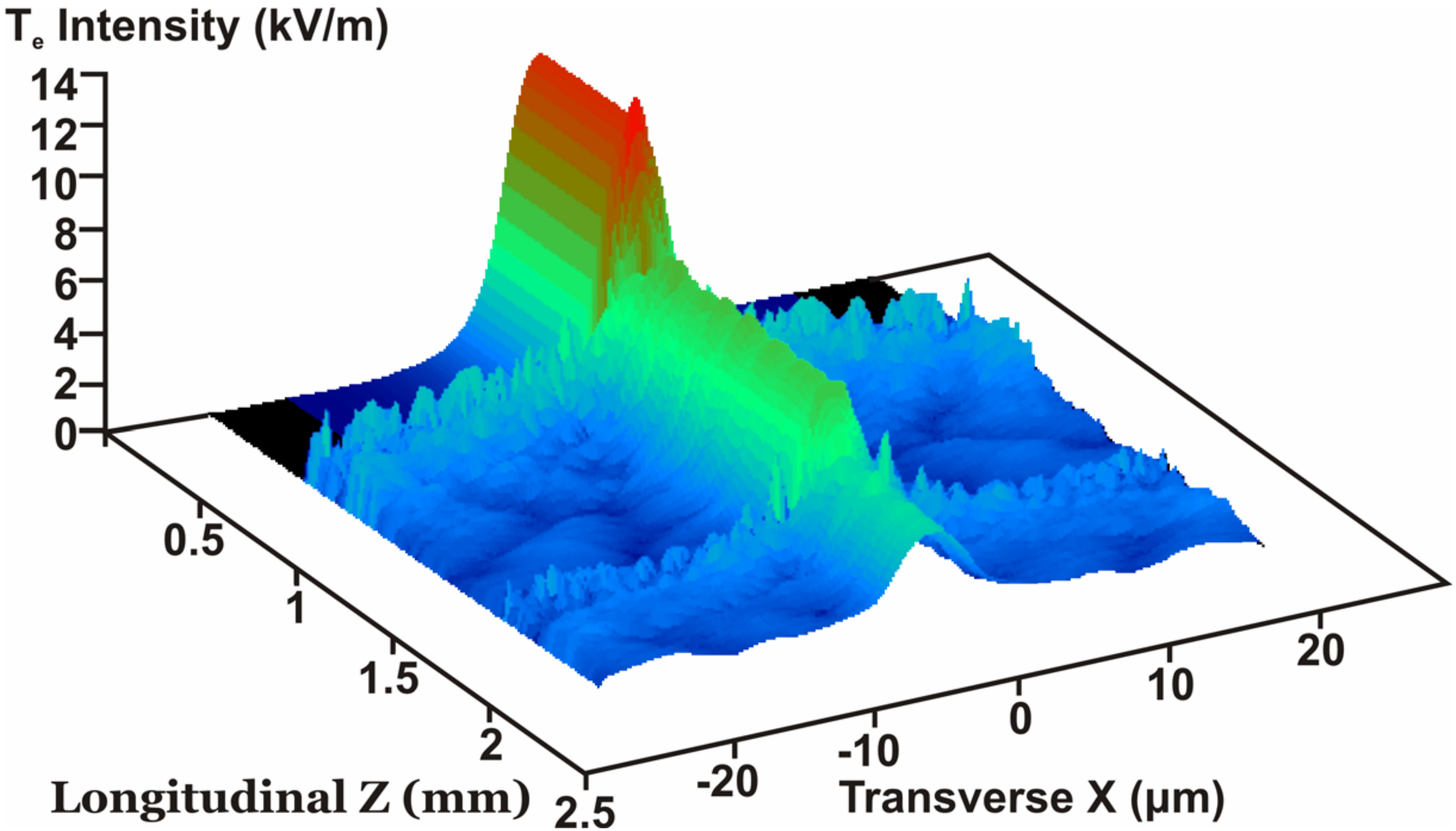
Fine Tuning Mechanism

- Imperfect cavity lengths will prevent quadrature from being realised
  - Losses
  - Fabrication limits
- Take advantage of Thermo – Optic effect
  - May calibrate the cavities using TO effect
  - NiCr thin film heater sputtered on top of waveguides to make slight adjustments as required

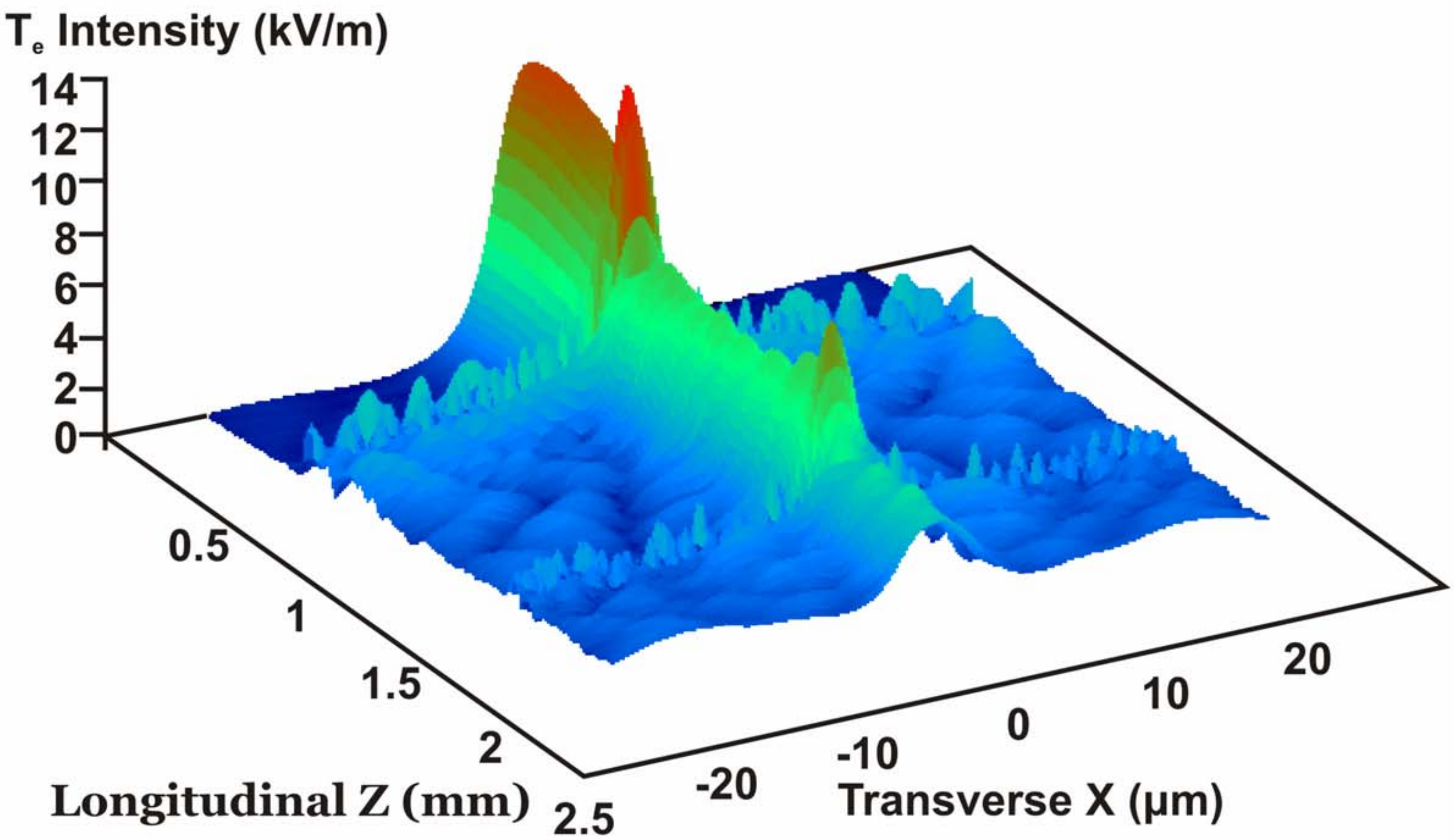
Simulations

- Multiple back reflections at the Fabry – Perot facets
  - Beam Propagation Method (BPM) is insufficient
  - Bidirectional BPMs are unstable or time consuming
  - FDTD is inefficient due to multiple facets
- Developed a Finite Element – BPM twinned with a Bidirectional Eigenmode Propagation (BEP) method
  - Permits modelling of back reflections
  - Avoids pitfalls of BPM or BEP standalones

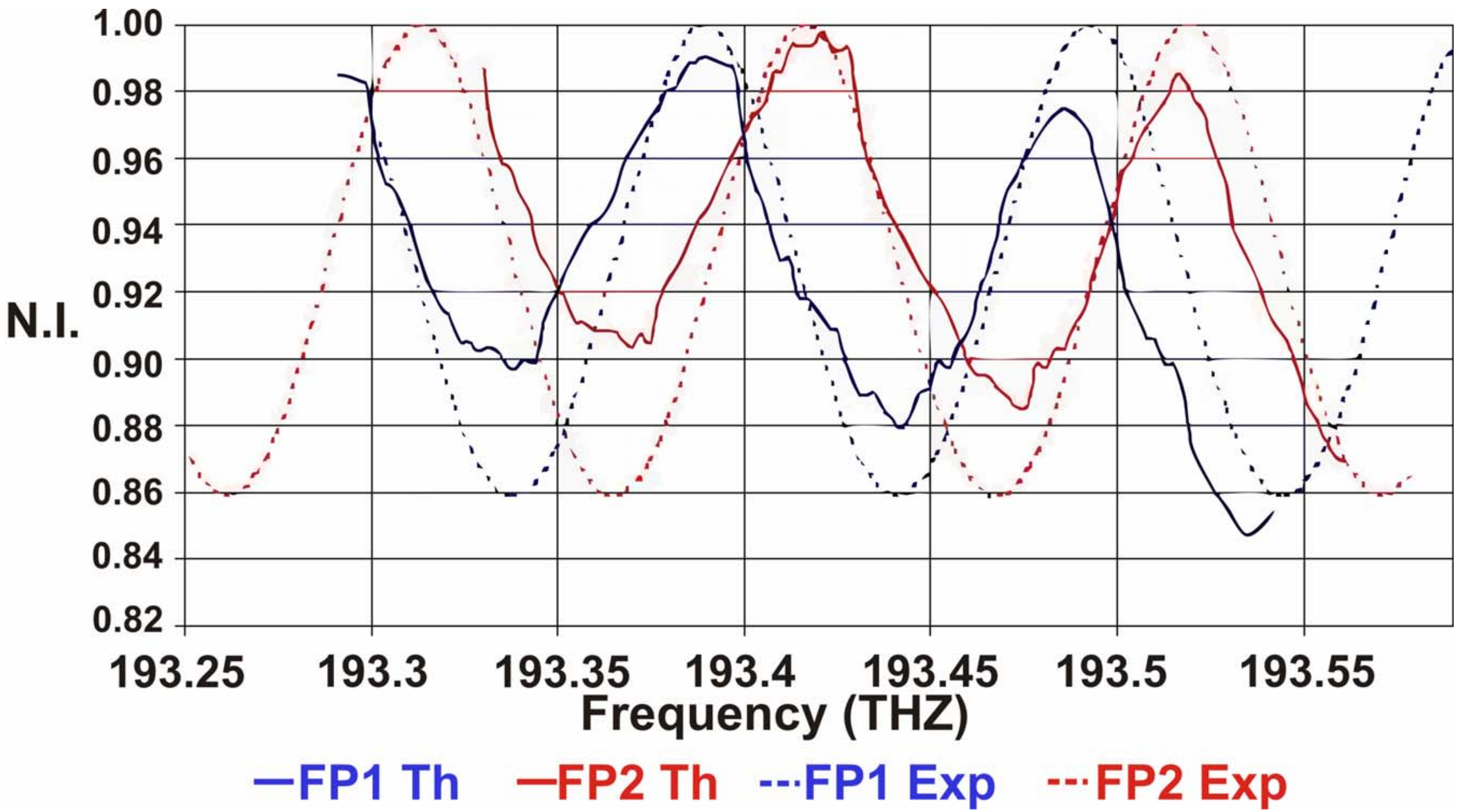
BPM simulation depicting 2 air trenches



BEP simulation depicting the same 2 air trenches



Experimental Results



- Portrays excellent correlation with quadrature theory

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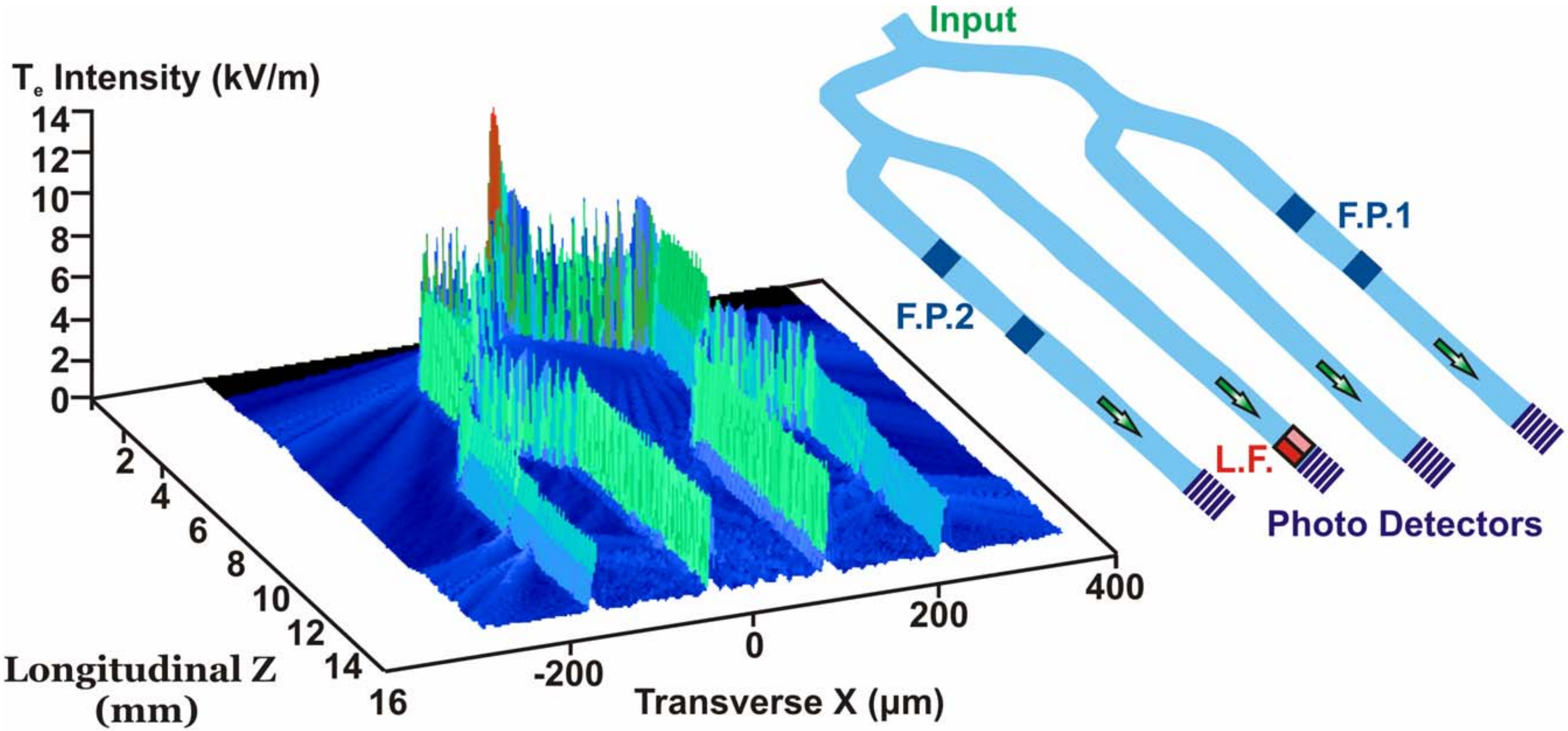
Merits of combining the FE – BPM with the BEP

- Arbitrarily pre – selecting the appropriate method for each sub – region enhances the accuracy of the simulation
  - Straight, tapered and bent waveguides may be analysed via the FE – BPM (providing no significant reflections occur)
  - Regions containing substantial reflections (the GLIC air trenches) can be handled with the BEP

Simulation after combining the FE – BPM with the BEP



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FE – BPM / BEP analysis

- Twinning the BEP and FE – BPM is an efficient method for simulating PLCs
  - Computational effort is minimalised
  - Speed of solution is acceptable
  - Appropriate Boundary Conditions may be applied
- The pitfalls of both methods may be largely avoided allowing this approach to be implemented on modest PCs

Proposals for Future Work

- Increase overall speed of the wavemeter
  - Implement the Optical Signal Processing (OSP) on an Application – Specific Integrated Circuit (ASIC) platform
  - Ultrafast photodetectors with response times <15ps
- Increase resolving power
  - materials such as Silver (R = 80%) or Aluminium (R = 75%) will increase visibility
- Test & improve Thermo – Optic tuning system
- Extend sensing capabilities
  - Application specific design criteria

Conclusions

- Fast accurate wavelength meter has been designed
  - Sub microsecond response time
  - 5pm precision
- An efficient numerical method has been implemented, accounting for the modal propagational profile and losses
- Theory of quadrature has been realised

Acknowledgements and References

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- **J.A. Ging and R.F. O'Dowd, "A Generic Lightwave Integrated Chip (GLIC) for fast, high resolution wavelength monitoring", SPIE Photonics Europe, Photon Mgmt. II. (6183) 2006**

- **J.A. Ging, "Advanced design solutions for passive & active Planar Lightwave Circuits", PhD. Thesis, Spring 2007**