Photolithographically Manufactured Acrylate Polymer Multimode Optical Waveguide Loss Design Rules

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Outline

1. Motivation:
    1. Optical versus Electronic interconnect
    2. Waveguide design rules
2. Photolithographic fabrication of acrylate polymer waveguides
3. Measurement technique
4. Loss measurement of waveguide components design rules
    1. Straight waveguides
    2. Crossings
    3. Bends
    4. Tapers
    5. Tapered bends
5. Optical system design

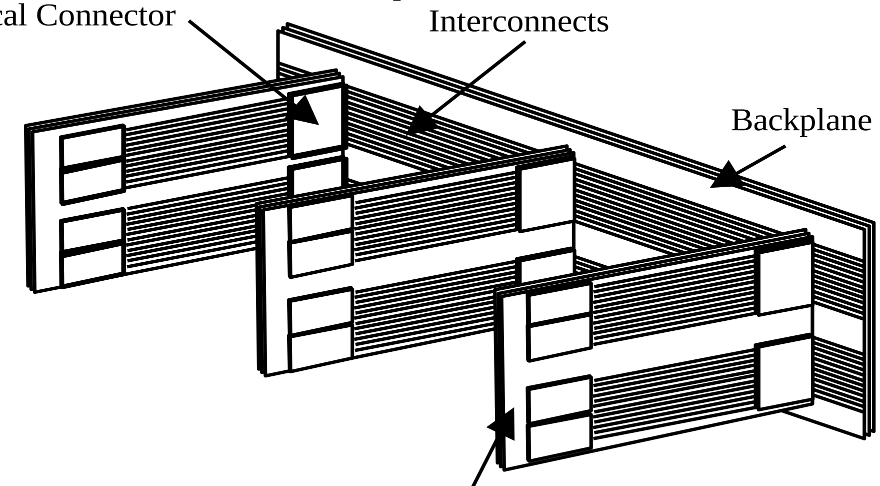
Optical versus Electronic Interconnect

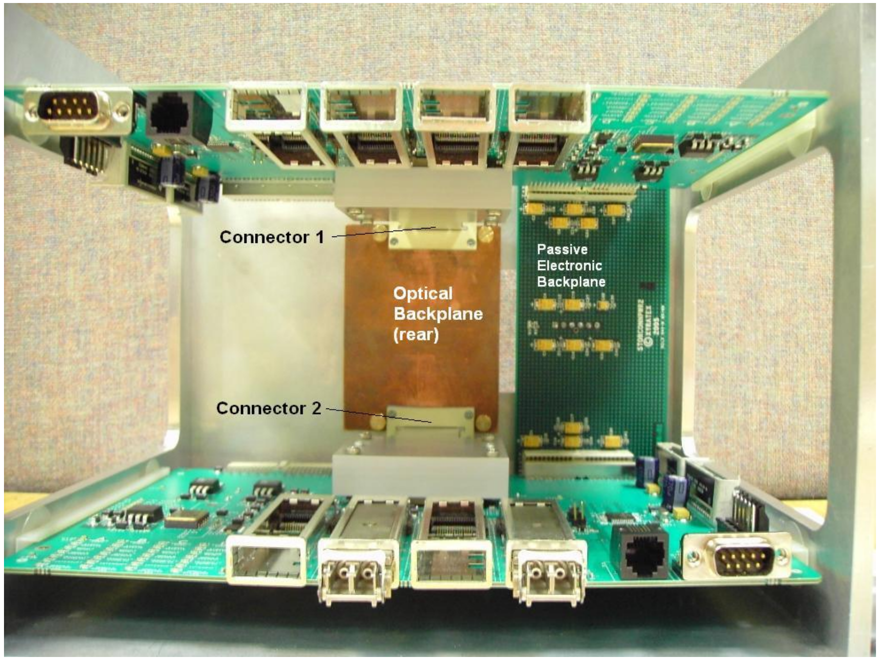
- Copper tracks become inefficient as data rates rise above 10 Gb/s
  - Skin effects in the conductors,
  - Cross-talk,
  - Electromagnetic Interference (EMI),
  - Reflection,
  - Signal loss and manufacture cost increases.
- Optical interconnect has potential benefits
  - Less delay due to no RC components,
  - High speed travel in optical materials,
  - Low propagation loss 0.03 ~ 0.06 dB/cm at 850 nm wavelength in waveguide $< 50 \times 50$ μm in cross-section,
  - Do not require impedance matching,
  - Wavelength division multiplexing is achievable.

Fabrication Parameters

- The optical loss depends on several factors:
  - Material,
  - Fabrication
  - Measurement Technique
- Photolithographically fabricated by Exxelis Ltd. using e-beam mask
- Truemode® acrylate polymer formulation
- Core refractive index 1.5560
- Cladding refractive index 1.5264
- NA = 0.302
- Cross sections typically 50 µm 50 µm and 70 µm 70 µm square

Electrical System with Optical Interconnect





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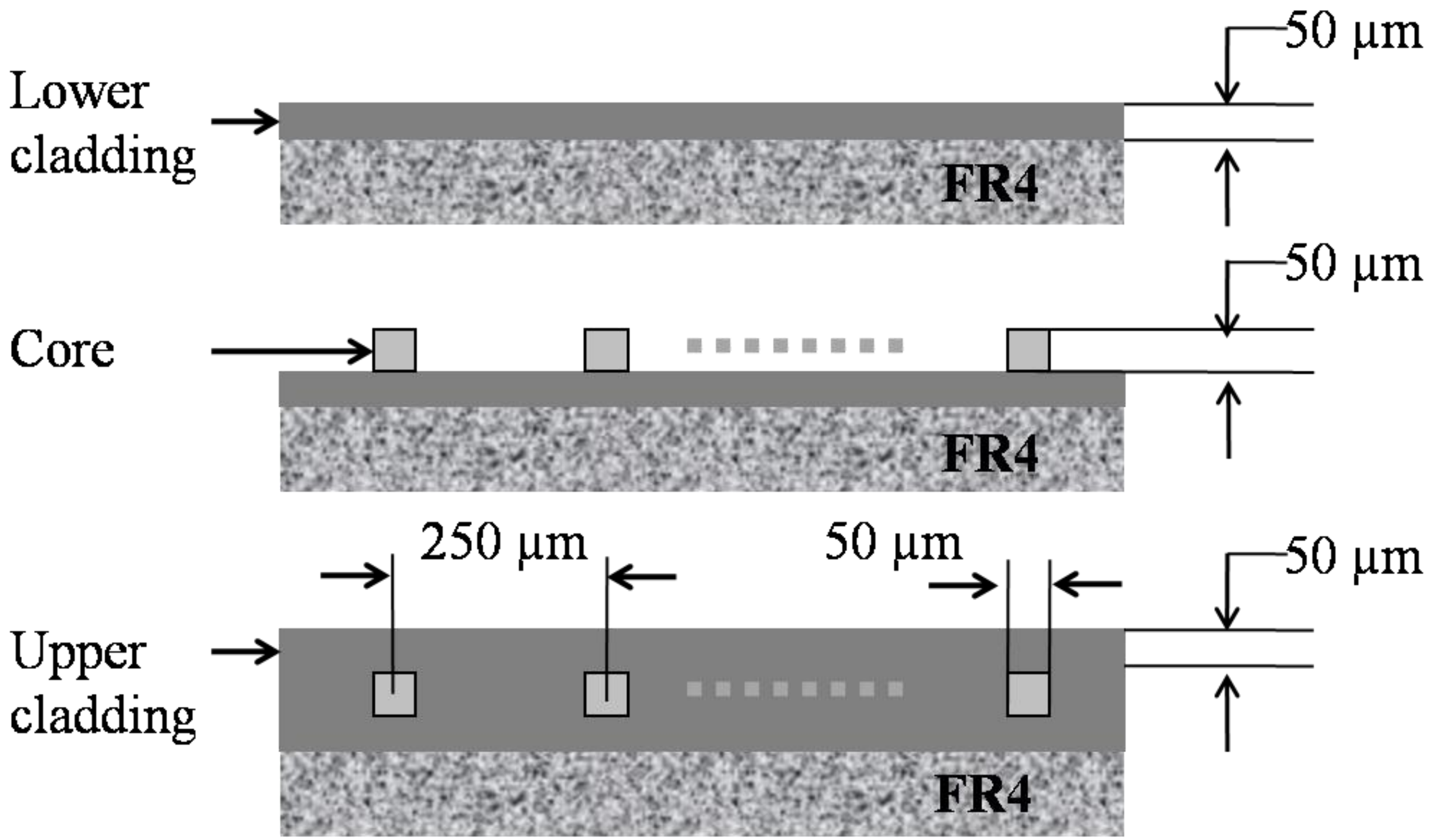
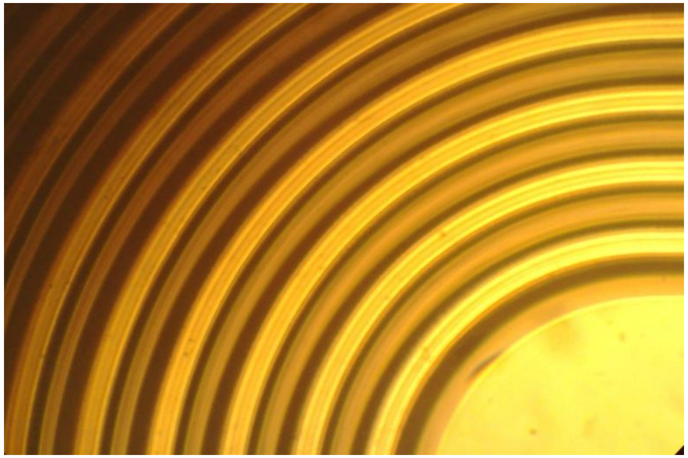
Photolithographic fabrication of waveguides, 50 μm × 50 μm Core

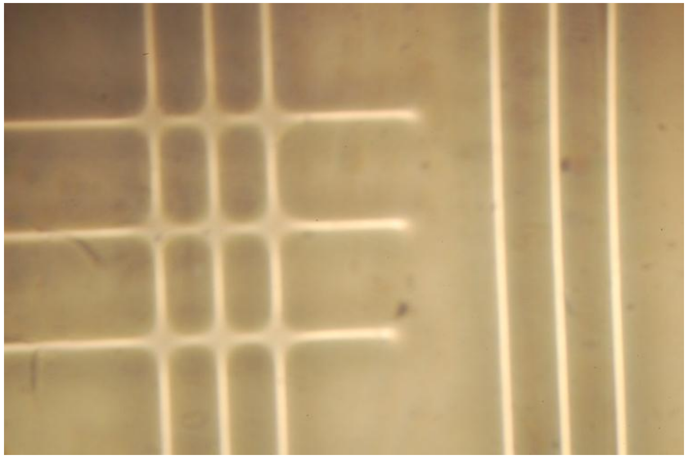


Waveguides Samples – Top View

Straight waveguides



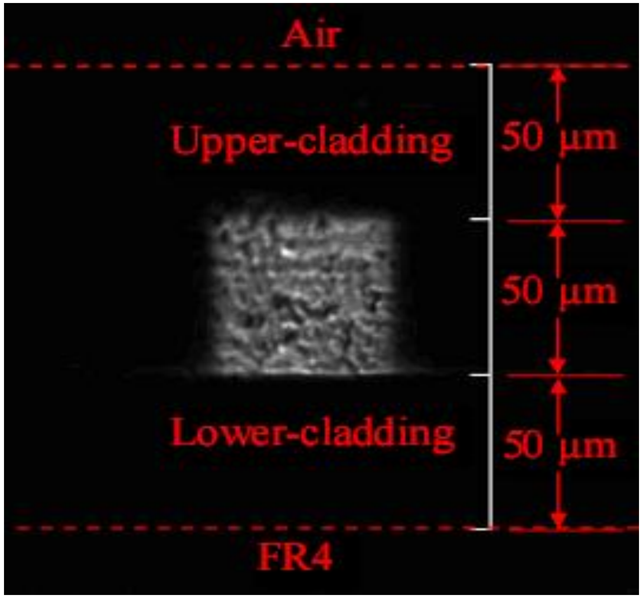
Bends



90° Crossings

50° Crossings

Waveguide Output Facet Photographs



VCSEL illuminated

Under nomarski microscope

- Photolithographicly fabricated by Exxelis, 50 μm × 50 μm waveguide
- Cut with a dicing saw, unpolished

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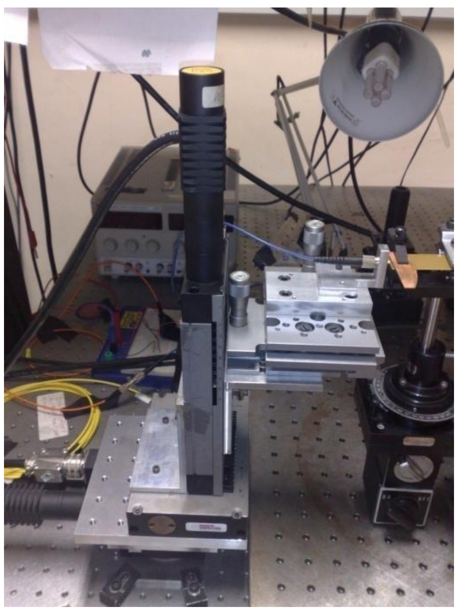
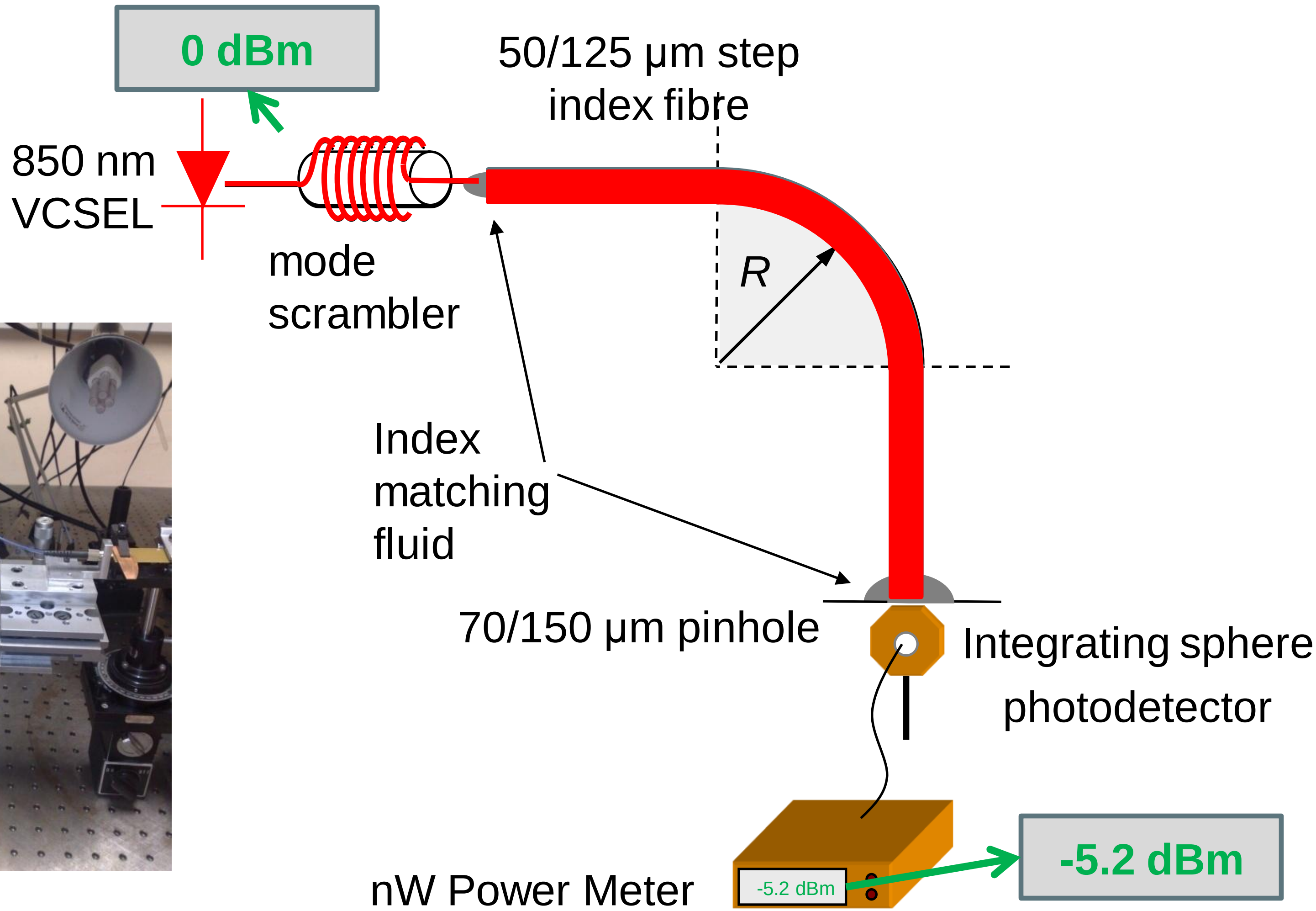
Optical Loss Measurement





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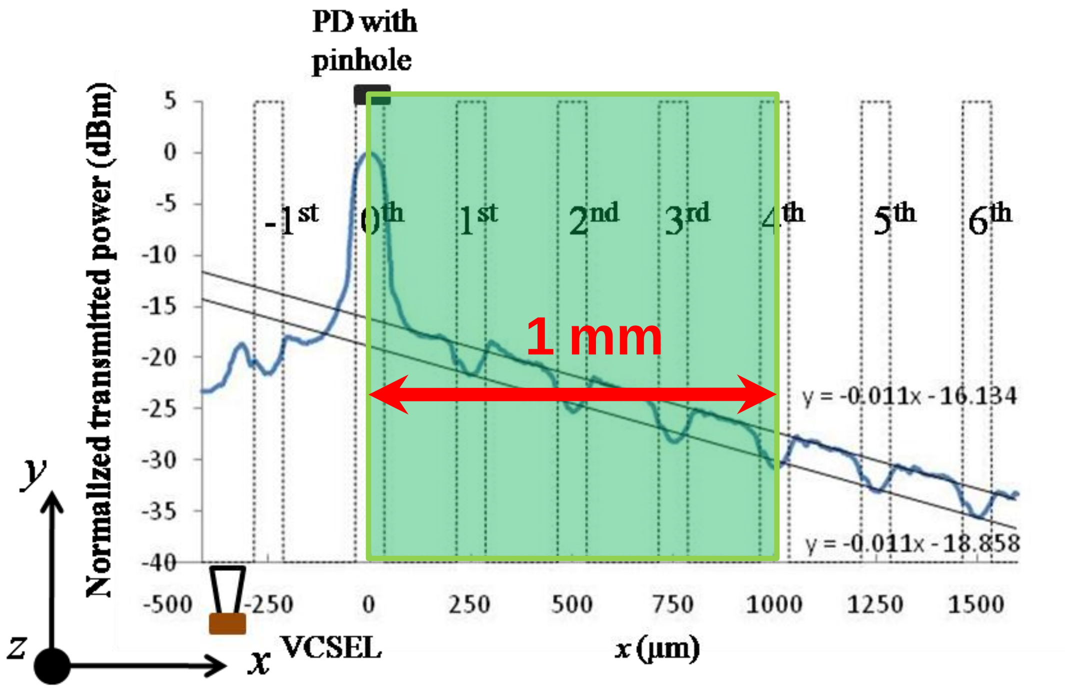
Design Rules for Inter-waveguide Cross Talk



- ❑ 70 µm × 70 µm waveguide cross sections and 10 cm long
- ❑ Waveguide end facets diced but unpolished scatters light into cladding
- ❑ In the cladding power drops linearly at a rate of 0.011 dB/µm
- ❑ Crosstalk reduced to -30 dB for waveguides 1 mm apart

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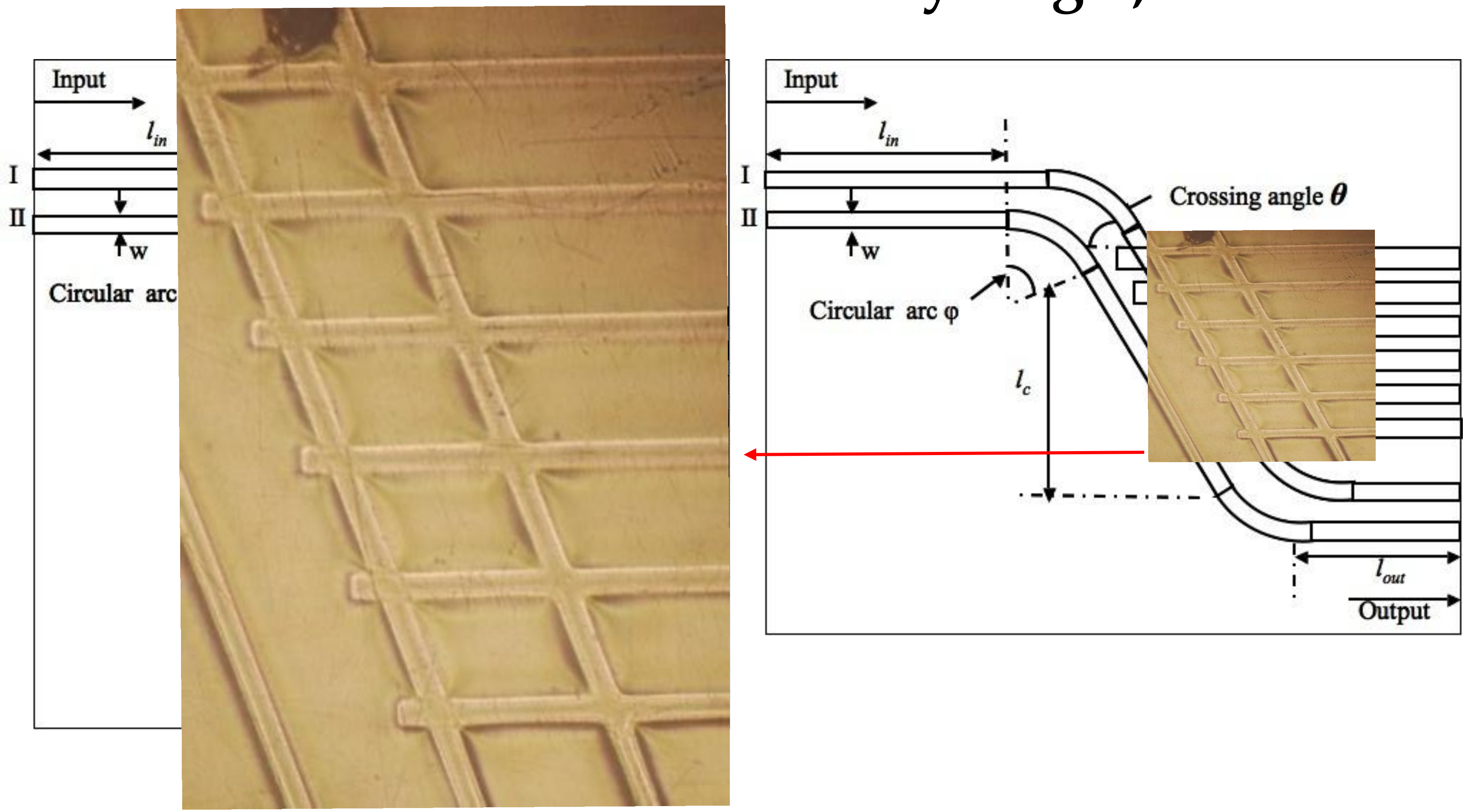
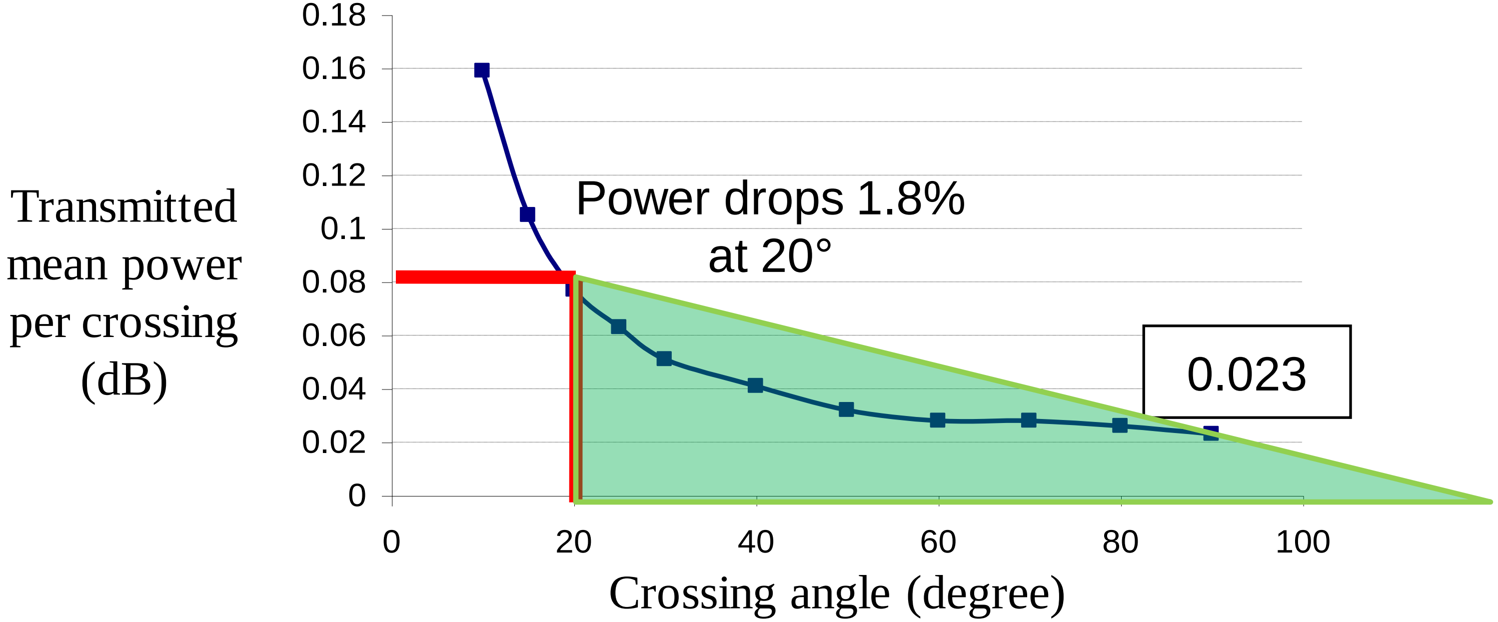
Schematic Diagram Of Waveguide Crossings at 90° and at an Arbitrary Angle, θ



Design Rules for Arbitrary Angle Crossings



- Loss of 0.023 dB per 90° crossing consistent with other reports
- The output power dropped by 0.5% at each 90° crossing
- The loss per crossing (L_c) depends on crossing angle (θ), $L_c=1.0779 \cdot \theta^{-0.8727}$.

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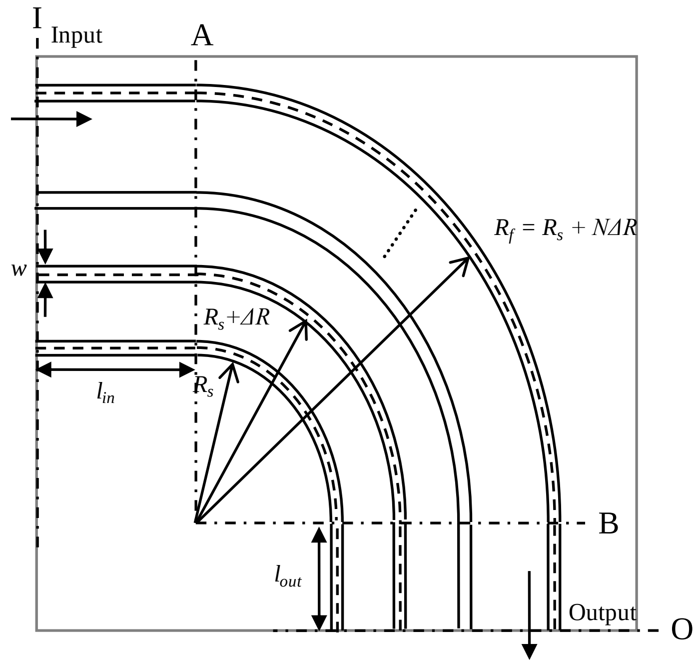
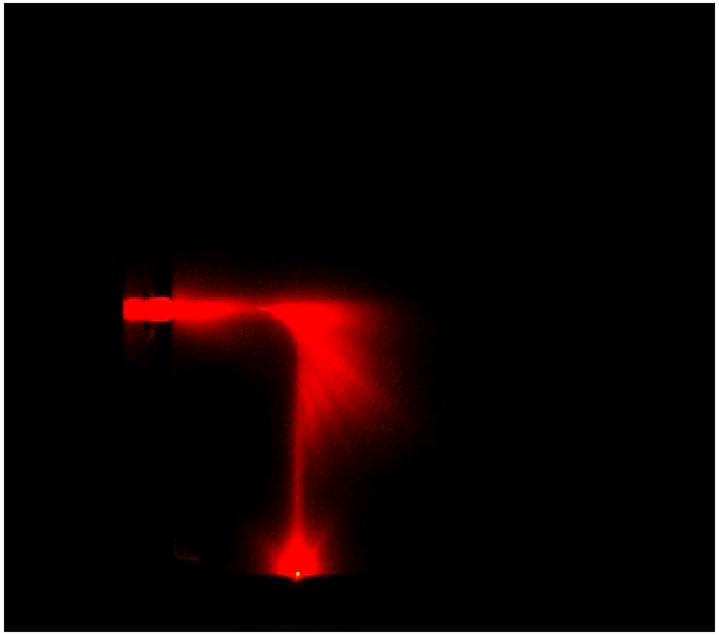
Optical Power Loss in 90° Waveguide Bends



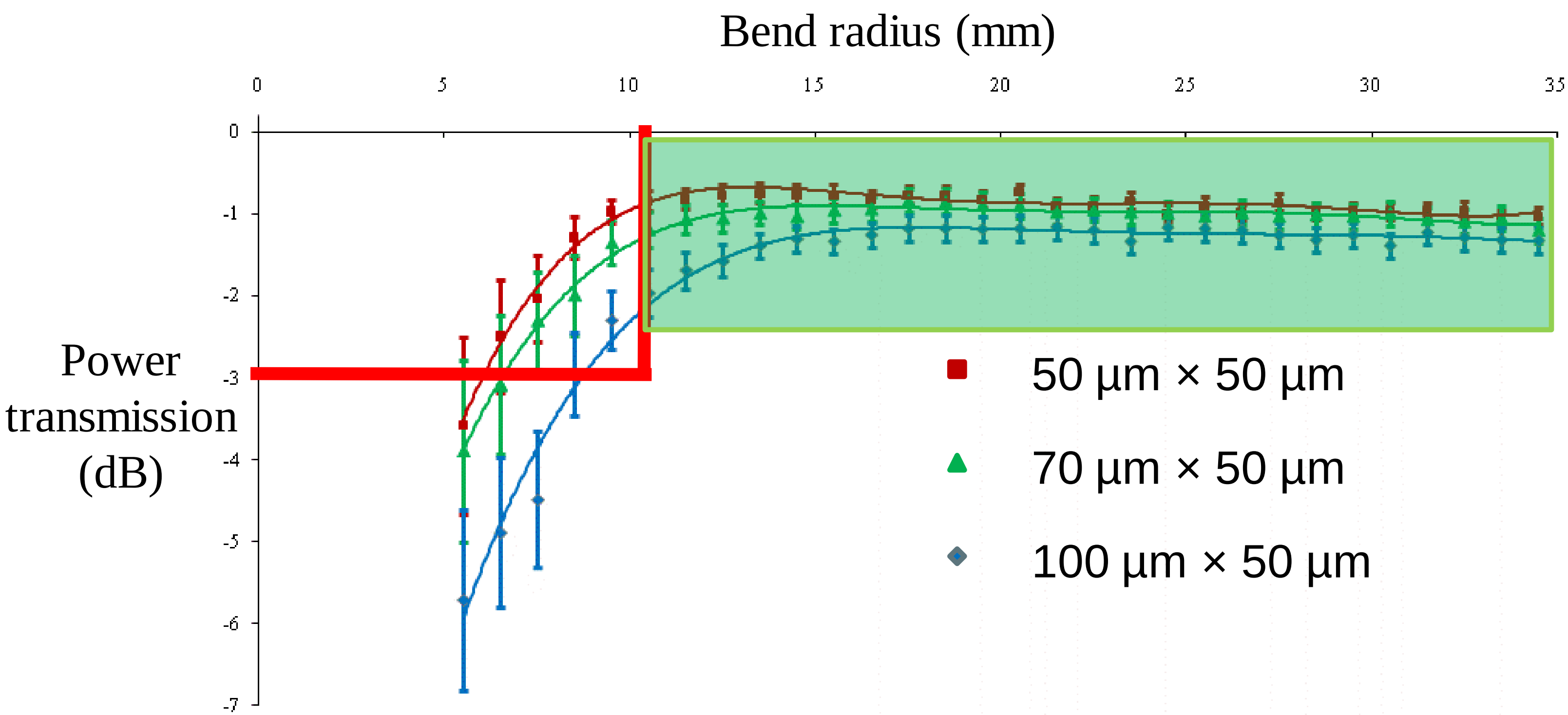
Schematic diagram of one set of curved waveguides.



Light through a bent waveguide of R = 5.5 mm – 34.5 mm

- Radius R, varied between 5.5 mm < R < 35 mm, ΔR = 1 mm
- Light lost due to scattering, mode miss-match loss, radiation loss, reflection and back-scattering
- Illuminated by a MM fibre with a red-laser.

Loss of Waveguide Bends



Width (µm)	Optimum Radius (mm)	Minimum Loss (dB)
50	13.5	0.74
75	15.3	0.91
100	17.7	1.18

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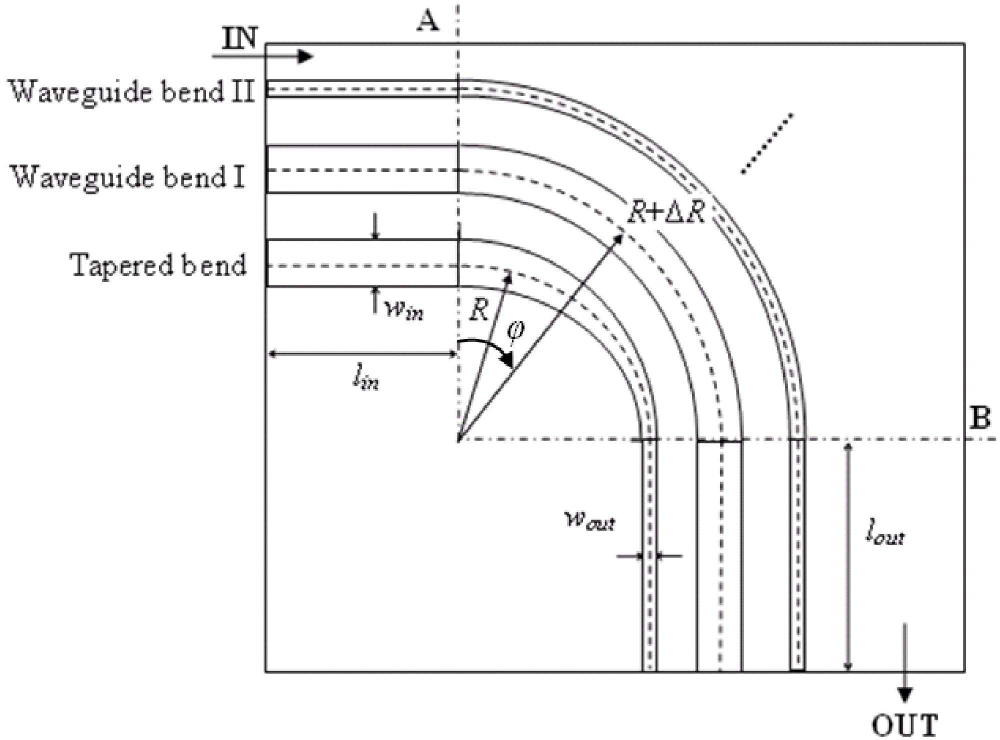
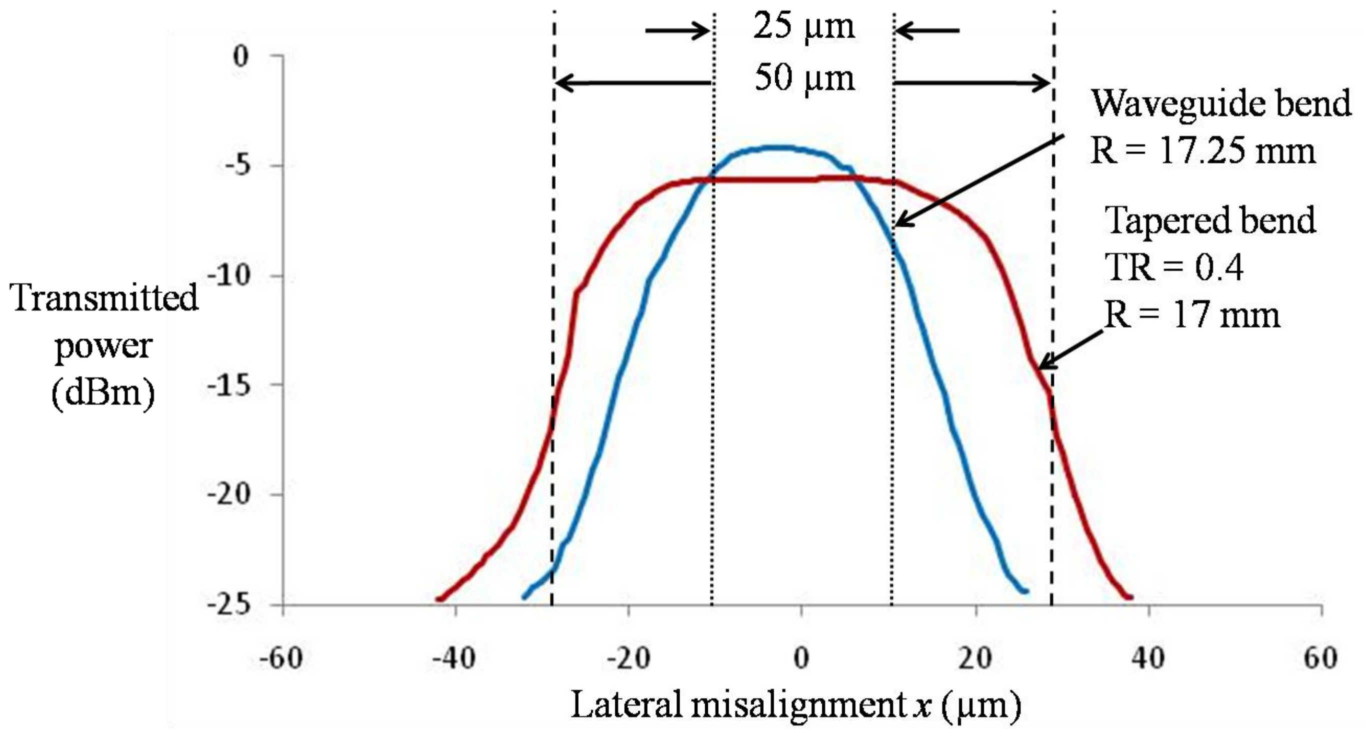
Design Rules for Tapered Bends



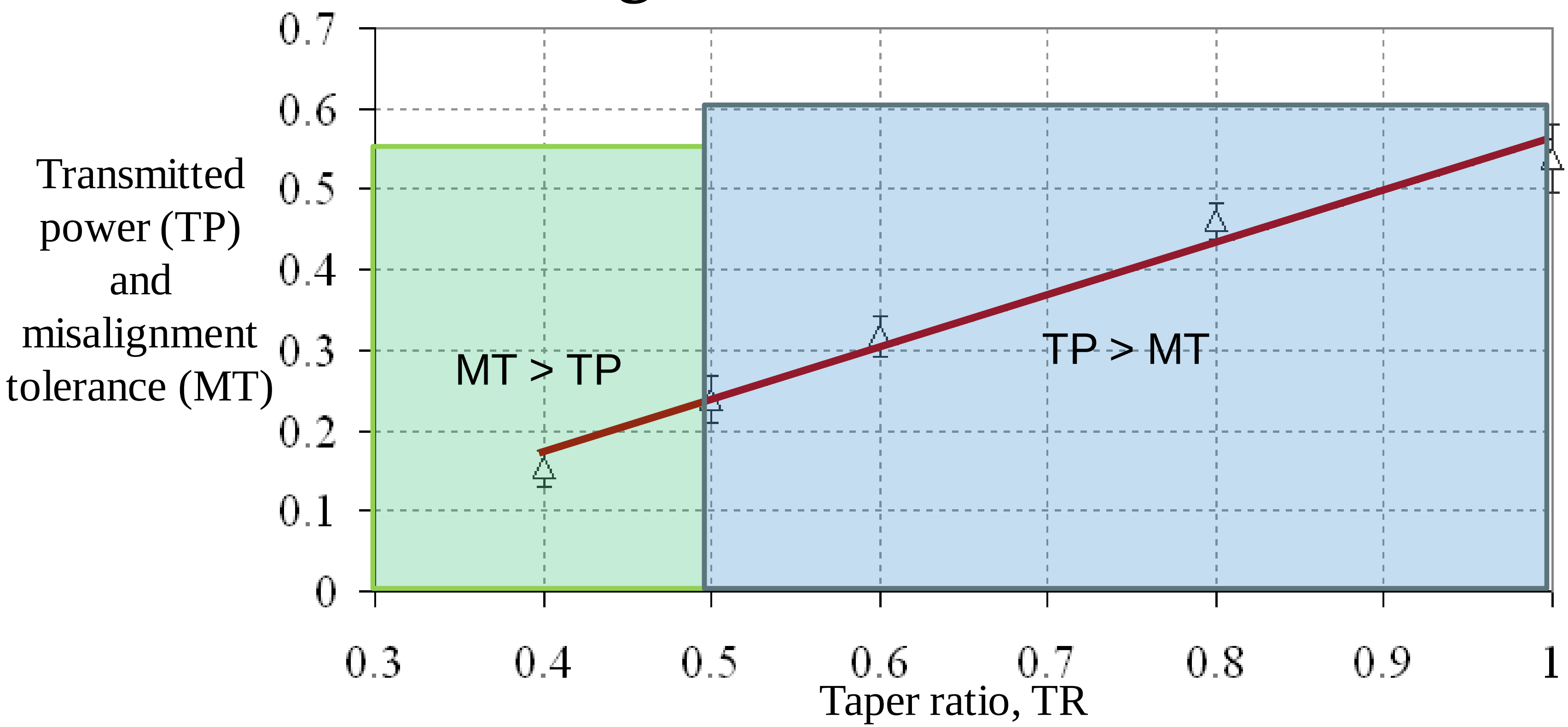
- The input section w_{in} = 50 µm, and its length l_{in} = 11.5 mm
- The tapered bend transforms the waveguide width from w_{in}, to w_{out}
- The width of the tapered bends varies linearly along its length
- Output straight waveguide length l_{out} = 24.5 mm.
- Output widths w_{out} = 10 µm, 20 µm, 25 µm, 30 µm and 40 µm

Misalignment Tolerance of a Tapered Bend



- ❑ Dashed lines correspond to the boundaries of the w_{in} = 50 µm tapered bend
- ❑ Dotted lines correspond to the boundaries of the 25 µm bend
- ❑ Tapered bend has more misalignment tolerance for a slight loss penalty

Product of Maximum Transmission And Misalignment Tolerance



- ❑The product of transmission and misalignment tolerance is a constant which increases linearly with TR such that the product = 0.650*TR* - 0.09
- ❑ This product is independent of the bend radius as experimental points almost coincide.

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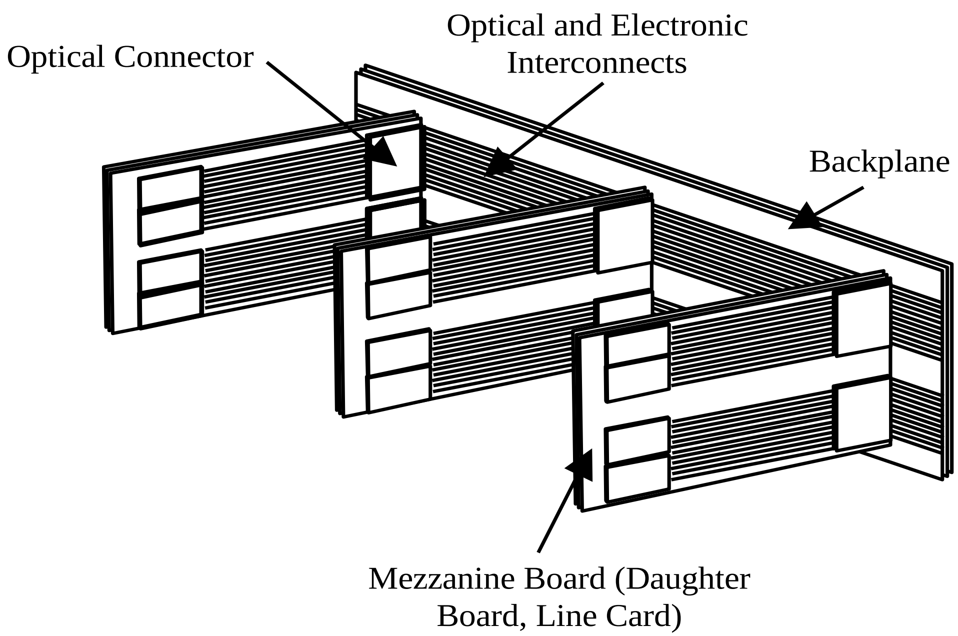
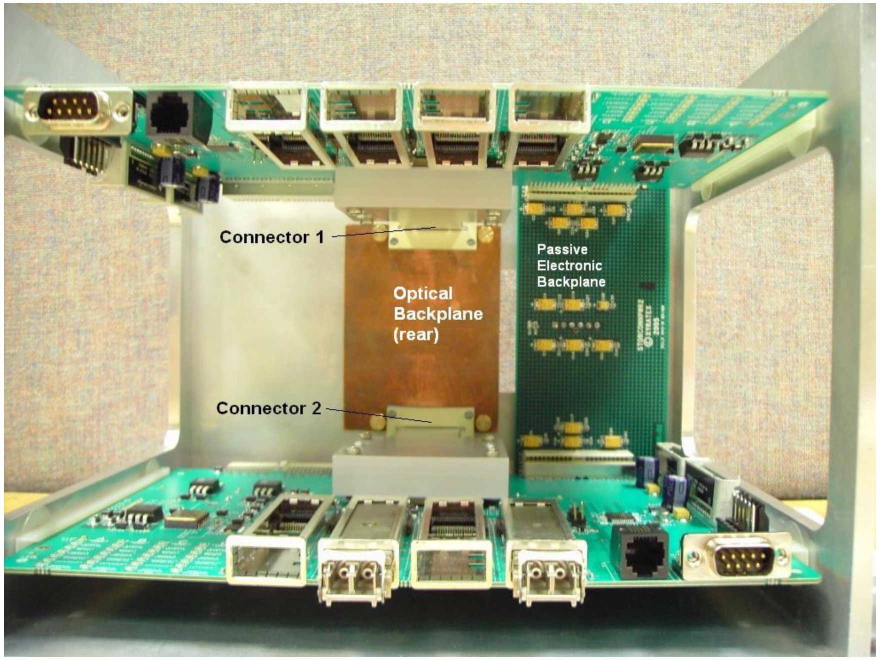
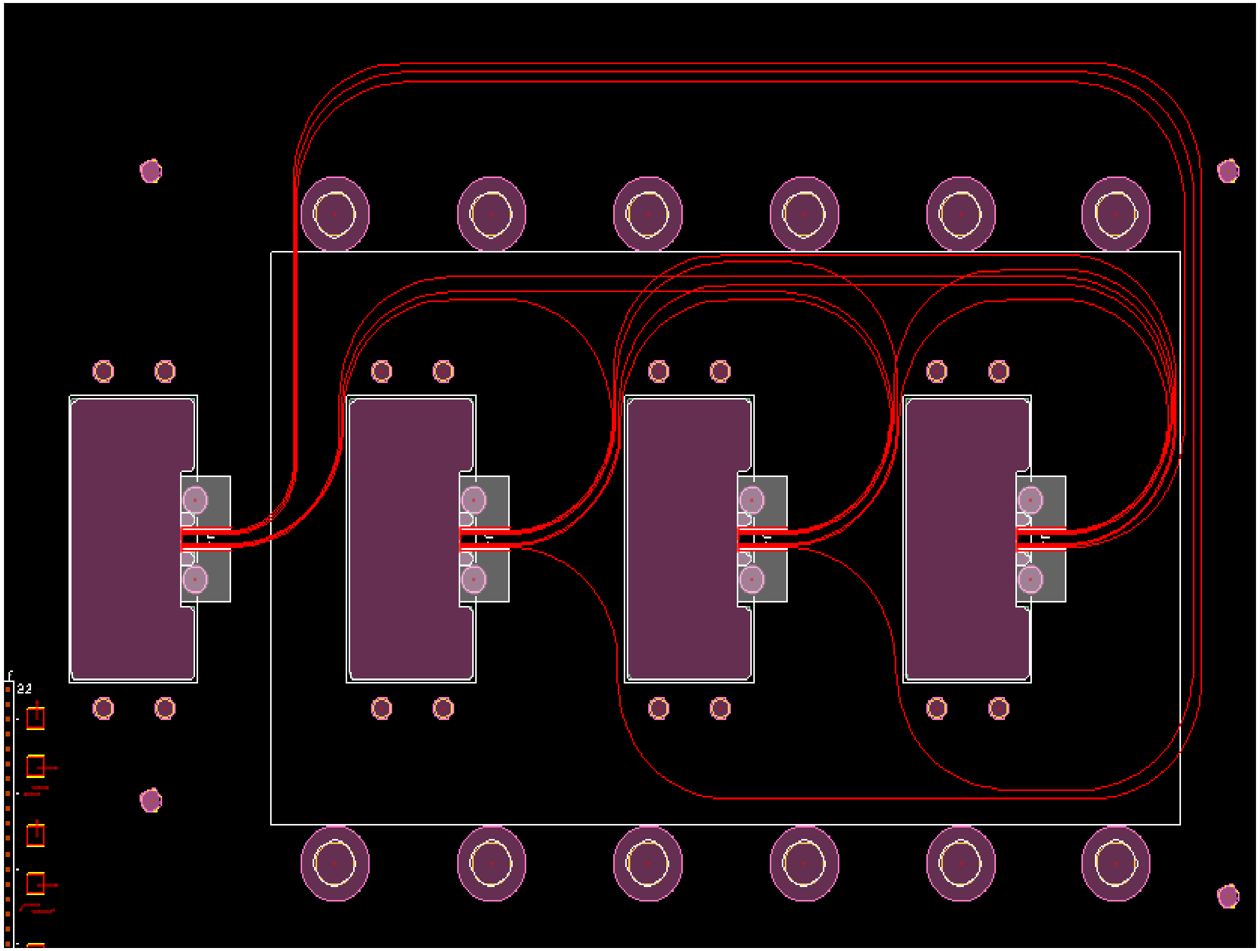




System Demonstrator



Fully connected waveguide layout using design rules

Conclusions and Acknowledgement

- Characterised photolithographically manufactured acrylate polymer multimode waveguide by measuring the optical loss of key waveguide components.
- Design rules derived from the experimental measurement to assist optical system designers to optimise OPCB layout.

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Thanks for Your Attention