Photonic waveguide investigation for fusion applications

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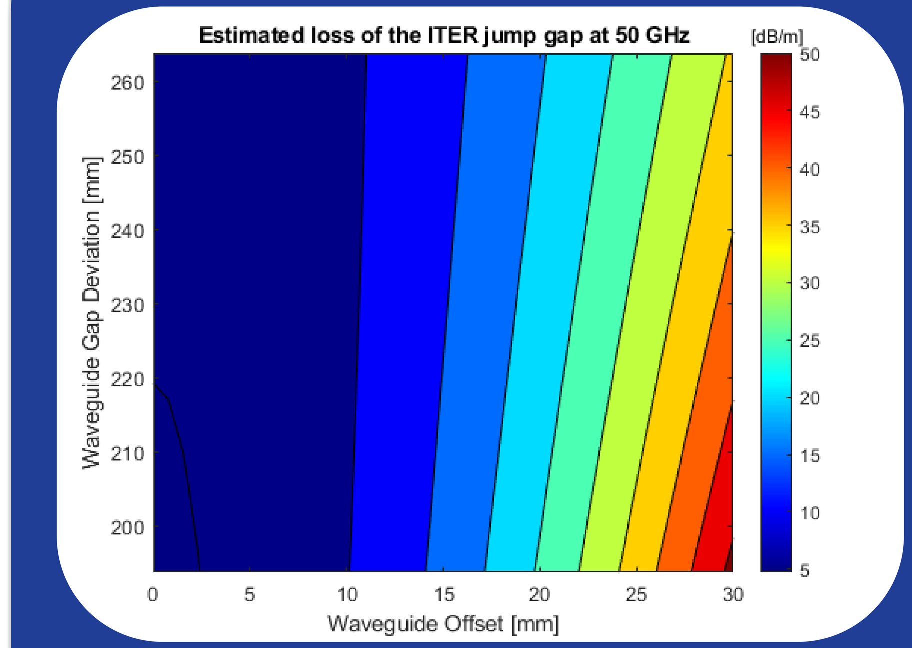
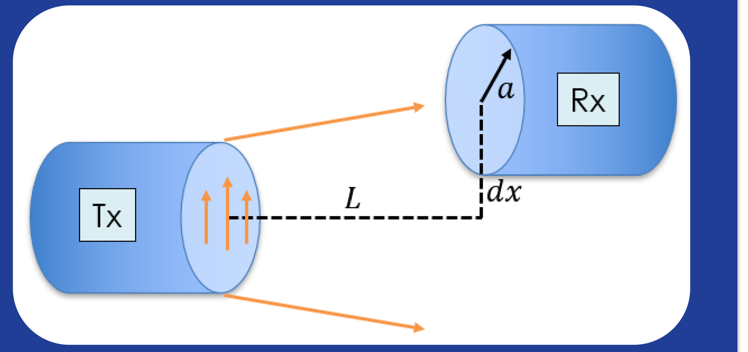
1 Thermal expansions in ITER will shift the LSFR port



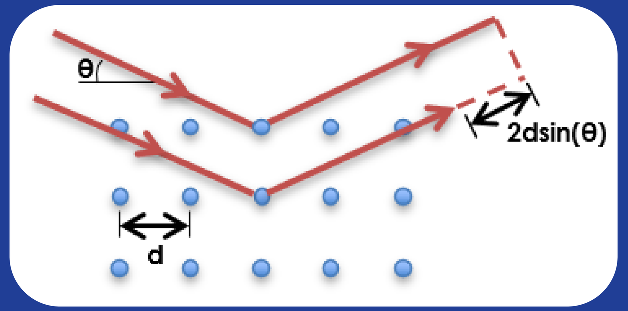


Swept Range:
- Nominal gap length: 22 cm
- Gap deviation range: -3 to 4 cm
- Offset range: 0 to 3 cm

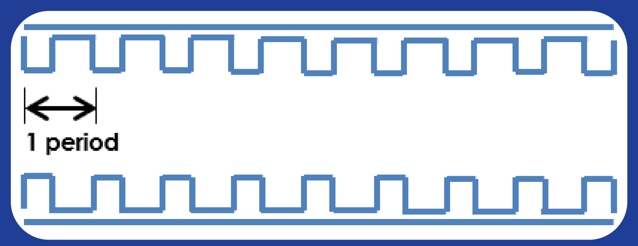
Mode conversions and other forms of losses are expected

2 Corrugated waveguides are physically limited

- **Bragg reflections limit bandwidth**
  - Bragg condition satisfied:
    - **nλ = 2d·sin(θ)**
    - reflection
  - High attenuation occurs when corrugation period is larger than ½ wavelength



- **Manufacturing constraints**
  - Corrugation periods less than 0.5 mm are difficult to create
  - This corresponds to Bragg reflections >300 GHz

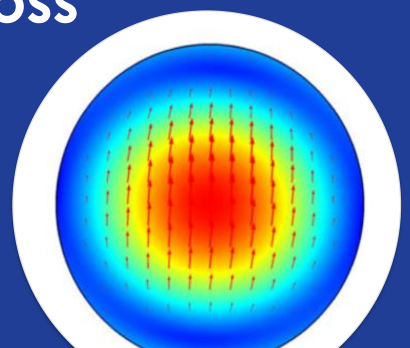


Flexible, low attenuation microwave waveguides would be useful for ITER-like tokamaks

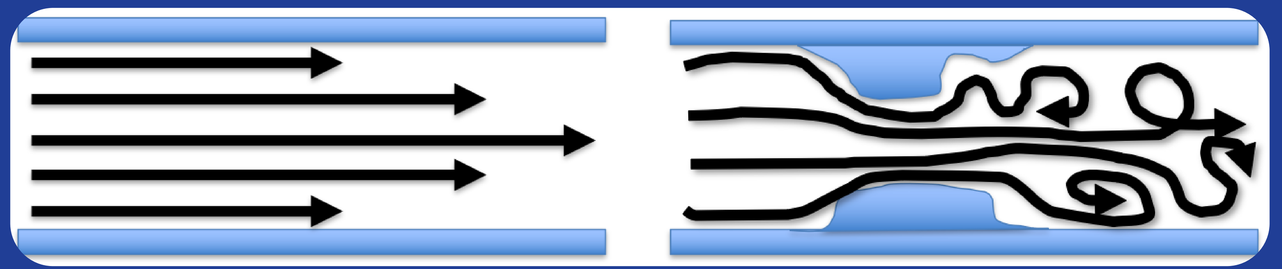
3 Designing lowest possible loss

- **Large cross section** relative to the wavelength of the transmitted wave

$$\alpha \propto \frac{1}{R} \propto \frac{1}{N}$$

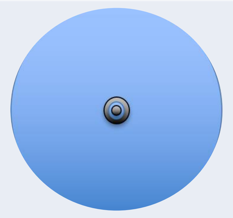
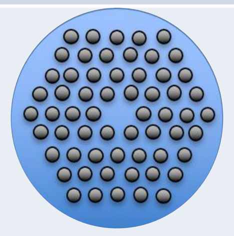
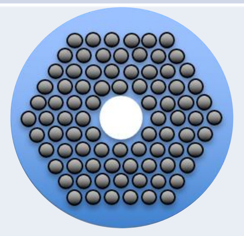


- **HE11 mode** is low loss and relatively robust to mode conversion (MC)



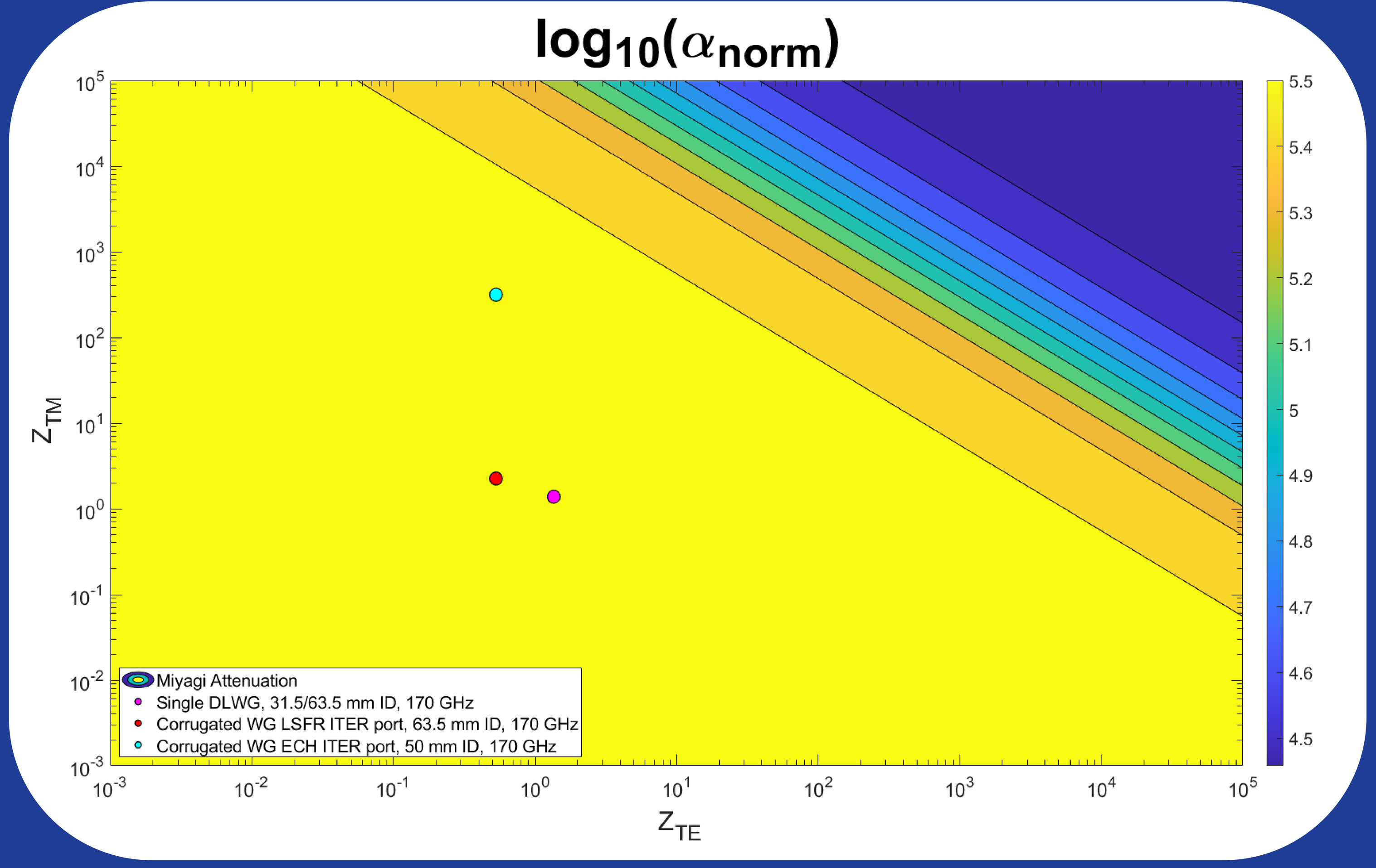
"Laminar Flow" (HE11 mode) "Turbulent Flow" (any other mode)

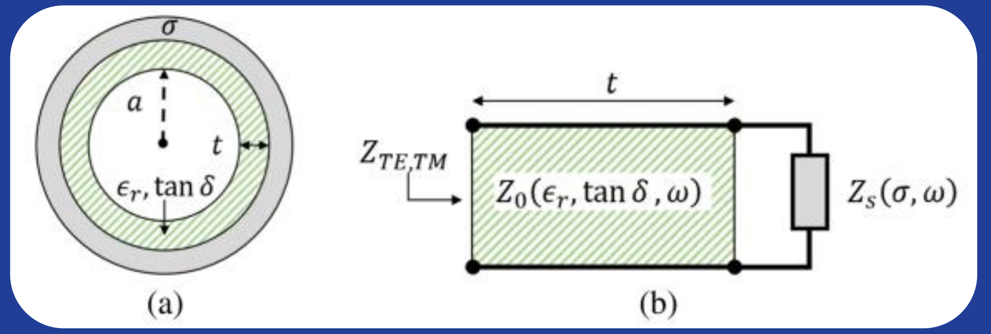
4 Criteria for determining applicability of various fibers in the microwave regime

	Optical Fibers	Holey Fibers	PBFs	Bragg Fibers
Loss [dB/m]	1e-6	~1e-6	1e-13 -- 1e0	~1e-3
Mode Conversion	Single Mode	Single Mode	~Single Mode (cladding)	~Single Mode (cladding)
Bandwidth	*Highly* dependent on material index	*Highly* dependent on material index	Microwave, THz, etc.	Microwave, THz, etc.
Cross Section				

Photonic crystal fibers and dielectric lined waveguides appear suitable for microwave applications

5 DLWG are comparably curve resistant compared to corrugated waveguides



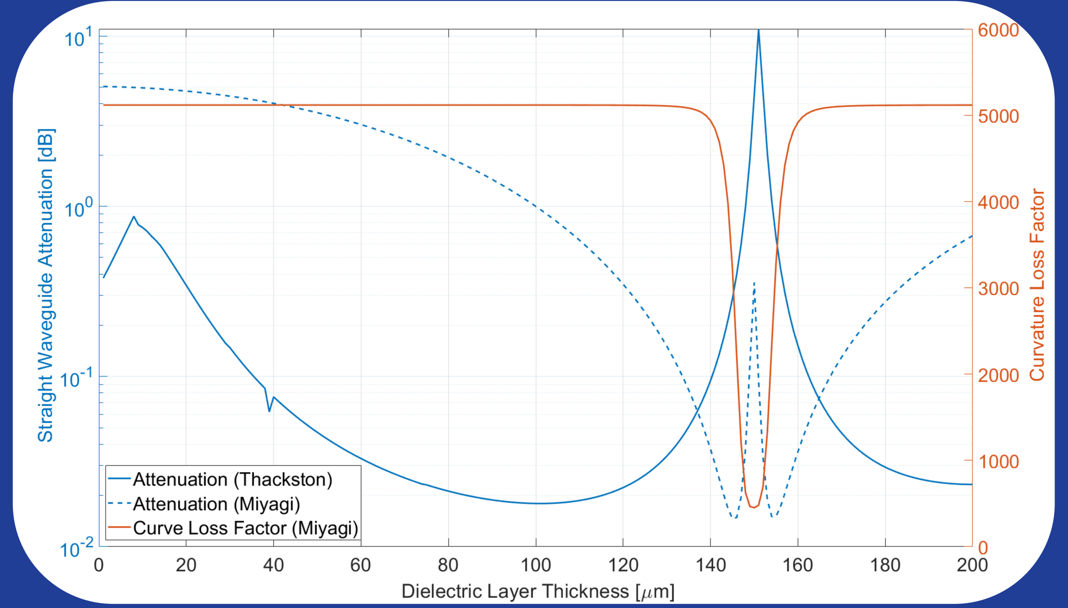


$$Z_{TE} = \frac{E_\phi}{H_z}\Big|_{r=a}$$

$$Z_{TM} = -\frac{E_z}{H_\phi}\Big|_{r=a}$$

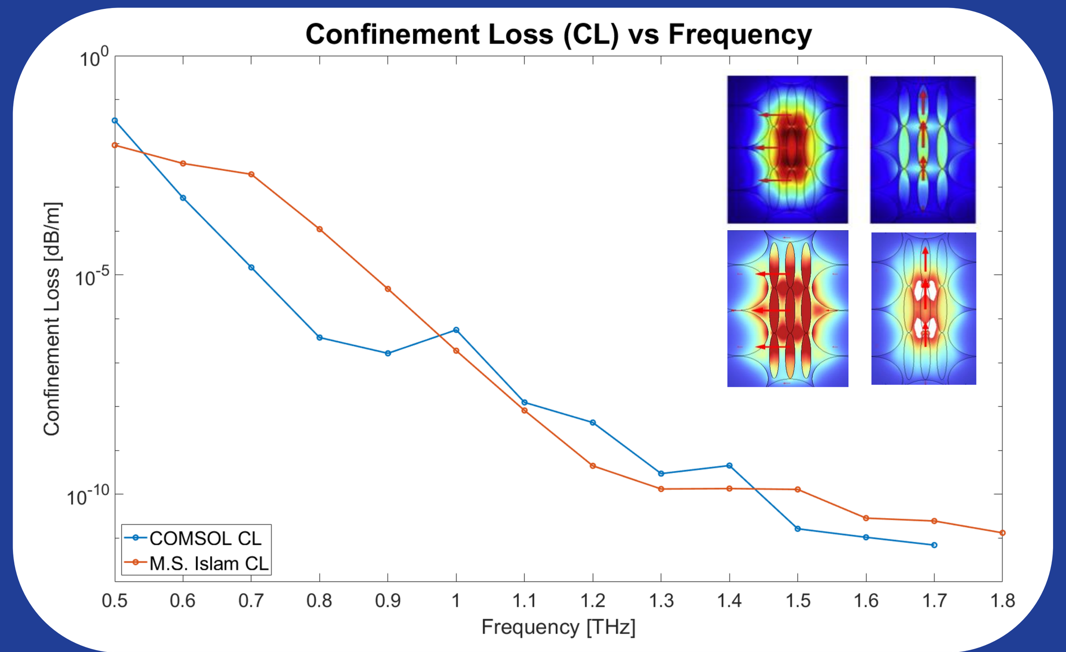
Transmition line model for wall impedances of a DLWG

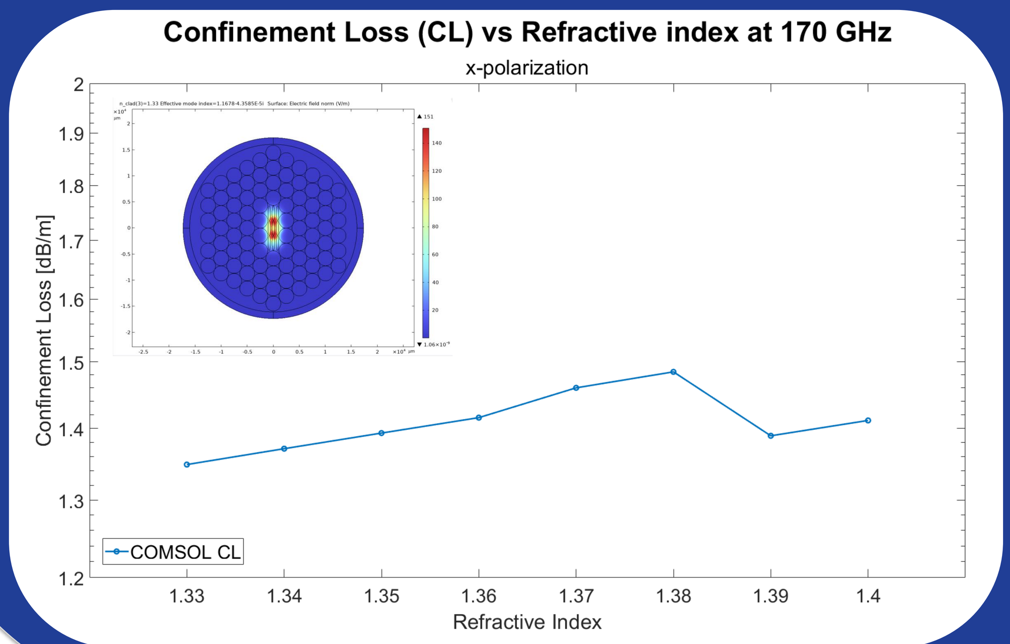
6 Single and Multi DLWG have no advantage for bending loss



Low bending loss from MC is only met by DLWGs when the coating thickness is resonant and therefore lossy

COMSOL reasonably predicts confinement loss in the optics regime at for x-polarization; field patterns in x and y-polarizations also show good agreement





Confinement loss for different refractive indices of scaled optics PCF to microwave regime; geometry scaled via the ratio of operating frequencies

7 Conclusions

- Loss due to field confinement (optics) and MC (microwave)
- DLWG and PCF favor the HE11 mode (more efficient & electrically small core, resp.), but propagate others
- DLWGs do not offer fundamentally different properties than corrugated waveguides in the microwave regime
- PCFs can be scaled to the microwave regime, but the loss is much higher than metal waveguides
- DLWGs cannot be optimized to minimize curvature induced MC without resulting in resonant layers with inherent high attenuation

8 References

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