Modelling Rayleigh Scattering Loss in Arbitrary Profile Fibers

Annesha Maity and Pramod R. Watekar
Center of Excellence, Sterlite Technologies Limited, MIDC Waluj, Aurangabad, Maharashtra, India
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Introduction

- Rayleigh scattering loss (RSL) contributes almost 80% to fiber attenuation
- Modern optical fibers have ultra-low attenuation with the limit being set by RSL
- RSL arises from random microscopic inhomogeneities which is directly proportional to dopant concentration
- Hence prediction of RSL is needed from designer’s point of view
- Here we model RSL for arbitrary profile fiber with graded-index fiber as an example
Theory and Computations
Graded refractive index profile

Definition and profile parameters

\[ n(r) = n_{\text{max}} \sqrt{1 - \Delta_{\text{max}} \left( \frac{r}{a} \right)^\alpha} \]

- \( n_{\text{max}} \): peak refractive index
- \( \Delta_{\text{max}} \): peak value of relative index difference \( \Delta \)
- \( n_{\text{sil}} \): refractive index of pure silica glass
- \( \alpha \): grading parameter
- \( a \): core radius

Relative index difference:

\[ \Delta(r) = \frac{(n(r)^2 - n_{\text{sil}}^2)}{(2n(r)^2)} \]
Varying the profile parameters

Increasing $\alpha$

$\alpha = 1$ (Triangular)  $\alpha = 2$ (Parabolic)  $\alpha = \infty$ (Step)

Increasing $\Delta$

Increasing $a$
Theory

- RSL is proportional to \(1/\lambda^4\), where \(\lambda\) is the light wavelength.
- RSL is proportional to the light power profile \(P(r)\).
- Finally, RSL is proportional to the Rayleigh scattering coefficient \(A(r)\) [1].

Thus RSL in the fiber core is given by:

\[ \alpha_R = \frac{1}{\lambda^4} \int_0^a A(r)P(r)rdr/\int_0^a P(r)rdr \]

- RSC of GeO\(_2\)-doped silica is given as [2]: \(A(r) = A_0(1 + 44|\Delta(r)|)\)

Computation in Comsol

- \( n(r) \) is defined
- Hence \( \Delta(r) \) is calculated
- Thereby, \( A(r) \) is calculated. Surface plot of \( A(r) \) is shown at the right
- \( \lambda \) was set to 1.55 \( \mu \)m
- **Mesh:** maximum mesh element size set to 0.25\( \mu \)m in the core and ‘normal’ otherwise
- Wave equations were solved using the ‘Wave Optics module’
- This gives the light power profile \( P(r) \)
• RSL was calculated as a function of $\alpha$ for different $\Delta$s.

• Core radius was set to the standard 4$\mu$m

• Plot suggests RSL increases when $\alpha$ and/or $\Delta$ increases
• RSL was calculated as a function of $\Delta$ for different core radii.

• Plot suggests RSL increases when $\Delta$ and/or core radius increases.
Results (3)

• RSL was calculated as a function of $\Delta$ for different core radii.

• Plot suggests RSL increases when $\Delta$ and/or core radius increases.
Explanation

more GeO_2 concentration, more scattering centers, RSL increases !!

Similar explanation holds for the cases of increasing Δ and core dimension
Conclusion

• Till date, there exists model for step-index or equivalent profiles in literature

• We have presented a COMSOL model to calculate RSL of arbitrary profile fiber with graded index fiber as an example

• This model can be useful for predicting fiber attenuation from a designer’s perspective
Thank You !!