DISPERSION ENGINEERING OF WHISPERING GALLERY MODE RESONATORS FOR FREQUENCY COMB GENERATION AND TELECOMMUNICATION APPLICATIONS

(1)University of Latvia, Institute of Atomic Physics and Spectrscopy;

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NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020

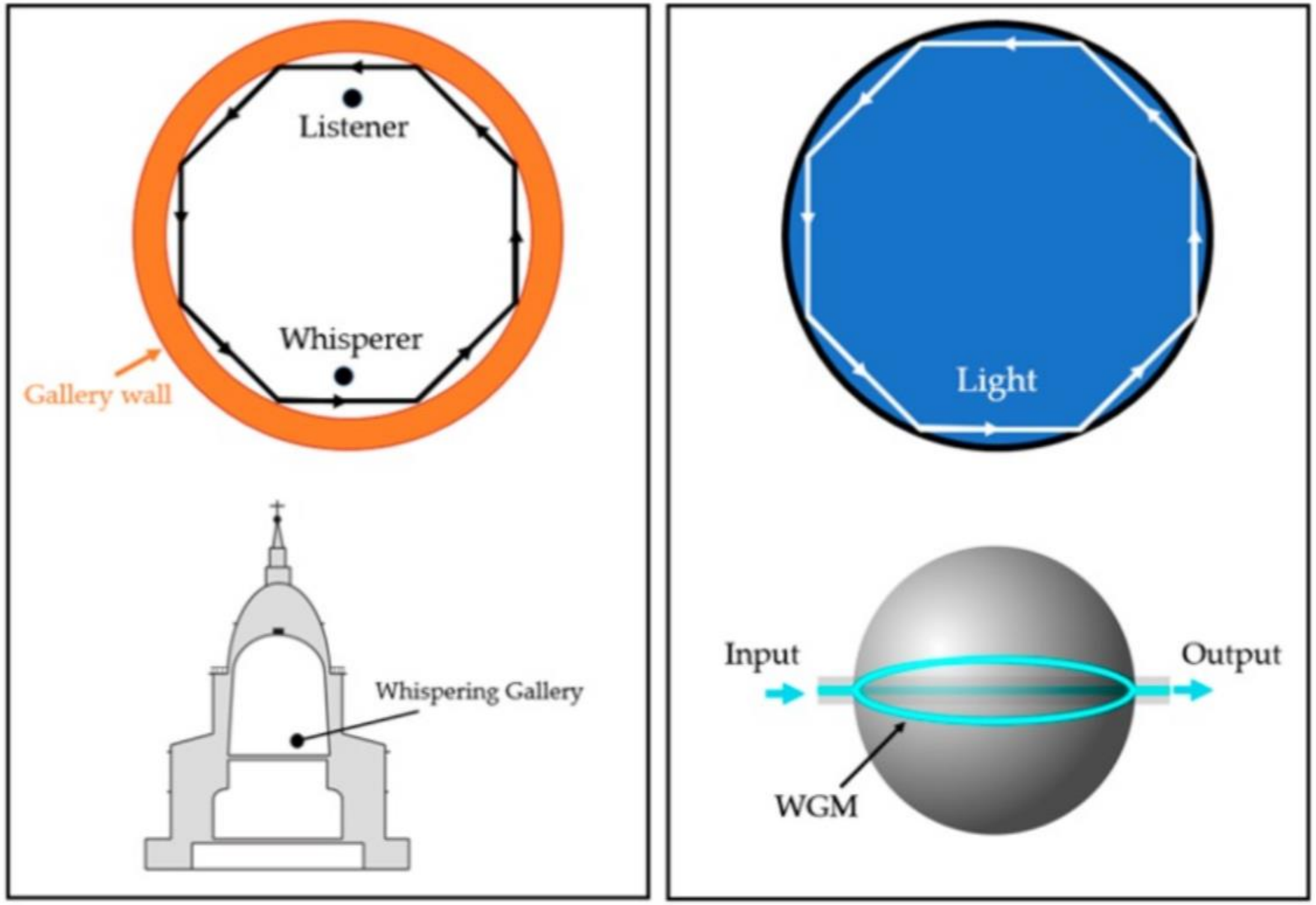
EIROPAS SAVIENĪBA
Eiropas Reģionālās attīstības fonds

IEGULDĪJUMS TAVĀ NĀKOTNĒ

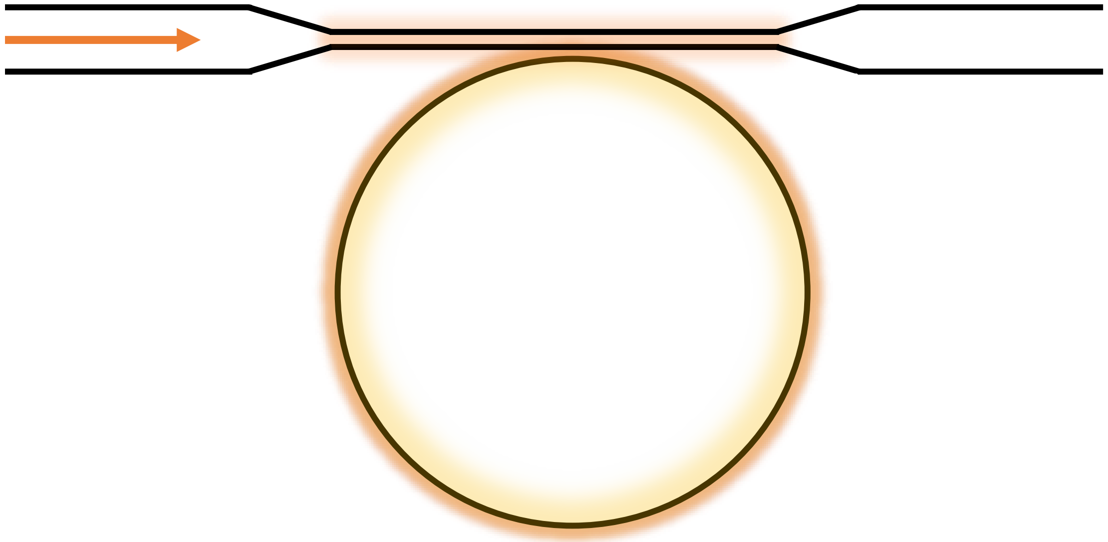
UNIVERSITY OF LATVIA

Whispering Gallery in St Paul`s Cathedral [1,2]

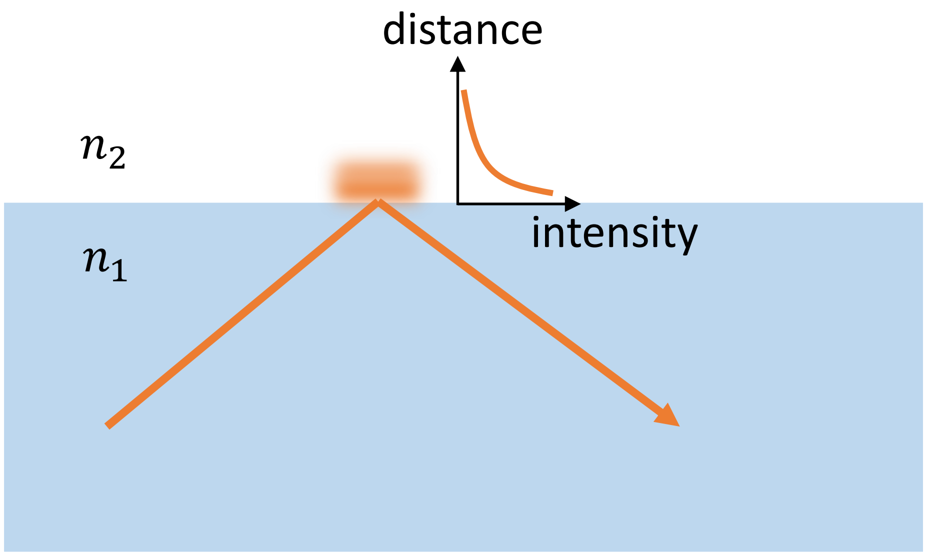
Whispering Gallery Mode Resonators (WGMRs) [3]



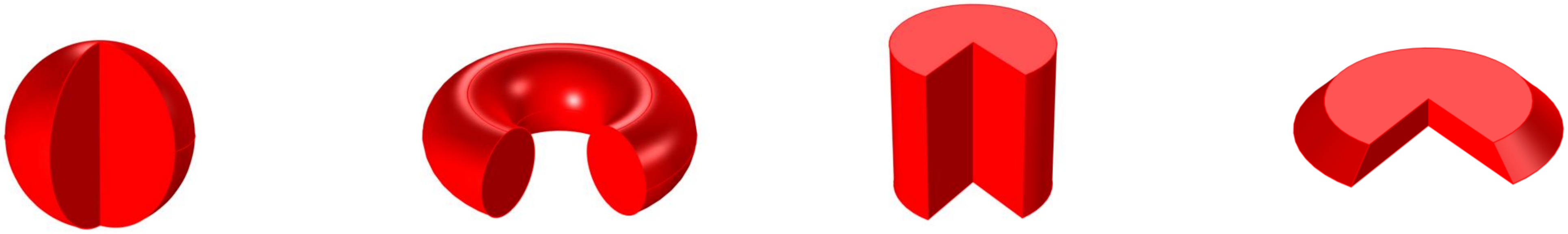
Coupling WGMR with light using evanescent field

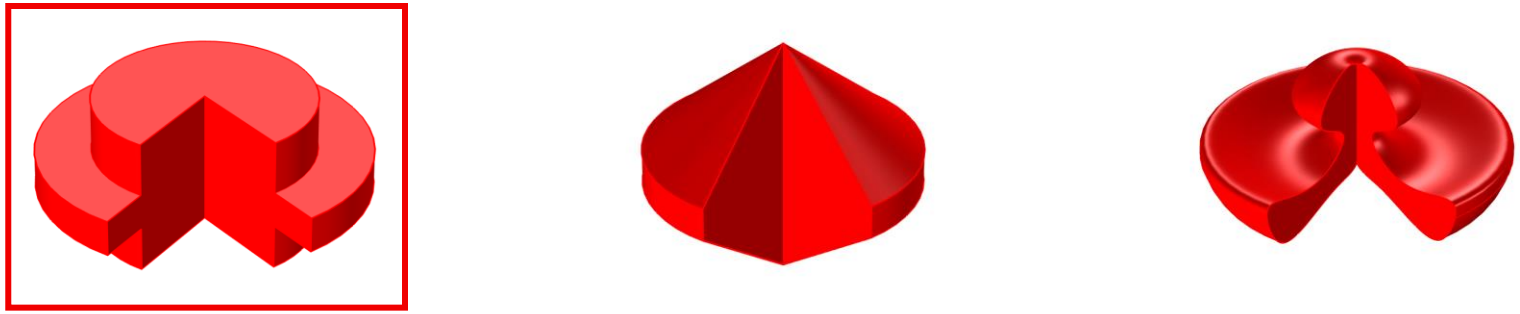


$$2\pi R n = \mathrm{m}\lambda$$



Different WGMR types

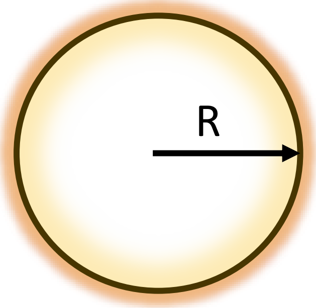




$$2\pi R n = \mathrm{m}\lambda$$

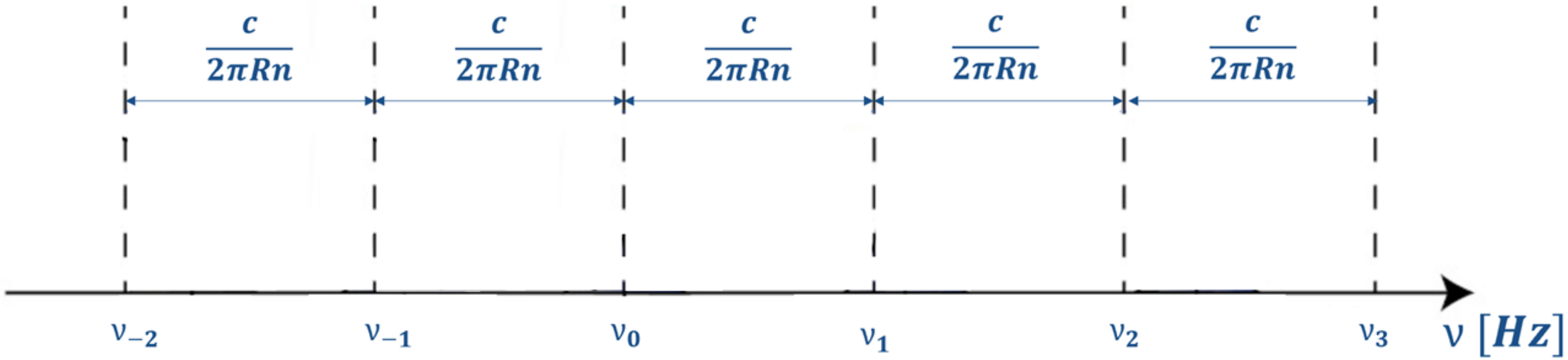
Free Spectral Range (FSR), applications in telecommunications

$$2\pi R n = m\lambda \qquad \lambda = \frac{c}{\nu} \qquad \nu_1 = \frac{mc}{2\pi R n} \qquad \nu_2 = \frac{(m+1)c}{2\pi R n}$$

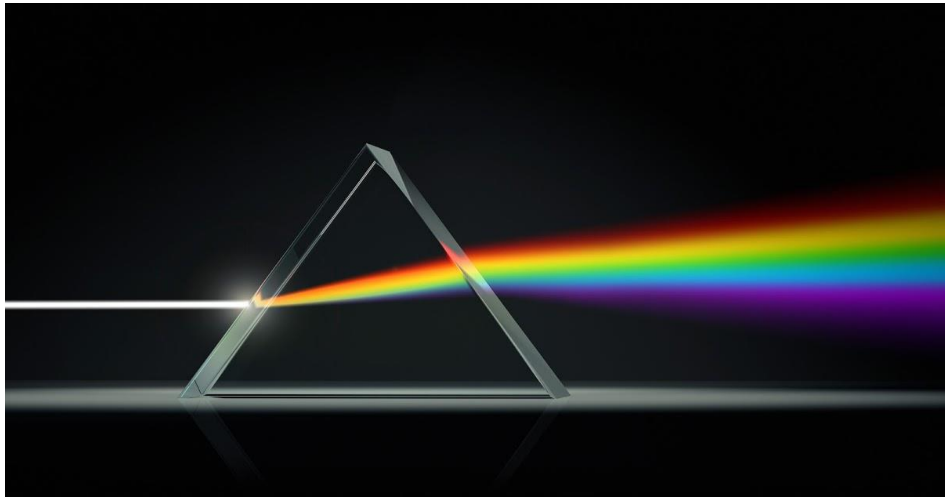


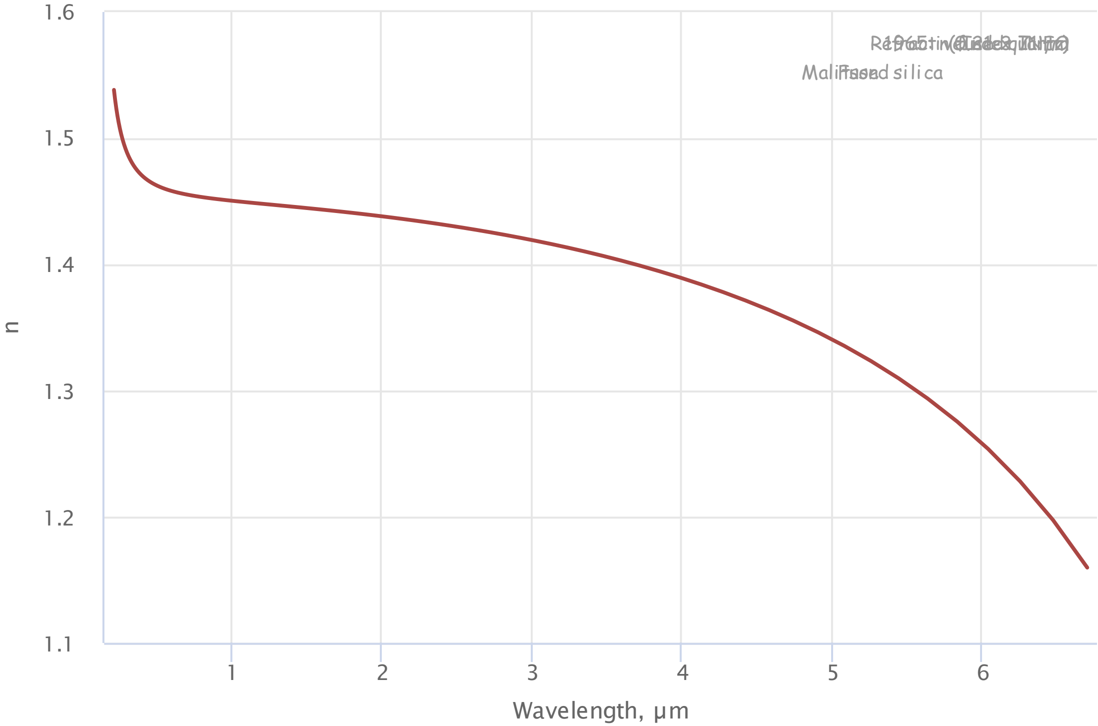
$$\Delta\nu = \nu_2 - \nu_1 = \frac{c}{2\pi R n} = \text{FSR}$$

$$R_{(\text{FSR}=100\text{GHz})} = 332\ \mu\text{m}$$



Material dispersion, Sellmeier`s equation (for SiO_2)





$$n^2 - 1 = \frac{0.6961663\lambda^2}{\lambda^2 - 0.0684043^2} + \frac{0.4079426\lambda^2}{\lambda^2 - 0.1162414^2} + \frac{0.8974794\lambda^2}{\lambda^2 - 9.896161^2}$$

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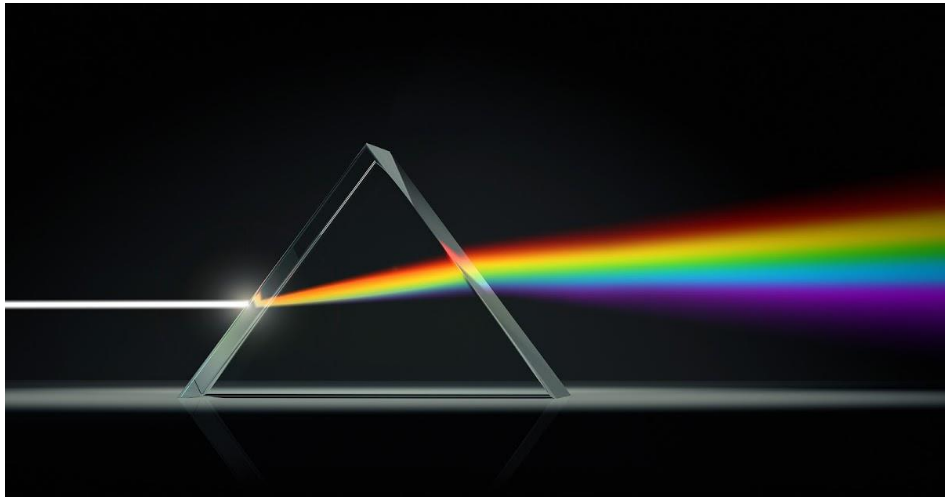

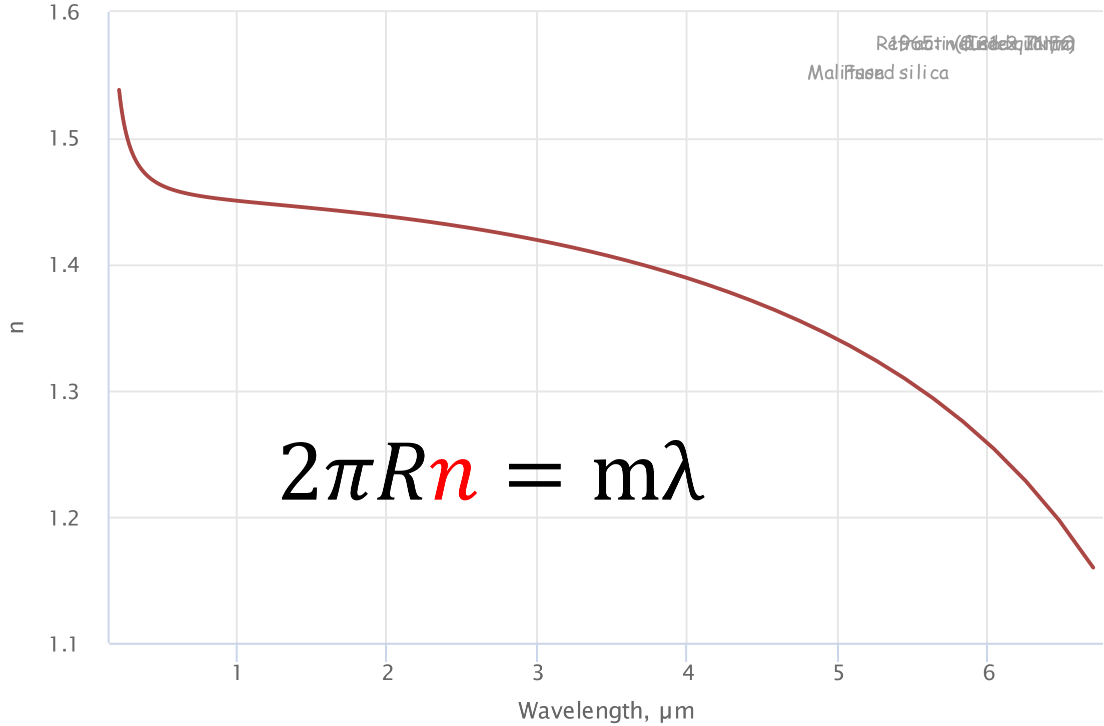

$$2\pi R n = m\lambda$$

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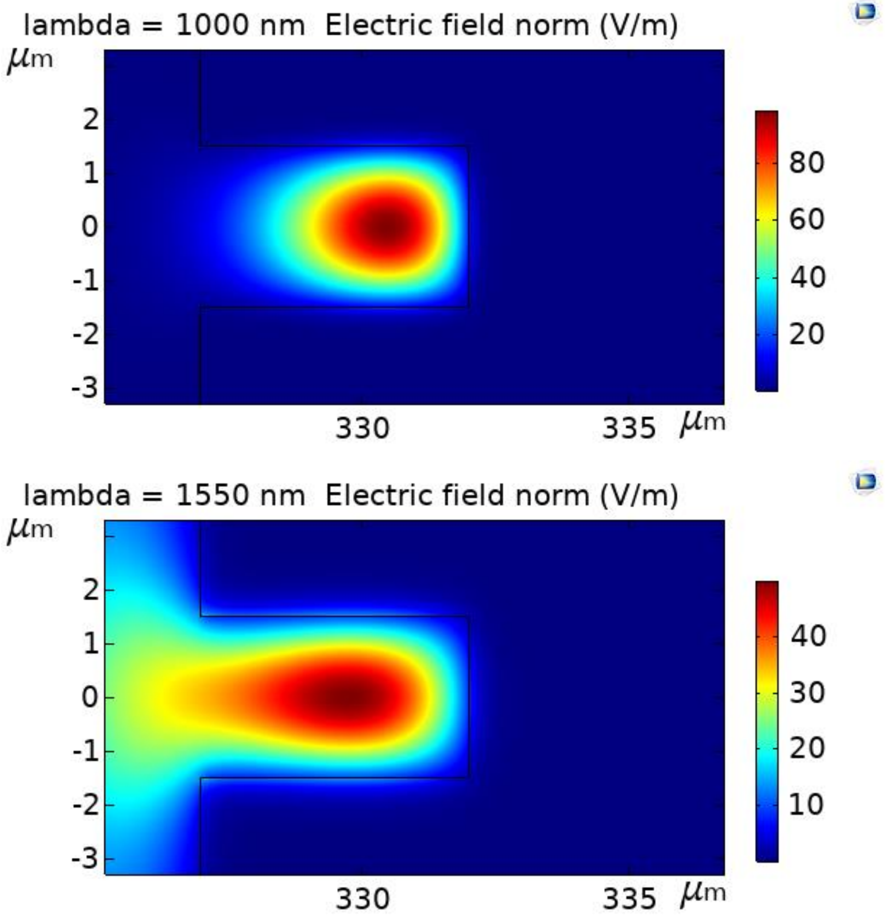
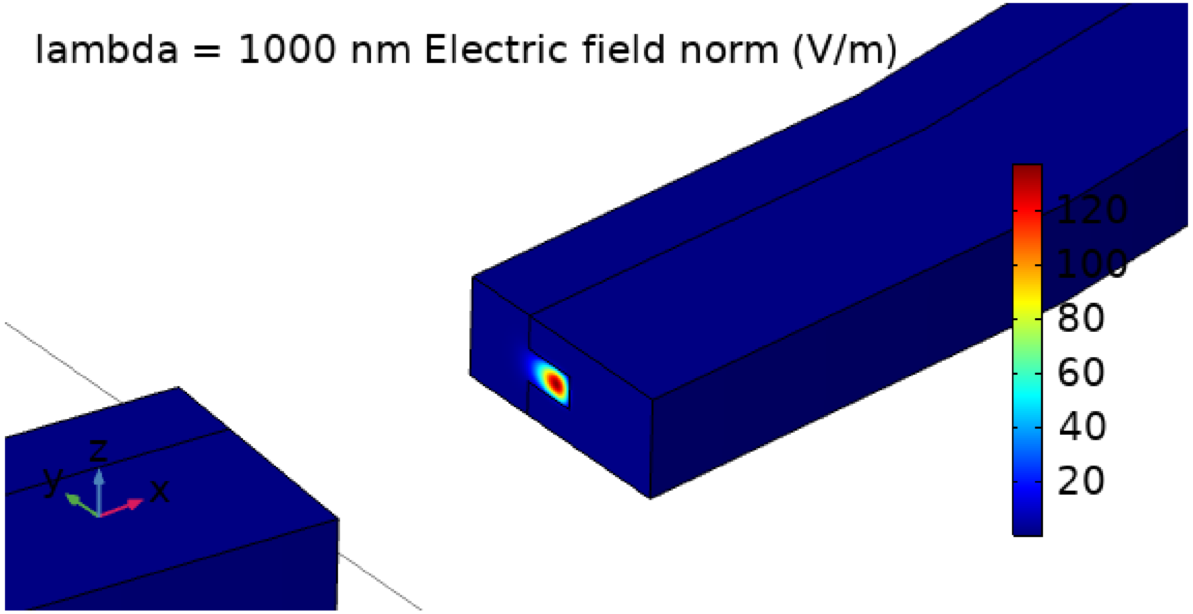
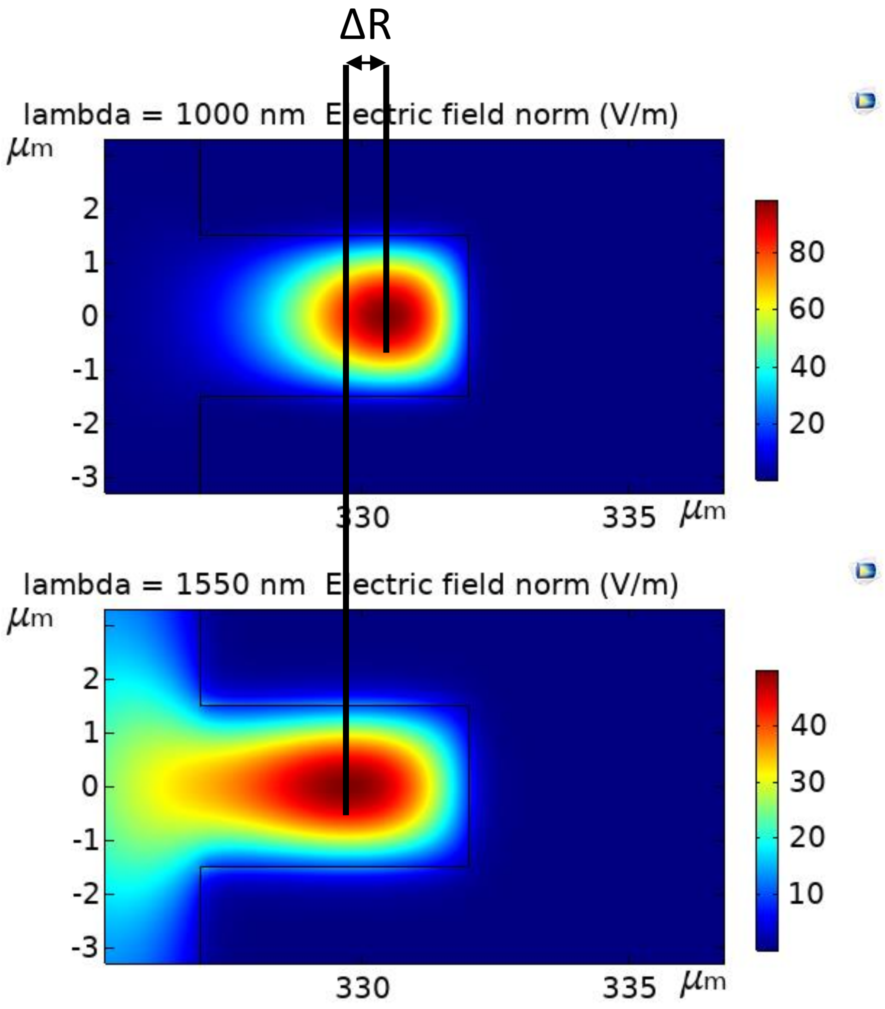
Geometric dispersion

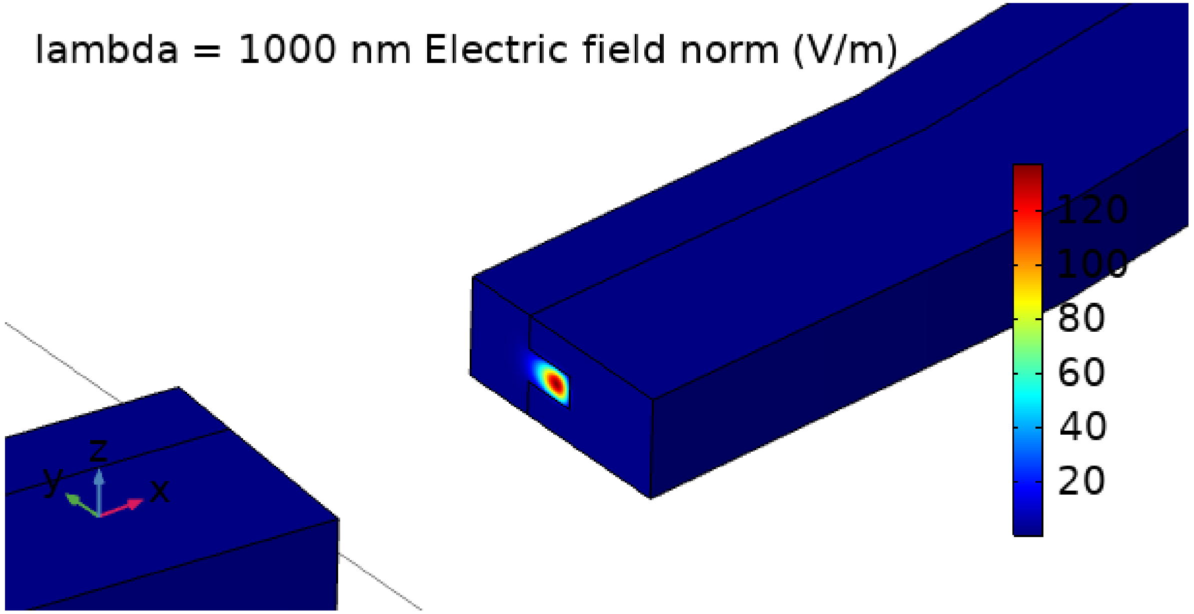




$$2\pi R n = m\lambda$$

Geometric dispersion





$$2\pi R n = m\lambda$$

Dispersion analysis using Finite Element Method (FEM) simulations

OPEN READINGS

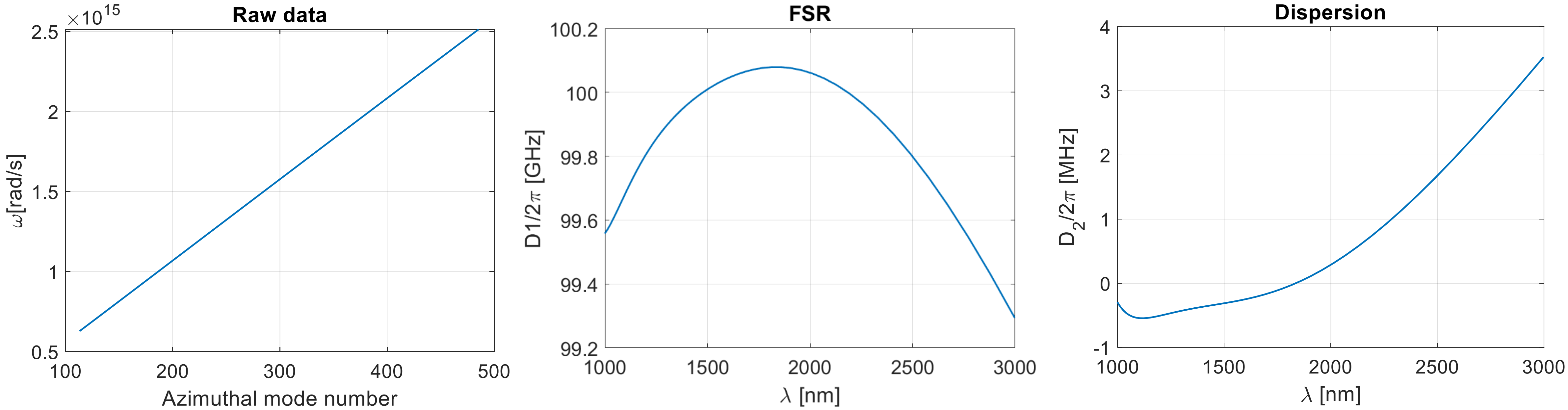
Expression	Unit	Description
ewfd.freq	Hz	Frequency
ewfd.neff/r1	1/m	Refractive index n
Esq^2/Equa	um^2	Mode area
Esqr/Esq	µm	Effective radius
ewfd.neff*2*pi*ewfd.freq/c_const	1/m	m

$$FSR = D_1 = \left.\frac{\partial\omega}{\partial m}\right|_{m_0} [\mathrm{rad/s}]$$

$$D_2 = \left.\frac{\partial^2\omega}{\partial m^2}\right|_{m_0} [\mathrm{rad/s}]$$

freq	n	Aeff	Reff	m
1E+14	1.3187878	31.39729	317.362	917.639695
1.04E+14	1.3238103	29.66119	317.7076	958.731791
1.08E+14	1.3283721	28.09027	318.0327	999.762435
1.12E+14	1.3325382	26.66243	318.3391	1040.74308
1.16E+14	1.3363614	25.35935	318.6285	1081.68292
1.2E+14	1.3398857	24.1657	318.9025	1122.58941
1.24E+14	1.3431473	23.06855	319.1623	1163.46863
1.29E+14	1.3461771	22.05695	319.409	1204.32561
1.33E+14	1.3490008	21.12151	319.6438	1245.16456
1.37E+14	1.3516407	20.25418	319.8674	1285.98895
1.41E+14	1.3541157	19.44801	320.0809	1326.80177
1.45E+14	1.3564423	18.69692	320.2848	1367.60551
1.49E+14	1.3586347	17.99563	320.4799	1408.40232
1.53E+14	1.3607053	17.3395	320.6667	1449.19403
1.57E+14	1.3626652	16.72445	320.8459	1489.98223
1.61E+14	1.3645240	16.14687	321.0179	1530.76829
1.65E+14	1.3662902	15.60355	321.1832	1571.55341
1.69E+14	1.3679713	15.09162	321.3421	1612.33864
1.73E+14	1.3695742	14.60855	321.4952	1653.12488
1.78E+14	1.3711048	14.15204	321.6427	1693.91296

Dispersion analysis using Finite Element Method (FEM) simulations



$$\omega = \omega(m)\ [\mathrm{rad/s}]$$

$$FSR = D_1 = \left.\frac{\partial \omega}{\partial m}\right|_{m_0} [\mathrm{rad/s}]$$

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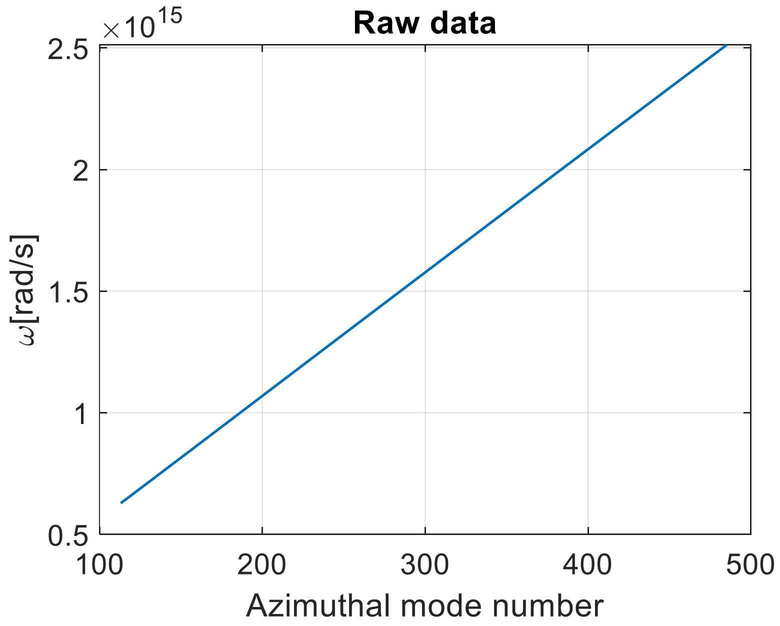
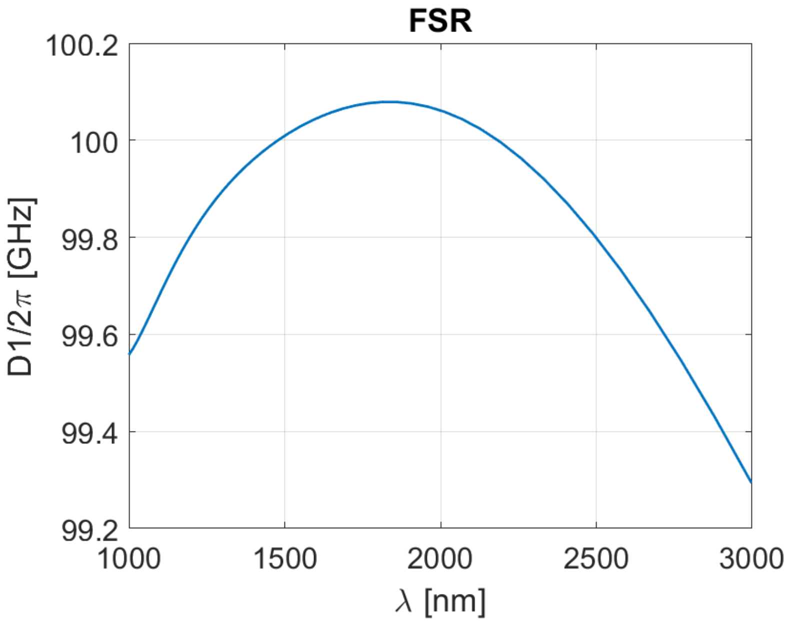
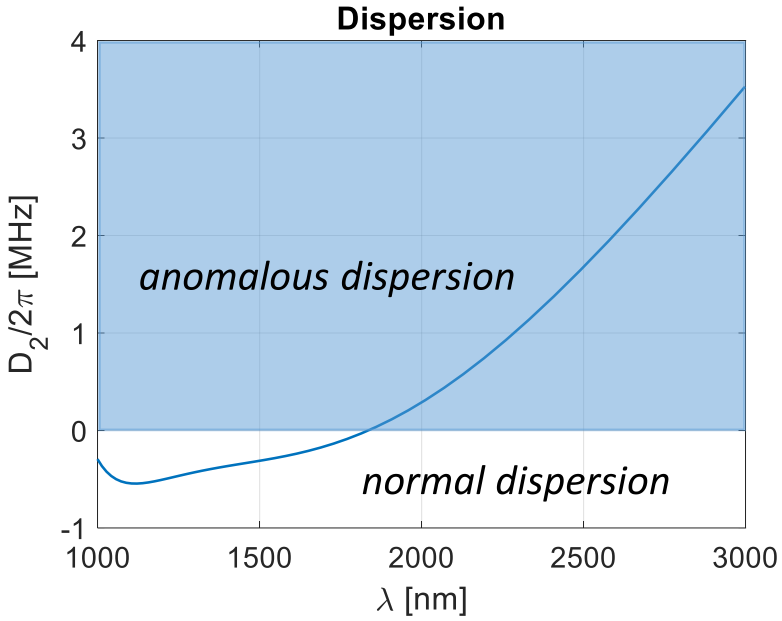
Dispersion analysis using Finite Element Method (FEM) simulations







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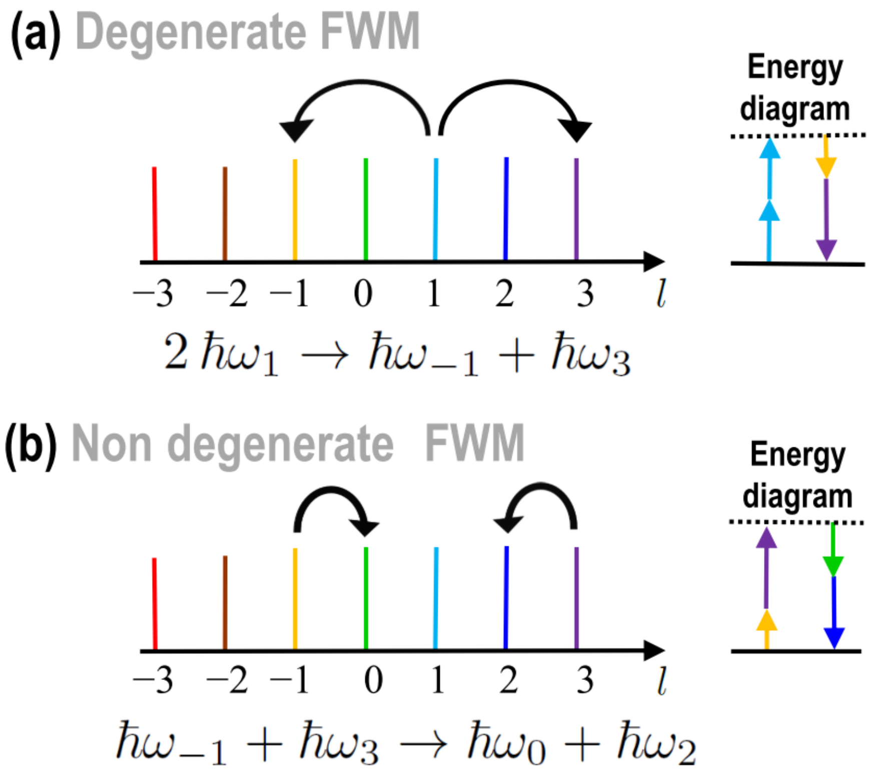
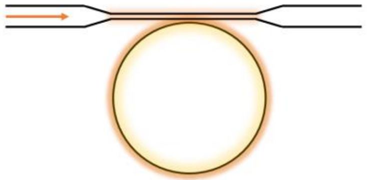
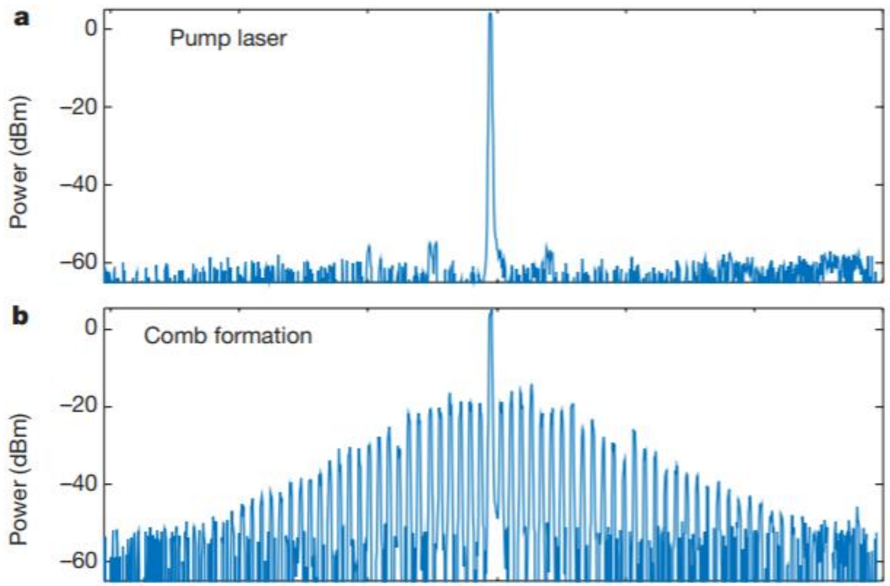
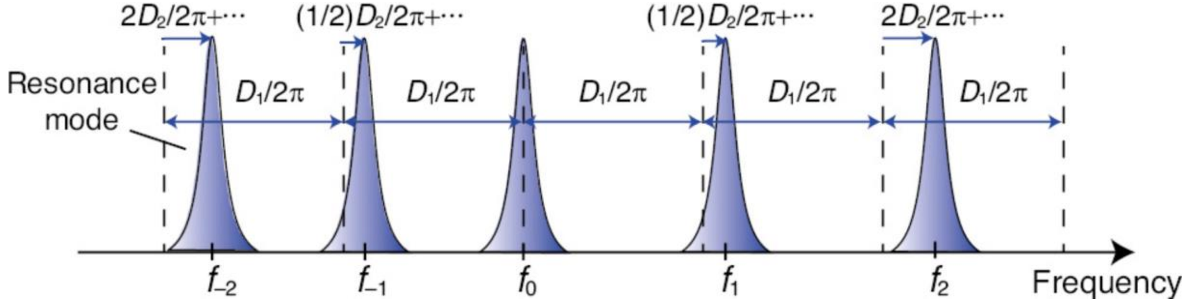
Four Wave Mixing (FWM), anomalous dispersion [4, 5, 6]

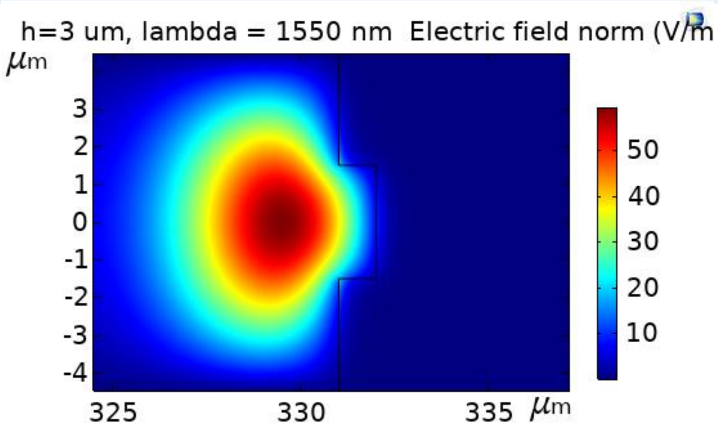


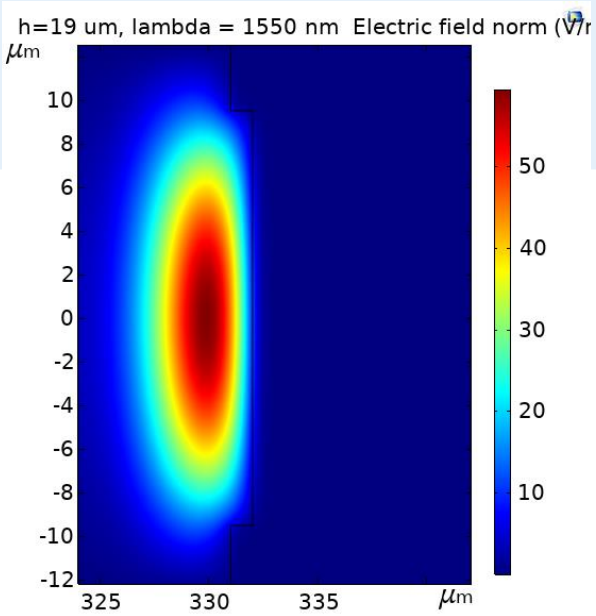


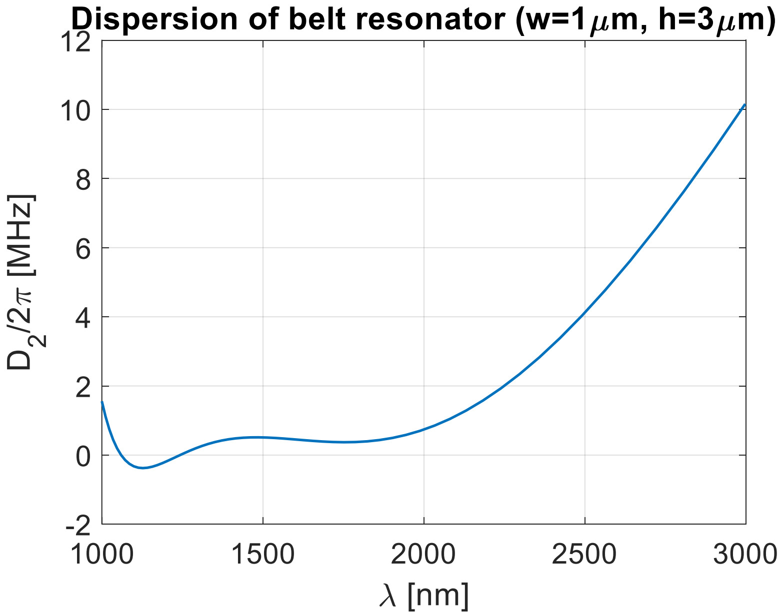


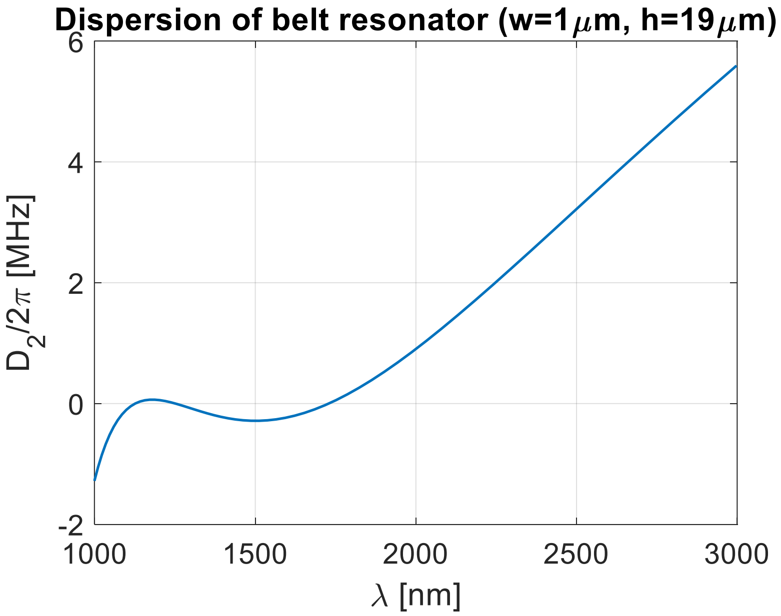


Dispersion engineering

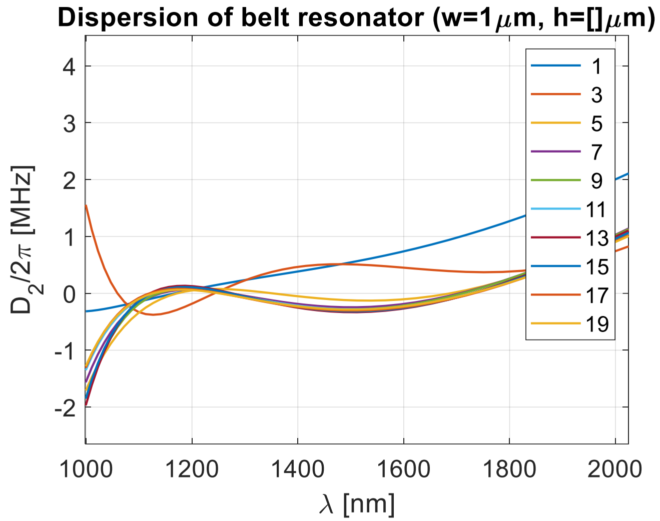


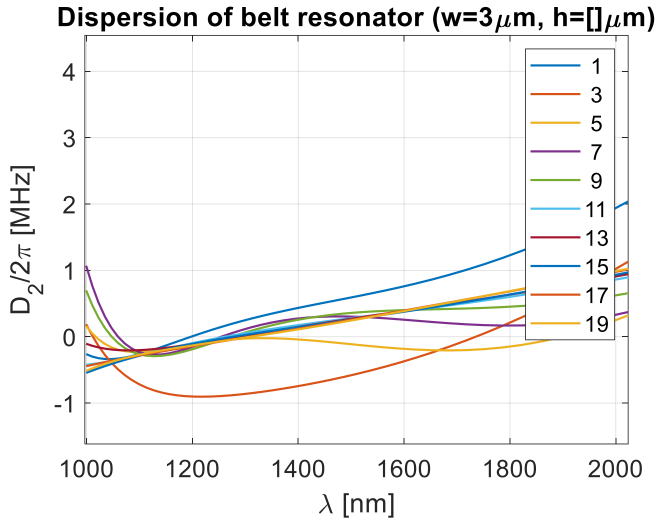


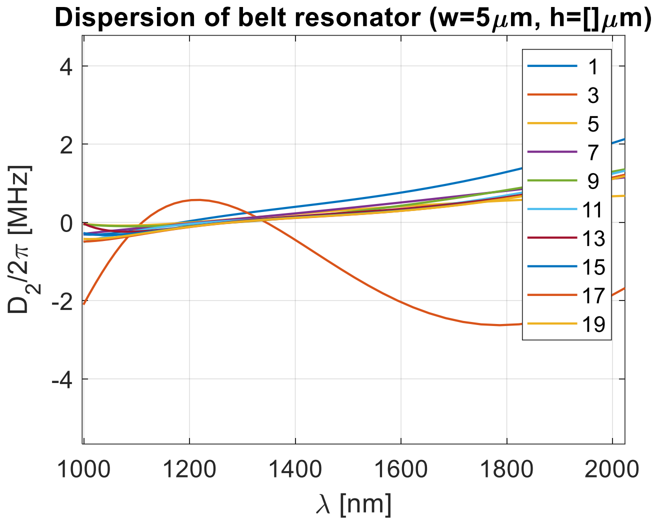


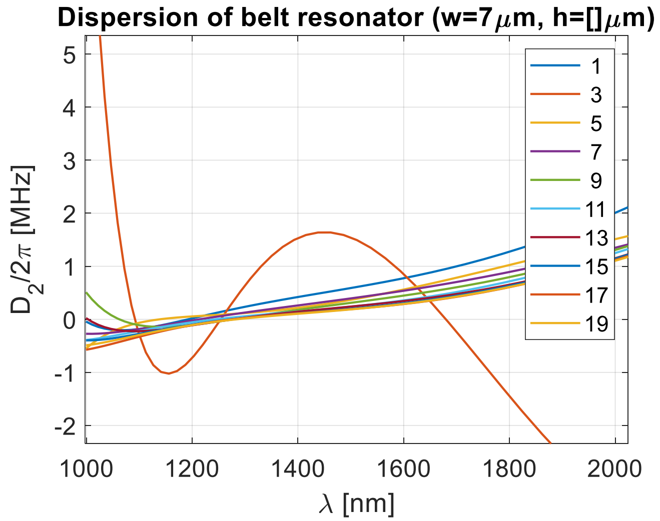


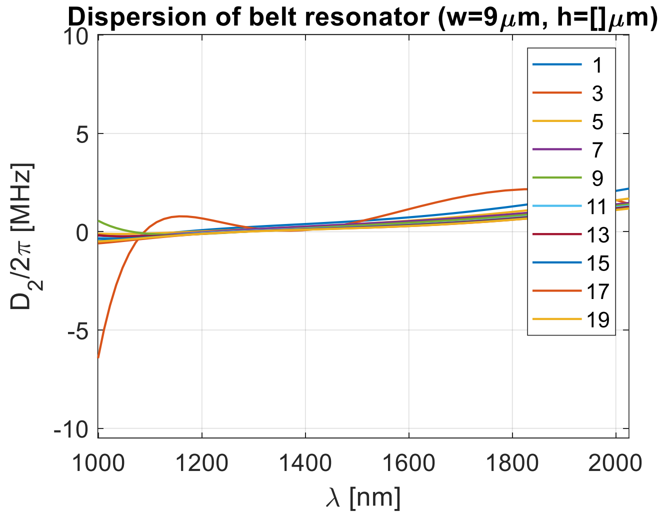
Dispersion engineering

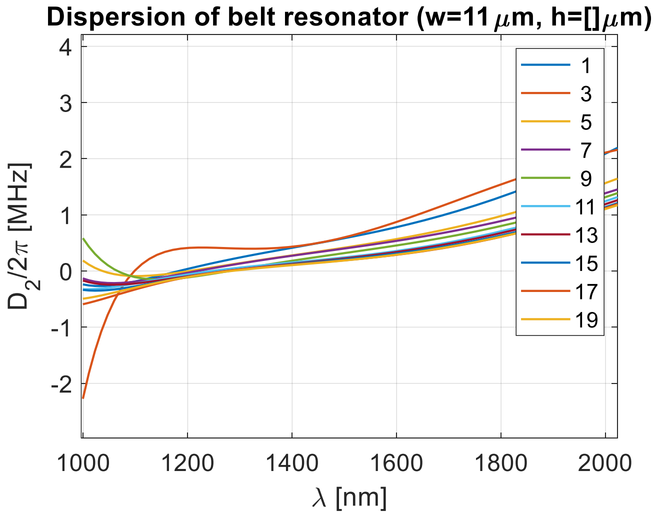








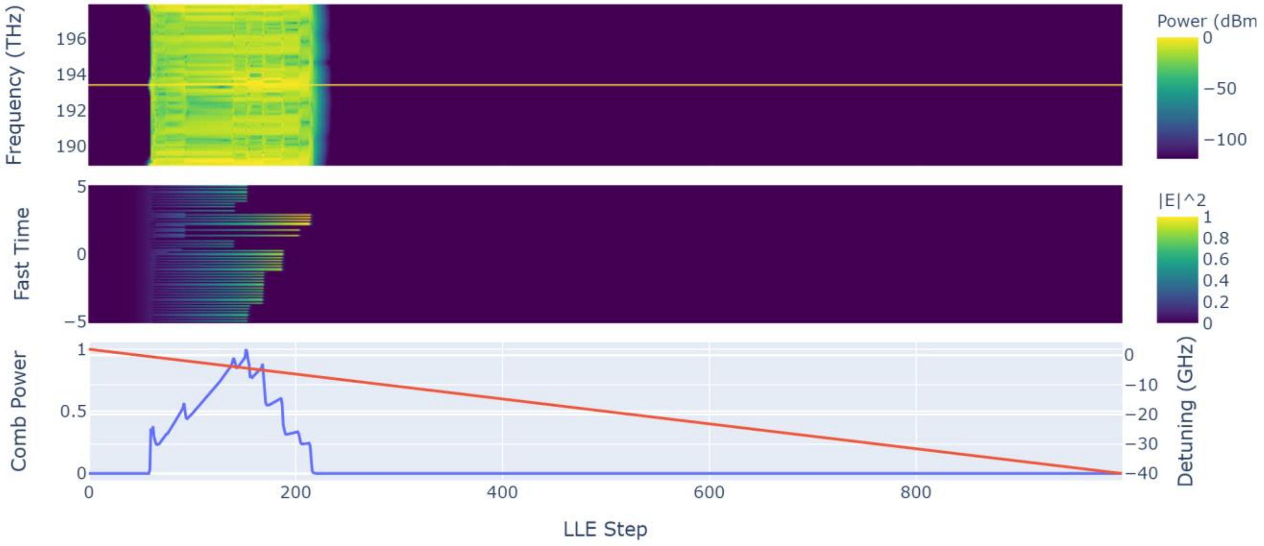




Modeling combs in pyLLE [7]

$$t_R \frac{\partial E(t,\tau)}{\partial t} = -\left(\frac{\alpha'}{2} - i\delta_0\right) E + i \cdot \mathrm{FT}^{-1}\left[-t_R D_{int}(\omega) \cdot \mathrm{FT}\left[E(t,\tau)\right]\right] + \gamma |E|^2 E + \sqrt{\theta} E_{in}$$

```
-- Solving standard LLE --
        Simulation Parameters
                R = 332.00 µm
                Qi = 10.00 M
                Qc = 10.00 M
                γ = 1.55
        Simulation Parameters
                Pin = 190.00 mW
                Tscan = 0.50 x1e6 Round Tri
                f_pmp = 193.41 THz
                δω_init = 2.00 x2π GHz
                δω_end = -40.00 x2π GHz
                µ_sim = [-45.00,45.00]
                µ_fit = [-45.00,45.00]
```




```
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1853,189144011447497.00
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1855,189342233094932.00
1856,189441344114439.00
1857,189540455263051.00
1858,189639566539706.00
1859,189738677943345.00
1860,189837789472915.00
1861,189936901127361.00
1862,190036012905635.00
1863,190135124806692.00
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```
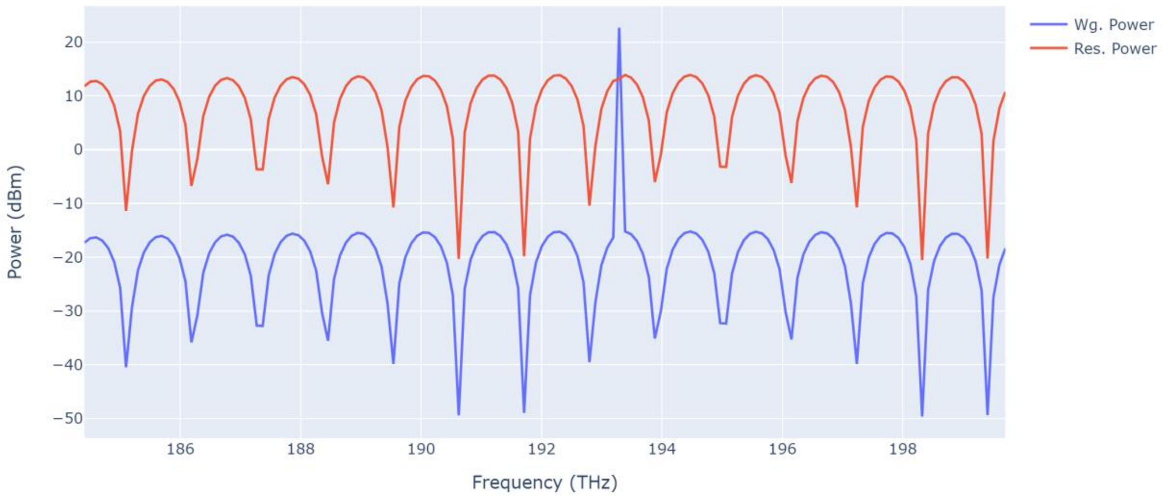
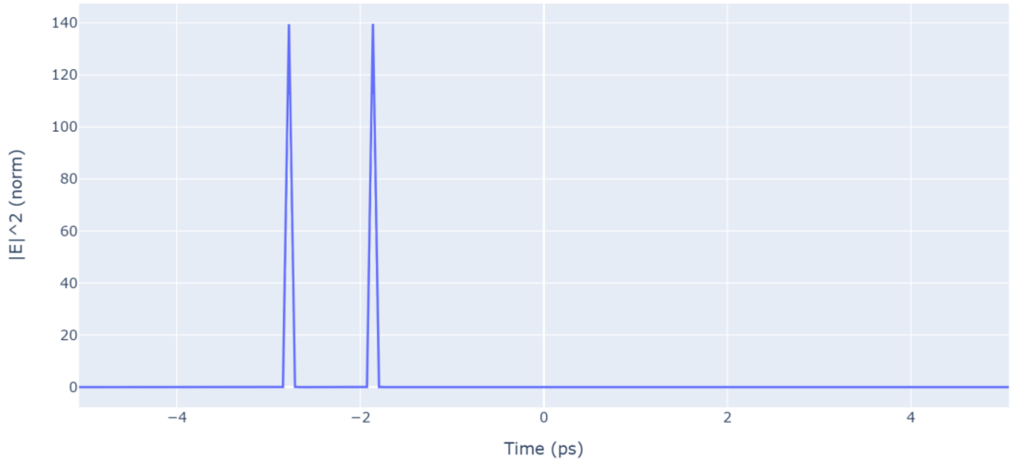
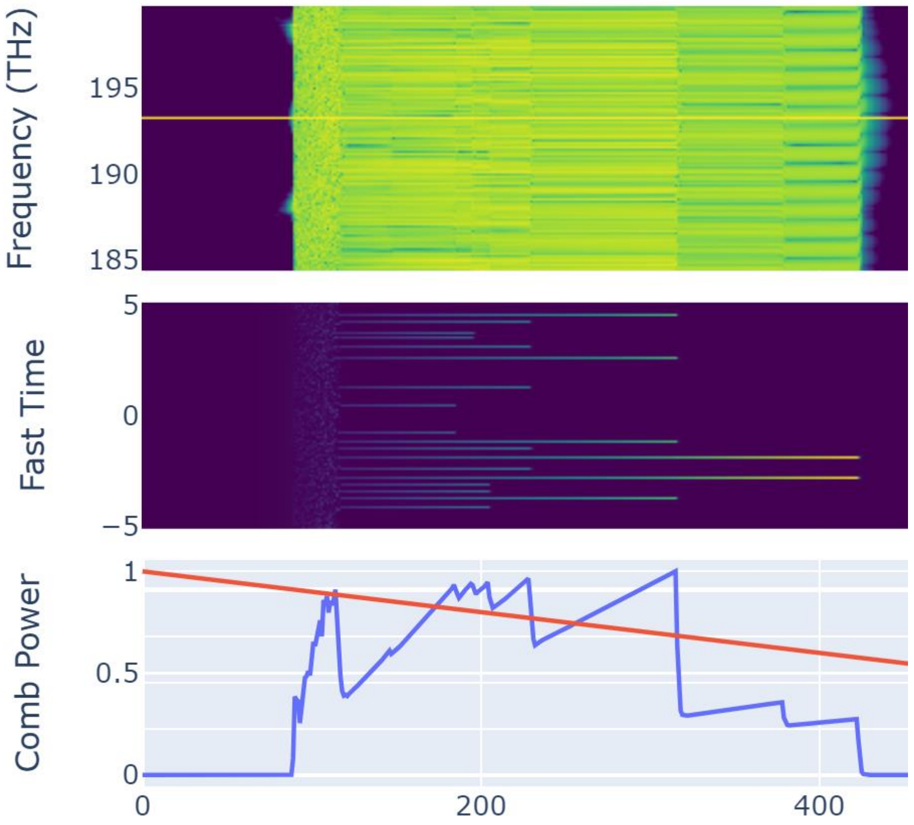

Modeling combs in pyLLE







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[1] https://www.anglicannews.org/ImageGen.ashx?image=/media/1863503/garry-knight-flickr_st-pauls-cathedral-london-england_700x467.jpg

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Thank you for attention!

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