

DESIGN GRADE DE BRAGG

SEMANA 1

ESTUDO DE REFERENCIAS

ESTUDO DE REFERENCIAS

Ref: T. Erdogan, "Fiber grating spectra," in Journal of Lightwave Technology, vol. 15, no. 8, pp. 1277-1294, Aug. 1997, doi: 10.1109/50.618322.

Para uma grade do tipo FBG, é interessante calcular analiticamente sua transmissão e refletância teorica

Para um caso mais simples as variáveis que podemos controlar são:

Neff, Comprimento da grade, refletância maxima

ESTUDO DE REFERENCIAS

Podemos calcular r através da seguinte equação:

$$r = \frac{\sinh^2\left(\sqrt{\kappa^2 - \hat{\sigma}^2}L\right)}{\cosh^2\left(\sqrt{\kappa^2 - \hat{\sigma}^2}L\right) - \frac{\hat{\sigma}^2}{\kappa^2}}.$$

Logo, so precisamos definir κ e $\hat{\sigma}$

ESTUDO DE REFERENCIAS

K pode ser calculado a partir da reflexão máxima:

$$r_{\max} = \tanh^2(\kappa L)$$

$$k = \frac{\arctang(\sqrt{r_{\max}})}{L}$$

ESTUDO DE REFERENCIAS

E sabendo que:

$$\hat{\sigma} \equiv \delta + \sigma - \frac{1}{2} \frac{d\phi}{dz}$$

Dado que a grade é uniforme: $\frac{d\phi}{dz} = 0$

Desprezando o self-coupling: $\sigma = 0$

$$\text{Logo: } \hat{\sigma} \equiv \delta = 2\pi n_{\text{eff}} \left(\frac{1}{\lambda} - \frac{1}{\lambda_D} \right)$$

ESTUDO DE REFERENCIAS

E sabendo que:

$$\hat{\sigma} \equiv \delta + \sigma - \frac{1}{2} \frac{d\phi}{dz}$$

Dado que a grade é uniforme: $\frac{d\phi}{dz} = 0$

Desprezando o self-coupling: $\sigma = 0$

$$\text{Logo: } \hat{\sigma} \equiv \delta = 2\pi n_{\text{eff}} \left(\frac{1}{\lambda} - \frac{1}{\lambda_D} \right)$$

ESTUDO DE REFERENCIAS

Exemplo 1

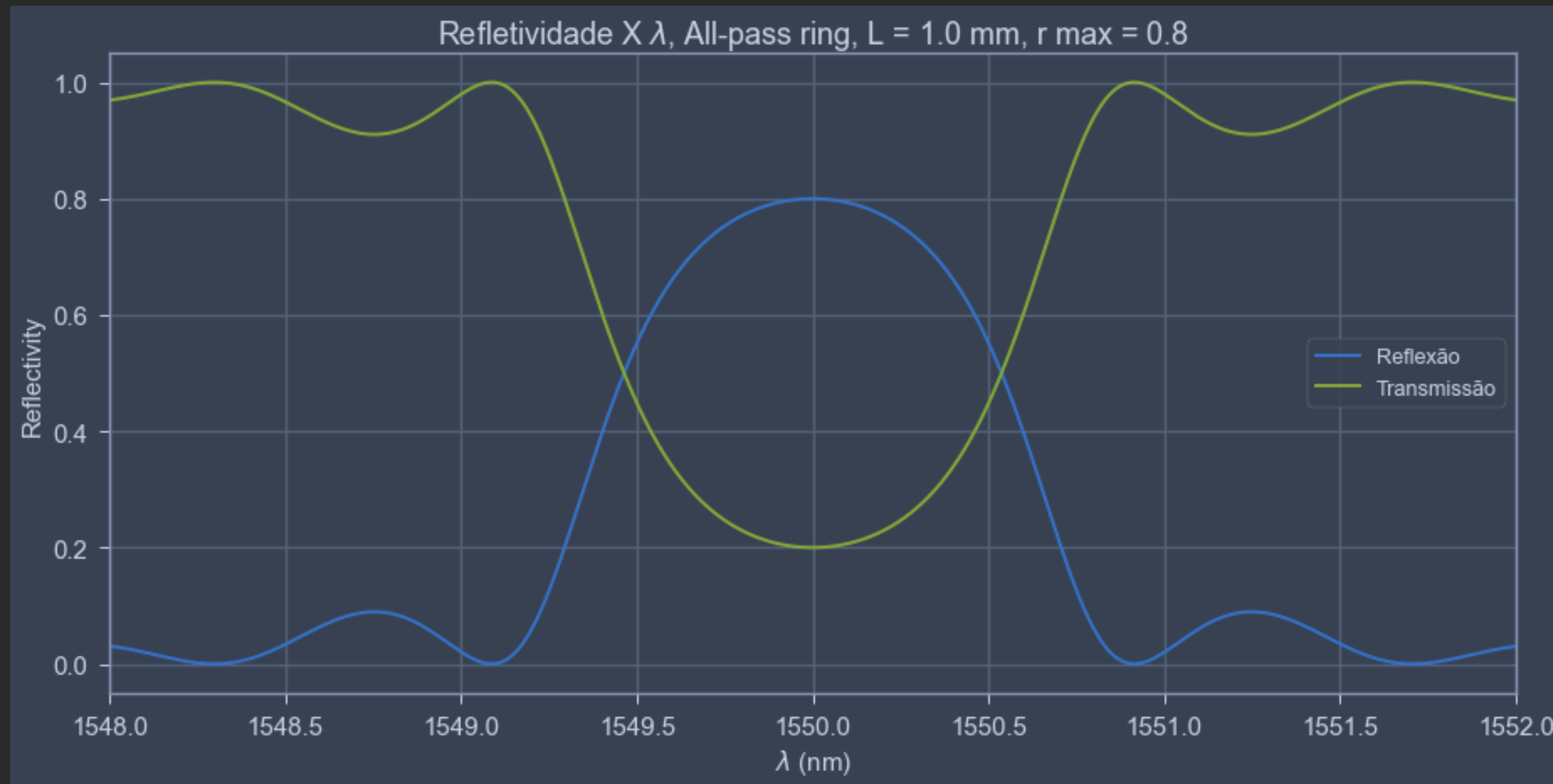
$L = 1 \text{ mm}$,

$r_{\text{max}} = 0.8$,

Comprimento central = 1550 nm

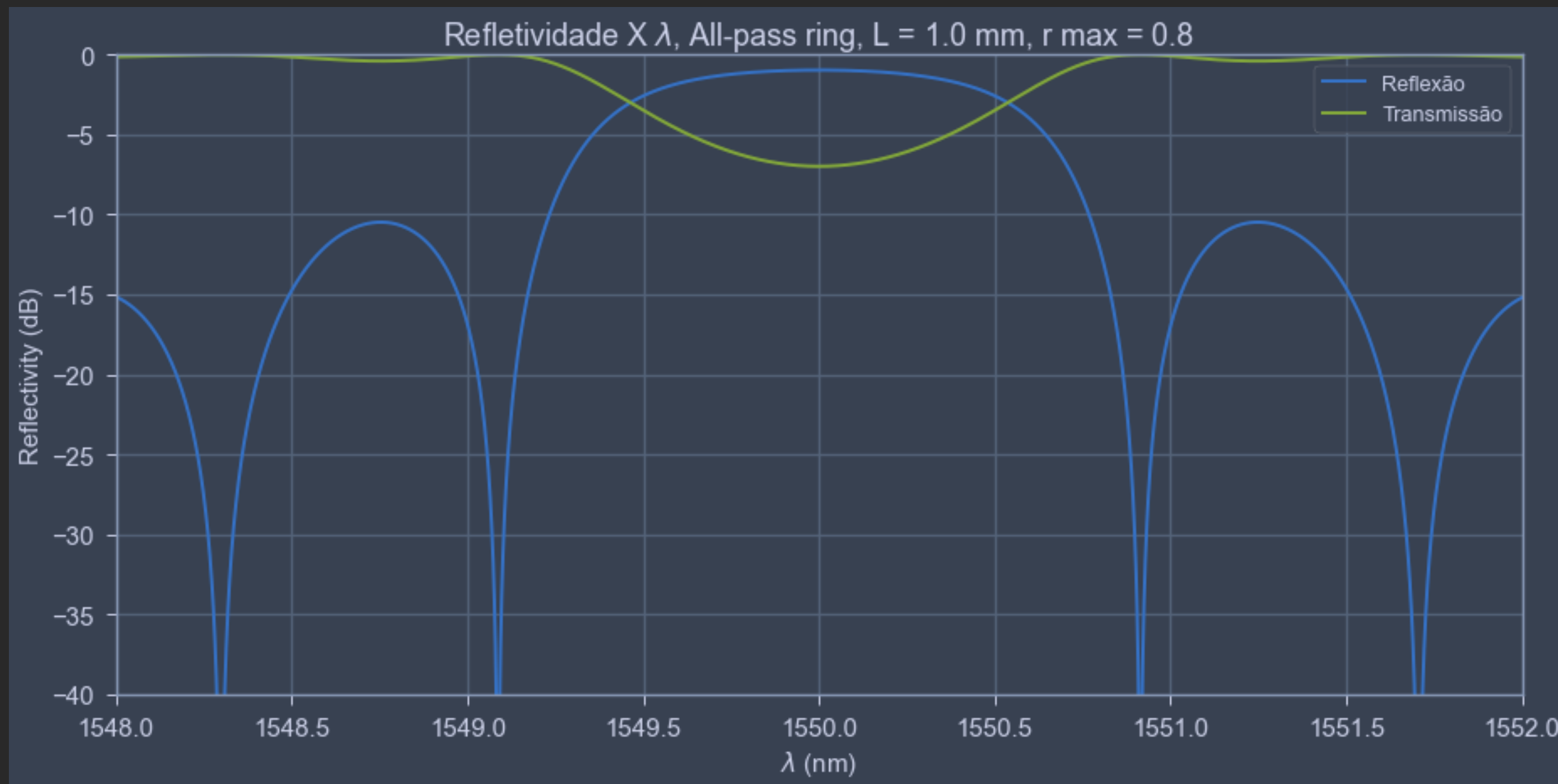
ESTUDO DE REFERENCIAS

Exemplo 1



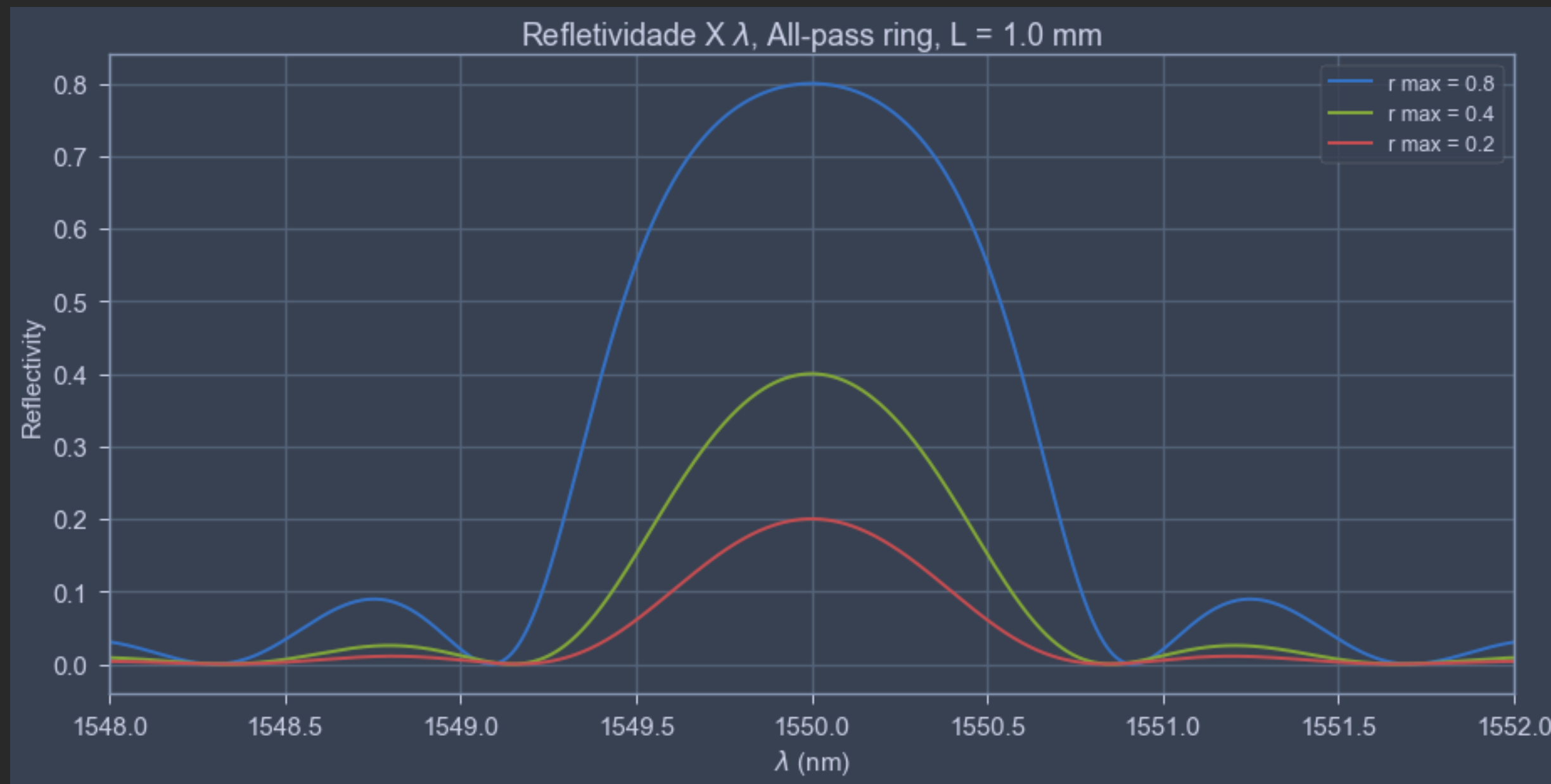
ESTUDO DE REFERENCIAS

Exemplo 1



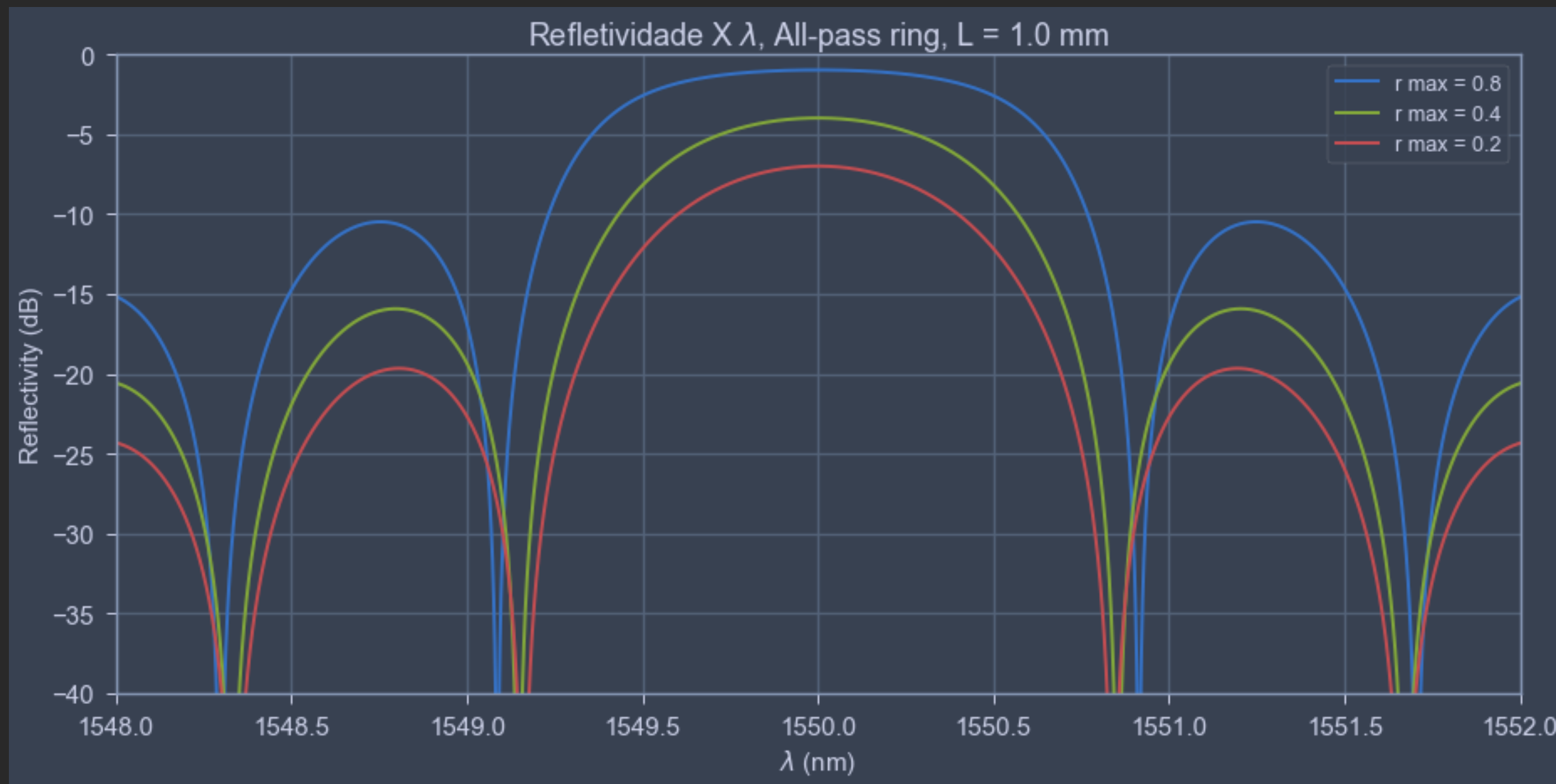
ESTUDO DE REFERENCIAS

Exemplo 1



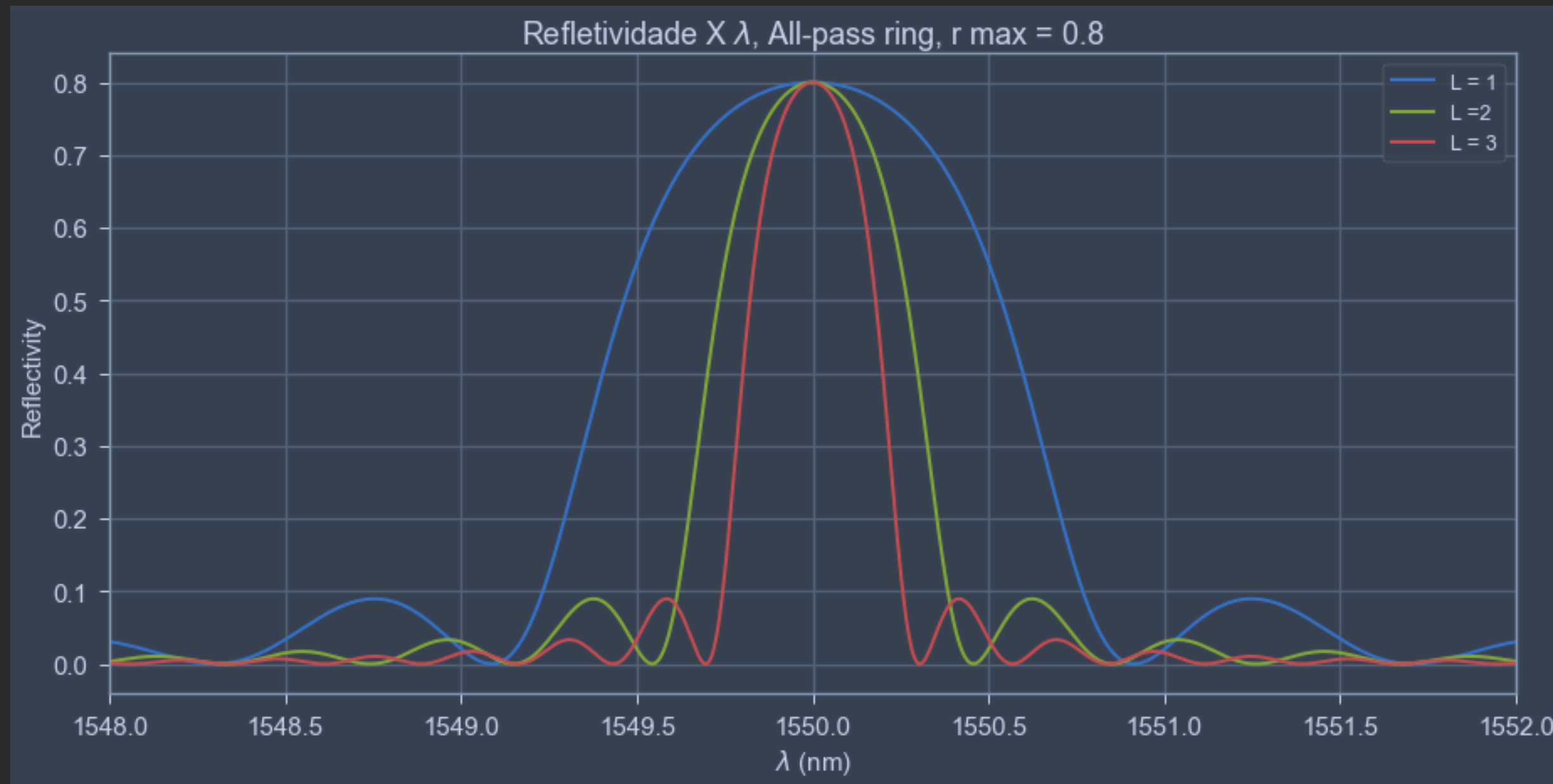
ESTUDO DE REFERENCIAS

Exemplo 1



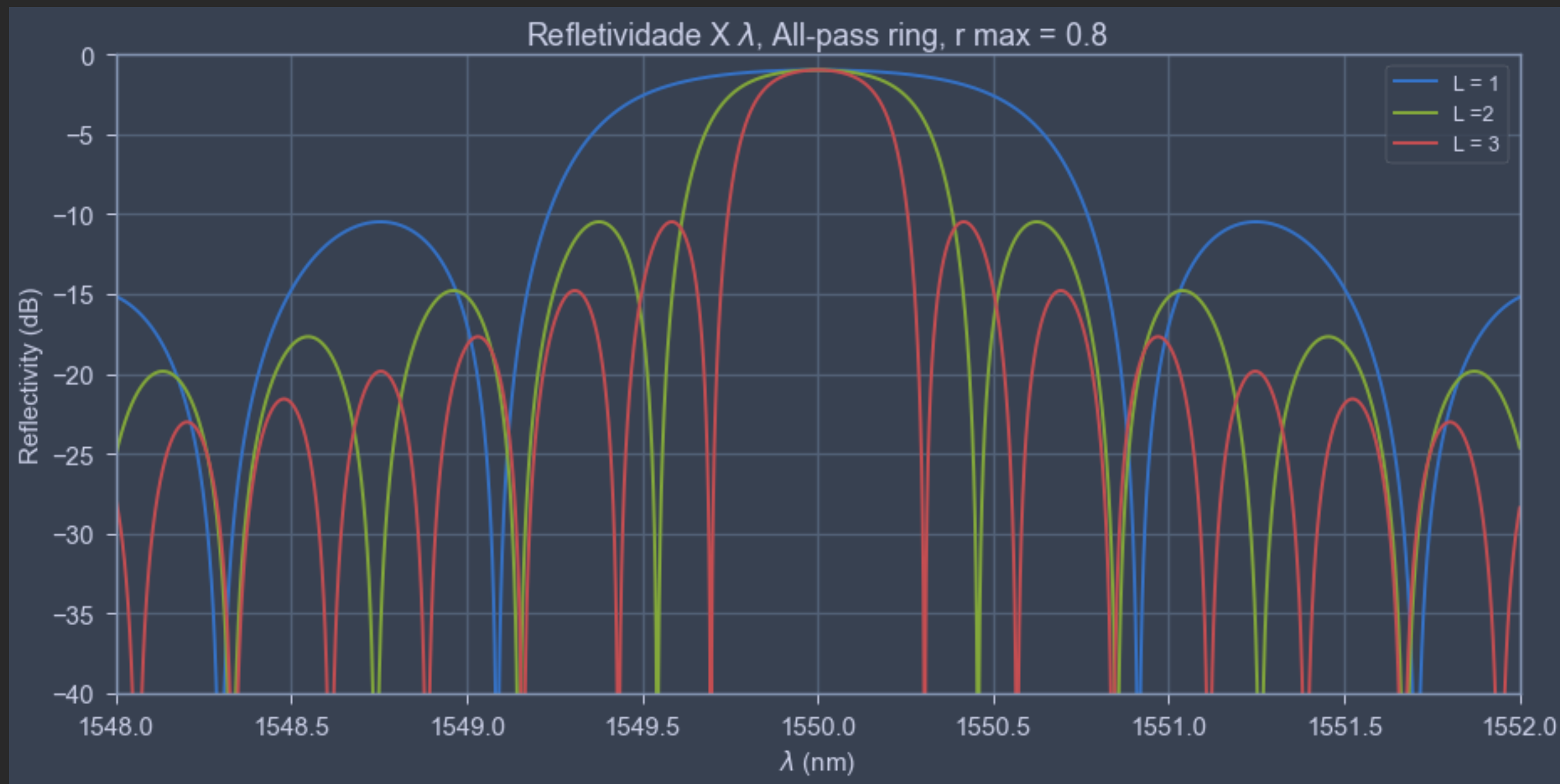
ESTUDO DE REFERENCIAS

Exemplo 1



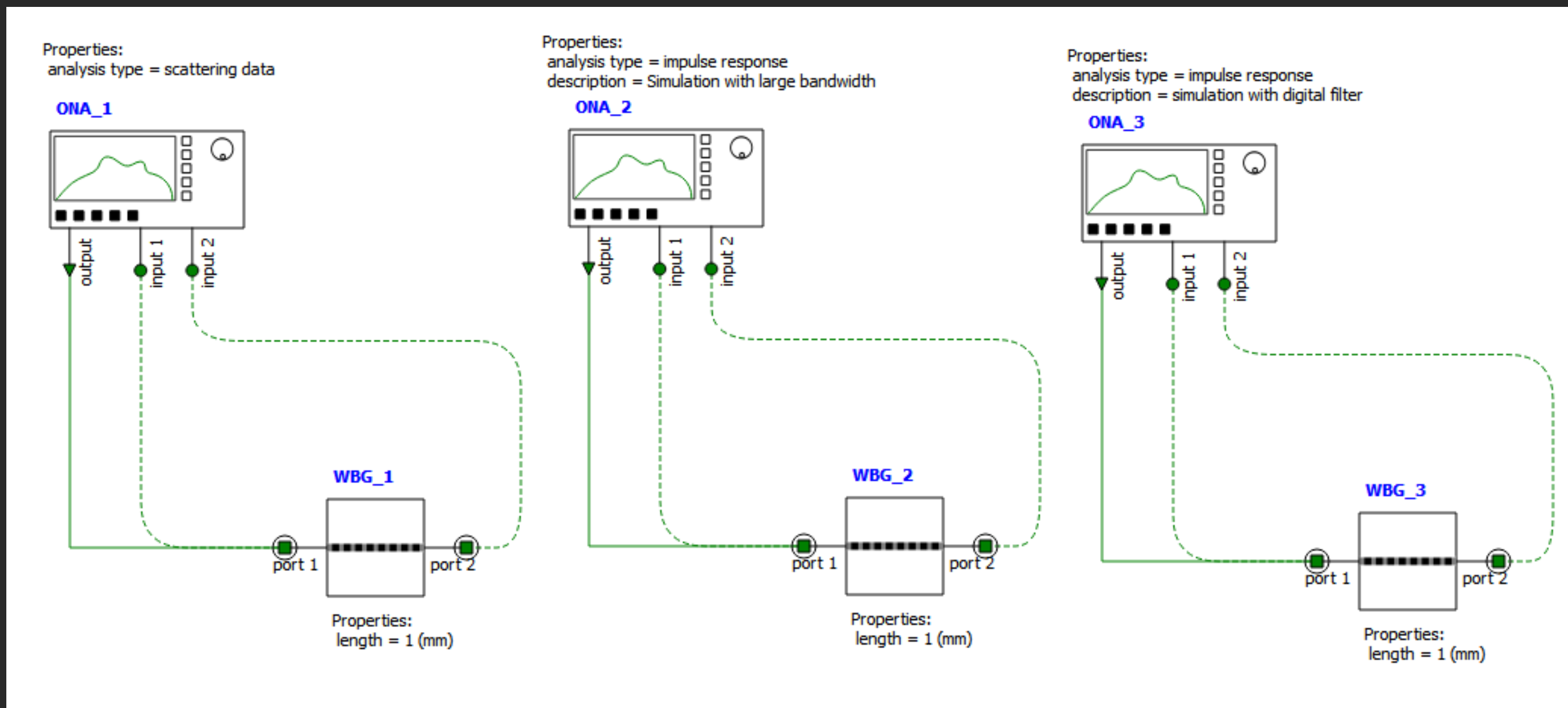
ESTUDO DE REFERENCIAS

Exemplo 1



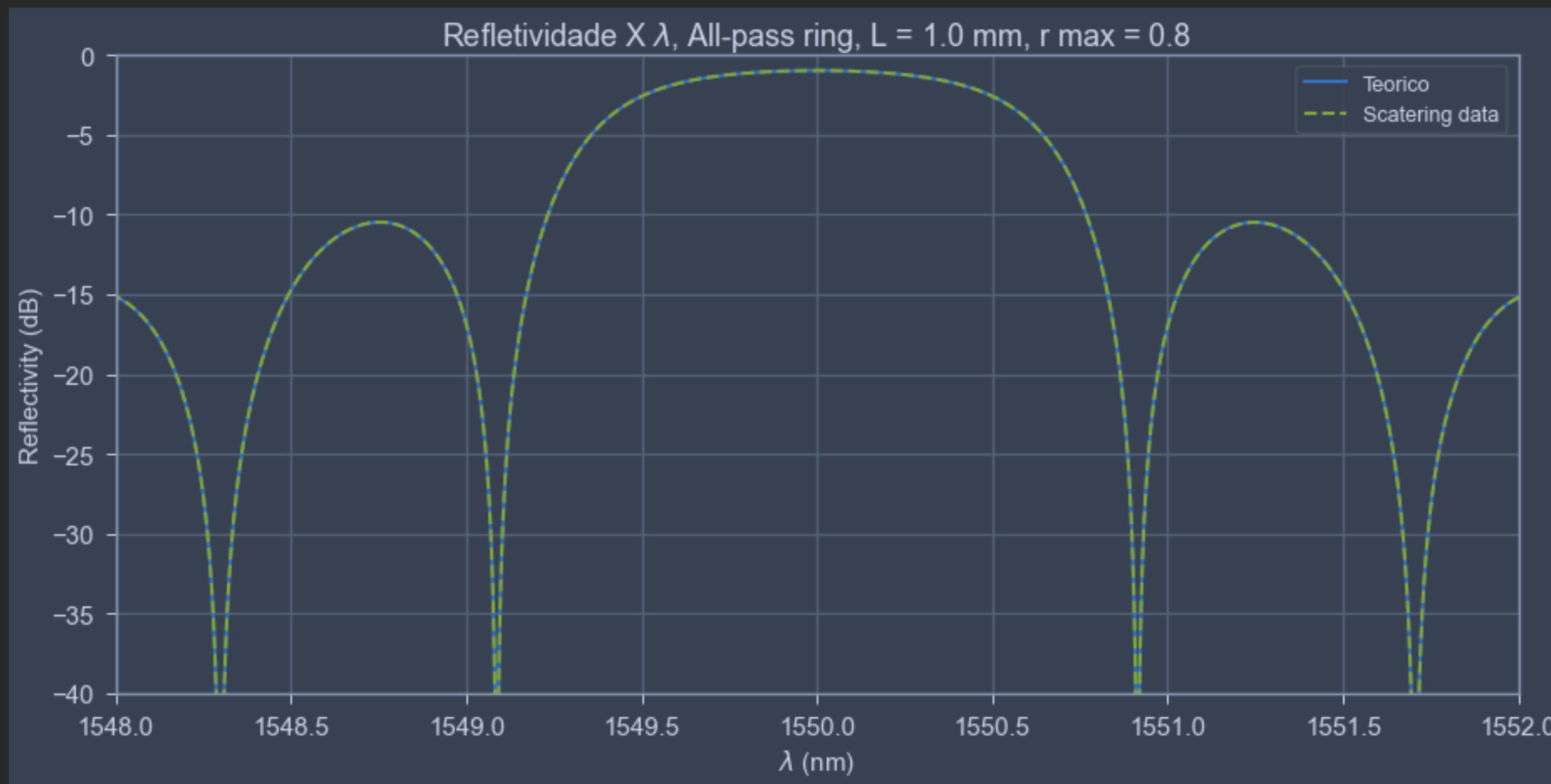
ESTUDO DE REFERENCIAS

Simulação interconnect Exemplo 1



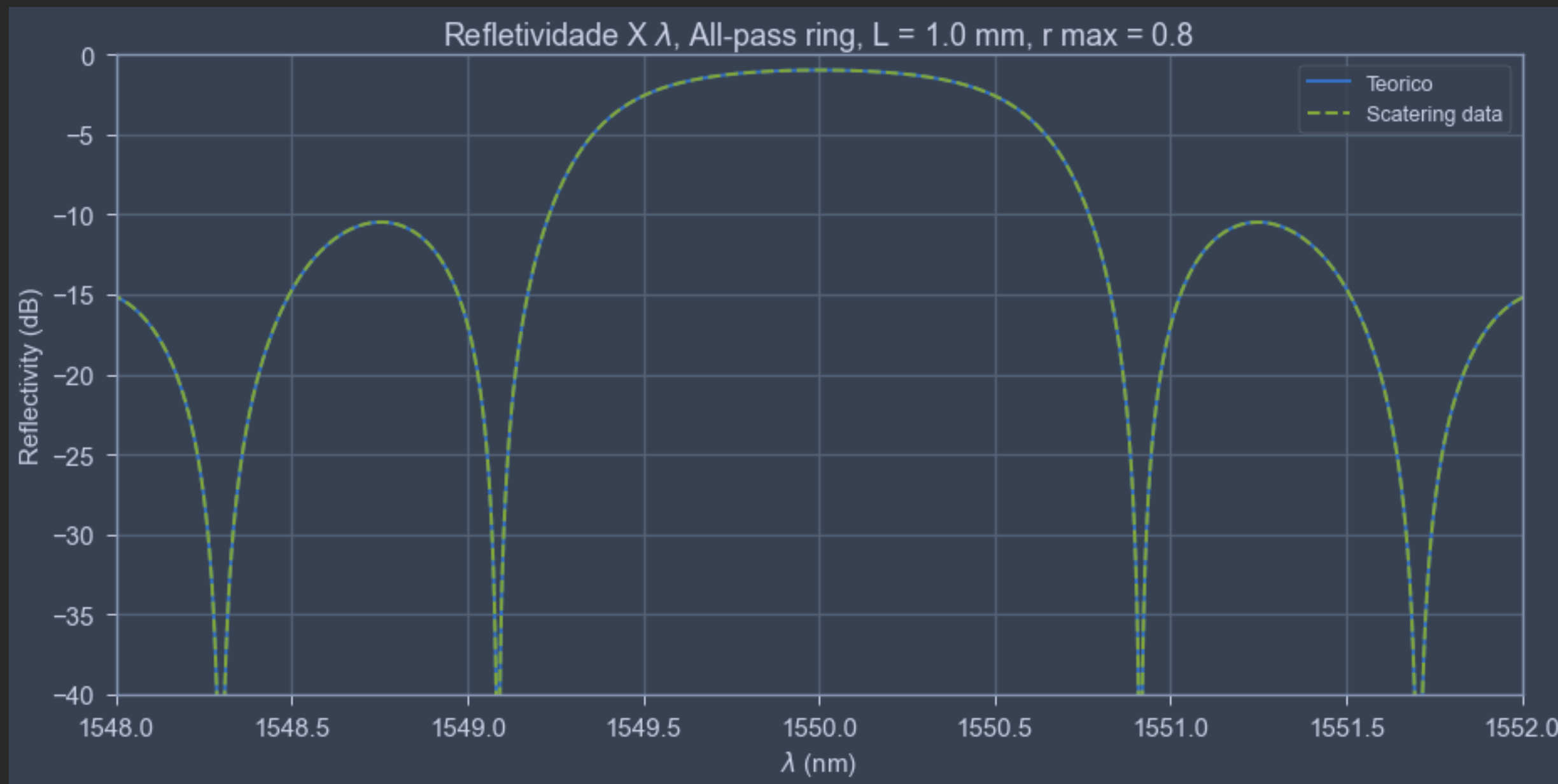
ESTUDO DE REFERENCIAS

Resultados



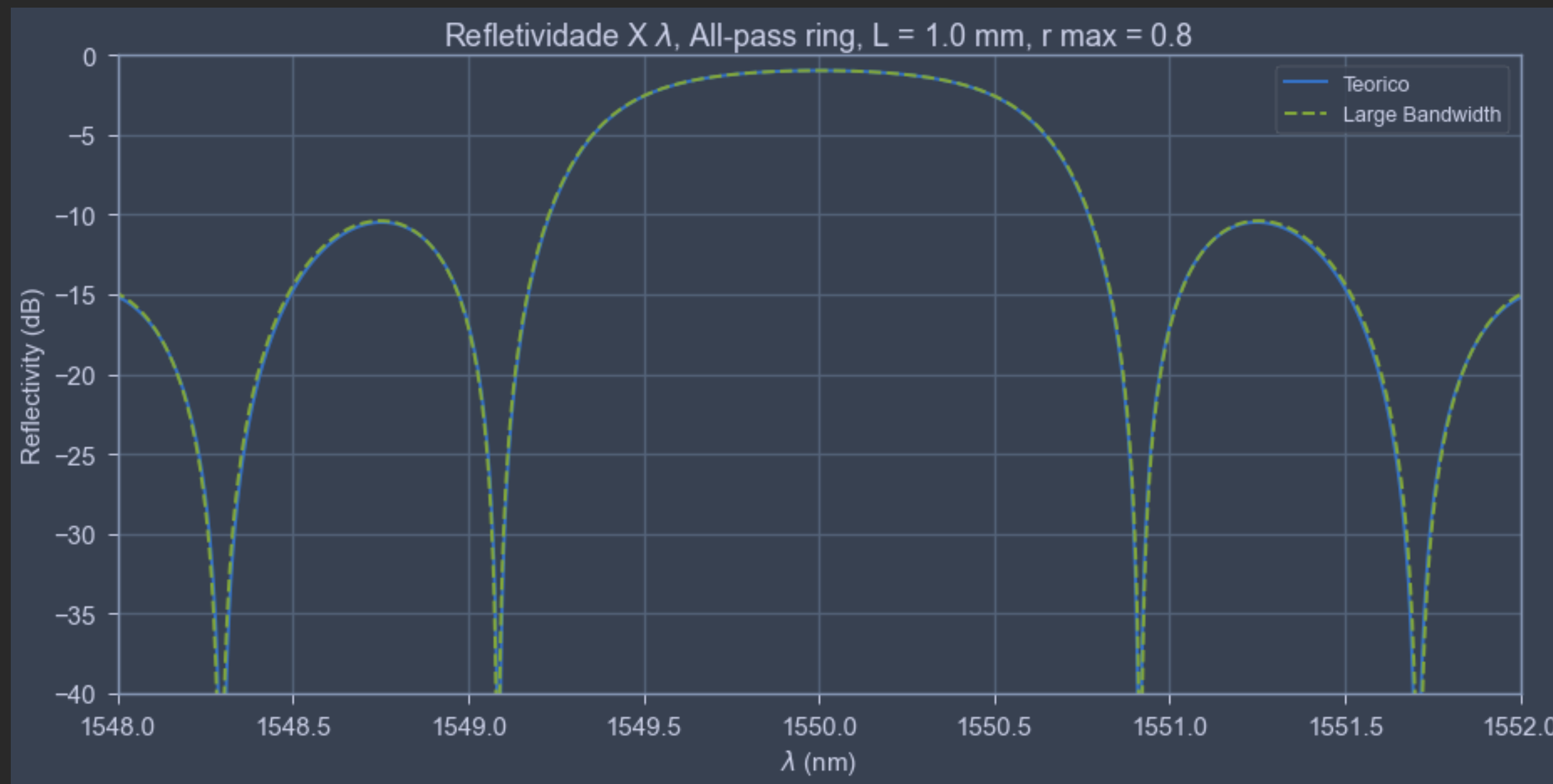
ESTUDO DE REFERENCIAS

Resultados



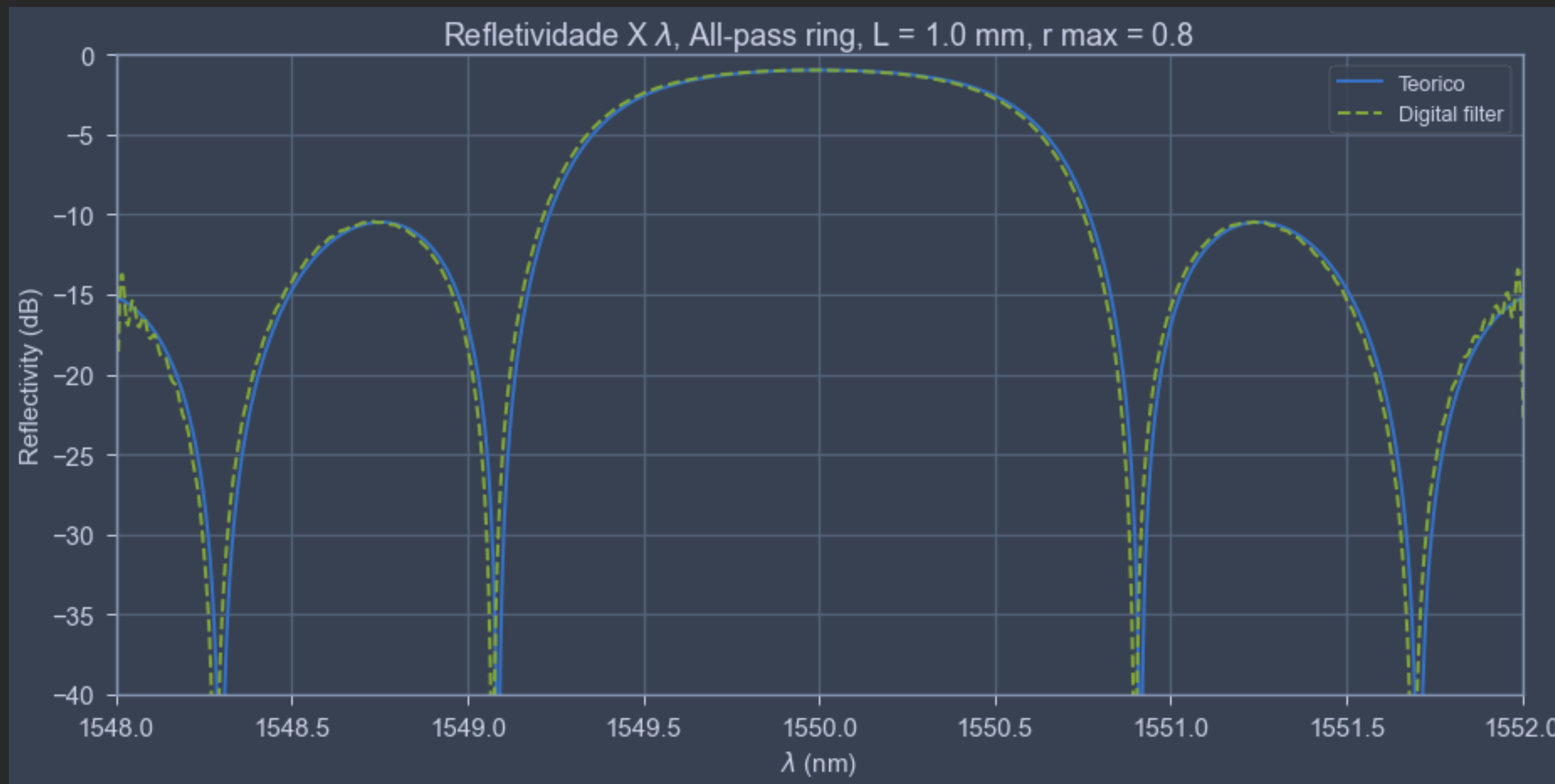
ESTUDO DE REFERENCIAS

Resultados



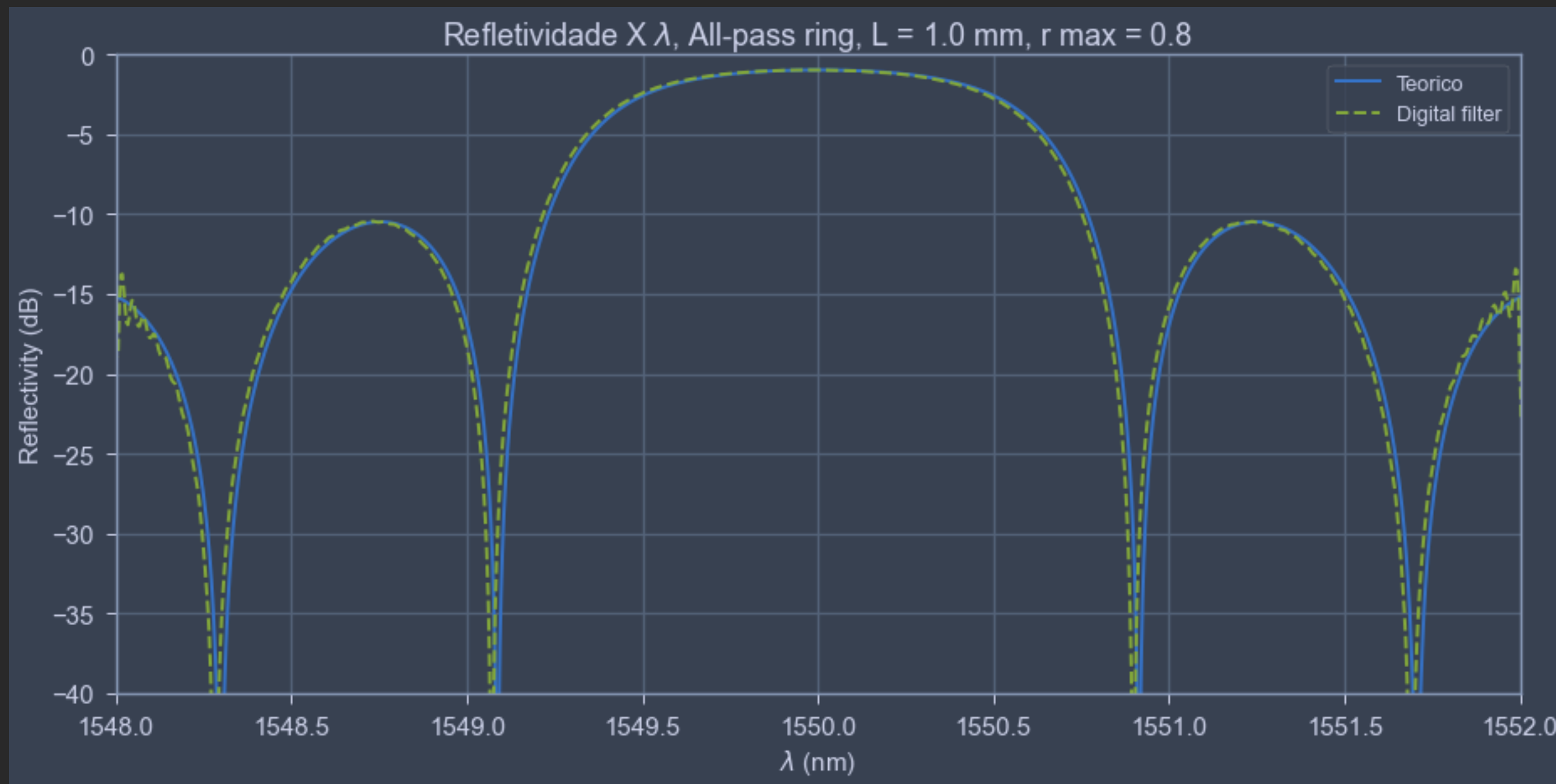
ESTUDO DE REFERENCIAS

Resultados



ESTUDO DE REFERENCIAS

Resultados



SEMANA 2

DESIGN DE FILTRO COM GRADE DE BRAGG

SEMANA 2

Design de filtro com Grade de Bragg

DESIGN

Parametros

Comprimento central = 1540 nm

Fwhm = 20 nm

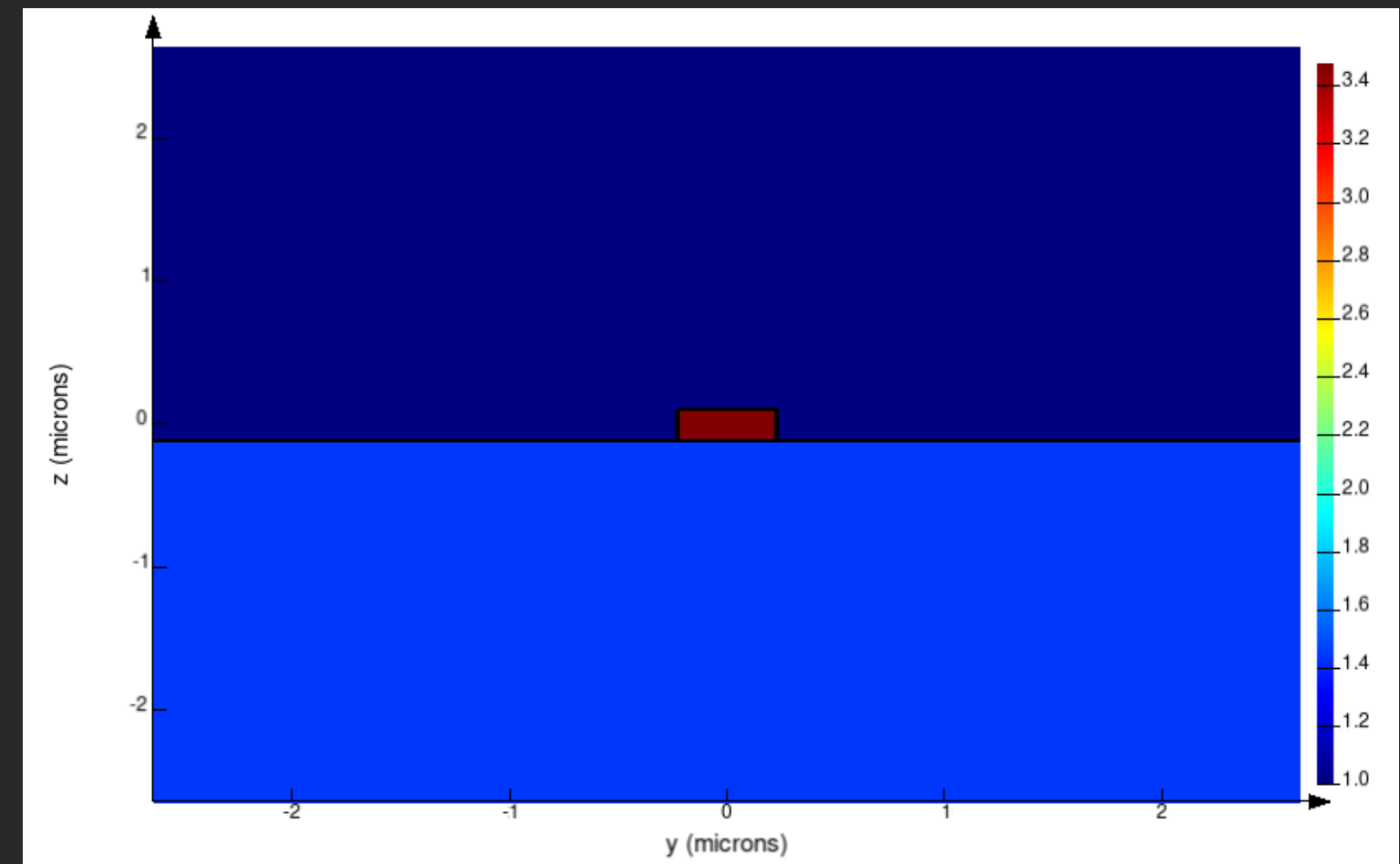
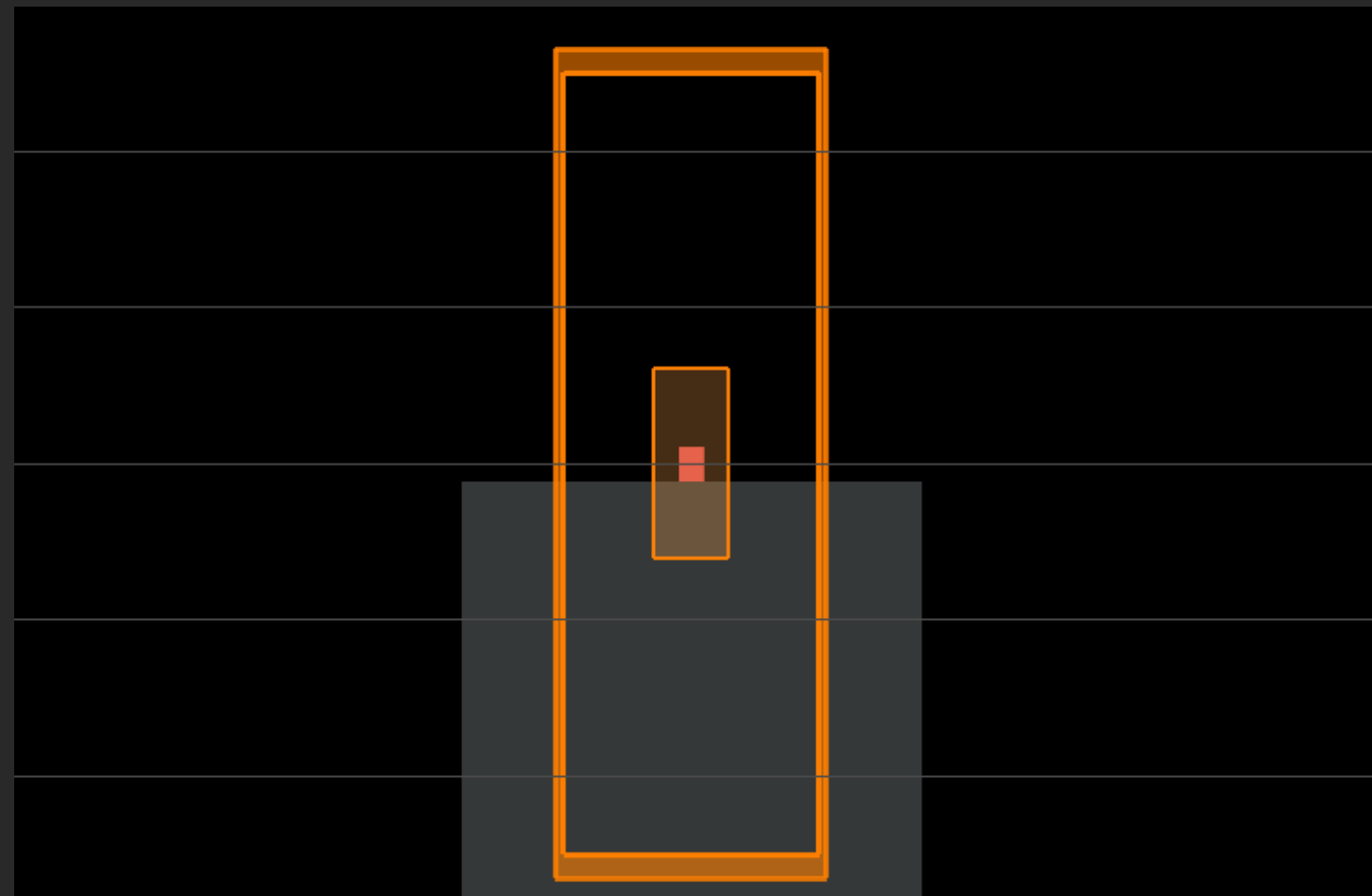
Guia: 450 x 220 nm, SOI

Neff = 2.2875

Ng = 4.5878

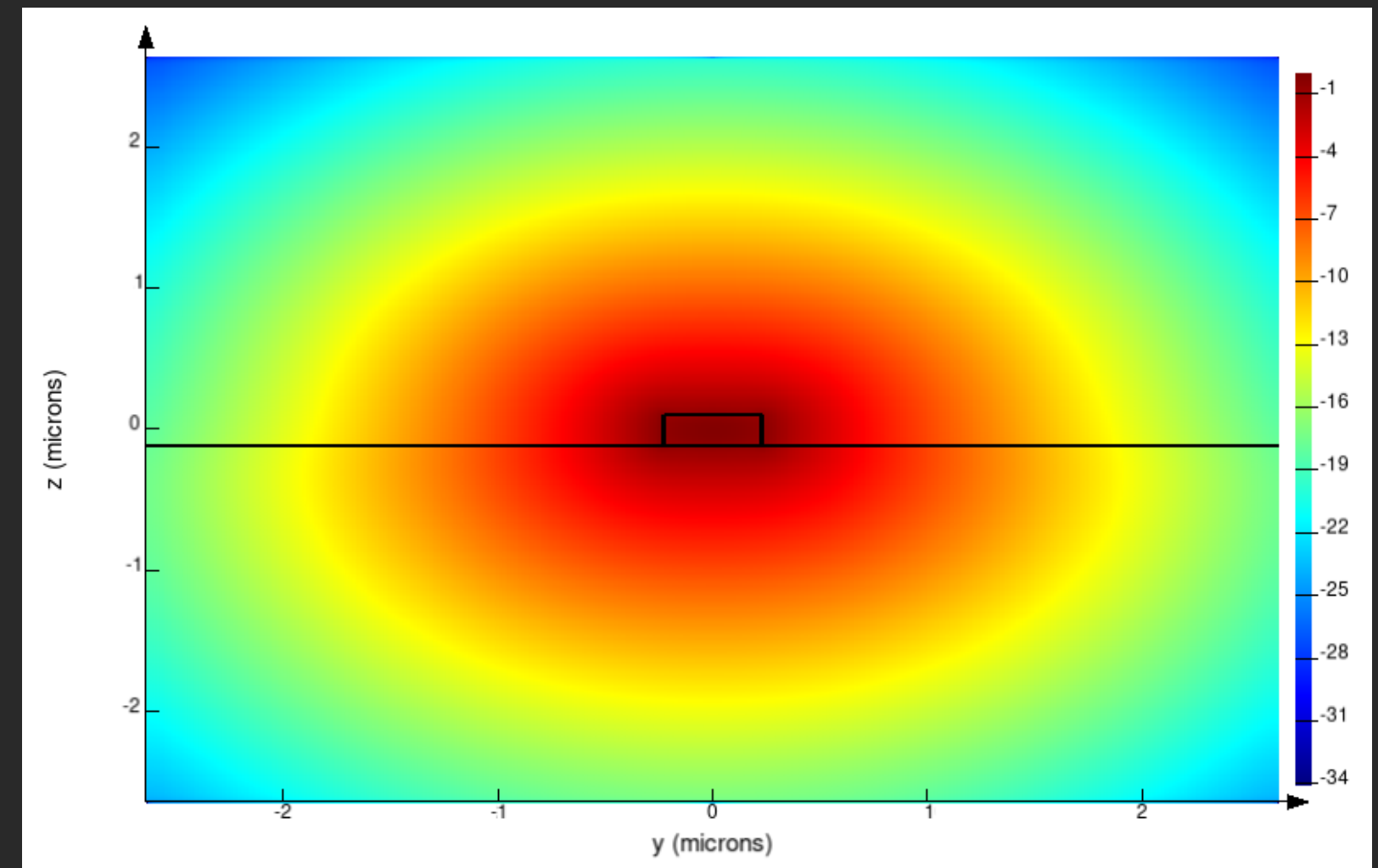
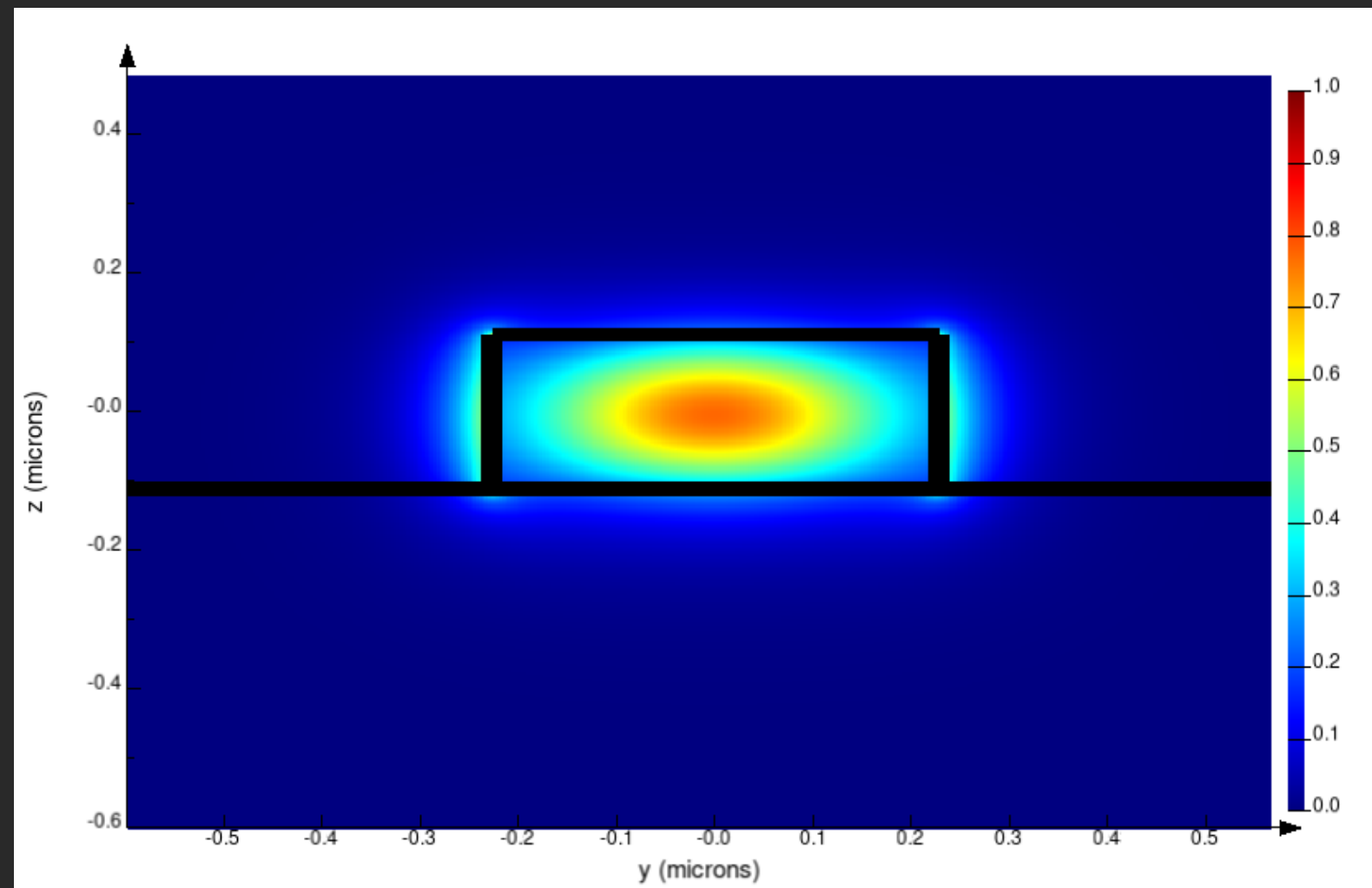
DESIGN

Parametros



DESIGN

Simulação do guia



mode # ▾	effective index	wavelength (μm)	loss (dB/cm)	group index	TE polarization fraction (Ey)	waveguide TE/TM fraction (%)
1	2.287553-6.070278e-18i	1.54	-2.1512e-12	4.587824-8.341346e-16i	97	68.69 / 82.03
2	1.553599-2.755374e-07i	1.54	-0.097646	3.383983+2.583202e-05i	8	73.55 / 87.94

DESIGN

Parametros:

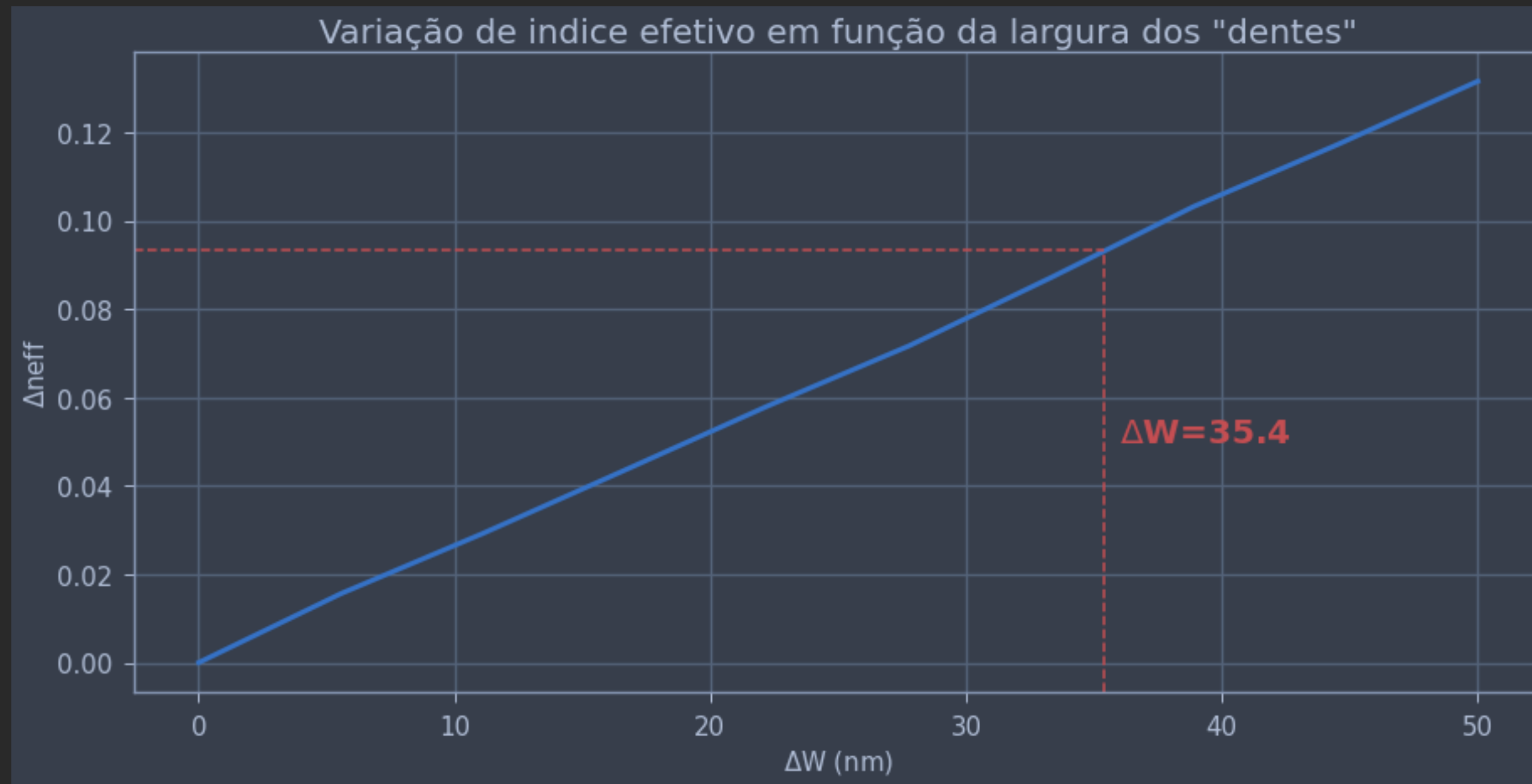
Para $n_{eff} = 2.287$: Período da grade = 336.612 nm

Para Número de períodos = 100: $L = 33.6612 \mu m$

Para $L = 336.612 \mu m$, $\Delta n_{eff} = 0.09331$

DESIGN

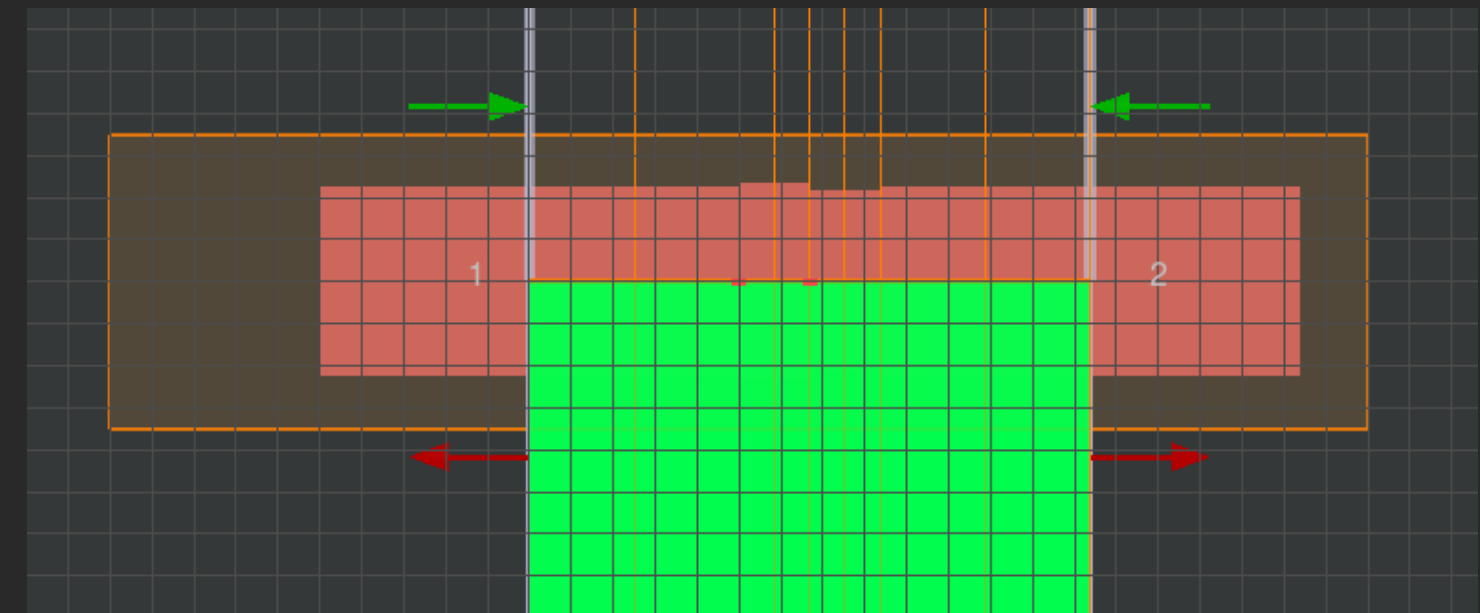
Calculo do Delta W



DESIGN

Simulação no EME

#	Name	Type	Value	Unit
1	[l] W	Length	0.45	um
2	[l] altura	Length	0.22	um
3	[l] deltaW	Length	0.0354	um
4	[l] periodo	Length	0.336612	um
5	[l] material	Material	Si (Silicon) - ...	
6	[l] substrato	Material	SiO2 (Glass) -...	



DESIGN

Simulação no EME

EME Analysis Window

Define propagation distance

Cell group definition

energy conservation

make passive

	group spans (μm)	cells	subcell method	modes	custom	cell range	start (μm)	stop (μm)
1	0.5	2	none	10	default	[1,2]	-0.5	0
2	0.168306	2	none	10	default	[3,4]	0	0.168306
3	0.168306	2	none	10	default	[5,6]	0.168306	0.336612
4	0.5	2	none	10	default	[7,8]	0.336612	0.836612

Select source

amplitude

1

source port

port 1

source mode

mode 1

override max modes

max modes

1

override wavelength

wavelength (μm)

1.55

Override periodicity

	start cell group	end cell group	periods
1	1	1	1
2	2	3	100
3	4	4	1

Cell group sequence

[(1)^1,(2,3)^100,(4)^1]

include fast diagnostics

include slow diagnostics

update monitors

calculate group delays

eme propagate

[Help me use diagnostics...](#)

advanced options ...

Propagation sweep

parameter

group span 1

start (μm)

0

stop (μm)

0

interval

0

number of points

2

eme sweep

visualize eme sweep

Wavelength sweep

start wavelength (μm)

1.52

stop wavelength (μm)

1.56

number of wavelength points

5000

calculate group delays

wavelength sweep

visualize wavelength sweep

export to file

Mode convergence sweep

start mode

1

mode interval

1

mode sweep

visualize mode sweep

S-matrix index mapping

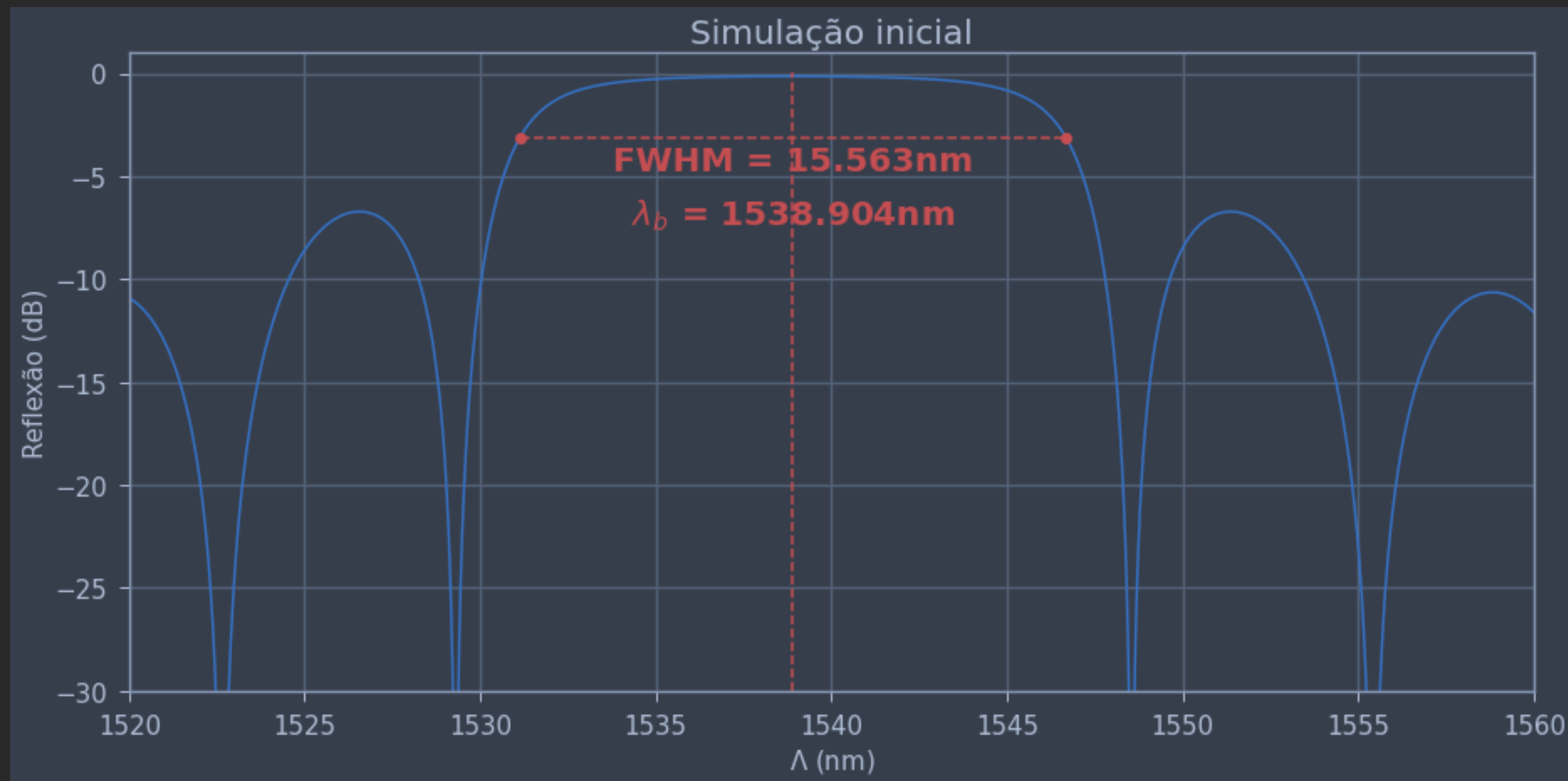
S-matrix index	Source mode
1	port 1 mode 1
2	port 2 mode 1

Redock

Hide

DESIGN

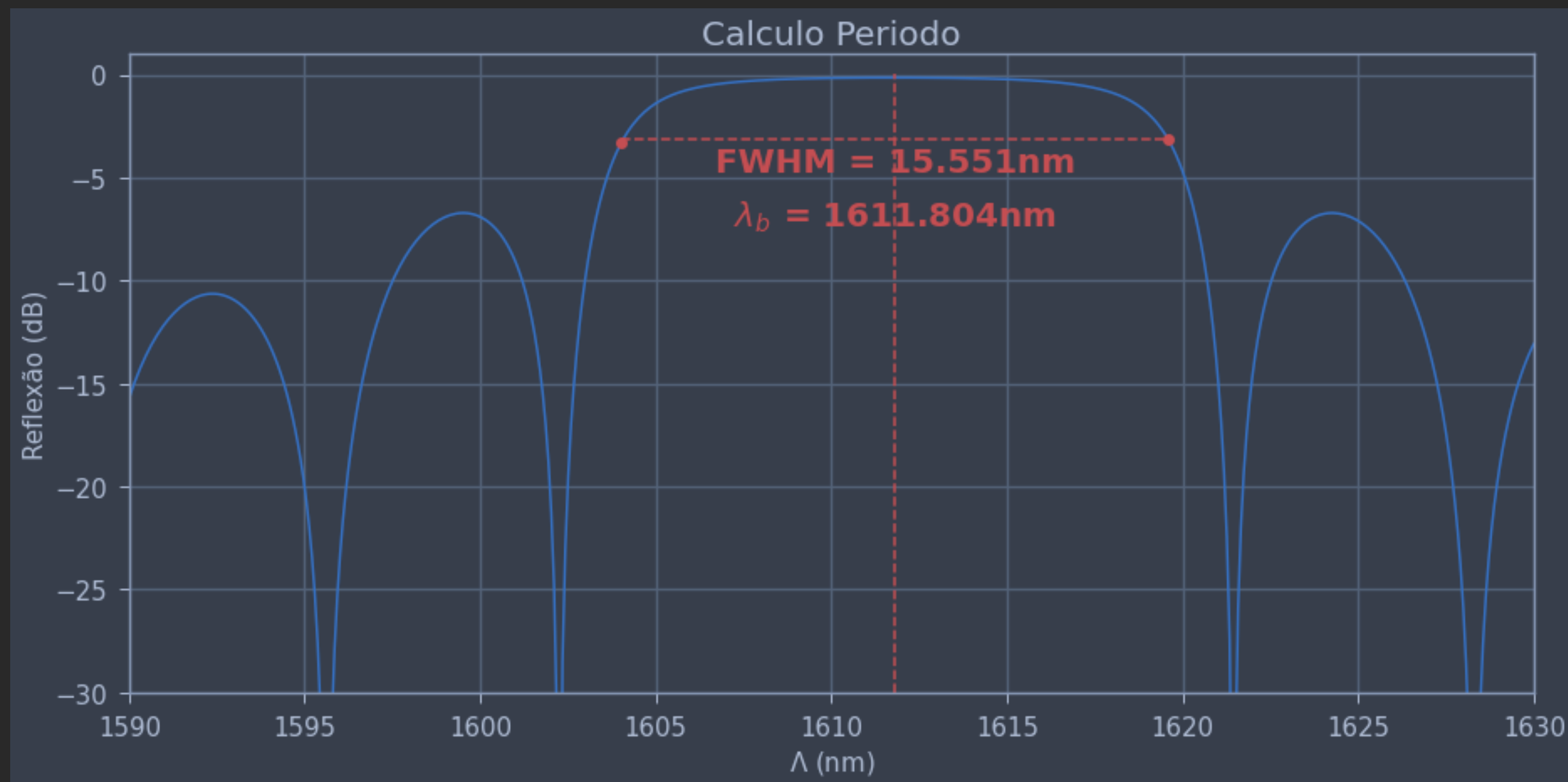
Resultados Iniciais



DESIGN

Calculando novo periodo ideal

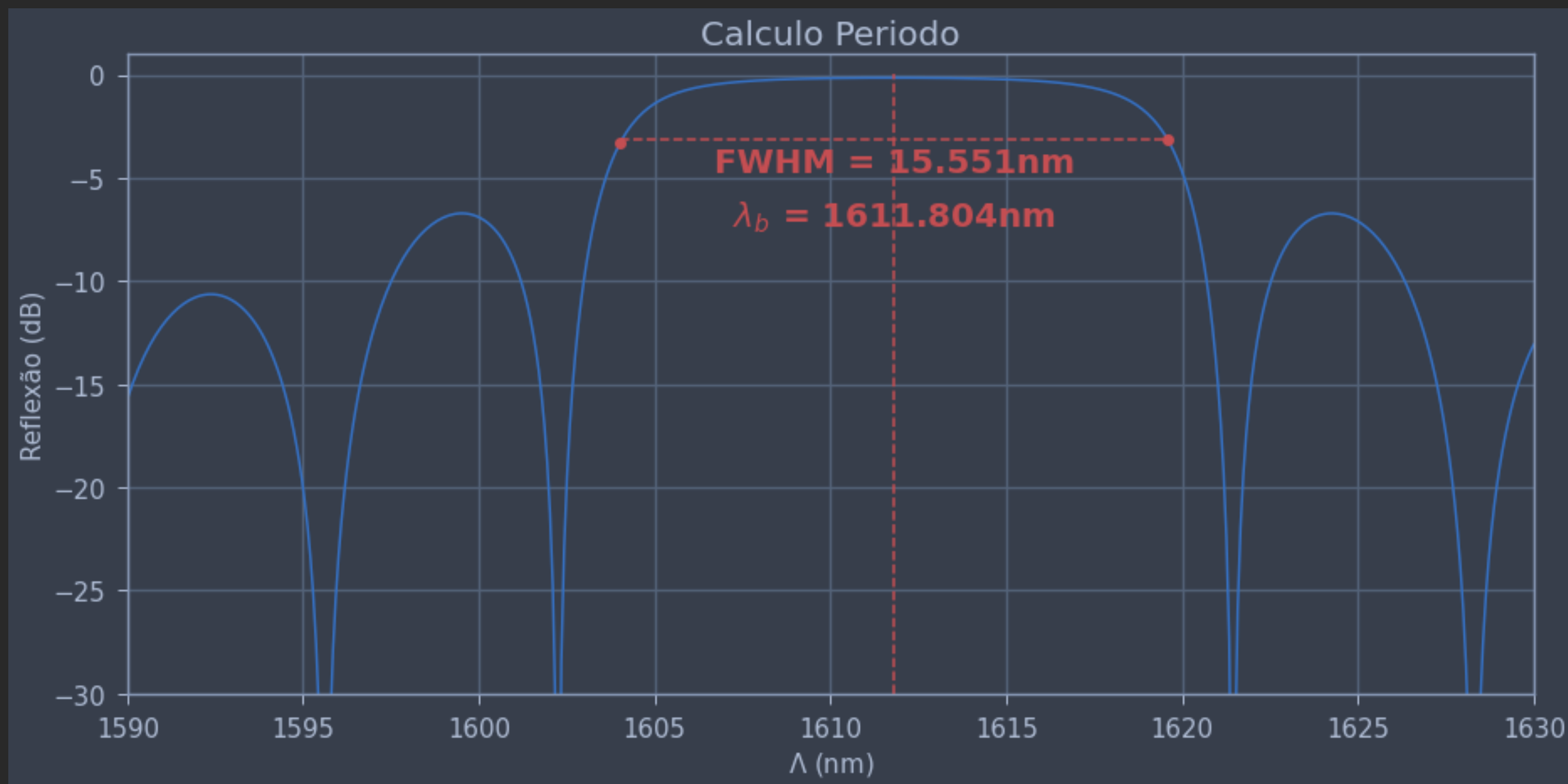
$$P = 0.3534426 \text{ nm (x1.05)}$$



DESIGN

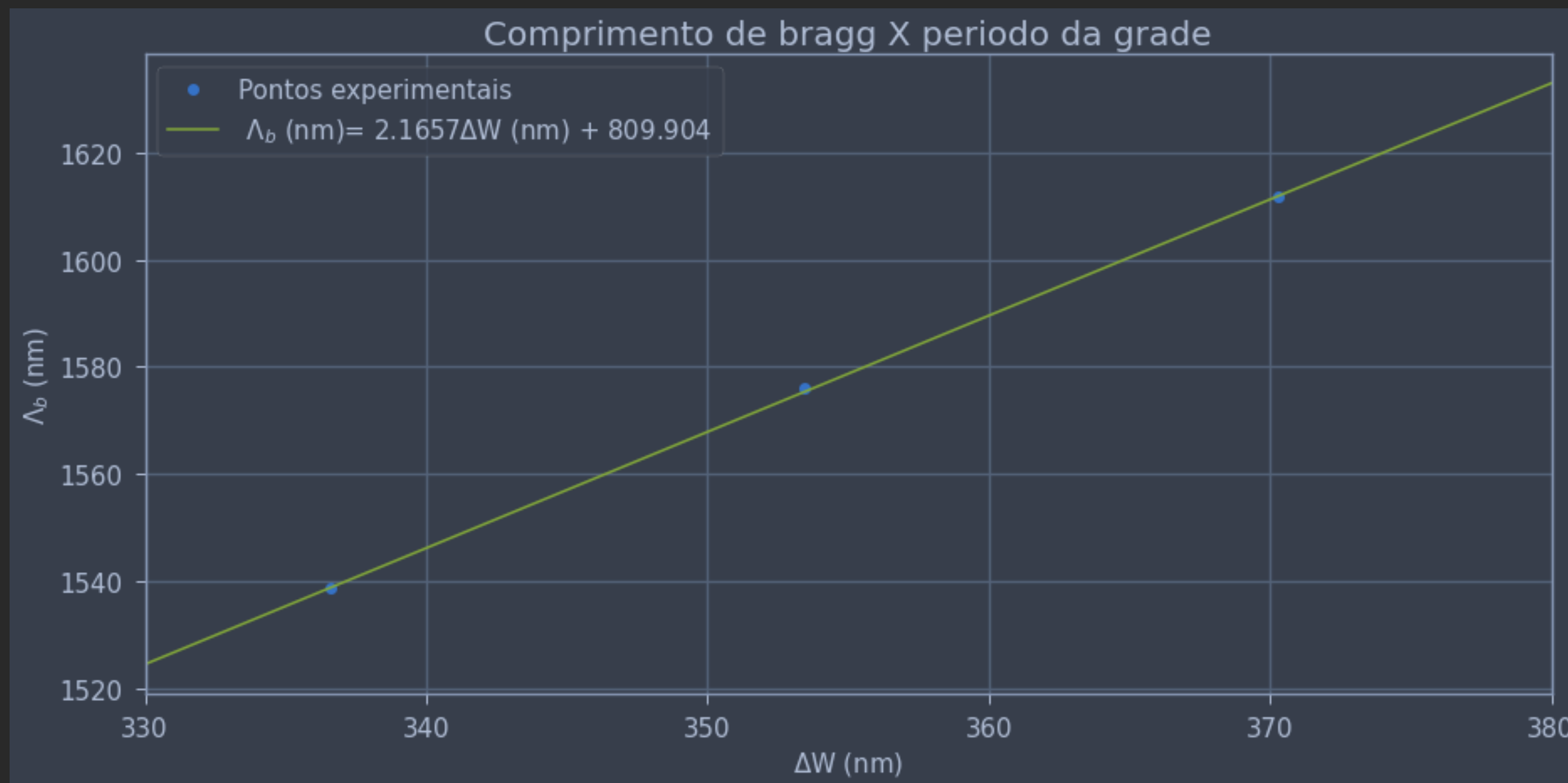
Calculando novo periodo ideal

$$P = 0.3702732 \text{ nm (x1.1)}$$



DESIGN

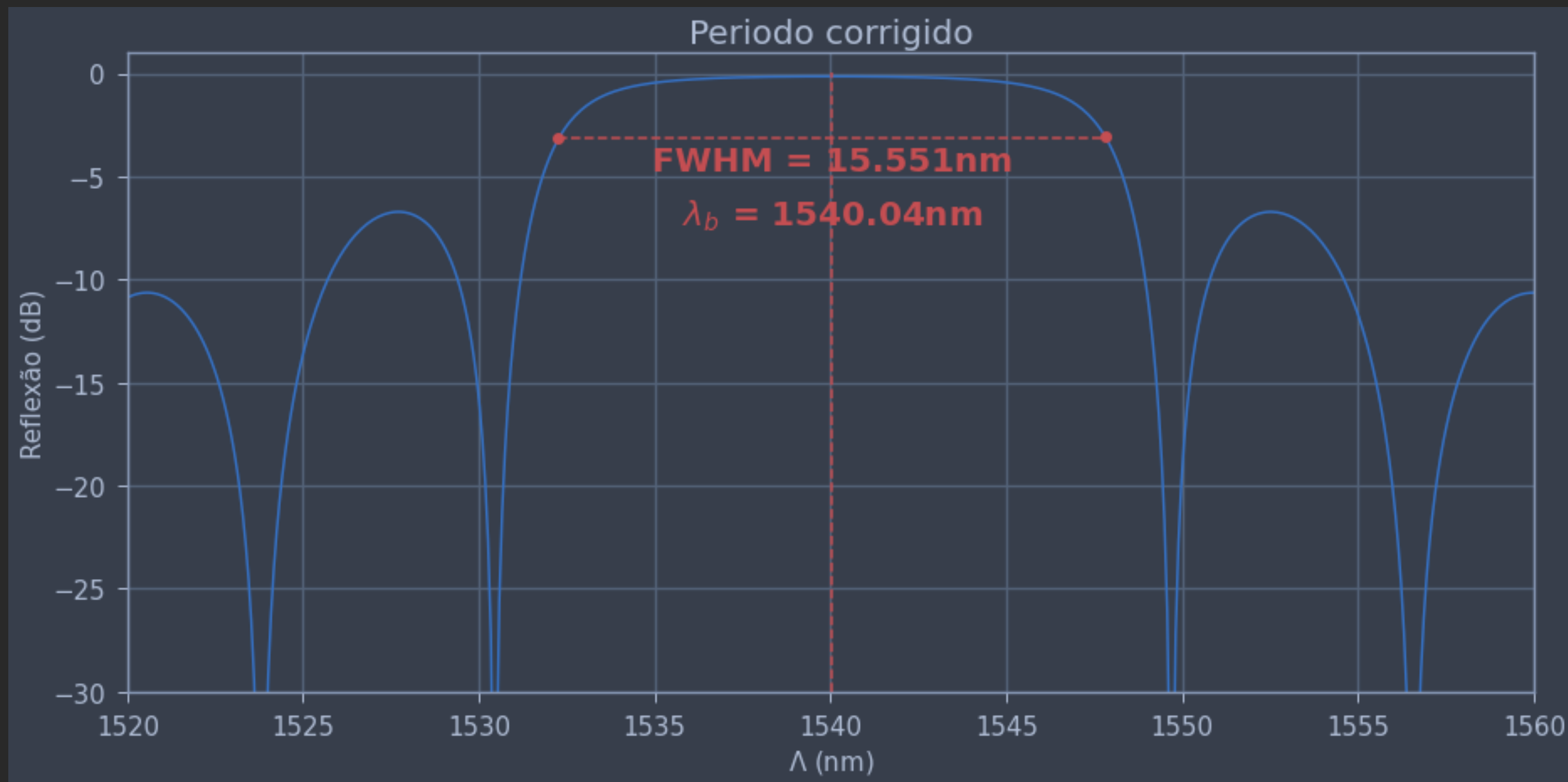
Calculando novo periodo ideal



DESIGN

Novo periodo teorico

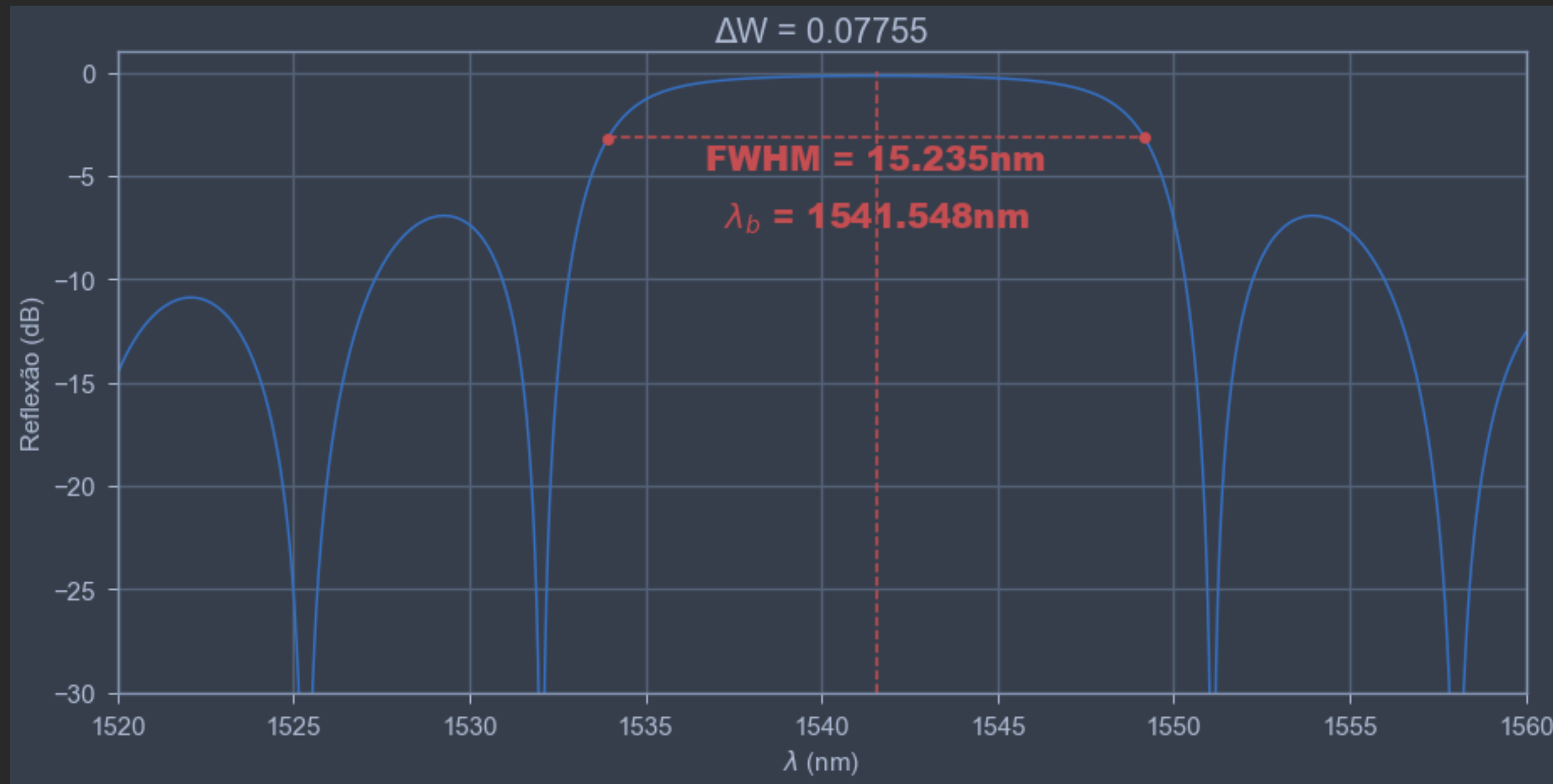
$$P = 0.337118 \text{ } \mu\text{m} \text{ (E = 0.15\%)}$$



DESIGN

Corrigindo o FWHM, calculo de ΔW

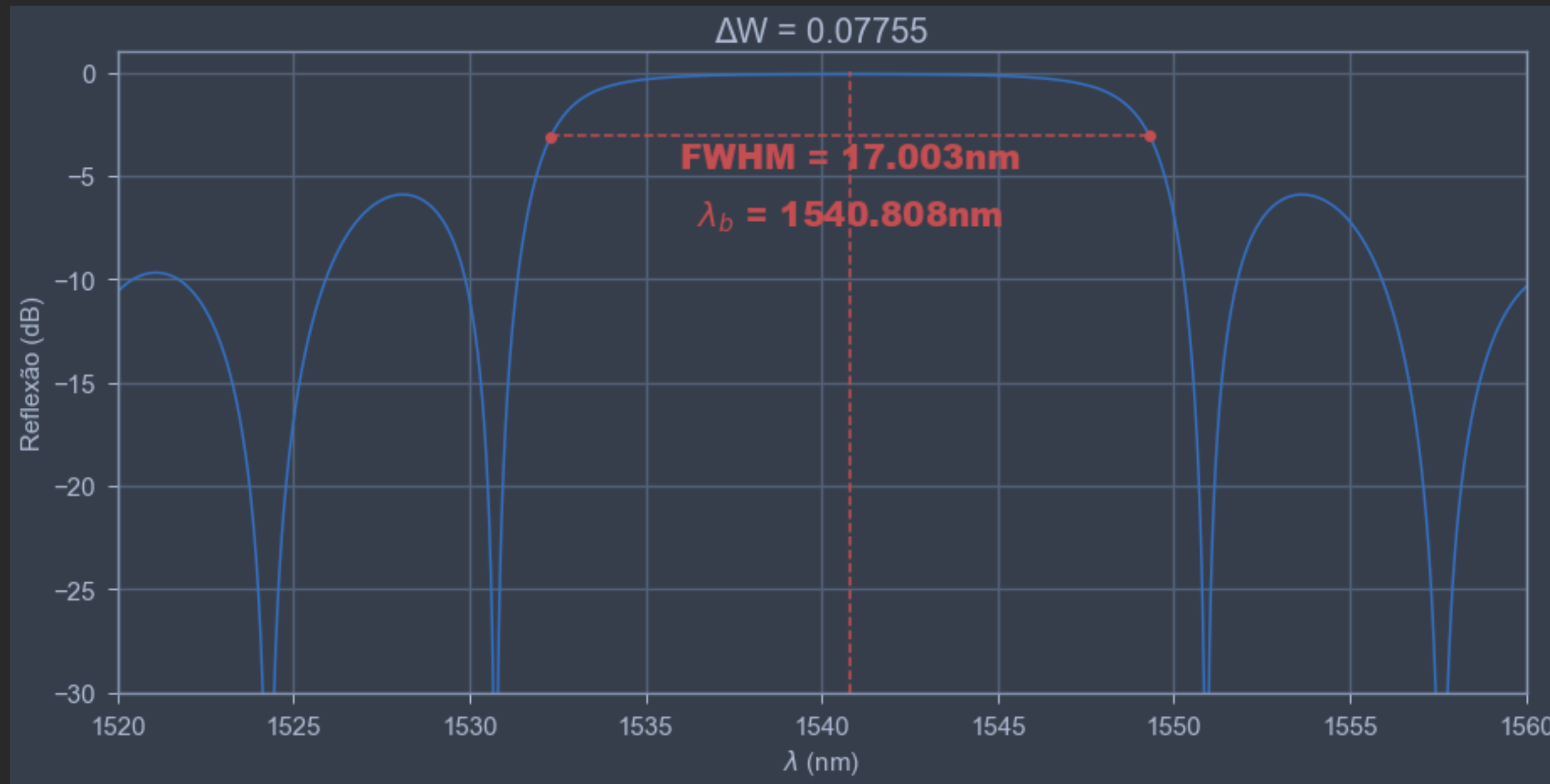
$$\Delta W = 0.03894 \text{ (x1.1)}$$



DESIGN

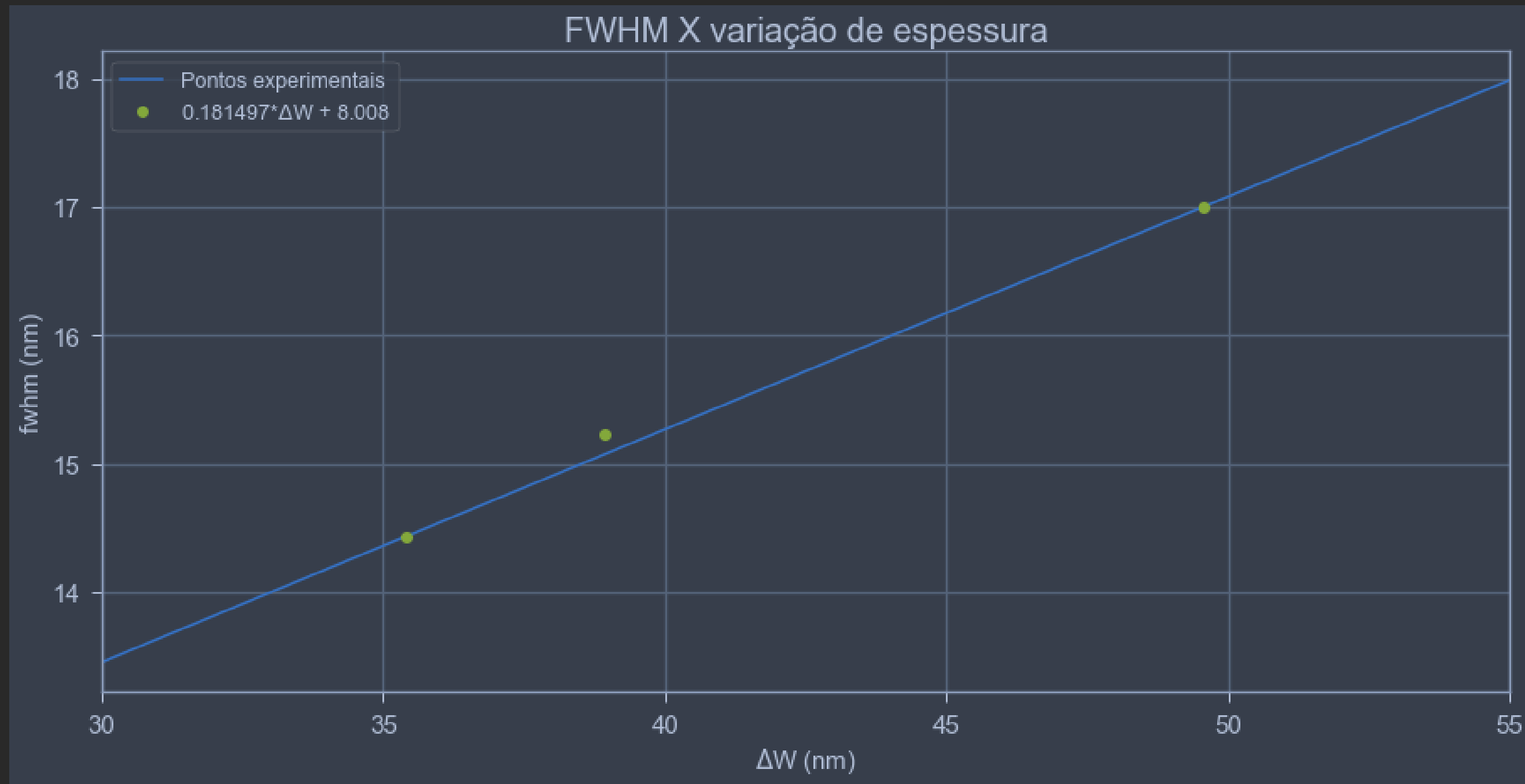
Corrigindo o FWHM, calculo de ΔW

$$\Delta W = 0.04956 \text{ (x1.5)}$$



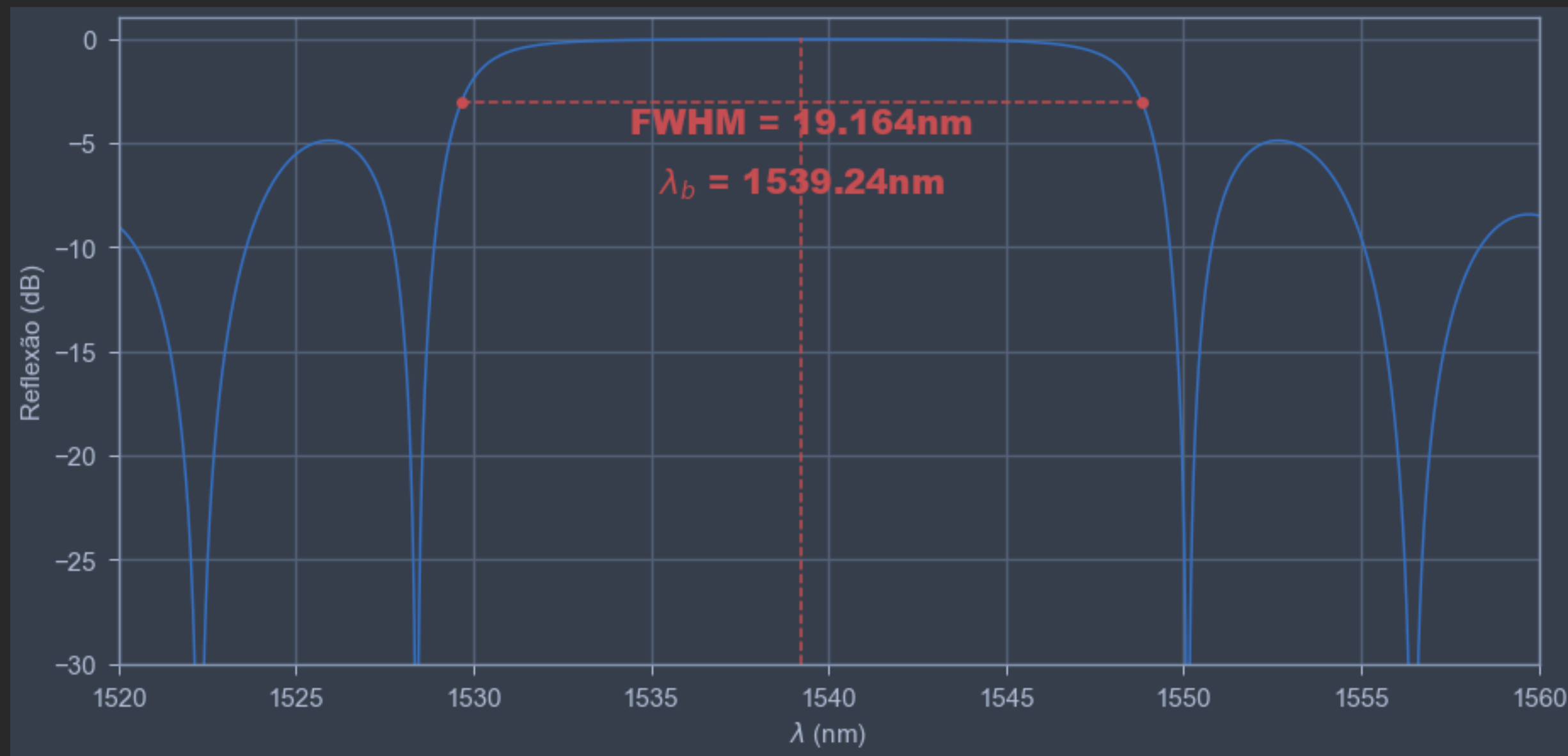
DESIGN

Corrigindo o FWHM, calculo de ΔW
 ΔW teorico = 0.0660727 μm (E = 87.6%)



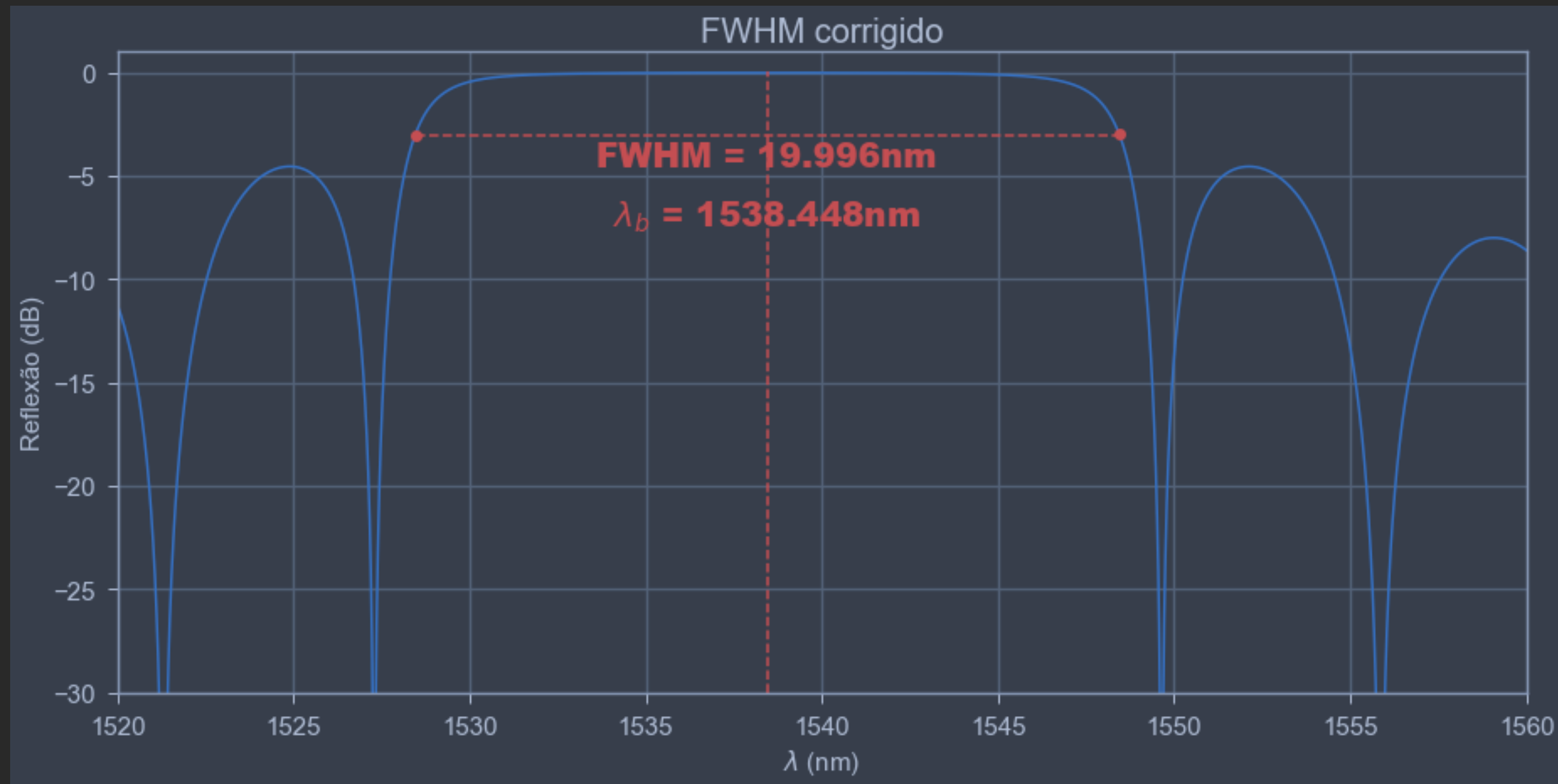
DESIGN

Correção do FWHMW



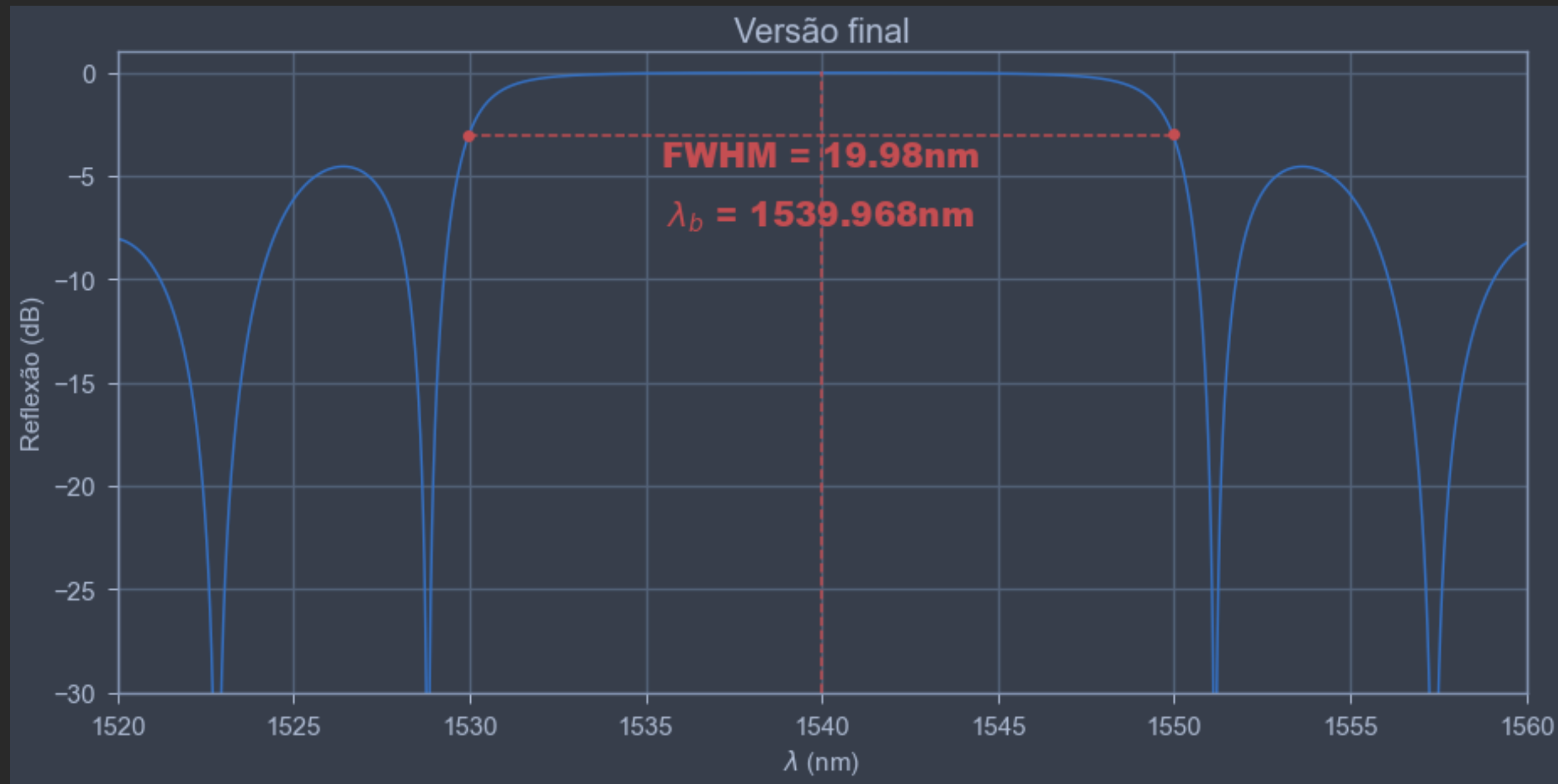
DESIGN

Correção do FWHMW



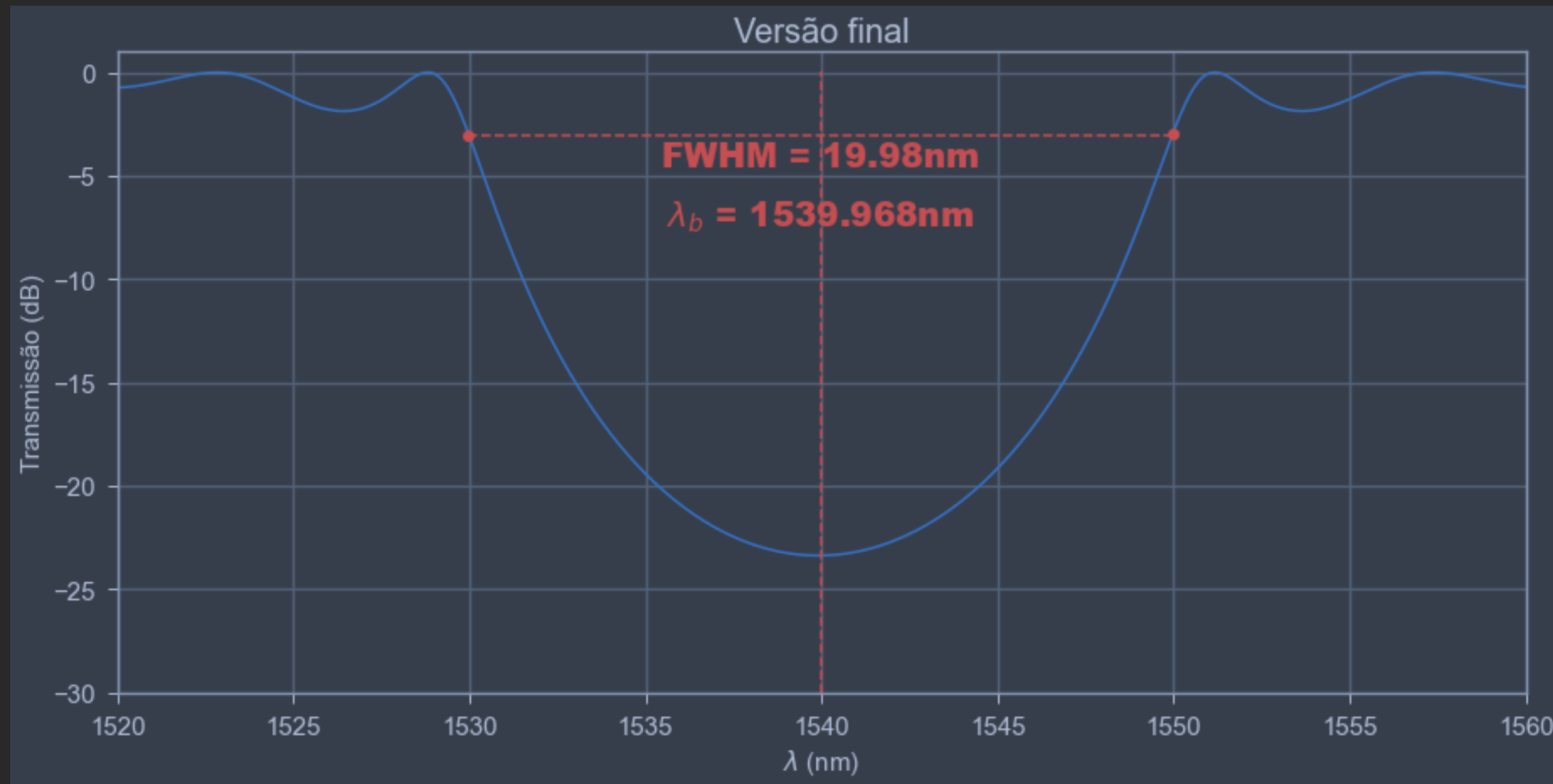
DESIGN

2º correção do periodo










DESIGN

2º correção do periodo



DESIGN

Design Final

1	 W	Length	0,45	um
2	 altura	Length	0,22	um
3	 deltaW	Length	0,0734068	um
4	 periodo	Length	0,338535	um
5	 N	Number	100	
6	 material	Material	Si (Silicon) - Palik	
7	 substrato	Material	SiO2 (Glass) - P...	

DESIGN

Analise variação de temperatura

Ref: Handbook of Thermo-optic Coefficients of Optical Materials With Applications

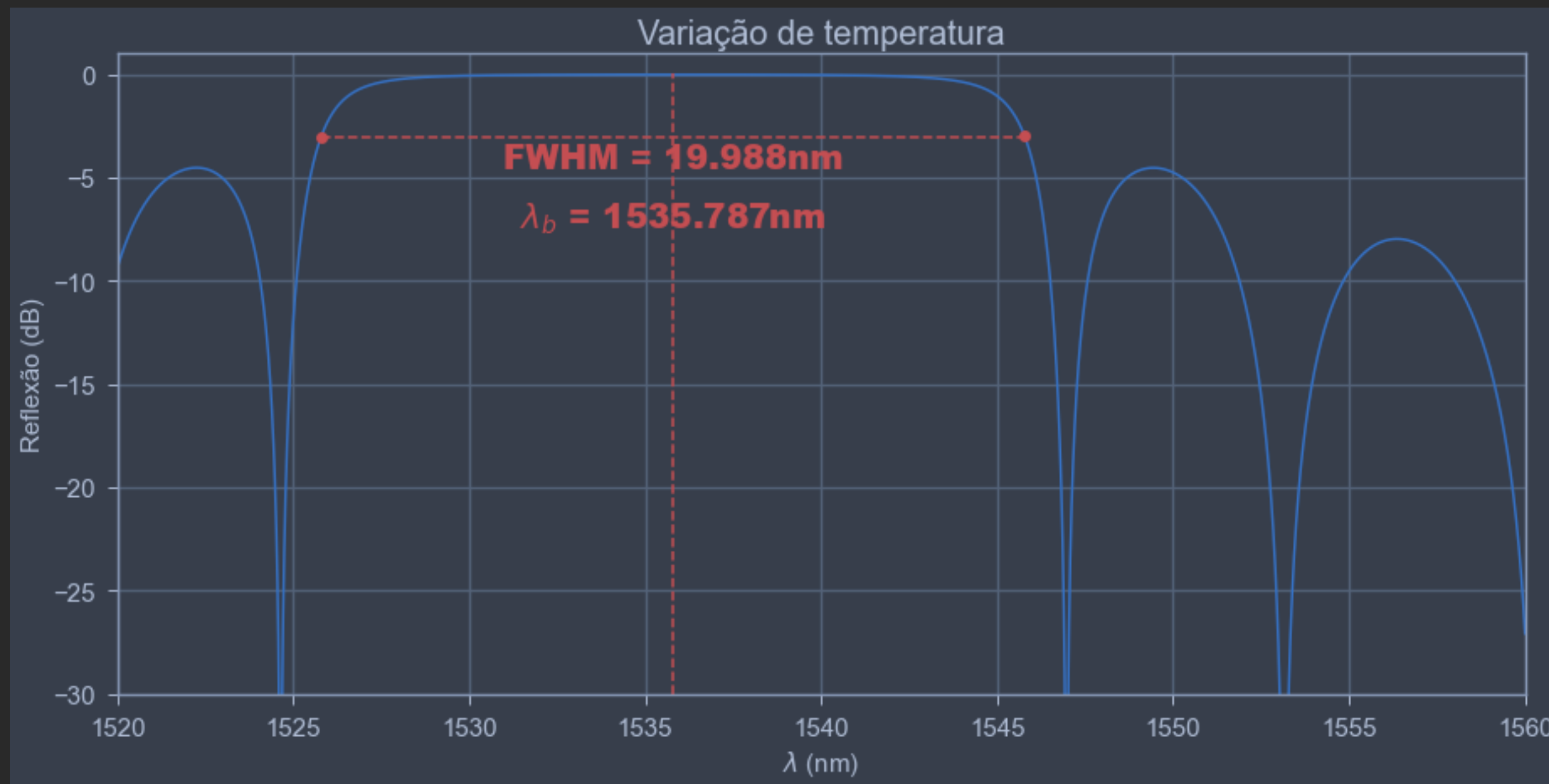
Material [Ref.]	Wavelength [μm]	Refractive index	$\frac{dn}{dT}$ [$10^{-4}/\text{K}$]		Differ- ence	Av. Dev. <-[10^{-6}]->	RMS Dev.
			Recom. values	Computed (This work)			
Si at 20°C [144]	16.00	3.9999	4.016	4.036	-0.0202	0.71	0.80
	17.00	3.9997	4.015	4.035	-0.0198		
	18.00	3.9996	4.013	4.034	-0.0206		
	1.20	3.5167	1.983	2.000	-0.0168		
	1.22	3.5133	1.970	1.983	-0.0131		
	1.24	3.5102	1.957	1.967	-0.0103		
	1.26	3.5072	1.945	1.953	-0.0075		
	1.30	3.5016	1.923	1.925	-0.0024		
	1.32	3.4990	1.912	1.913	-0.0009		
	1.34	3.4965	1.902	1.901	0.0009		
	1.36	3.4941	1.892	1.890	0.0020		
	1.38	3.4918	1.883	1.879	0.0036		
	1.40	3.4896	1.874	1.869	0.0046		
	1.50	3.4799	1.835	1.826	0.0089		
	1.55	3.4757	1.818	1.808	0.0099		
	1.65	3.4684	1.789	1.777	0.0116		
	1.70	3.4653	1.776	1.764	0.0117		
	1.90	3.4550	1.734	1.723	0.0110		
	2.00	3.4510	1.717	1.707	0.0098		
	2.25	3.4431	1.685	1.677	0.0077		
	2.50	3.4375	1.662	1.656	0.0056		
	2.75	3.4334	1.645	1.641	0.0038		
	3.00	3.4302	1.632	1.630	0.0022		
	4.00	3.4229	1.602	1.604	-0.0020		
	5.00	3.4195	1.588	1.592	-0.0043		
	6.00	3.4177	1.581	1.586	-0.0050		
	7.00	3.4165	1.576	1.582	-0.0063		
	8.00	3.4158	1.573	1.580	-0.0068		
	9.00	3.4153	1.571	1.578	-0.0071		
	10.00	3.4150	1.570	1.577	-0.0069		
	11.00	3.4147	1.569	1.576	-0.0070		
	12.00	3.4145	1.568	1.575	-0.0074		
	13.00	3.4144	1.567	1.575	-0.0078		
	14.00	3.4142	1.567	1.574	-0.0075		

T base = 293.1

DESIGN

Análise variação de temperatura

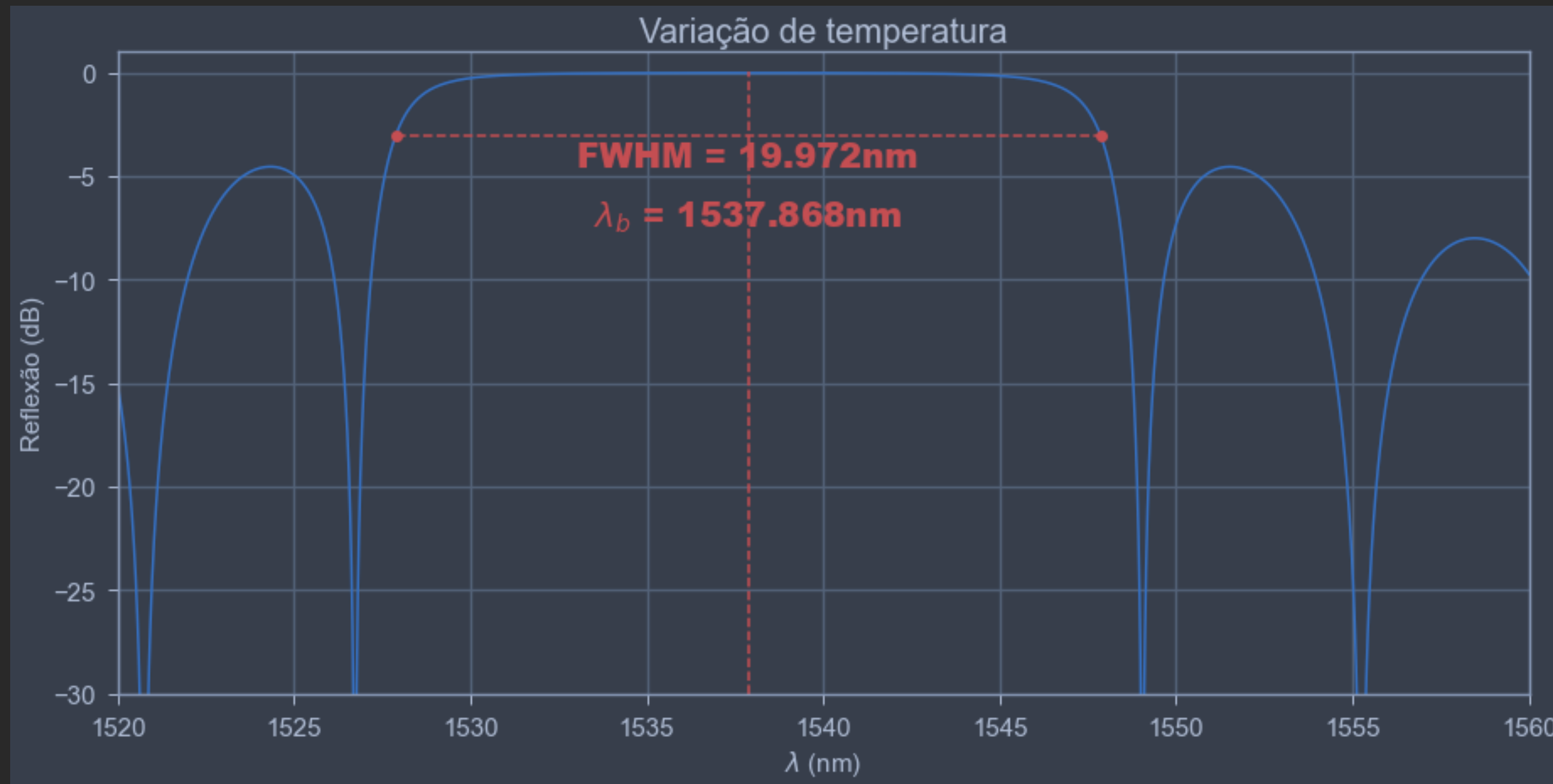
$$T = 234.5 \text{ (x 0.8)}$$



DESIGN

Análise variação de temperatura

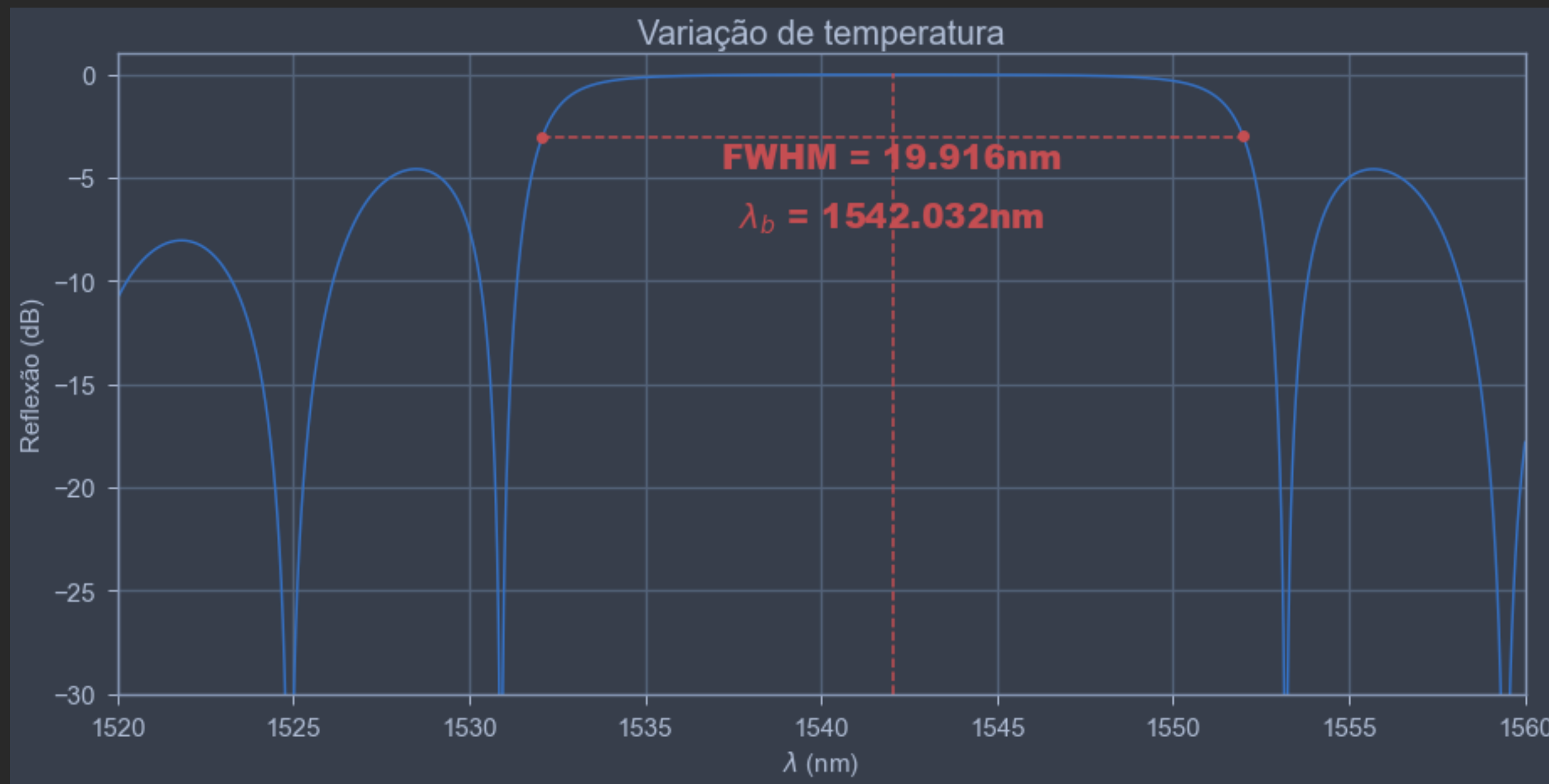
$$T = 263.8 \text{ (x 0.9)}$$



DESIGN

Análise variação de temperatura

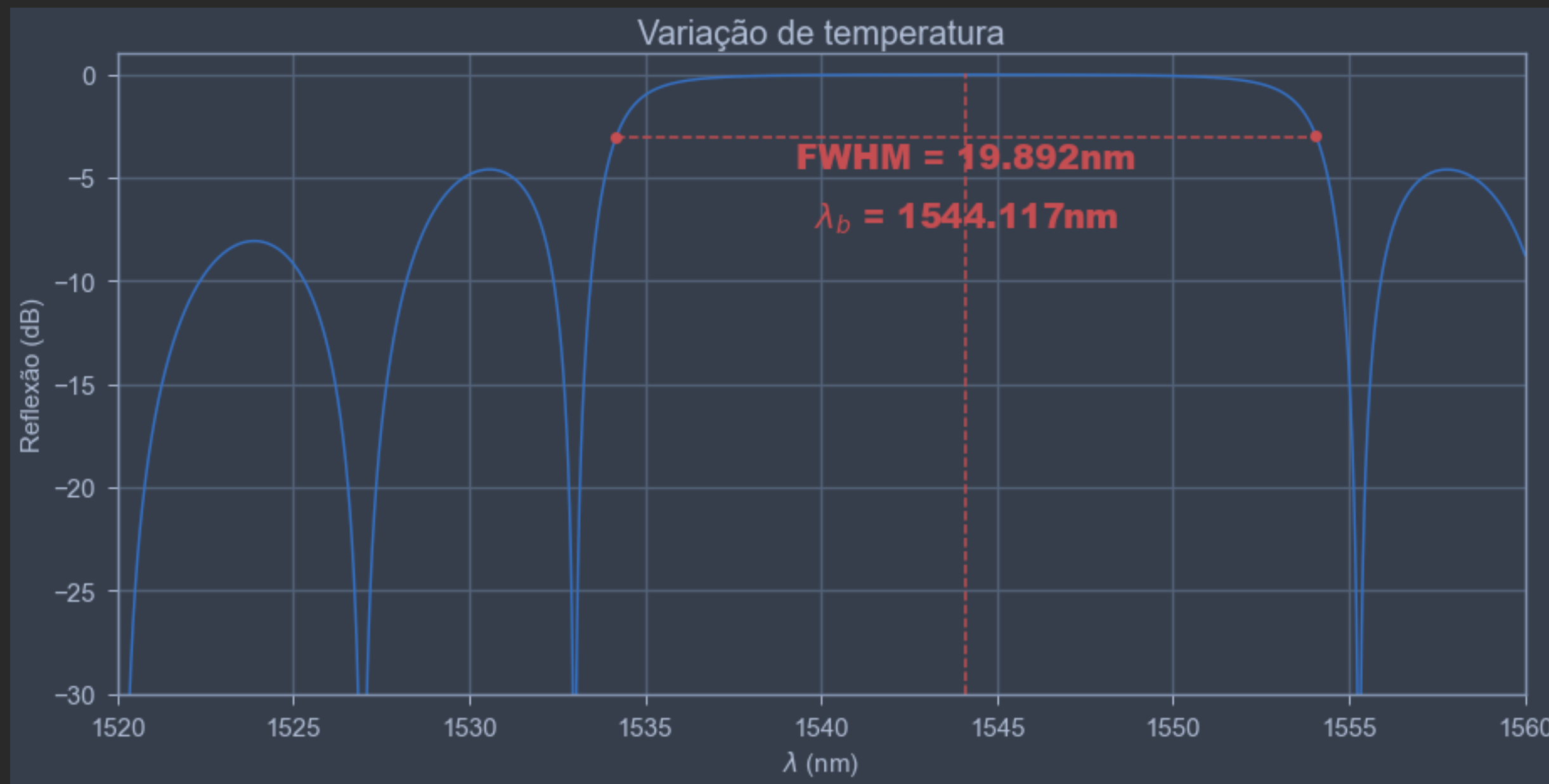
$$T = 322.4 \text{ (x 1.1)}$$



DESIGN

Análise variação de temperatura

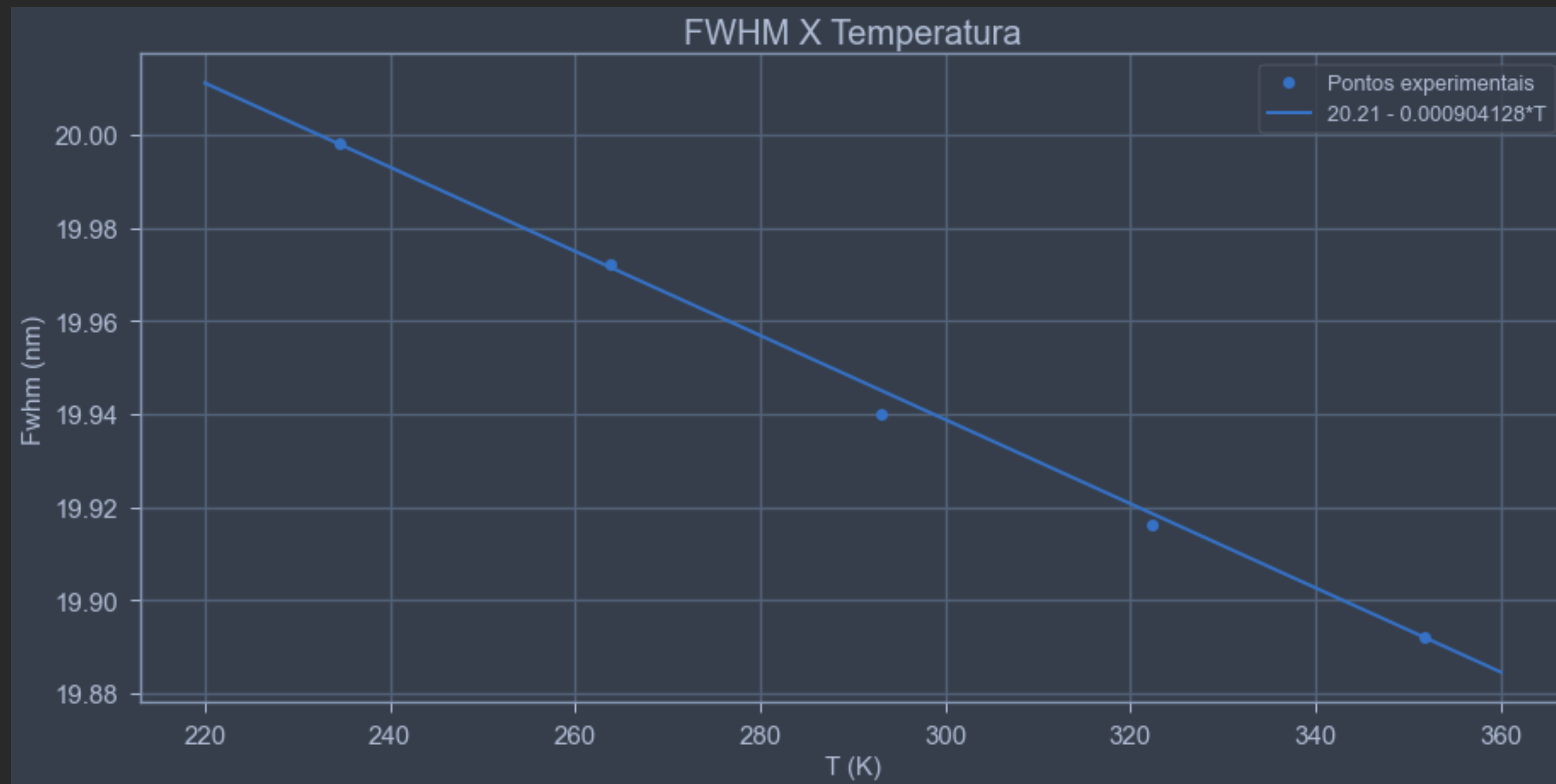
$$T = 351.72 \text{ (x 1.2)}$$



DESIGN

Analise variação de temperatura

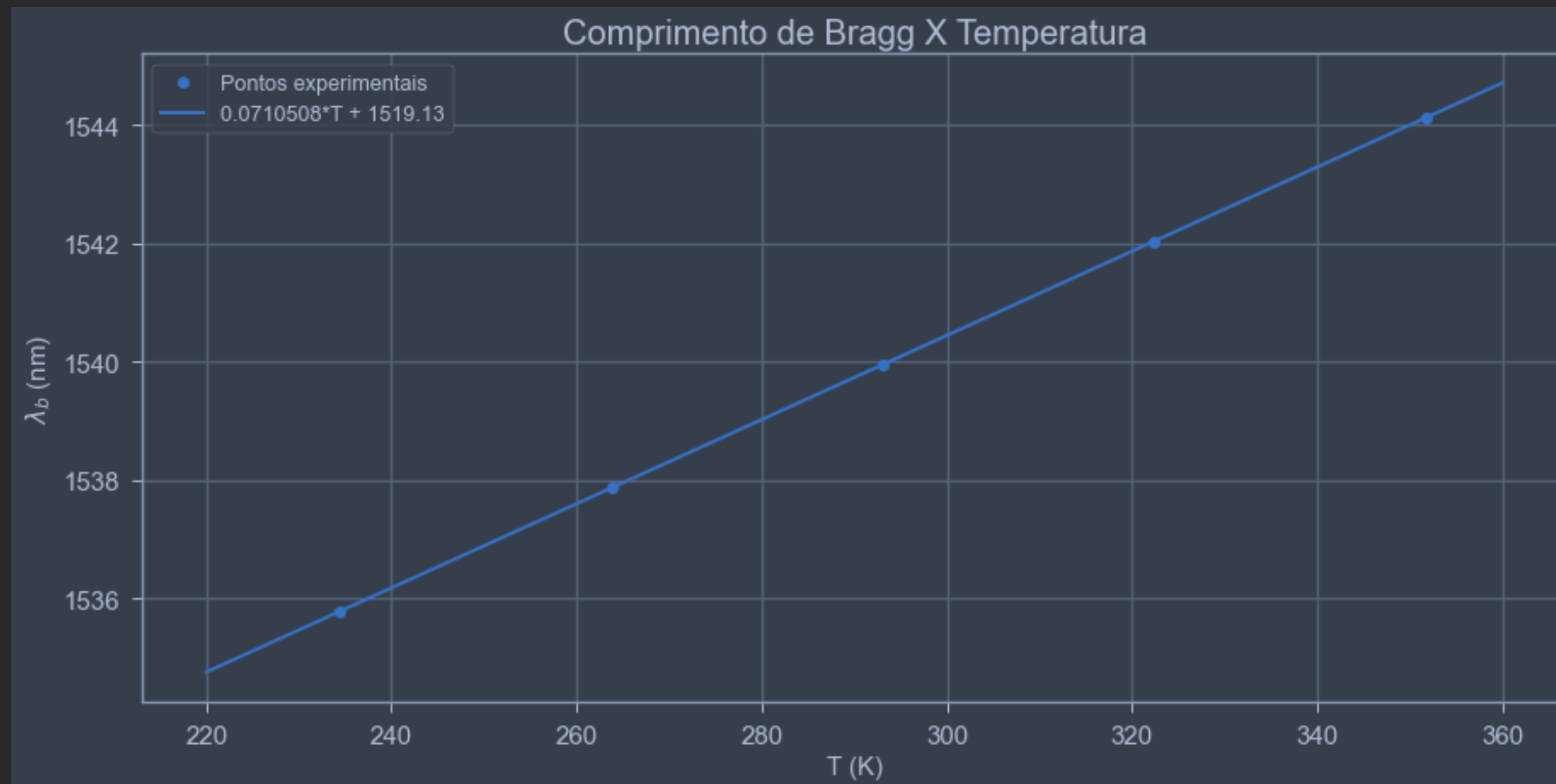
Fwhm



DESIGN

Análise variação de temperatura

Banda central

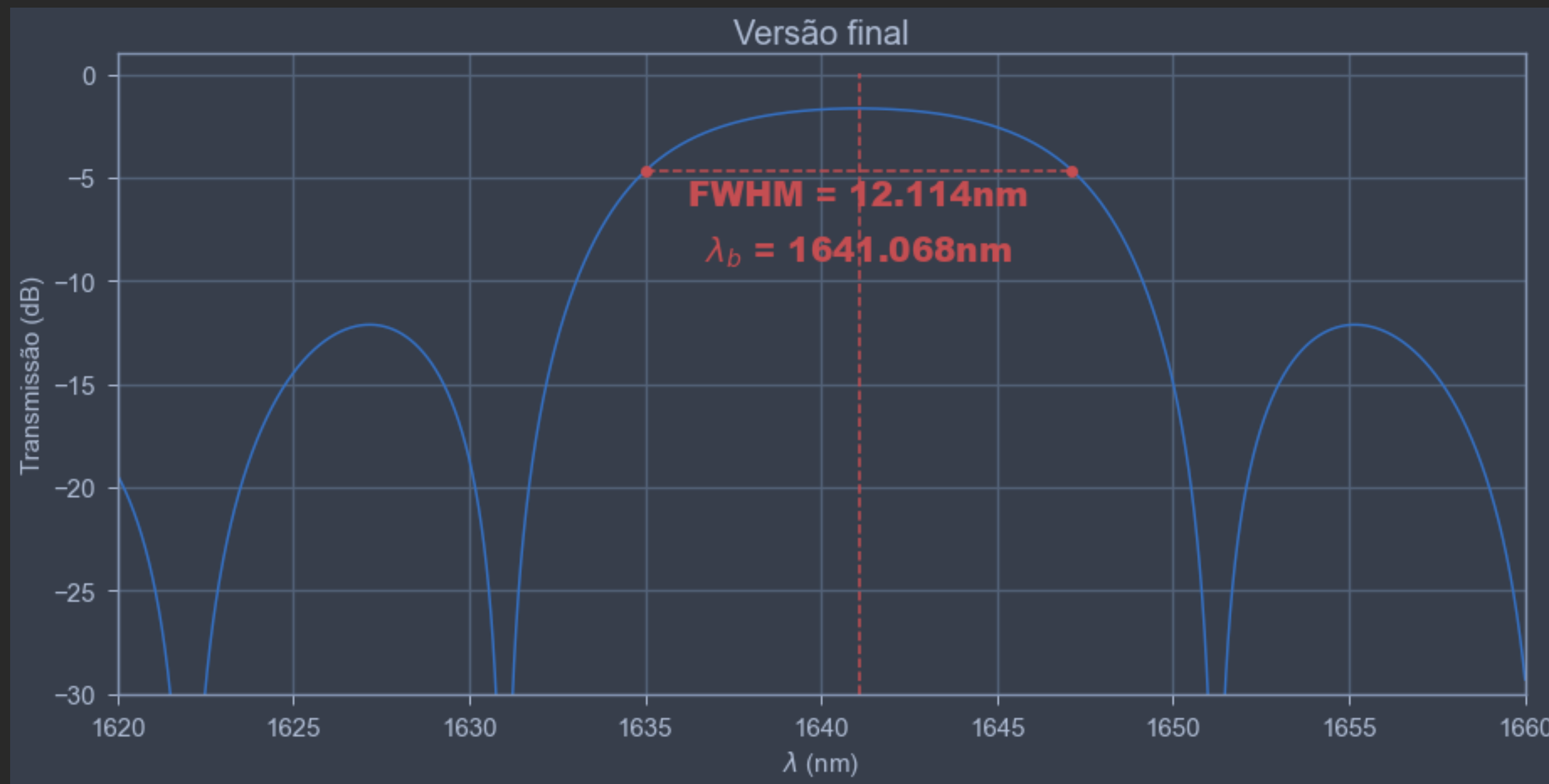


DESIGN

ALTERANDO O GUIA PARA 600 NM

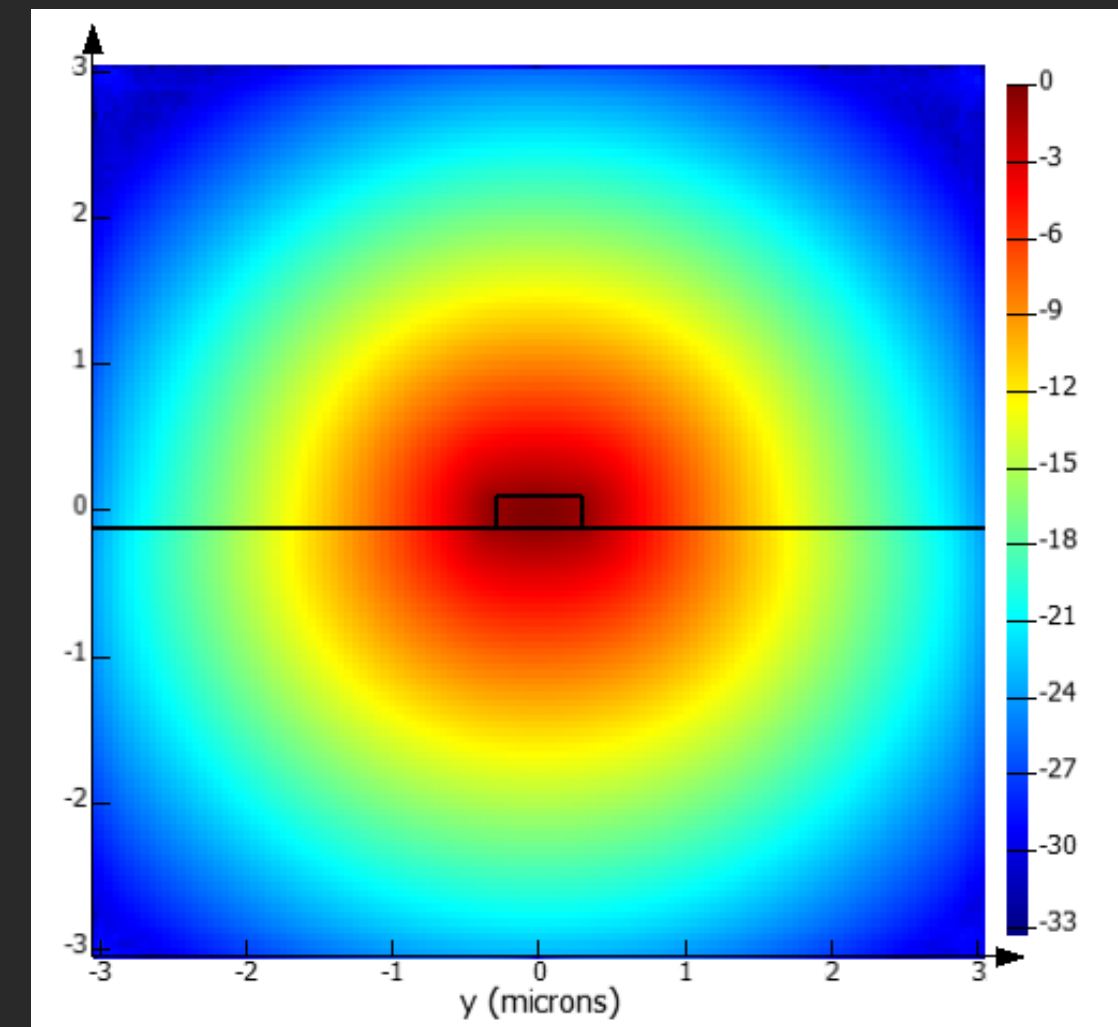
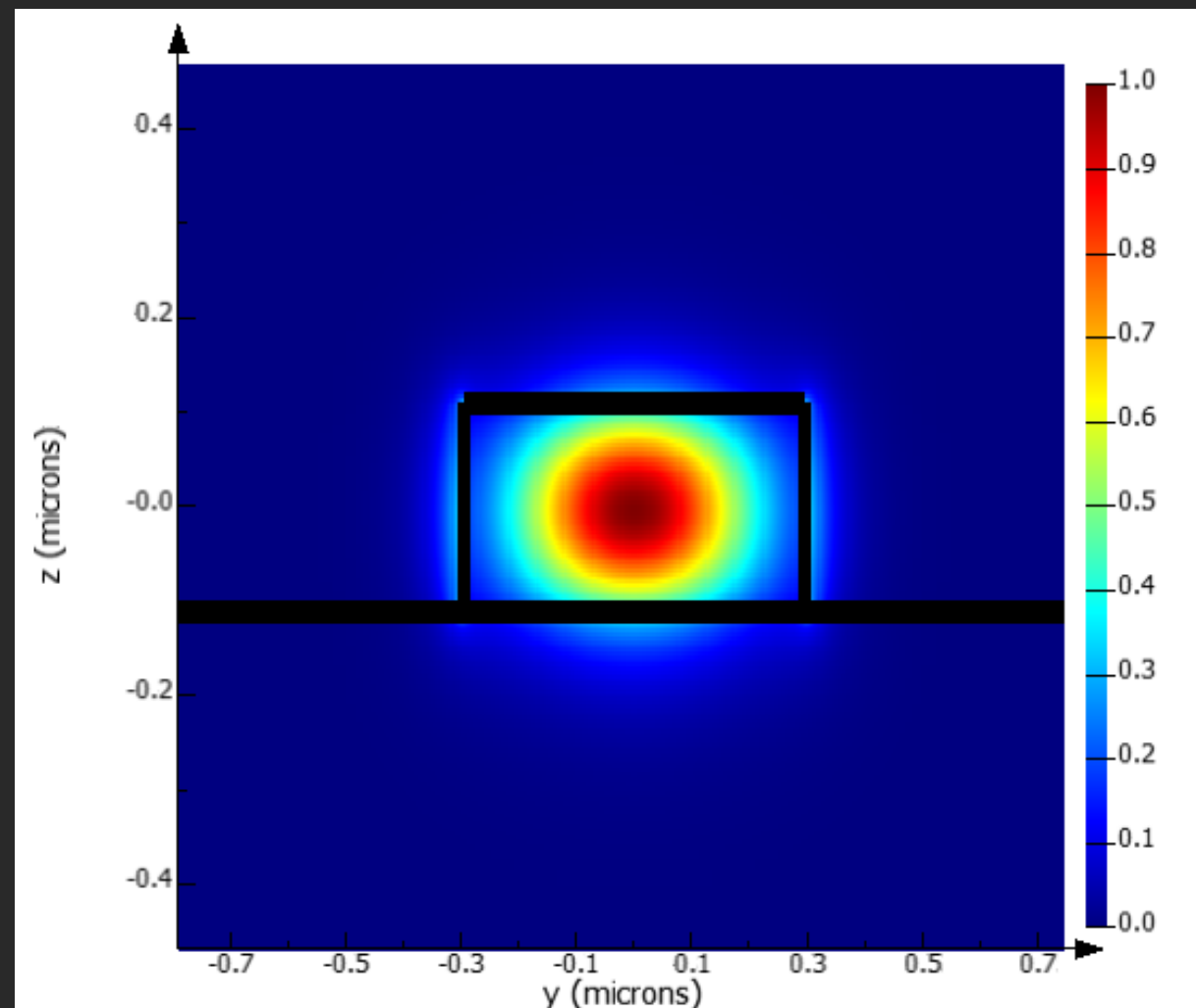
DESIGN

Alterando o guia para 600 nm



DESIGN

Simulação do guia



mode #	effective index	wavelength (μm)	loss (dB/cm)	group index	TE polarization fraction (Ey)	waveguide TE/TM fraction (%)
1	2.537329+8.301567e-17i	1.54	2.9419e-11	4.198189+3.531844e-17i	99	80.25 / 81.12
2	1.667813+5.340745e-11i	1.54	1.8927e-05	3.920935-4.571173e-09i	12	67.94 / 90.11

DESIGN

Parametros:

Para $n_{eff} = 2.5373$

Periodo da grade = 303.468 nm

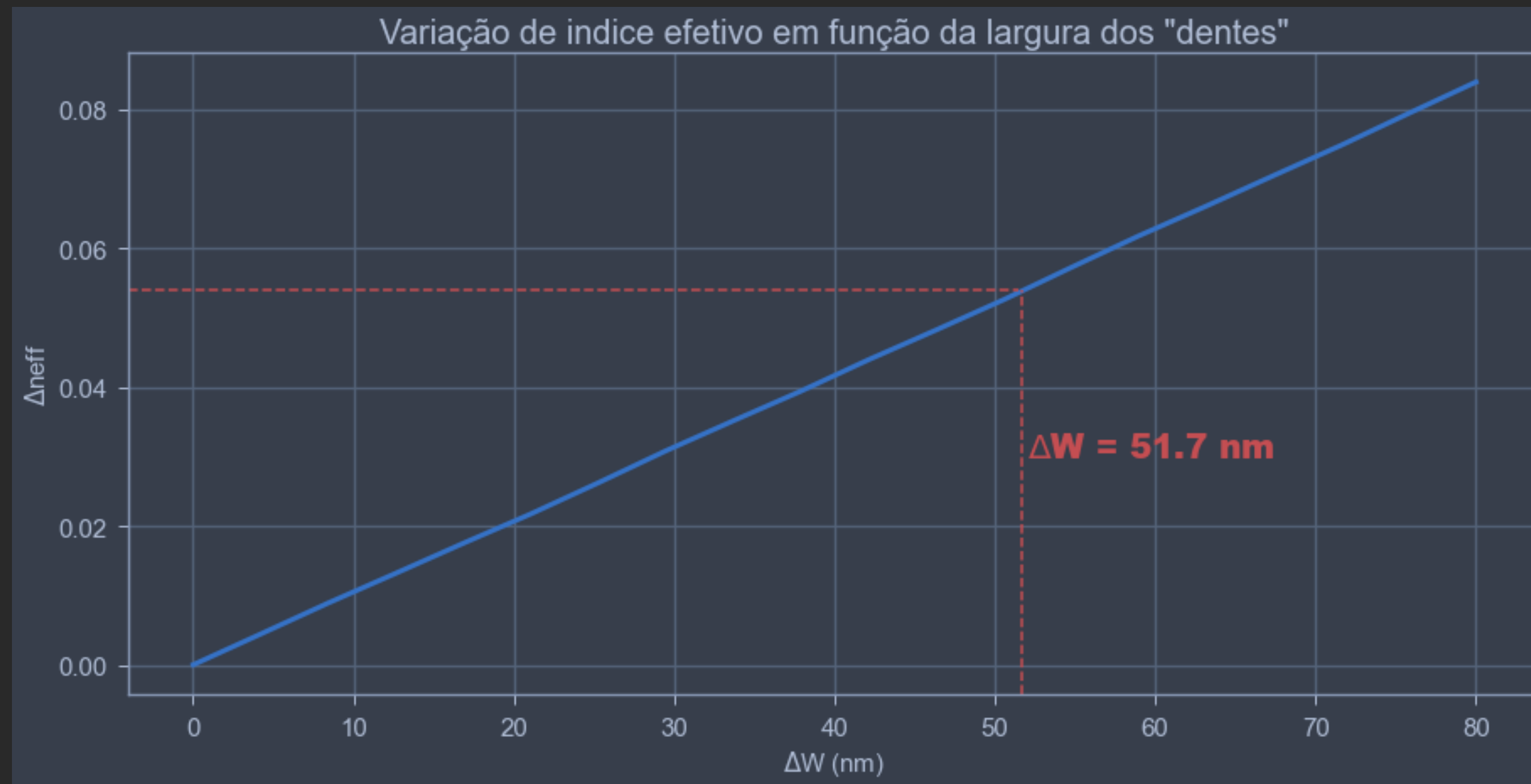
Para Numero de periodos = 250: $L = 75.867 \text{ um}$

Para $L = 36.416 \text{ um}$, $\Delta n_{eff} = 0.05405$

$R_{max} = 0.988$

DESIGN

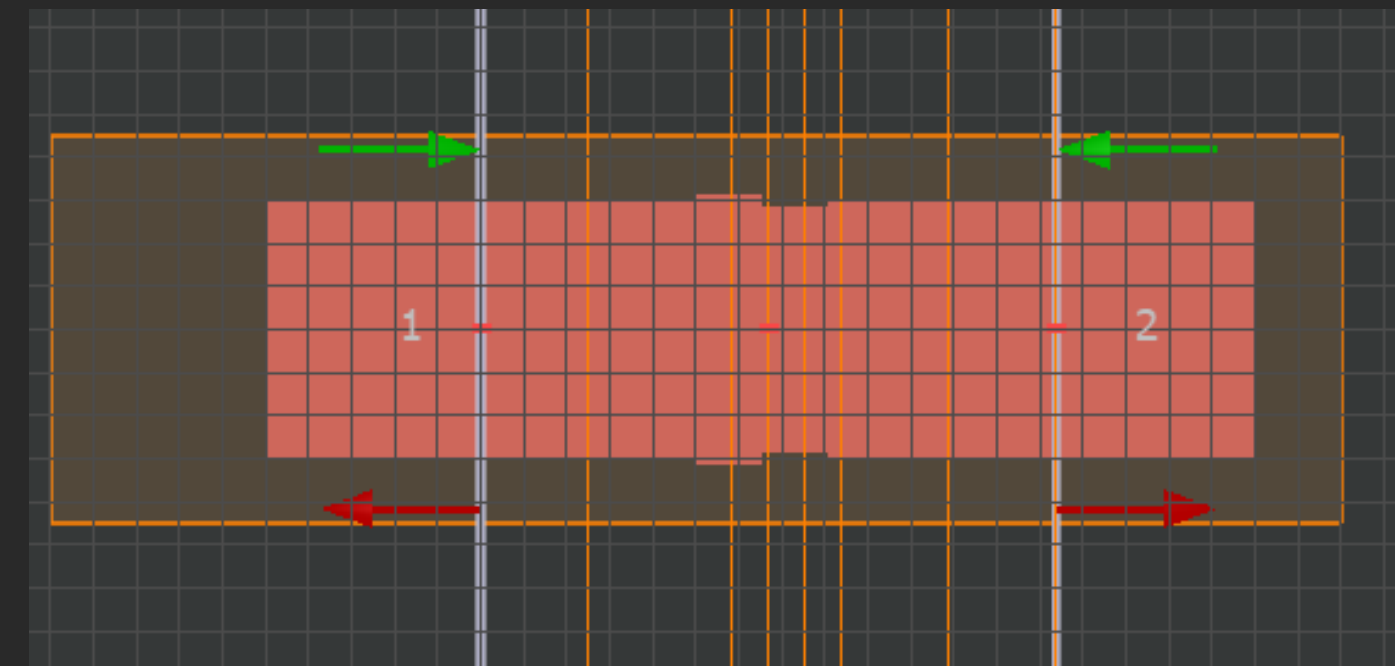
Calculo do Delta W



DESIGN

Simulação no EME

1	[l] W	Length	0,6	um
2	[l] altura	Length	0,22	um
3	[l] deltaW	Length	0,0517	um
4	[l] periodo	Length	0,303469	um
5	[icon] material	Material	Si (Silicon) - Palik	
6	[icon] substrato	Material	SiO2 (Glass) - P...	
7	[icon] N	Number	120	



DESIGN

Simulação no EME

General EME setup Transverse mesh settings Boundary conditions Material Advanced options

cell geometry

x min (μm) number of cell groups

energy conservation number of modes for all cell groups

☐ allow custom eigensolver settings

cell group definition

	group spans (μm)	cells	subcell method	modes	custom	cell range
1	0.5	2	CVCS	20	default	[1,2]
2	0.151734	2	CVCS	20	default	[3,4]
3	0.151734	2	CVCS	20	default	[5,6]
4	0.5	2	CVCS	20	default	[7,8]

< >

☒ display cells

y (μm) y min (μm)

y span (μm) y max (μm)

z (μm) z min (μm)

z span (μm) z max (μm)

periodicity

number of periodic groups

periodic group definition

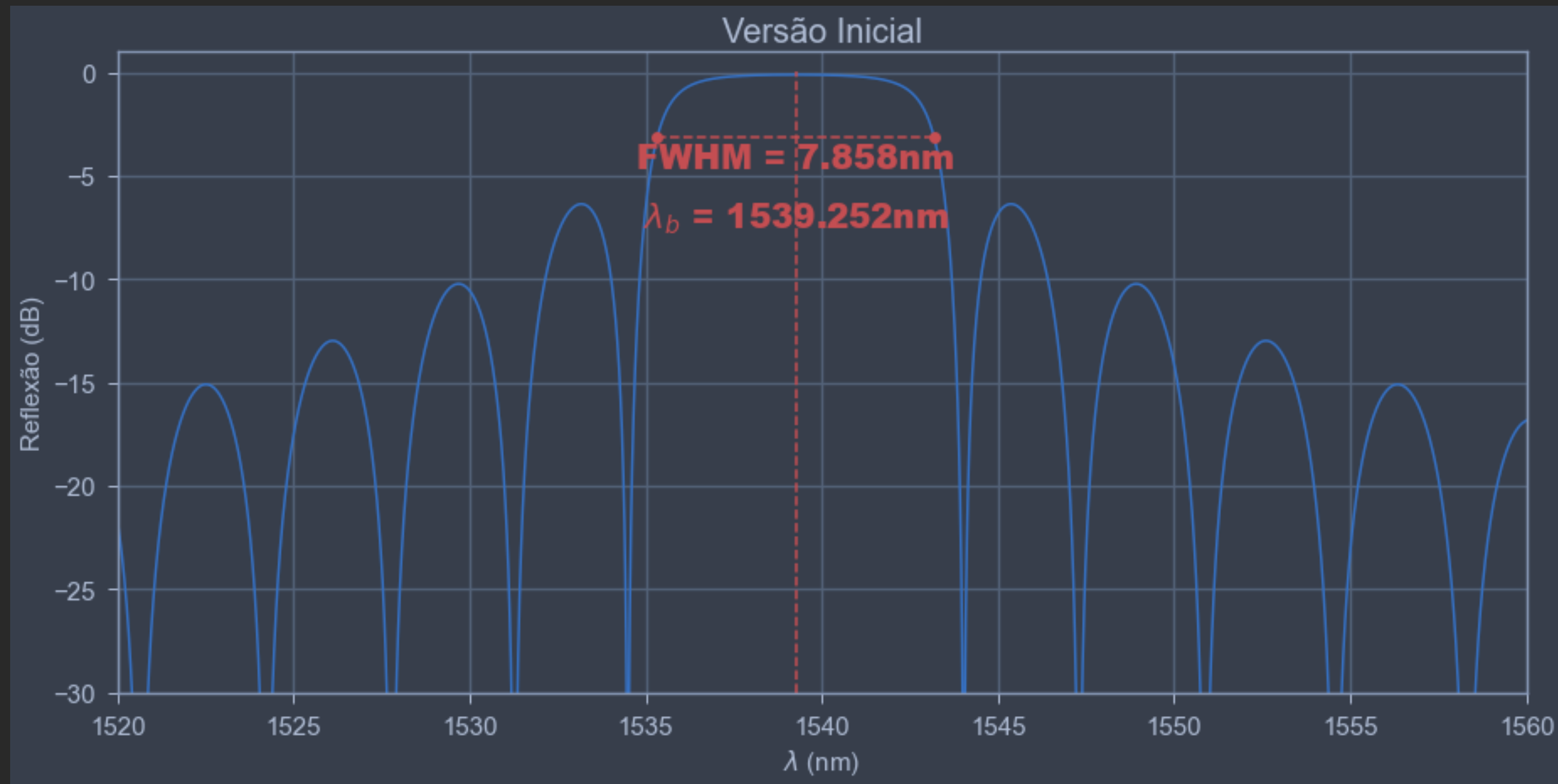
	start cell group	end cell group	periods
1	1	1	1
2	2	3	120
3	4	4	1

cell group sequence

$[(1)^1, (2,3)^{120}, (4)^1]$

DESIGN

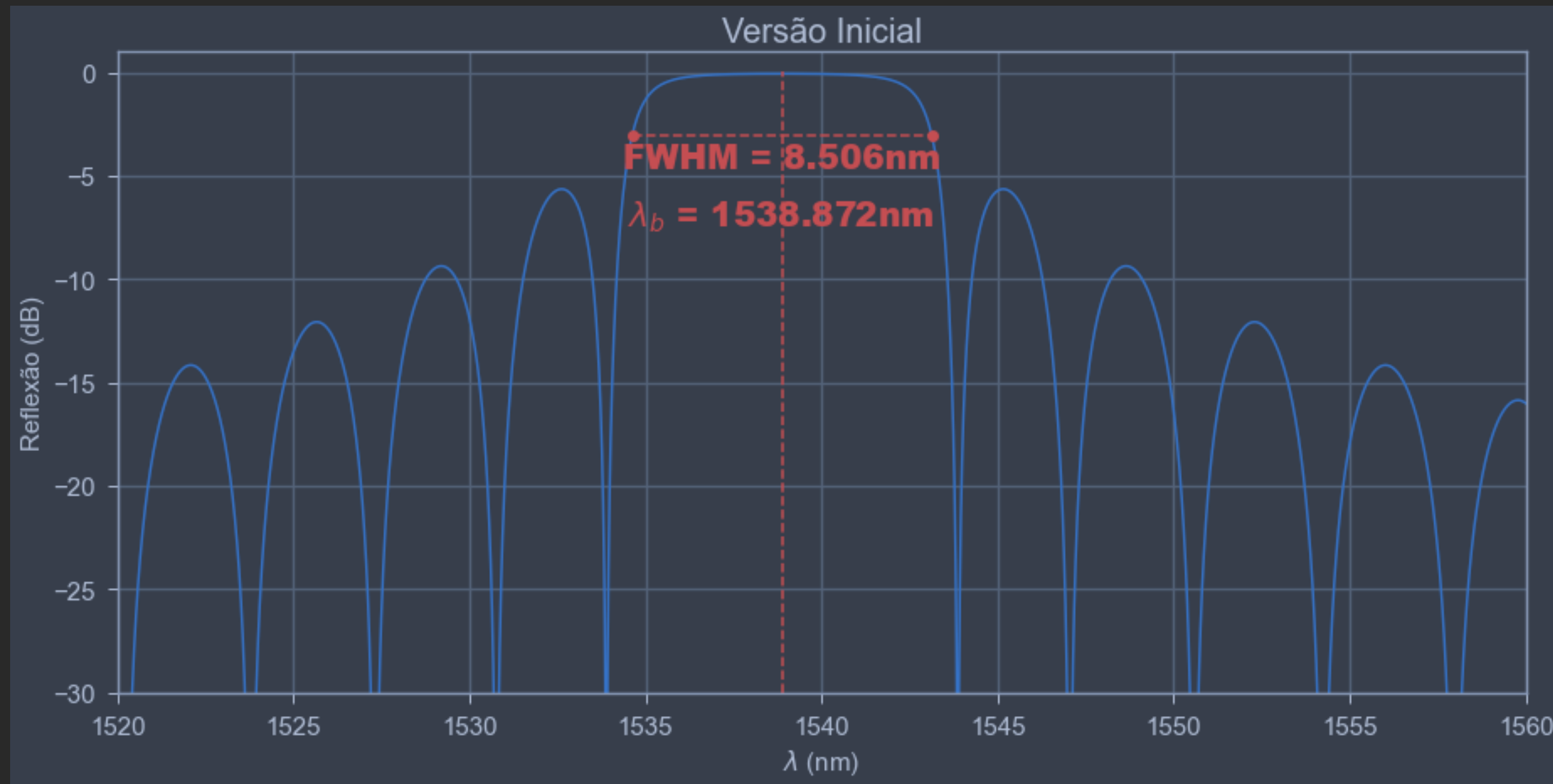
Resultados Iniciais



DESIGN

Correção do FWHM

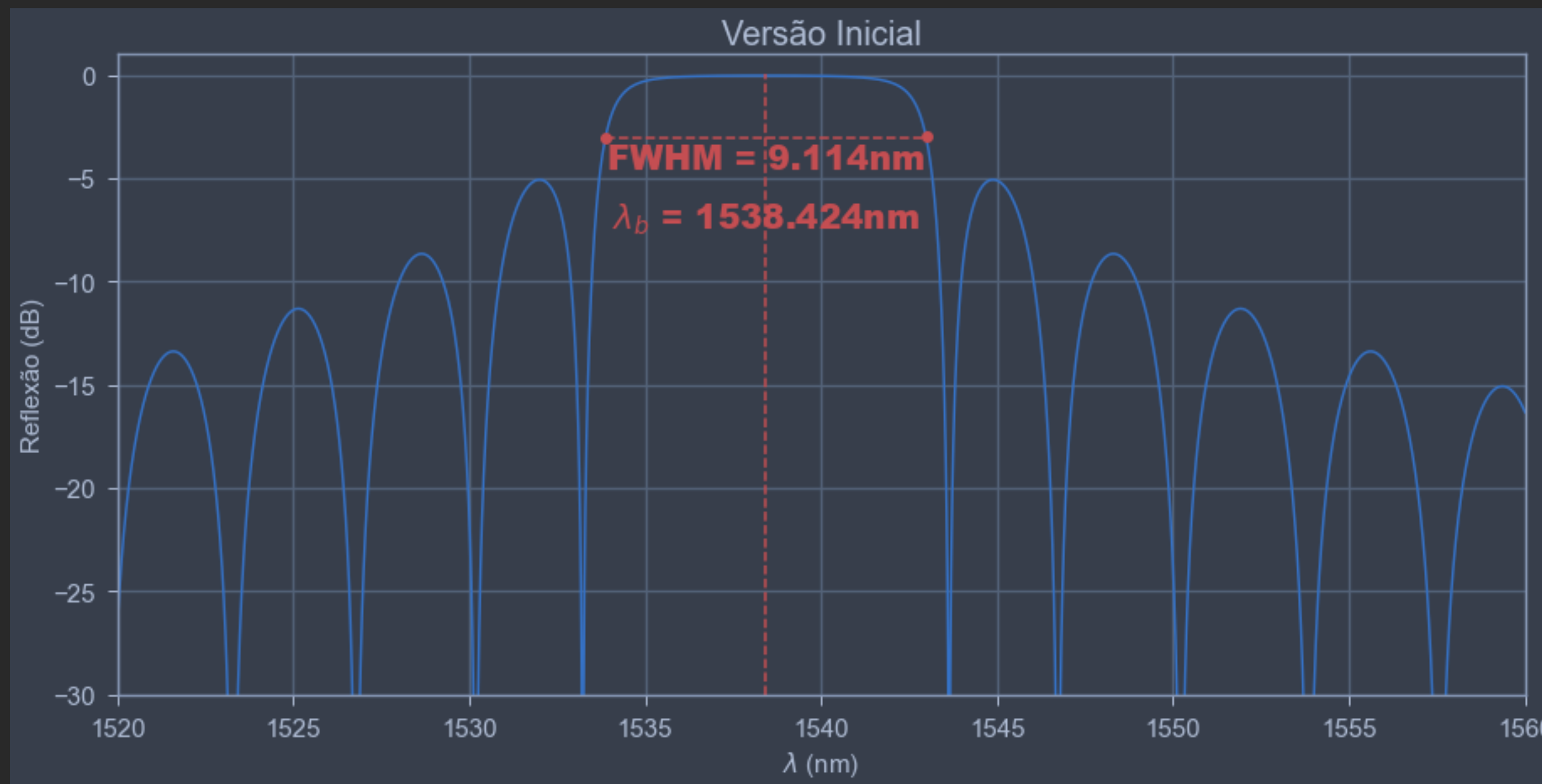
$$\Delta W = 0.064625 \text{ (x1.25)}$$



DESIGN

Correção do FWHM

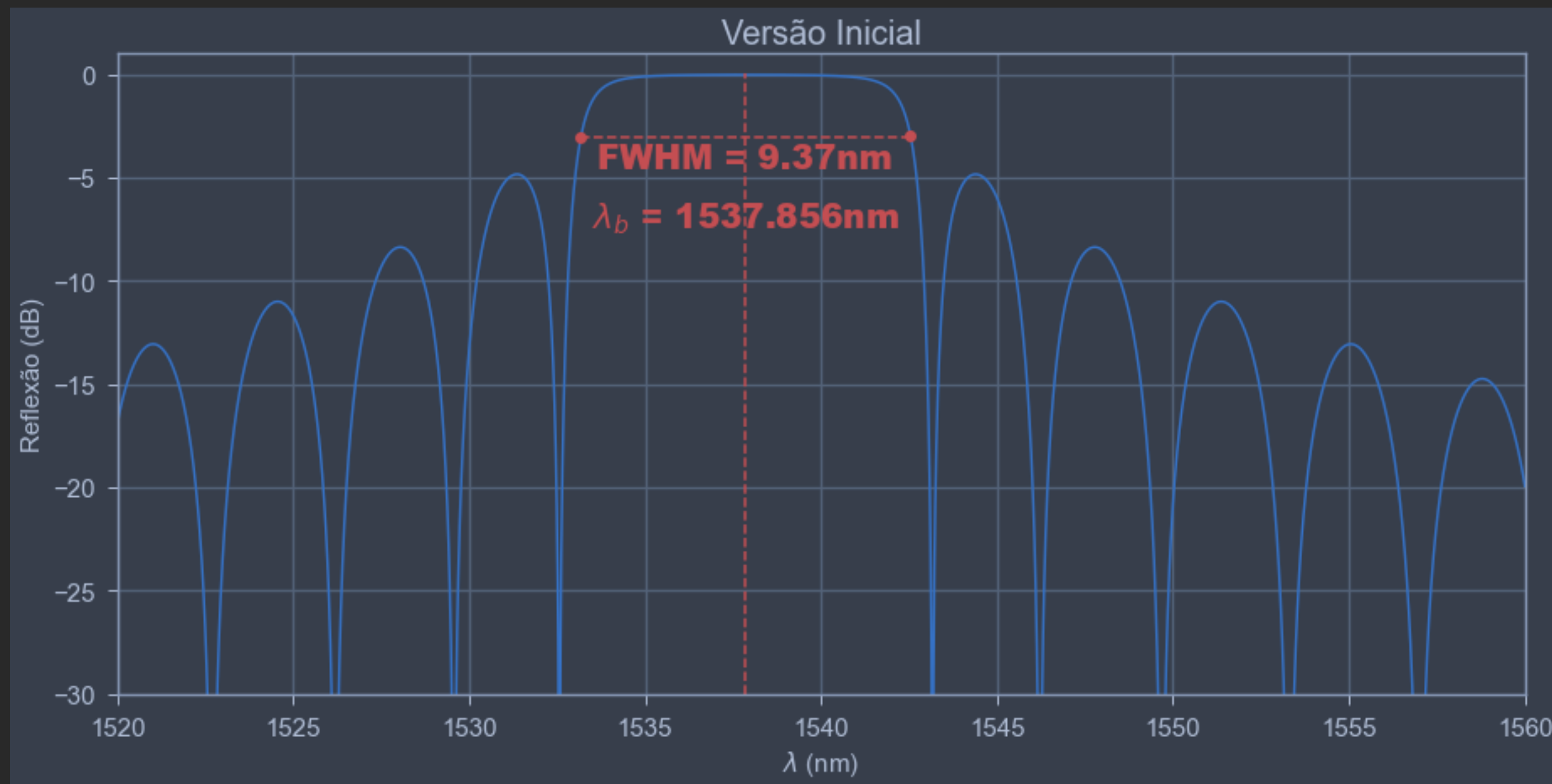
$$\Delta W = 0.07755 \text{ (x1.5)}$$



DESIGN

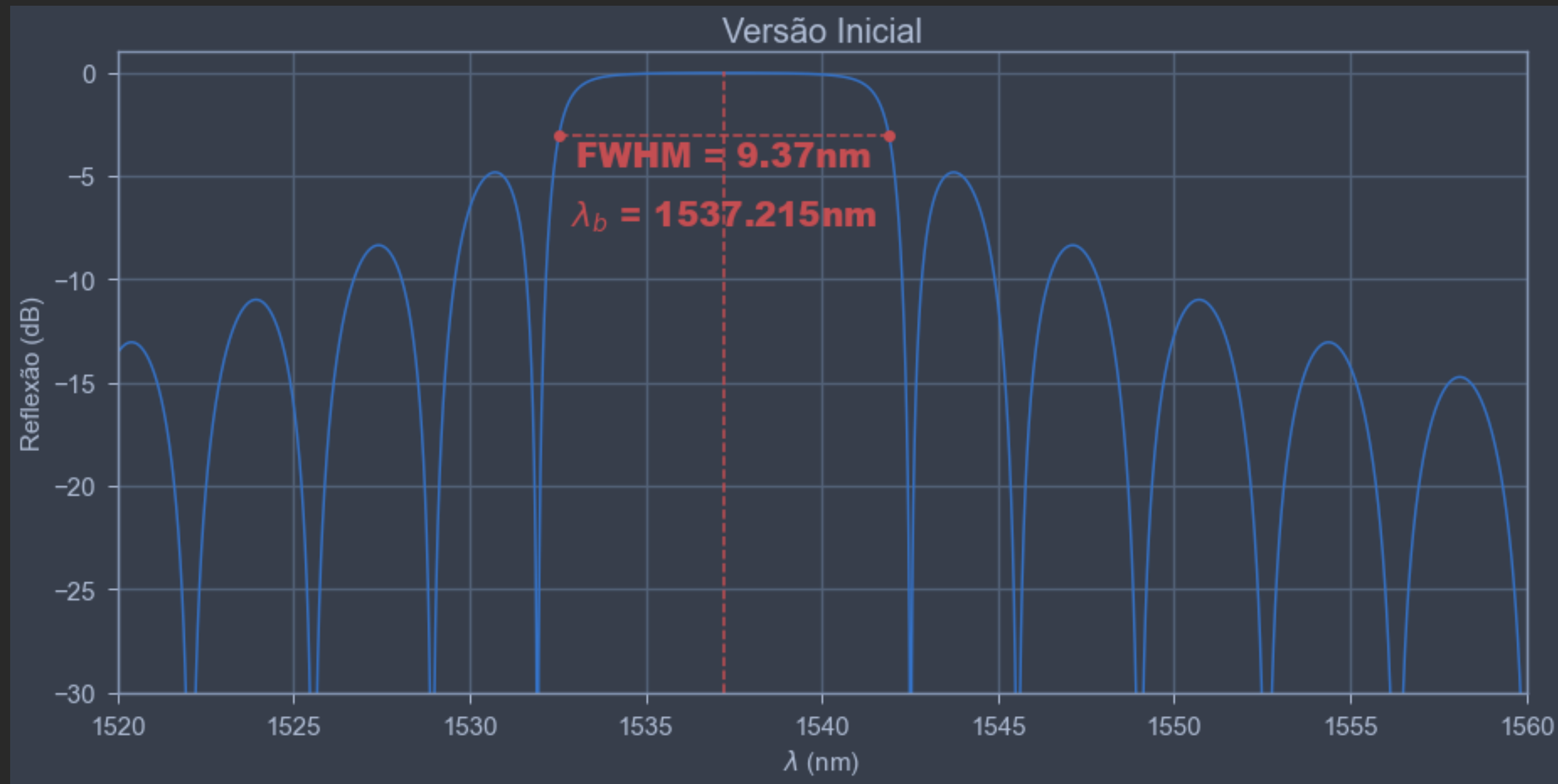
Correção do FWHM

$$\Delta W = 0.090475 \text{ (x1.75)}$$



DESIGN

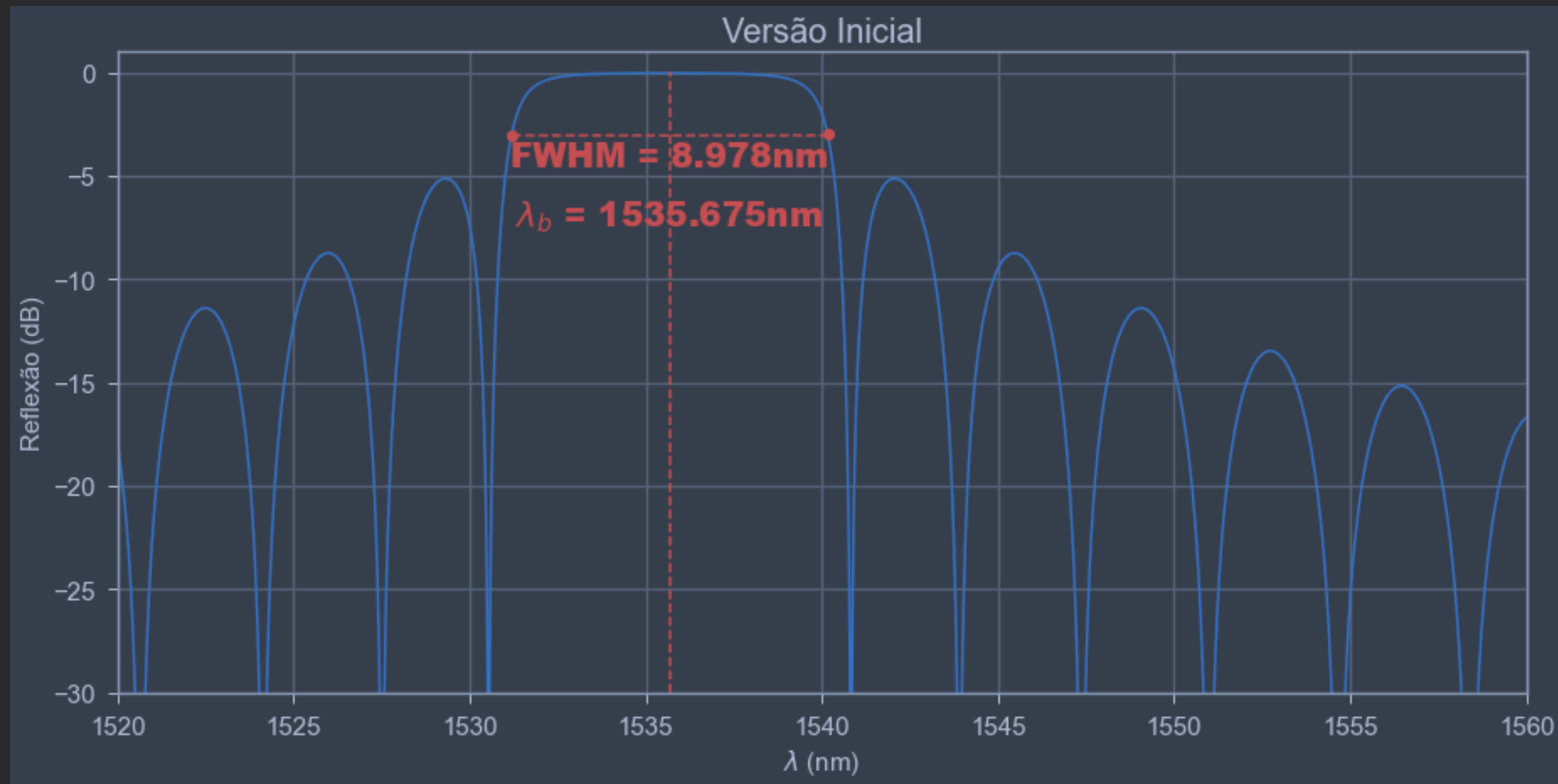
Correção do FWHM

$$\Delta W = 0.1034 \text{ (x2)}$$


DESIGN

Correção do FWHM

$$\Delta W = 0.12925 \text{ (x2.5)}$$



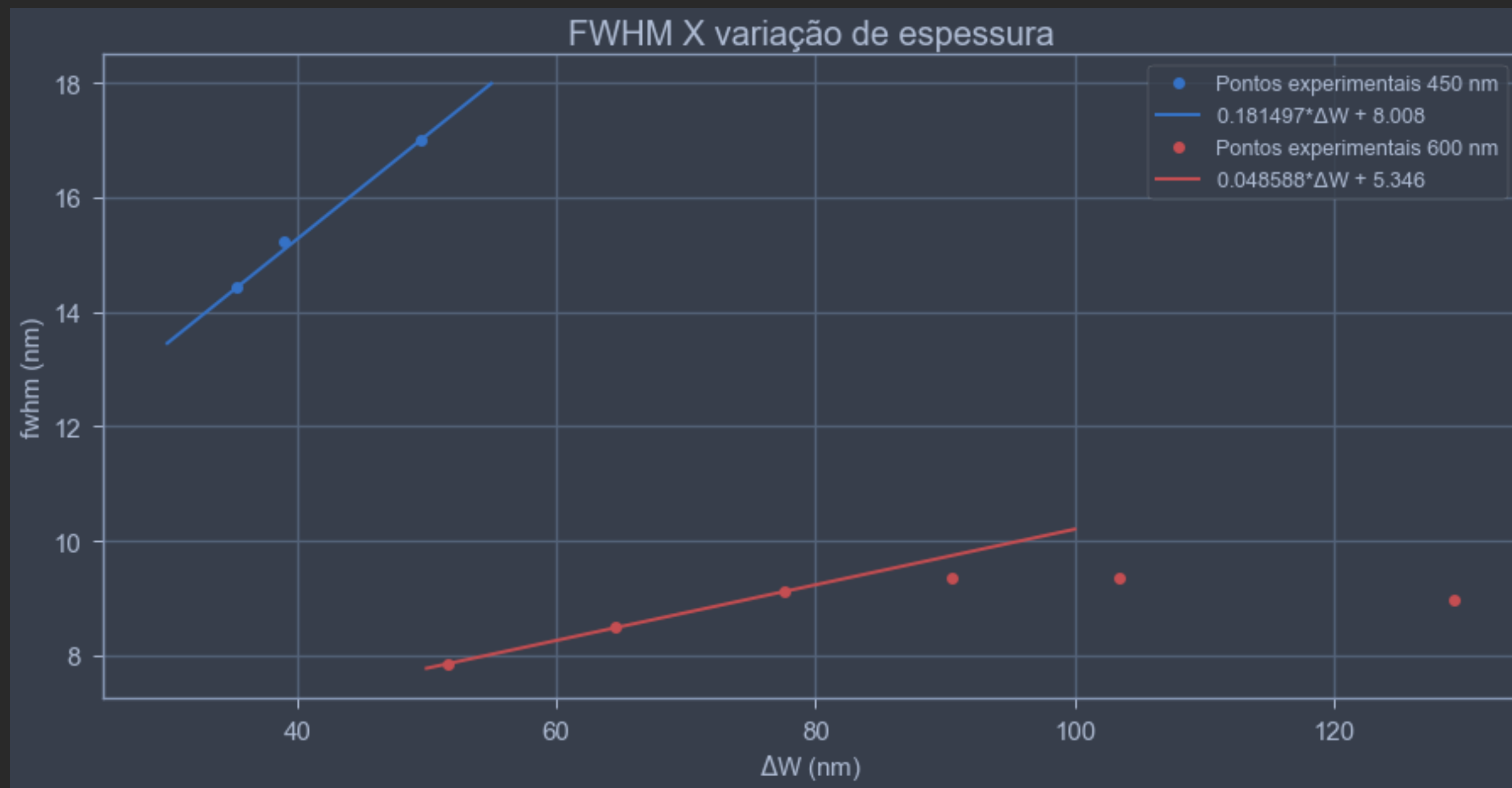
DESIGN

Analise do FWHM



DESIGN

Comparação com a grade anterior

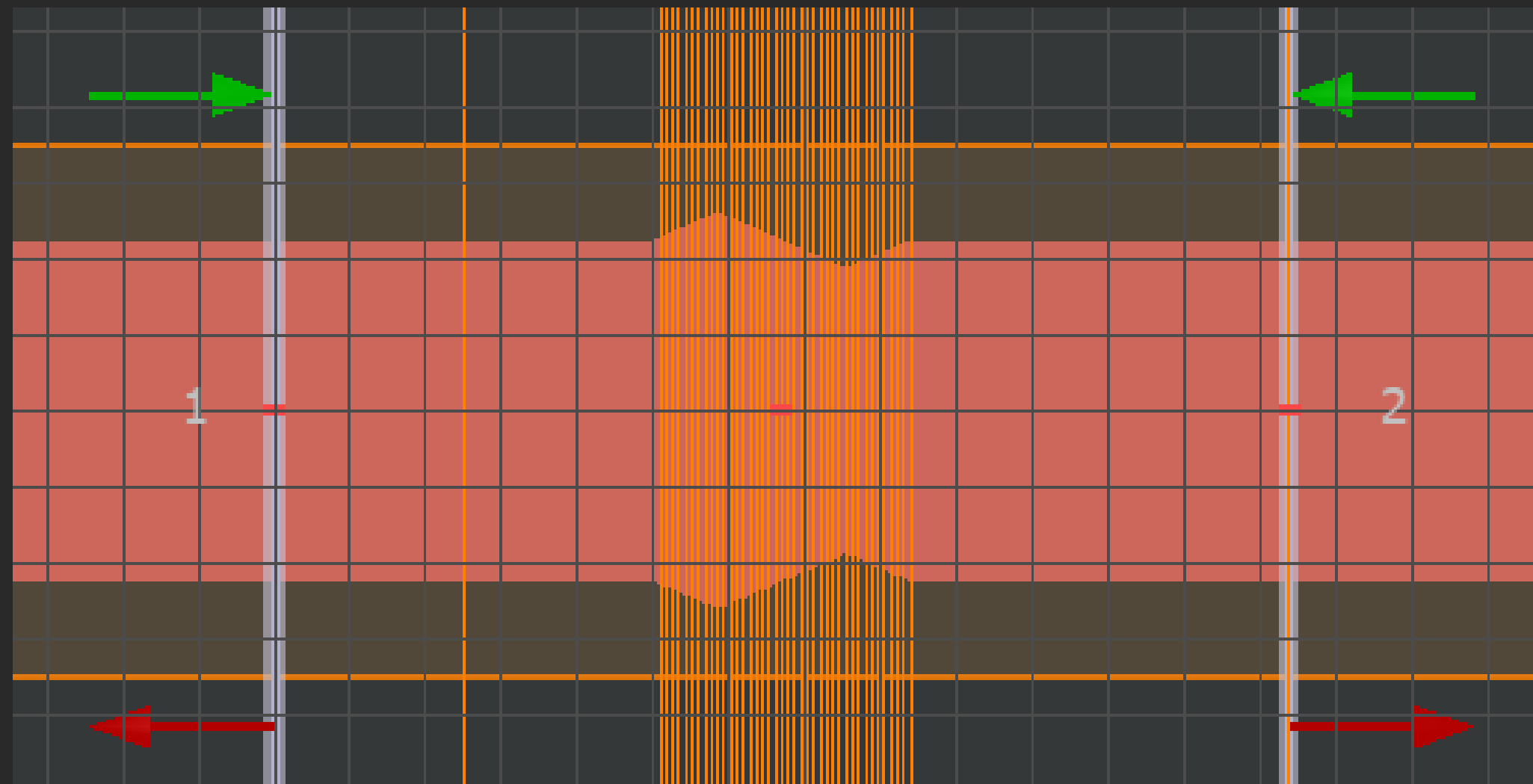


DESIGN

ALTERANDO A GEOMETRIA DA 1 GRADE

DESIGN

Gemetria triangular



DESIGN

Gemetria triangular

Edit EME solver

name

General

EME setup

Transverse mesh settings

Boundary conditions

Material

Advanced options

cell geometry

x min (μm)

number of cell groups

energy conservation

number of modes for all cell groups

☐ allow custom eigensolver settings

cell group definition

	group spans (μm)	cells	subcell method	modes	custom	cell range
1	0.5	2	CVCS	2	default	[1,2]
2	0.0846337	10	CVCS	2	default	[3 ... 12]
3	0.169267	20	CVCS	2	default	[13 ... 32]
4	0.0846337	10	CVCS	2	default	[33 ... 42]
5	0.5	1	none	2	default	[43]

☒ display cells

Clear settings for cell group 1

Custom settings for cell group 1

y (μm)

y span (μm)

y min (μm)

y max (μm)

z (μm)

z span (μm)

z min (μm)

z max (μm)

periodicity

number of periodic groups

periodic group definition

	start cell group	end cell group	periods
1	1	1	1
2	2	3	100
3	4	4	1

cell group sequence

[(1)^1,(2,3)^100,(4)^1,5]

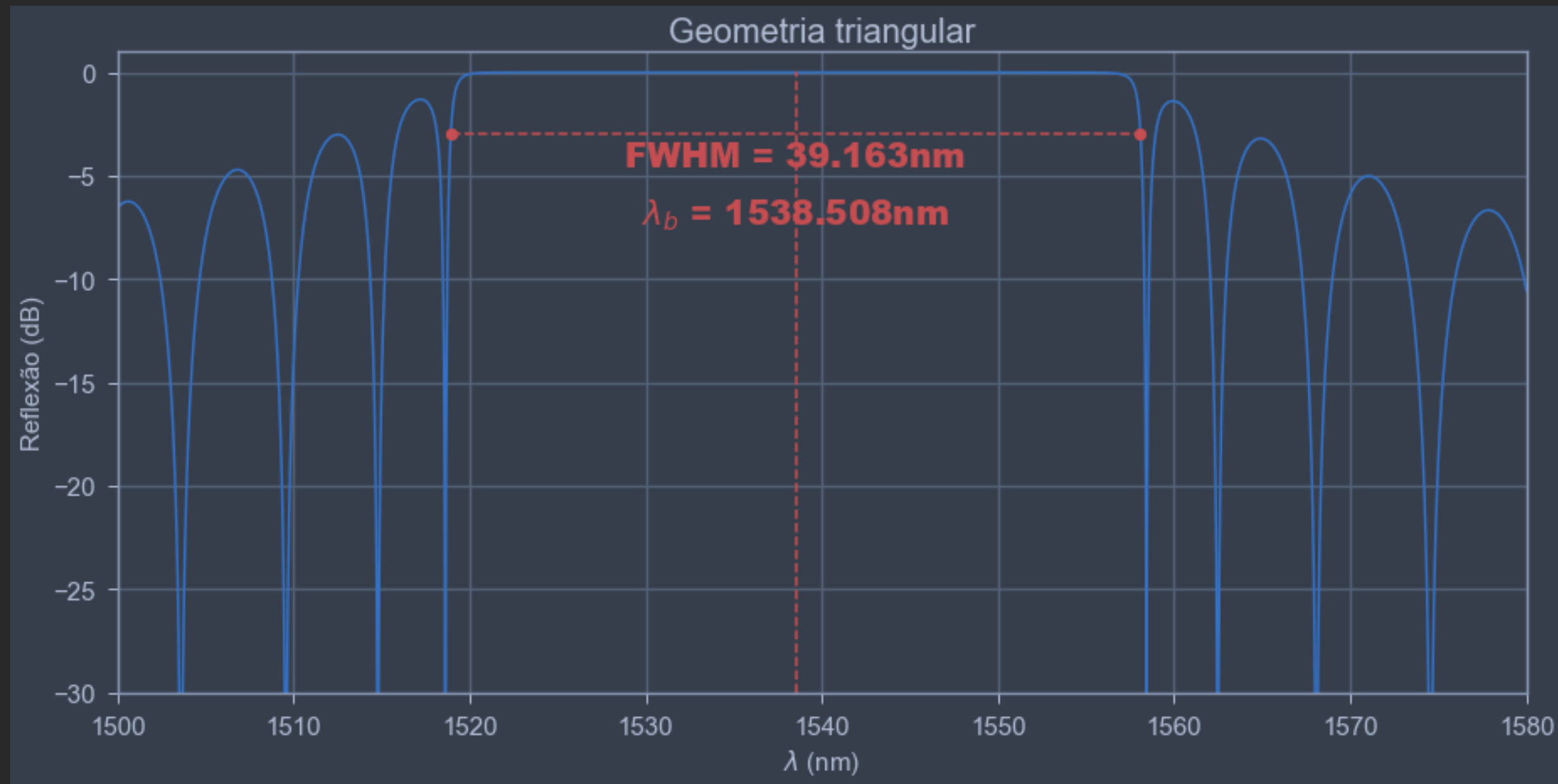
OK

Apply

Cancel

DESIGN

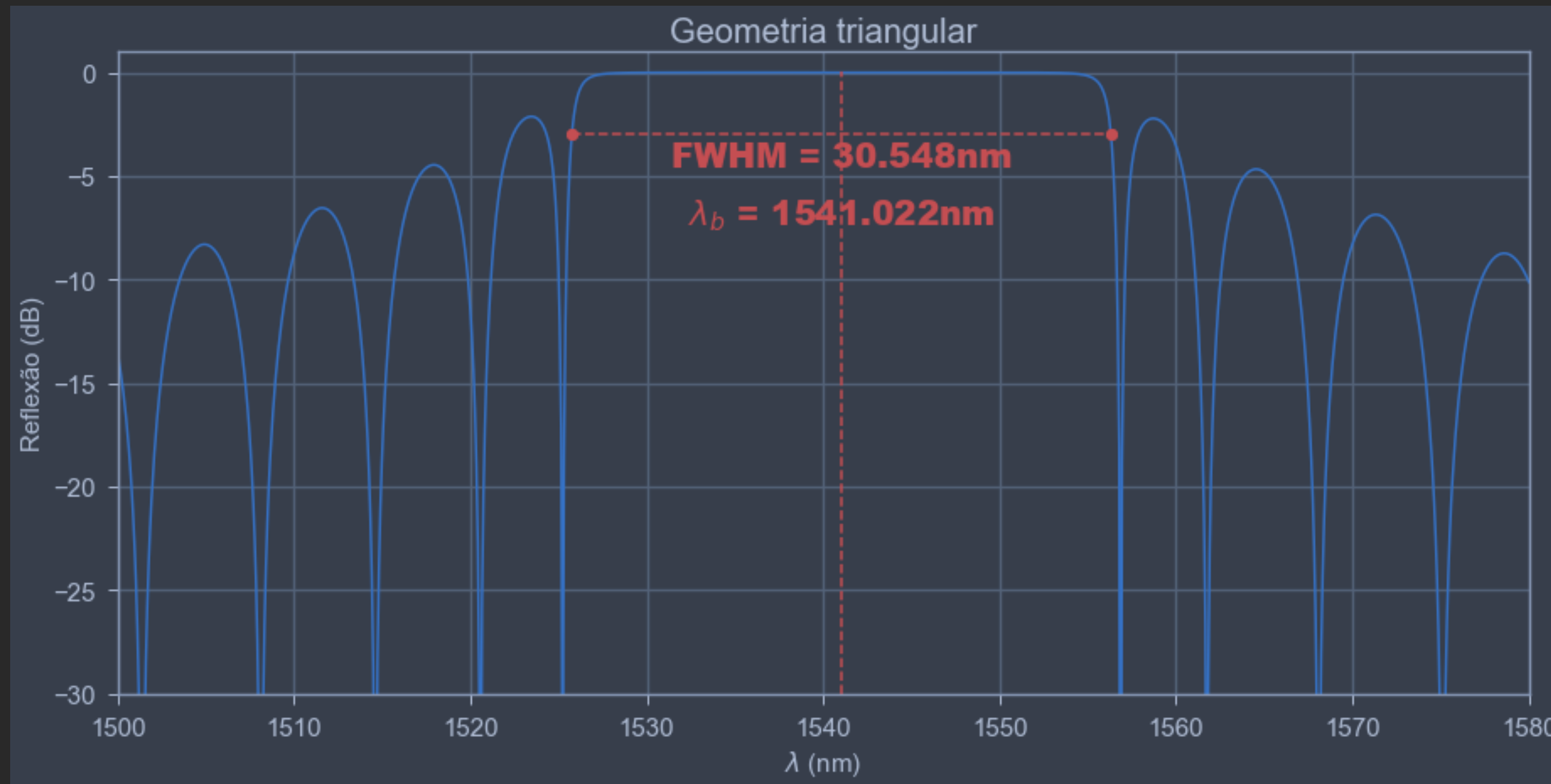
Gemetria triangular



DESIGN

Variando o ΔW

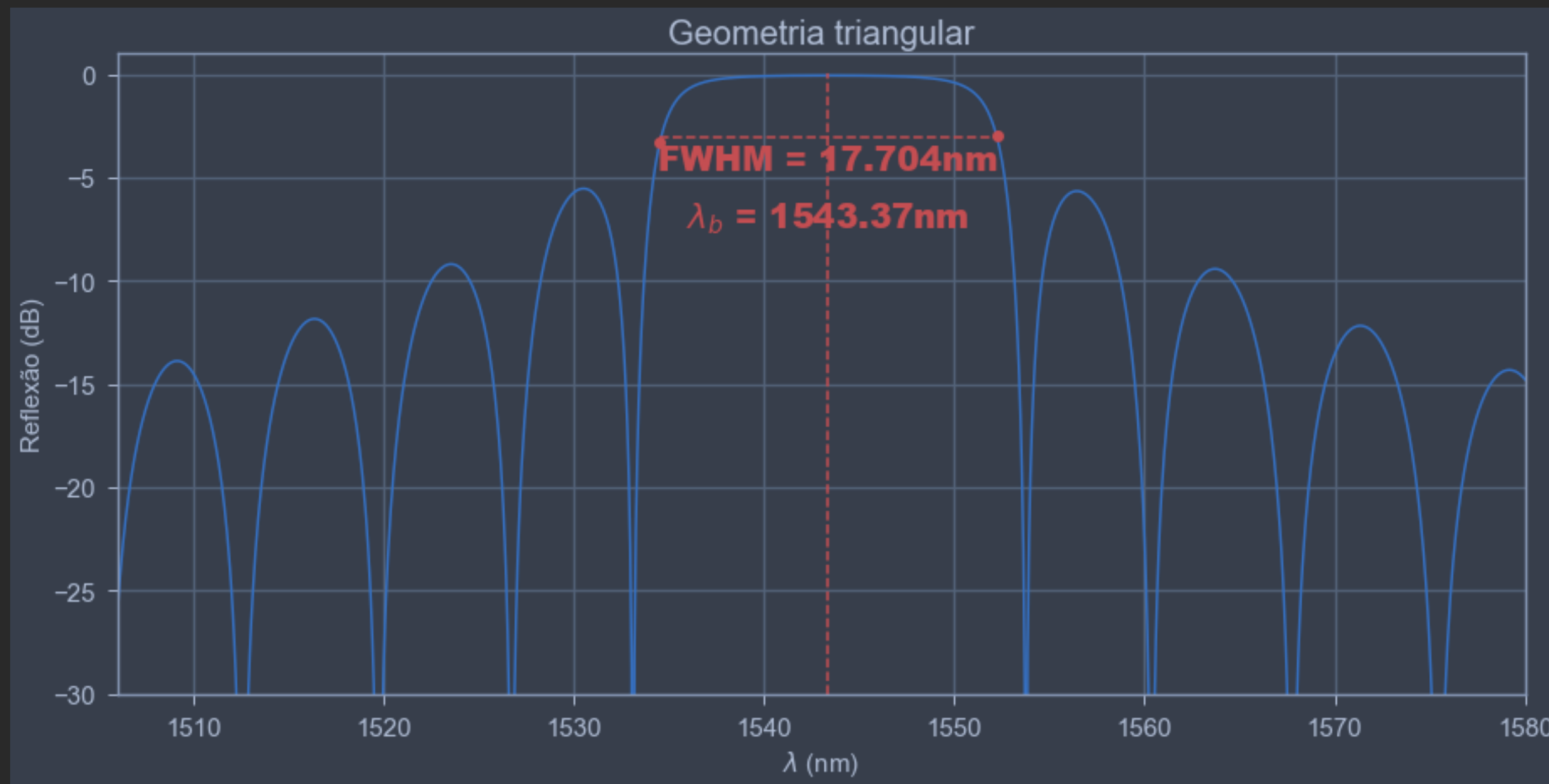
$$\Delta W = 0.0550551 (\times 0.75)$$



DESIGN

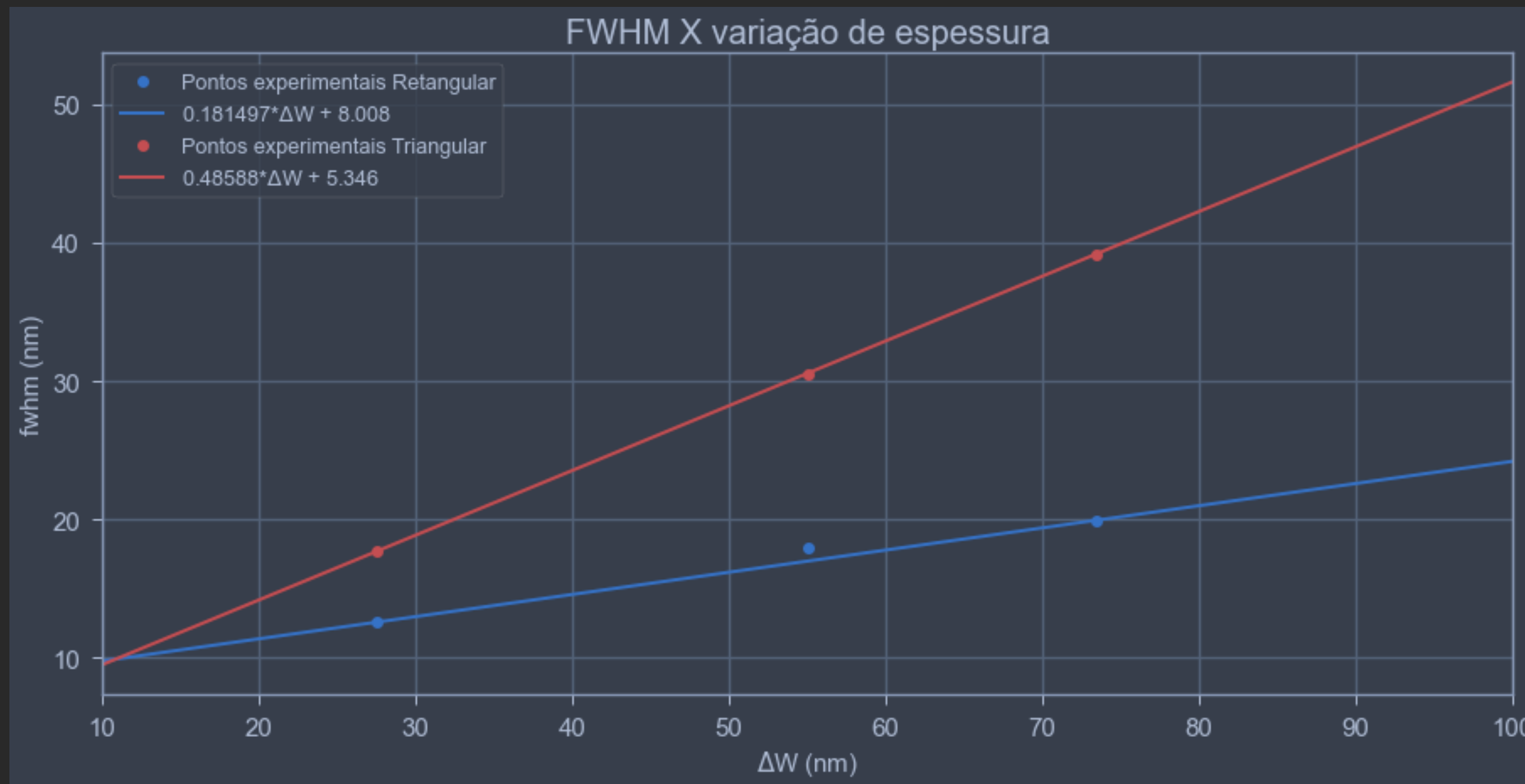
Variando o ΔW

$$\Delta W = 0.02752755 (\times 0.375)$$



DESIGN

Comparação entre grades

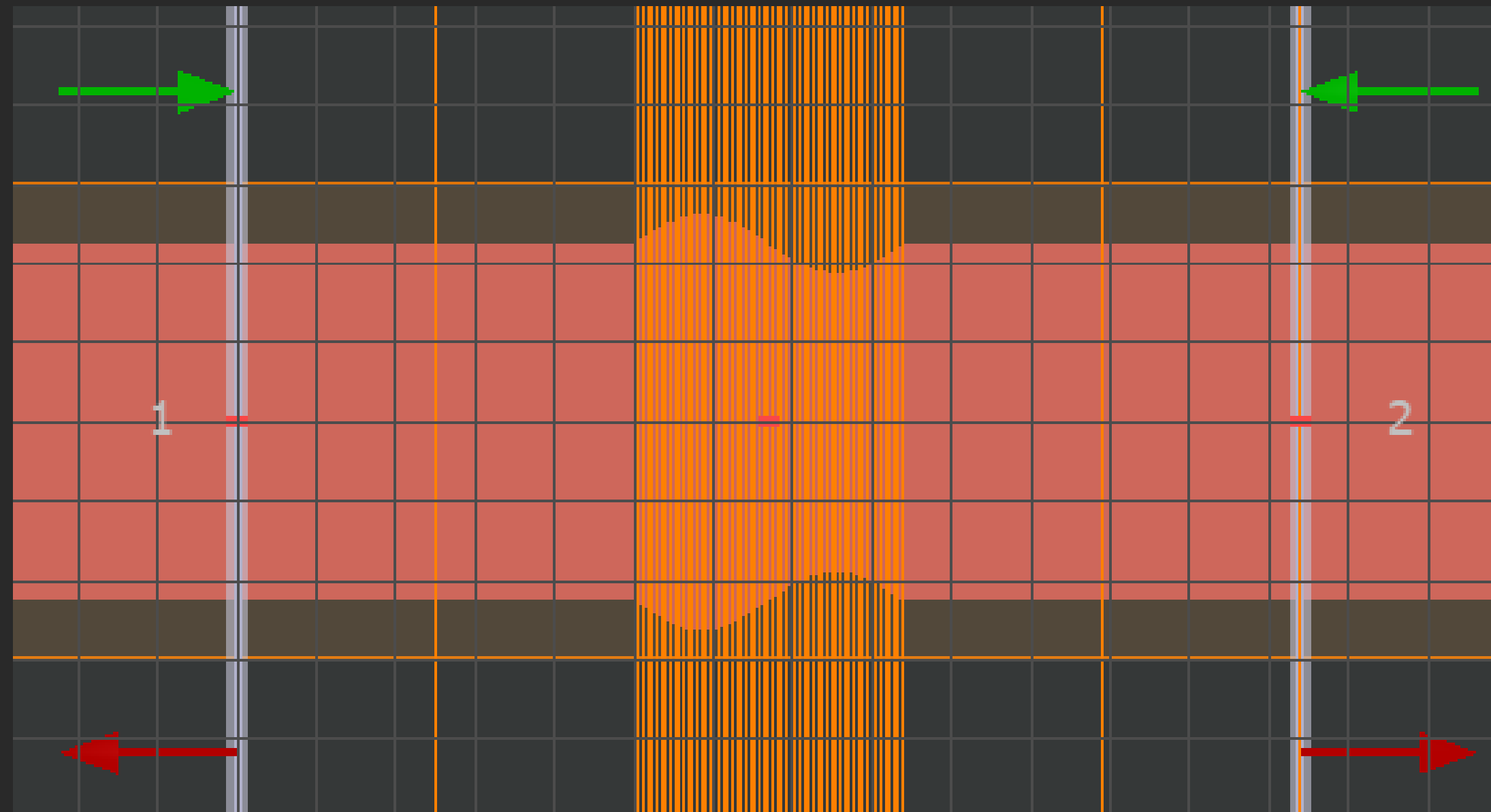


DESIGN

ALTERANDO A GEOMETRIA DA 1 GRADE

DESIGN

Gemetria Senoidal



DESIGN

Gemetria triangular

cell geometry

x min (μm)

-0.5

energy conservation

make passive

number of cell groups

3

number of modes for all cell groups

2

☐ allow custom eigensolver settings

cell group definition

	group spans (μm)	cells	subcell method	modes	custom	cell range
1	0.5	2	CVCS	2	default	[1,2]
2	0.338535	60	CVCS	2	default	[3 ... 62]
3	0.5	2	none	2	default	[63,64]

<

>

☒ display cells

Clear settings for cell group 1

Custom settings for cell group 1

y (μm)

0

y min (μm)

-2.5

y span (μm)

5

y max (μm)

2.5

z (μm)

0

z min (μm)

-2

z span (μm)

4

z max (μm)

2

periodicity

number of periodic groups

3

periodic group definition

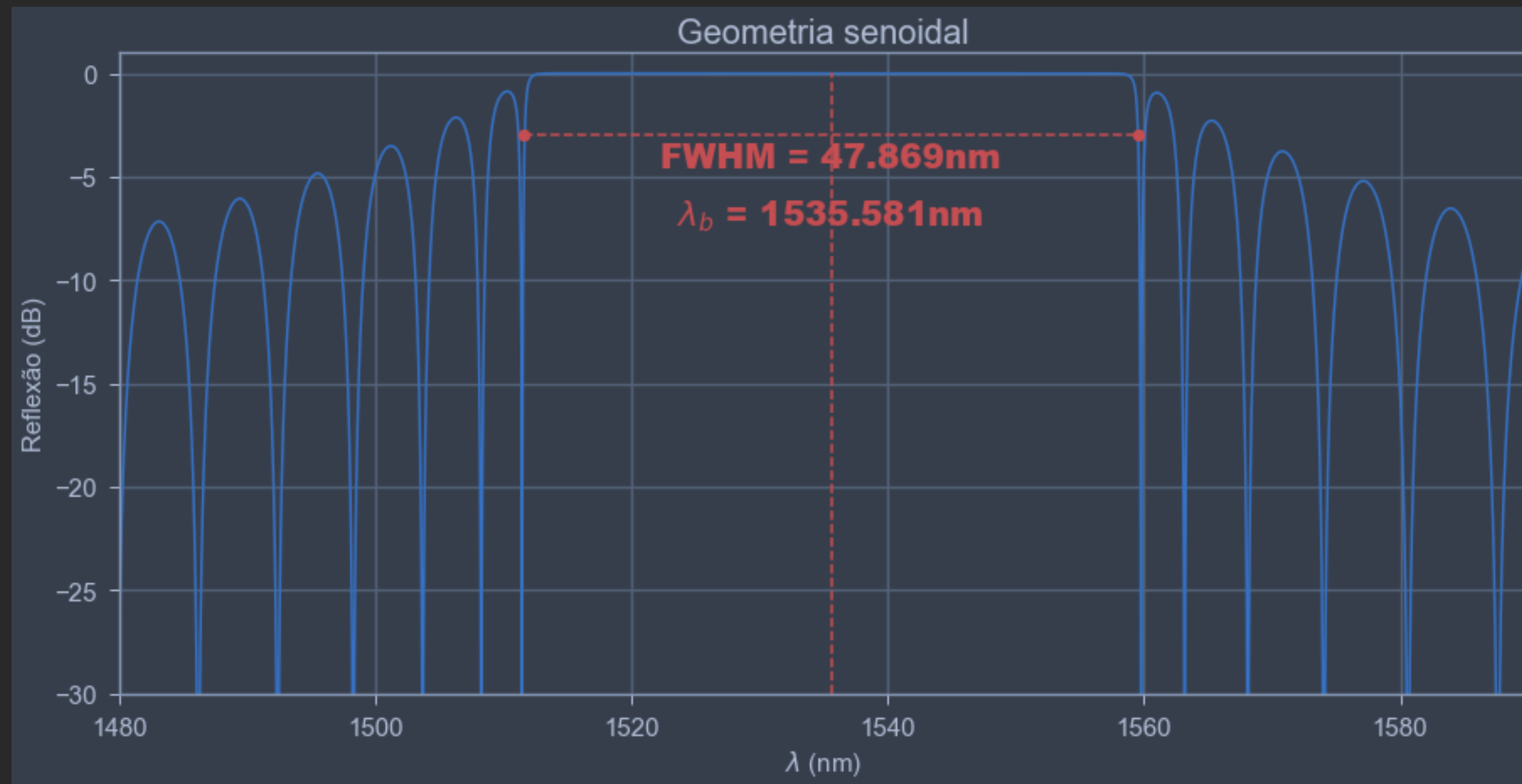
	start cell group	end cell group	periods
1	1	1	1
2	2	2	100
3	3	3	1

cell group sequence

[(1)^1,(2)^100,(3)^1]

DESIGN

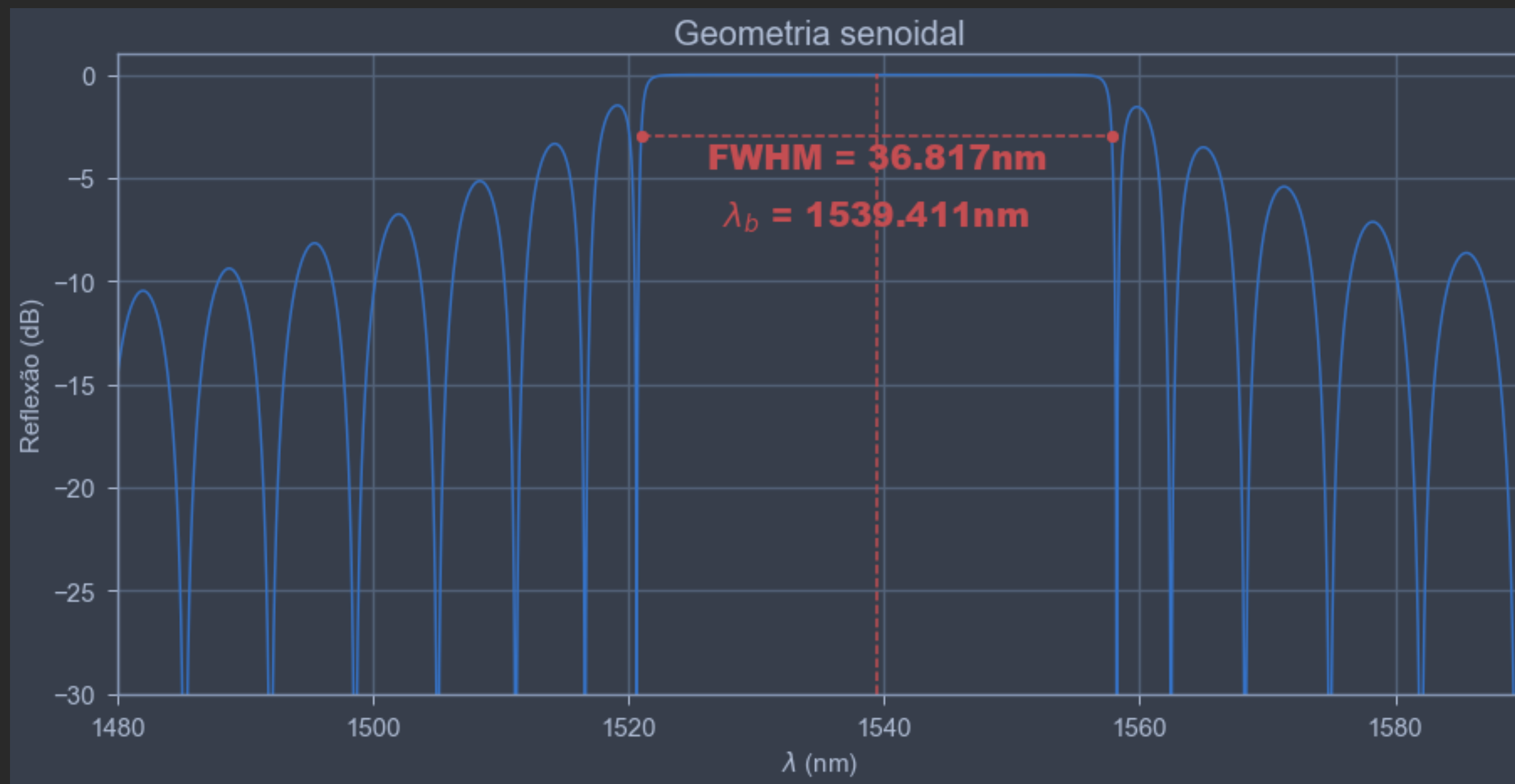
Gemetria triangular



DESIGN

Variando o ΔW

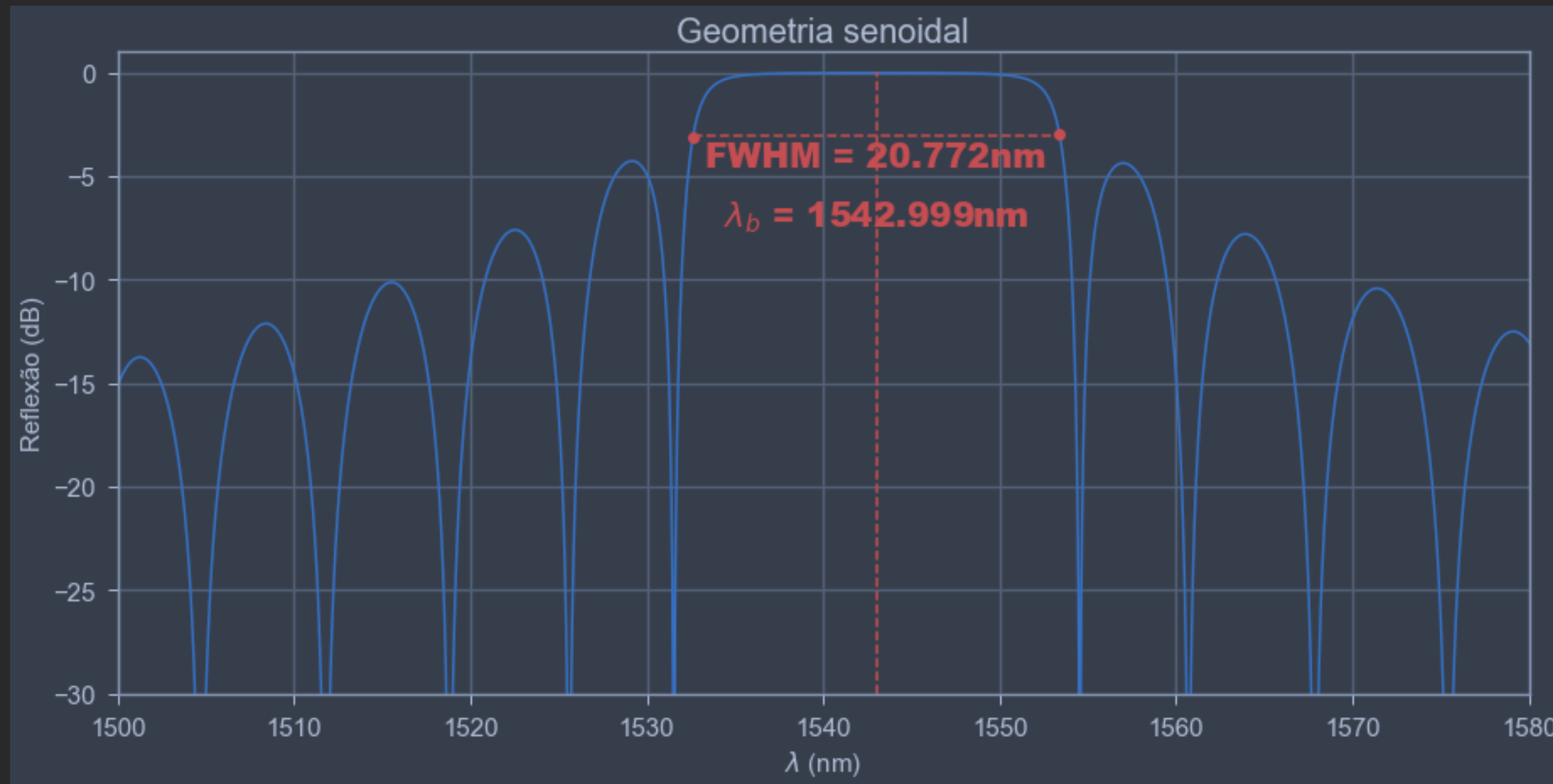
$$\Delta W = 0.0550551 (\times 0.75)$$



DESIGN

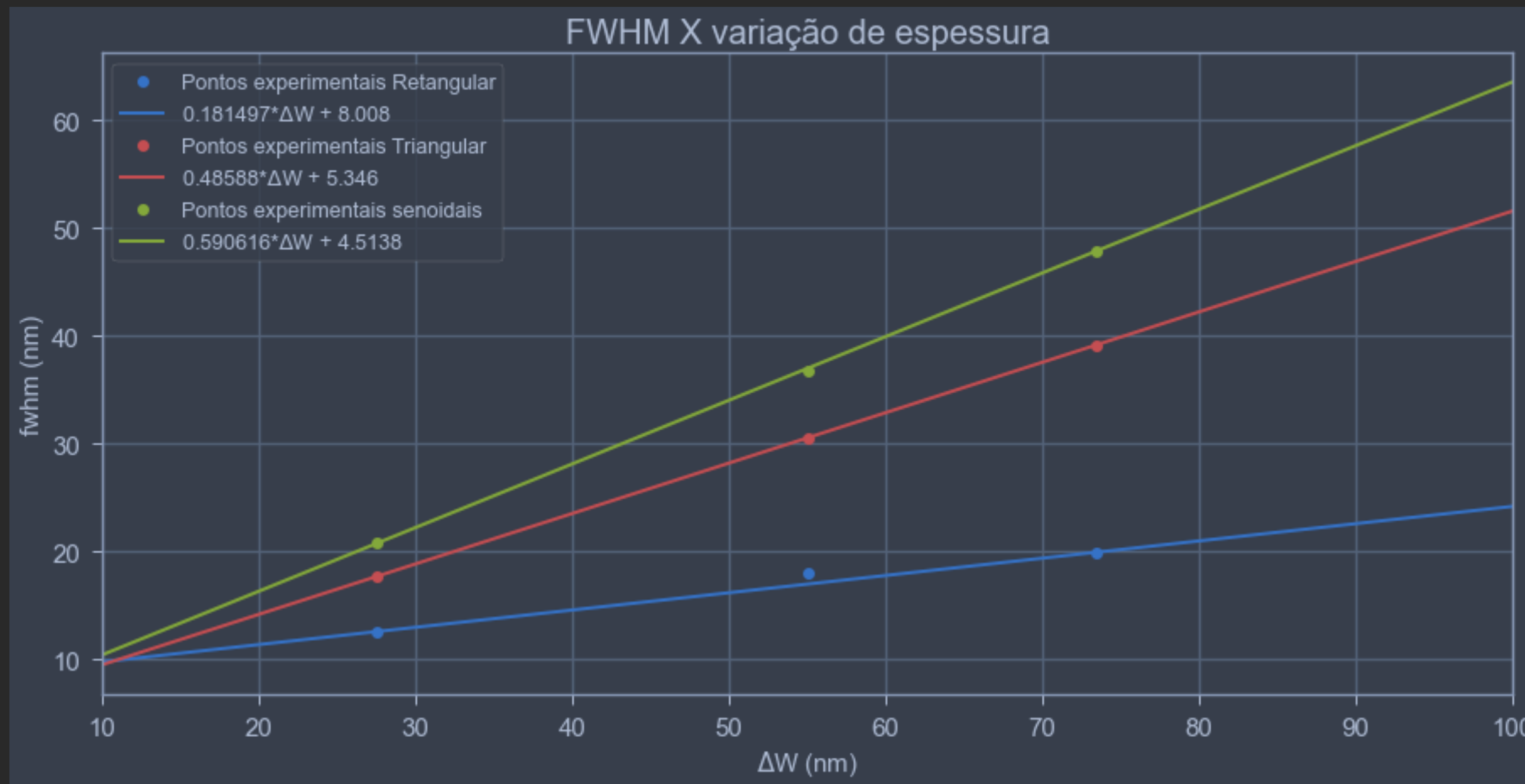
Variando o ΔW

$$\Delta W = 0.02752755 (\times 0.375)$$



DESIGN

Comparação entre grades

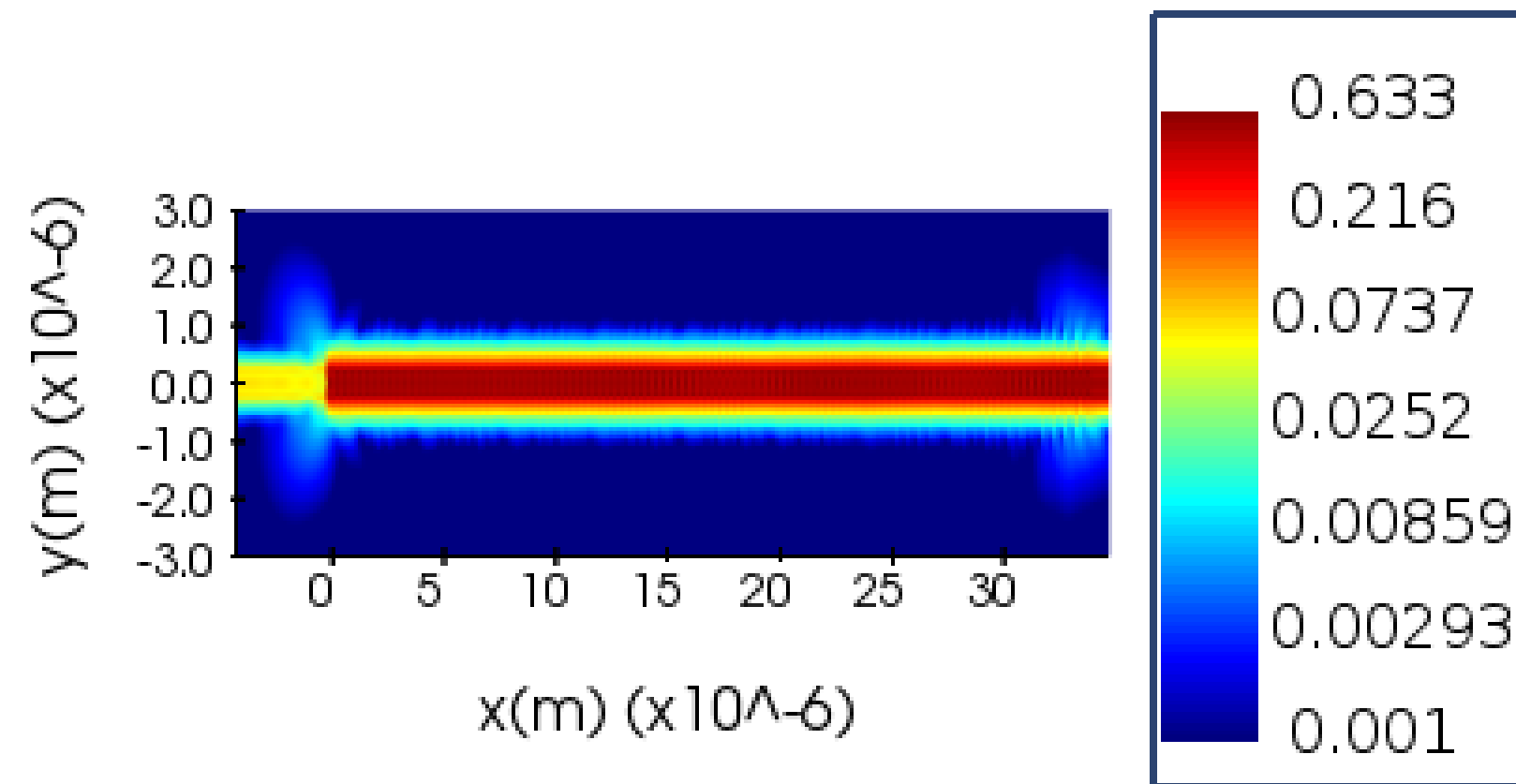


SEMANA 3

Simulação FDTD

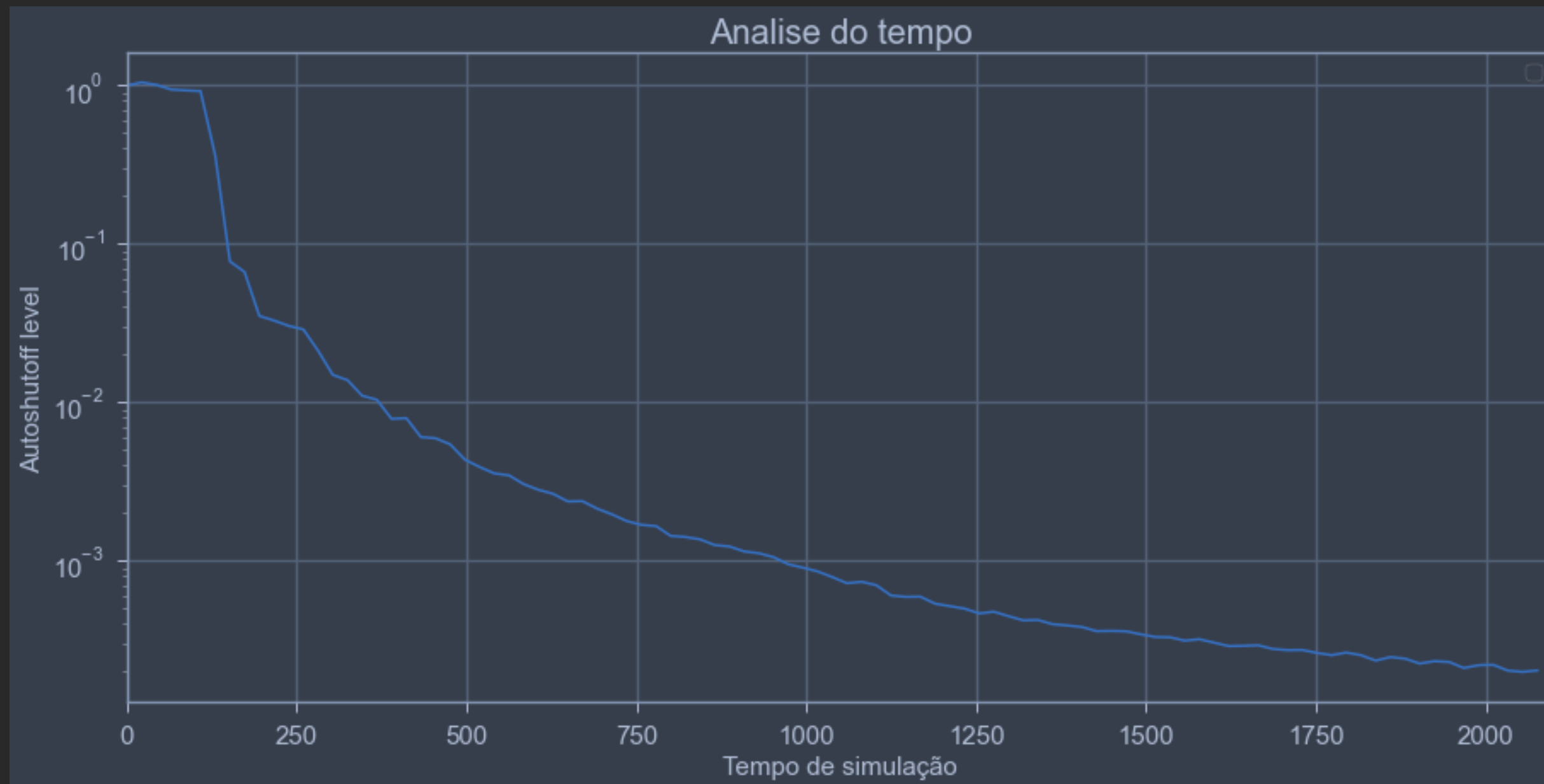
DESIGN

Convergencia do Campo



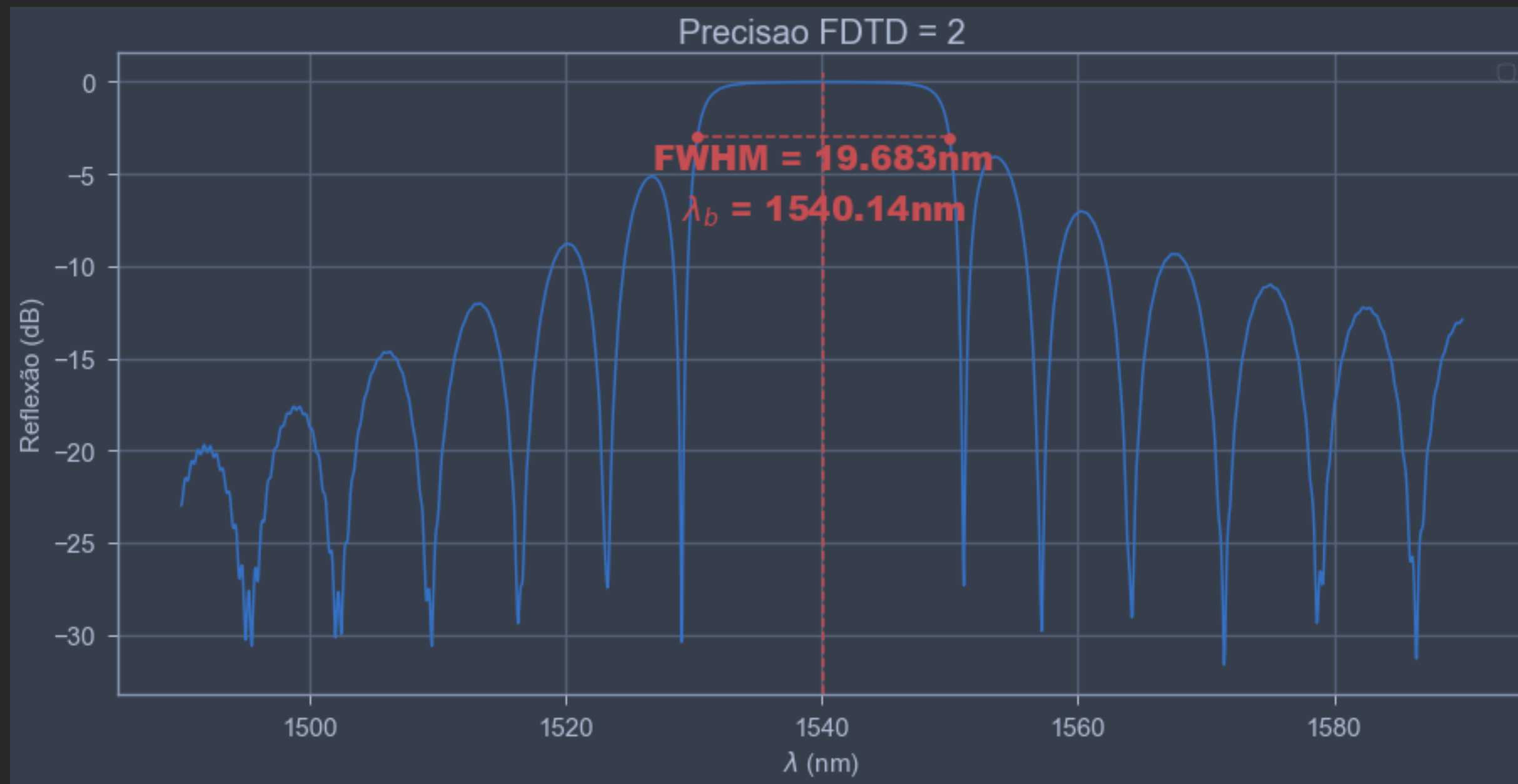
DESIGN

Convergencia no tempo



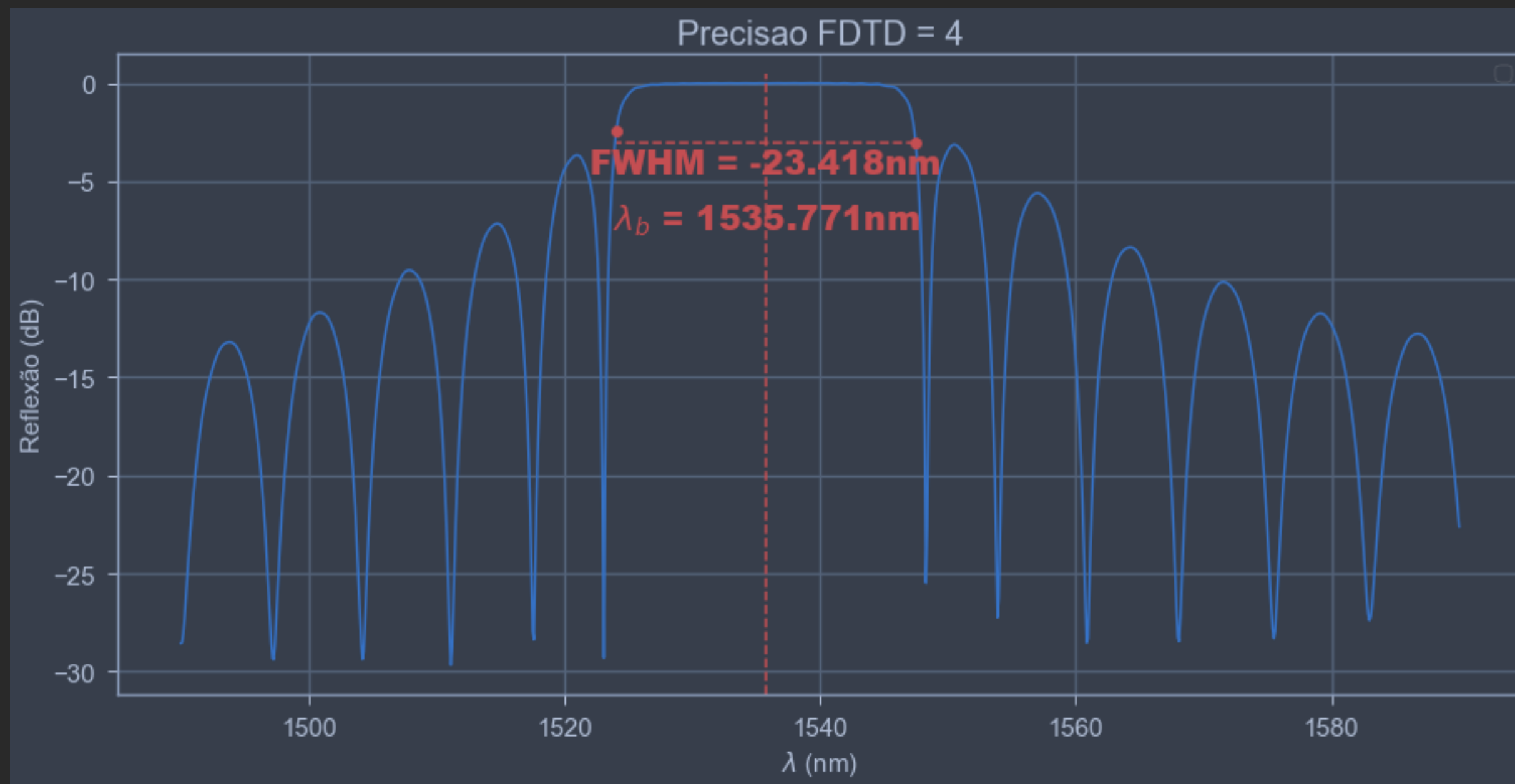
DESIGN

Resultados



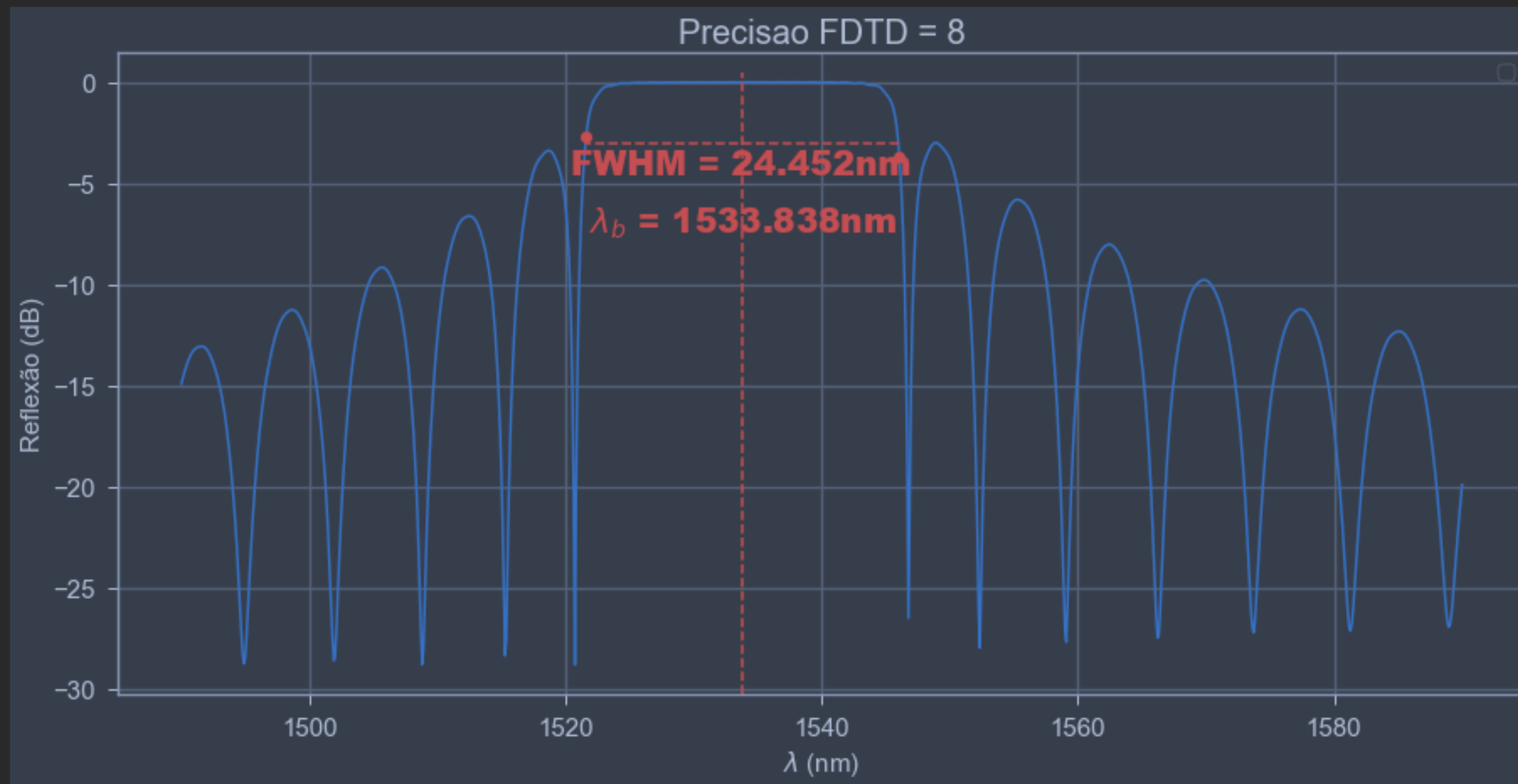
DESIGN

Resultados



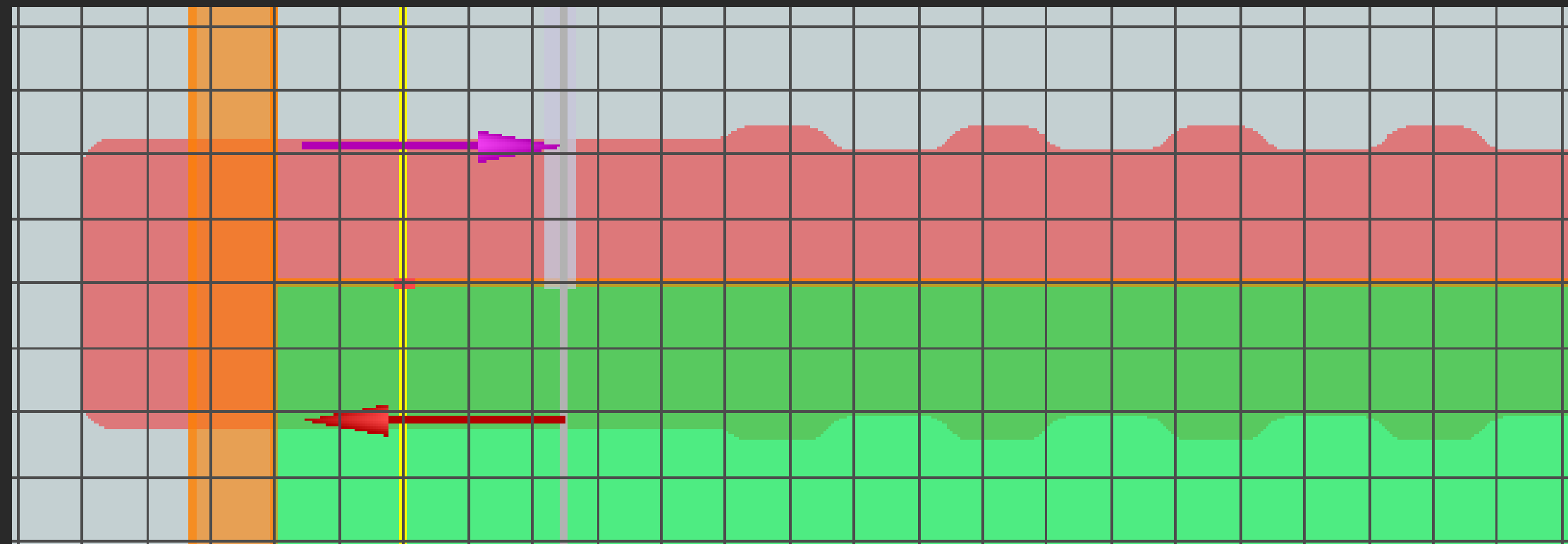
DESIGN

Resultados



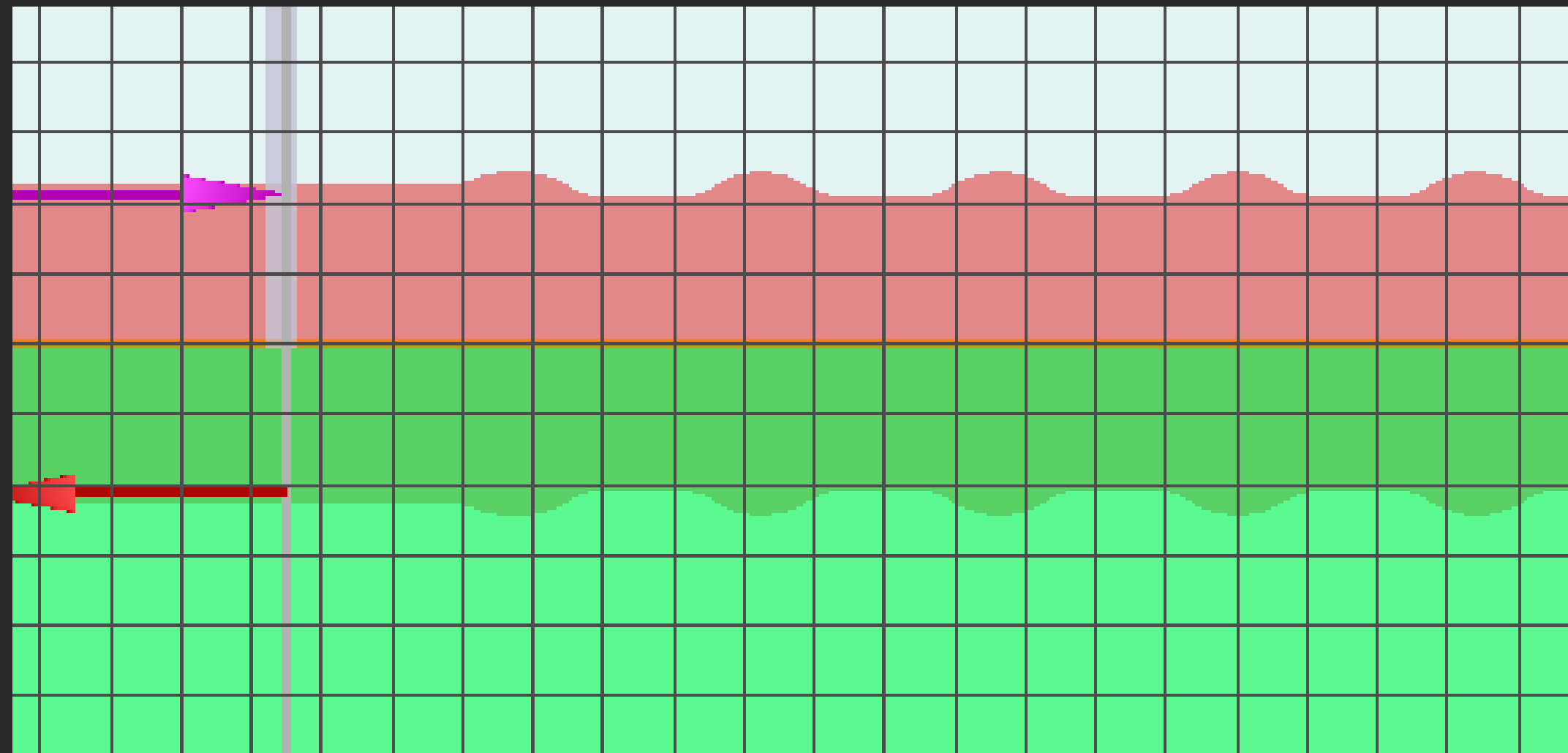
DESIGN

Aplicando o filtro de litografia
node size = 45nm



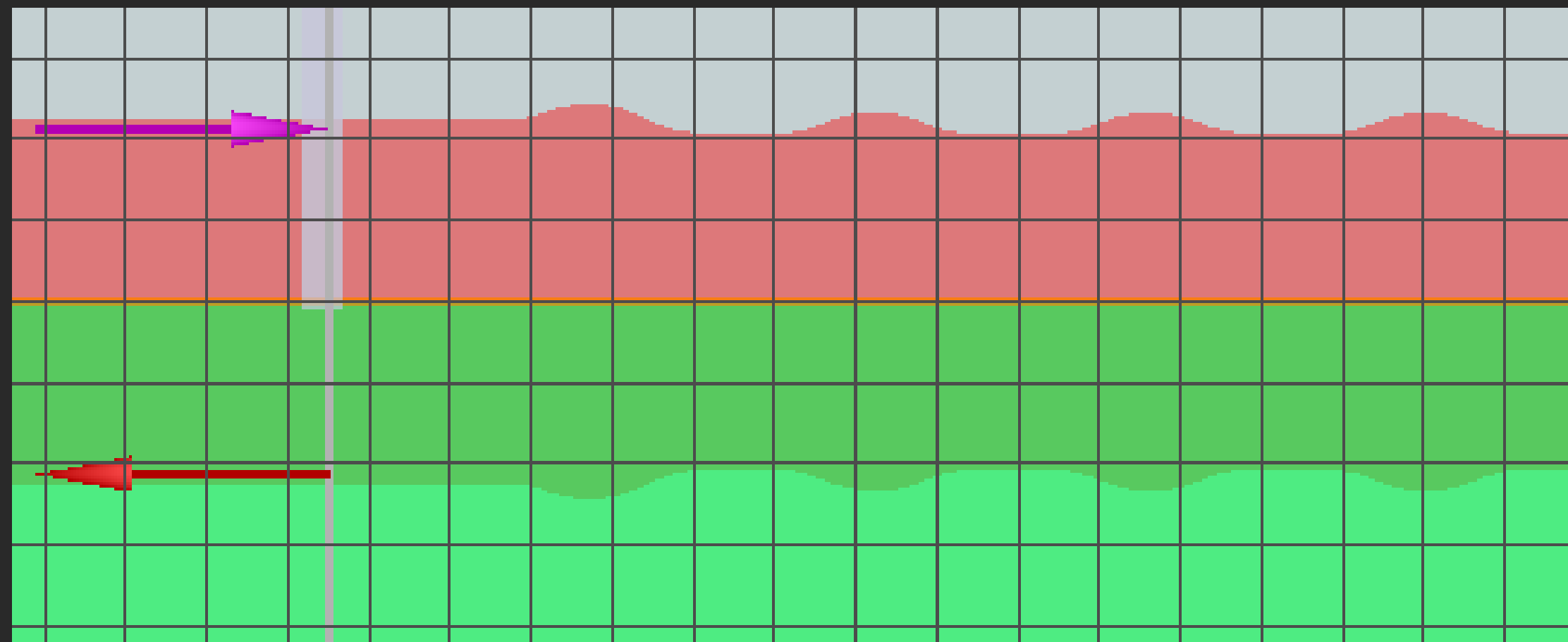
DESIGN

Aplicando o filtro de litografia
node size = 100 nm



DESIGN

Aplicando o filtro de litografia
node size = 150nm



DESIGN

Resultado do filtro de litografia
node size = 100 nm

