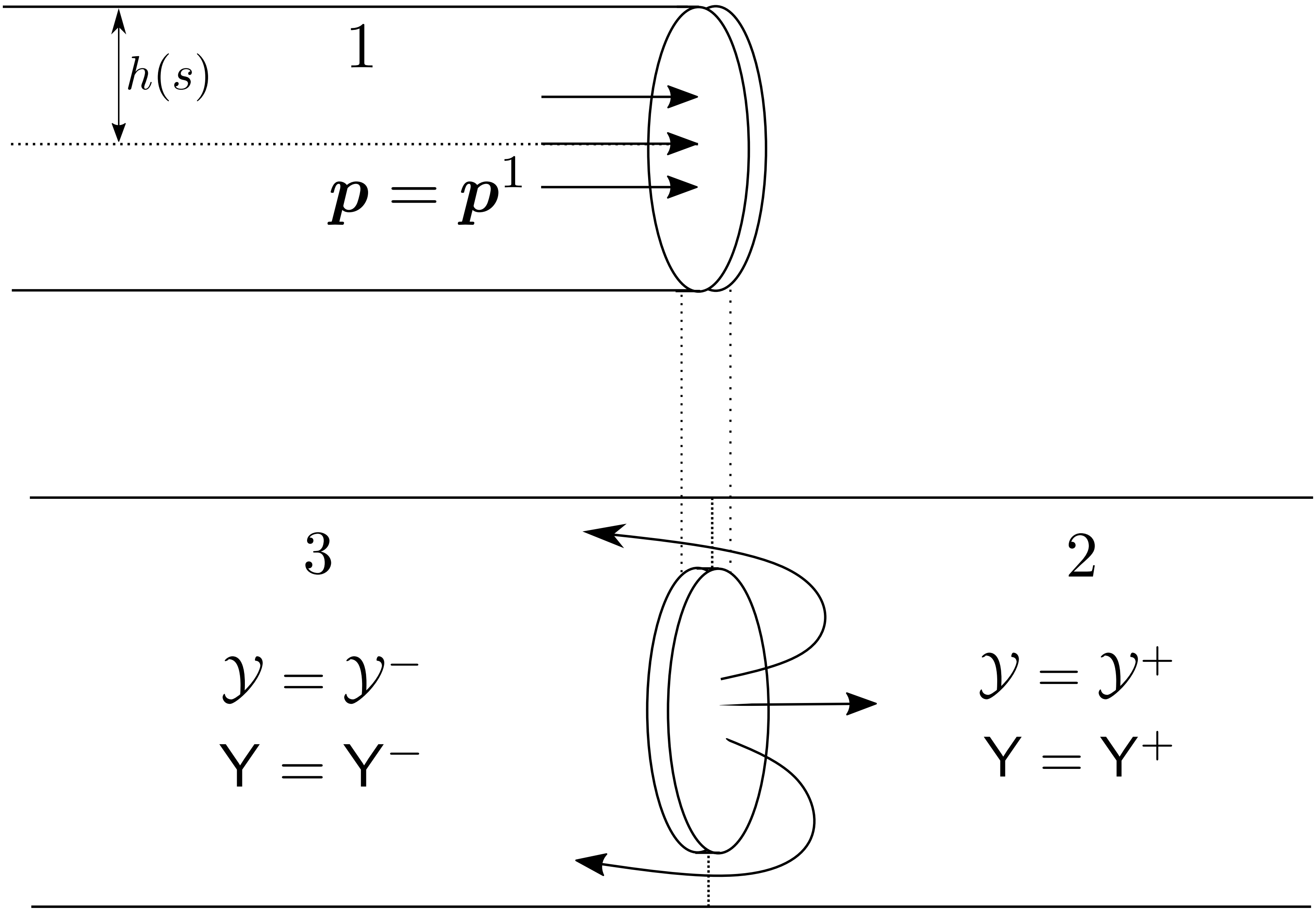
Open ended ducts I



Open ended ducts II

Putting this together is a bit comlicated, but get

$$\mathsf{Y}^1 = \frac{1}{2}\left(\mathsf{Y}^1_h + \mathsf{Y}^1_d\right)$$

$$\mathcal{Y}^1 = \frac{1}{2}\Big(\mathcal{Y}^1_h - \mathsf{F}\mathcal{Y}^+[\mathsf{Z}^+\mathsf{F}^T\mathsf{Y}^1_h, \mathsf{Z}^+\mathsf{F}^T\mathsf{Y}^1_h]\Big) + \mathsf{F}\mathcal{Y}^+\Big[\frac{1}{2}\Big(\mathsf{Z}^+\mathsf{F}^T\mathsf{Y}^1_h + \mathsf{F}^T\Big), \frac{1}{2}\Big(\mathsf{Z}^+\mathsf{F}^T\mathsf{Y}^1_h + \mathsf{F}^T\Big)$$

To find the pressure outside the duct in “free space” we first calculate $\boldsymbol{u}^1_h$ using

$$\boldsymbol{u}^1_h = \mathsf{Y}^1_h\boldsymbol{p}^1 + \mathcal{Y}^1_h[\boldsymbol{p}^1, \boldsymbol{p}^1]$$

Calculate $\boldsymbol{u}^2_h = \mathsf{F}^T\boldsymbol{u}^1_h$ and $\boldsymbol{u}^2_h$ gives $\boldsymbol{p}^2_h$. Then find $\boldsymbol{p}^2_d = \mathsf{F}^T\boldsymbol{p}^1$.

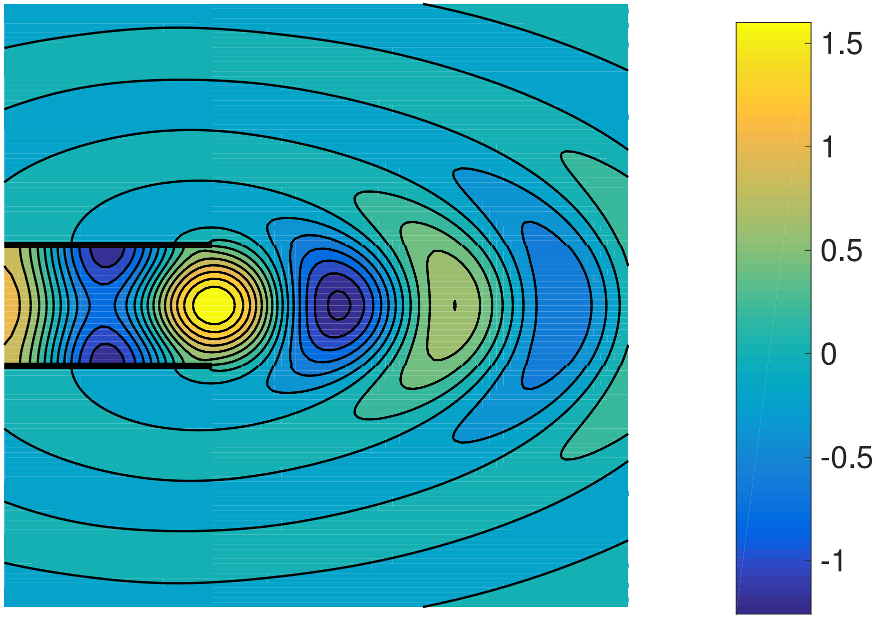
For $s > 0$, $$\boldsymbol{p}^2 = \frac{1}{2}\left(\boldsymbol{p}^2_h + \boldsymbol{p}^2_d\right)$$

For $s < 0$, $$\boldsymbol{p}^3 = \frac{1}{2}\left(\boldsymbol{p}^2_h - \boldsymbol{p}^2_d\right)$$

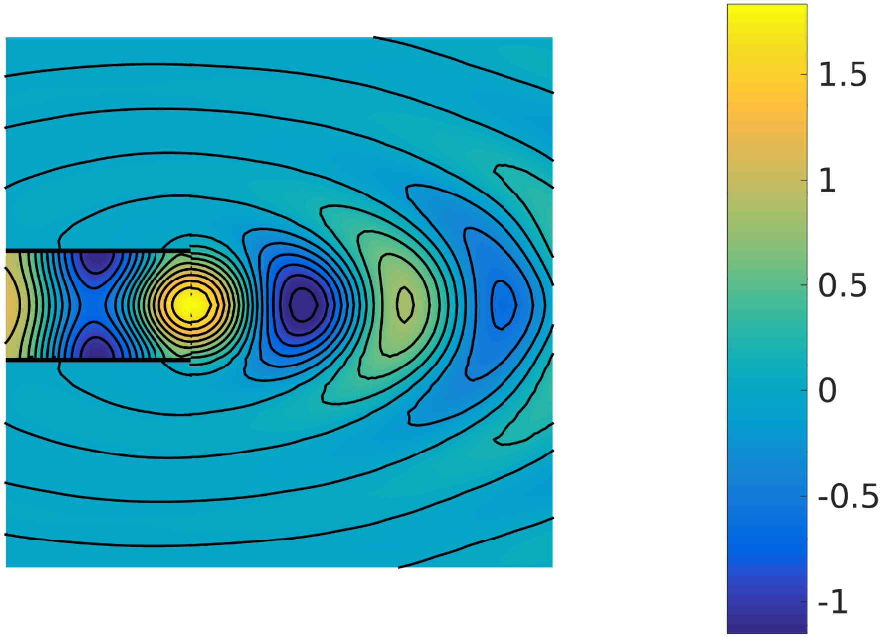
Propagate in the positive s direction using Y^+ and $\mathcal{Y}^+$.
Propagate in the negative s direction using Y^- and $\mathcal{Y}^-$.

Neglects reflections from the outside of the inner duct.

Comparison of duct exit with Wiener–Hopf

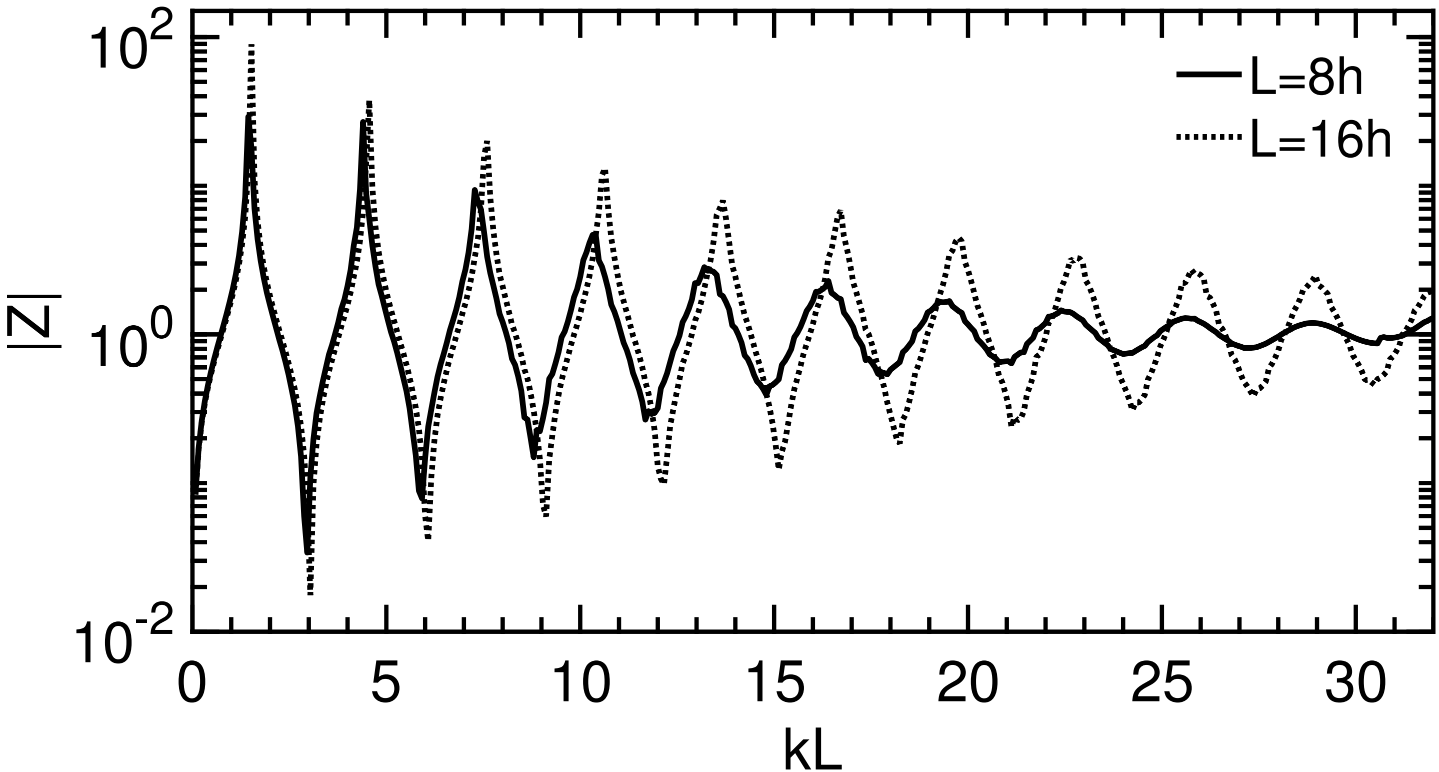


Analytic solution (Levine & Schwinger 1948)

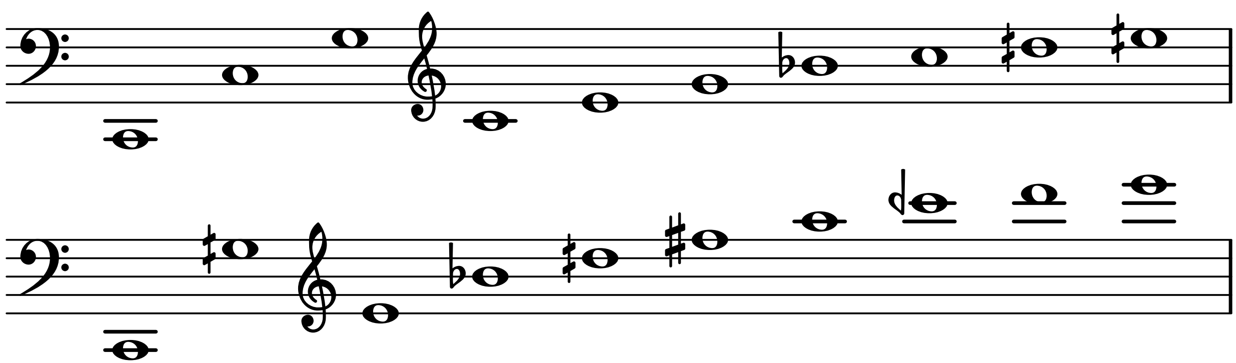


Numerical solution

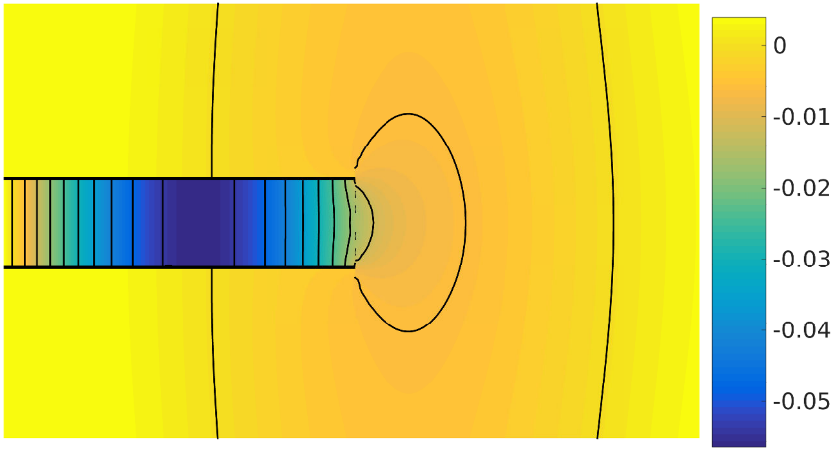
Linear resonances of an open duct

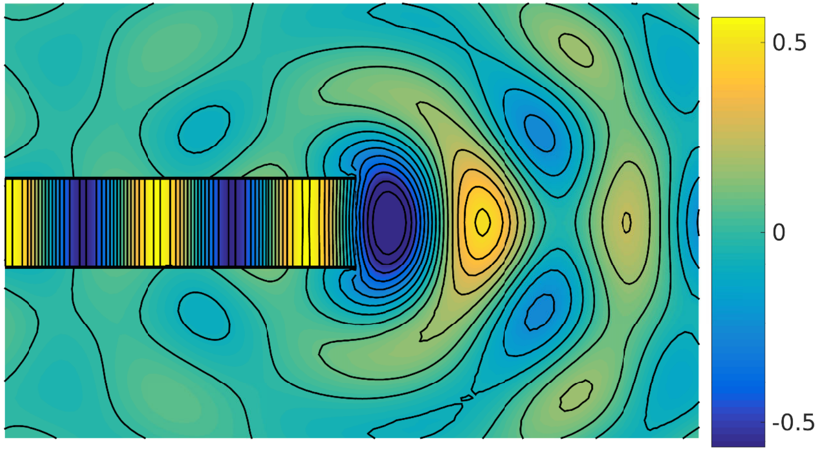


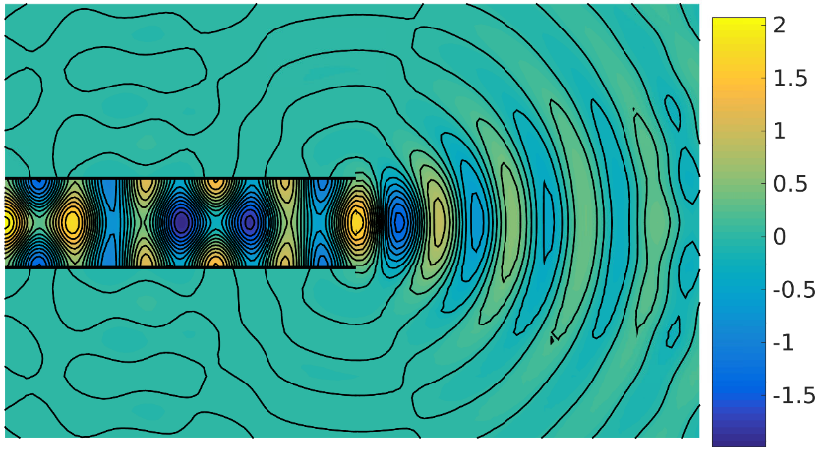
$L = 8$:



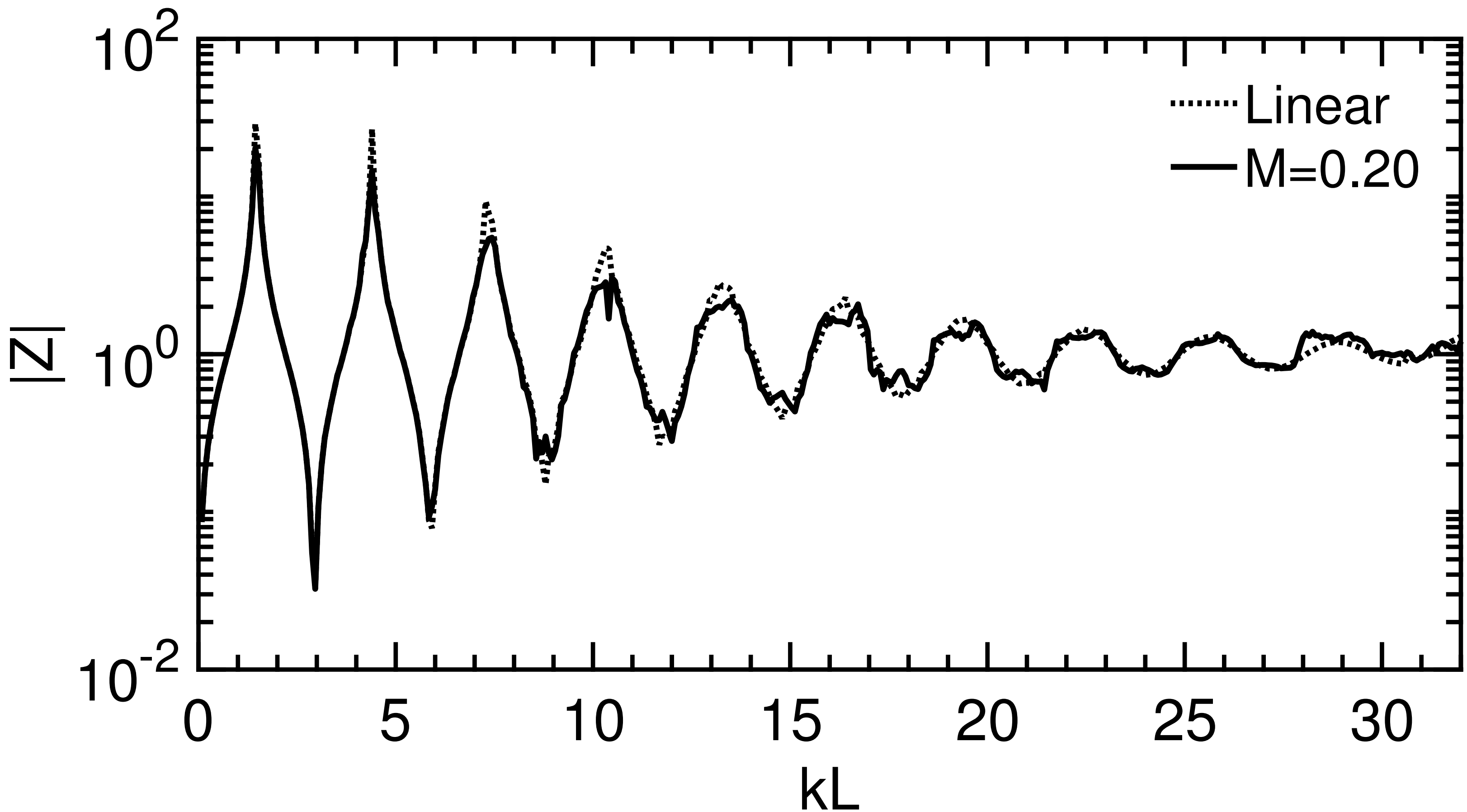
Linear resonances (1, 5 and 10)





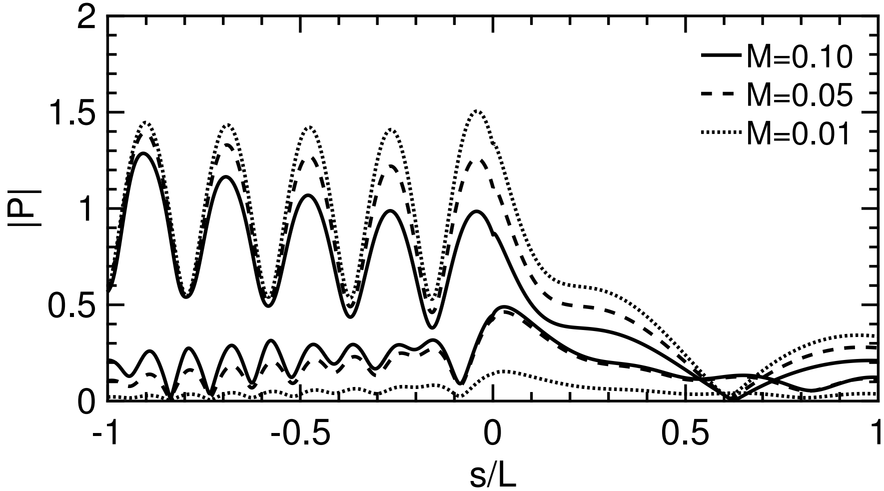


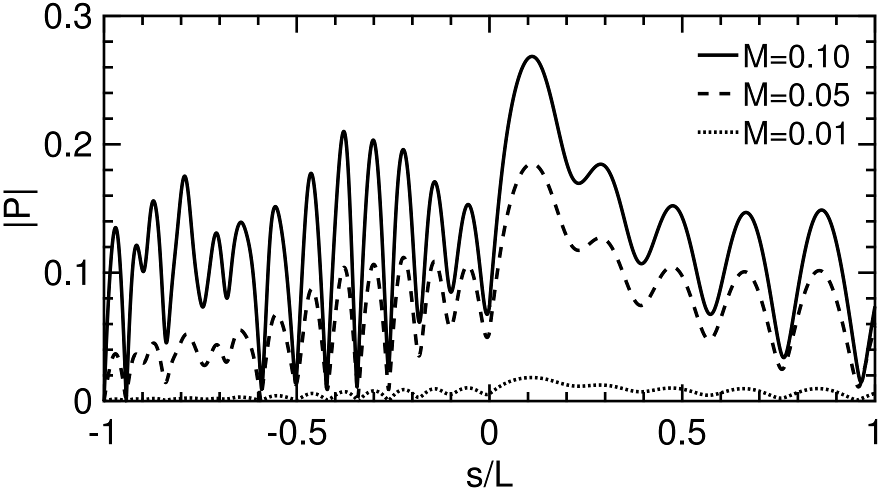
Linear vs nonlinear impedance for $L = 8h$



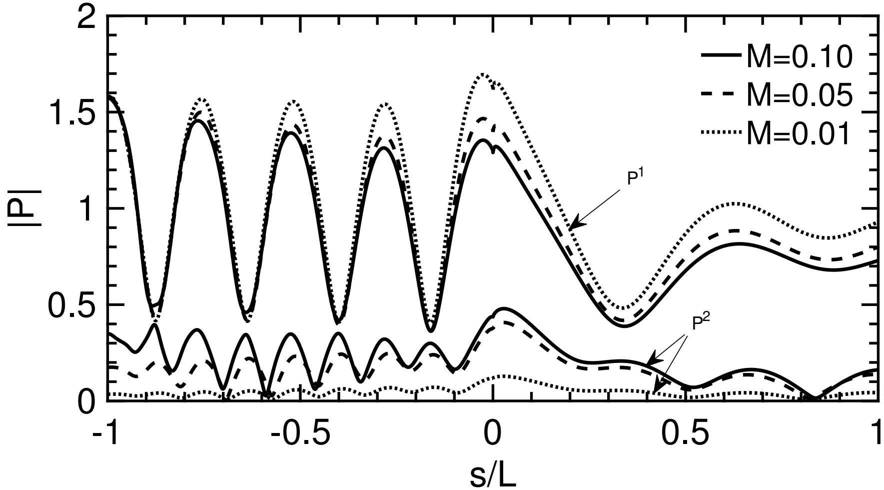
Modal amplitudes at 5th resonance

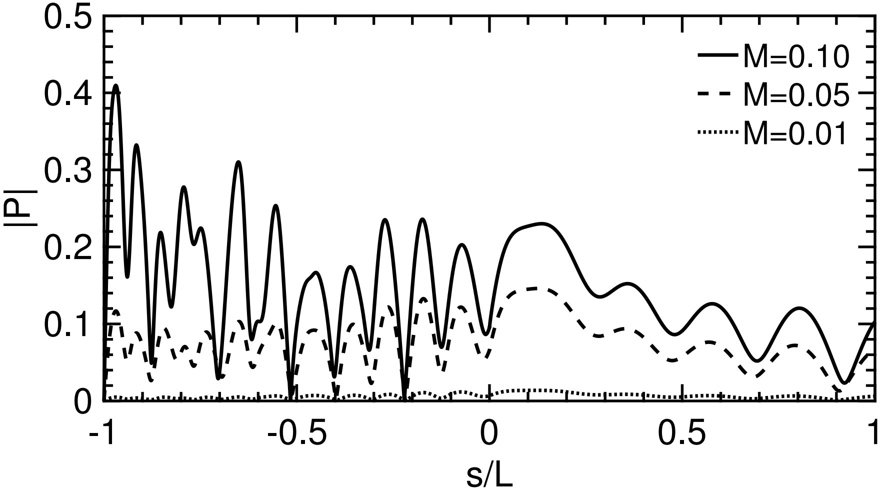
Open:





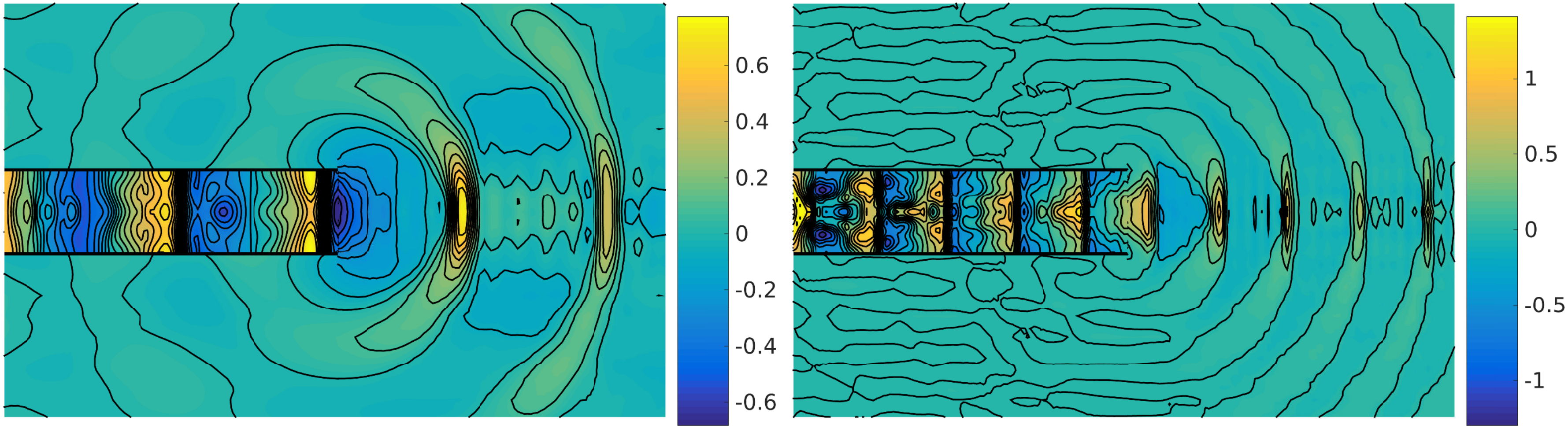
Closed:



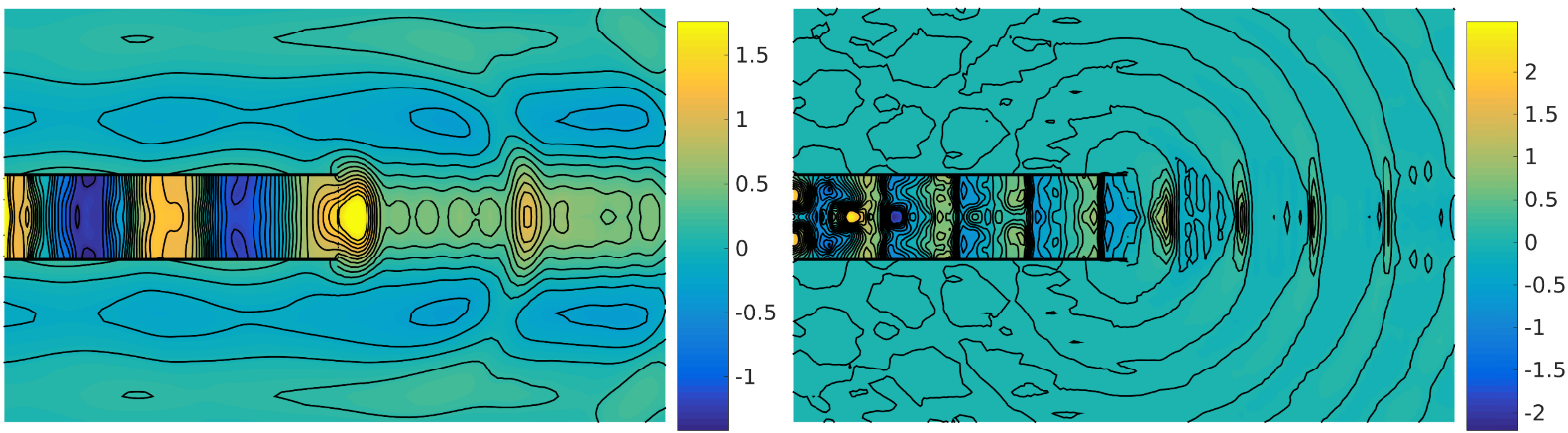


Duct exit at resonance (5th and 10th), $L = 8h$, $M = 0.1$

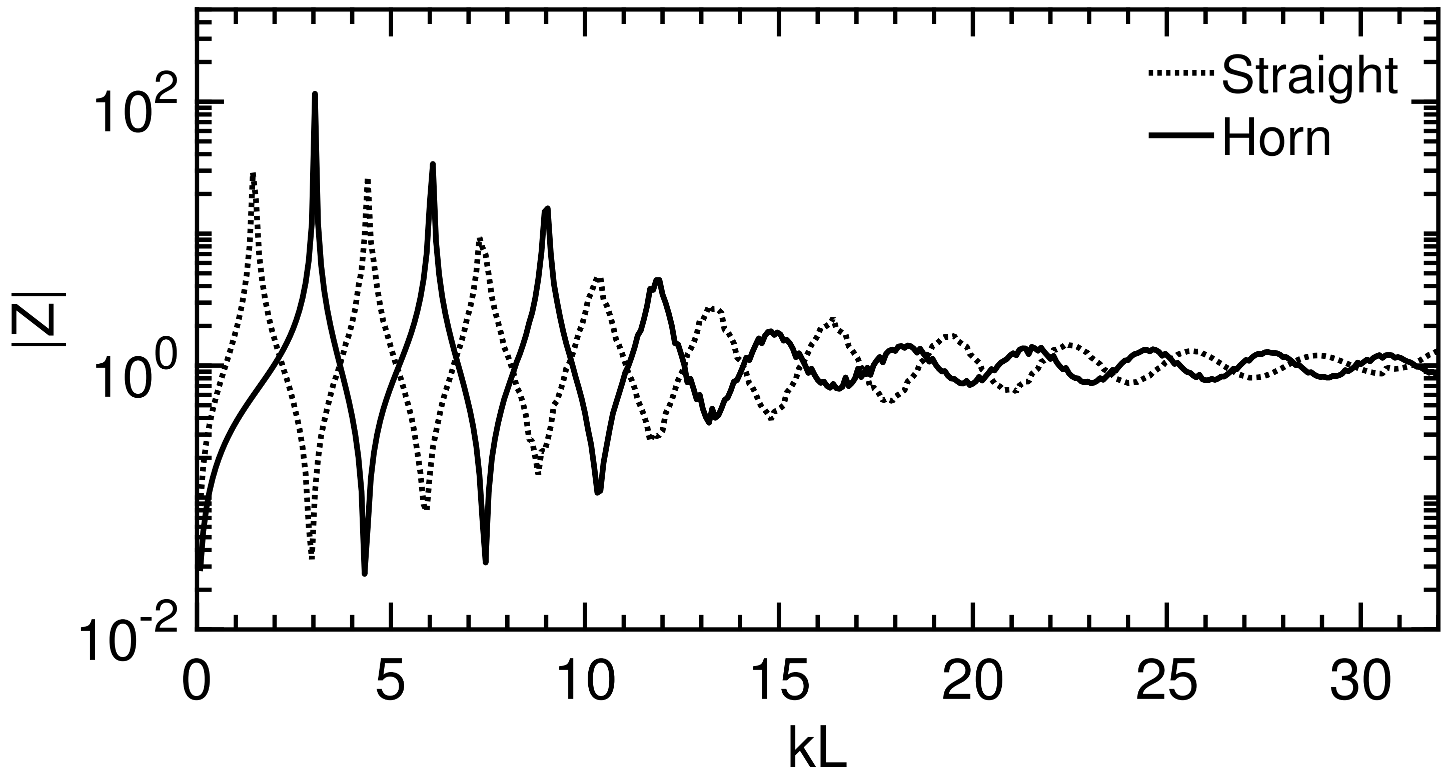
Open:



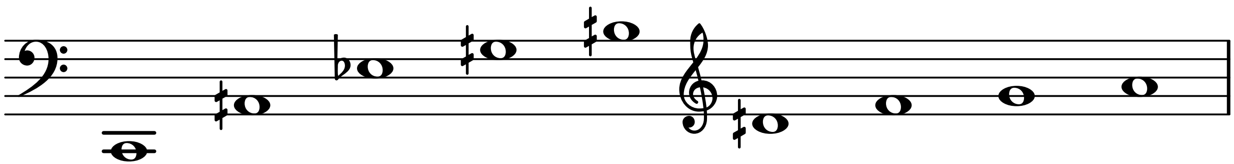
Closed:



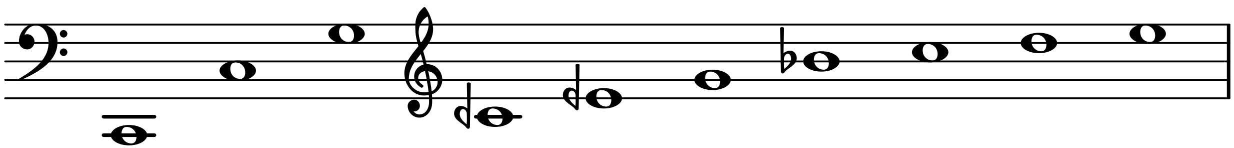
Exponential horn vs equivalent length straight duct



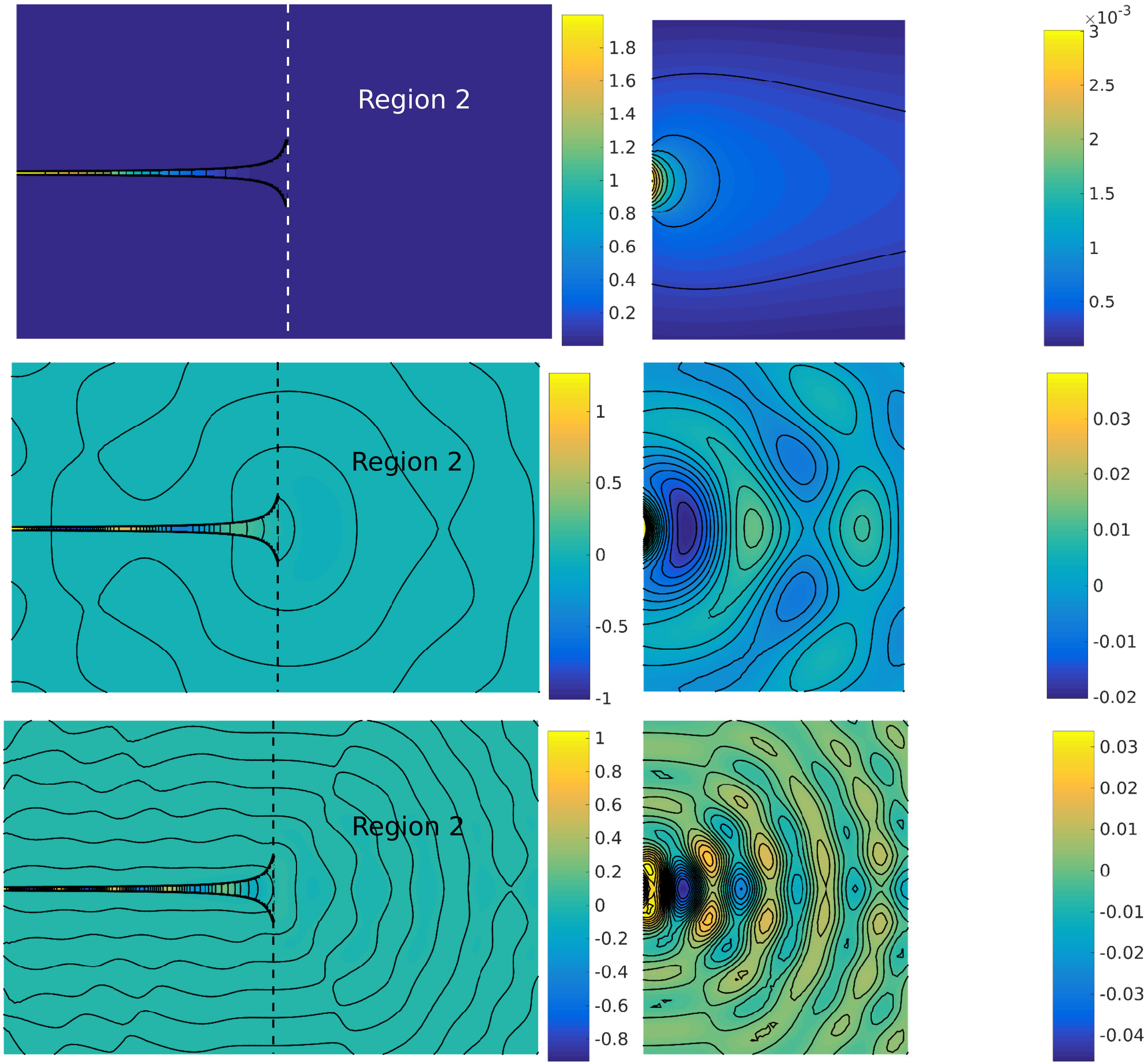
Open:



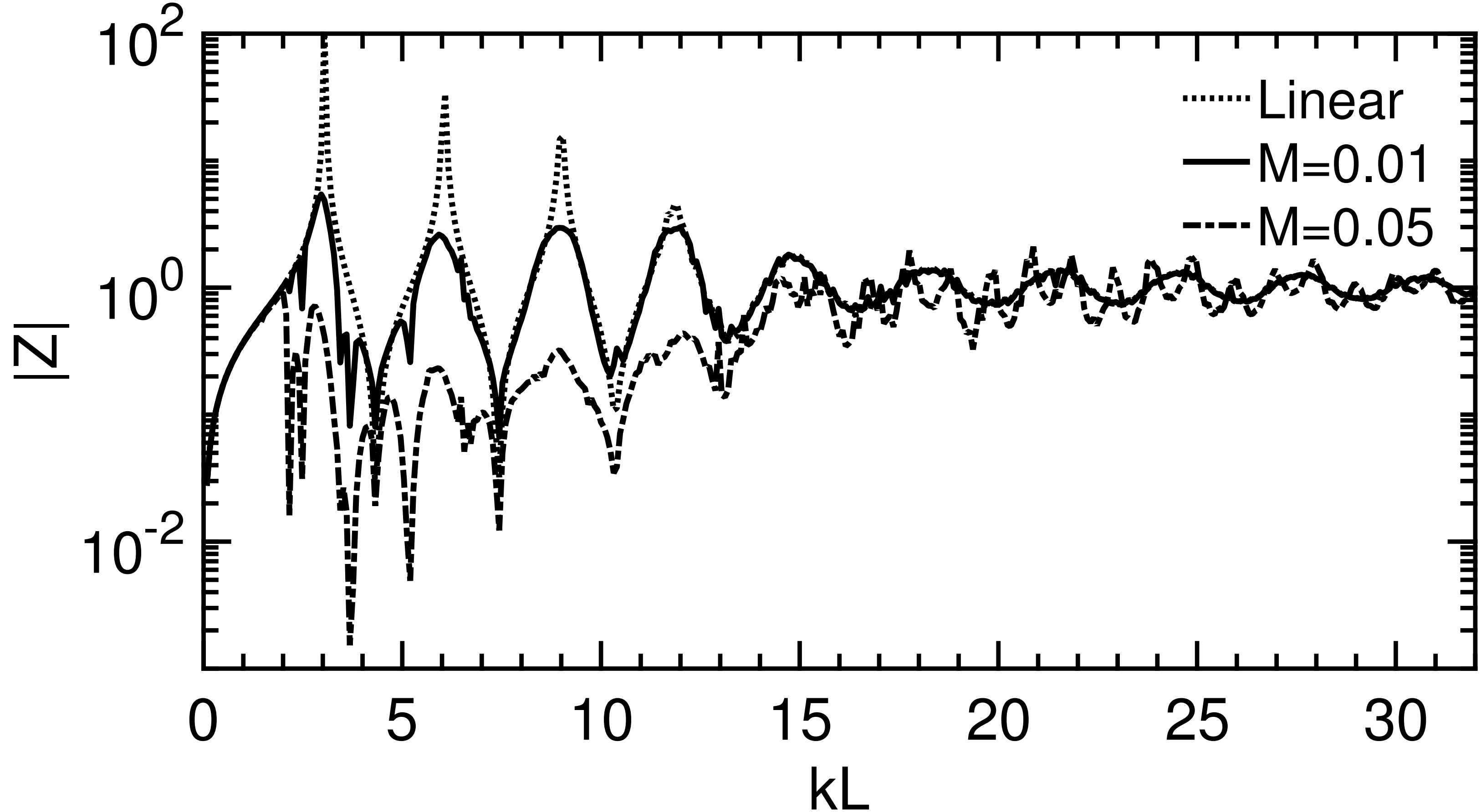
Closed:



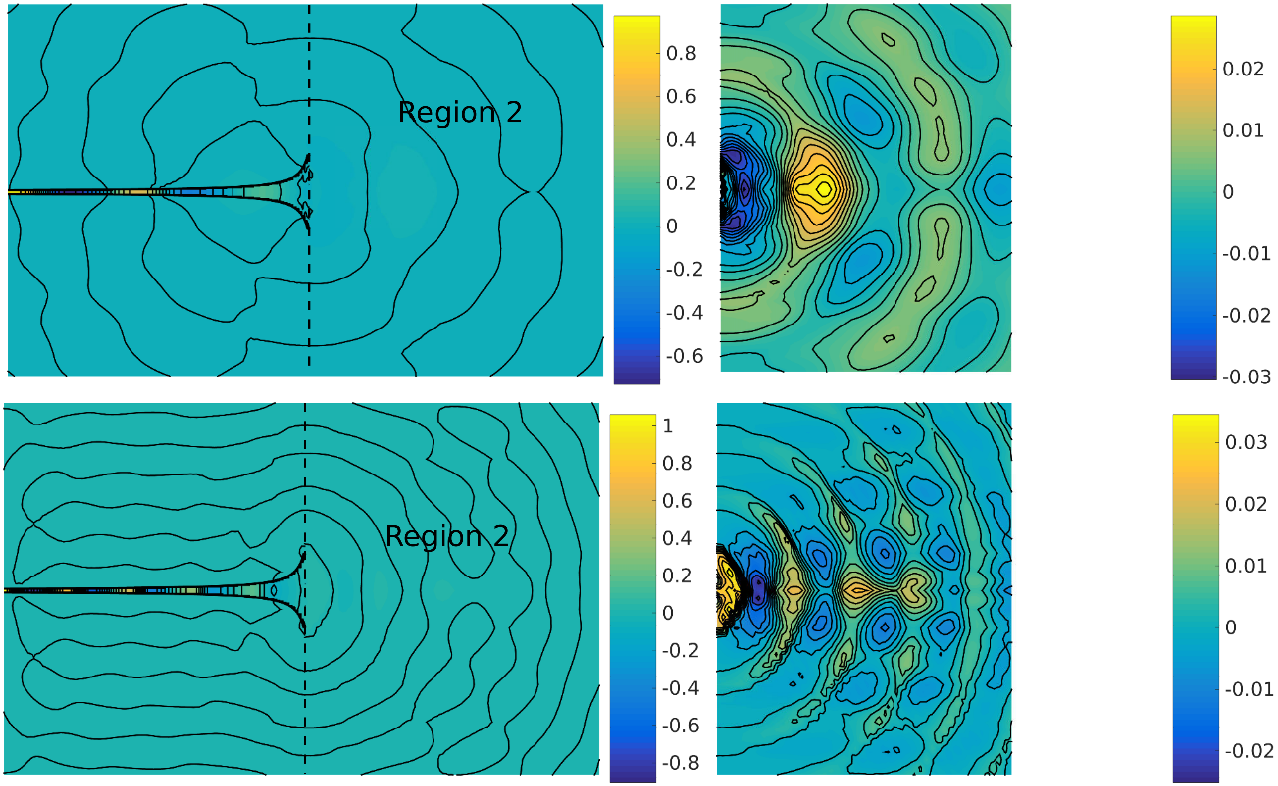
The closed horn at resonances (1, 5 and 10)



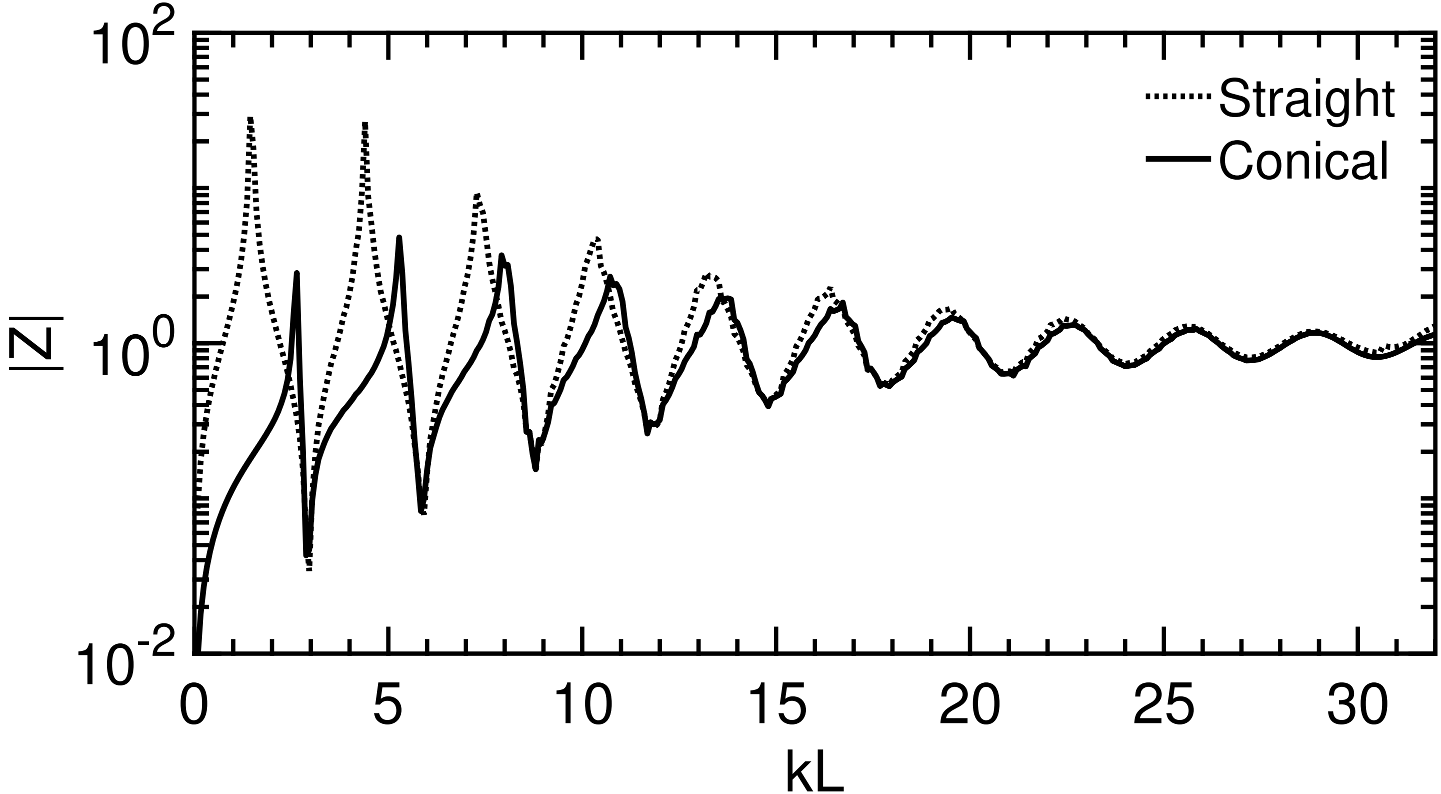
Linear vs Nonlinear impedance in an exponential horn

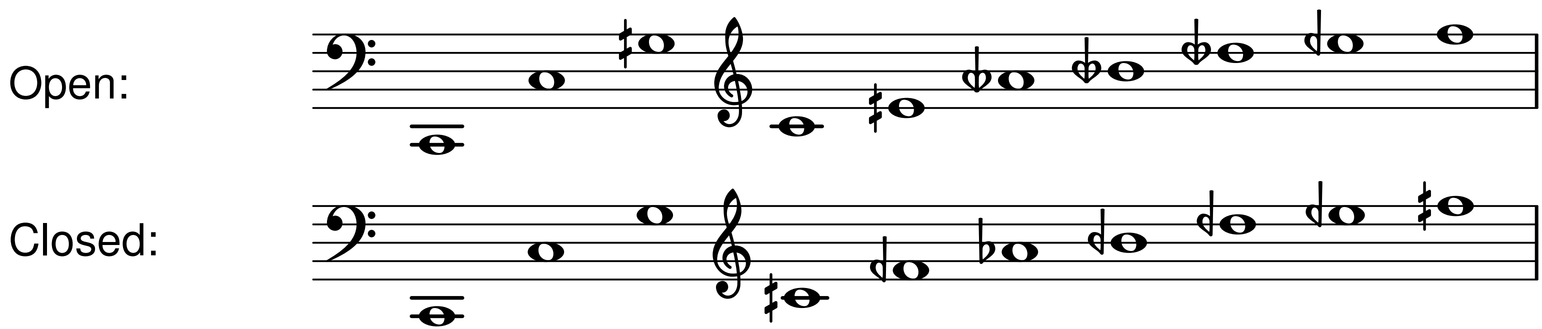


Closed horn at resonance (5th and 10th), $M = 0.05$

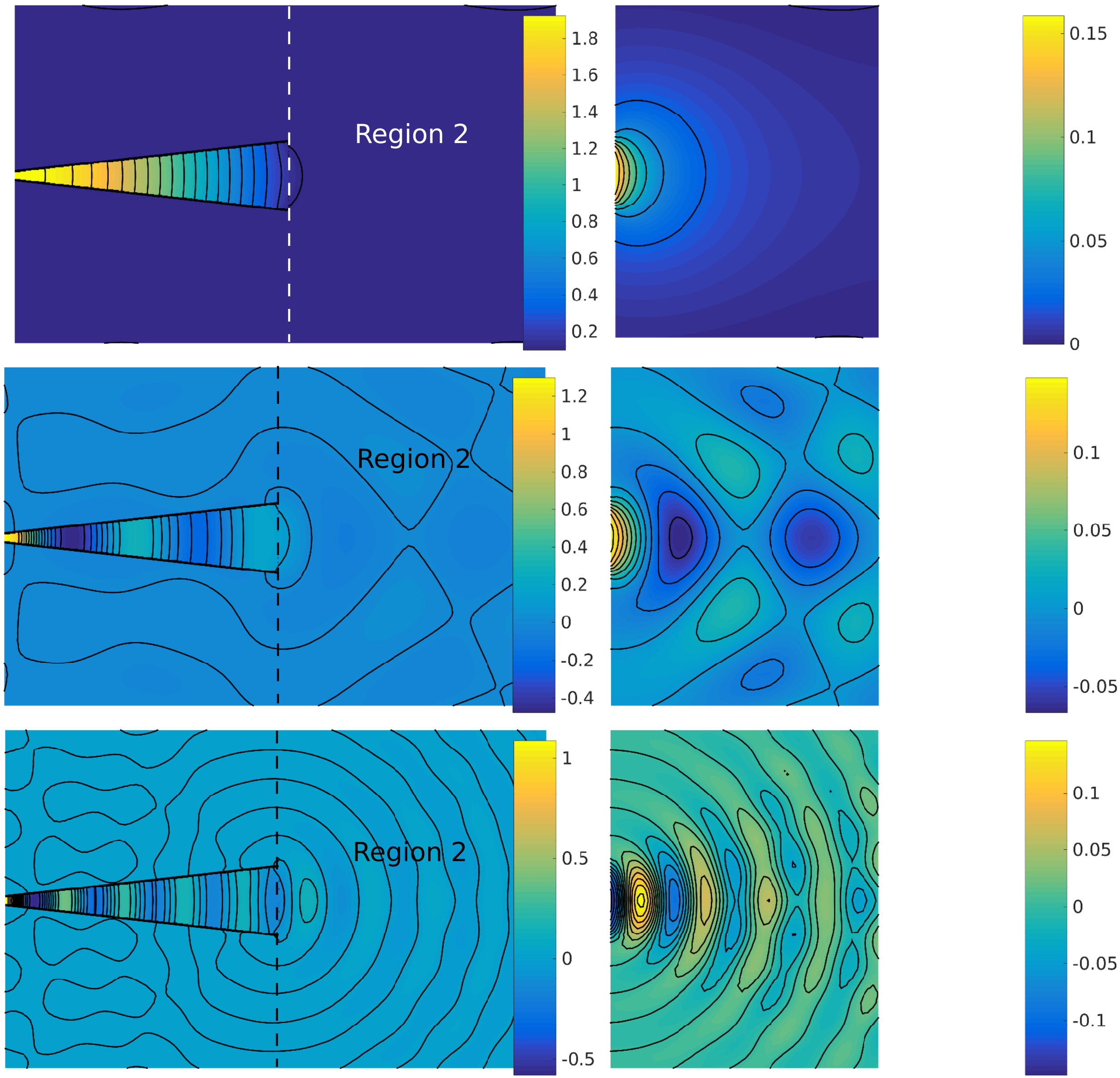


Conical vs straight duct impedance

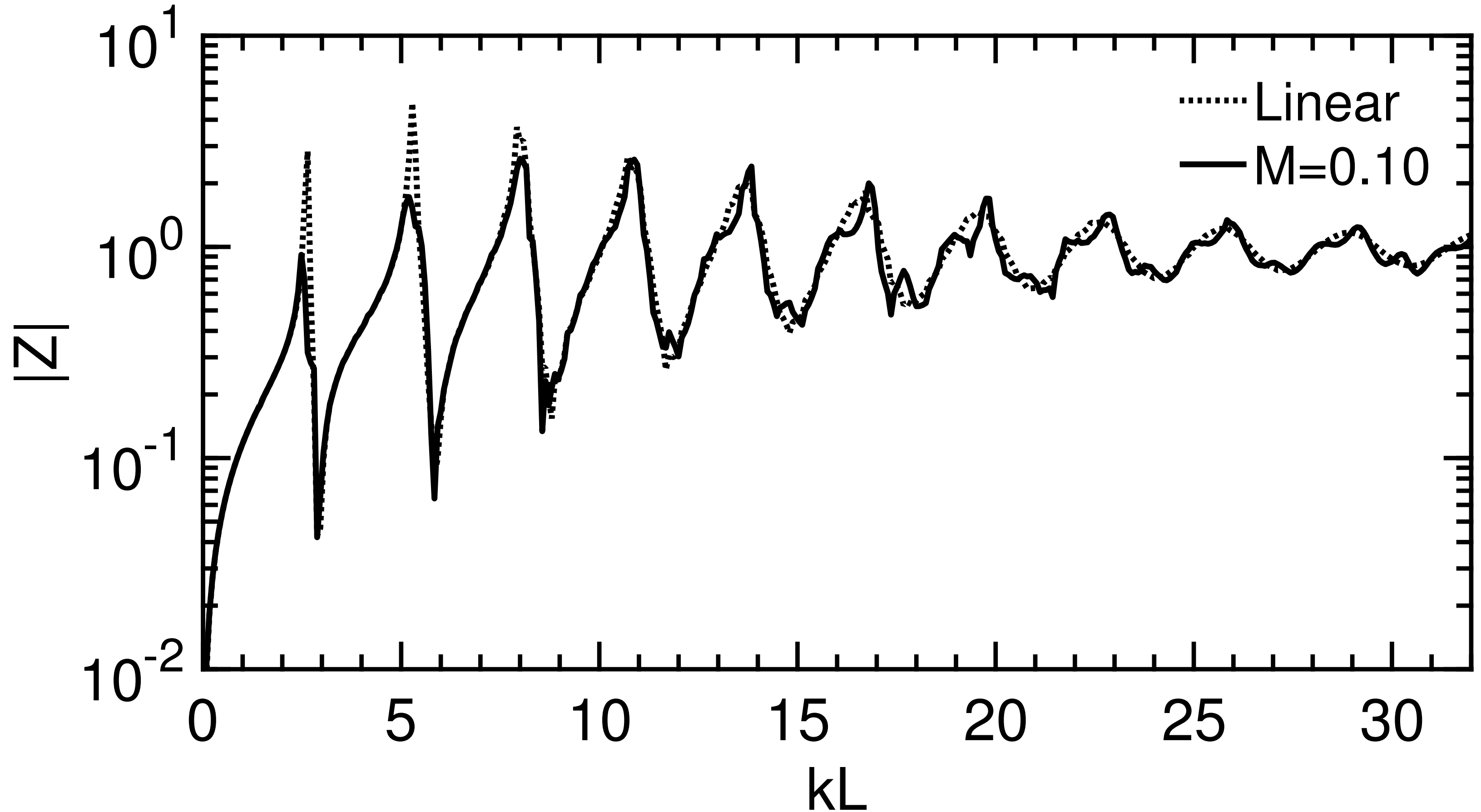




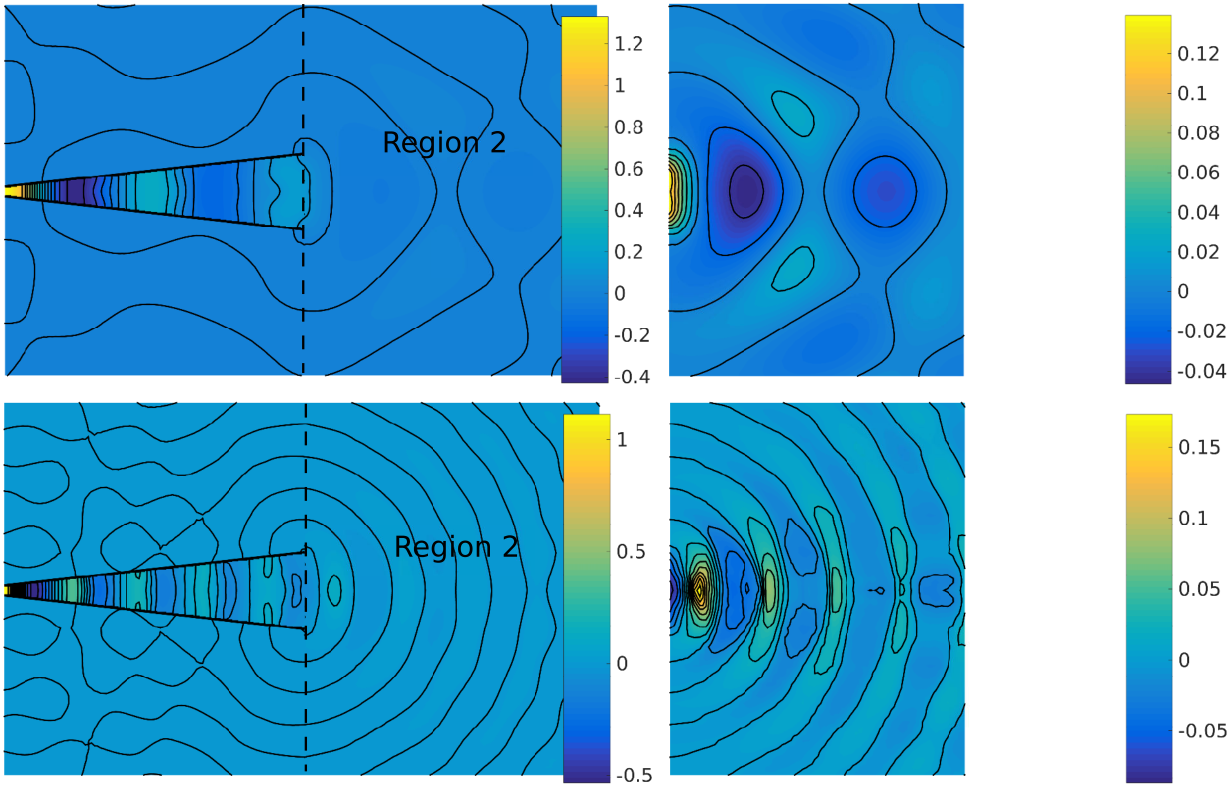
Closed conical horn at resonance (1st, 5th and 10th)



Linear vs nonlinear for a conical duct



Closed conical duct at resonance (5th and 10th), $M = 0.1$



Curved vs straight cylindrical duct