Compact lowpass ladder filters using tapped coils

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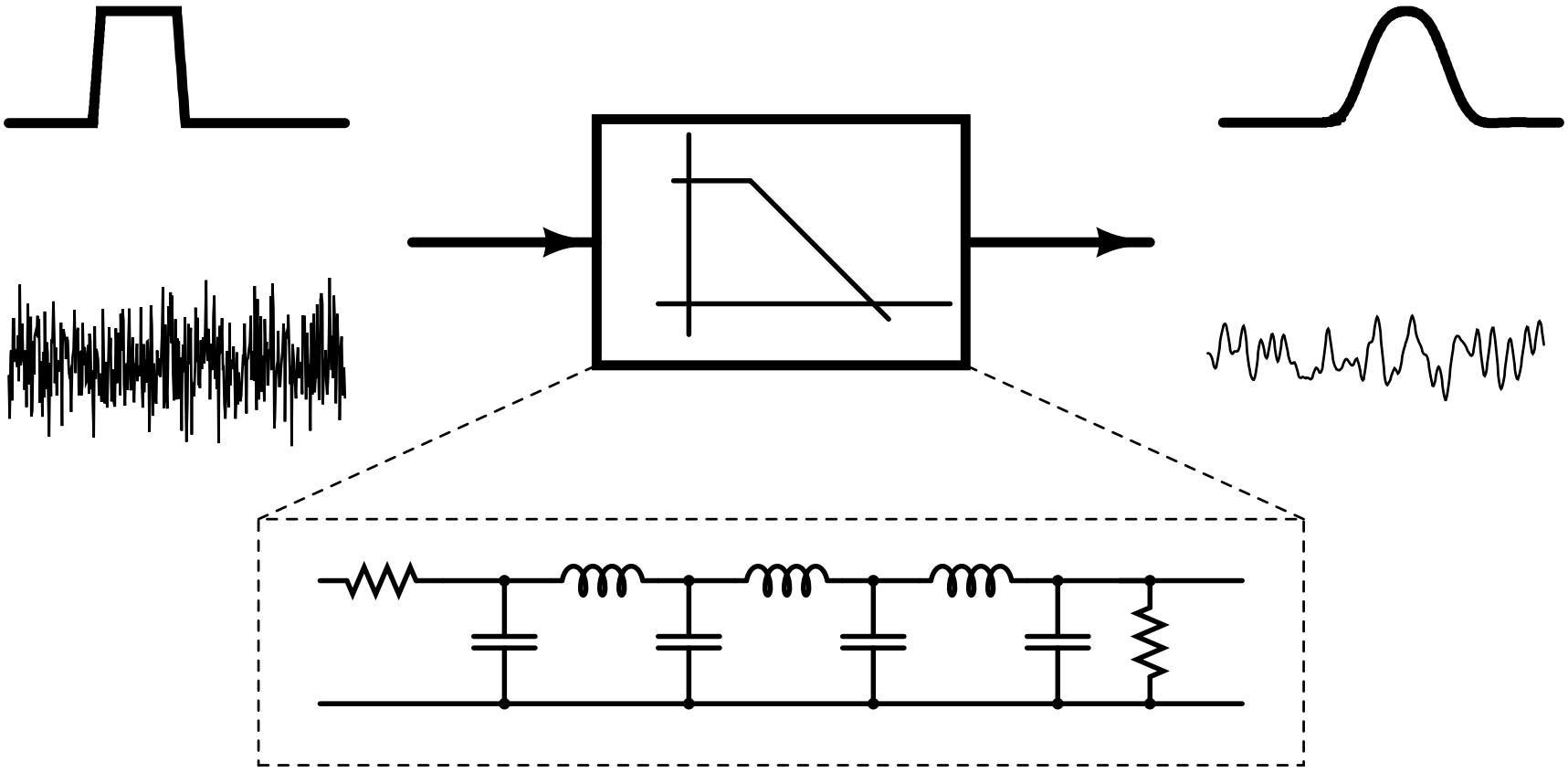
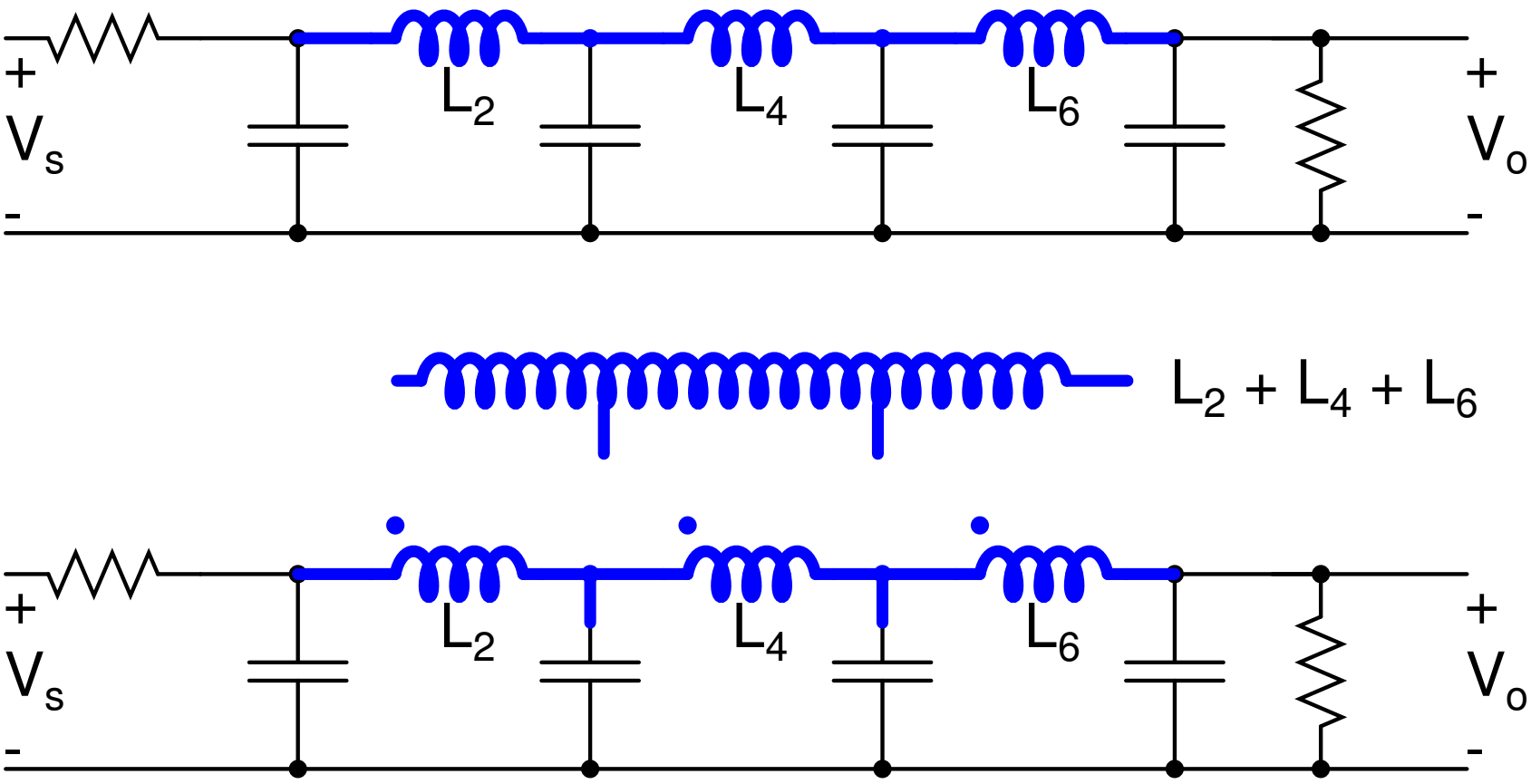
Pulse shaping filters in serial links



- Spiral inductors occupy large chip area

LC ladder filters for pulse shaping

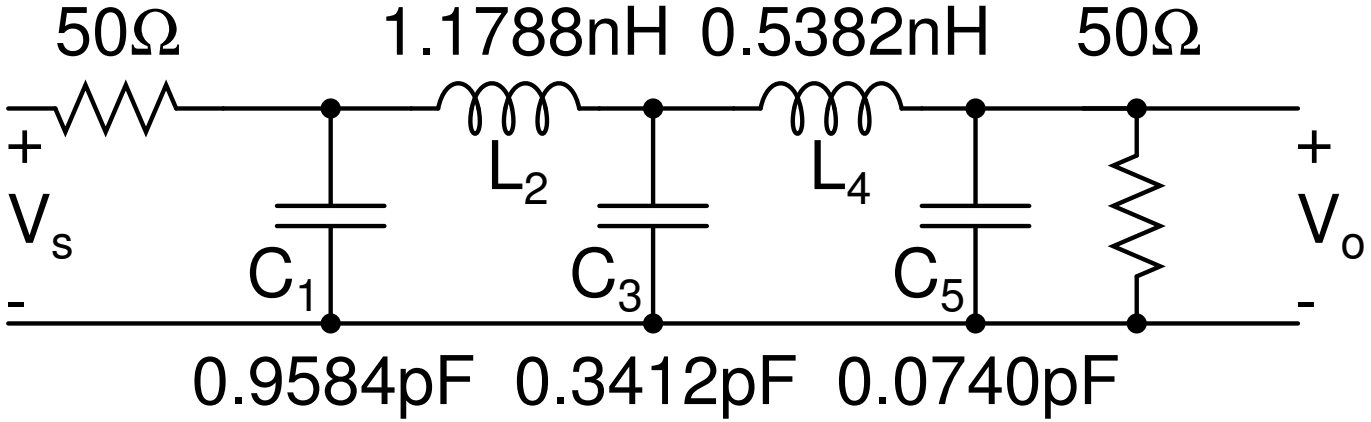


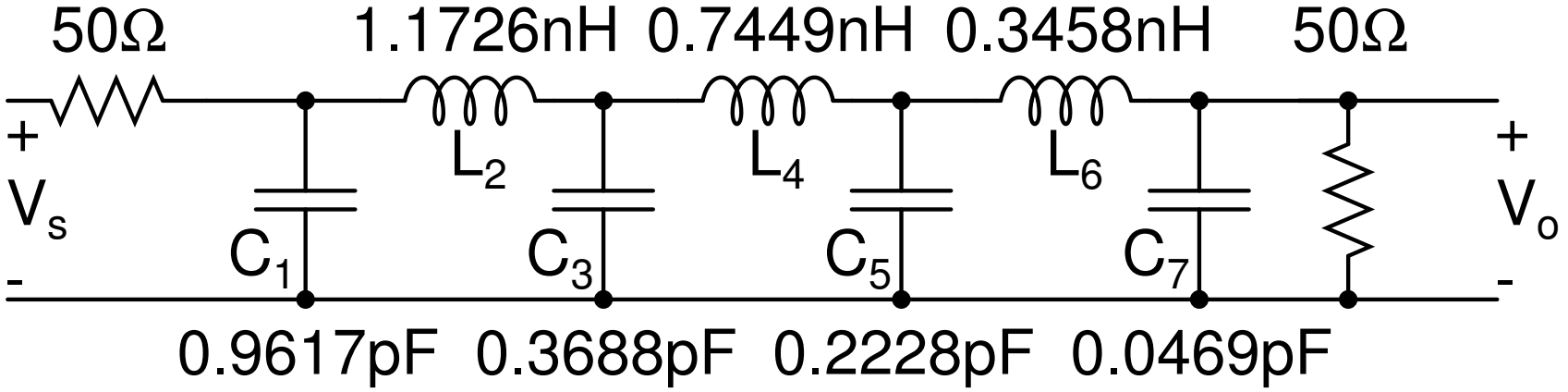
- Use a single spiral with multiple taps to save area

Outline

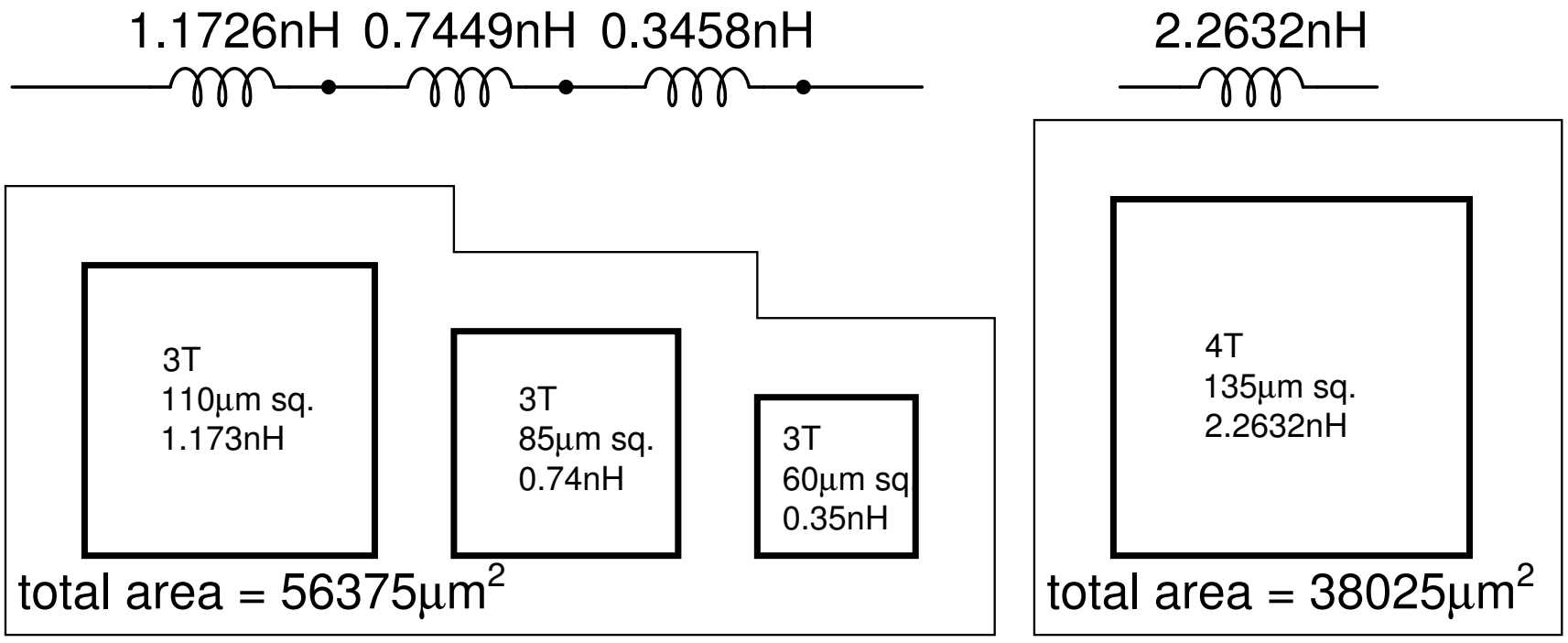
- Single inductor with multiple taps versus multiple inductors
- Effect of coupling between inductors in a ladder filter
- Cancelling the effect of coupling
- Seventh order Bessel filter using a single spiral
- Simulation results
- Conclusions

7.5 GHz Bessel filters for 10 Gb/s data



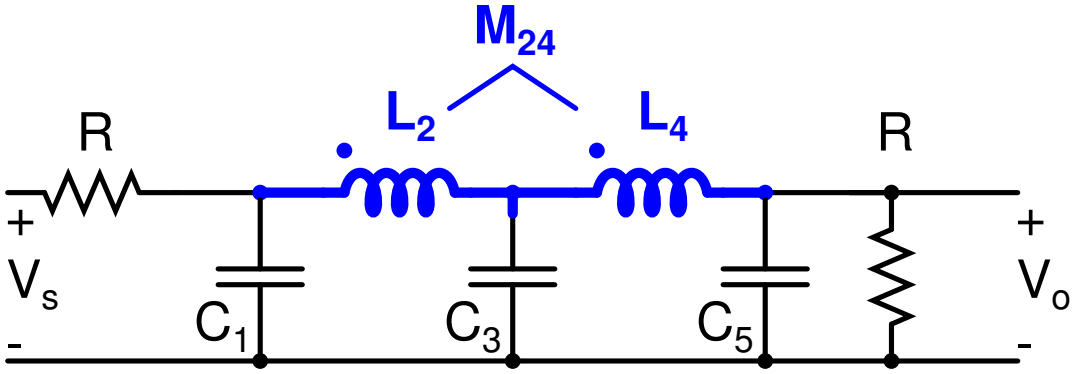


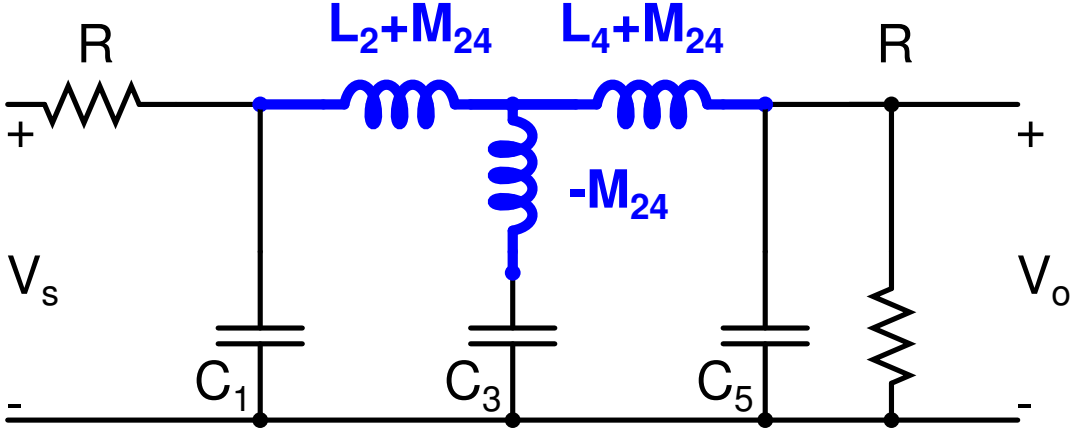
Single spiral versus multiple spirals



* The area of the single spiral is incorrectly given as 27225µm^2 in the paper

Coupling between adjacent inductors

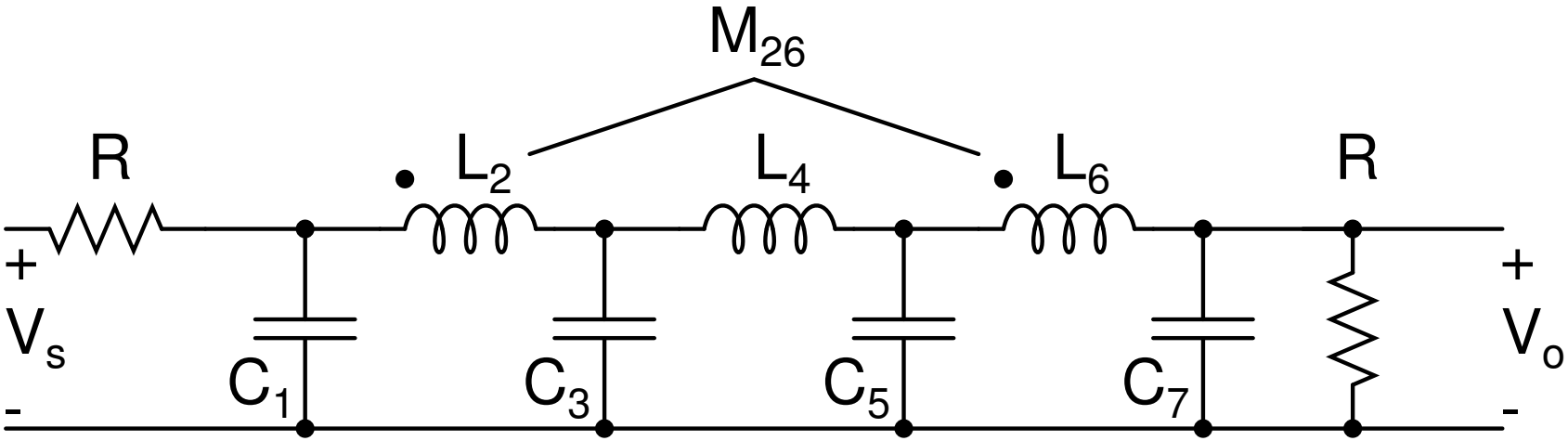




$$\frac{V_o(s)}{V_s(s)} = \frac{1 - s^2 M_{24} C_3}{D_5(s)}$$

- Zeros at $\pm\sqrt{1/M_{24}C_3}$
- Undershoot
- Reduced attenuation

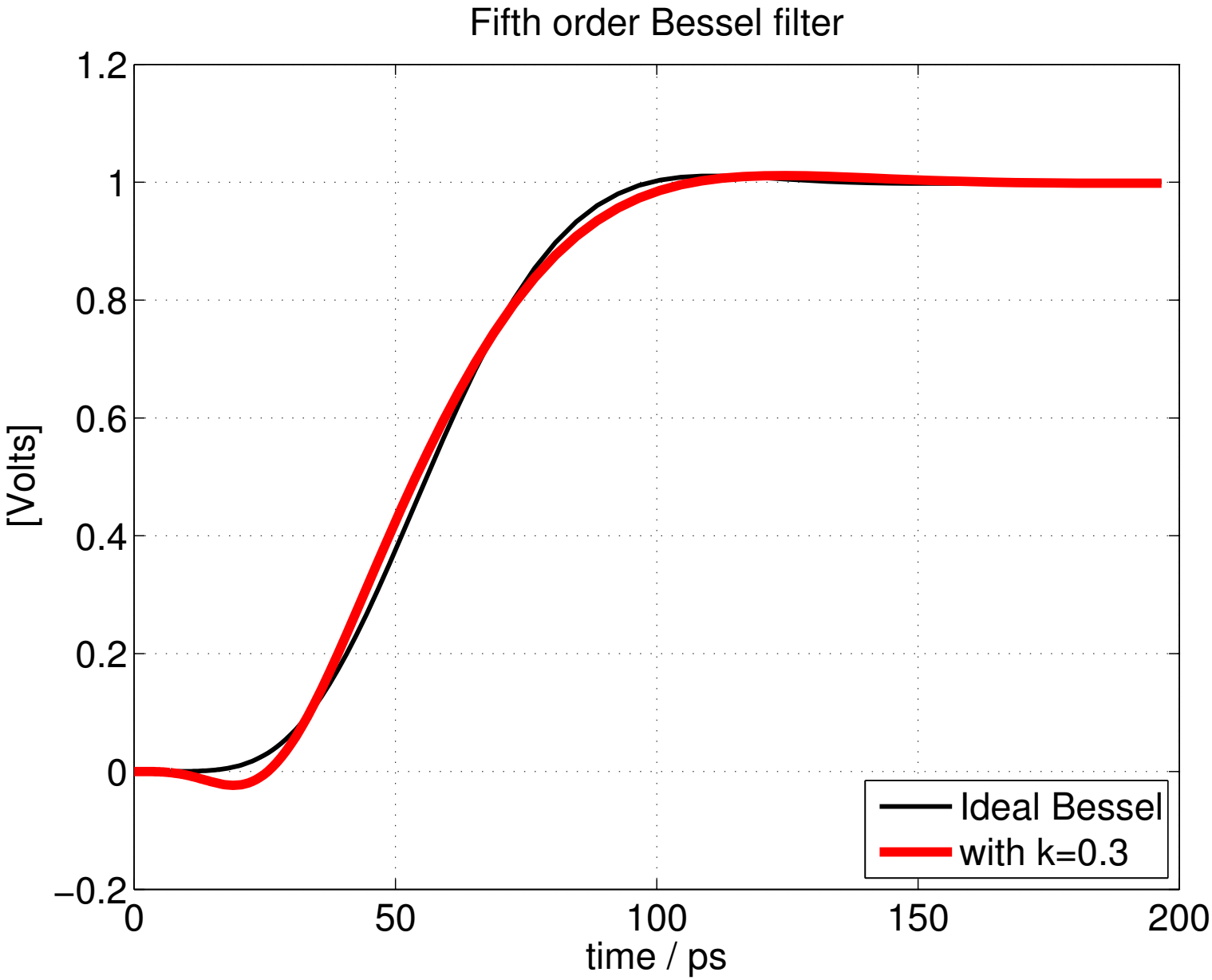
Coupling between alternate inductors



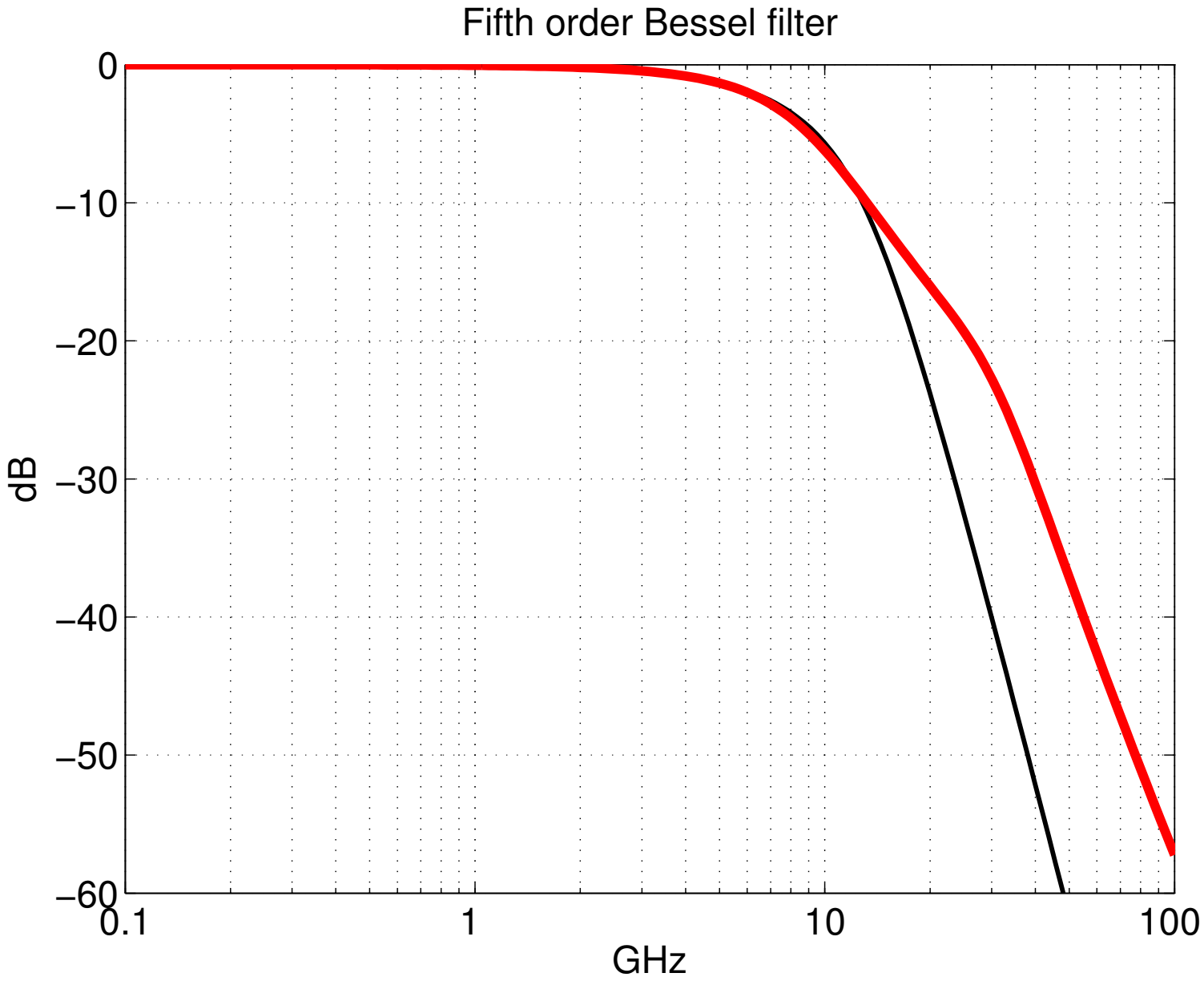
$$\frac{V_o(s)}{V_s(s)} = \frac{1 - s^2(C_3 + C_5)M_{26} - s^4 C_3 C_5 L_4 M_{26}}{D_7(s)}$$

- A pair of zeros on the real axis
- A pair of zeros on the imaginary axis
- Undershoot, notch, reduced high frequency attenuation

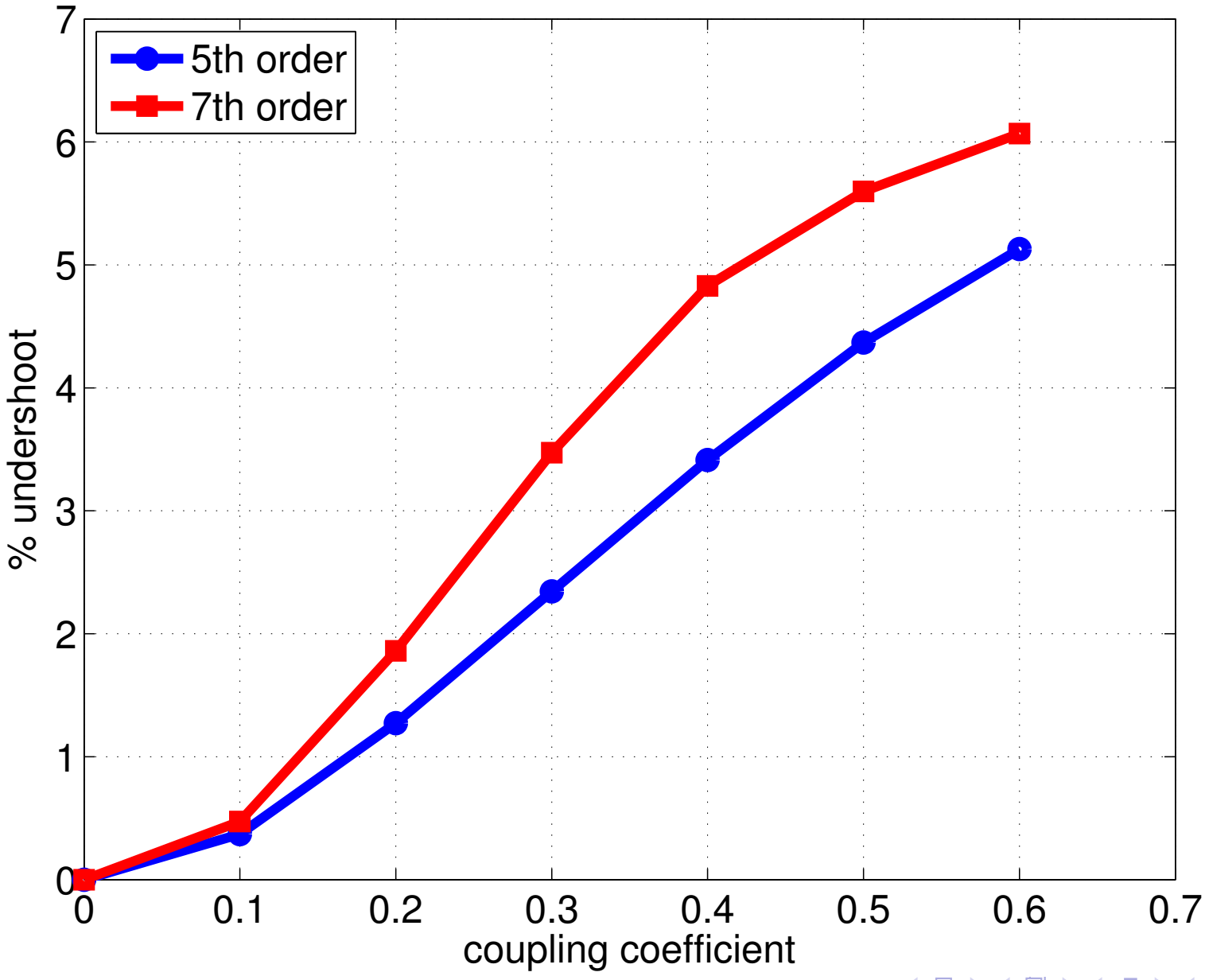
Step response with coupling



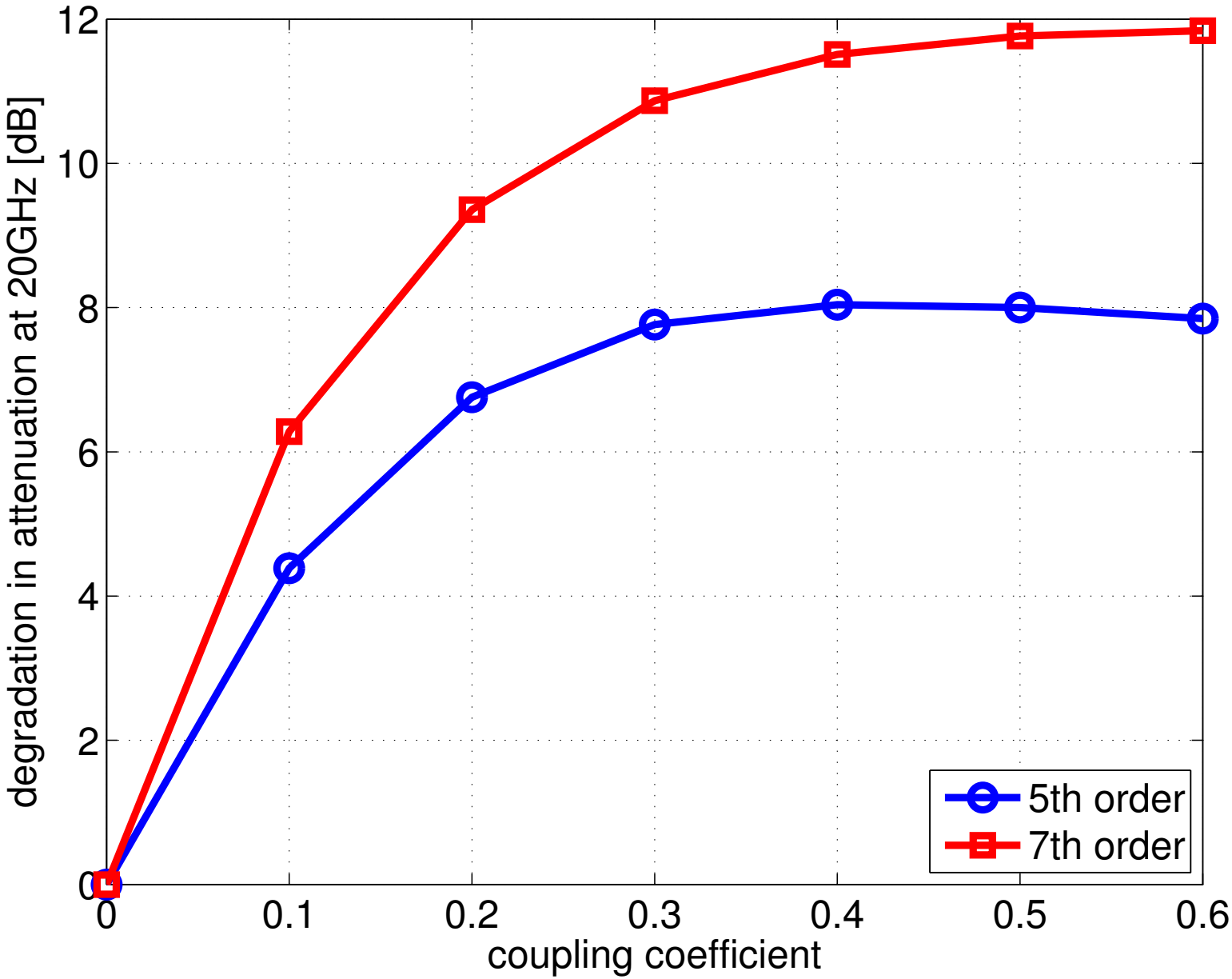
Magnitude response with coupling



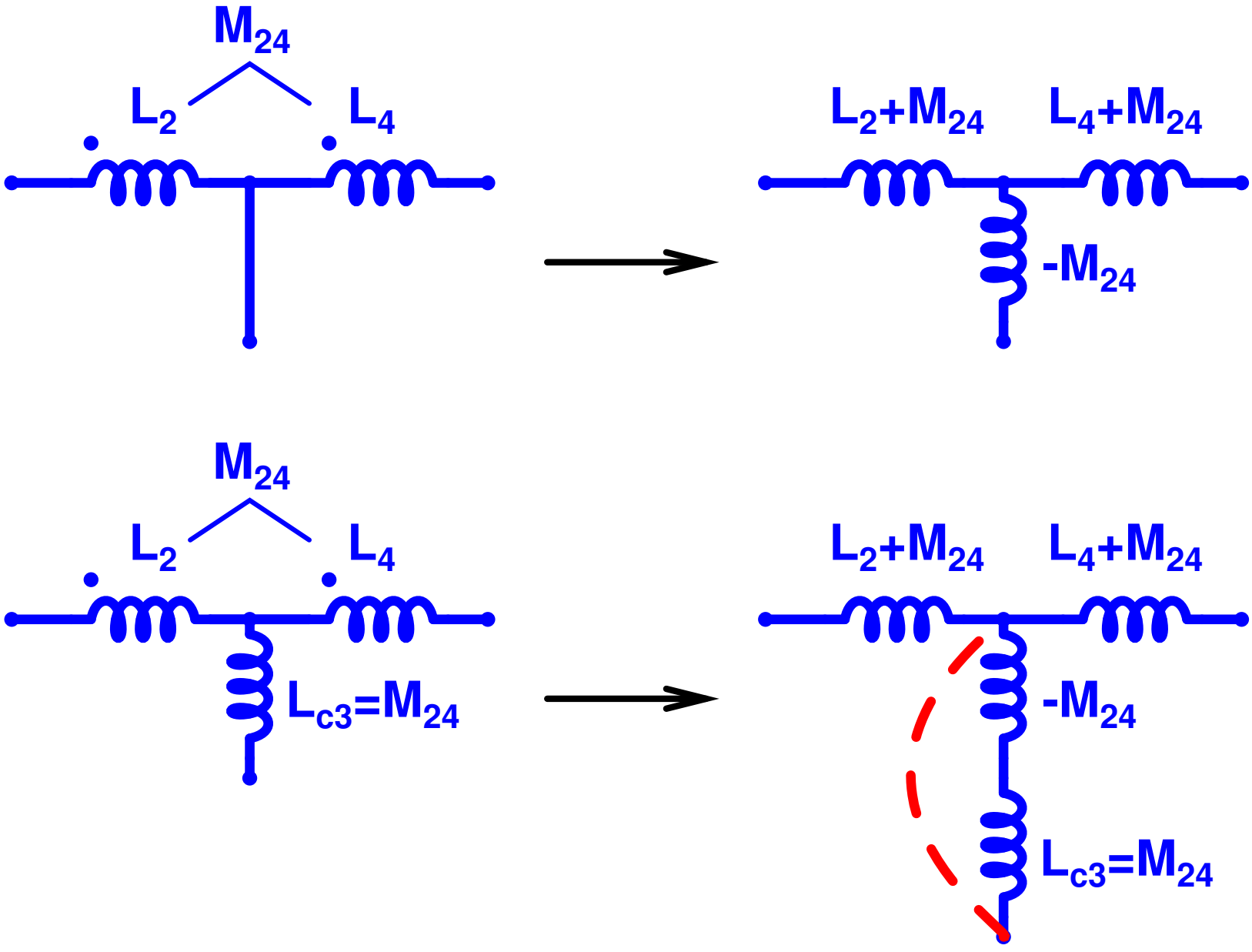
Effect of coupling on the step response



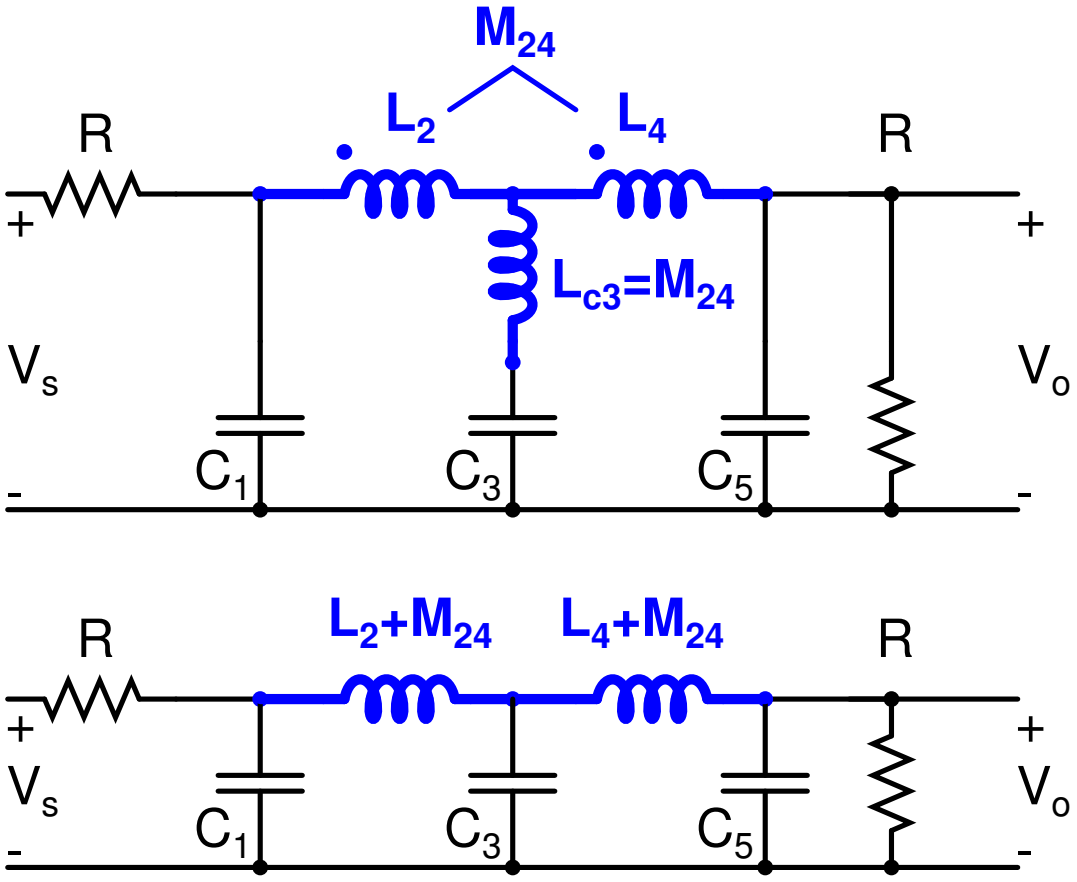
Effect of coupling on the magnitude response



Cancelling the effect of coupling between adjacent coils

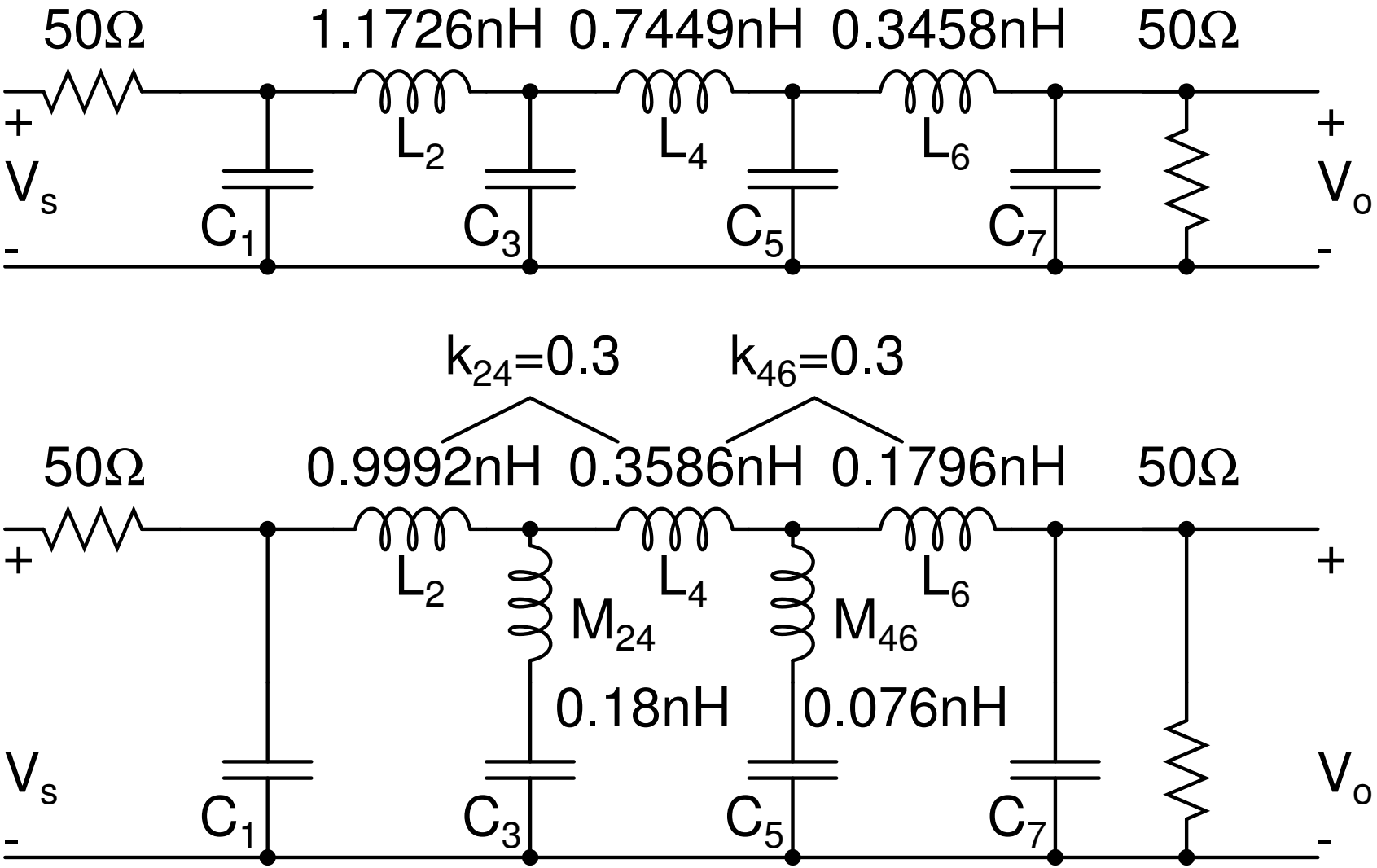


Cancelling the effect of coupling between adjacent coils

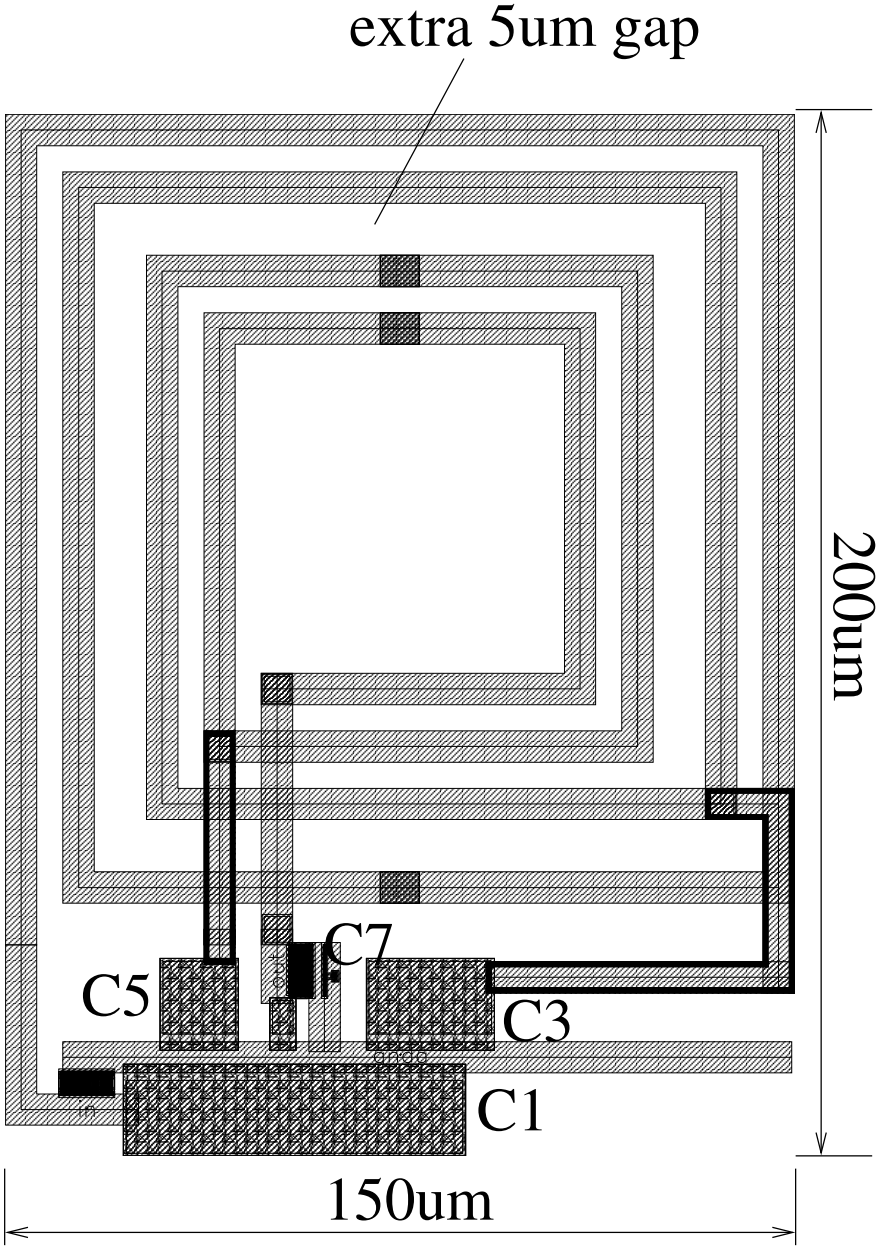


- Series inductance cancels the effect of coupling
- Inductance of the tap line can suffice

7.5 GHz seventh order Bessel filter



7.5 GHz seventh order Bessel filter

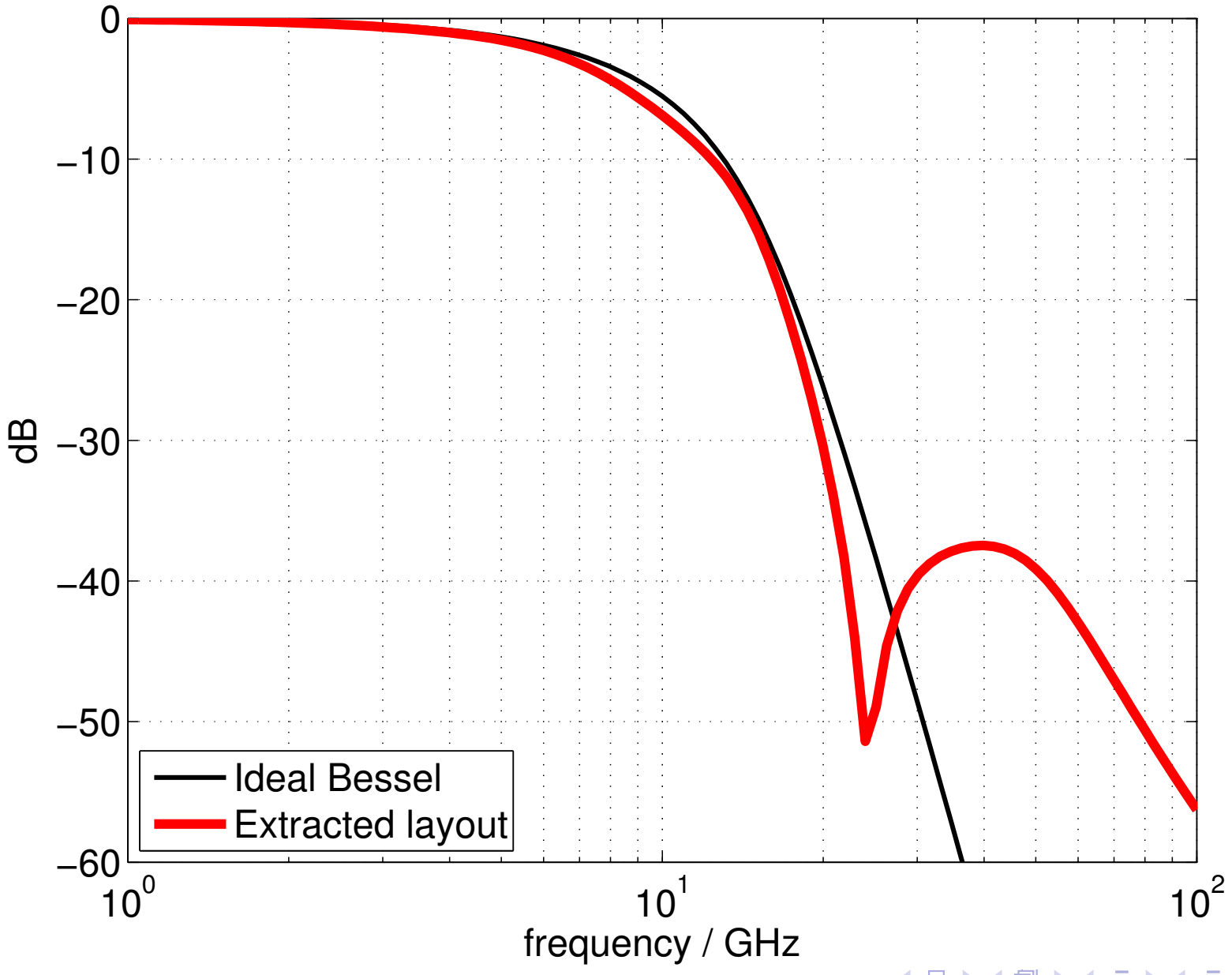


- $48,300\ \mu\text{m}^2$
- $56,375\ \mu\text{m}^2$ for separate spirals (excl. capacitors)

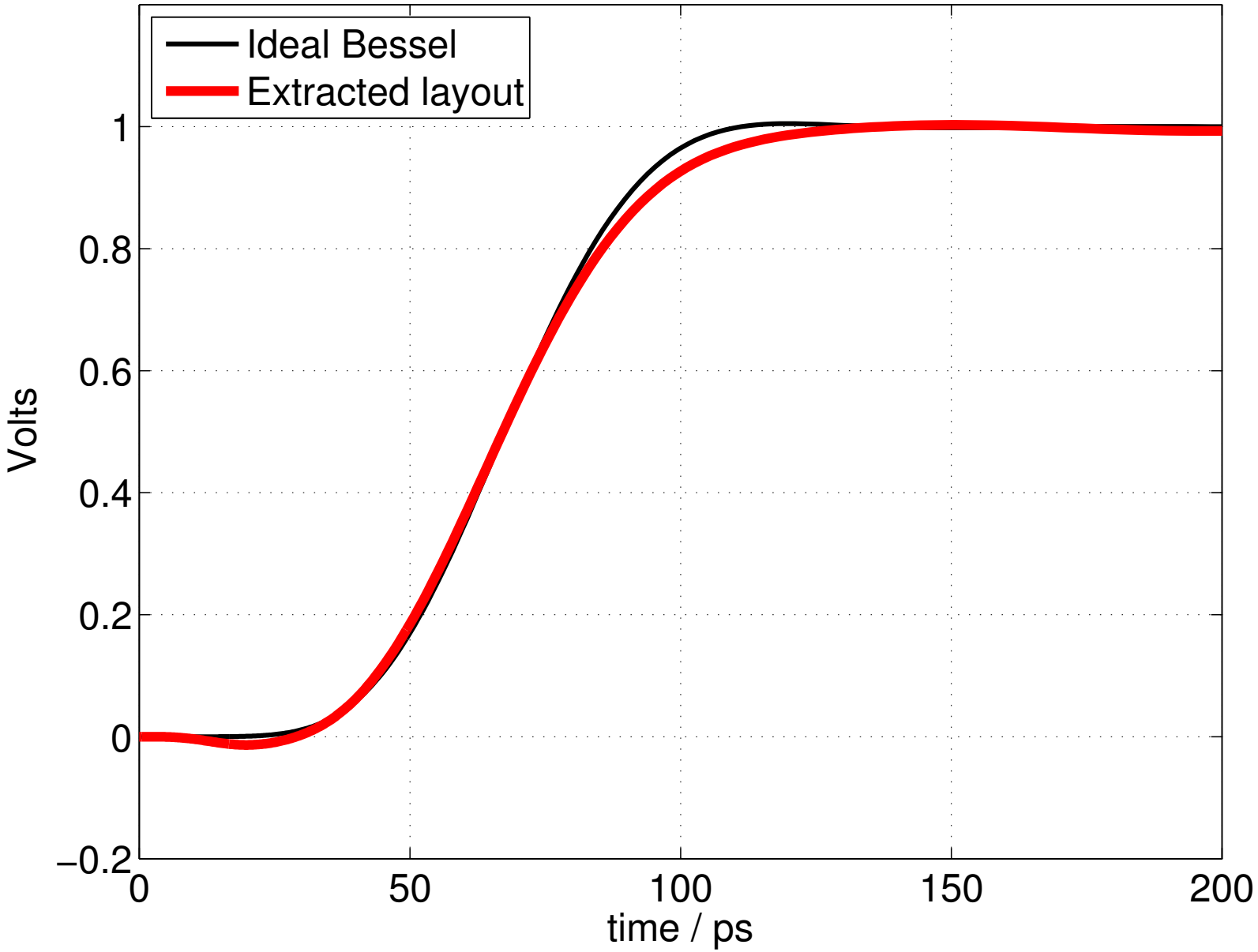
Simulated parameters of the multi-tap inductor

	Desired	Obtained		Desired	Obtained
L_2	0.9992 nH	0.957 nH	k_{24}	0.3	0.308
L_4	0.3586 nH	0.424 nH	k_{46}	0.3	0.339
L_6	0.1796 nH	0.187 nH	k_{26}	0	0.160
L_{c3}	180 pH	96 pH	L_{c5}	76 pH	24 pH

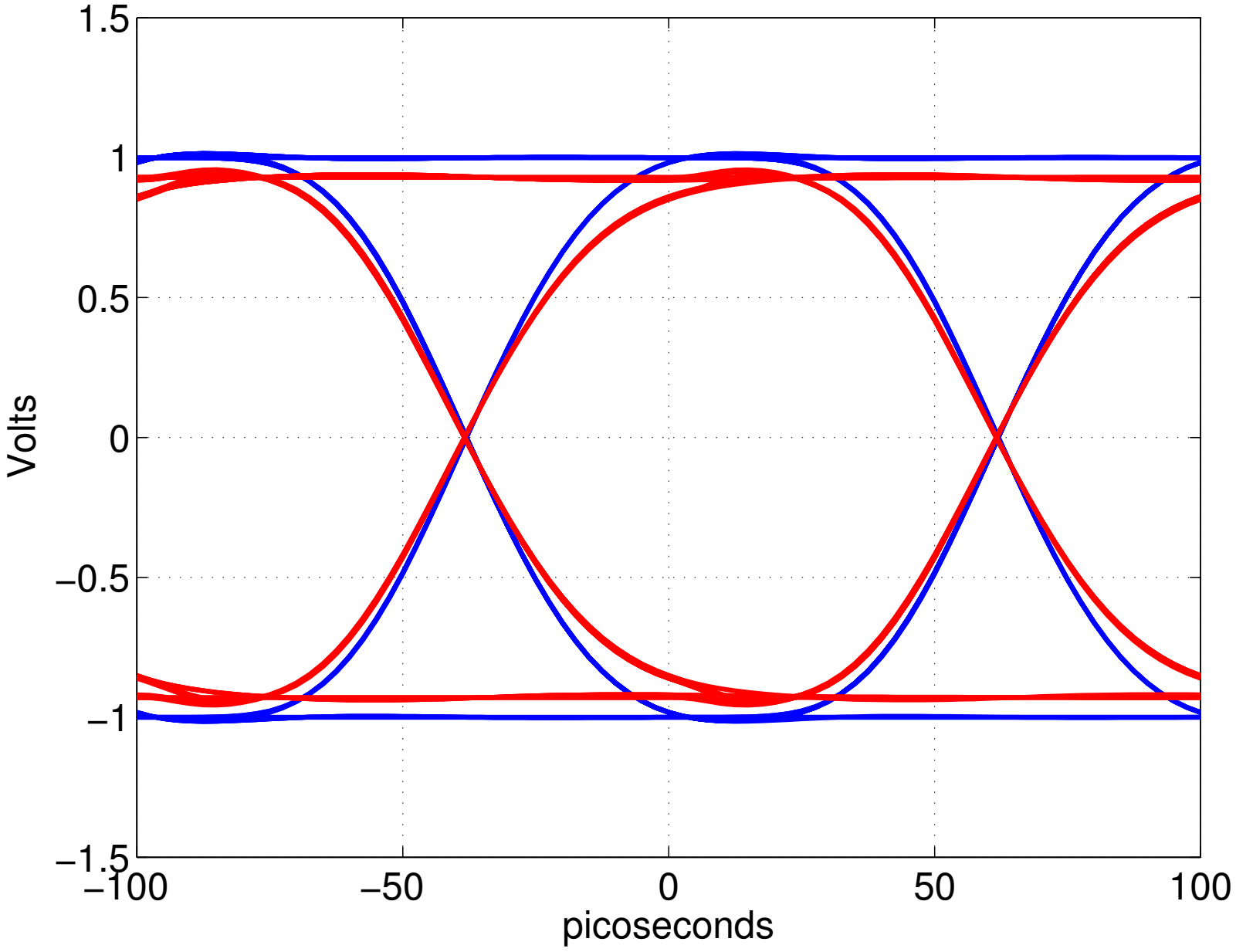
Magnitude response of the realized filter



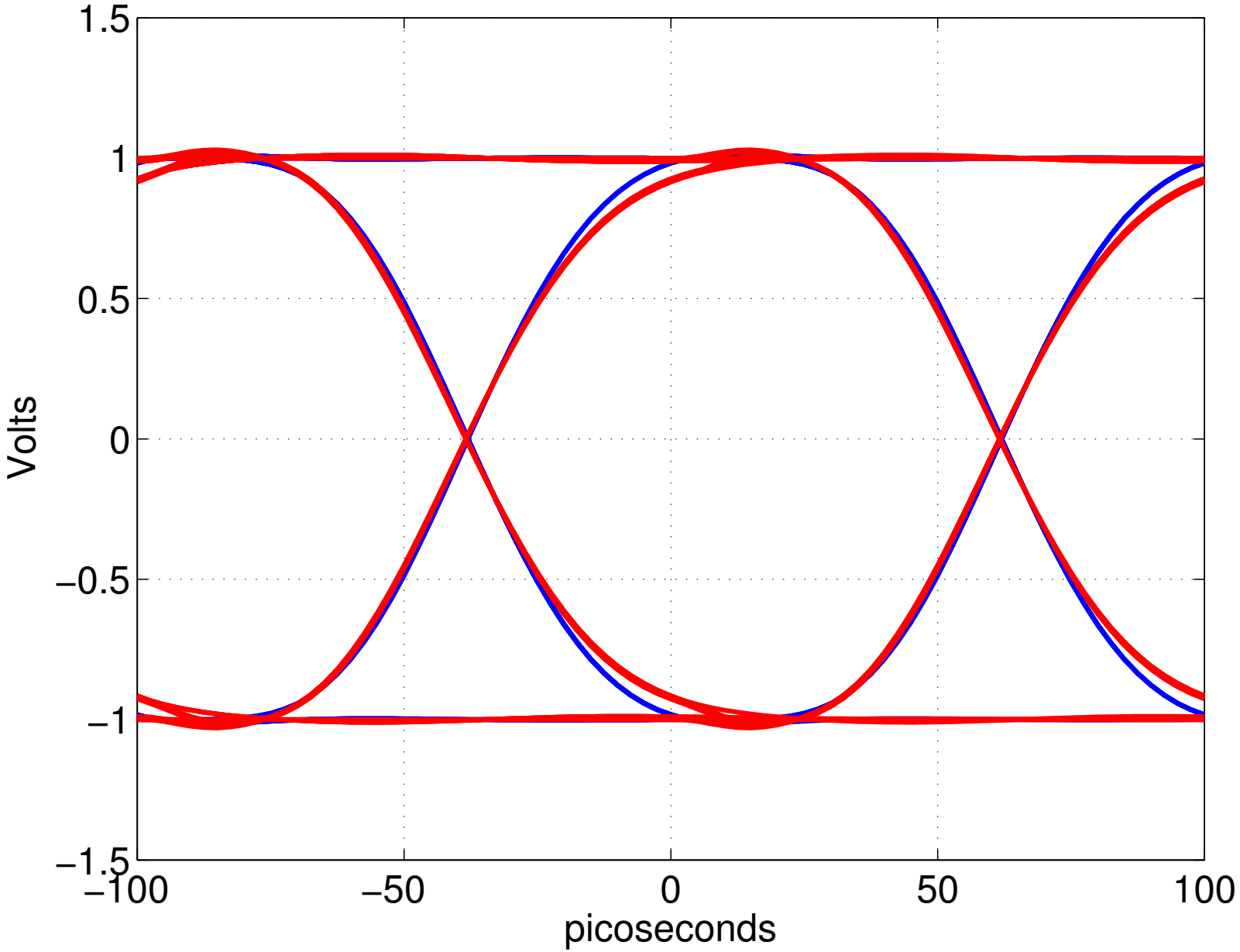
Step response of the realized filter



Eye diagram at 10Gb/s



Eye diagram at 10Gb/s—normalized to dc gain



Conclusions

- Single spiral with multiple taps reduces layout area
- Mutual coupling results in additional zeros
- Adjacent coupling cancelled using series inductances
- 15% to 30% area savings in practice
- Also useful for conventional LC ladders and on PCB filters

References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