Rapid Elliptic-Filter Design

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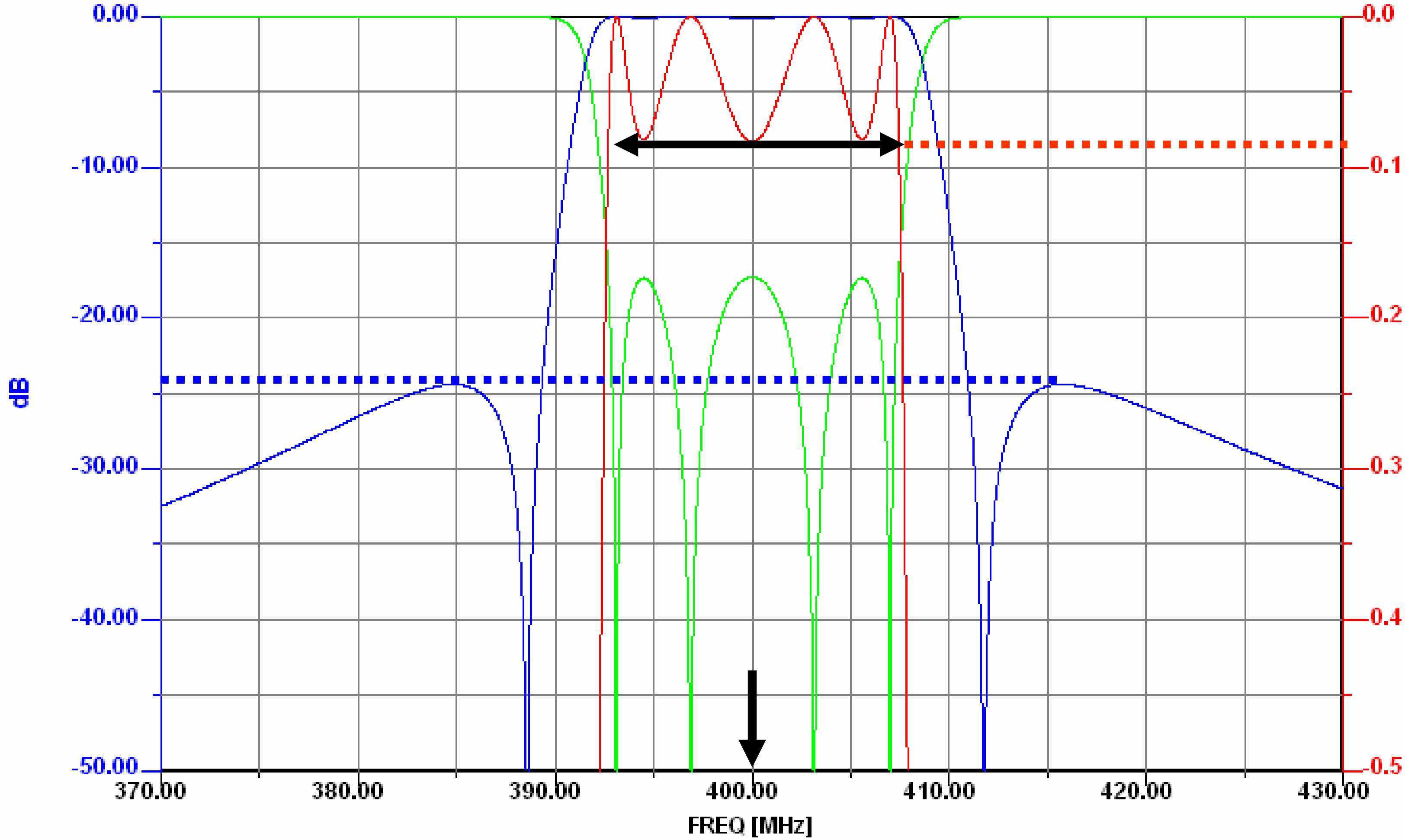
Ansoft Designer and HFSS
team up to produce elliptic band-pass filter
with small ripple and high selectivity.

Specifications to be met



Design a 3D RF elliptic band-pass filter completely in software

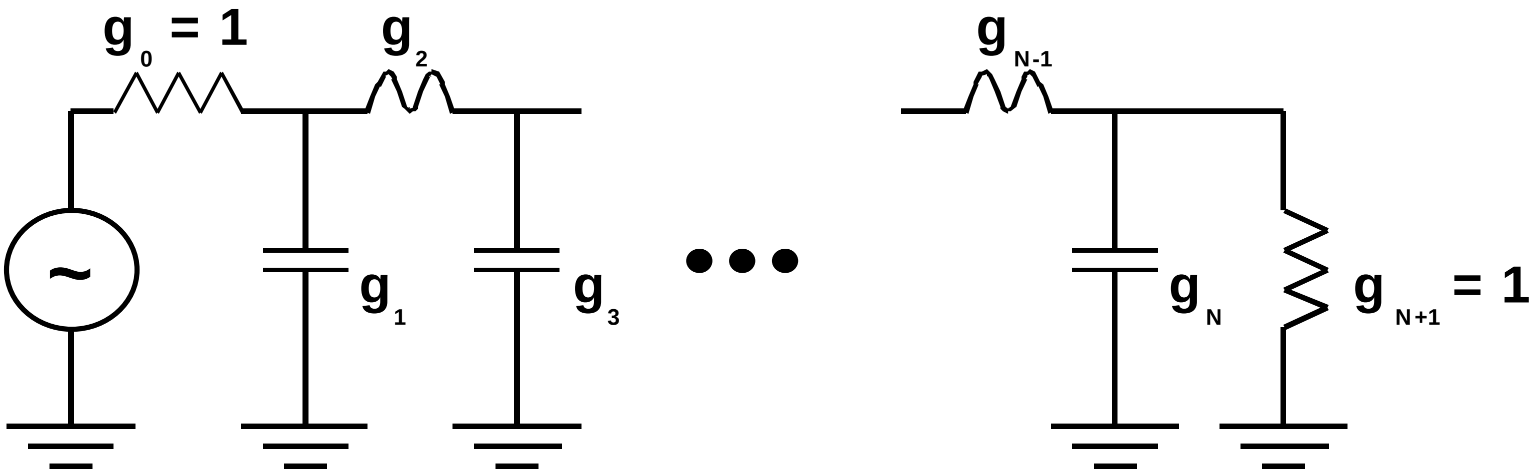
Obtain circuit representation using known filter theory.

Link design parameters of 3D prototype filter to circuit parameters using calibration projects representing only parts of 3D filter.

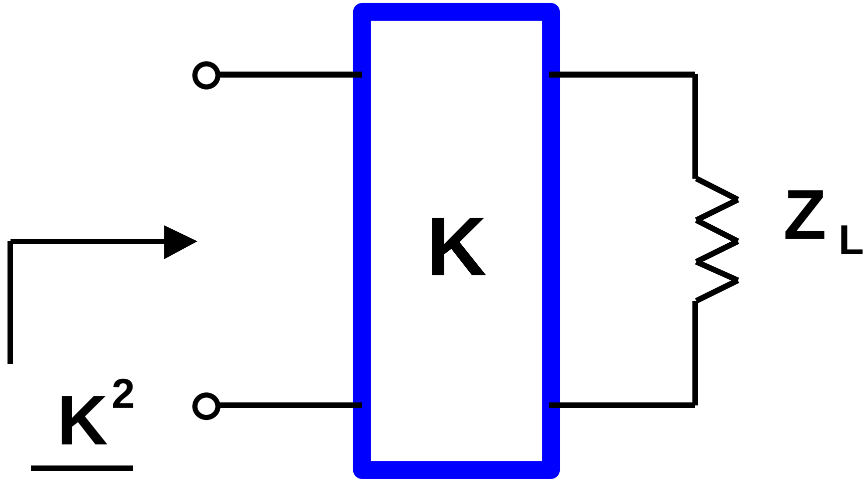
Simulate complete 3D filter in HFSS until specs are met.

Perform curve fitting in Ansoft Designer to obtain corrections needed.

LC prototype low-pass filter

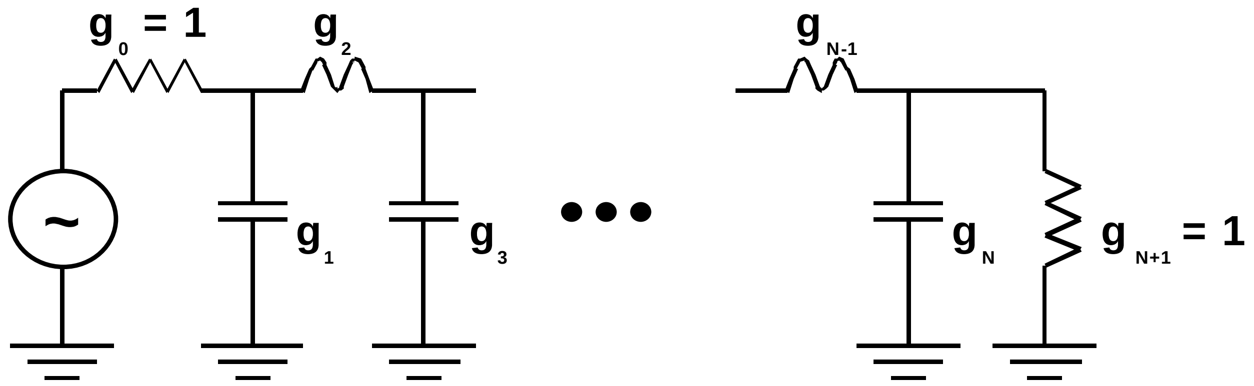


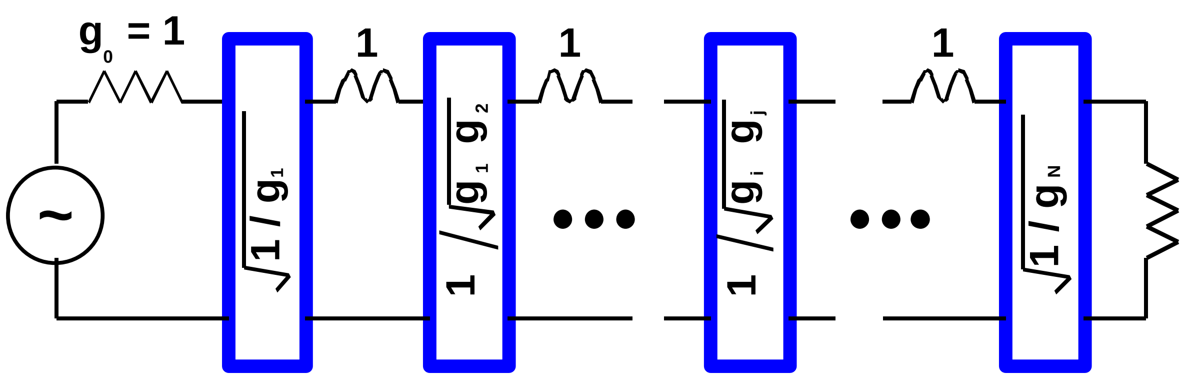
Impedance inverter



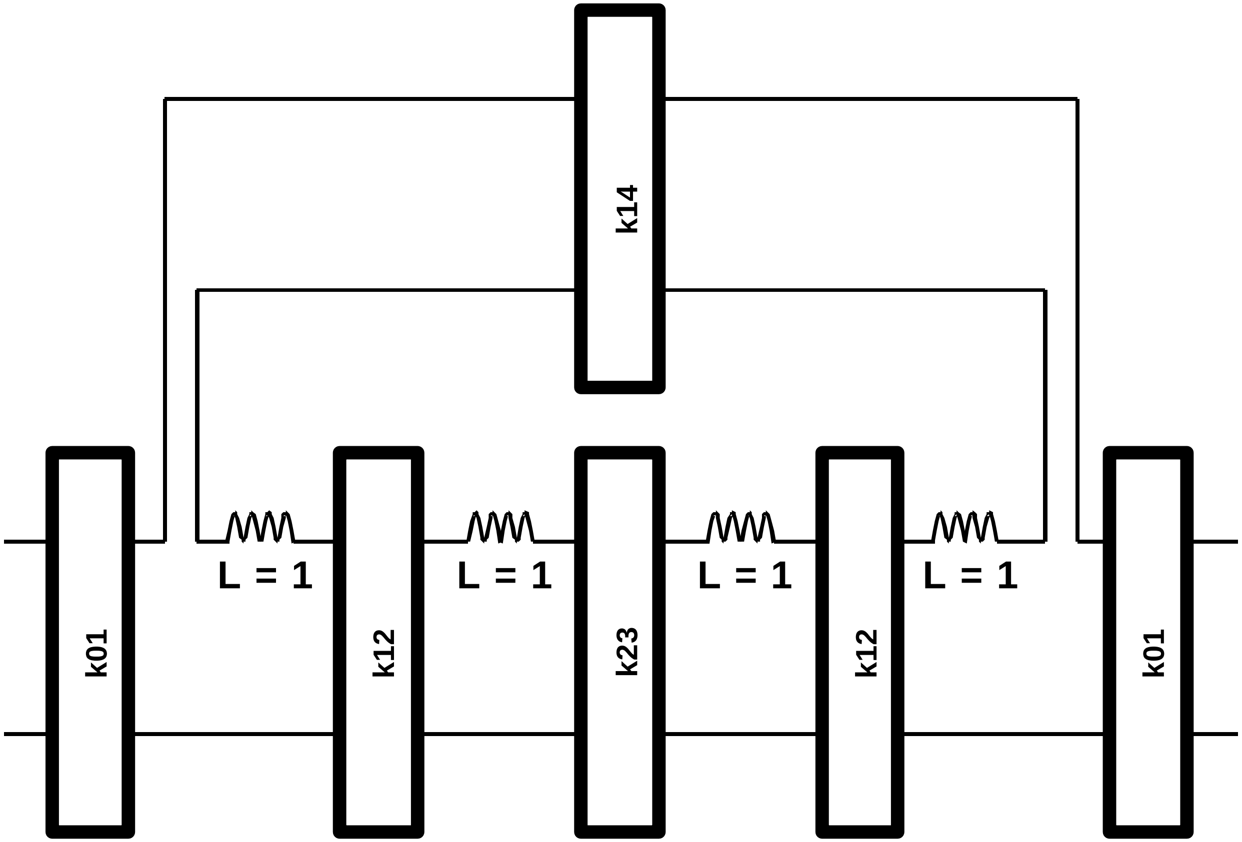
$$Z_{IN} = \frac{K^2}{Z_L}$$

Impedance inverter prototype low pass filter

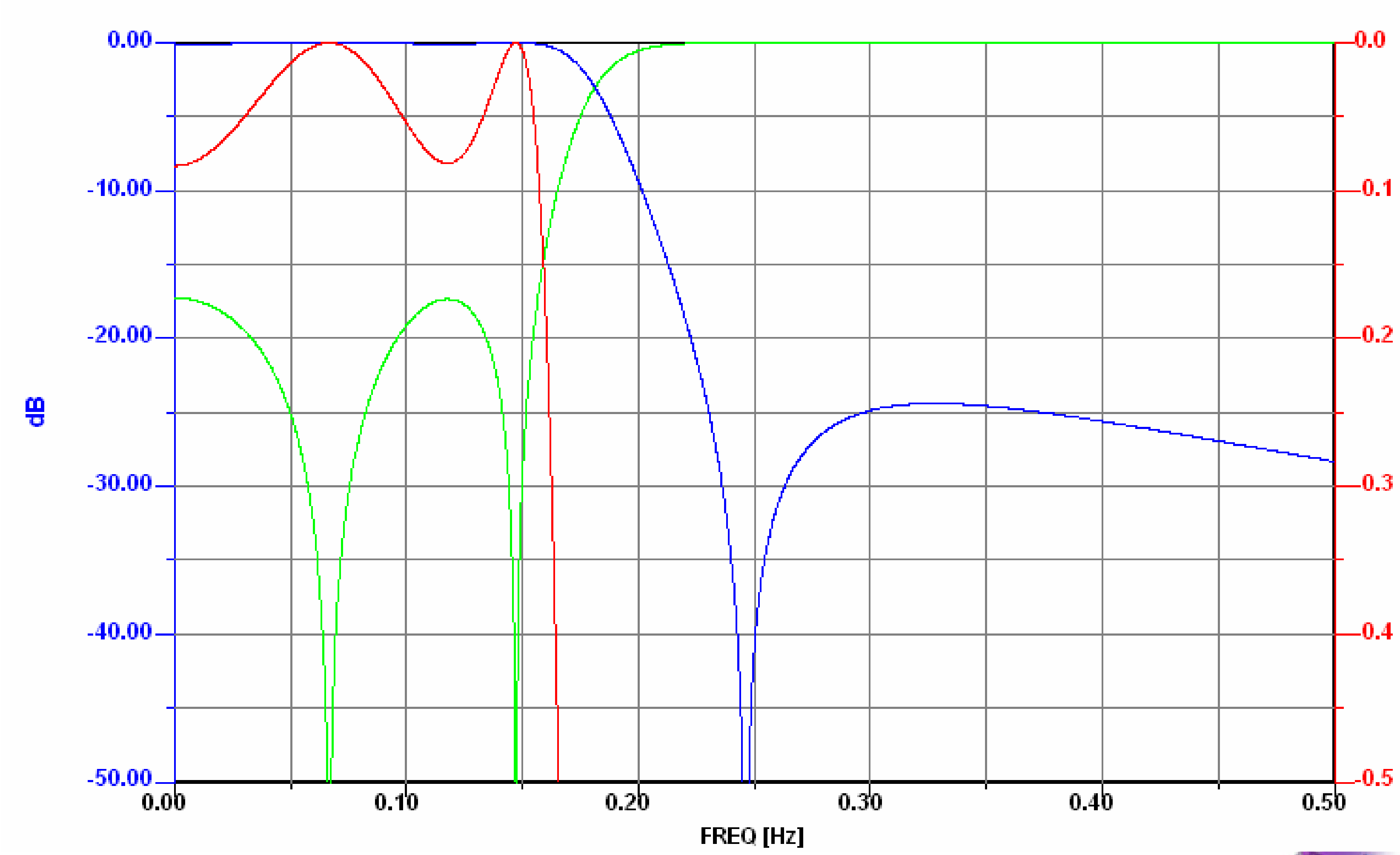




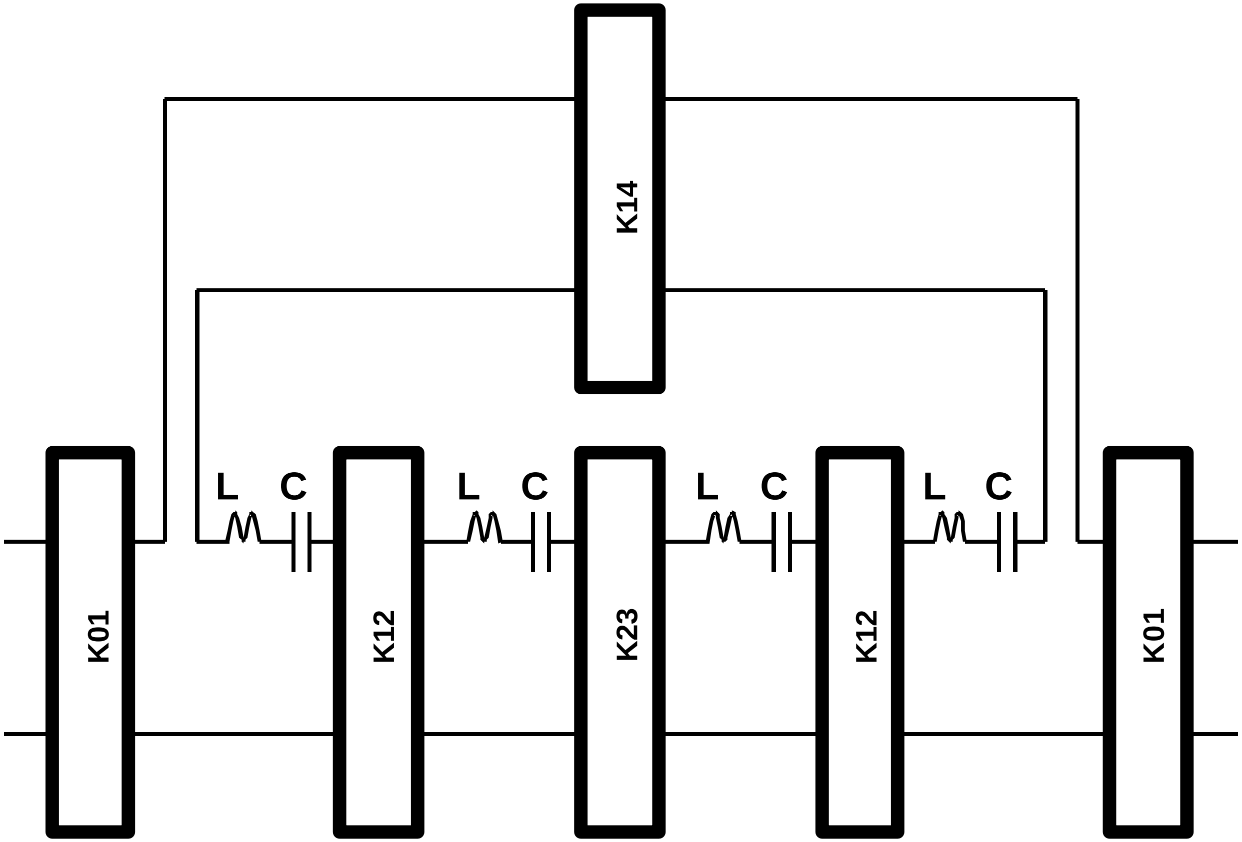
Prototype low pass filter: elliptic filter response



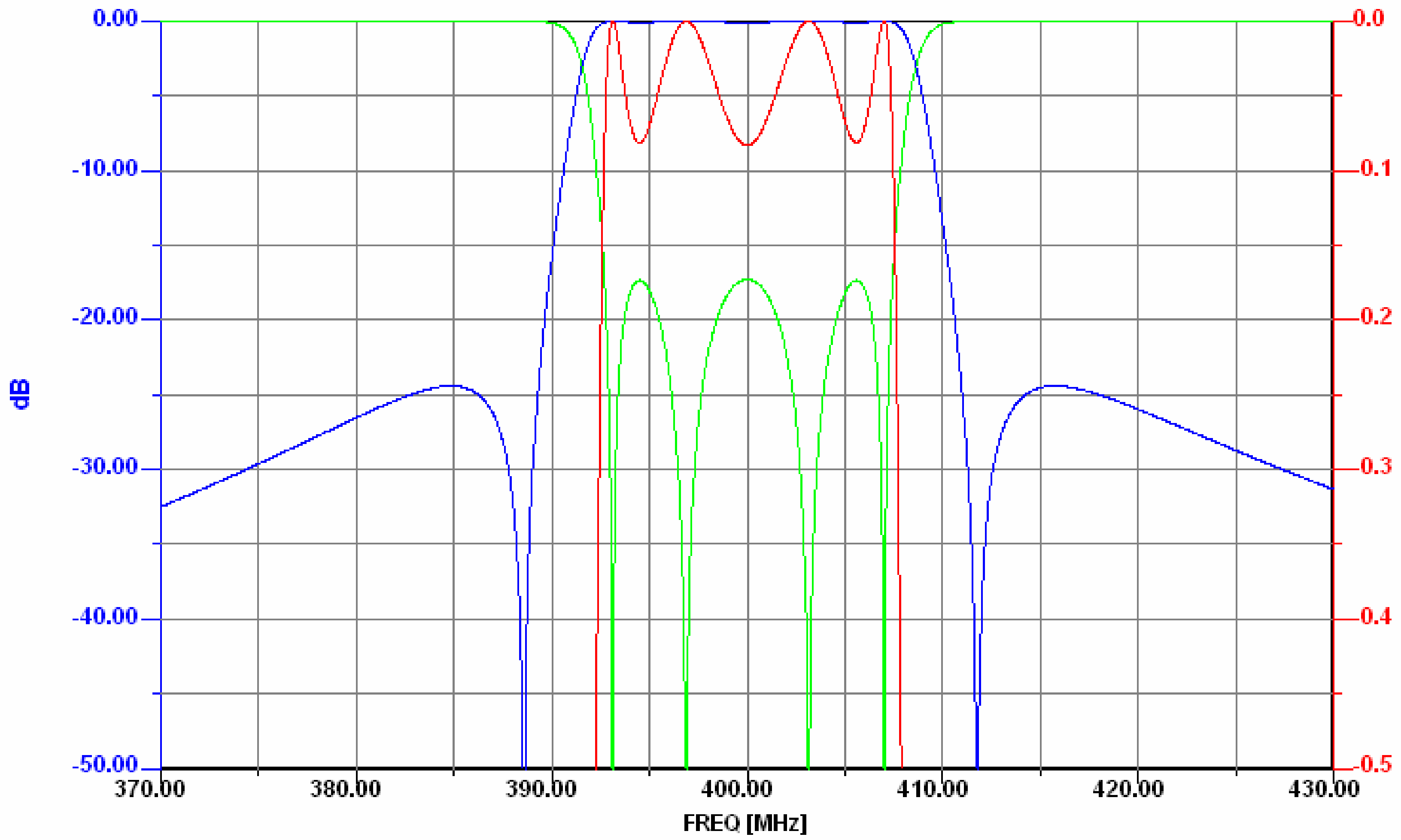
Elliptic filter response



Filter theory – from low pass to bandpass

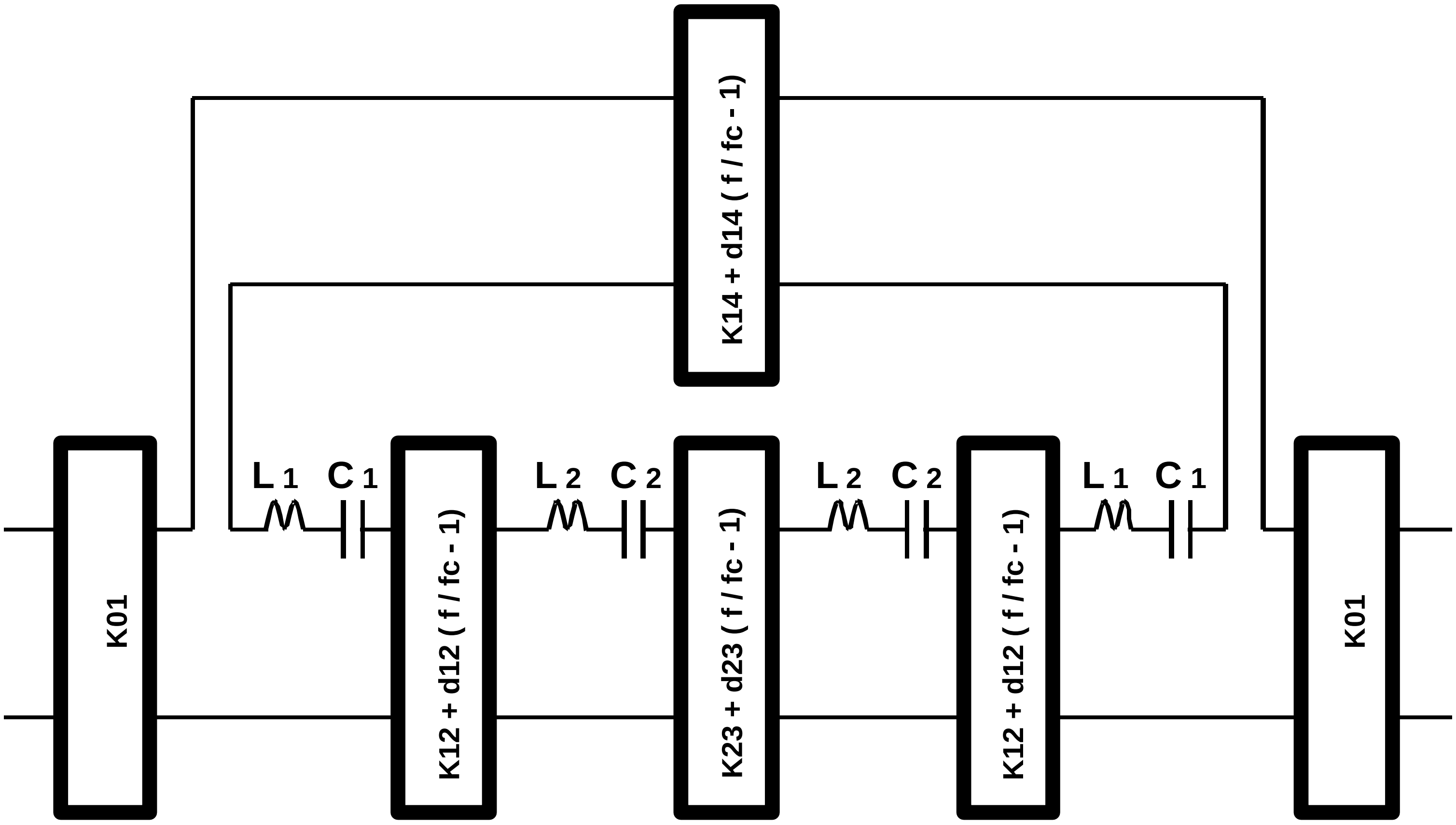


Bandpass filter response



ANSOFT CORPORATION

Enhanced Circuit Model

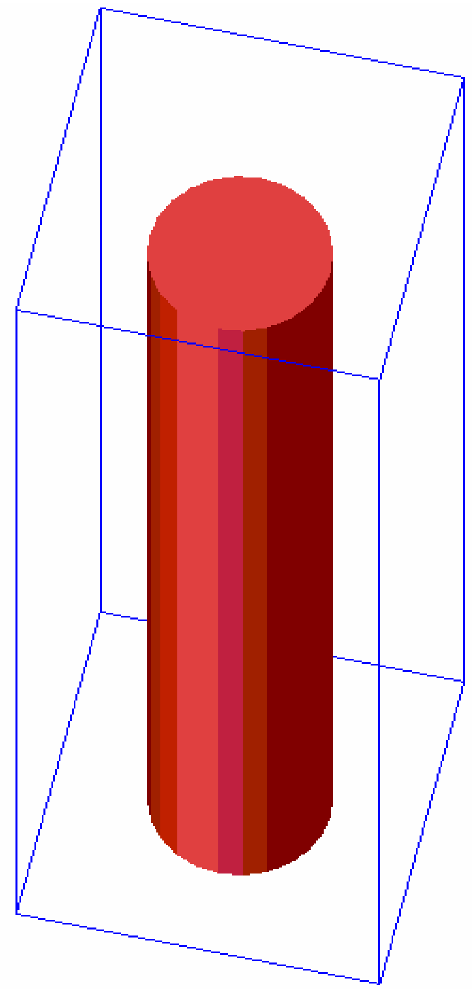


What filter theory gives us

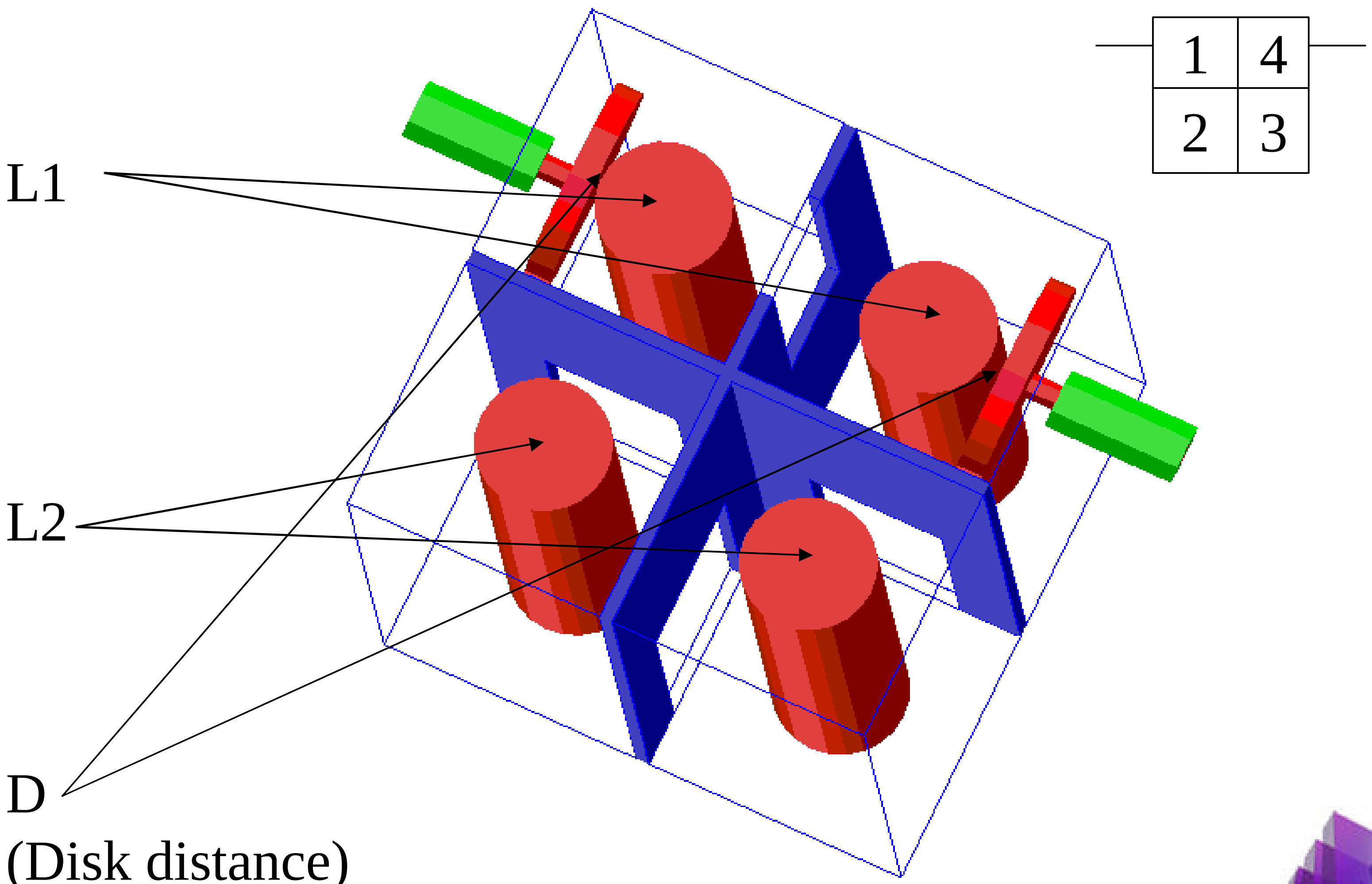
- f1 = 400 MHz resonant freq. resonators 1&4
- f2 = 400 MHz resonant freq. resonators 2&3
- K12 = 0.02894 coupling constant 1-2 and 3-4
- K23 = 0.02863 coupling constant 2-3
- K14 =-0.00942 coupling constant 1-4
- Q_L = 29.69 loaded Q, coupling to source & load
- d12 = 0 }
- d23 = 0 } frequency-INdependent coupling
- d14 = 0 } (for now)

Basic resonator

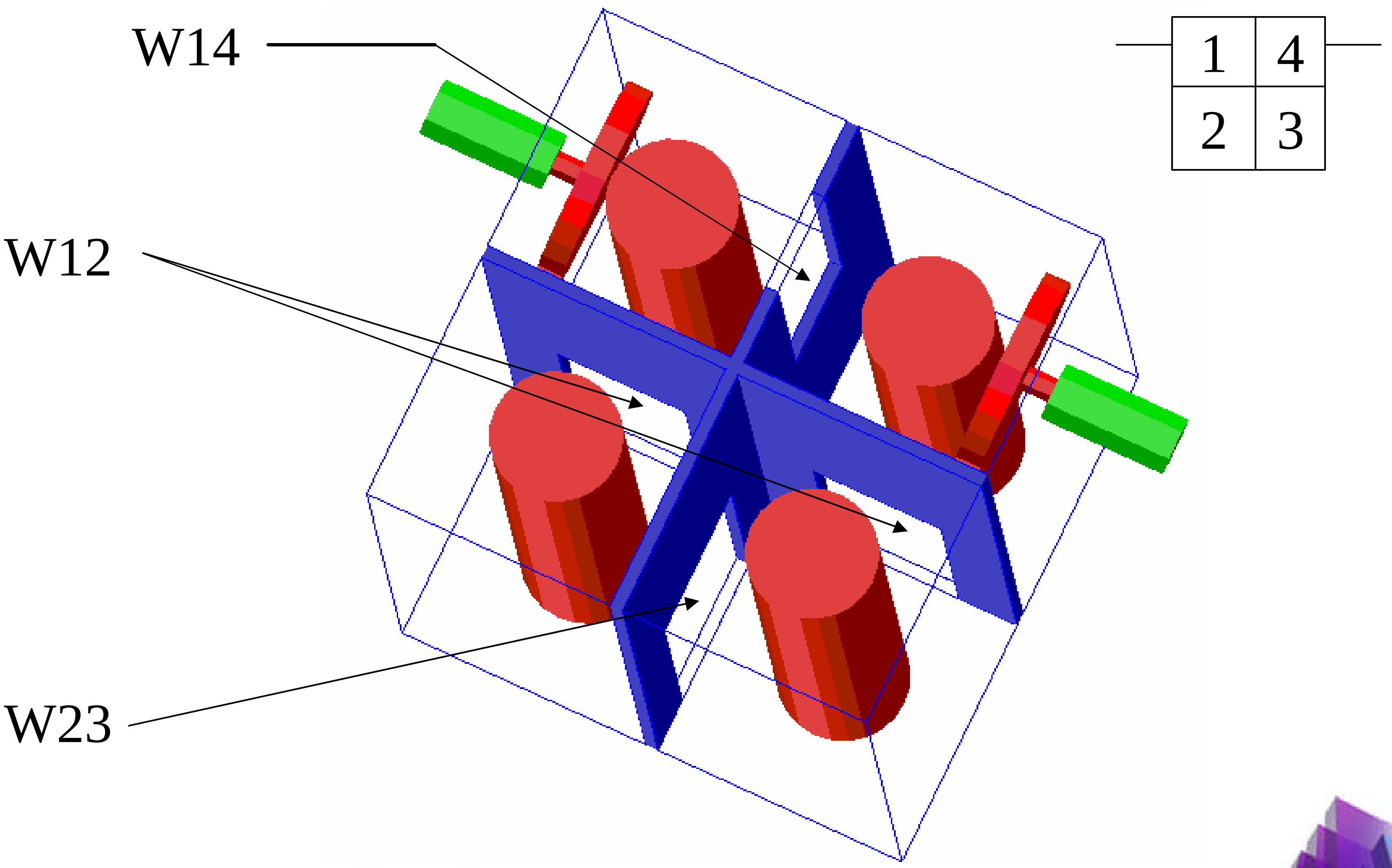
- Cavity 20×20×200 mm
- Metal walls, air inside
- Metal cylinder R=5 mm
- Cylinder stands on cavity floor, does not touch ceiling.
- Cylinder length is varied to tune the resonance.
- Irises in walls, not shown here, will provide coupling to other resonators.



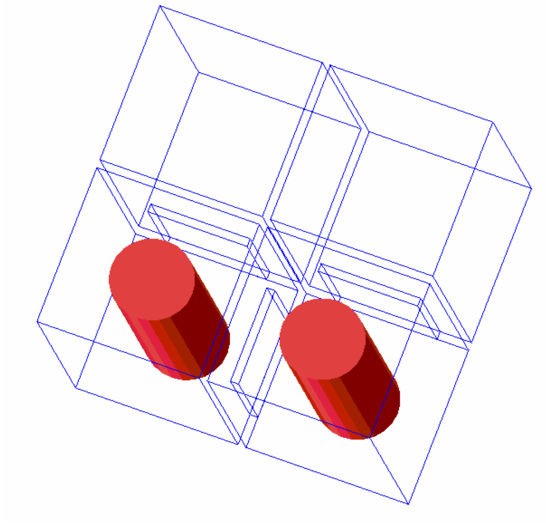
Elliptic Filter, basic design

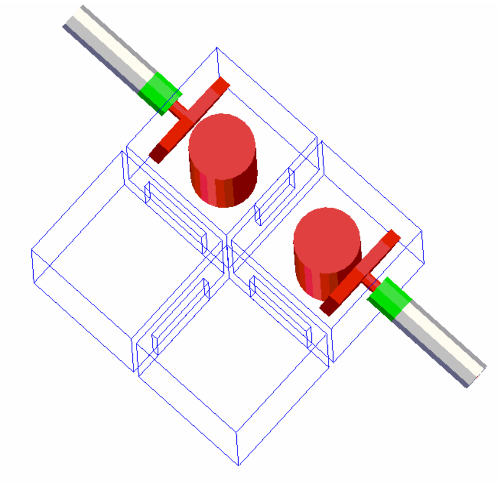


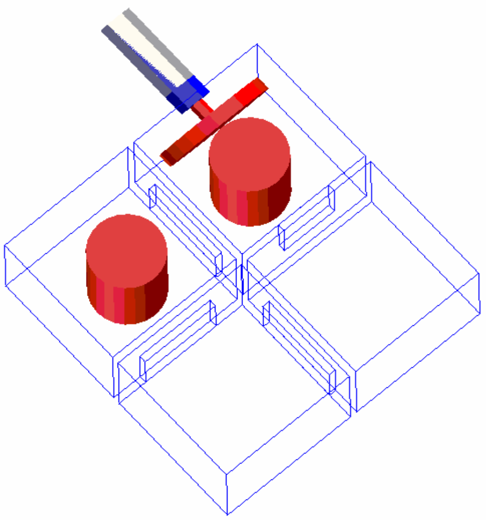
Elliptic filter, basic design II



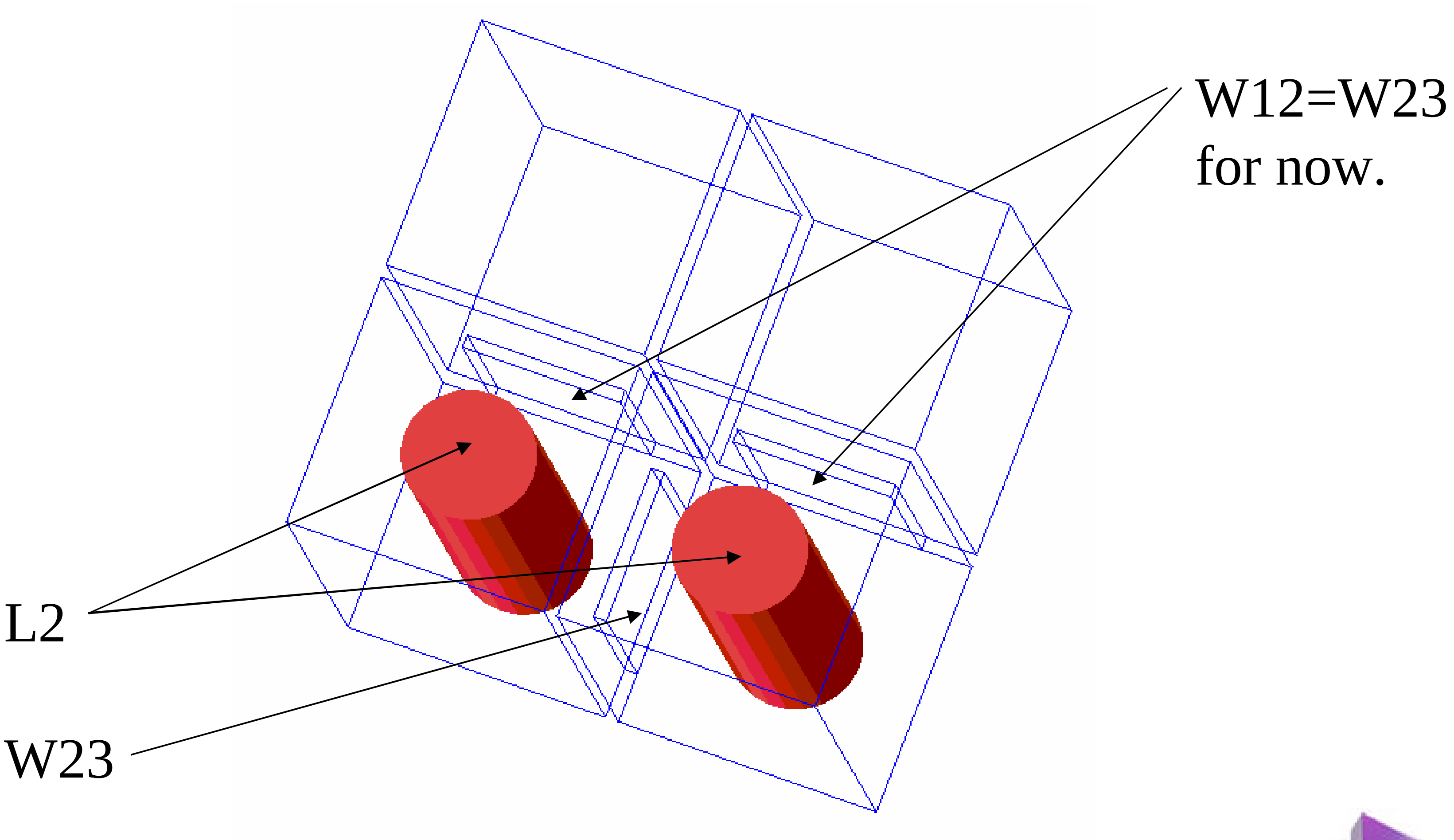
Calibration Projects



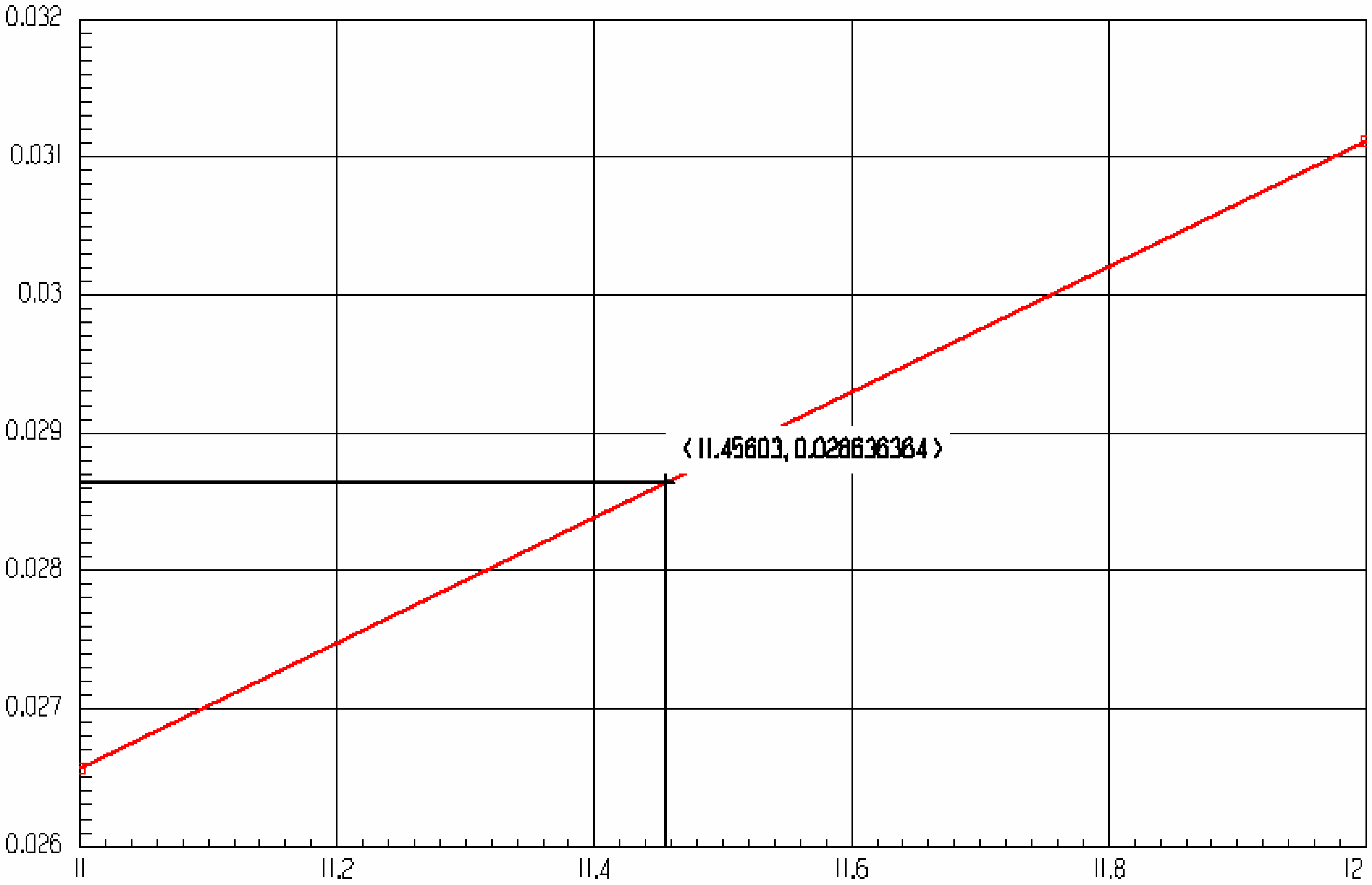




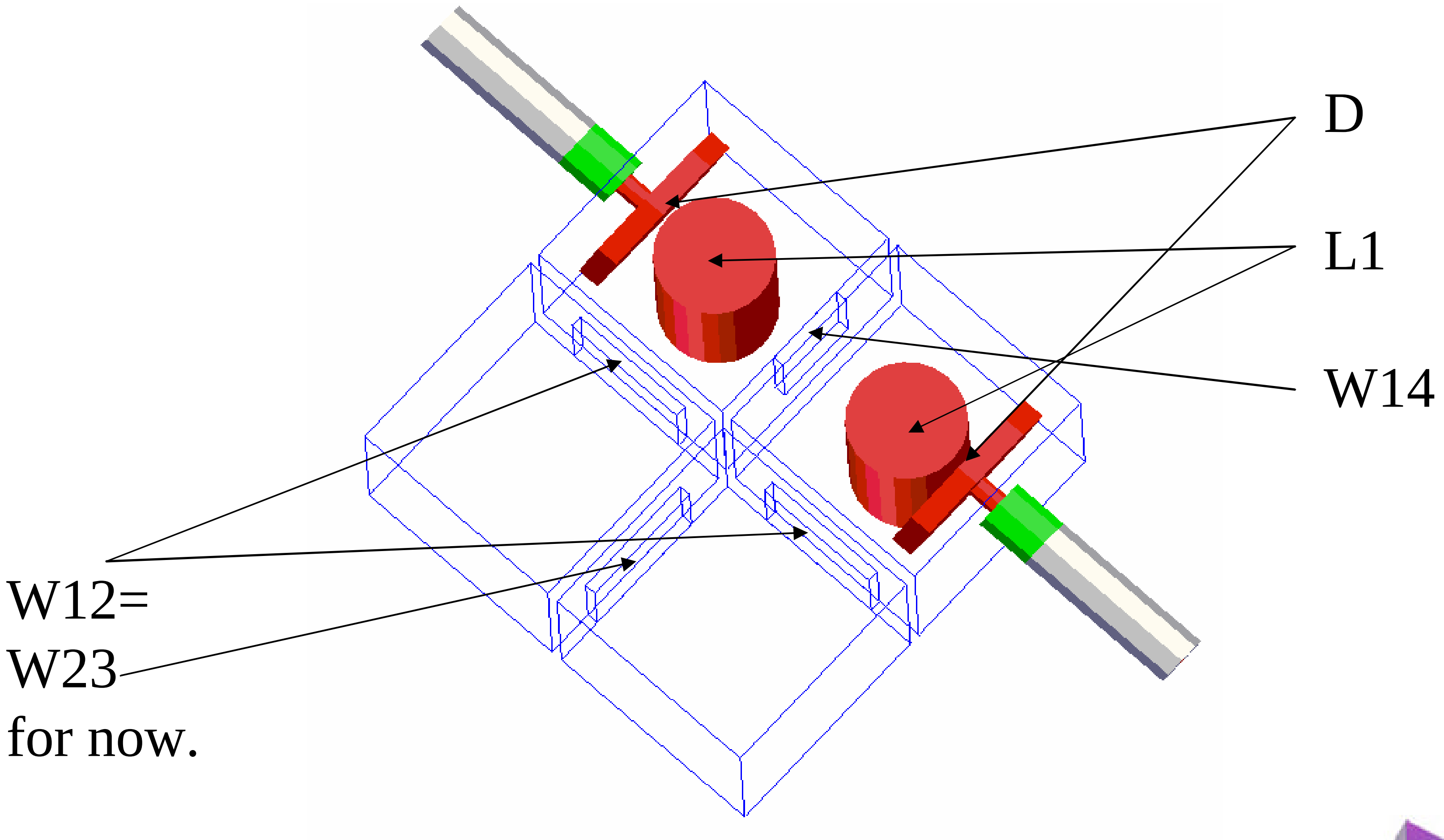
First calibration: W23 and L2



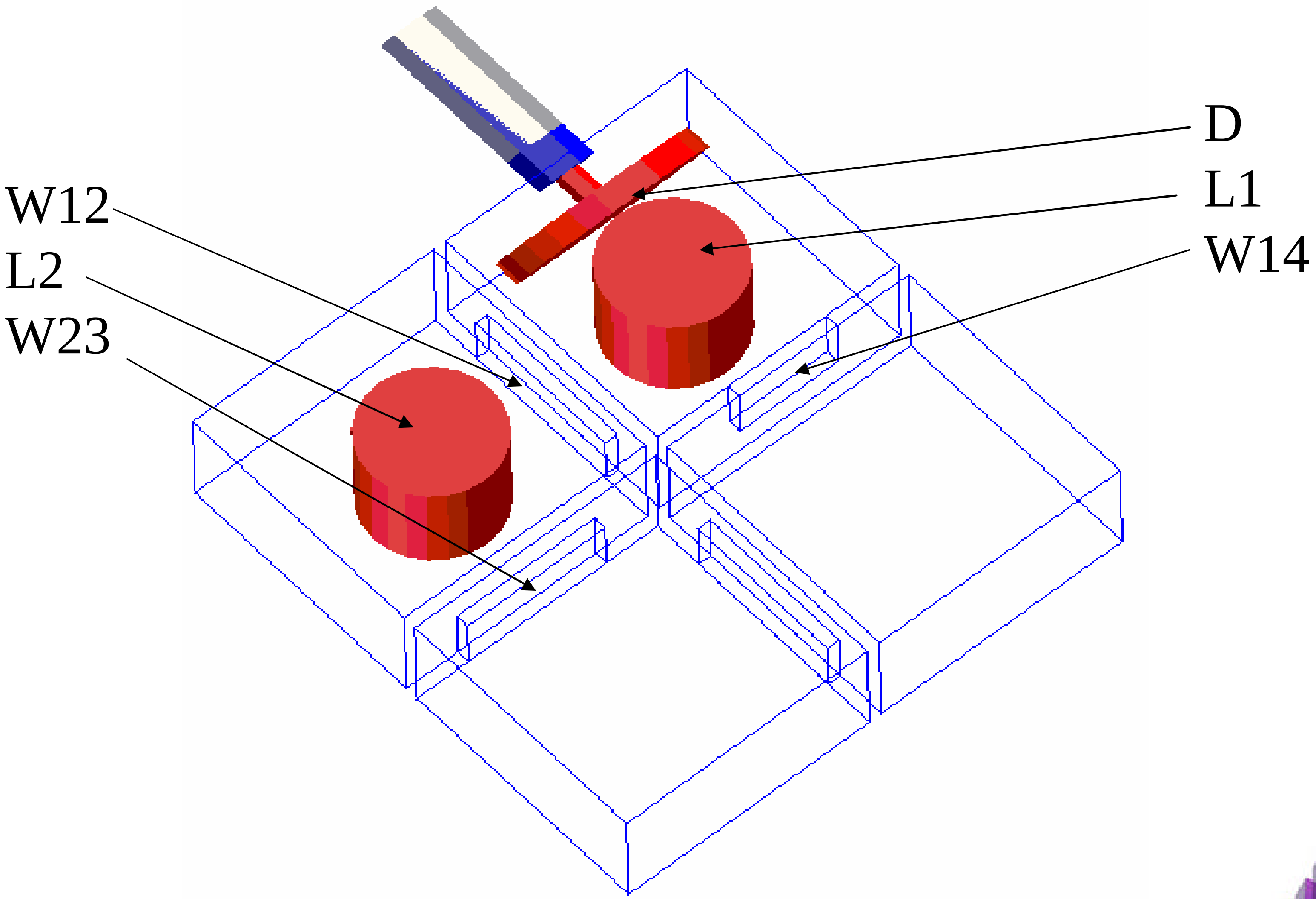
K23 as a function of W23



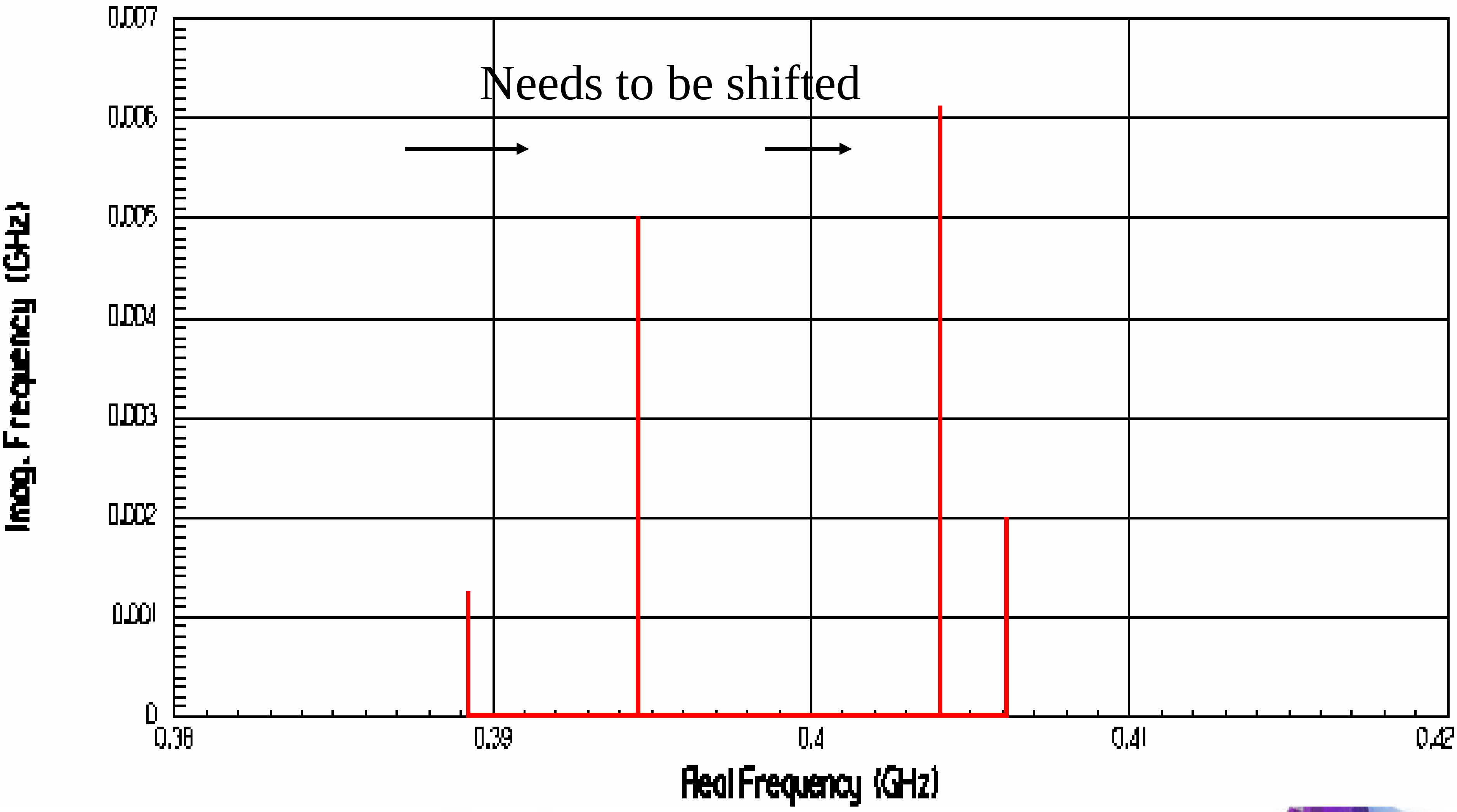
Second Calibration: W14, a and L1



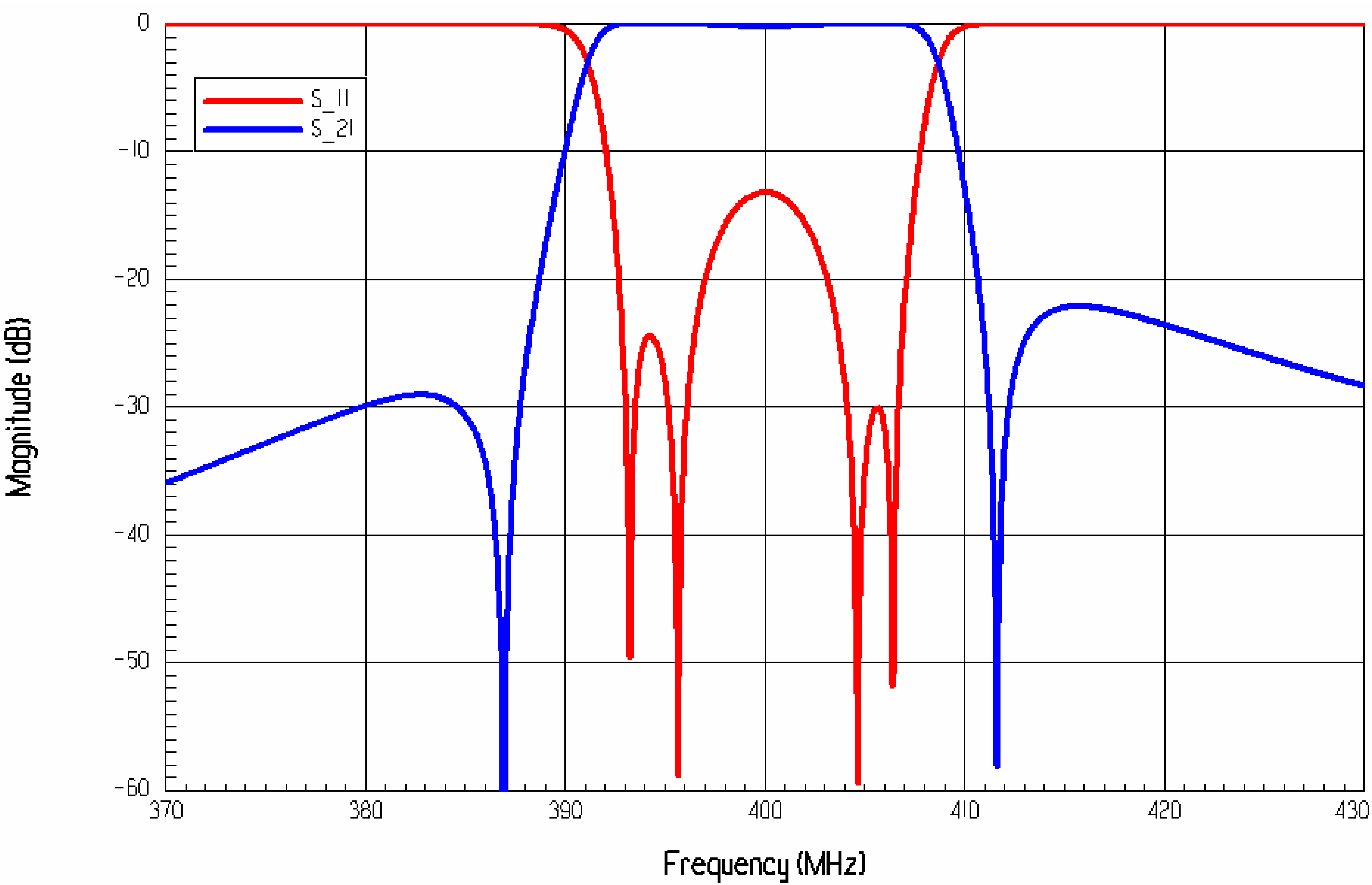
Third Calibration: W12



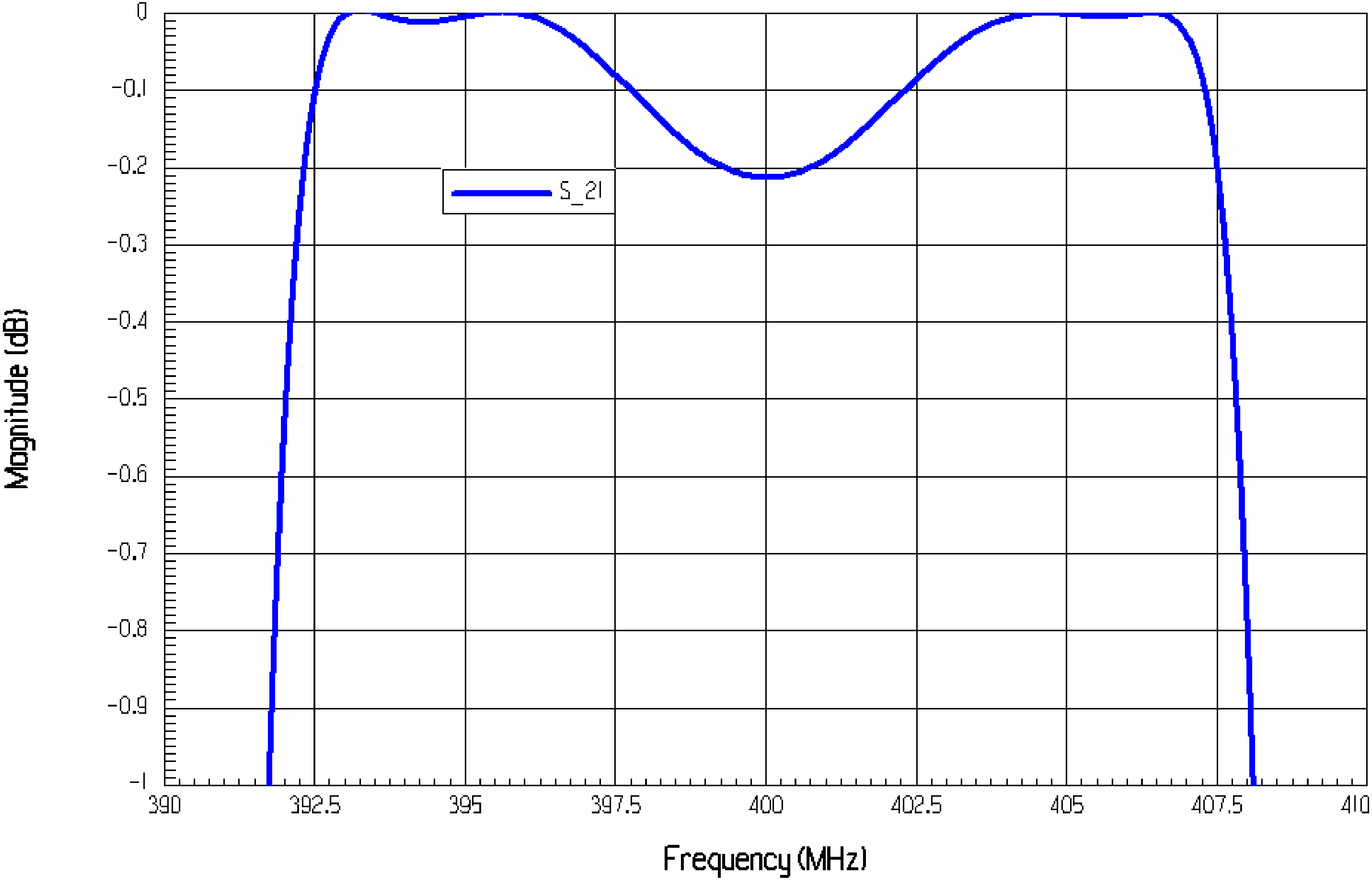
First filter – eigen frequencies



Corrected first filter



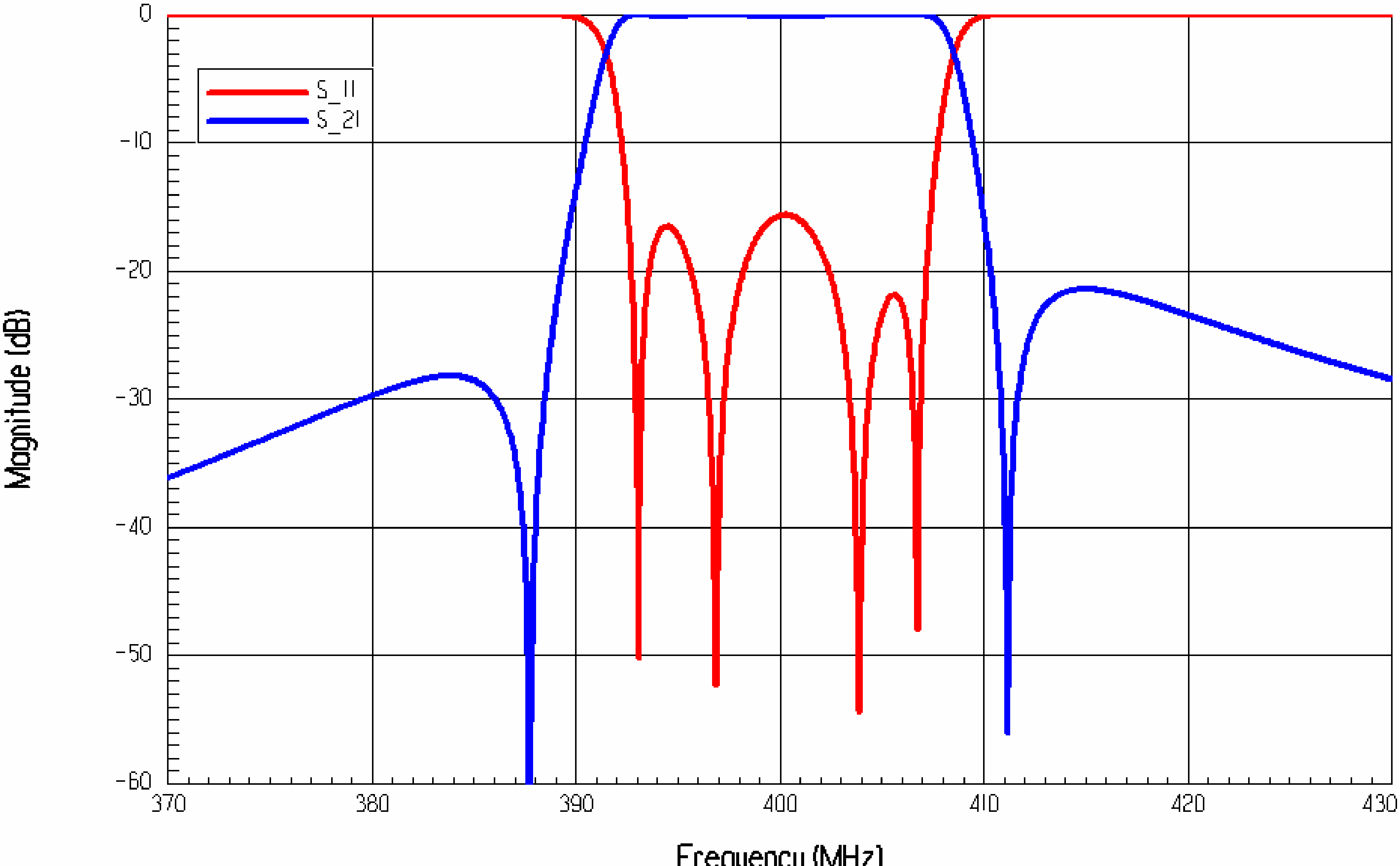
Corrected first filter



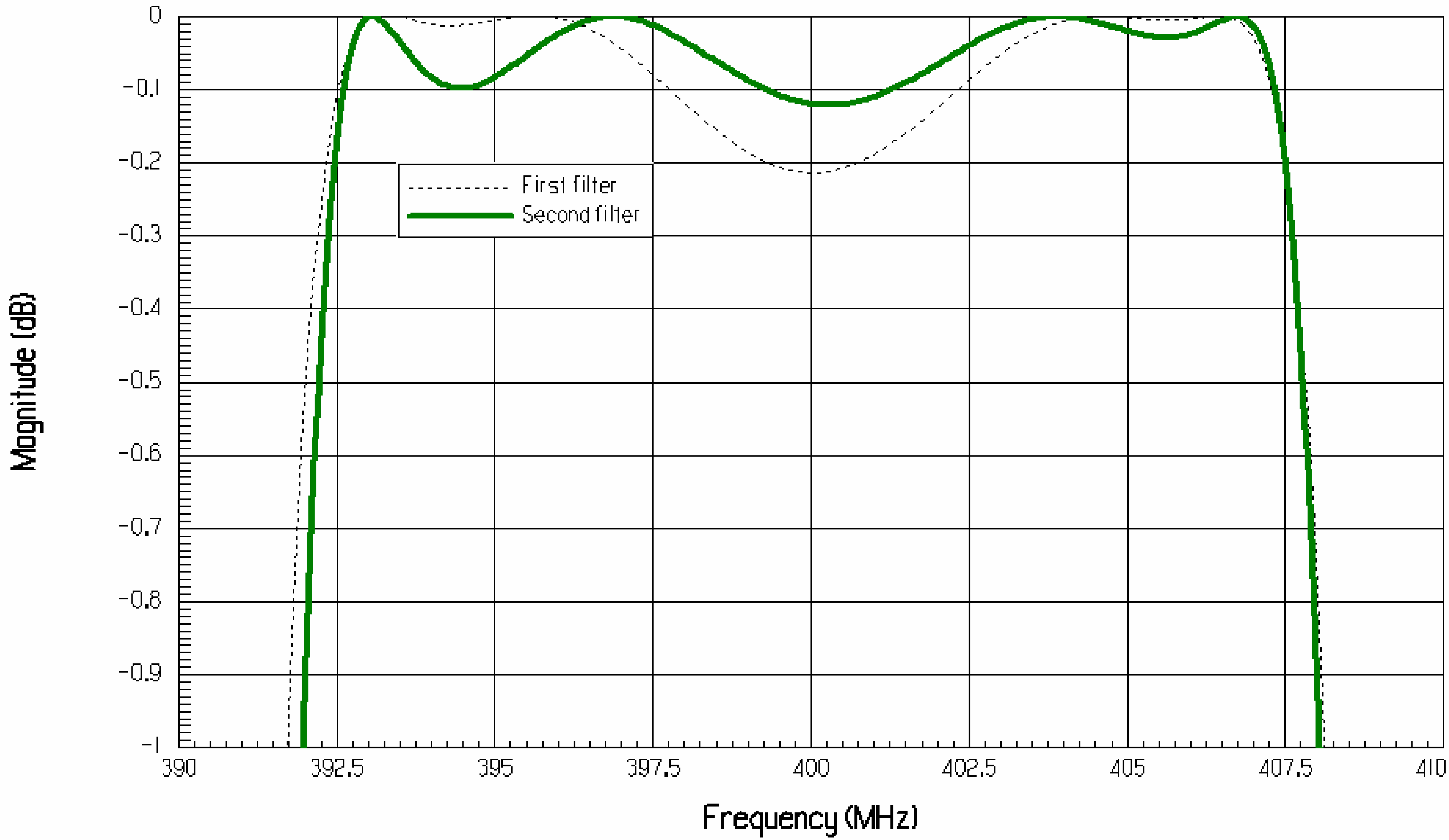
Curve fitting

Curve fitting results		Original targets
f1	= 399.93 MHz	400 MHz
f2	= 400.10 MHz	400 MHz
K12	= 0.03122	0.02894
K23	= 0.02819	0.02863
K14	=-0.00930	-0.00942
Q_L	= 28.43	29.69
d12	=-0.0082	}
d23	=-0.0410	} were zero in circuit
d14	= 0.0363	}

Second filter



Second filter



Change the goals!!

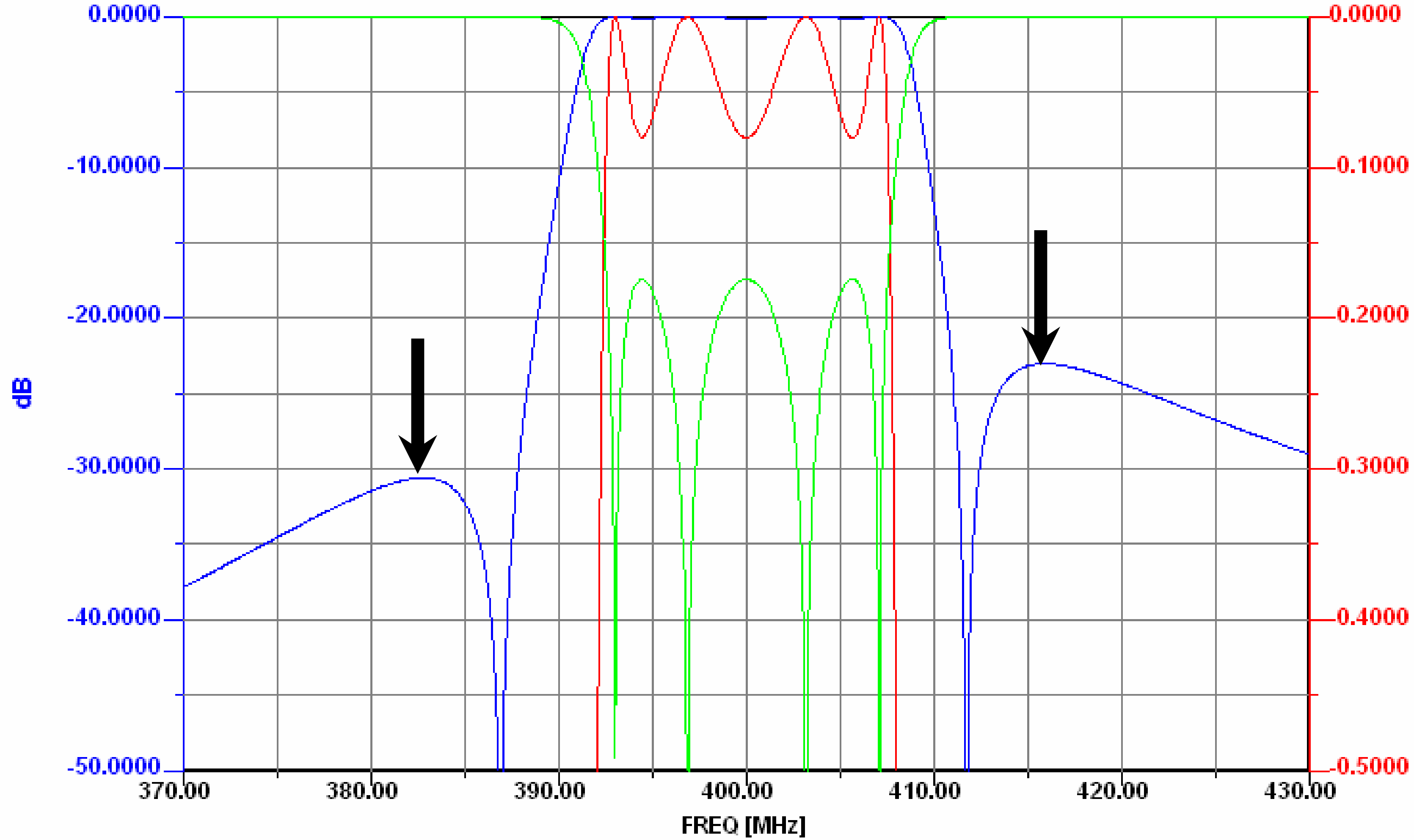
- Curve fitting shows that we have
  d12=-0.0004
  d23=-0.0405
  d14= 0.0405
- If we try to get closer to the original goals, with d-factors all zero, we won't see any more improvement.
- We need new circuit parameters that are based on the nonzero d-factors.
- We know desired points in the theoretical filter characteristic and we know d-factors. Curve-fit the rest and voila…

New goals

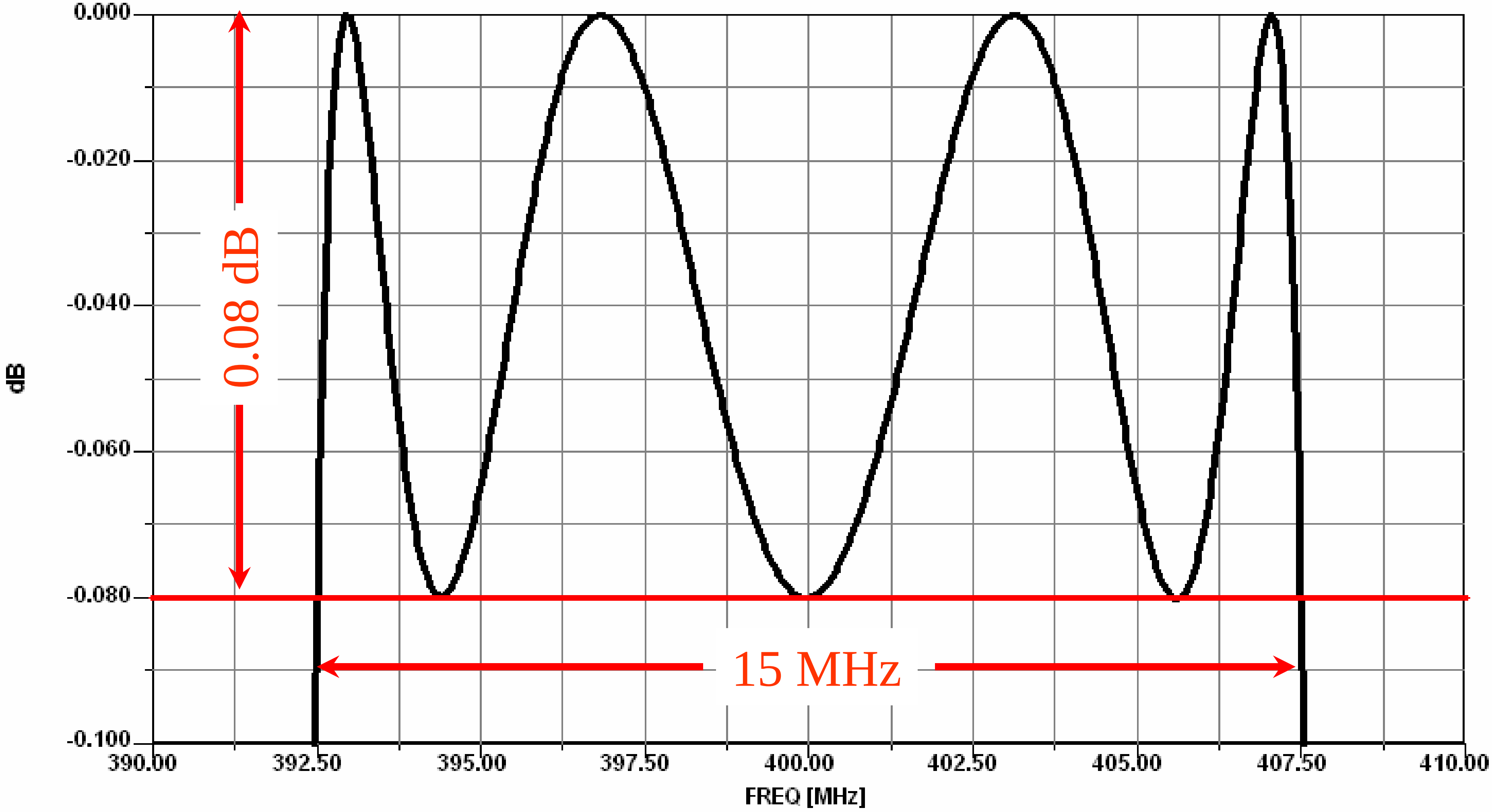
New targets to aim for		Original targets	HFSS 2nd filter
f1	= 399.85 MHz	400 MHz	400.11
f2	= 400.14 MHz	400 MHz	400.16
K12	= 0.02981	0.02894	0.02924
K23	= 0.02876	0.02863	0.02837
K14	=-0.00864	-0.00942	-0.00942
Q_L	= 28.97	29.69	29.84

based on d12=-0.0004, d23=-0.0405, d14=0.0405.

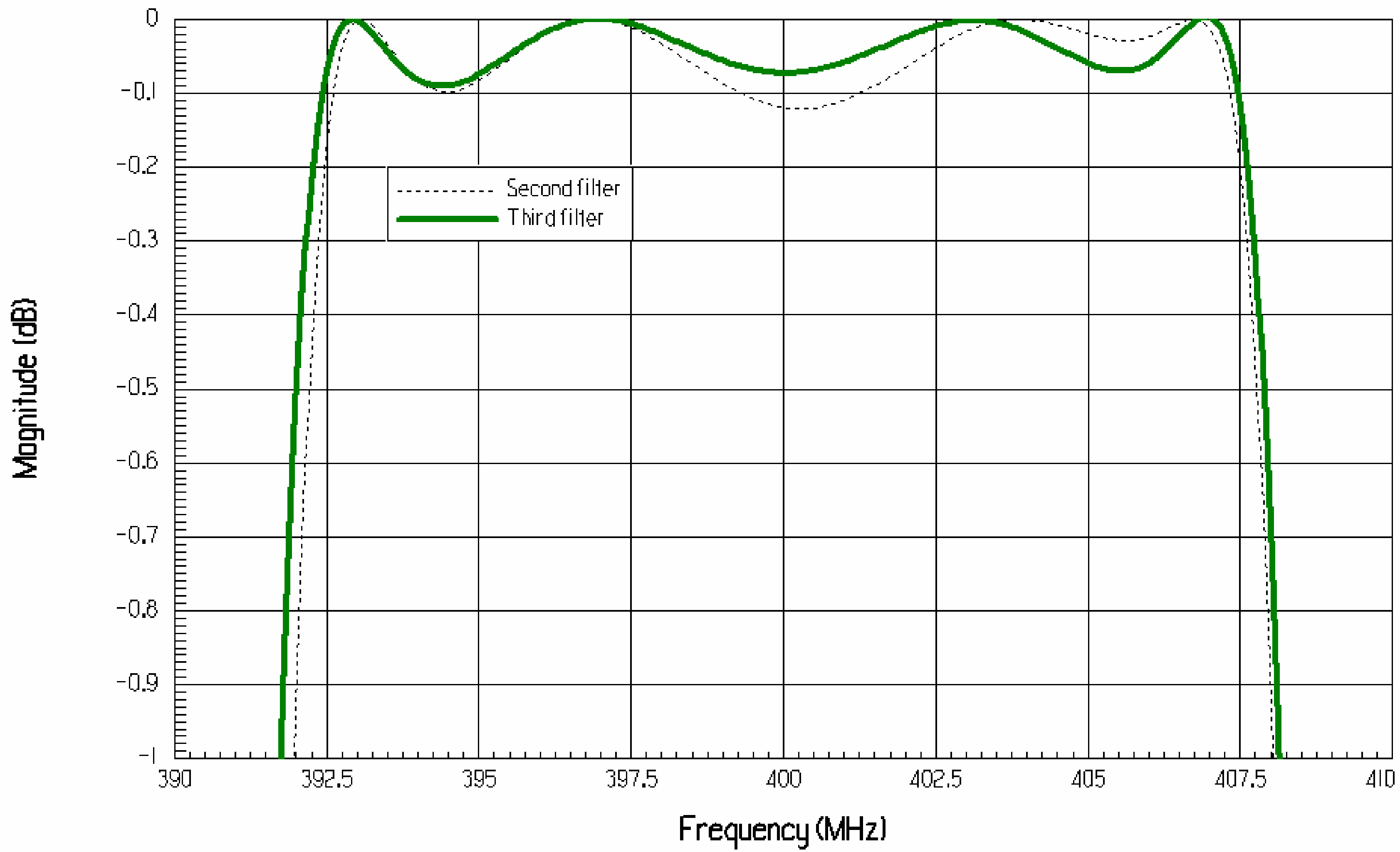
Filter response with d?0



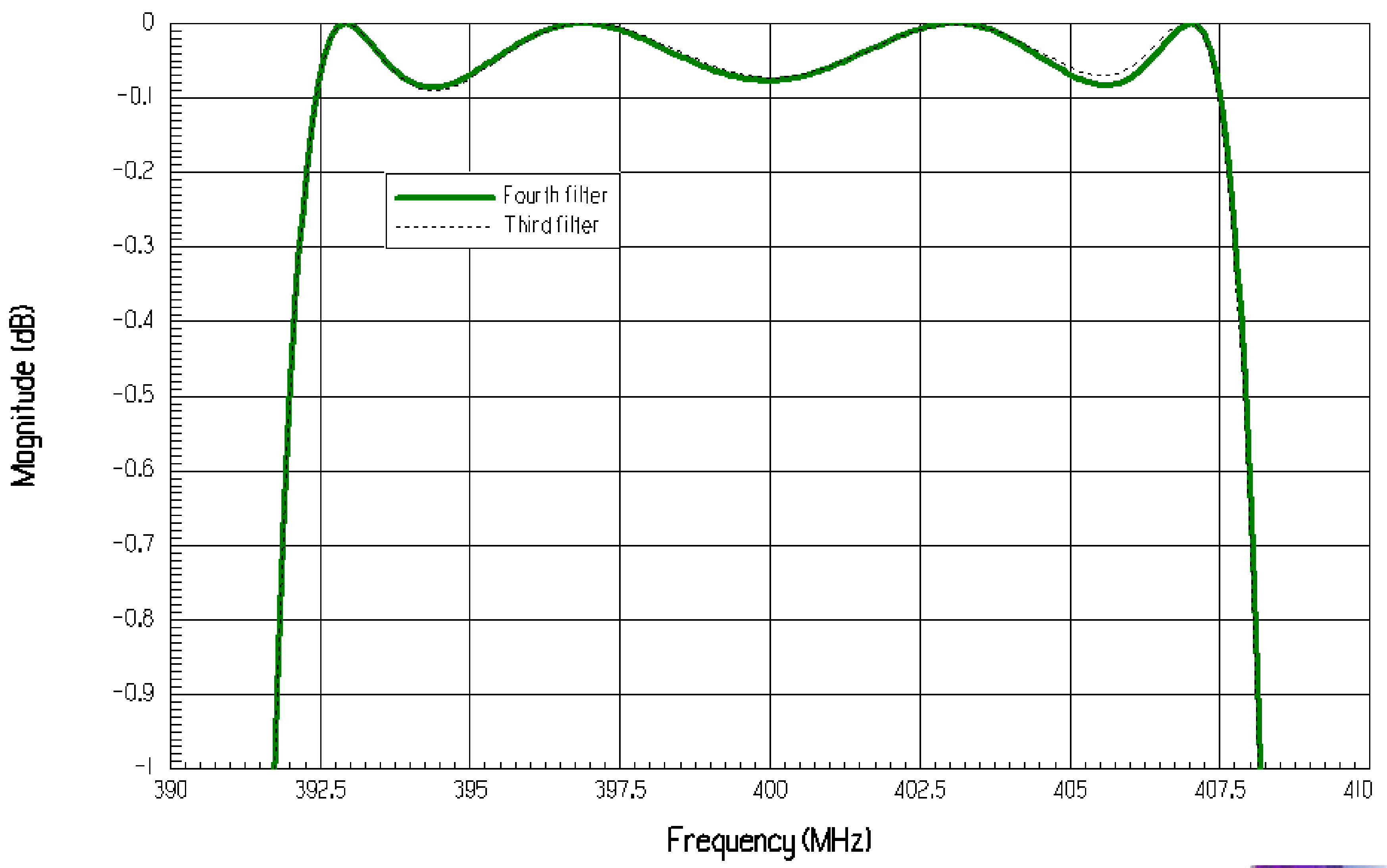
Filter response with d?0



Third filter

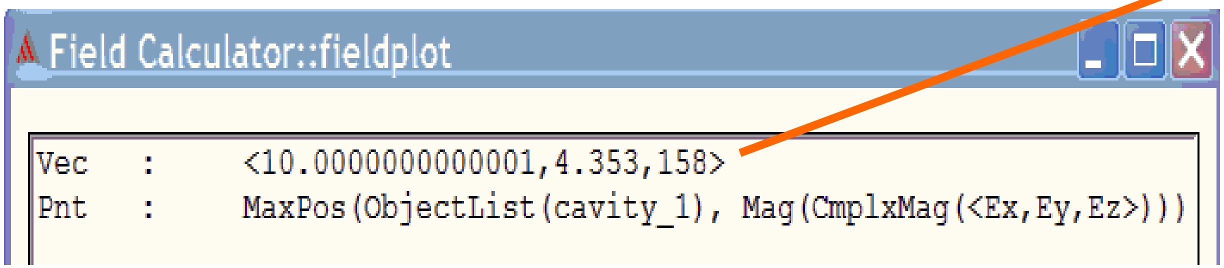


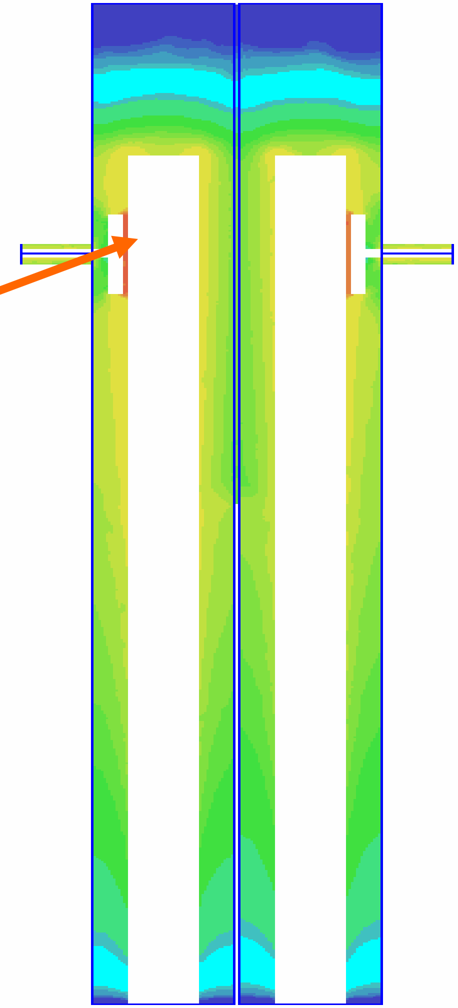
Fourth filter



Power analysis – Look inside

Maximum field strength is determined easily. Fields calculator gives **value and position(!)**.

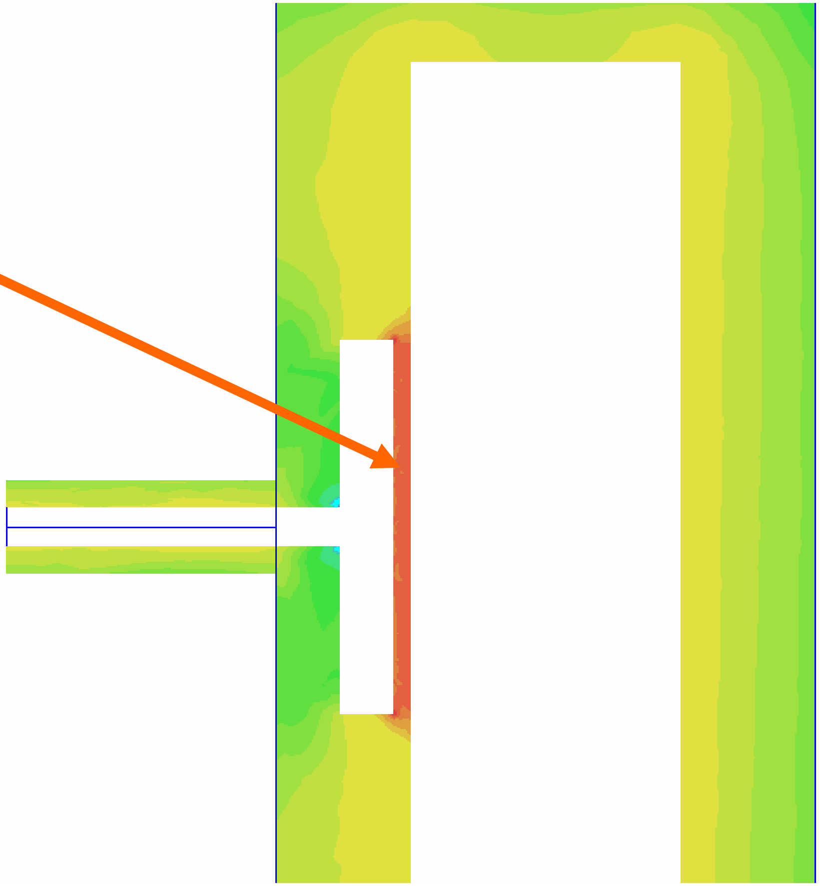




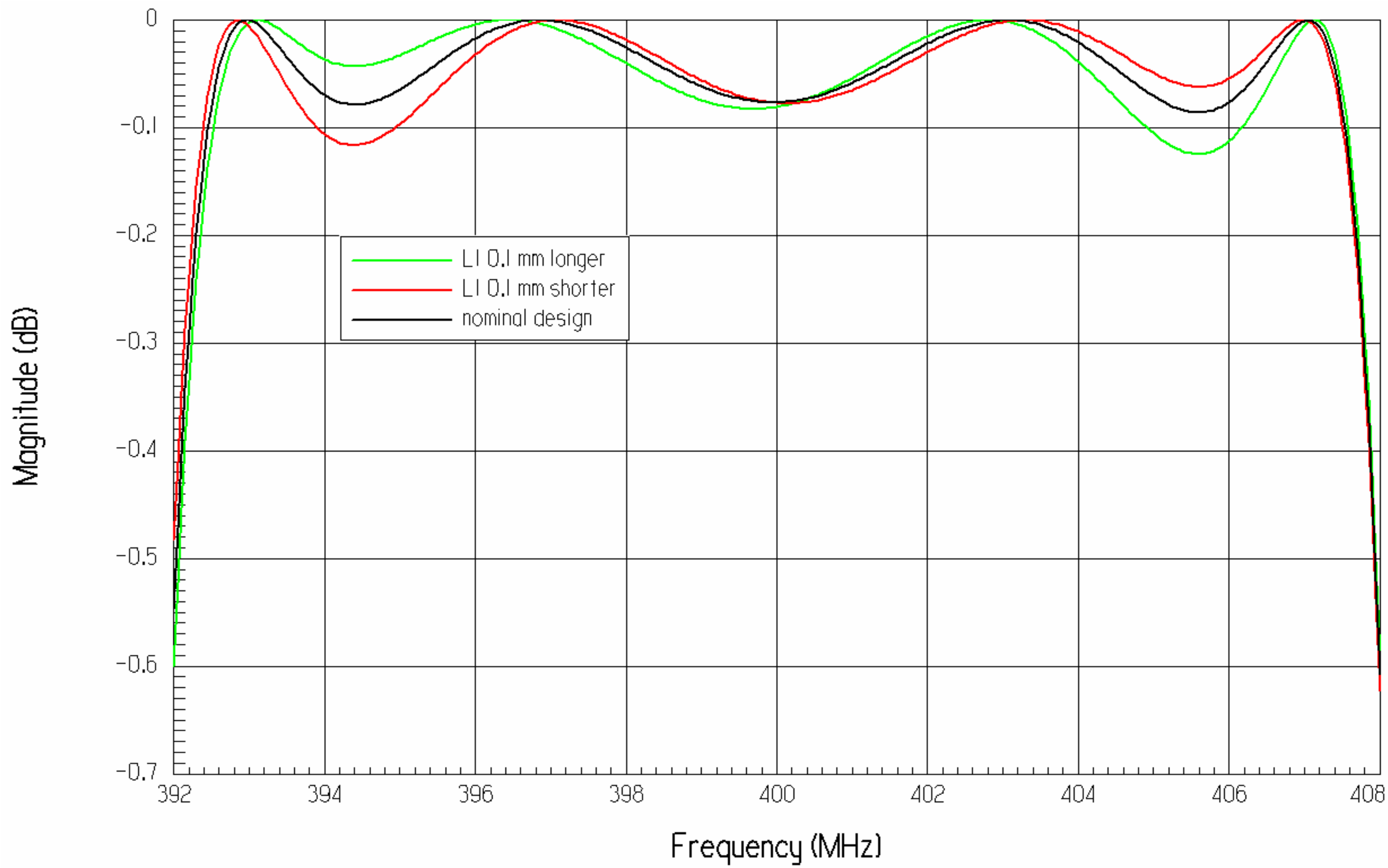
E fields are shown in a plane through center of disks and two resonators. Logarithmic scale from 100 V/m (blue) to 1E5 V/m (red).

Power analysis

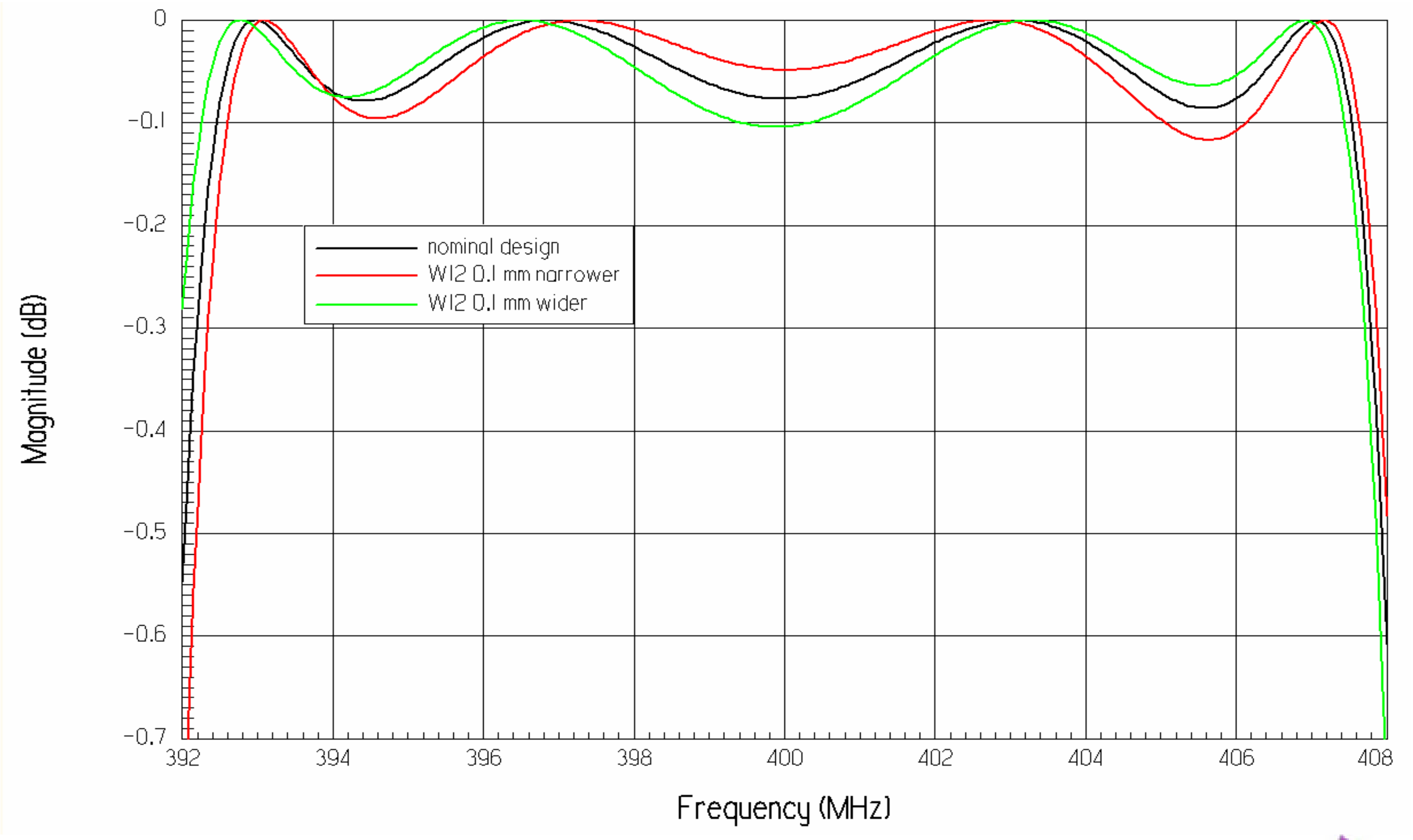
- Maximum E field 80,000 V/m at 1 W input power. (scale not shown)
- Hence 1 MV/m at 156 W.
- This design should be operated below 156 W.



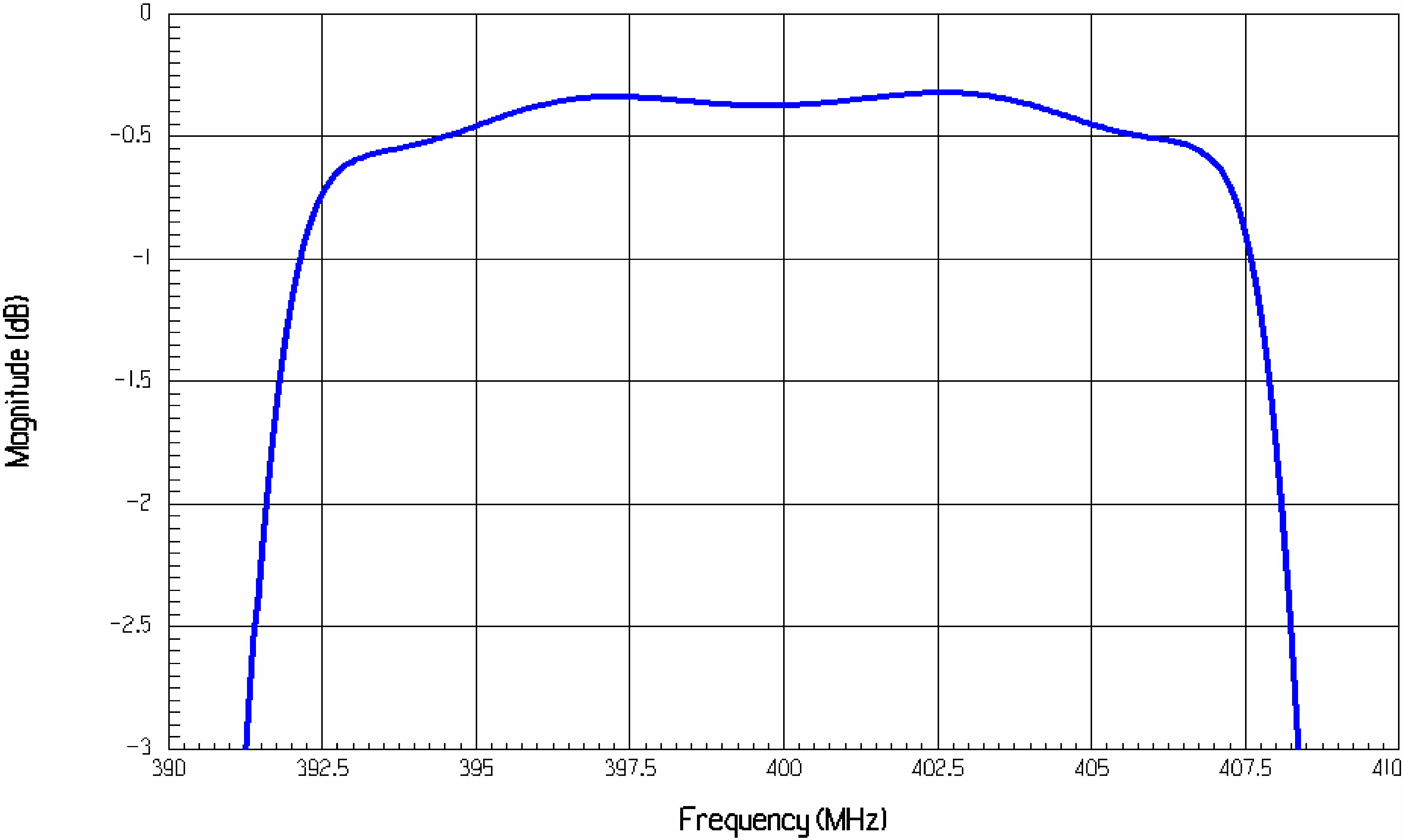
Sensitivity to L1



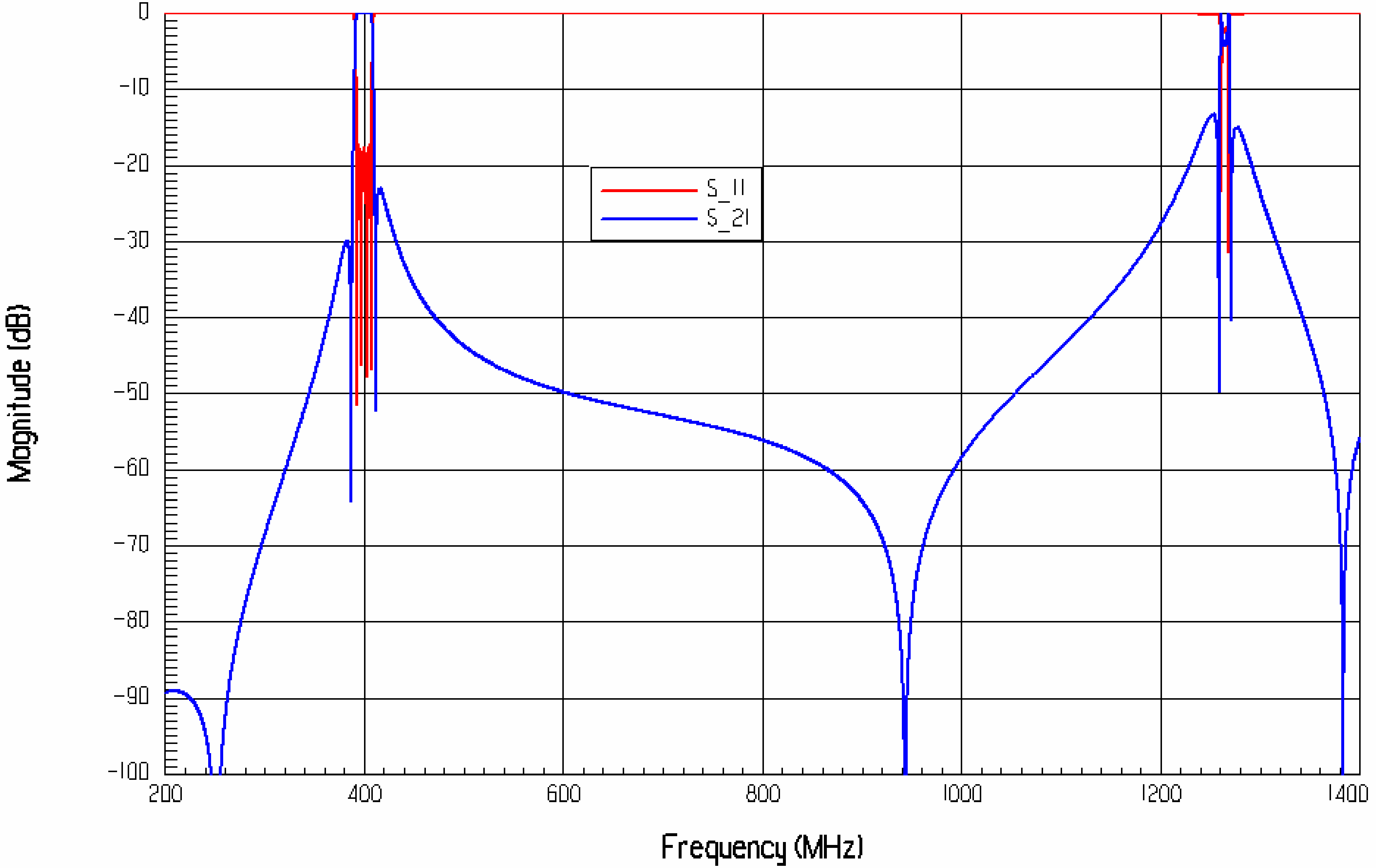
Sensitivity to W12



Silver instead of perfect conductor



What happens far out?



First design saves time

TRADITIONAL

Rule of thumb first design & manufacturing: 2 weeks
measurement & tuning: 1 week
Adaption of geometry and / or new design: 2 ½ weeks
measurement & tuning: 1 week
tolerance determination, high power tests, etc. : 2 ½ weeks

TOTAL: 9 weeks

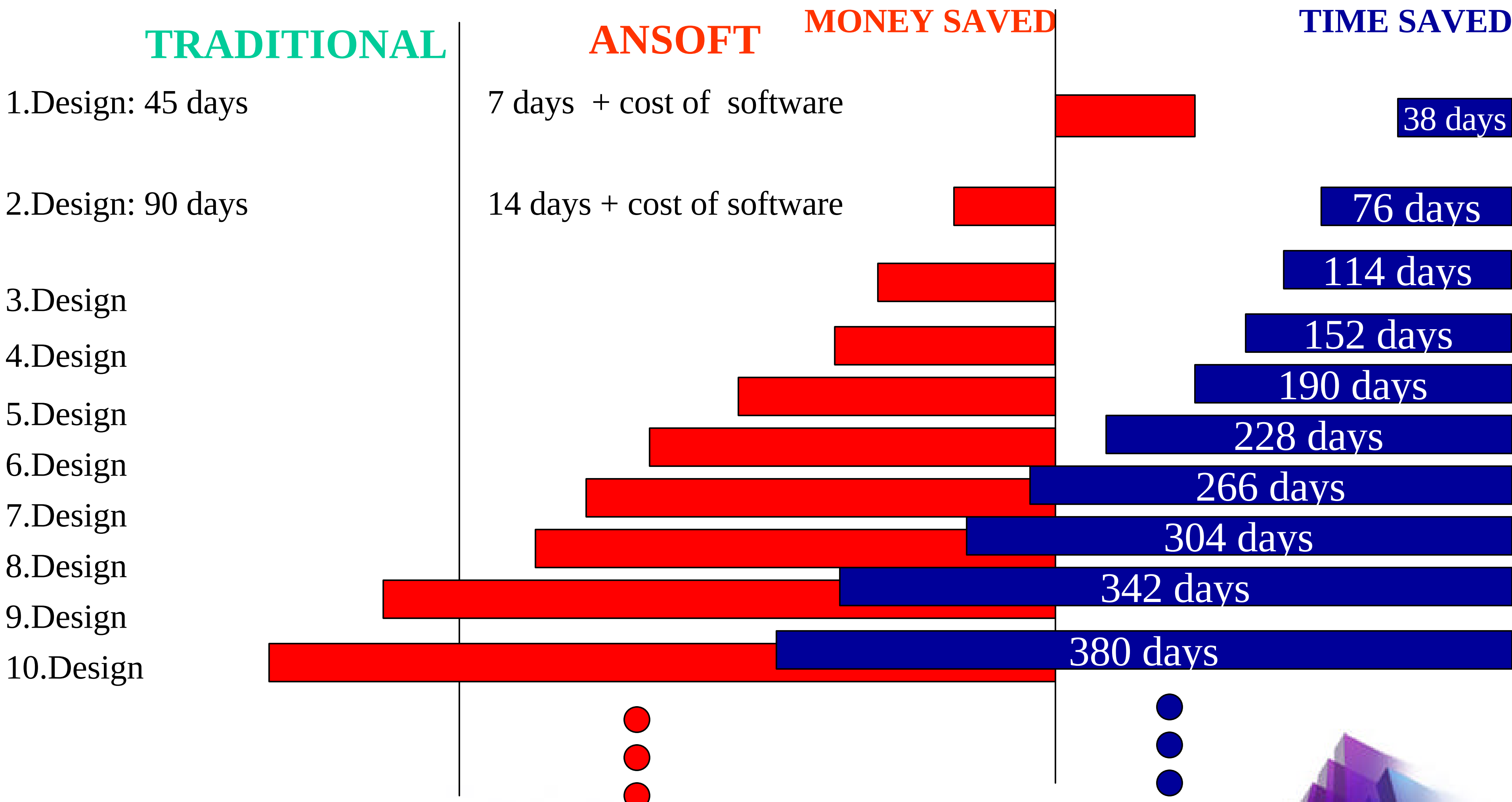
TIME

ANSOFT

Run calibration projects: 2 days
Initial design: 1 day
Corrected design: 1 day
Final design: 1 day
power & sensitivity analysis: 2 days

TOTAL: 7 days

Further designs save time AND money



Conclusions

- Experts told us elliptic filters couldn't be designed completely in software. We came up with a new method that involves frequency-dependent coupling factors.
- Tools used are Ansoft Designer, HFSS and Optimetrics. Only Ansoft has the combination of tools and features needed.
- The method converges fast: the third design is within 0.01 dB.
- Potential savings in time and money are enormous: from nine weeks to seven days is almost

  an order of magnitude improvement!