Combline Filter Design Using HFSS to Implement the Q_{ext} and k Method

Combline Basics

- Combline Filters Basics
  - "Tapped" input connected directly to first resonator
  - Resonators are metal cylinders or bars 30 to 70 electrical degrees long, grounded on one end
  - Tuned to resonance with variable capacitance to ground on ungrounded end
  - Bandwidths achievable from 1% to a full octave
  - Preferable configuration to interdigital filters
    - Unloaded Q can be higher for ground plane spacing of 0.15 lambda
    - Mechanical mounting or machining of resonators all on one side
    - Single configuration can be tuned over wide range

Qext and k Method

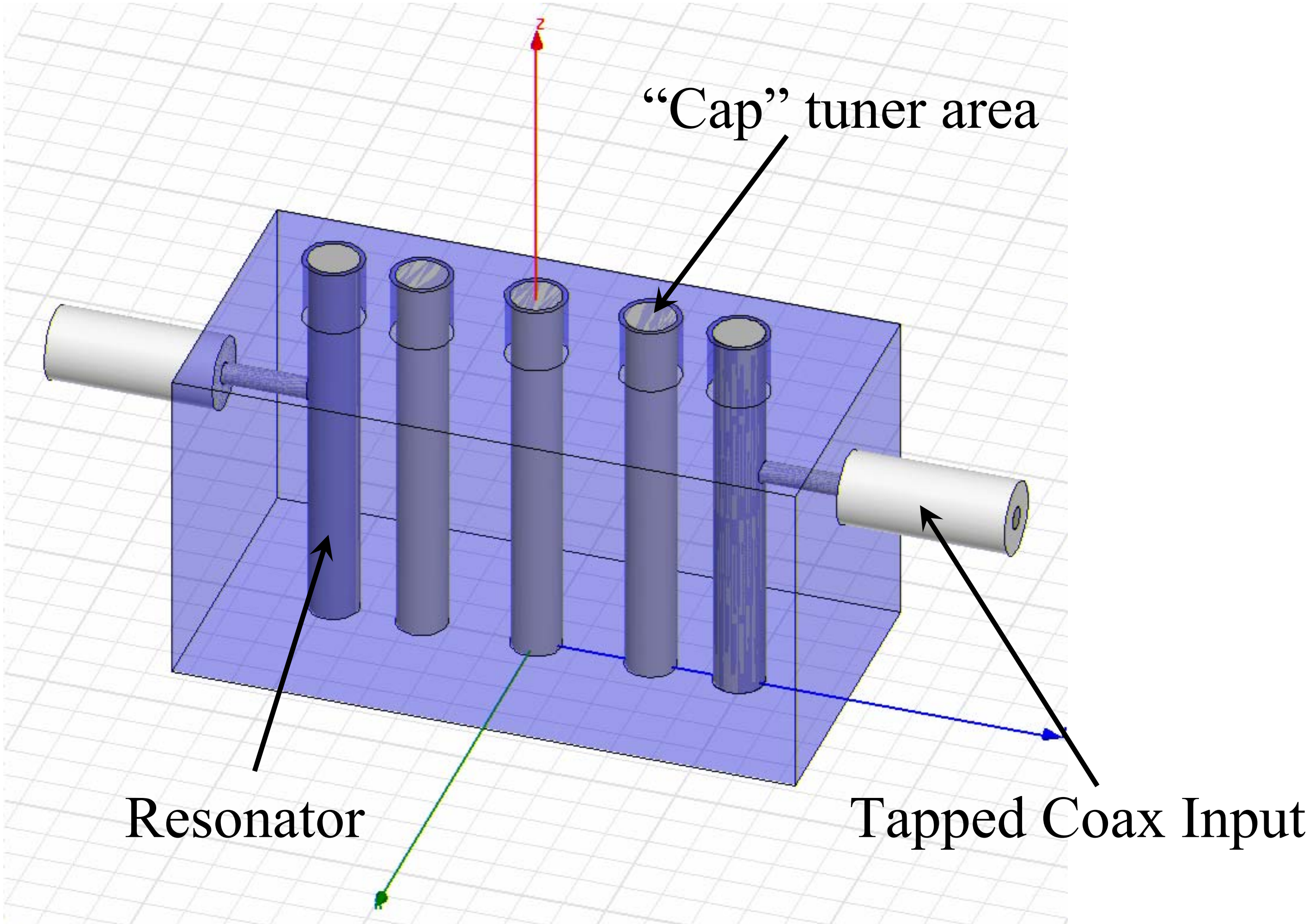
Standard Method

- Standard combline design uses g values to calculate coupled line transmission line model
- Coupled line model fails at large ground plane spacings. Yields bandwidths that are too wide.

k&Q Method

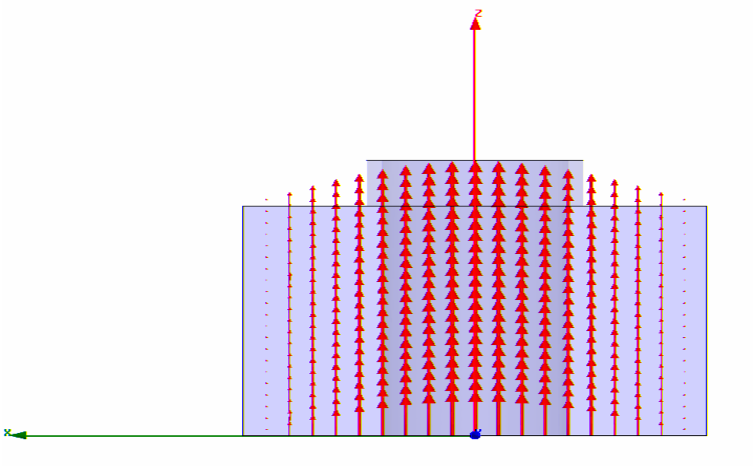
- Calculate external Q and coupling coefficient (k's) directly from low pass g values.
- Generate Physical dimensions for specified Qext and k's with test configurations in the lab or on HFSS. Yields correct bandwidth.
- Use external ports to tune resonance & to *decrease EM simulator burden*

Finished HFSS Model

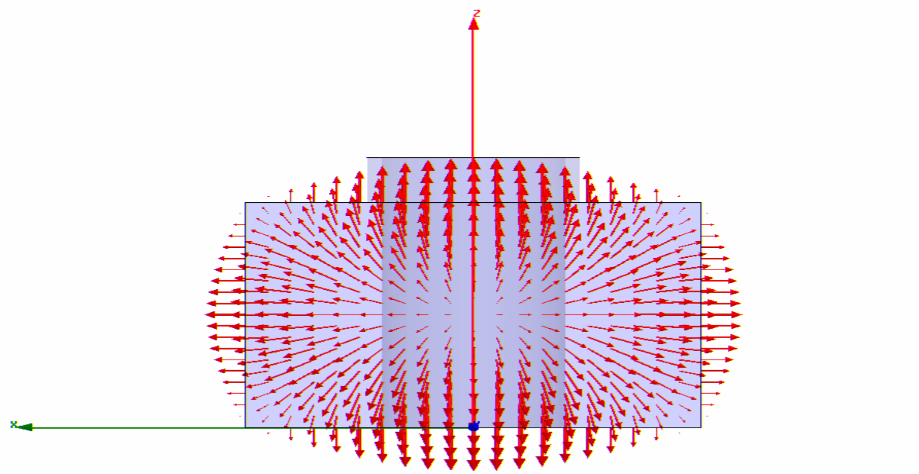


Dominate Modes

- Bandwidth "expansion" in coupled line model is caused by different propagation constants of TE_{01} and TM_{11} modes as ground plane spacing increases.



TE_{01} has H field of "even mode"



TM_{11} has E field of "odd mode"

Calculating Desired Q_{ext} and k

- Q_{ext} and k values are calculated from standard lowpass g values:

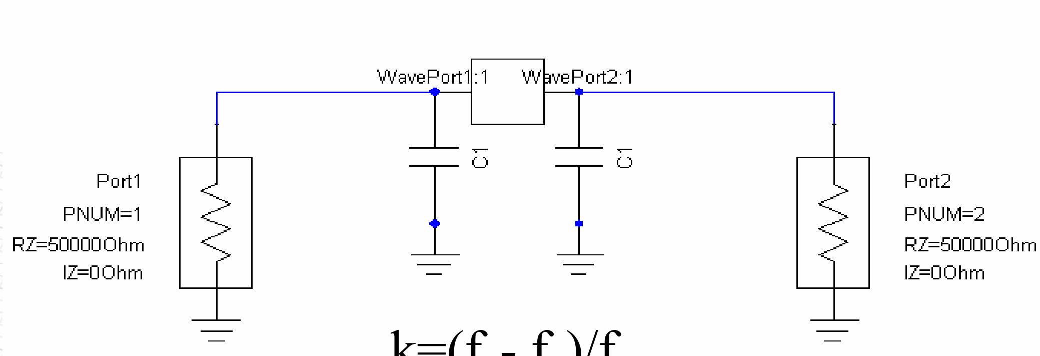
$$\mathbf{Q_{ext} = g_0\, g_1/\Delta w}$$ [1]

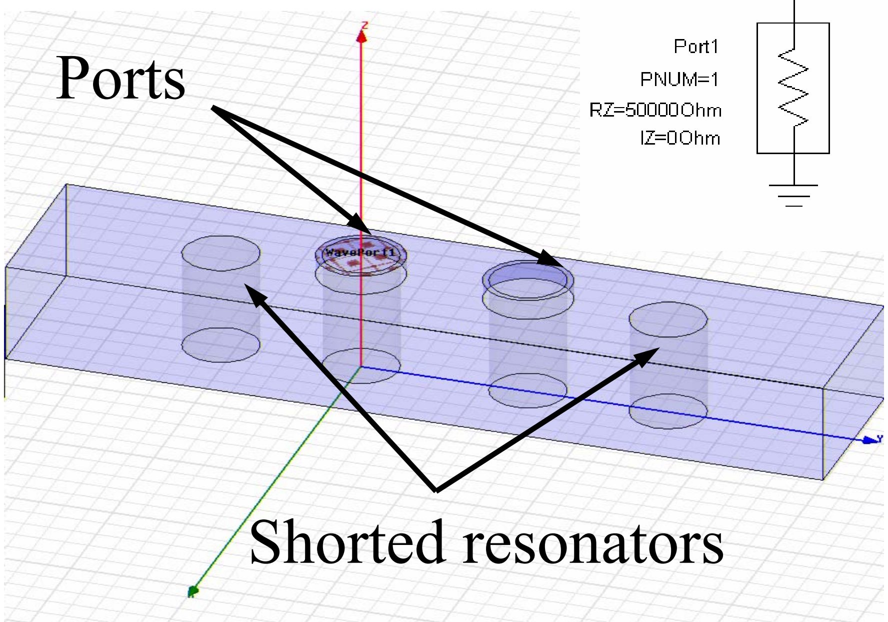
$$\mathbf{k_{IJ} = \Delta w/sqrt(g_I\, g_J)}$$ [1]

$$\mathbf{\Delta w = (w_2 - w_2)\ /sqrt(w_2\, w_1)}$$ [1]

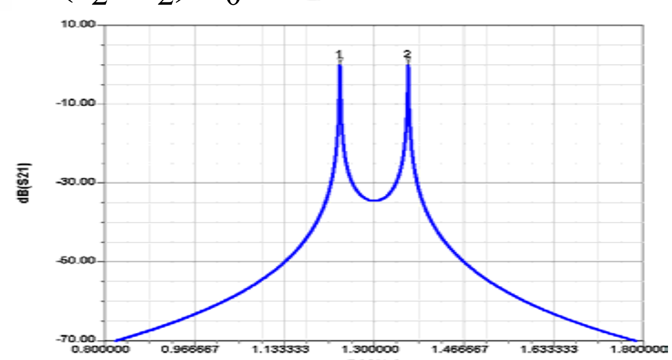
Simulating k values

- Usual method involves performing a time consuming eigenmode calculation or "sniffer' port solution and adjusting mechanical tuners
- Method proposed by Swanson and Wenzel : put a port where tuning element exists and tune on linear simulatior[2]. Detunes resonance in EM simulator



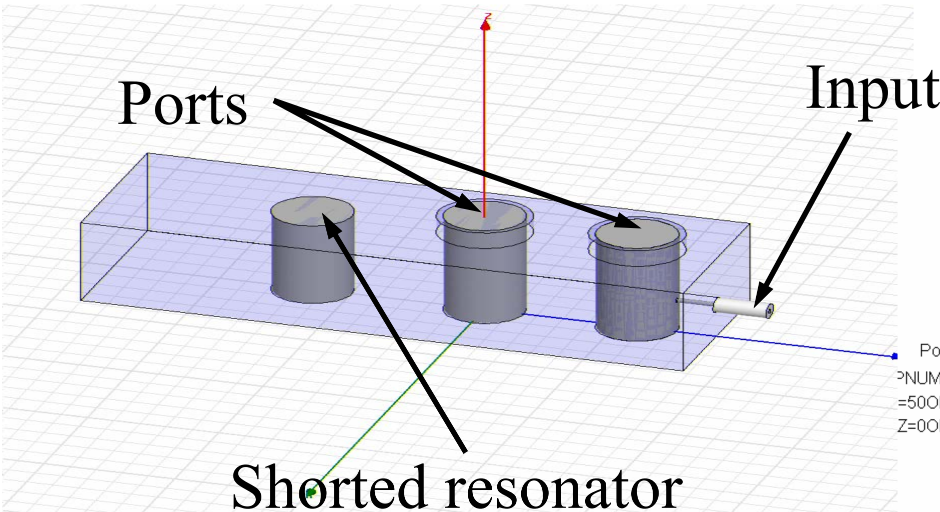


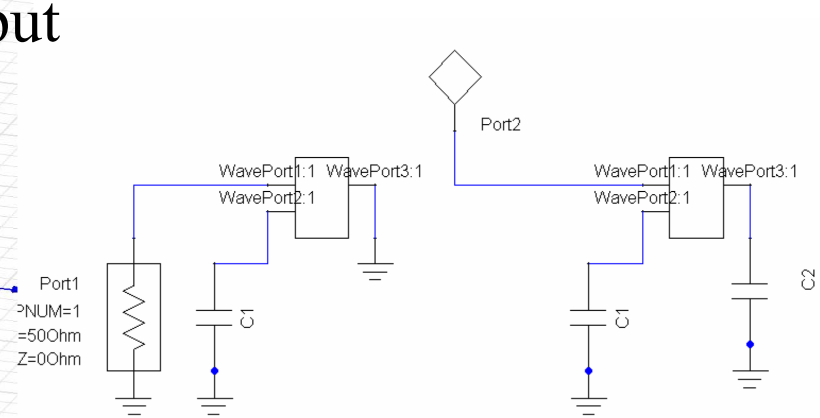
$k = (f_2 - f_2)/f_0$



Simulating Q_{ext} and k_{12}

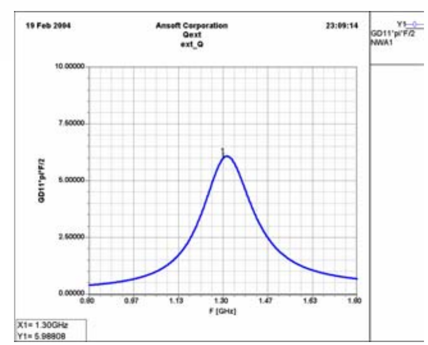
- Measure Q_{ext} and k_{12} using group delay method[3]

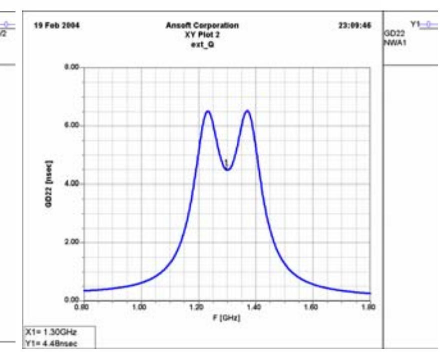




$Q_{ext}=\Gamma_{d1}w_0/4$

$k_{12}=\text{sqrt}\{4/(\Gamma_{d2}w_0 Q_{ext})\}$





Designing the Filter

- Choose a ground plane spacing for loss

  Q_u=(Kb)sqrt(f) : b in inches, f in GHz, and good Ag [5]
  K~14000(b/λ)+200 for 0.1 < (b/ λ) <0.2 [5]

  $L \sim 4.343 f_0 \Sigma g's/(\Delta w\ Q_u)$ (in dB)
- Choose rod diameter ~ 0.2 to 0.4 b
- Form low impedance coax section for port (~10 ohms) and model coax length and stray capacitance to find minimum achievable cap value
- Choose Y to give values above minimum cap value

  $Cap \sim (2\pi f\ Z_0 \tan Y)^{-1}$

Sample Filter

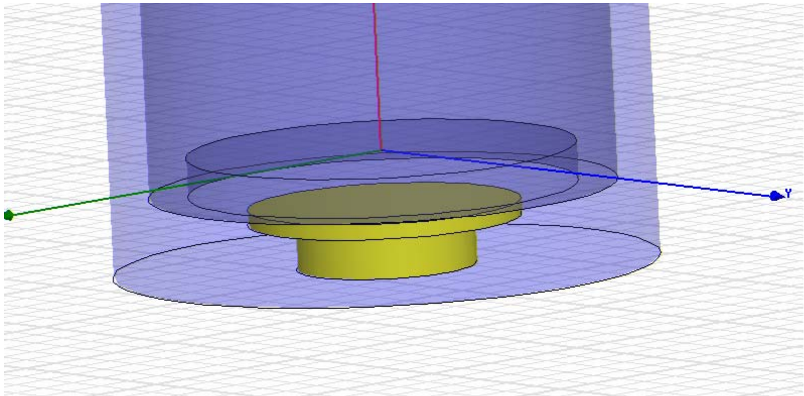
- f_0 = 1.3 GHz, Δw=0.15
- n=5 Tchevbyscheff, 0.3 dB ripple
- Designer generates g's

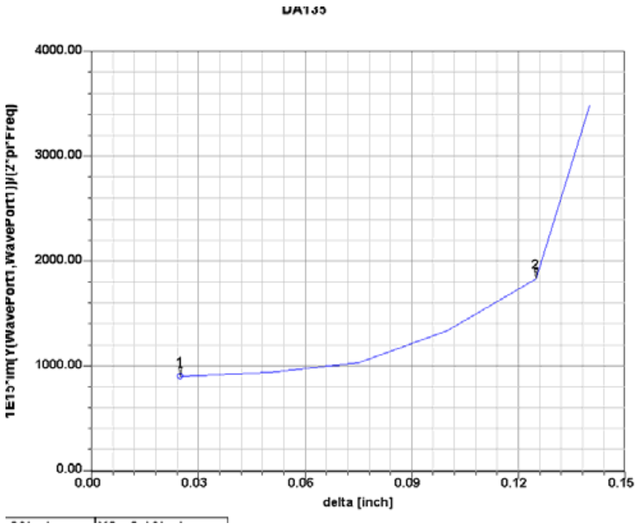
  g_0=1, g_1=0.9089, g_2=1.3619, g_3=1.7384
- Calculate Q_{ext} and k's

  Q_{ext} = 6.0598, k_{12} = 0.1348, k_{23} = 0.0975
- Chose b/λ = 0.165, b=1.5 inches
  - Q_u~4400 & Loss~0.4 dB
- Chose Y = 40 deg for cap values

Capacitor Section

- Simulate capacitor section of resonator intrusion into cavity
- Tline cap plus stay capacitance and capacitance of tuning element
- Tline cap ~ $L/(Z_{low}c)$
  - 0.03 inches protrusion
  - 254 fF

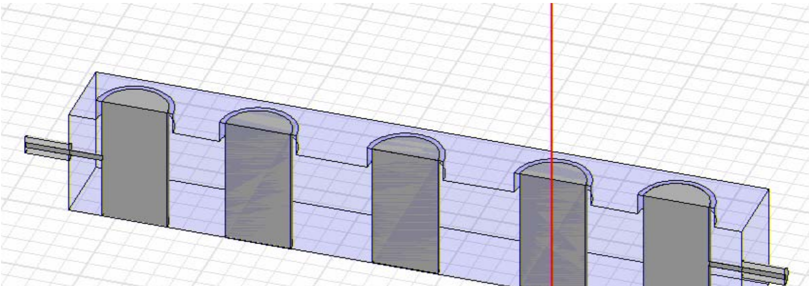




Filter Design Continued

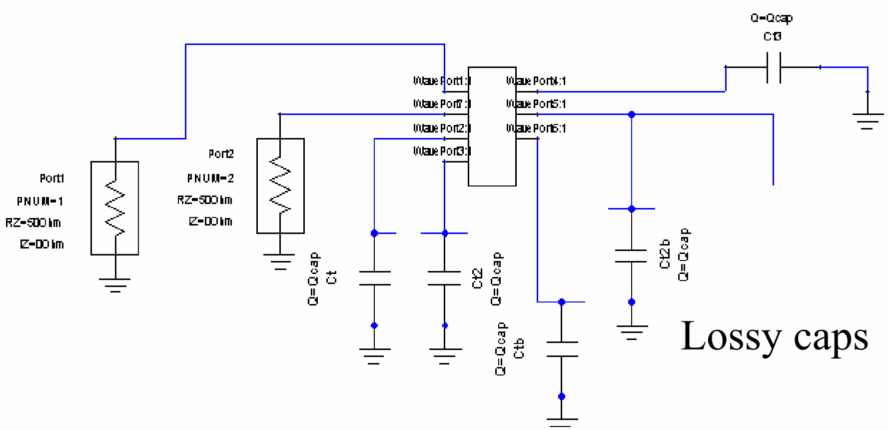
- Simulate k and Q_{ext} test circuits and calculate physical dimensions
- Simulate entire filter with ports at all tuner locations
- Tune filter in Designer using lumped caps
  - Dishal method [4]
  - Group Delay method [3]
- Measure completed filter k and Q_{ext} and tweak
- Optimize versus ideal bandpass in Designer
- Add loss to lumped caps to estimate insertion loss

Filter Dimensions



Lossless filter model

coax intrusion reference plane keep here



Lossy caps

Dimensions (inches)

- d_{12}=1.13
- d_{23}=1.346
- tap=0.604 (from gnd)
- b=1.5, L=1, diam=0.6
- tap length = 0.3
- cap port diam = 0.7
  - 0.03 insert

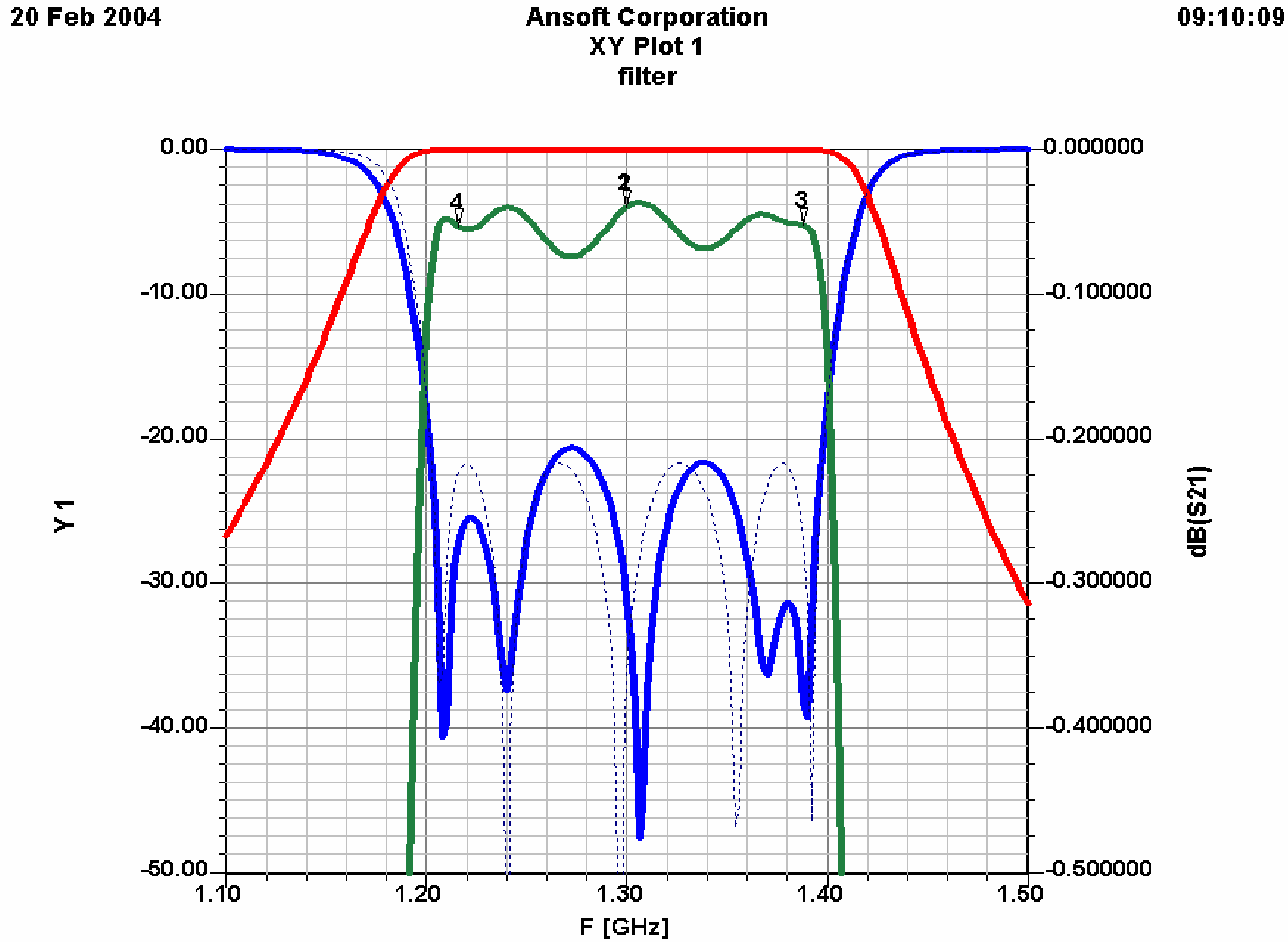
Final Q's and K's

Parameter	Desired	Simulated
Q_{ext}	6.0598	6.067
k_{12}	0.1348	0.1346
k_{23}	0.0975	0.0976

Empirical Loss modeling

- Loss from Levy [5] Q_u and MYJ : 0.04 dB
- Ideal filter with Levy [5] Q_u : 0.04-0.07 dB
- HFFS filter with silver conductivity degraded 20% : 0.06 dB average
- Ideal filter with Q of cap elements set to ½ Q_u : 0.04-0.075

Simulated Filter Results

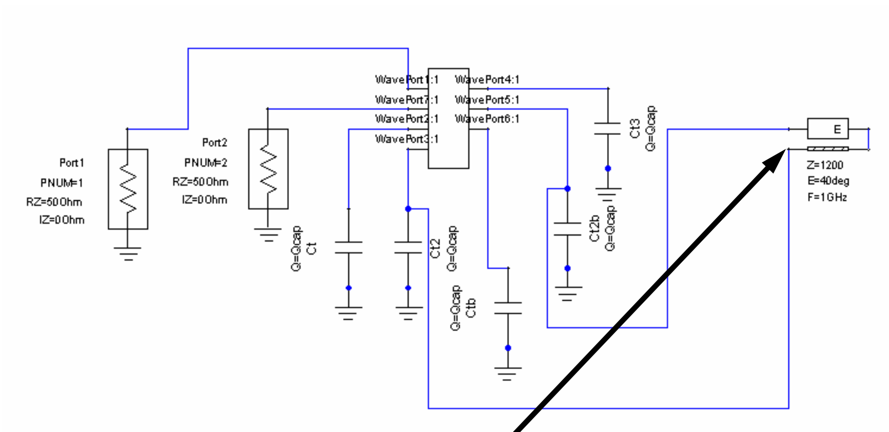


X1= 1.30GHz Y1= -0.039847	X2= 1.30GHz Y2= -0.039847	X3= 1.39GHz Y3= -0.051865	X4= 1.22GHz Y4= -0.052853

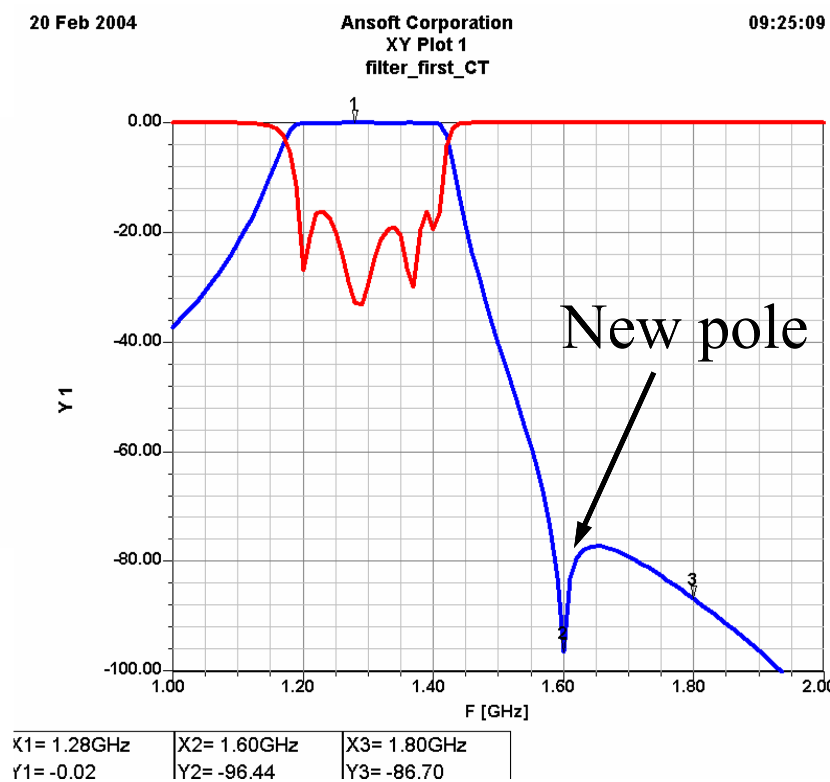
Things to keep in mind

- Designer interpolation works poorly on k value test design. Use parametric sweep and plot. Should be straight line on log scale.
- Have adjacent shorted resonators in EM sim to include nearest neighbor interaction
- Remember to short all other resonators in full filter design when measuring internal resonator k's.
- Q_{ext} and k_{12} are coupled, so have single test design including both.
- Use group delay to measure Q_{ext} and k_{12}. Measuring k_{12} by shorting input can be done, but finding proper reference plane is problematic.
- Remember to keep track of the reference plane bookkeeping for the capacitor.

Fun stuff : CT section

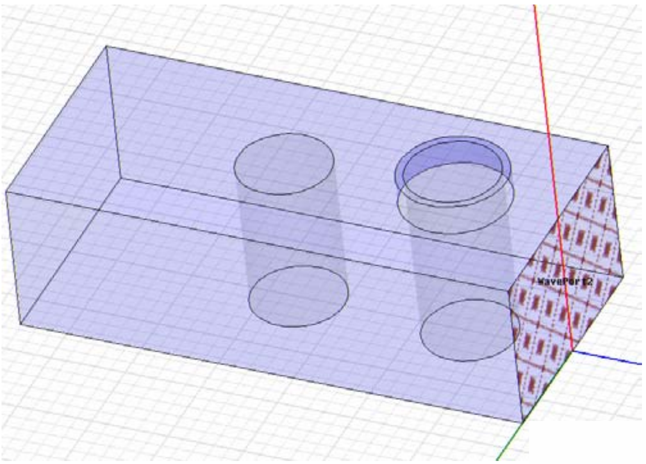


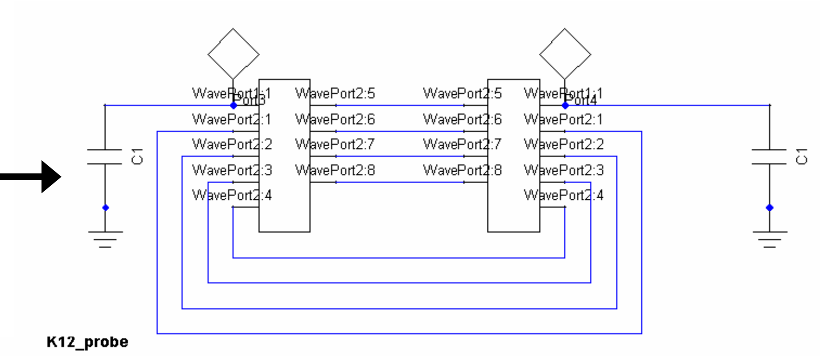
Cross coupled CT section

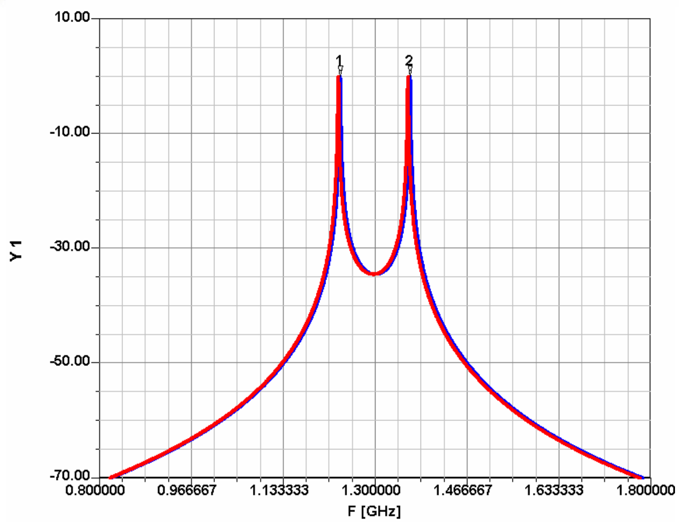


New pole

One Step Further …







References

1. MYJ
2. Swanson and Wenzel, "Fast Analysis and Optimization of Combline Filters Using FEM," 2001 MTT Digest.
3. Ness, "A Unified Approach to the Design, Measurement, and Tuning of Coupled-Resonator Filters," MTT vol 46, #4, April 1998
4. Dishal, "A Simple Design Procedure for Small Percentage Bandwidth Round-Rod Interdigital Filters," MTT-13, September 1965
5. Levy, "Transistional Combline/Evanescent-Mode Microwave Filters," MTT vol 45, #12, December 1997

Dawson RF Design

- Designs, prototypes, and production support from 1-200 GHz:
  - MMICs, MEMs, LNAs, Mixers, DROs, Gunn Oscillators
  - Printed circuit antennas, Planar Filters, Wilkinsons, and Hybrids
  - Capacitors, Spiral Inductors, Vias and Airbridge Structures
  - Waveguide Couplers, Magic Tees, Hybrids, and Diplexers
  - Waveguide Combline, Corrugated, Iris, Evanescent, and DR Filters

- Phone : 818-434-6965
- email:douglas@dawson-rf.com