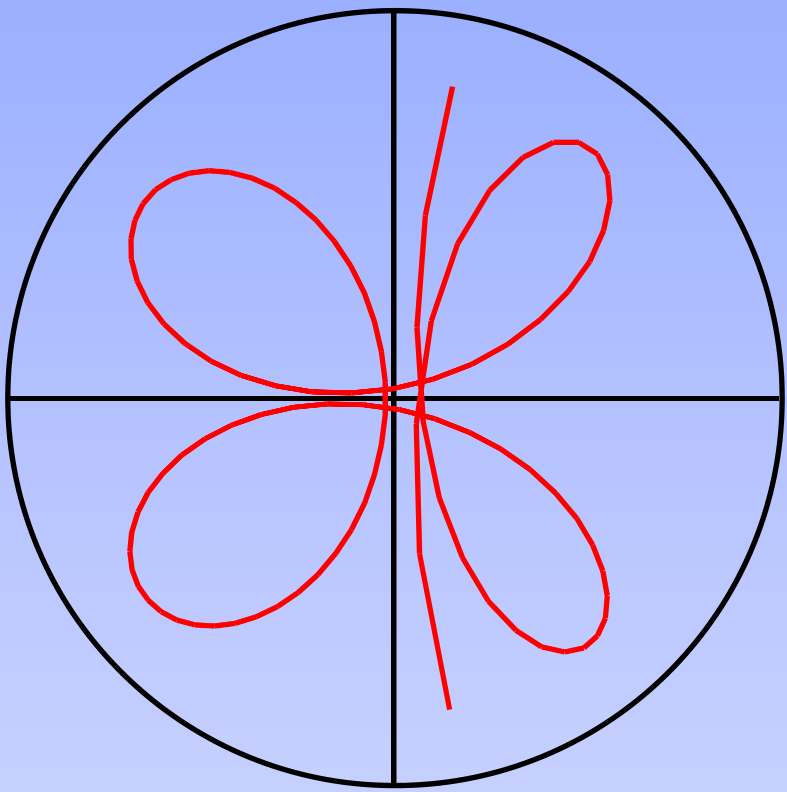

Filter Optimization With Port Tuning and CST MWS Moving Mesh

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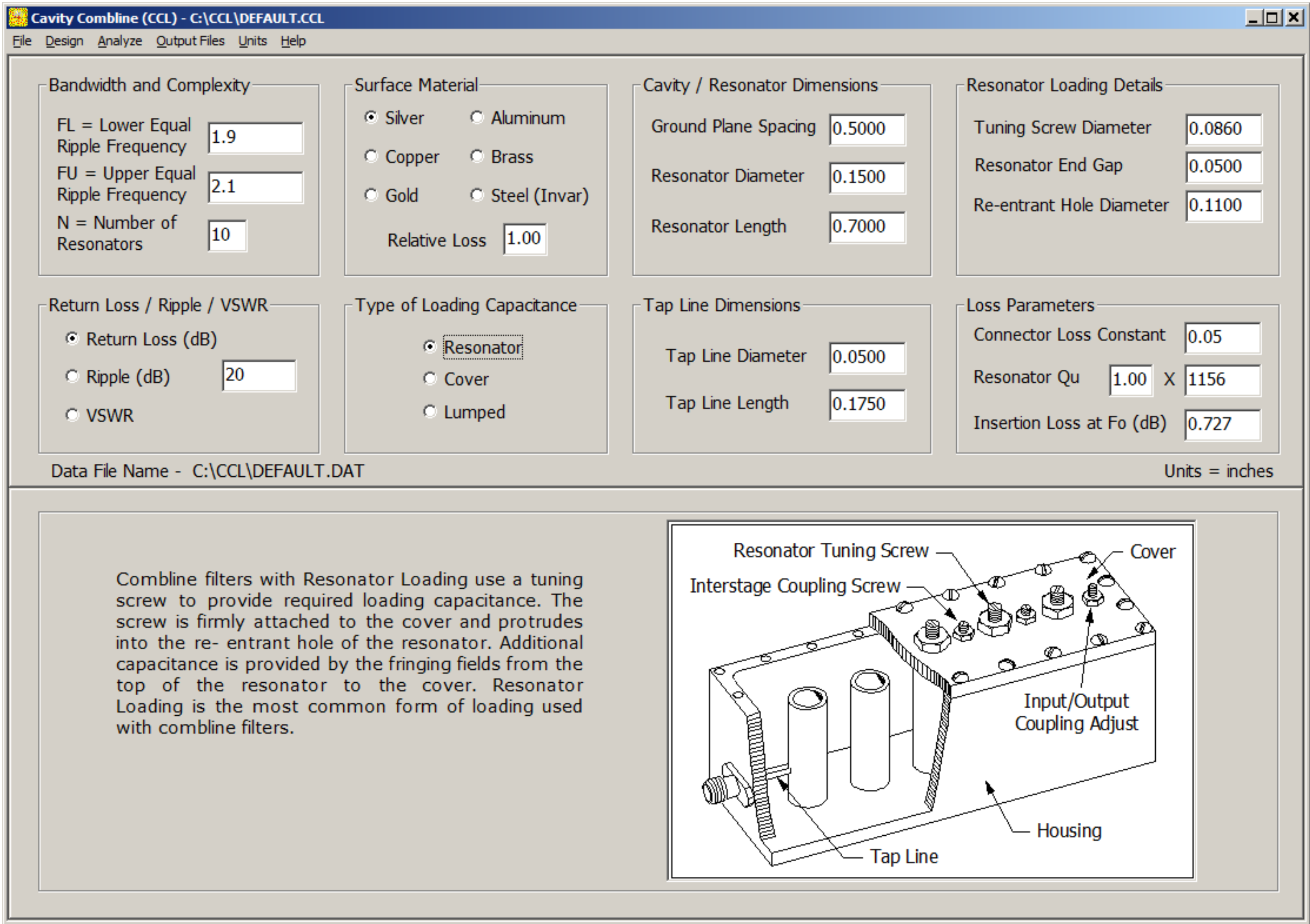
Introduction

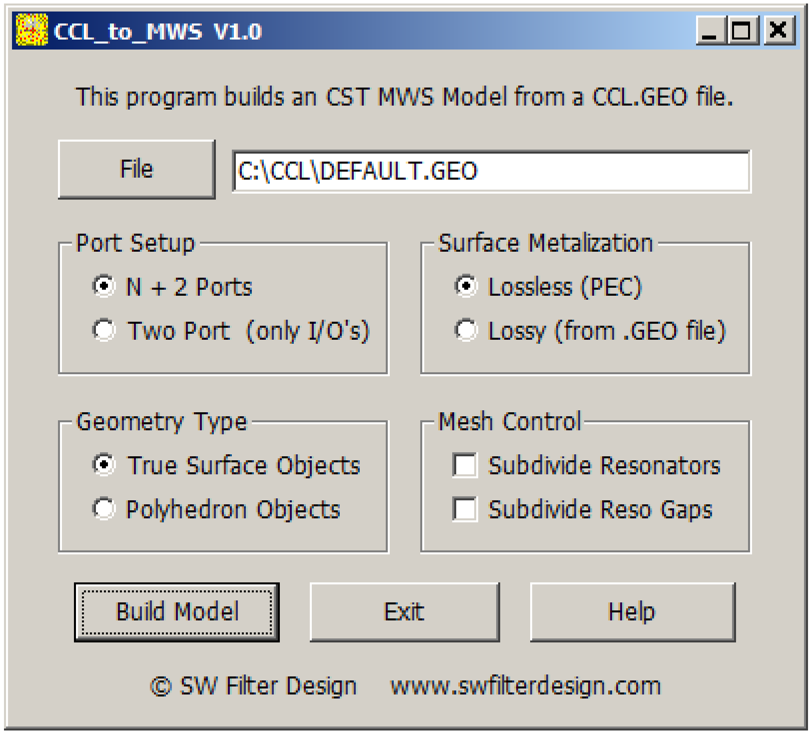
- Optimization of microwave filters using port tuning is a well established practice.
- Filters like a cavity combline have such a broad tuning range that we seldom try to make the EM model exact.
- However, there are cases where an exact two port EM model is useful:
  - Voltage breakdown analysis
  - Multipaction analysis
  - Passive intermodulation analysis
- Optimizing the filter geometry directly in the EM domain is not very efficient or even practical in many cases.
- But we can use port tuning to extract tuning sensitivities and geometry corrections very efficiently in the circuit theory domain.

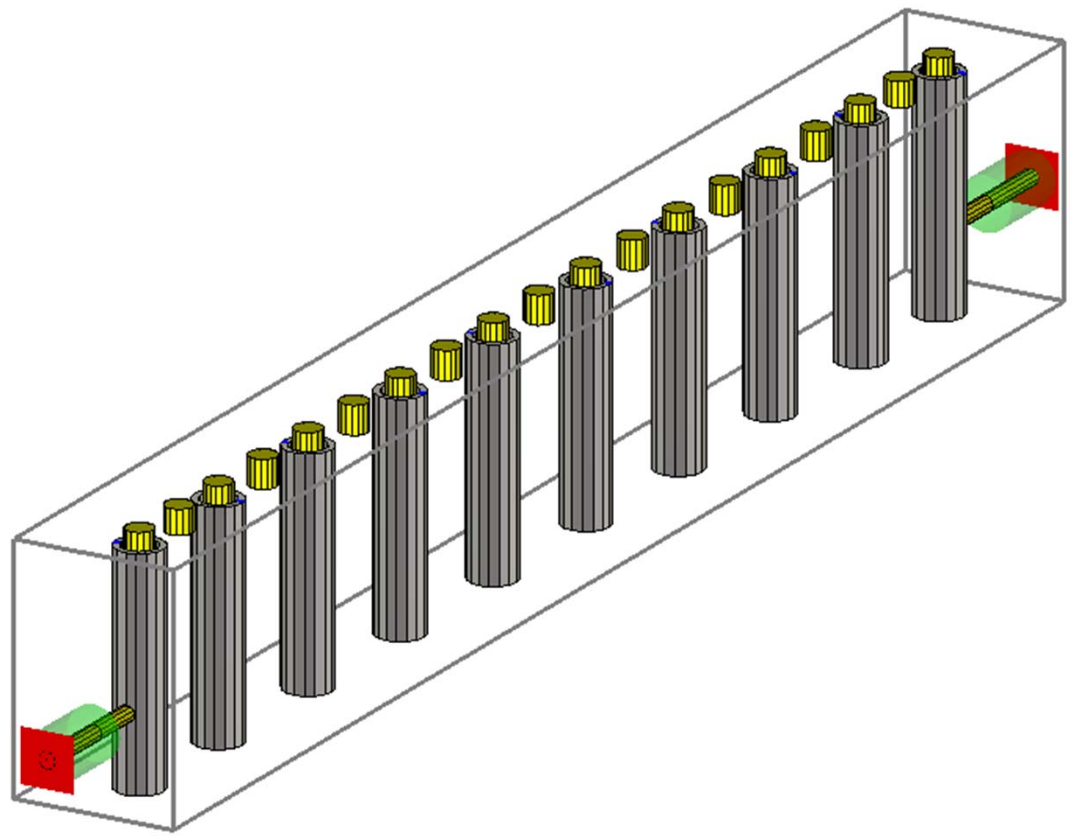
Cavity Combline (CCL) Design Program



- Combination of synthesis, analytical modeling and optimization.
- Coupling screws are not included in the design.

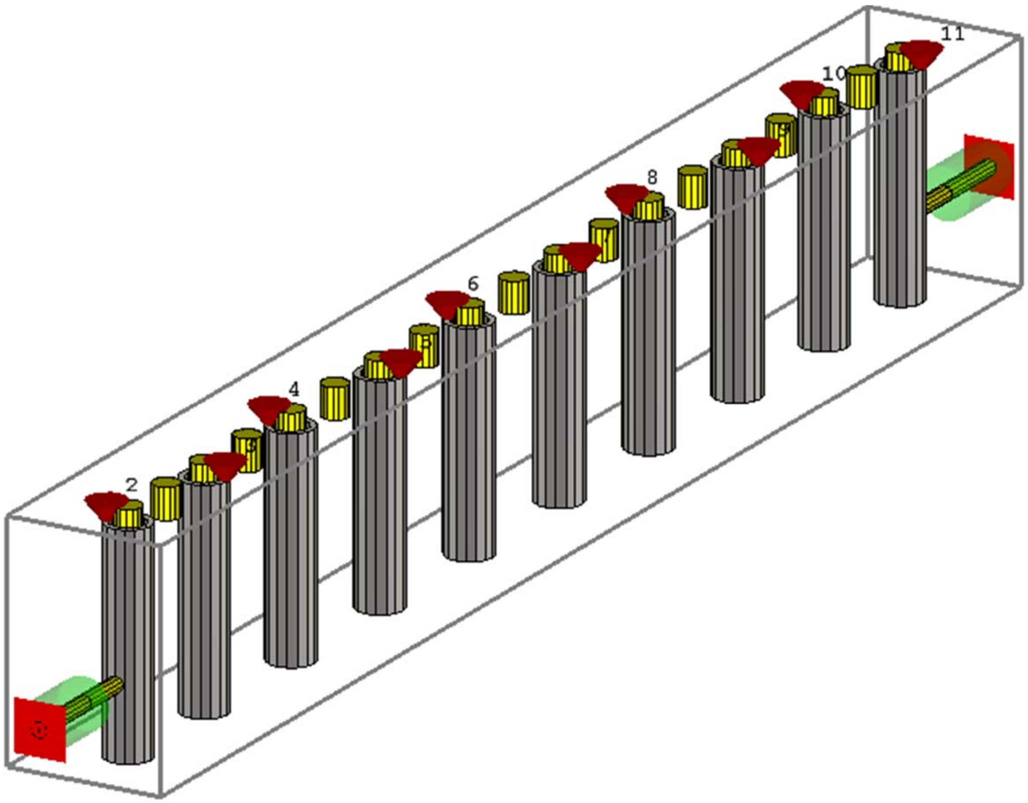
CCL_to_MWS Model Builder

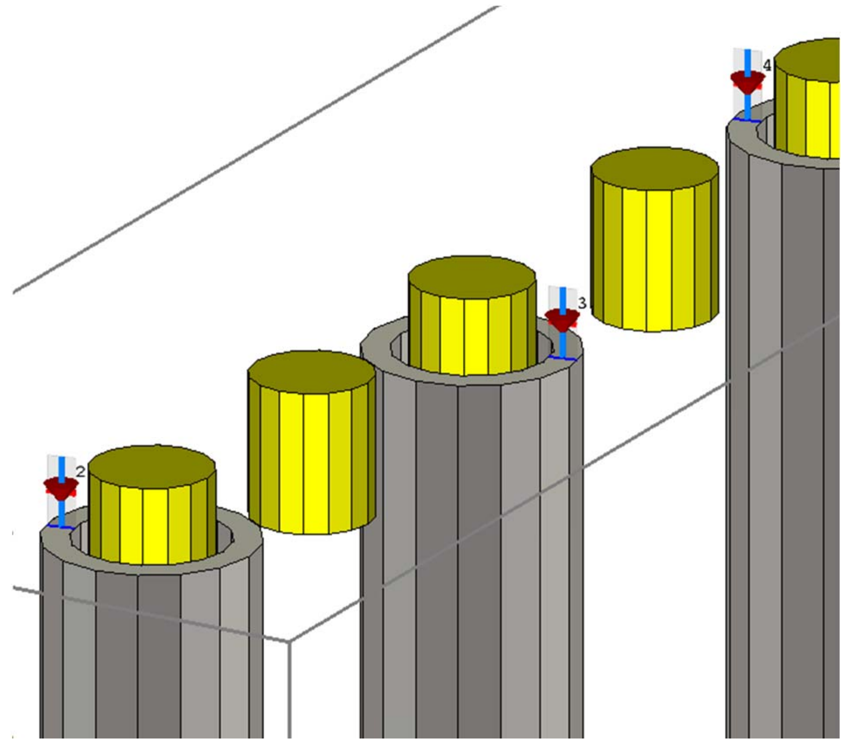




- ❍ Automatically builds CST MWS model from CCL geometry data.
- ❍ Two port model or port tuned model.

N=10 Combline Filter Example





- Arbitrarily set diameter and depth for coupling screws.
- CCL sets tuning screws a little too deep and makes bandwidth a little narrow to allow for coupling screws.
- We expect dimensions and port tunings to be symmetrical, but we are not forcing symmetry in the optimization process.

Moving Mesh in CST MWS

- For small changes in geometry the existing mesh is deformed rather than forming a completely new mesh.
- In an optimization routine, this reduces numerical noise due to the meshing process.
- It also greatly reduces simulation time, as the adaptive meshing process typically takes much longer than a fast frequency sweep.

Equal Ripple Optimization

- Fast, robust equal ripple optimization is a also a key element in this optimization strategy.
- At each iteration the optimizer consistently finds the same Chebyshev transfer function across the desired filter passband.
- If we don’t consistently find the same solution as we vary the geometry, this will introduce noise into the optimization.

Port Tuning

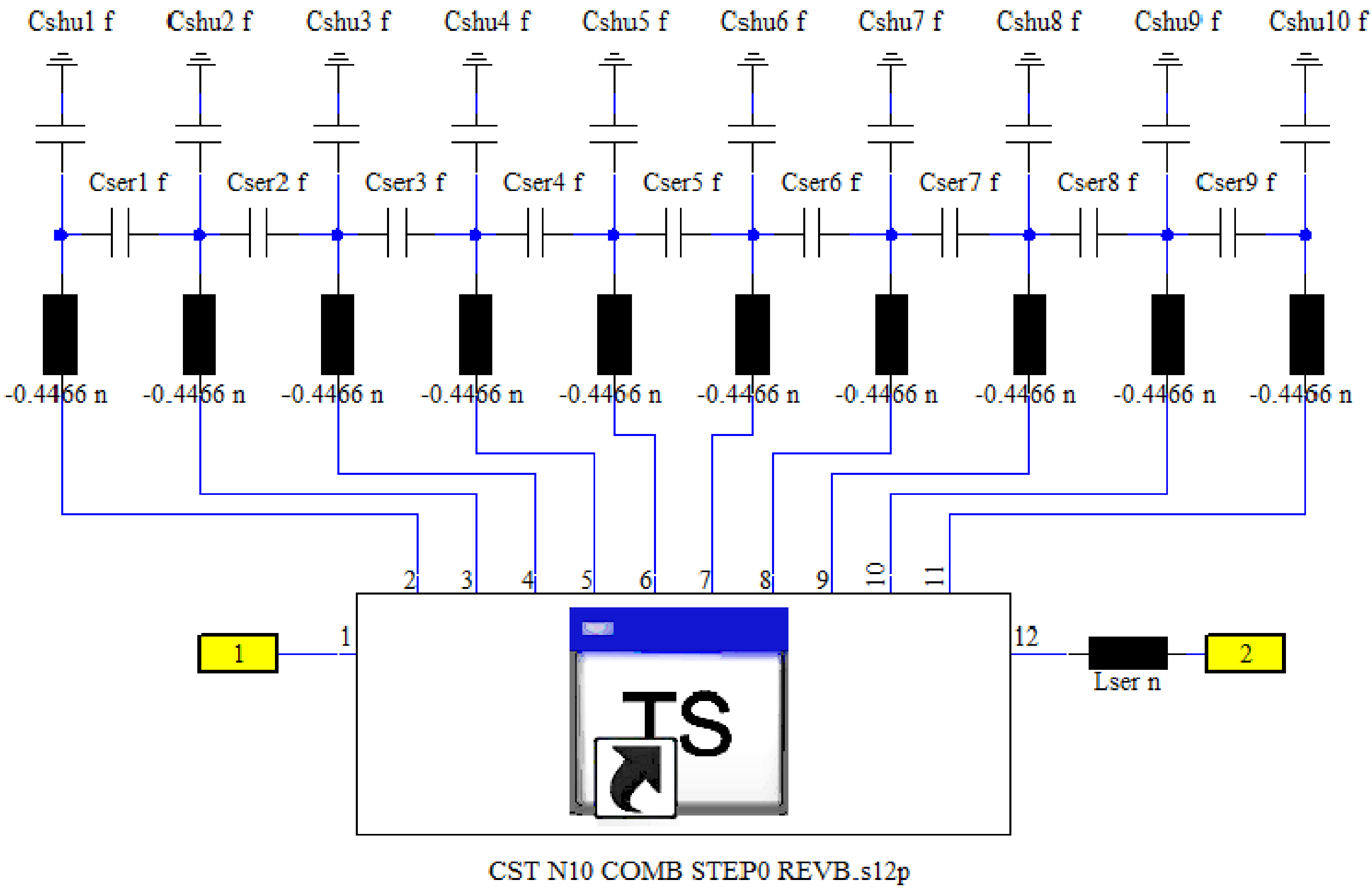
- With the Port Tuning method there is a one-to-one correspondence between the computed tunings and the geometry corrections.
- Only the Time Domain Tuning method has a similar correspondence between computed tunings and geometry corrections.
- When combined with equal ripple optimization and linear interpolation we get the magnitude and direction of corrections to the physical model.

Optimization Strategy

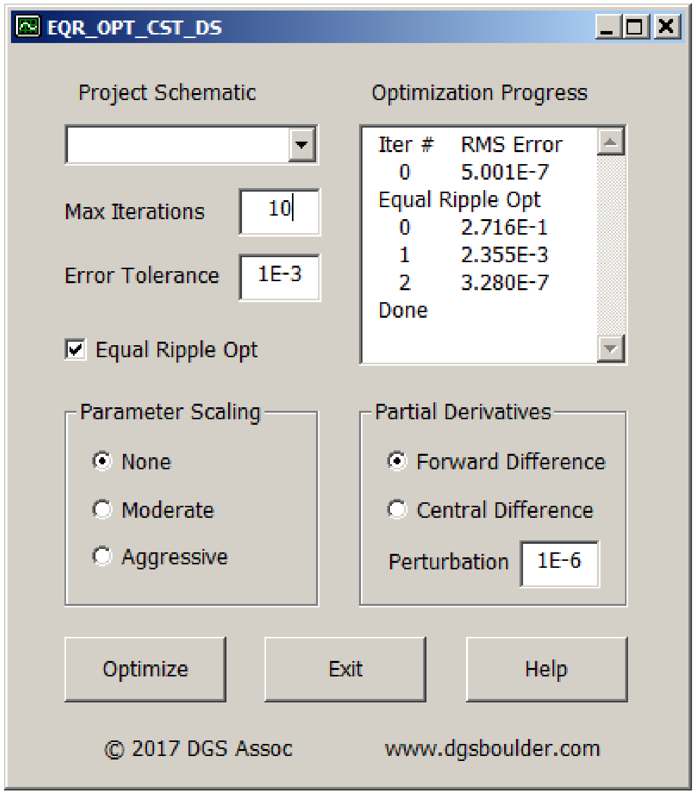
1. Simulate the initial geometry and port tune.
2. Apply a small delta to all the tuning screws, solve with moving mesh and port tune again.
3. Use the port tunings to compute tuning sensitivities for each screw and corrections to screw lengths.
4. Loop back to Step 1 with the new nominal geometry.

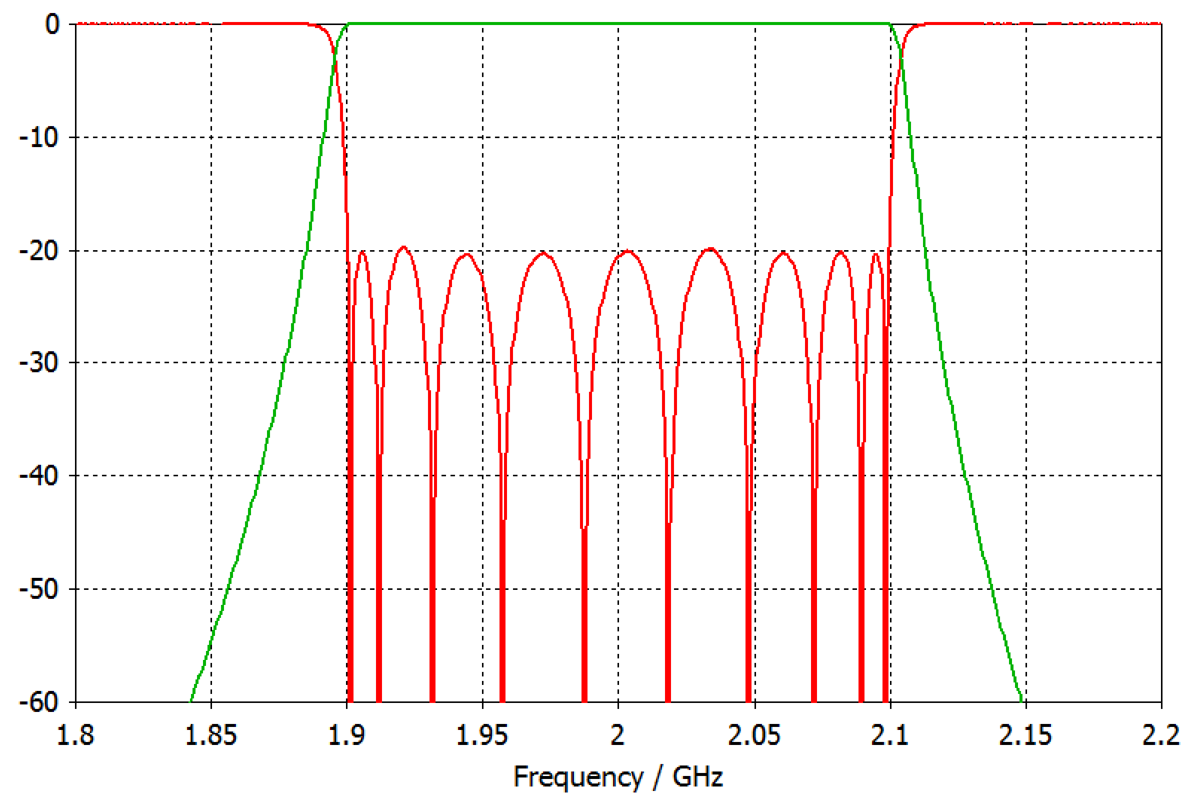
Note: no gradients or sensitivities are computed in the EM domain. It is all done in the circuit theory domain. Convergence can occur with very few EM simulations.

Port Tuning Schematic



EQR_OPT_CST_DS





- Using the COM interface and scripting our optimizer reads the Design Studio schematic, computes changes to the variables and writes them back to the schematic.
- Because it knows it is looking for a filter transfer function, it is faster than any general purpose optimizer for this type of problem.

First Iteration

	Nominal Length (in)	Delta	Nom - Delta	Nominal Cap Tunes (fF)	Nom – Delta Cap Tunes (fF)	Sensitivity fF / inch	New Deltas	New Nominal
TScrew1	0.2195	0.0020	0.2175	-221.2726	-208.553750	6359.425	-0.0348	0.18471
TScrew2	0.1934	0.0020	0.1914	-214.48318	-201.841560	6320.810	-0.0339	0.15947
TScrew3	0.1921	0.0020	0.1901	-209.12063	-196.648460	6236.085	-0.0335	0.15857
TScrew4	0.1919	0.0020	0.1899	-208.63887	-196.199150	6219.860	-0.0335	0.15836
TScrew5	0.1919	0.0020	0.1899	-208.53985	-196.123010	6208.420	-0.0336	0.15831
TScrew6	0.1919	0.0020	0.1899	-208.66971	-196.260580	6204.565	-0.0336	0.15827
TScrew7	0.1919	0.0020	0.1899	-208.3521	-195.948730	6201.685	-0.0336	0.15830
TScrew8	0.1921	0.0020	0.1901	-209.07374	-196.609700	6232.020	-0.0335	0.15855
TScrew9	0.1934	0.0020	0.1914	-214.33134	-201.797480	6266.930	-0.0342	0.15920
TScrew10	0.2195	0.0020	0.2175	-221.16372	-208.498460	6332.630	-0.0349	0.18458
CScrew1	0.1	0.0020	0.0980	1.7615636	1.6069175	-77.323	-0.0228	0.07722
CScrew2	0.1	0.0020	0.0980	0.14908167	0.08703365	-31.024	-0.0048	0.09519
CScrew3	0.1	0.0020	0.0980	0.25941599	0.19439702	-32.509	-0.0080	0.09202
CScrew4	0.1	0.0020	0.0980	0.045562052	-0.000905	-23.234	-0.0020	0.09804
CScrew5	0.1	0.0020	0.0980	0.24328	0.18269475	-30.293	-0.0080	0.09197
CScrew6	0.1	0.0020	0.0980	0.046584859	-0.001064102	-23.824	-0.0020	0.09804
CScrew7	0.1	0.0020	0.0980	0.2660559	0.20164969	-32.203	-0.0083	0.09174
CScrew8	0.1	0.0020	0.0980	0.15186231	0.088884193	-31.489	-0.0048	0.09518
CScrew9	0.1	0.0020	0.0980	1.7556528	1.5996165	-78.018	-0.0225	0.07750

Note: capacitance units are femto Farads.

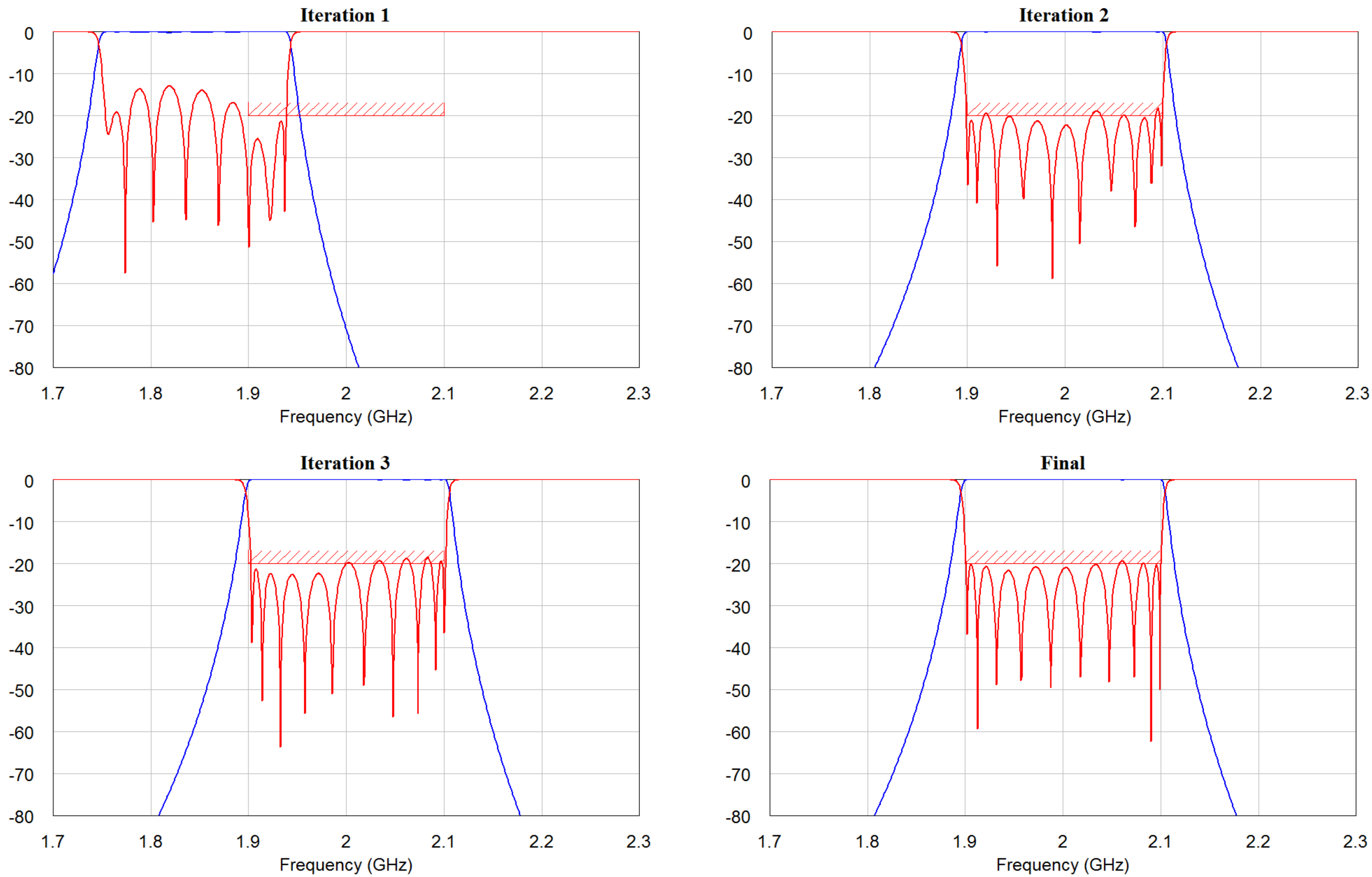
Second Iteration

	Nominal Length (in)	Delta	Nom - Delta	Nominal Cap Tunes (fF)	Nom – Delta Cap Tunes (fF)	Sensitivity fF / inch	New Deltas	New Nominal
TScrew1	0.18471	0.0010	0.18371	-1.5421017	4.564569	6106.671	-0.0003	0.18445
TScrew2	0.15947	0.0010	0.15847	-3.1046238	2.955899	6060.523	-0.0005	0.15895
TScrew3	0.15857	0.0010	0.15757	-2.9164345	3.121065	6037.499	-0.0005	0.15808
TScrew4	0.15836	0.0010	0.15736	-2.6306642	3.373317	6003.981	-0.0004	0.15792
TScrew5	0.15831	0.0010	0.15731	-2.4686954	3.537969	6006.664	-0.0004	0.15790
TScrew6	0.15827	0.0010	0.15727	-2.3993836	3.630211	6029.594	-0.0004	0.15787
TScrew7	0.15830	0.0010	0.15730	-2.2040713	3.848372	6052.443	-0.0004	0.15794
TScrew8	0.15855	0.0010	0.15755	-2.839142	3.168873	6008.015	-0.0005	0.15808
TScrew9	0.15920	0.0010	0.15820	-1.4061972	4.659366	6065.563	-0.0002	0.15897
TScrew10	0.18458	0.0010	0.18358	-0.61086622	5.511614	6122.480	-0.0001	0.18448
CScrew1	0.07722	0.0010	0.07622	0.066356314	-0.007357763	-73.714	-0.0009	0.07632
CScrew2	0.09519	0.0010	0.09419	0.42342428	0.38602312	-37.401	-0.0113	0.08387
CScrew3	0.09202	0.0010	0.09102	0.22162645	0.18353334	-38.093	-0.0058	0.08620
CScrew4	0.09804	0.0010	0.09704	0.50896901	0.47650543	-32.464	-0.0157	0.08236
CScrew5	0.09197	0.0010	0.09097	0.2254481	0.19023192	-35.216	-0.0064	0.08557
CScrew6	0.09804	0.0010	0.09704	0.50778912	0.47611425	-31.675	-0.0160	0.08201
CScrew7	0.09174	0.0010	0.09074	0.21189601	0.17458339	-37.313	-0.0057	0.08606
CScrew8	0.09518	0.0010	0.09418	0.4242675	0.38610603	-38.161	-0.0111	0.08406
CScrew9	0.07750	0.0010	0.07650	0.089116751	0.01542347	-73.693	-0.0012	0.07629

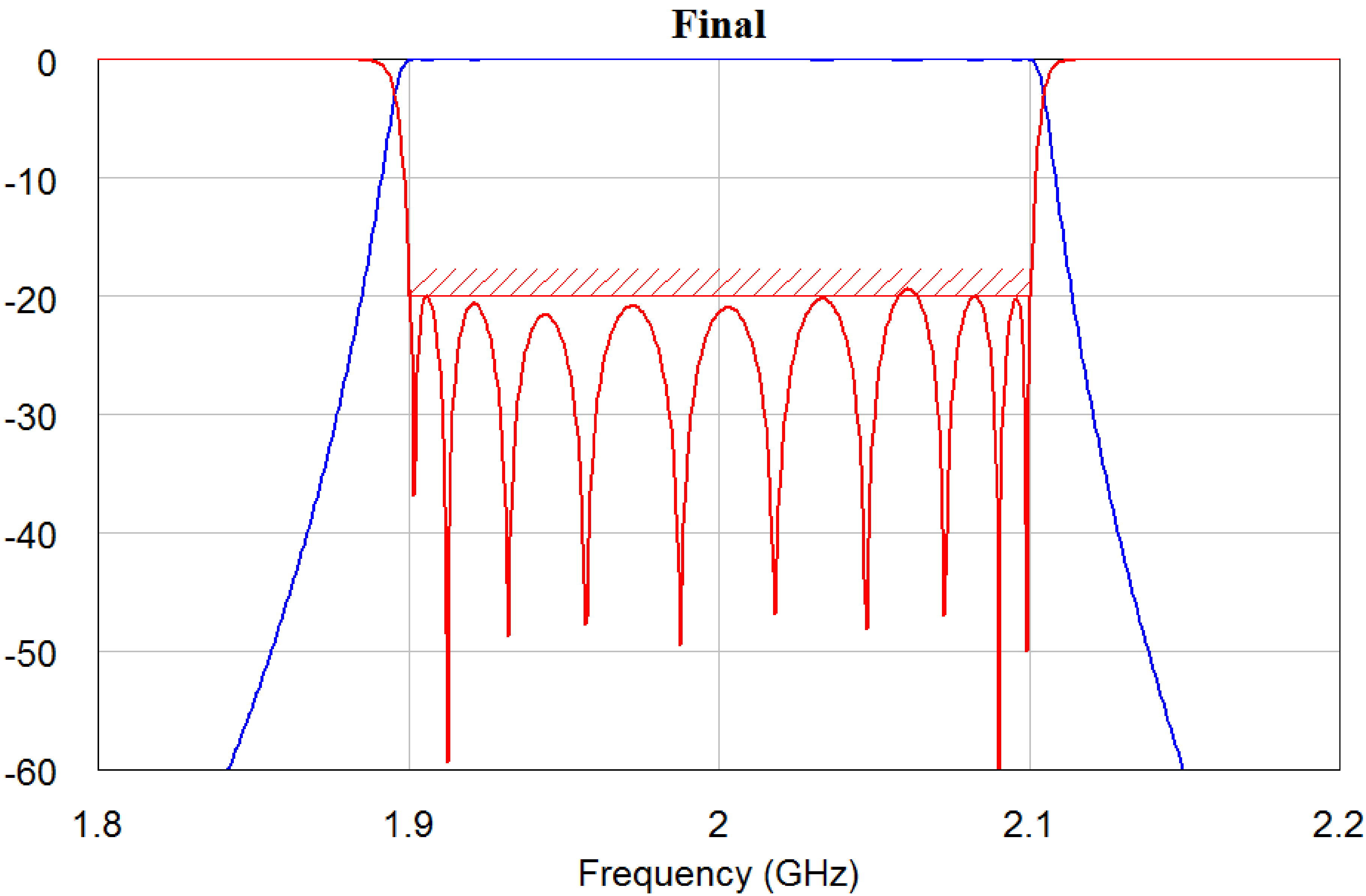
Third Iteration

	Nominal Length (in)	Delta	Nom - Delta	Nominal Cap Tunes (fF)	Nom – Delta Cap Tunes (fF)	Sensitivity fF / inch	New Deltas	New Nominal
TScrew1	0.18445	0.0005	0.18395	0.041878749	3.039716	5995.674	0.0000	0.18446
TScrew2	0.15895	0.0005	0.15845	1.3657547	4.354053	5976.597	0.0002	0.15918
TScrew3	0.15808	0.0005	0.15758	1.1498128	4.107458	5915.290	0.0002	0.15828
TScrew4	0.15792	0.0005	0.15742	1.7164073	4.677440	5922.066	0.0003	0.15821
TScrew5	0.15790	0.0005	0.15740	1.5366092	4.490859	5908.500	0.0003	0.15816
TScrew6	0.15787	0.0005	0.15737	1.6763853	4.630377	5907.983	0.0003	0.15815
TScrew7	0.15794	0.0005	0.15744	1.4730974	4.423333	5900.471	0.0002	0.15819
TScrew8	0.15808	0.0005	0.15758	1.4146623	4.362540	5895.756	0.0002	0.15832
TScrew9	0.15897	0.0005	0.15847	0.95715667	3.940363	5966.413	0.0002	0.15913
TScrew10	0.18448	0.0005	0.18398	-0.33181872	2.682758	6029.153	-0.0001	0.18442
CScrew1	0.07632	0.0005	0.07582	0.019846459	-0.018071665	-75.836	-0.0003	0.07606
CScrew2	0.08387	0.0005	0.08337	-0.1038578	-0.12071585	-33.716	0.0031	0.08695
CScrew3	0.08620	0.0005	0.08570	-0.015073101	-0.032824399	-35.503	0.0004	0.08663
CScrew4	0.08236	0.0005	0.08186	-0.13726445	-0.15128263	-28.036	0.0049	0.08726
CScrew5	0.08557	0.0005	0.08507	-0.016865018	-0.033685657	-33.641	0.0005	0.08607
CScrew6	0.08201	0.0005	0.08151	-0.1519833	-0.1661654	-28.364	0.0054	0.08737
CScrew7	0.08606	0.0005	0.08556	-0.016915071	-0.03549339	-37.157	0.0005	0.08651
CScrew8	0.08406	0.0005	0.08356	-0.093581766	-0.11104692	-34.930	0.0027	0.08674
CScrew9	0.07629	0.0005	0.07579	0.015366979	-0.023057591	-76.849	-0.0002	0.07609

Two Port Filter Simulations



Final Two Port Simulation



Summary of Dimensions and Tunings

	Iteration 1 Length (in)	Iteration 2 Length (in)	Iteration 3 Length (in)	Final Length (in)	Iteration 1 Cap Tunes (fF)	Iteration 2 Cap Tunes (fF)	Iteration 3 Cap Tunes (fF)	Final Cap Tunes (fF)
TScrew1	0.2195	0.18471	0.18445	0.18446	-221.273	-1.54210	0.04188	-0.11145
TScrew2	0.1934	0.15947	0.15895	0.15918	-214.483	-3.10462	1.36575	-0.34501
TScrew3	0.1921	0.15857	0.15808	0.15828	-209.121	-2.91643	1.14981	-0.43169
TScrew4	0.1919	0.15836	0.15792	0.15821	-208.639	-2.63066	1.71641	-0.45181
TScrew5	0.1919	0.15831	0.15790	0.15816	-208.540	-2.46870	1.53661	-0.48252
TScrew6	0.1919	0.15827	0.15787	0.15815	-208.670	-2.39938	1.67639	-0.49731
TScrew7	0.1919	0.15830	0.15794	0.15819	-208.352	-2.20407	1.47310	-0.50496
TScrew8	0.1921	0.15855	0.15808	0.15832	-209.074	-2.83914	1.41466	-0.36658
TScrew9	0.1934	0.15920	0.15897	0.15913	-214.331	-1.40620	0.95716	-0.30247
TScrew10	0.2195	0.18458	0.18448	0.18442	-221.164	-0.61087	-0.33182	-0.04037
CScrew1	0.1	0.07722	0.07632	0.07606	1.76156	0.06636	0.01985	-0.00517
CScrew2	0.1	0.09519	0.08387	0.08695	0.14908	0.42342	-0.10386	0.03612
CScrew3	0.1	0.09202	0.08620	0.08663	0.25942	0.22163	-0.01507	-0.00219
CScrew4	0.1	0.09804	0.08236	0.08726	0.04556	0.50897	-0.13726	0.04333
CScrew5	0.1	0.09197	0.08557	0.08607	0.24328	0.22545	-0.01687	-0.00191
CScrew6	0.1	0.09804	0.08201	0.08737	0.04658	0.50779	-0.15198	0.05006
CScrew7	0.1	0.09174	0.08606	0.08651	0.26606	0.21190	-0.01692	-0.00365
CScrew8	0.1	0.09518	0.08406	0.08674	0.15186	0.42427	-0.09358	0.02219
CScrew9	0.1	0.07750	0.07629	0.07609	1.75565	0.08912	0.01537	-0.00280
Delta	0.002	0.001	0.0005					

19 Variables

4 EM simulations with adaptive meshing

3 EM simulations with moving mesh

If We Ignore The Port Parasitic

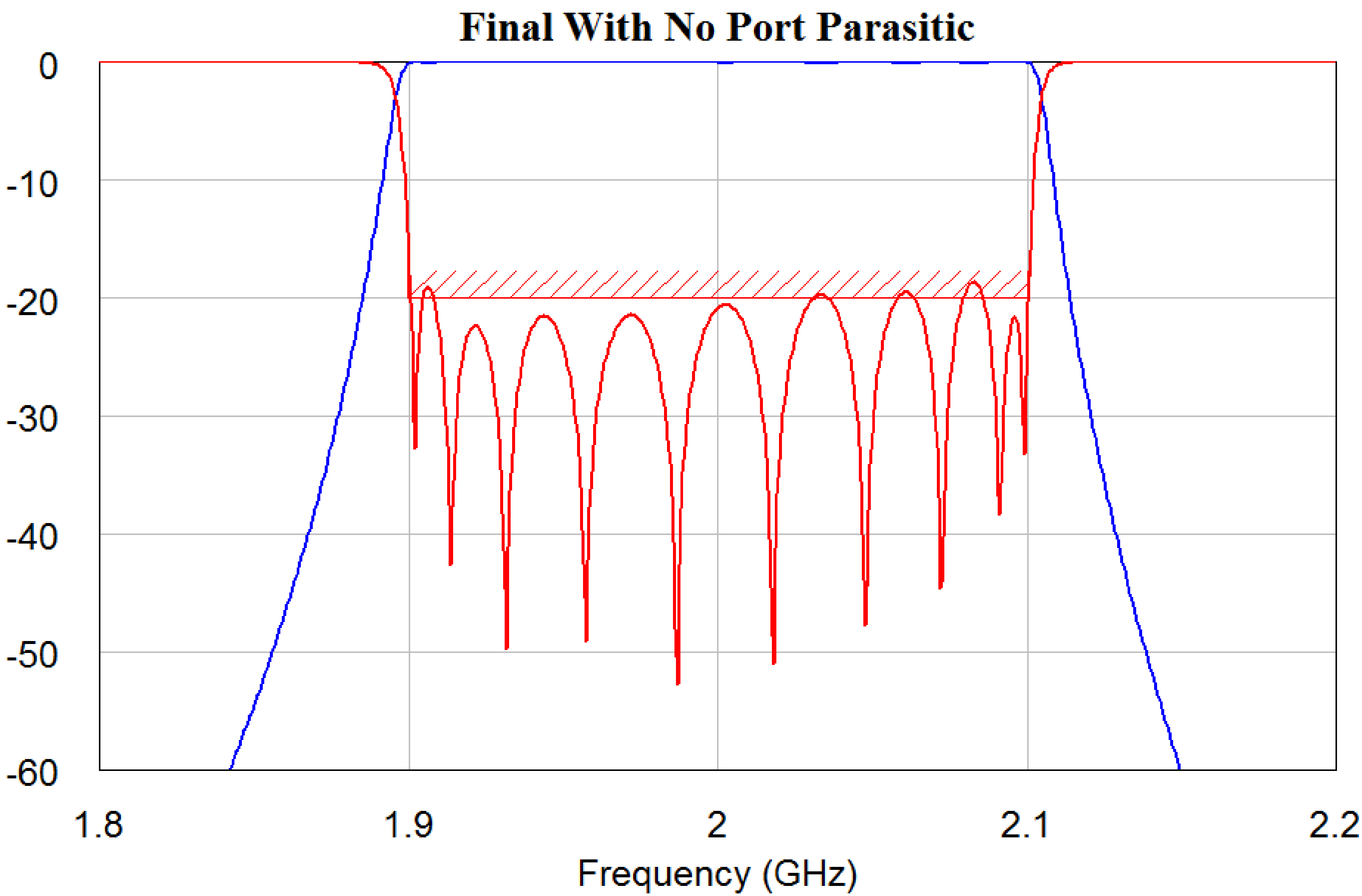
	Nominal Length (in)	Delta	Nom - Delta	Nominal Cap Tunes (fF)	Nom – Delta Cap Tunes (fF)	Sensitivity fF / inch	New Deltas	New Nominal
TScrew1	0.2195	0.0010	0.2185	-234.05116	-226.861640	7189.520	-0.0326	0.18695
TScrew2	0.1934	0.0010	0.1924	-223.54707	-216.589110	6957.960	-0.0321	0.16127
TScrew3	0.1921	0.0010	0.1911	-217.85676	-211.068160	6788.600	-0.0321	0.16001
TScrew4	0.1919	0.0010	0.1909	-216.33942	-209.618220	6721.200	-0.0322	0.15971
TScrew5	0.1919	0.0010	0.1909	-216.71403	-210.052740	6661.290	-0.0325	0.15937
TScrew6	0.1919	0.0010	0.1909	-216.57243	-209.872610	6699.820	-0.0323	0.15957
TScrew7	0.1919	0.0010	0.1909	-216.74399	-209.999360	6744.630	-0.0321	0.15976
TScrew8	0.1921	0.0010	0.1911	-217.61921	-210.853090	6766.120	-0.0322	0.15994
TScrew9	0.1934	0.0010	0.1924	-223.18734	-216.294280	6893.060	-0.0324	0.16102
TScrew10	0.2195	0.0010	0.2185	-233.77772	-226.577890	7199.830	-0.0325	0.18703
CScrew1	0.1	0.0010	0.0990	1.2970636	1.2428821	-54.181	-0.0239	0.07606
CScrew2	0.1	0.0010	0.0990	-0.14092251	-0.14899664	-8.074	0.0175	0.11745
CScrew3	0.1	0.0010	0.0990	-0.24966279	-0.25333378	-3.671	0.0680	0.16801
CScrew4	0.1	0.0010	0.0990	-0.26083807	-0.263129	-2.291	0.1139	0.21386
CScrew5	0.1	0.0010	0.0990	-0.28306405	-0.28514504	-2.081	0.1360	0.23602
CScrew6	0.1	0.0010	0.0990	-0.25872632	-0.25979373	-1.067	0.2424	0.34239
CScrew7	0.1	0.0010	0.0990	-0.25350614	-0.25586718	-2.361	0.1074	0.20737
CScrew8	0.1	0.0010	0.0990	-0.12174891	-0.13198099	-10.232	0.0119	0.11190
CScrew9	0.1	0.0010	0.0990	1.3075304	1.2504064	-57.124	-0.0229	0.07711

Port Parasitic Ignored

	Iteration 1 Length (in)	Iteration 2 Length (in)	Iteration 3 Length (in)	Iteration 4 Length (in)	Iteration 5 Length (in)	Final Length (in)
TScrew1	0.2195	0.18695	0.18450	0.18445	0.18449	0.18446
TScrew2	0.1934	0.16127	0.15872	0.15915	0.15910	0.15907
TScrew3	0.1921	0.16001	0.15664	0.15809	0.15822	0.15819
TScrew4	0.1919	0.15971	0.15501	0.15756	0.15811	0.15808
TScrew5	0.1919	0.15937	0.15377	0.15717	0.15801	0.15808
TScrew6	0.1919	0.15957	0.15120	0.15593	0.15775	0.15817
TScrew7	0.1919	0.15976	0.15173	0.15615	0.15780	0.15813
TScrew8	0.1921	0.15994	0.15602	0.15785	0.15821	0.15822
TScrew9	0.1934	0.16102	0.15878	0.15911	0.15912	0.15909
TScrew10	0.2195	0.18703	0.18449	0.18449	0.18448	0.18445
CScrew1	0.1	0.07606	0.07694	0.07601	0.07648	0.07641
CScrew2	0.1	0.11745	0.08624	0.08596	0.08620	0.08615
CScrew3	0.1	0.16801	0.09806	0.08475	0.08691	0.08636
CScrew4	0.1	0.21386	0.11677	0.08583	0.08587	0.08600
CScrew5	0.1	0.23602	0.12764	0.09015	0.08505	0.08632
CScrew6	0.1	0.34239	0.18748	0.10952	0.08442	0.08607
CScrew7	0.1	0.20737	0.11477	0.08668	0.08647	0.08647
CScrew8	0.1	0.11190	0.08571	0.08615	0.08628	0.08625
CScrew9	0.1	0.07711	0.07674	0.07596	0.07656	0.07648

We still get to a good solution, but it takes two extra iterations.

Final Two Port Simulation



Conclusion

- At the end of the day, this technique is just simple linear interpolation, but it works.
- The combination of port tuning, equal ripple optimization and the moving mesh in CST MWS allow us to compute geometry corrections with very few EM simulations.
- Clearly this method scales very well as the problem size grows larger. In this case we tuned 19 physical variables with only 7 total EM simulations.
- We are confident that many other filter topologies, including multiplexers, can be optimized with this method.