Generating Spectrally Rich Data Sets Using Adaptive Band Synthesis Interpolation

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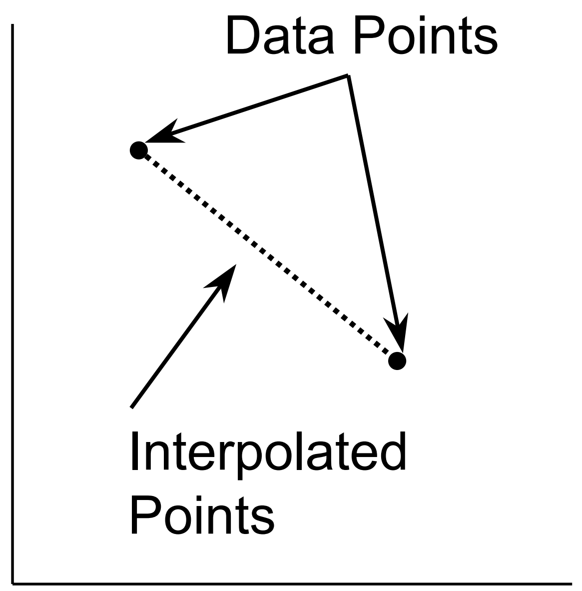
Interpolation Primer

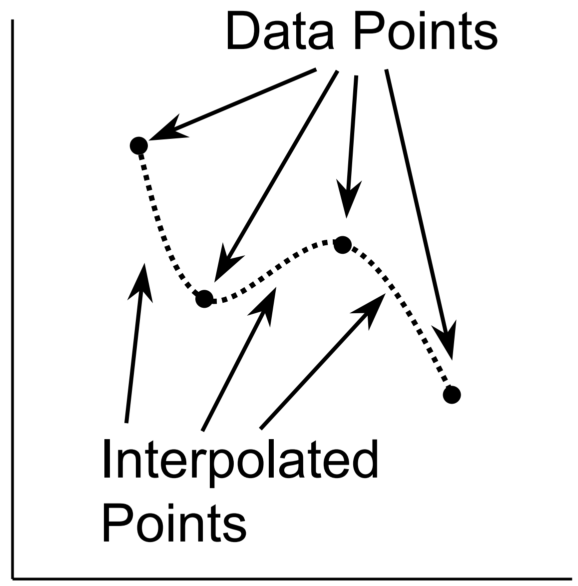
- Linear interpolation
  - Draw a straight line between each data point.
  - Interpolated points fall on that line.



$$y = a + bx$$

Interpolation Primer

- Cubic spline
  - Take four data points.
  - Calculate cubic curve that goes exactly through all four points.
  - Interpolated data lies on that line.



$$y = a + bx + cx^2 + dx^3$$

Interpolation Primer

- Cubic spline uses $y = a + bx + cx^2 + dx^3$.
- Taking a hint from Laplace transform theory, try:

$$y = \frac{a_0 + a_1 x + a_2 x^2 + \ldots}{1 + b_1 x + b_2 x^2 + \ldots}$$

- This is known as a Padé polynomial.

ABS Algorithim

1. Analyze first, last, and mid frequency.
2. Form several interpolation models.
3. Estimate interpolation error.
4. Find frequency of worst error.
5. If worst error is small enough, quit.
6. Otherwise, analyze worst frequency and return to step 2.

Padé Polynomial Problems

$$y = \frac{a_0 + a_1 x + a_2 x^2 + \ldots}{1 + b_1 x + b_2 x^2 + \ldots}$$

- Perfect for lumped circuits, but band limited for distributed circuits.
- Matrix has terms like $(\text{freq})^N$, matrix precision problem likely for large N.
- Must be able to estimate interpolation error so we know where to take next data point and when to quit.

Bandwidth Solutions

- Extract additional internal information from moment matrix.
- Estimate zero locations.
- Build much higher order Padé polynomial model.
- Much wider bandwidth now possible.

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Interpolation Error

- Interpolation error is difference between the interpolation and the correct answer.
- To estimate error, do two different interpolations on same data.
- Difference between interpolations is error estimate.

Interpolation Error

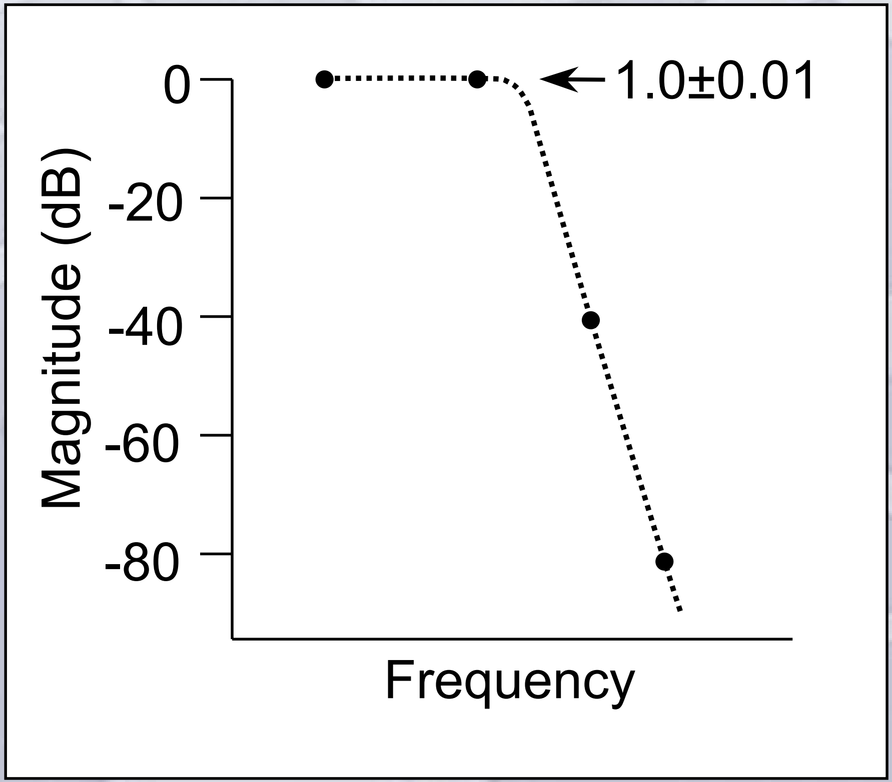
- With 4 data points:
  - Do interpolation with 4 data points.
  - Do interpolation with 3 data points.
  - Difference is error estimate.
- Next analysis frequency goes at frequency with largest error estimate.
- When largest error estimate is very small, all done!

Interpolation Error

- True error can sometimes be up to 20 dB worse than estimated error.
- For a good plot, true error must be 20 dB less than the data being plotted.
- Thus, we continue until the error estimate is over 40 dB less than the data being plotted.

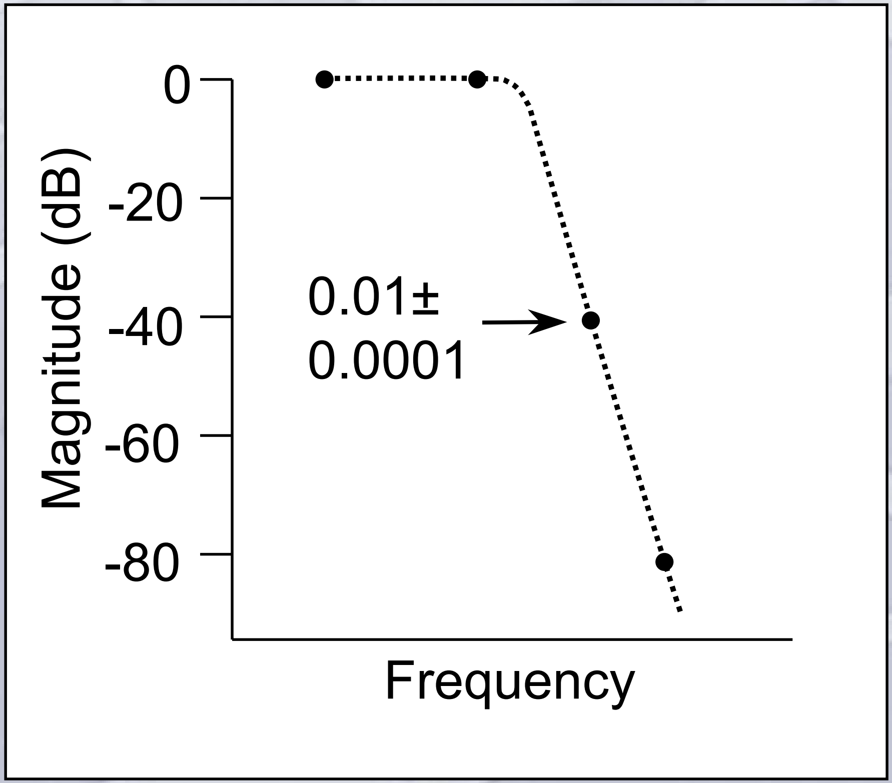
Interpolation Error Example

- At 0 dB (mag=1.0), error is 40 dB down if mag is ±0.01.



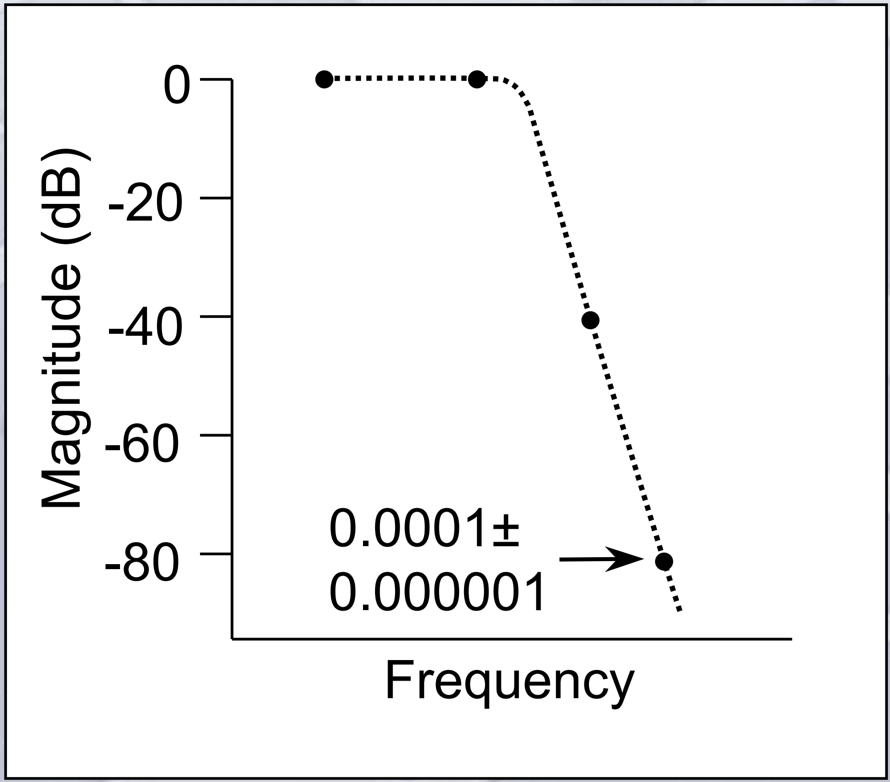
Interpolation Error Example

- At -40 dB (mag=0.01), error is 40 dB down if mag is ±0.0001.



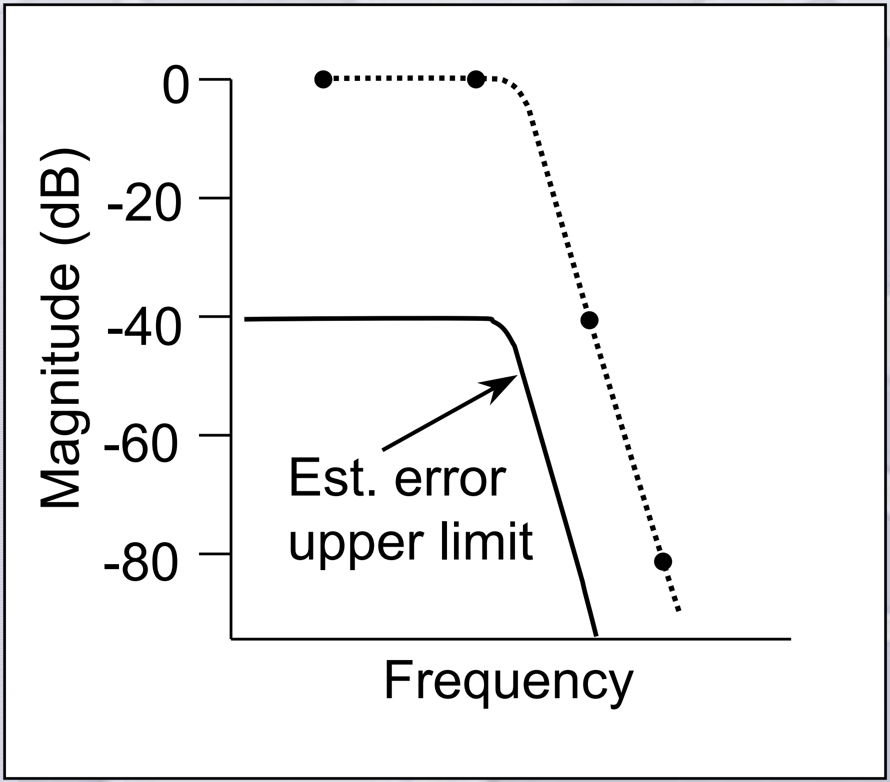
Interpolation Error Example

- At -80 dB (mag=0.0001), error is 40 dB down if mag is ±0.000001.



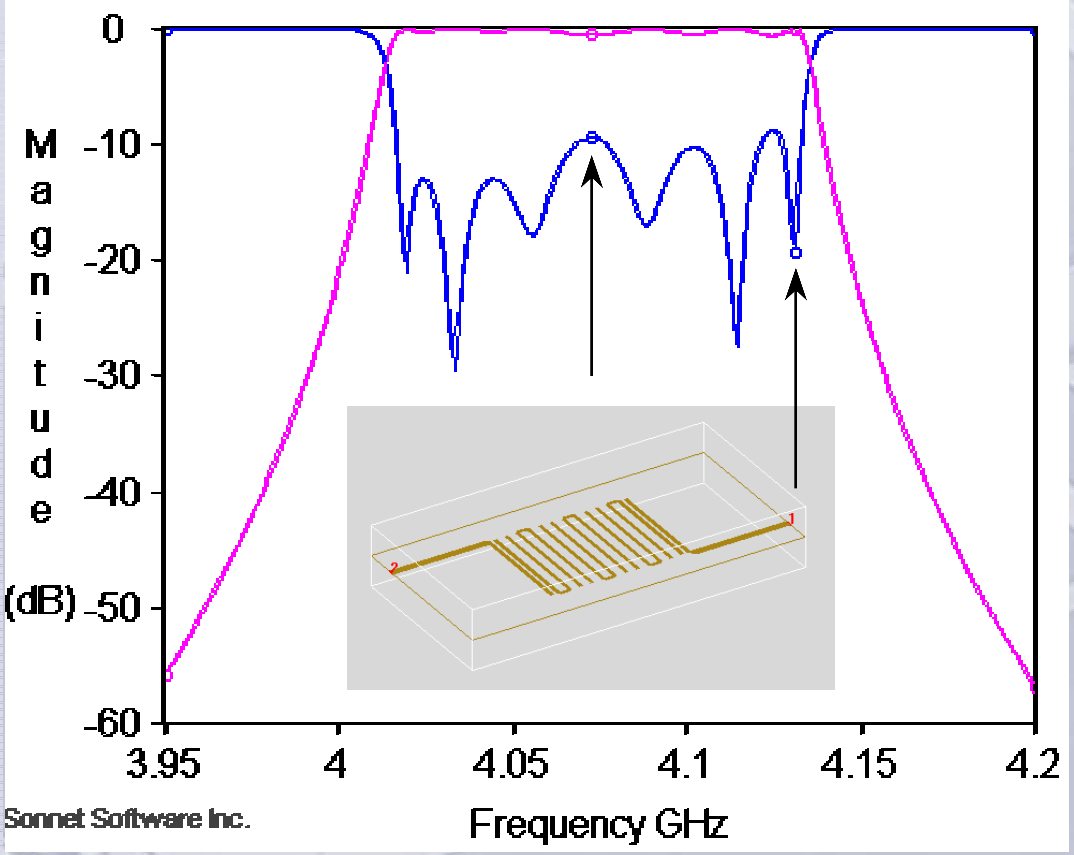
Interpolation Error Example

- We ran 150 test circuits and plotted true versus interpolated.
- All plots visually identical when estimated error 40 dB or more below data.



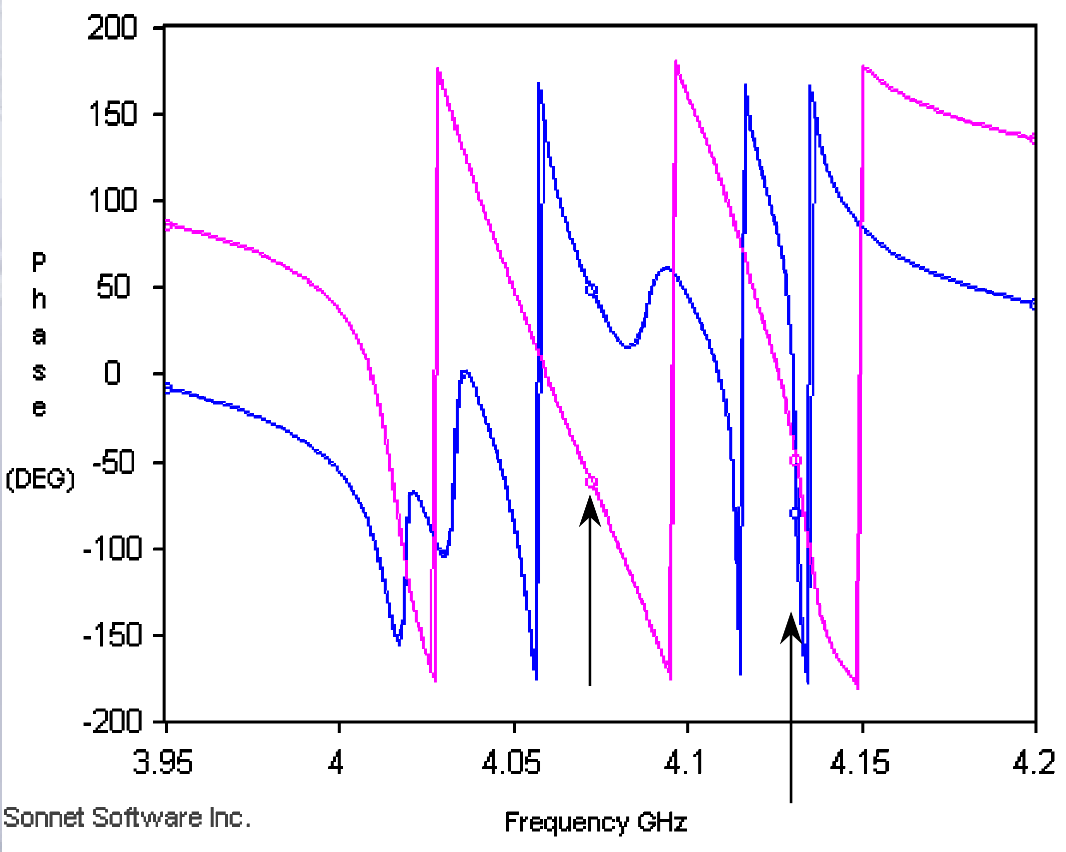
Hairpin Filter

- 300 data points.
- Sonnet ABS interpolated from analysis at four frequencies.
- Results visually identical.



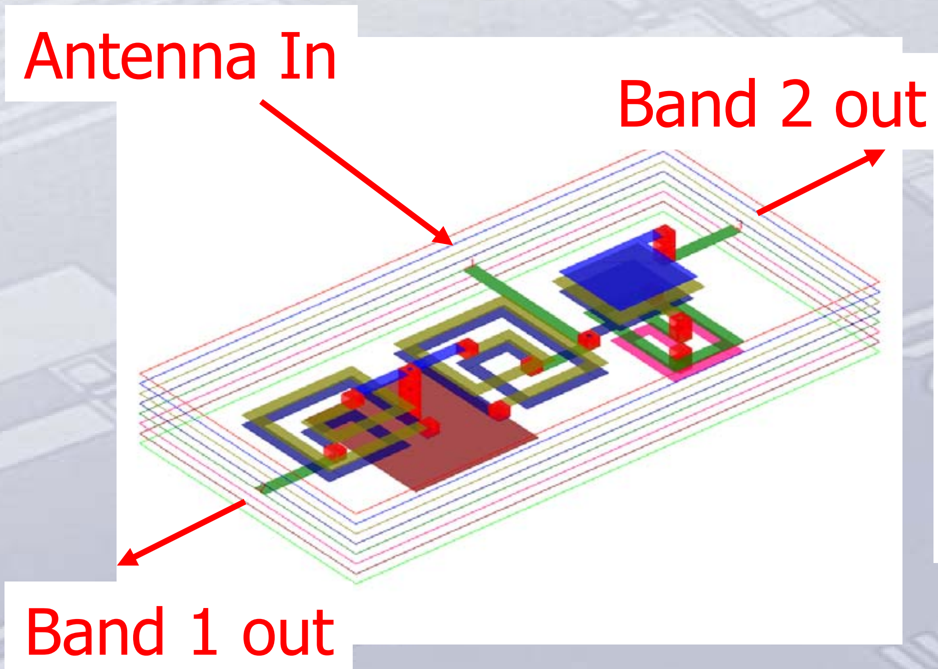
Hairpin Filter

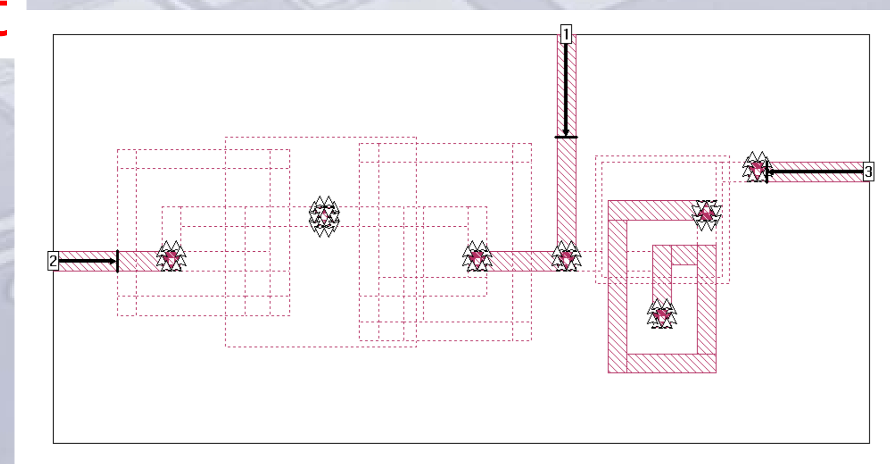
- Phase also gives visually identical results.



Diplexer

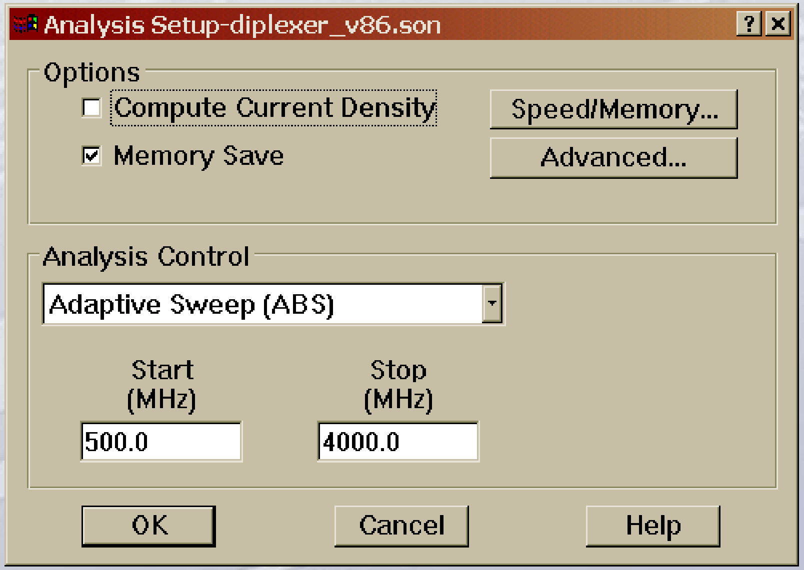
7-Layer LTCC Design

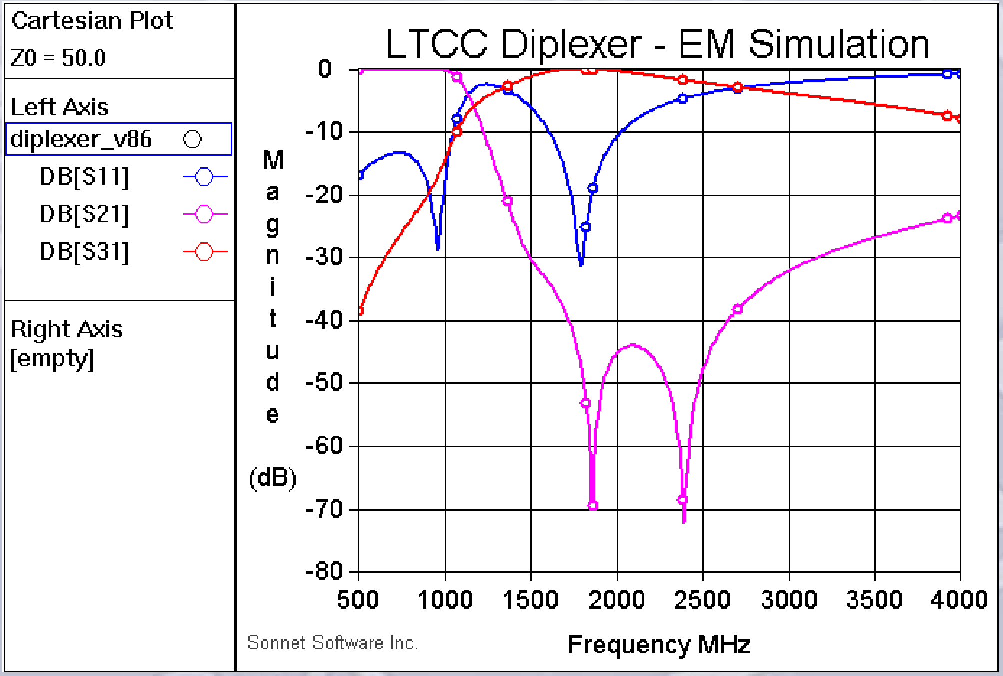




Diplexer

7-Layer LTCC Design



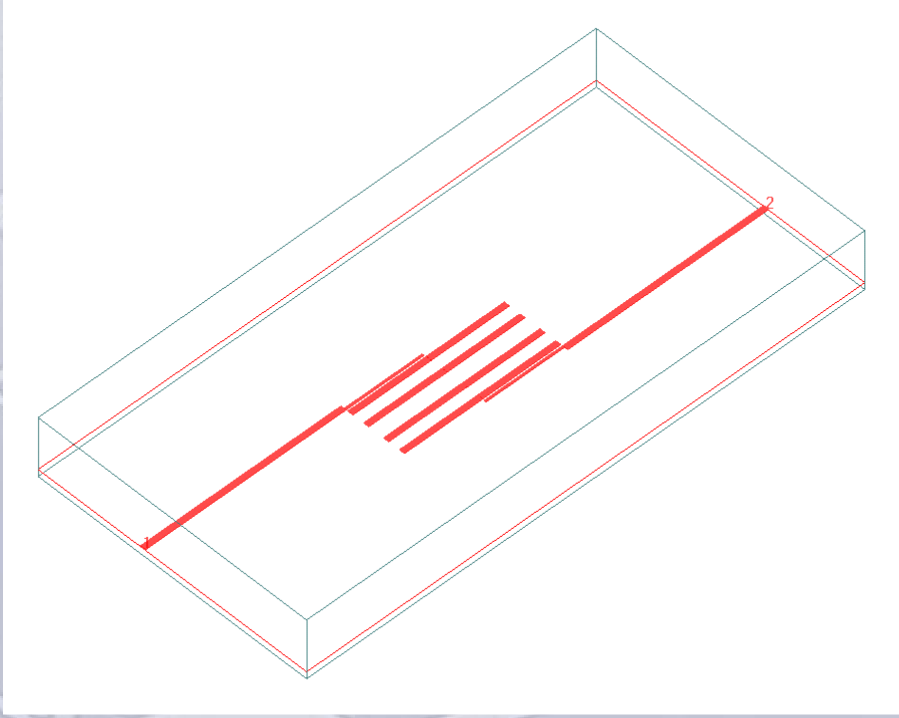


9 Discrete EM Frequencies required, 320 frequencies provided over 8x Bandwidth

Band Pass Filter

High Temp Superconductor Microstrip Filter

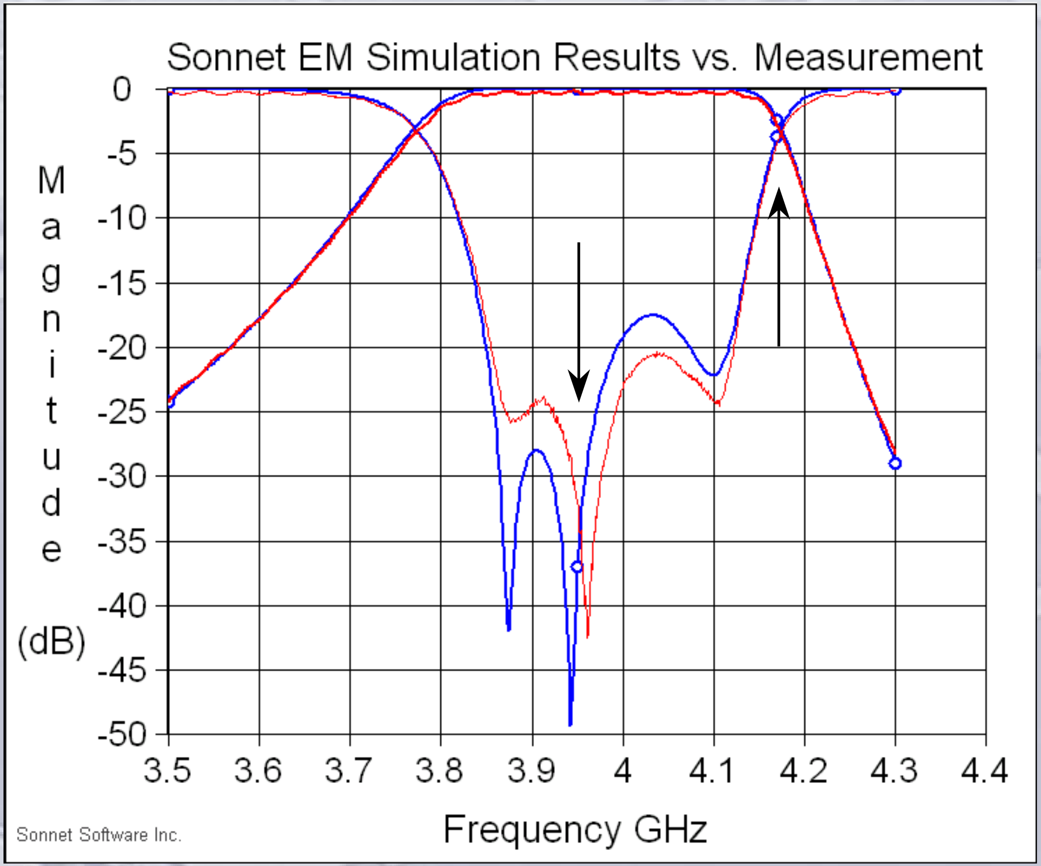
- HTSC filter inside rectangular housing.
- Precise enclosure effects are very important and are included. (Microwaves &RF, Dec 98, pp. 119-130)
- ABS yields detailed response.



Band Pass Filter

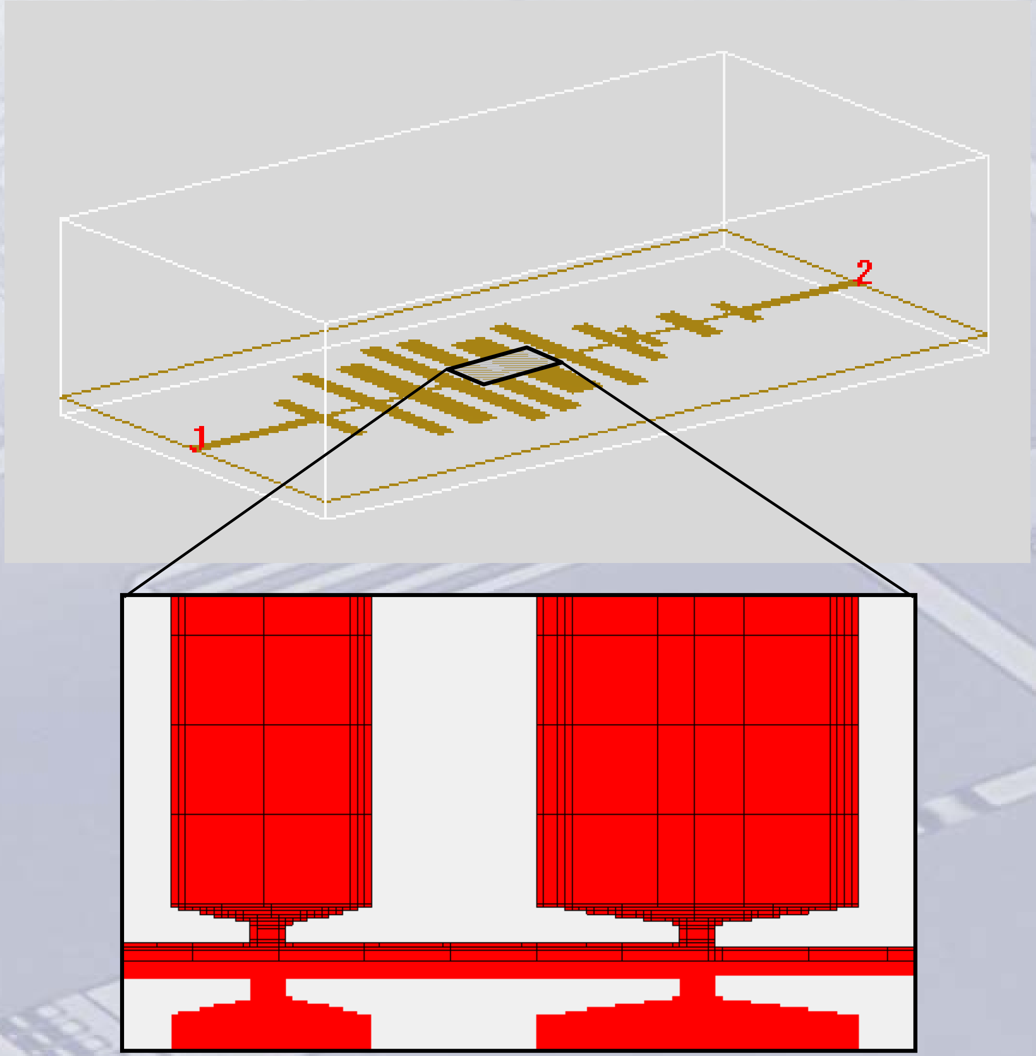
High Temp Superconductor Microstrip Filter

- Four frequency ABS analysis.
- Total time: 6 minutes on 1 GHz laptop PC
- Measured versus calculated.
- Filter courtesy George Matthaei.



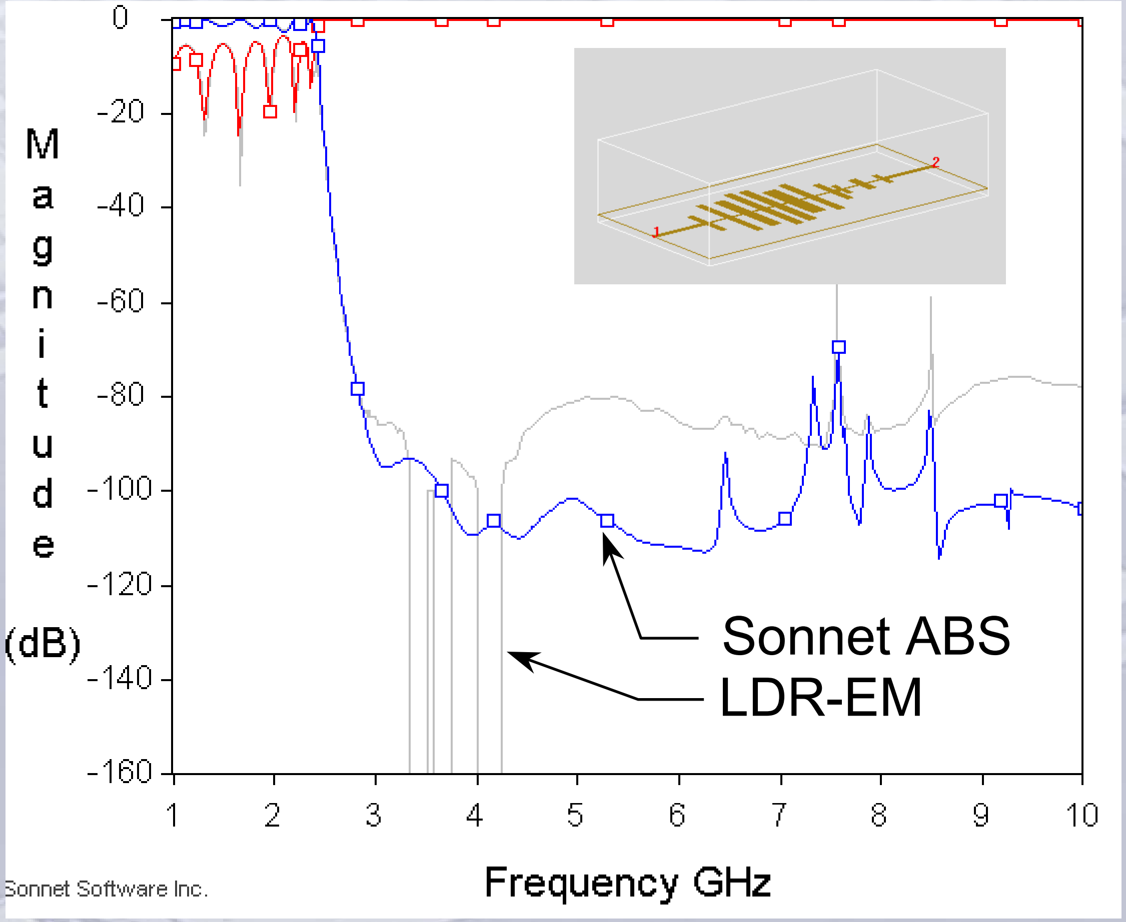
Big Low Pass Filter

- Extremely fine subsectioning used.
- 2m 3s per frequency (1.5 GHz P4).
- Note fine geometry along center line.



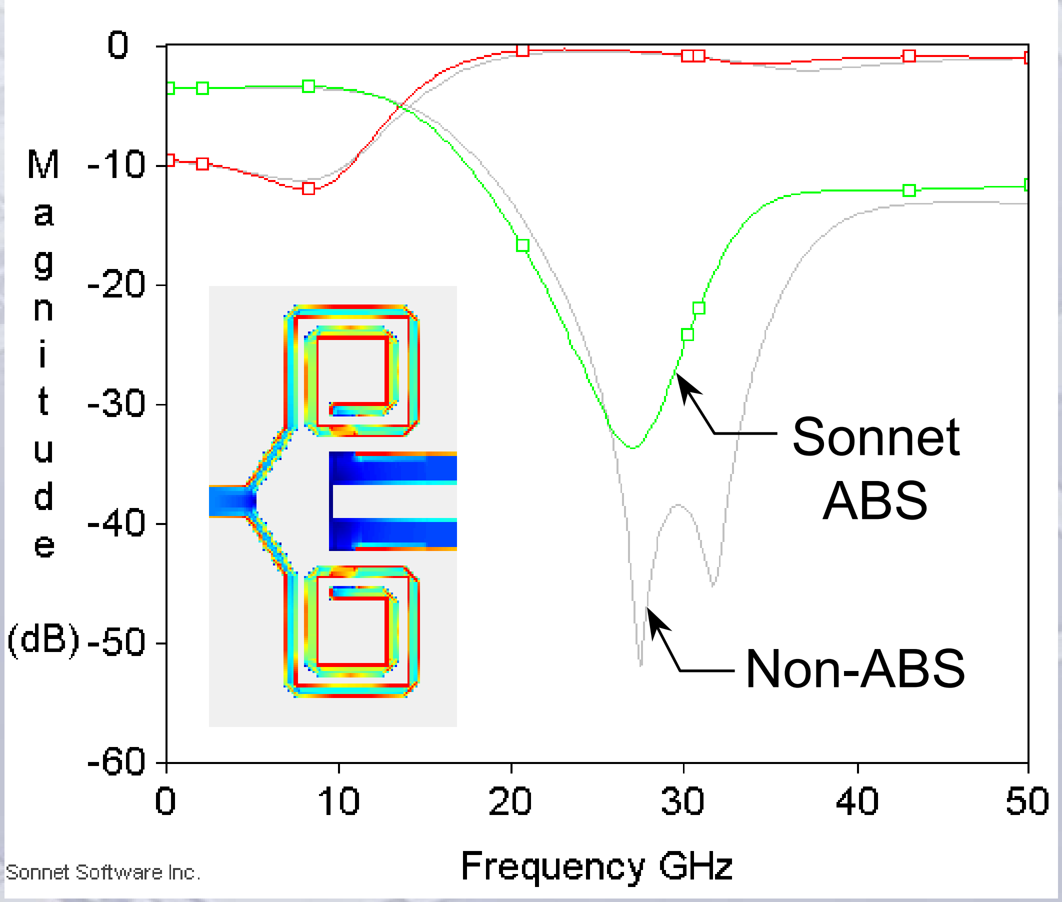
Big Low Pass Filter

- Sonnet ABS uses 13 frequencies, 30 minutes.
- Lower dynamic range analysis (LDR-EM) needs 117 frequencies, about 2.5 days.
- EM dynamic range is important!



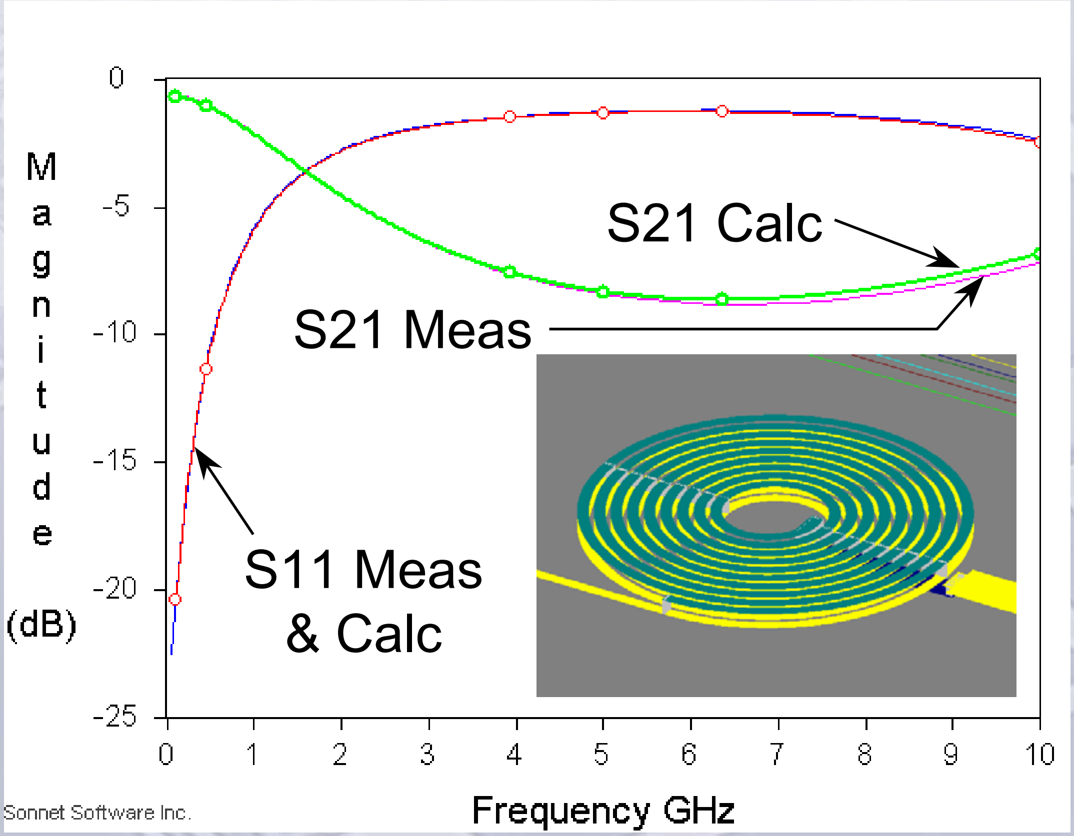
Spiral Splitter

- Sonnet ABS uses 8 frequencies.
- Non-ABS approach uses 23.
- Information from MoM matrix is important!



Spiral Inductor on Silicon

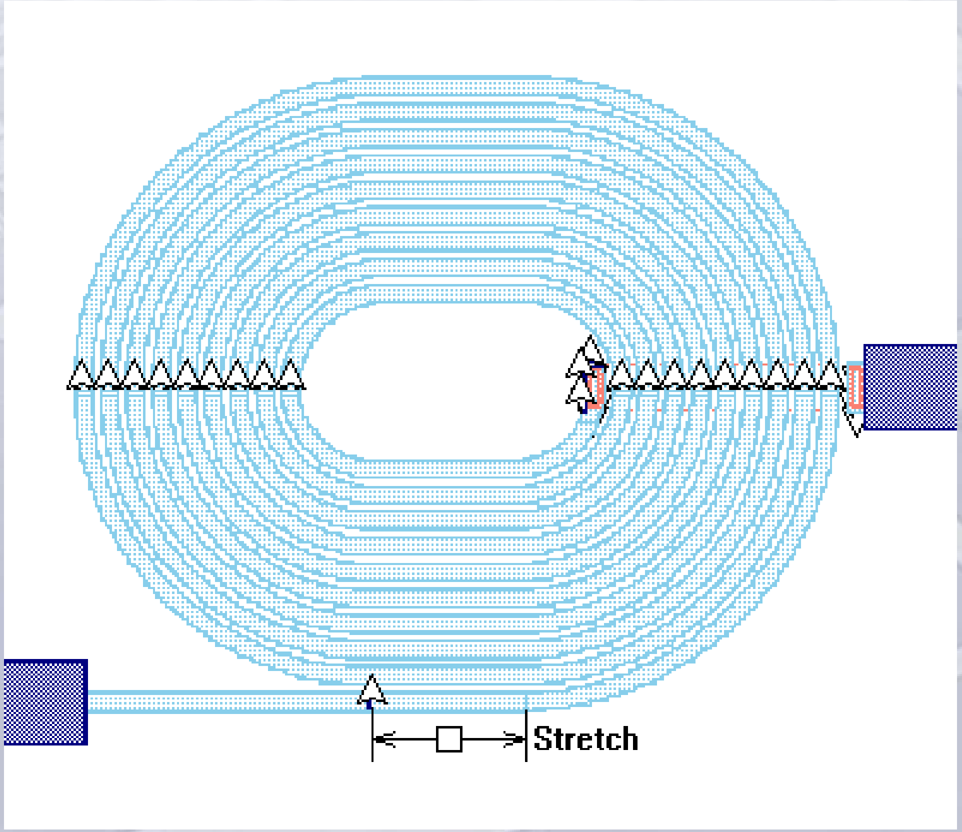
- Eight turn spiral.
- 2-layer thick metal model.
- Conformal meshing.
- Measured and calculated essentially identical.
- ABS w/6 frequencies.



Data courtesy of Motorola, circuit uses Motorola High Voltage IC (HVIC) Si RF-LDMOS process.

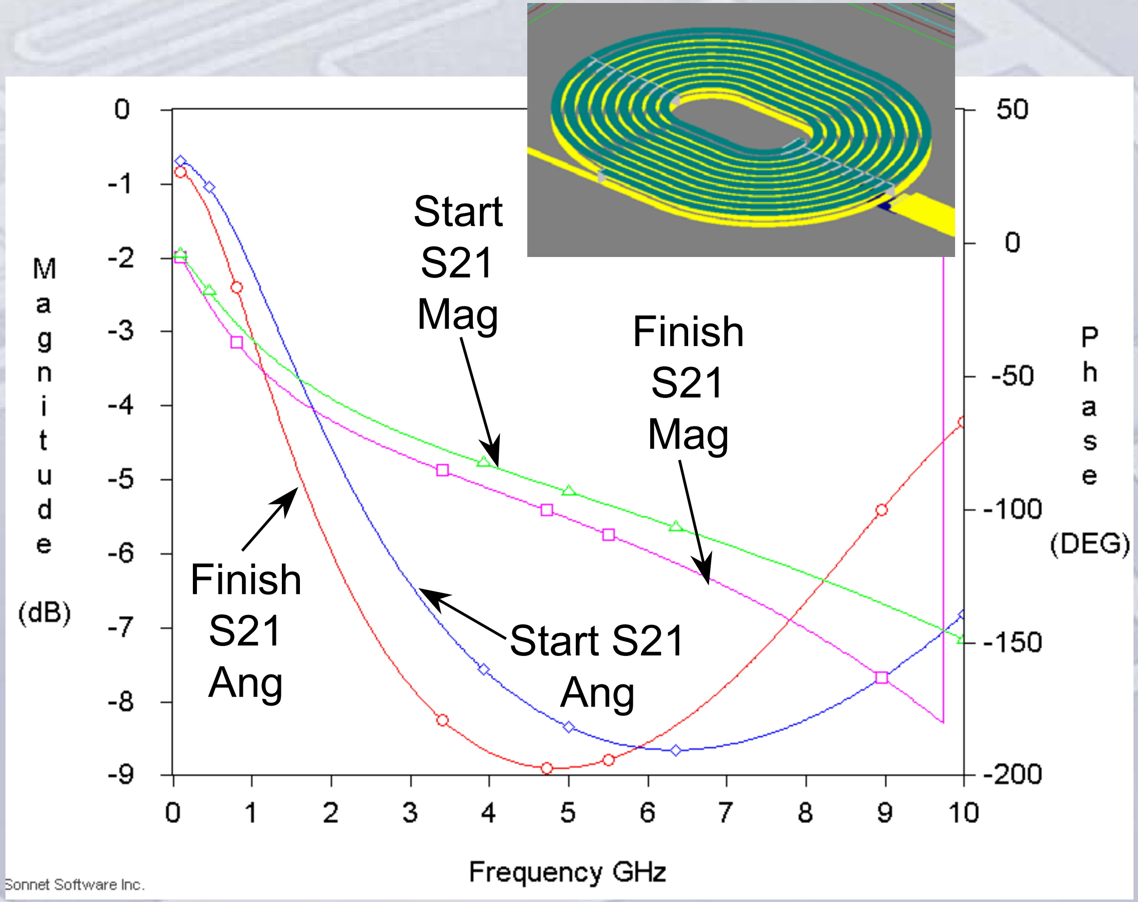
Optimization Example

- Optimize low freq (0.5 GHz) inductance for S21 phase from –19.8° to –25°.
- Vary parameter "Stretch" from 50 to 100 microns.



Optimization Result

- Requires 7 EM analyses, 26 minutes per analysis, 1.3 GHz P4.
- 1.6 μm cell size, 6.4 μm line width.
- Optimal "Stretch" = 57.4 μm.



Conclusion

- Sonnet ABS uses Padé polynomial.
- Bandwidth problems overcome by making extensive use of internal EM data.
- High dynamic range EM software is critical!
- Octave bandwidth typical with < 6 analyses.
- Decade bandwidth typical with < 15 analysis.
- Fast, spectrally rich broad band data sets allow detailed optimization goals and result presentation.