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# Optimum Frequency Sampling in S-Parameter Extraction and Simulation

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# Agenda

- Issues in S-parameter creation (model generation strategies)
- Handling bad S-parameters (simulation strategies)
- Tools to check S-parameter quality

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# S-parameter creation

- Suppliers often ship S-parameter representations of their product (package, connector, amplifier, *etc*.)
- S-parameter models are extracted by test and measurement equipment or by numerical methods (*i.e.*, simulation)

# Issues in S-parameter creation

- S-parameter “table” model typically shows its weakness when…
  - Limited frequency range coverage
  - DC point absent
  - Coarse sampling
  - Unintentional non-passivity
    - Especially with bad terminations
  - Measurement noise
  - etc…

# Influence on simulation results

- Frequency domain accuracy verification (AC analysis)
  - Key point: get required frequency point from provided S-parameter table model using inter-/extrapolation method.
- Time domain accuracy verification (Transient analysis)
  - Key point: Get time domain impulse response h(t) and do convolution

# Key points in obtaining h(t)

- IFFT
  - Equally spaced 2^N points needed
  - Need to cover wide enough frequency range, from DC to several harmonics of input signal
- Rational Function Approximation
  - Delay extraction
  - Sampling and start pole determination
  - Avoid measurement noise

***Accurately obtaining not-given S-parameters from the table model is extremely important to simulation results!***

# AC analysis example (sparse vs. dense)

- Sparse: narrow range, few samples

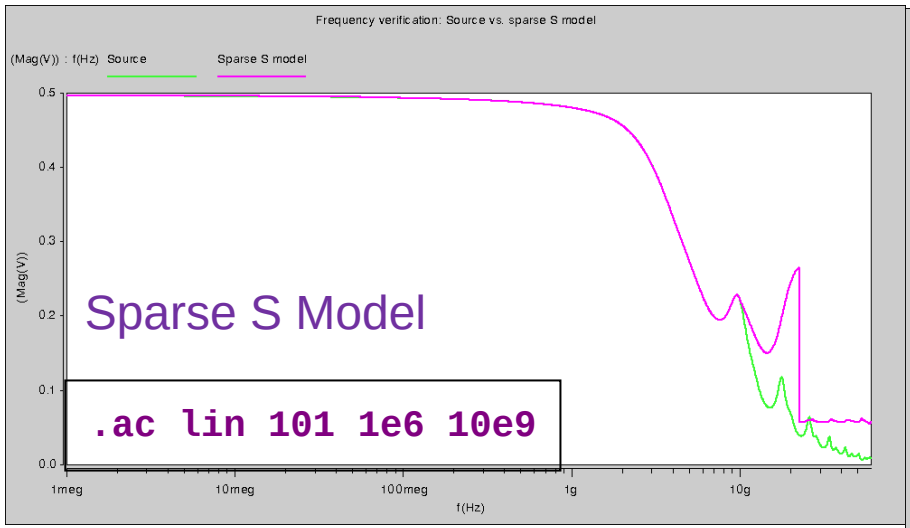
```
.ac lin 101 1e6 10e9
```

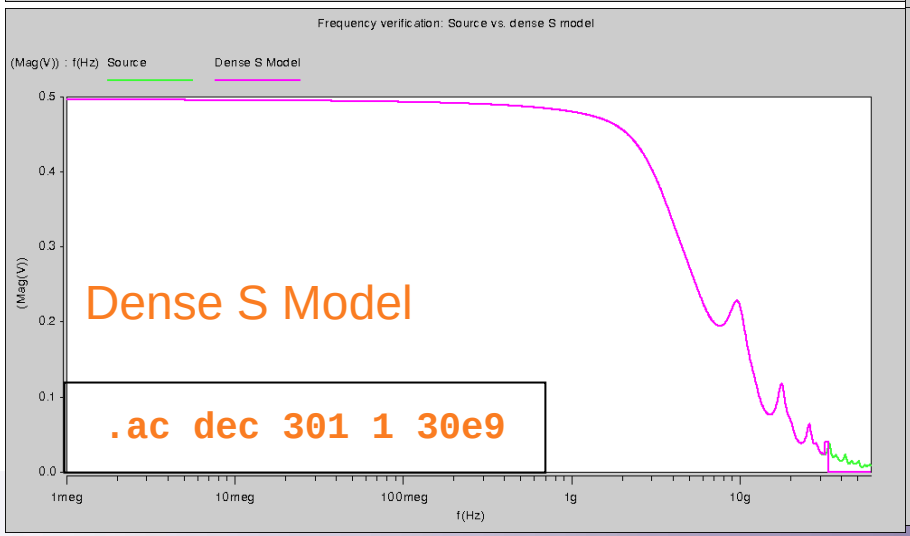
- Dense: wide range, lots of samples

```
.ac dec 301 1 30e9
```

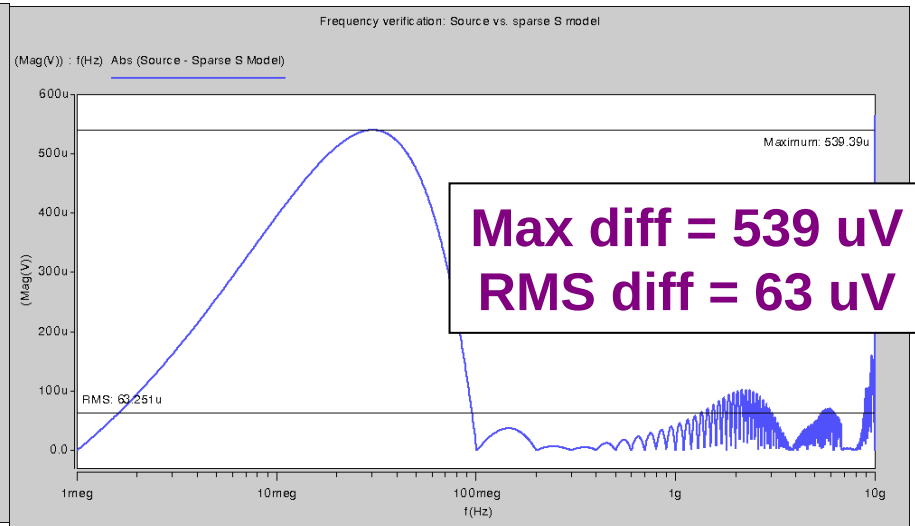
# AC verification results: 1 MHz - 60 GHz

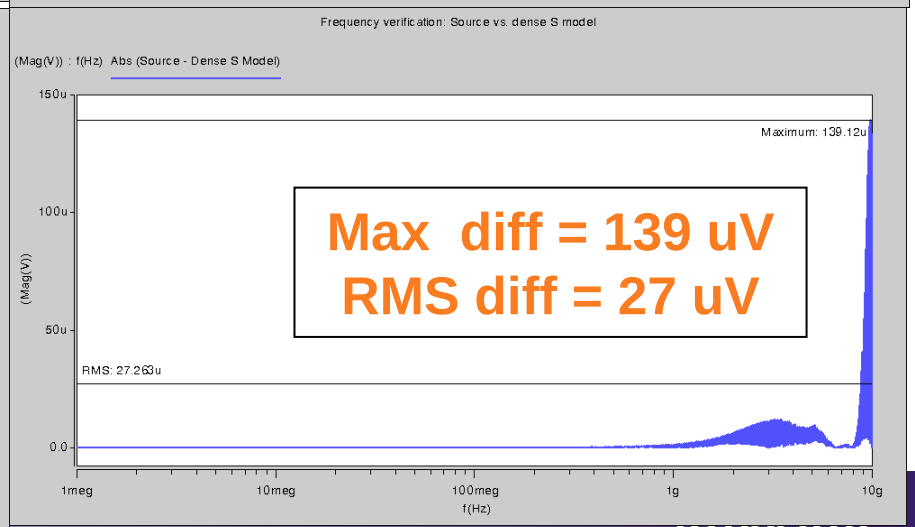
**Magnitude vs Frequency (1 MHz - 60 GHz)**



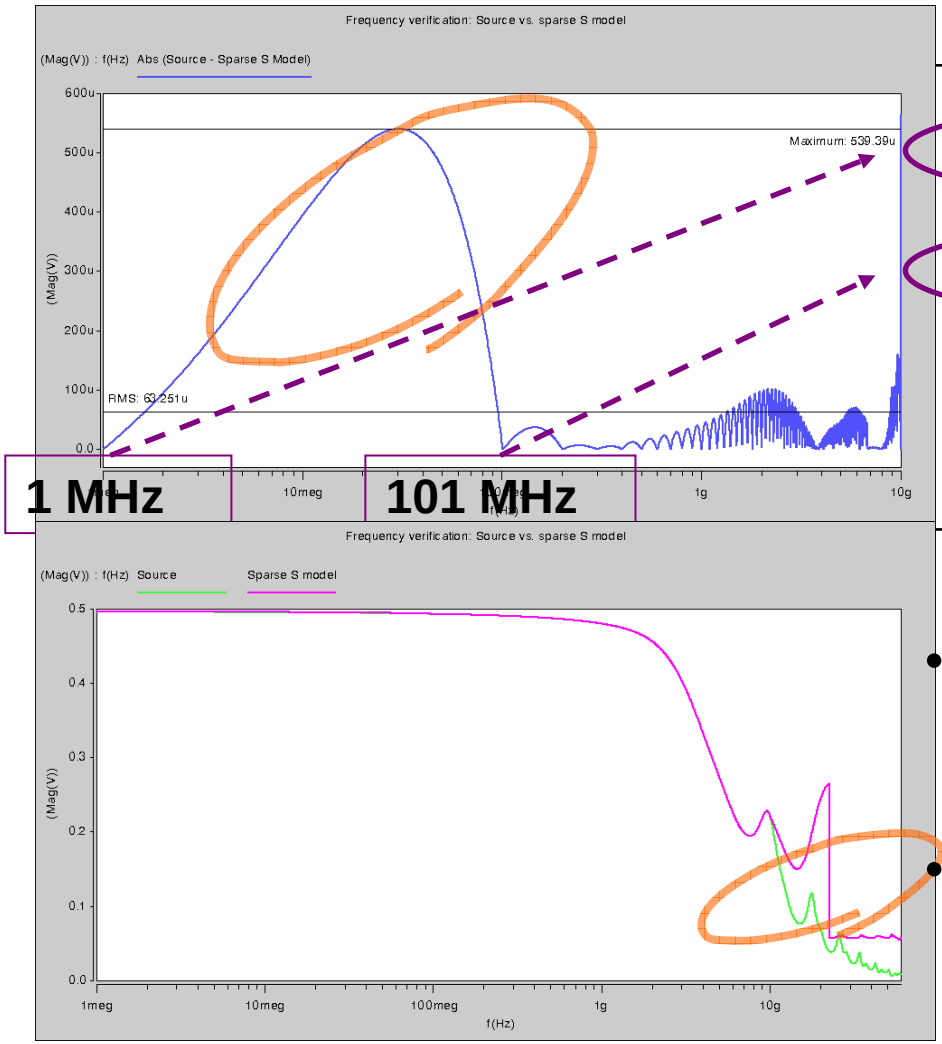

**Absolute Diff (1 MHz - 10 GHz)**



# Sparse S Model issues in AC

## Sparse S Model: 1 MHz - 10 GHz




### Interpolation error

```
 # Hz S MA R     50.0000
0.100000E+07   0.925839E-02   6.32755 . . .
               . . .
               0.368301E-03   16.4700 . . .
0.100990E+09   0.354922E-01   60.3283 . . .
               0.205661E-02   47.4395 . . .
               . . .
0.200980E+09   0.608898E-01   66.5493 . . .
               0.314144E-02   46.8725 . . .
```

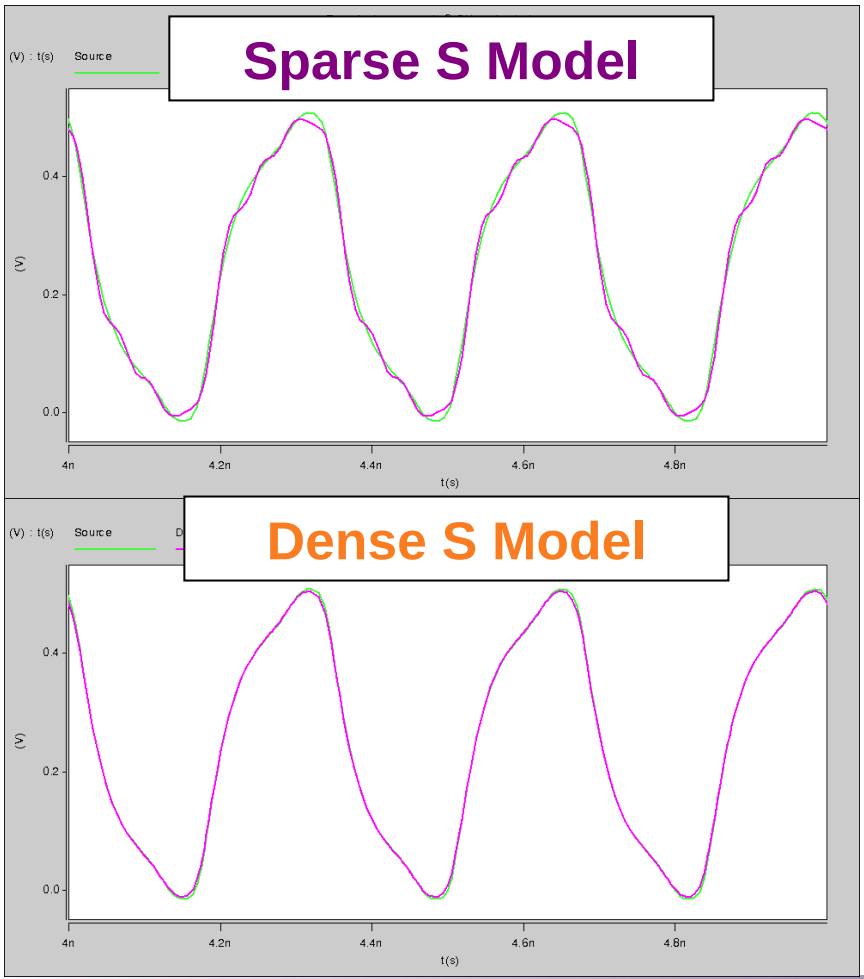
### Extrapolation error

- The "**`.ac lin 101 1e6 10e9`**" generated S model data **up to 10 GHz**
- AC verification test bench specified fstop of **60 GHz**

# Transient response - 3 GHz Pulse

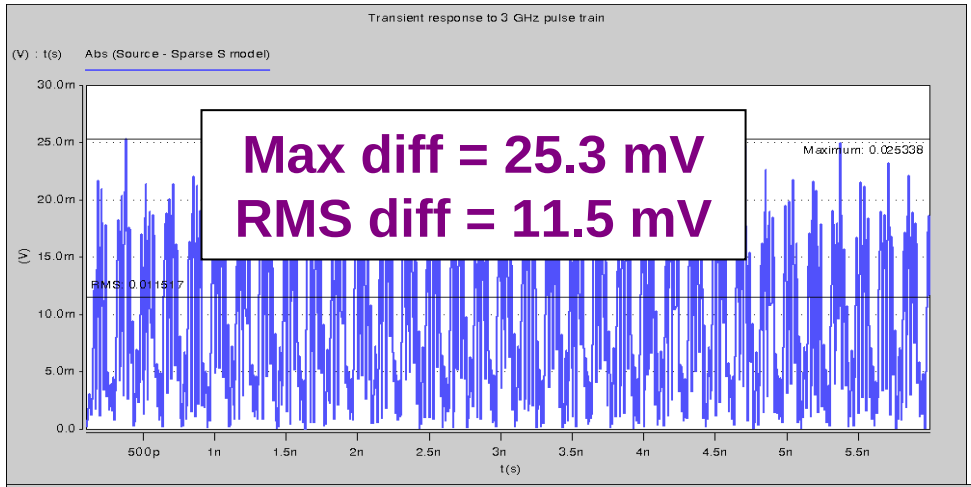
**Transient waveform**

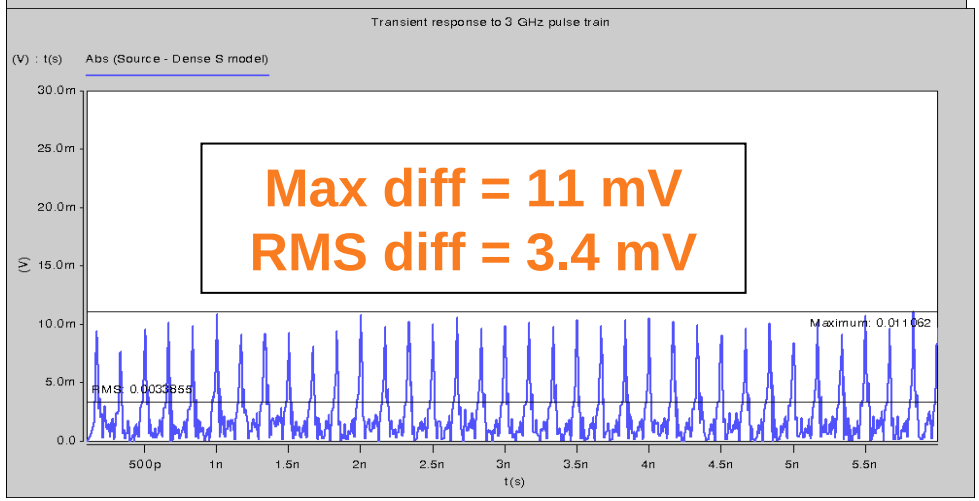
**Absolute Diff**









# What does “good” S-parameter look like?

- Provide DC point
- Covers wide enough frequency range
  - From DC to several harmonics of input signal
- Necessary dense data point (but not too dense to avoid big data files)
- Passive, within the unit circle in Smith Chart
- Smooth, without measurement noise
- etc…

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# Using bad S-parameters?

- S-parameter “table” model typically shows its weakness when…
  - Limited frequency range coverage
  - DC  point absent
  - Coarse sampling
  - Unintentional non-passivity
    - Especially with bad terminations
  - Measurement noise
  - etc…

- Can we use this kind of S-parameters if they are provided?

***Yes, if…***

# Guessing not-given values

- Interpolation & extrapolation
  - Piecewise constant
  - Piecewise linear
  - Spline
  - Partially apply rational function approximation
  - Hybrid method
  - etc…
- Base data format
  - Real/Imaginary(RI)
  - Magnitude/Angle(MA)
  - etc…

***Physical modeling (guess) based on provided table model!!***

# Interpolation method comparison

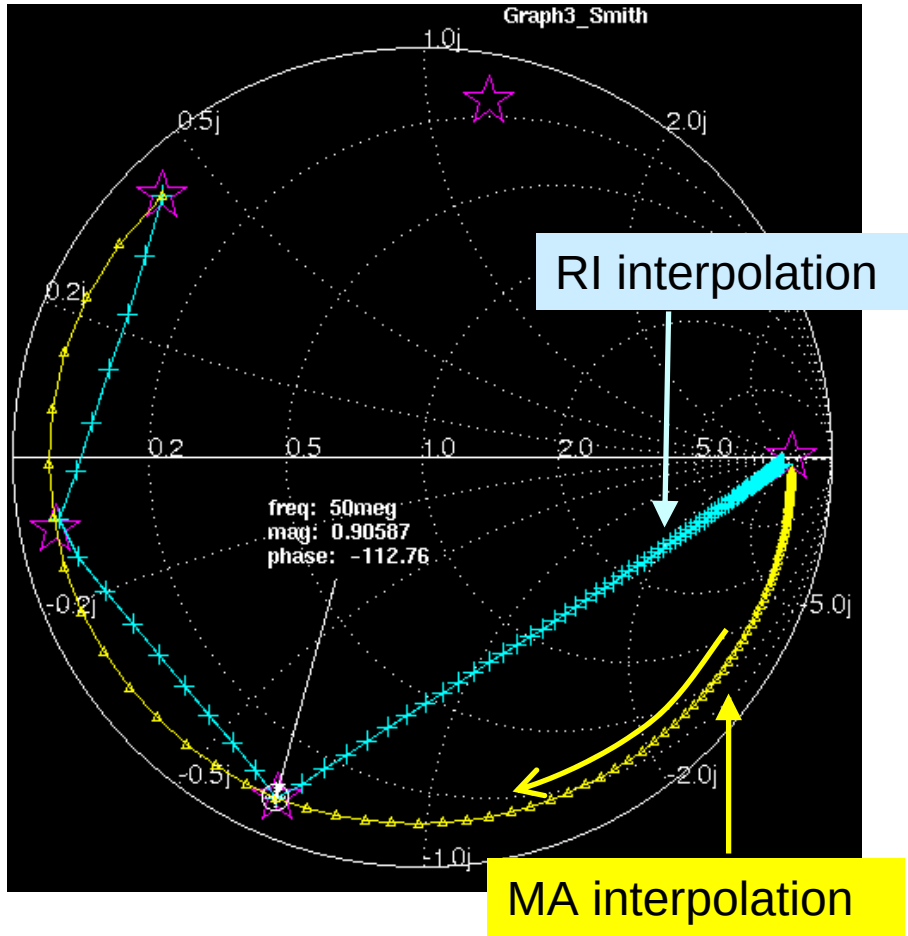
| Inter-/extrapolation method | Numerical polynomial approximation (Piecewise constant, linear, spline, etc.) | Partially apply rational function approximation | Hybrid method |
|---|---|---|---|
| Advantages | . Quick<br>. Bounded error | . Consider causality<br>. Accurate phase estimation | . Combing advantages of several methods |
| Disadvantages | . Causality & passivity issue<br>. Phase estimation difficulties | . Time consuming<br>. Passivity violation<br>. Noise sensitive | . False switch between each method<br>. Noise sensitive |
| Suggestions | ***Efficient for most common cases*** | ***Usually used in hybrid method*** | ***Use for cases with local resonances*** |

# Interpolation method comparison

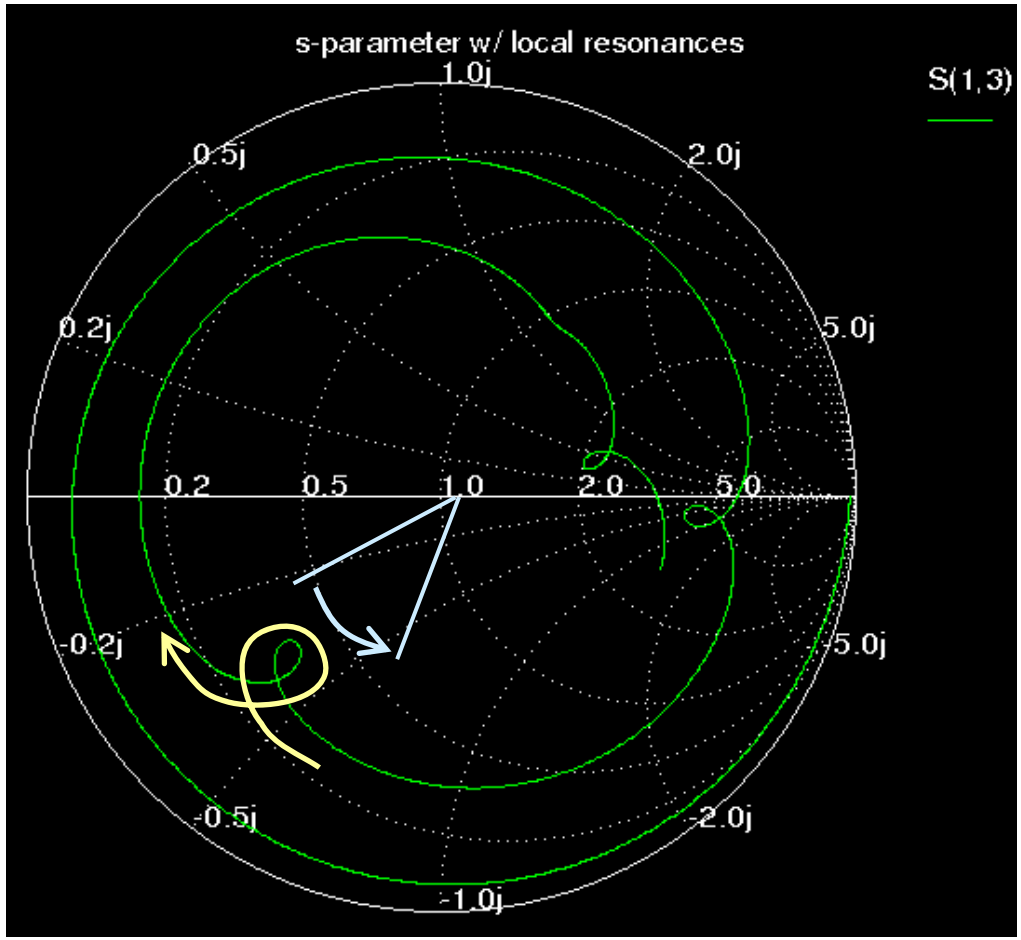
| Base data format | Real/Imaginary(RI) | Magnitude/Angle(MA) |
|---|---|---|
| Advantages | . No phase over-estimation issue in local resonance region | . Smooth curves connecting given sample points (more physical) |
| Disadvantages | . May under-estimate phase information<br>. Straight line between given sample points (unphysical) | . May over-estimate phase change in local resonance region |
| Suggestions | ***use with very dense table model*** | ***Efficient for most cases*** |

# RI v.s. MA (linear) interpolation

- Real/Imaginary
  - Straight line
- Magnitude/Angle
  - Circled
  - Suitable for linear systems
  - Requires unwrapped phase guess
    - Clockwise assumption



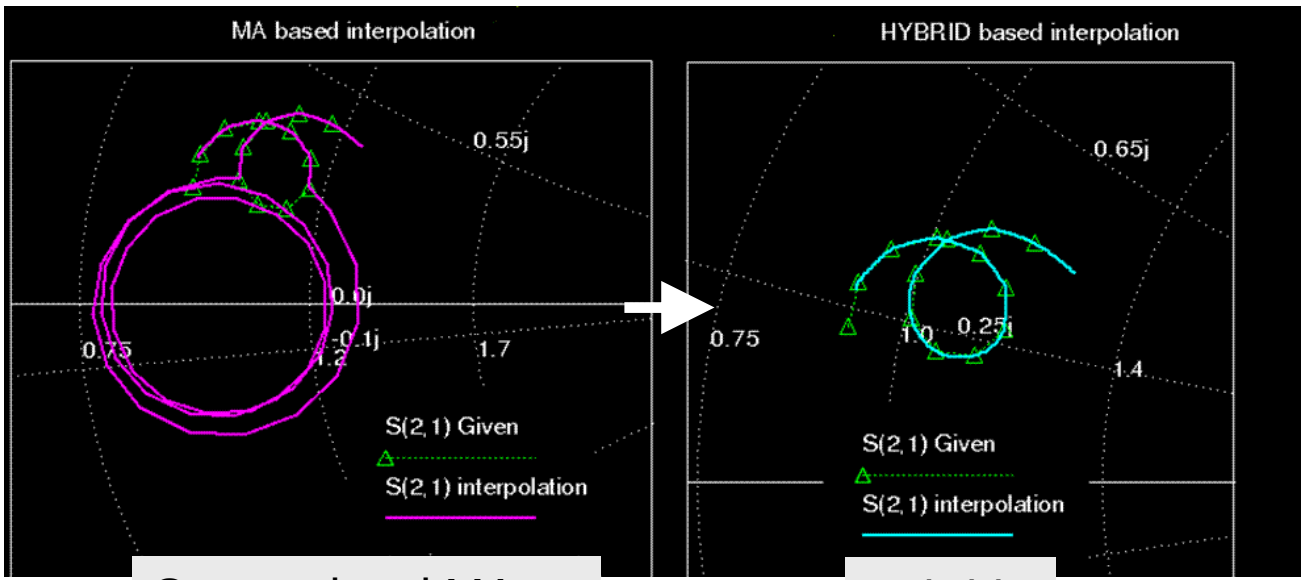
# Local resonances




Turning clockwise locally, looks counter-clockwise globally

# Hybrid interpolation

- Combine possible best ways
  - Advantage of MA based interpolation
  - Capture local resonances
    - Finding local centers
    - Use rational functions

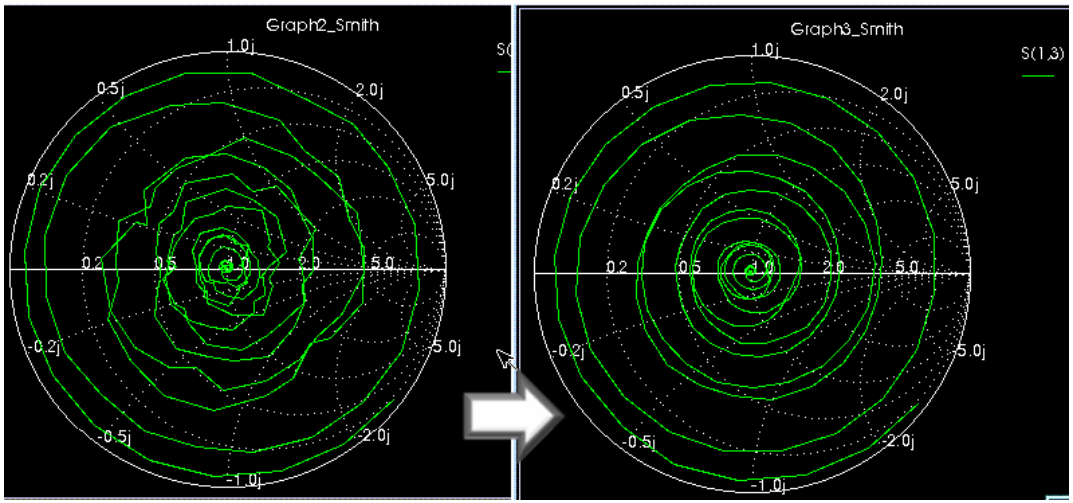



Conventional MA

Hybrid

# Noise reduction

- Data smoothing functions



# Passivity check/enforcement

- Passivity violation makes unintentional oscillator
  - Voltage blows up
- Passivity checker
  - Check eigenvalues of I-SS’ (S’: conjugate transpose)
- Passivity enforcement
  - “modify” original parameters
  - Add minimum amount of constant loss

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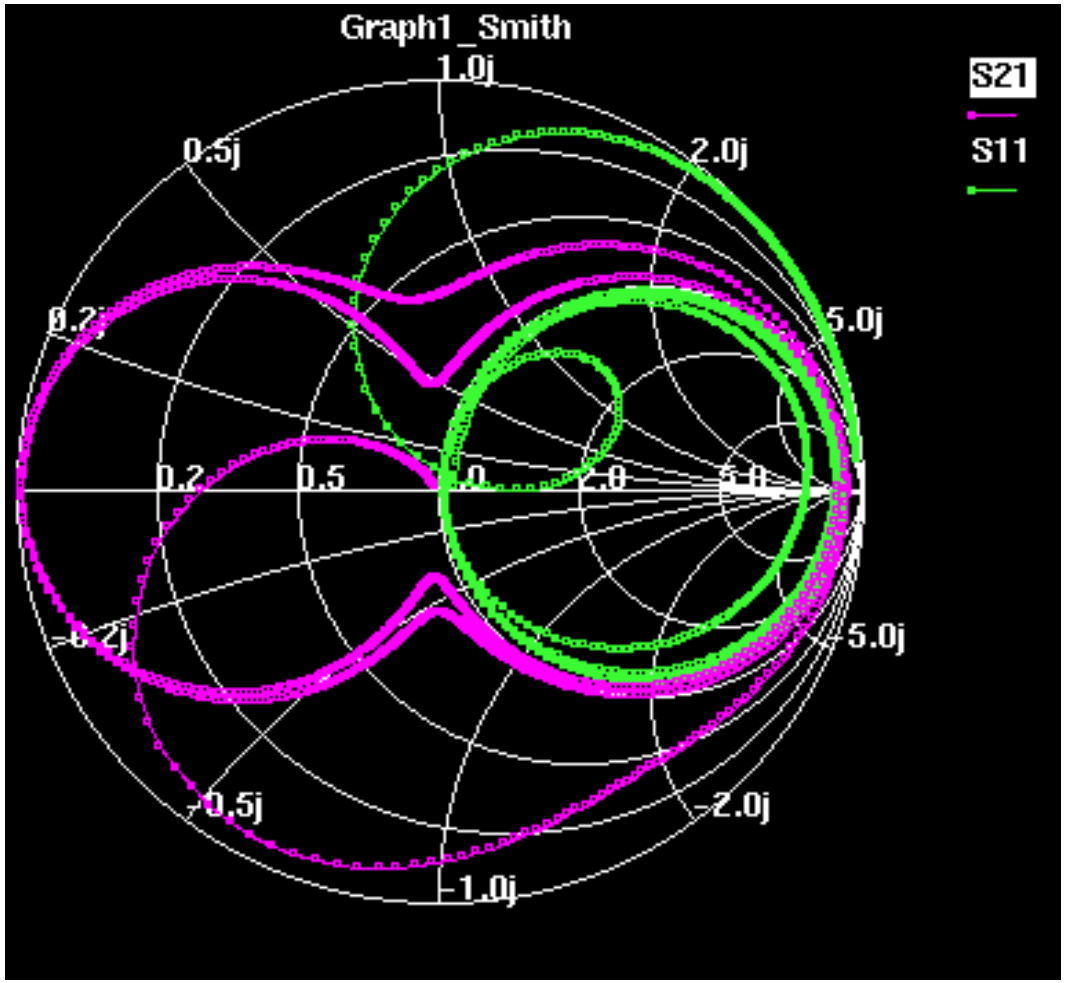
# How to select proper inter-/extrapolation method?

- Check your given S-parameter table model on Smith Chart
- Determine which method and what data format should to be used for inter-/extrapolation
- Check what you get from the selected inter-/extrapolation S-parameter data on Smith Chart

# What does good S-parameter look like?




***Good quality S-parameters always show beautiful curves on Smith Chart!***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