Introducing the Spectre S-Parameter Quality Checker and Rational Fit Model Generator

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Agenda

- Why are we doing this?
- S-parameter quality checking mode
- Model generation mode
- How to get help
- Summary

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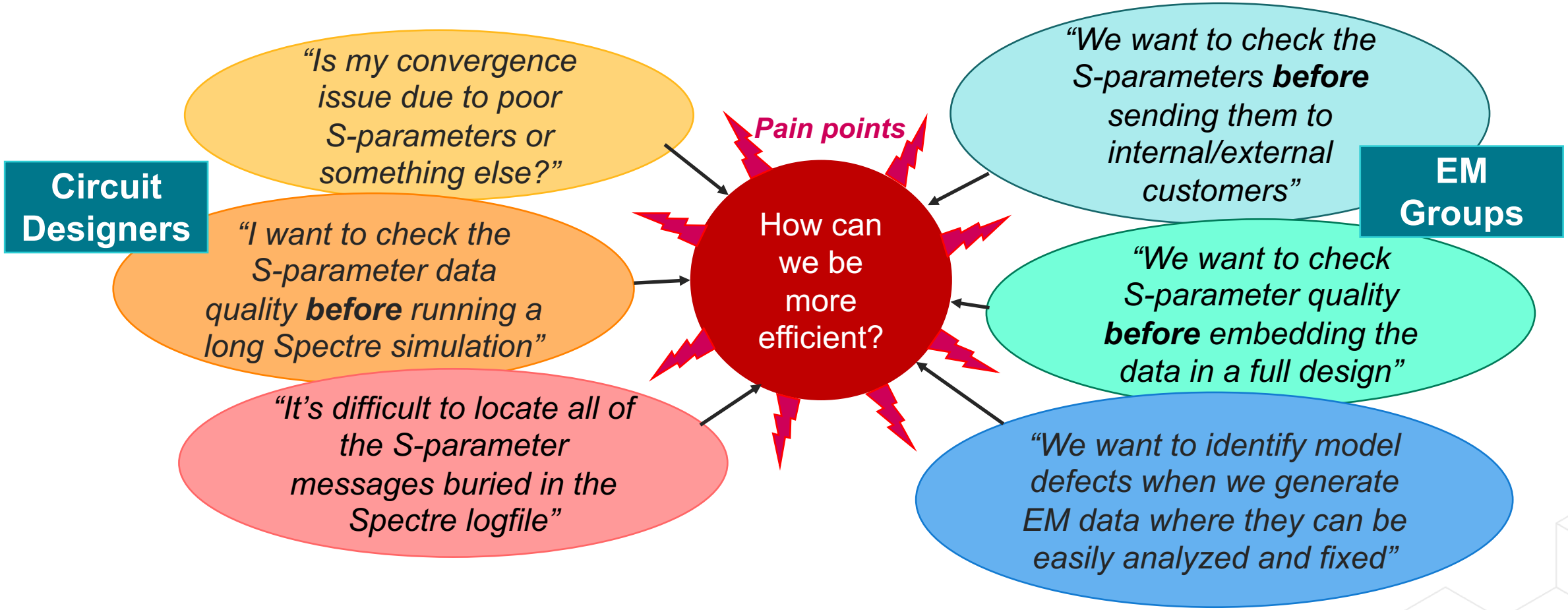
Why Are We Doing This?

- Simulating S-parameters in a time-domain (transient or periodic steady state) simulator is challenging
- Poor quality S-parameter models result in convergence and accuracy issues in Spectre® simulation, and often it's difficult to determine S-parameter model quality prior to simulation



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Introducing S-Parameter Quality Checker and RFM Generator

- New flow introduced in Spectre® 21.1 ISR
  - Spectre command line only
  - Contact Cadence to gain access
- Eases the transition from “EM simulation” to “Spectre circuit simulation”
  - Checks S-parameter quality right after EM simulation, when it is quicker and easier to fix
- Checks S-parameter data quality before Spectre simulation
  - Data can be from EMX®, Clarity™, or AXIEM® solvers, Spectre simulations, lab measurements, etc.
- Generates rational fitted models (RFM) from S-parameter data
  - Similar to what is currently done during Spectre simulation
  - RFM can be easier to simulate in transient analysis, compared to S-parameters
  - RFM are causal and passive by construction.
- Tuned specifically for Spectre algorithms
- Multithreading supported

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Important Notes

Goal: Assist customers in debugging problematic S-parameter files and improving Spectre® simulation

- *The new tool is not a "magic bullet"*
- Intended to reduce rate of problematic data coming downstream to Spectre simulator
  - It is not possible to *completely* eliminate all false positives / false negatives
- When developing S-parameter quality tests, each test has thresholds that must be tuned
  - Quality Checker thresholds are determined by statistical analysis on a collection of real-life S-parameter datasets

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Two Functionalities

- Quality checking tool: Generates a table in the output logfile with important checks on S-parameters
  -
- RFM fitting tool: Generates a rational fitted model (RFM)
  - Models are passive and causal by construction
  - Summary of the fitting process printed in the output logs, shows average of relative fitting error
  - Fitted S-parameter Touchstone file generated from the rational model
    - Can compare fitted model to the original S-parameter file
  - RFM can be entered into the nport properties and used in Spectre® simulations

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Running the Spectre S-parameter Quality Checking Tool

- Basic command:

```
spectre +sparam <Sparam_filename> +checking -o <output_directory>
```

- Checks performed and reported:
  - **DC point:** Was a DC point provided? Is the imaginary component of the DC point equal to zero?
  - **Lowest frequency**: Lowest (non-DC) frequency point
  - **Highest frequency**: Used to calculate fastest rise time
  - **#freq data points per decade:** Indication of data density
  - **Reciprocity:** Is the S-parameter matrix is symmetric?
  - **Discontinuity in real/imaginary:** Discontinuities in either the real or imaginary part can impact simulation
  - **Discontinuity in phase:** Discontinuities in phase can impact simulation
  - **Data rotation in polar coordinate system:** Elements with counter-clockwise rotations indicate possible causality issues, which can impact simulation
  - **Passivity:** Absolute tolerance of the passivity criteria is 1e-6, passivity issues impact simulation
- Quality Checking Tool is geared specifically for the RFM Generator in Spectre® simulator

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Snapshot of S-Parameter Quality Checking Tool Output

```
spectre +sparam <Sparam_filename> +checking -o <output_folder>
```

Example 1: Snapshot of the Quality Checking Tool output

Summary of Sparam Checking Tool		
Parameters	Results	comments
DC	DC is provided. Imag DC is not detected.	Passed
Lowest frequency	5e+07 Hz	Inconclusive
Highest frequency	1e+11 Hz	
To preserve signal integrity in the time domain, we recommend using this s-parameter in circuits where the rise time is slower than 3e-11 sec.		
#freq points [10^7,10^8)(Hz) #freq points [10^8,10^9)(Hz) #freq points [10^9,10^10)(Hz) #freq points [10^10,10^11)(Hz) #freq points [10^11,10^12)(Hz)	2 17 180 1800 1	
Reciprocity	No non-reciprocal points.	Symmetric
Discontinuity in Real/Imaginary	Not detected.	Passed
Discontinuity in Phase	Discontinuity in Phase is not detected.	Passed
Data rotation in Polar coordinate system	Counterclockwise rotation is detected in: S1,1 S2,2 S2,4 S3,3 S4,4 Data may be non causal.	Inconclusive
S2,4 has the maximum percentage of CCW rotations of 24.462%.		
Passivity	Passivity violation is detected, but is smaller than 1e-6%. Data is almost passive.	Passed

Note: The RFM Generator may still create a good RFM even if there are some "fails" in the Checker output

Example 2: Snapshot of Quality Checking Tool output

Parameters	Results	comments
DC	DC is missing.	Failed
Lowest frequency	3e+05 Hz	
Highest frequency	1.4e+10 Hz	
To preserve signal integrity in the time domain, we recommend using this s-parameter in circuits where the rise time is slower than 2.14e-10 sec.		
#freq points [10^5,10^6)(Hz) #freq points [10^6,10^7)(Hz) #freq points [10^7,10^8)(Hz) #freq points [10^8,10^9)(Hz) #freq points [10^9,10^10)(Hz) #freq points [10^10,10^11)(Hz)	1 1 10 103 1028 458	
Reciprocity	No non-reciprocal points.	Symmetric
Discontinuity in Real/Imaginary	Not detected.	Passed
Discontinuity in Phase	Discontinuity in Phase is detected in: S1,1 at 3.8852e+09 Hz. S1,1 at 3.9027e+09 Hz. S1,2 at 3.8502e+09 Hz. S1,2 at 3.9115e+09 Hz. S1,2 at 3.9727e+09 Hz. S1,2 at 4.034e+09 Hz. S1,2 at 1.393e+10 Hz. S1,2 at 1.3939e+10 Hz. S2,2 at 2.3452e+09 Hz.	Failed
S1,2 at 1.3939e+10 Hz has the largest phase jump of 179.33 degrees.		
Data rotation in Polar coordinate system	Counterclockwise rotation is detected in: S1,1 S1,2 S2,2 Data may be non causal.	Failed
S1,2 has the maximum percentage of CCW rotations of 33.834%.		
Passivity	The maximum passivity violation is 54%, detected at freq 1e+10 Hz. Data is non-passive.	Failed

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Running the Rational Fitting Mode

Rational Fitting Mode creates a rational fitted model for the S-parameter data

- Use command line options **+sparam** and **+fitting**:

```
spectre +sparam <Sparam_filename> +fitting=rfm -o <output_directory>
```

- Fitted S-parameter data and encrypted RFM files placed inside the `RFMOutput` folder when the `-o` option used
  - Otherwise, results put in current working directory
  - Only `rfm` supported. Linear interpolation to be considered in the future.
- S-parameter data file format detected automatically; must be `spectre`, `touchstone`, `citi` or `bnp`
- Both absolute and relative paths supported

```
Top_level_directory/
    mySparams.s106p   <-- Input
    SparamCheckerOut/ <-- Output
        mySparams.out
        RFMOutput/
            fitted_mySparams.s106p
            mySparams_SPEC_ENCRYPT.rfm
```


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Output of RFM Generator

Successful:

```
Average of relative fitting error is: 1.045774e-02.

S-parameter fitting finished successfully for datafile: mySparams.s6p.
Fitted s-parameters is stored in file:
/grid/tfo/vol168/tawna/SParamRFMtesting/SparamCheckerOutput/RFMOutput/fitted_mySparams.s6p

Time spent in sparam fitting: CPU =     623 ms,  elapsed =    1.321 s
```

Warning that RFM may not be accurate:

```
Average of relative fitting error is: 8.351971e-02.

S-parameter fitting finished successfully for datafile: mySparams.s147p.


Warning from spectre during circuit read-in.
    WARNING (CMI-3057): NPORT0: Relative element-wise error of fitted s-parameter
data is larger than 3.000000e-02. As a result, simulation results may be
inaccurate. Try interp = linear or spline for better results.
```

Note: The Checker may "pass" an S-parameter file, but the fitting may fail

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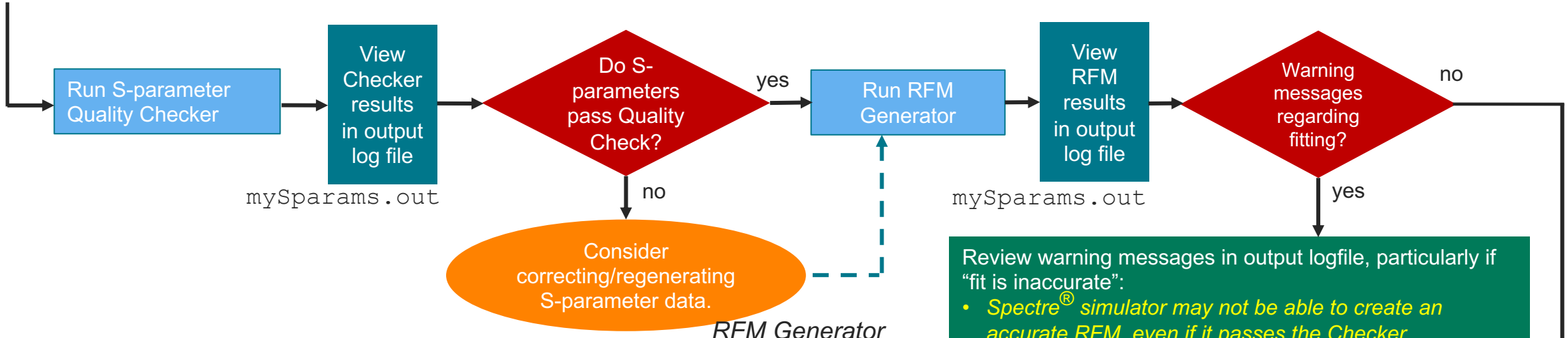
Summary of Flow

```
spectre +sparam mySparams.s106p +checking +fitting=rfm -o SparamCheckerOut
```




```
Top_level_directory/
    mySparams.s106p
    SparamCheckerOut/
        mySparams.out
        RFMOutput/
            fitted_mySparams.s106p
            mySparams_SPEC_ENCRYPT.rfm
```

Can enter
`mySparams_SPEC_ENCRYPT.rfm`
into the nport Add Instance or Edit Properties form.

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Accessing Command Line Help

spectre -h sparam

```
*****************************************************
Options for Sparam Standalone Checking and Fitting Tool
*****************************************************


 +checking
                                Checking quality of the original S-parameter data including:
                                DC: Checking if DC points are provided, and also DC imaginary is zero.
                                Lowest frequency: Reporting minimum freq in the data after DC point.
                                Highest frequency: Reporting maximum freq in the data.
                                #freq data points per decade: Reporting number of frequency data points per decade.
                                Reciprocity: Reporting if S-parameter matrix is symmetric.
                                Discontinuity in Real/Imaginary: Reporting S-parameter elements with discontinuity in either real or imaginary part.
                                Discontinuity in Phase: Reporting S-parameter elements with discontinuity in phase.
                                Data rotation in Polar coordinate system: Reporting S-parameter elements with counter-clockwise rotations and possible causality
issue.
                                Passivity: Checking S-parameter data passivity. Absolute tolerance of passivity criteria is 1e-6.
 +fitting [=rfm]
                               'rfm': only generates rational fitted model.
 +multithread=<N>
                                Enables the multithreading capability, where, N is the number of threads specified. A maximum of 64 threads are allowed.
                                '+mt' can be used as an abbreviation of '+multithread'.
```


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Summary

- Spectre® S-parameter Quality Checker and RFM Generator available in Spectre 21.1 ISR
  - Contact Cadence to obtain access
- Successfully tested on >350 representative testcases (1-port to 700-port size)
- EM designers can easily determine S-parameter quality when it's quicker/easier to fix in the flow, *before* embedding S-parameters in a full design or sending to others
- Circuit designers now have new rational fit model (RFM) option (passive and causal by construction), which Spectre simulator can use in time-domain simulations
- Reduced rate of problematic S-parameter data coming downstream to Spectre simulator; simulations faster and more robust
- S-parameter Quality Checker and RFM Generator increases designer productivity

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