Comparison of Interconnect Model Validation with FSV and SPS Metrics

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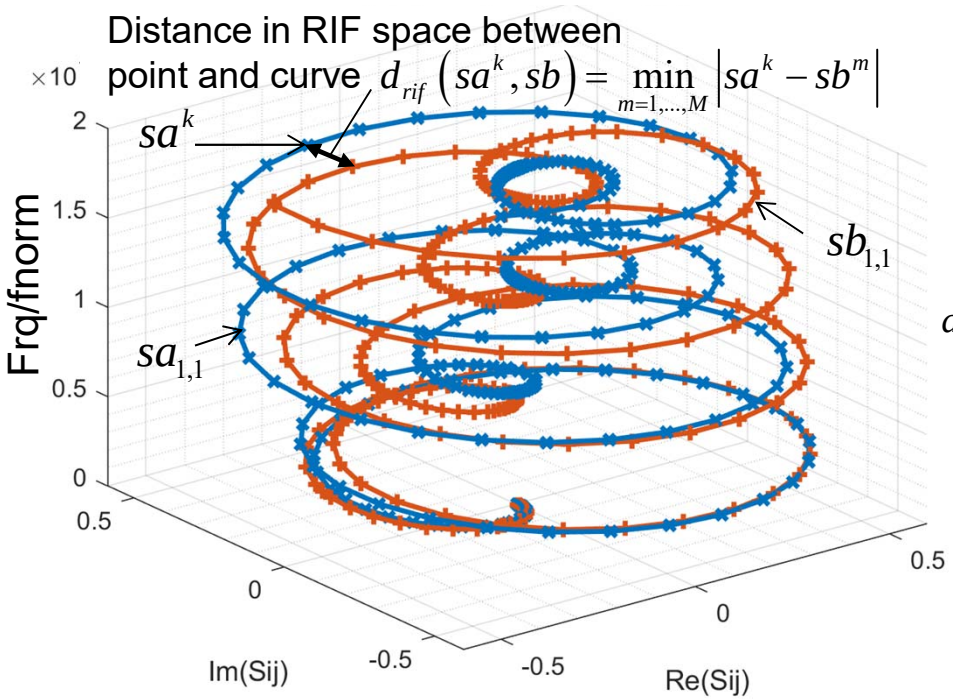
Introduction

- Any interconnect design process must include analysis to measurement validation step
- The validation requires formal and automated comparison of simulated and measured S-parameters
  - It can be done either with Feature Selective Validation (FSV)
    - A.P. Duffy, G. Zhang, FSV: State of the Art and Current Research Fronts, IEEE Electromagnetic Compatibility Magazine, Volume 9, #3, 2020, p. 55-62.
  - Or with recently introduced S-Parameter Similarity (SPS) metric
    - Y. Shlepnev “Evaluation of S-Parameters Similarity with Modified Hausdorff Distance”, May 20, 2021 at http://arxiv.org/abs/2105.10057
    - Y. Shlepnev, S-Parameters Similarity Metric, Simberian Inc., App note #2021_05, May 24, 2021. – available at https://www.simberian.com/AppNotes.php
- This presentation is the first attempt to compare two metrics…

S-Parameters Similarity (SPS) Metric

3D Spiral Plots of 2 S-parameters (Real-Imaginary-Frequency or RIF)



Modified Housdorff Distance(MHD) for S-Matrix Element *i,j*

$$d_{MH}\left(sa, sb\right) = \frac{1}{K}\sum_{k=1}^{K} d_{rif}\left(sa^k, sb\right)$$

MHD for S-Matrix *NxN*:

$$d_{MH}\left(SA, SB\right) = \max\left[d_{MH}\left(sa_{i,j}, sb_{i,j}\right),\ i, j = 1,\ldots,N\right]$$

S-Parameters Similarity (SPS) Metrics:

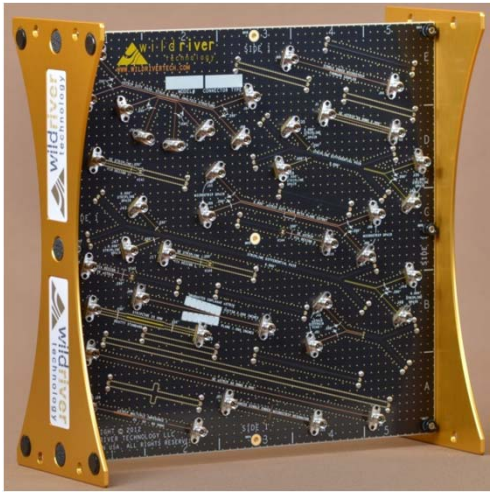
$$SPS\left(sa_{i,j}, sb_{i,j}\right) = 100 \cdot \max\left(1 - d_{MH}\left(sa_{i,j}, sb_{i,j}\right), 0\right)\%$$

$$SPS\left(SA, SB\right) = \min\left(SPS\left(sa_{i,j}, sb_{i,j}\right), i, j = 1,\ldots,N\right)\%$$

Frequency axis is scaled as Frq/fnorm for the distance measurement

Analysis to Measurement SPS for CMP-28

Designed and Measured by Wild River Technology
Modeled with Simbeor
Guide to CMP-28/32 Simbeor Kit, CMP-28 Rev. 4, Sept. 2014.



	Model	Measurement	SPS_SE 10 GHz	SPS_SE 35 GHz	SPS_SE 50 GHz
1	SL_SE_2inch_J6J5	cmp28_strpl_2in_50ohm_p1J6_p2J5_s2p	97.1513	92.5639	84.677
2	SL_SE_8inch_J7J8	cmp28_strpl_8inch_p1J7_p2J8_s2p	97.8176	91.8262	80.9387
3	SL_SE_Beatty_25Ohm_J28J27	cmp28_strpl_Beatty_25ohm_p1J28_p2J27_s2p	98.3164	91.7525	81.1544
4	SL_SE_Resonator_J23J24	cmp28_strpl_resonator_p1J23_p2J24_s2p	98.5621	92.8552	82.7012
5	SL_SE_Via_Capacitive_J18J17	cmp28_strpl_via_capacitive_p1J18_p2J17_s2p	94.9476	91.1739	82.8437
6	SL_SE_Via_Backdrilled_J14J13	cmp28_strpl_via_backdrilled_p1J14_p2J13_s2p	97.1172	90.8311	82.0804
7	SL_SE_2inch_Capacitive_J9J10	cmp28_strpl_2in_Capacitive_p1J10_p2J09_s2p	97.7805	93.0992	87.3275
8	SL_SE_2inch_Inductive_J11_J12	cmp28_strpl_2in_Inductive_p1J12_p2J11_s2p	97.8352	93.8351	87.8757
9	SL_DF_2inch	cmp28_strpl_diff_2inch_J39J40J35J36_s4p	95.9985	91.087	83.0354
10	SL_DF_6inch	cmp28_strpl_diff_6inch_J47J48J43J44_s4p	96.8208	93.0776	85.1746
11	MS_SE_2in_J1_J2	cmp28_mstrp_2in_p1J1_p2J2	97.9111	94.7303	91.8845
12	MS_SE_8in_J4_J3	cmp28_mstrp_8inch_p1J4_p2J3	97.6372	95.3771	91.645
13	MS_SE_Beatty_25Ohm_J25_J26	cmp28_mstrp_Beatty_25ohm_p1J25_p2J26	96.5268	93.3182	89.9407
14	MS_SE_Resonator_J21_J22	cmp28_mstrp_resonator_p1J21_p2J22	98.0708	94.1929	90.5811
15	MS_SE_GND_Voids_J74_J75	cmp28_gnd_voids_p1J74_p2J75	97.6512	88.4187	83.5582
16	MS_SE_GraduateCoplanar_J70_J69	cmp28_graduate_coplanar_p1J70_p2J69	97.6924	94.4118	91.4621
17	MS_SE_Via_Inductive_J15_J16	cmp28_mstrp_via_inductive_p1J15_p2J16	96.6664	93.596	90.0153
18	MS_SE_Via_Capasitive_J19_J20	cmp28_mstrp_via_capacitive_p1J19_p2J20	96.5088	93.969	90.1057
19	MS_SE_Via_Pathology_J65_J66	cmp28_via_pathology_p1J65_p2J66	97.2525	91.9582	88.486
20	MS_DF_2inch	cmp28_mstrp_diff_2inch_J38J37J34J33	95.4645	93.3429	90.407
21	MS_DF_6inch	cmp28_mstrp_diff_6inch_J46J45J42J41	95.5751	93.9318	90.9123
22	MS_DF_GND_Cutout	cmp28_mstrp_diff_gnd_cutout_J59J60J55J56	94.4506	91.4807	88.7113
23	MS_DF_Vias	cmp28_mstrp_diff_vias_J49J50J51J52	95.6808	91.6811	88.4878

Tires: [0, 80) **Bad;** [80, 90) **Inconclusive;** [90, 99) **Acceptable;** [99, 100] **Good;**

FSV vs SPS for 35 GHz Bandwidth

FSV:
[0, 0.1] Excellent
(0.1, 0.2] Very Good
(0.2, 0.4] Good
(0.4, 0.8] Fair
(0.8, 1.6] Poor
(1.6, inf) Very Poor

SPS:
[99, 100] **Good**
[90, 99) **Acceptable**
[80, 90) **Inconclusive**
[0, 80) **Bad**

FSV, 35 GHz

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
1	0.33	0.43	**0.59**	0.15	0.18	**0.26**	0.43	Fair
2	0.41	0.54	**0.76**	0.04	0.05	**0.07**	0.42	Fair
3	0.16	0.24	**0.33**	0.12	0.13	**0.19**	0.26	Good
4	0.25	0.35	**0.47**	0.09	0.16	**0.20**	0.34	Good
5	0.35	0.47	**0.66**	0.25	0.27	**0.41**	0.54	Fair
6	0.40	0.49	**0.72**	0.42	0.40	**0.64**	0.68	Fair
7	0.17	0.28	**0.36**	0.14	0.14	**0.22**	0.29	Good
8	0.35	0.37	**0.56**	0.19	0.23	**0.33**	0.44	Fair
9	0.39	0.44	**0.65**	0.11	0.19	**0.23**	0.44	Fair
10	0.43	0.44	**0.70**	0.05	0.06	**0.09**	0.40	Fair
11	0.45	0.51	**0.75**	0.11	0.15	**0.20**	0.48	Fair
12	0.44	0.60	**0.82**	0.03	0.04	**0.05**	0.44	Fair
13	0.24	0.40	**0.52**	0.15	0.18	**0.26**	0.39	Good
14	0.31	0.50	**0.66**	0.11	0.19	**0.24**	0.45	Fair
15	0.37	0.55	**0.73**	0.47	0.50	**0.75**	0.74	Fair-Poor
16	0.33	0.45	**0.63**	0.13	0.21	**0.28**	0.45	Fair
17	0.29	0.60	**0.73**	0.13	0.15	**0.22**	0.48	Fair
18	0.32	0.45	**0.61**	0.14	0.20	**0.27**	0.44	Fair
19	0.35	0.51	**0.69**	0.14	0.18	**0.25**	0.47	Fair
20	0.50	0.56	**0.83**	0.60	0.55	**0.91**	0.87	Poor
21	0.46	0.59	**0.83**	0.63	0.78	**1.13**	0.98	Poor
22	0.45	0.61	**0.85**	0.34	0.69	**0.83**	0.84	Poor
23	0.43	0.65	**0.86**	0.34	0.42	**0.61**	0.73	Fair-Poor

SPS, 35 GHz

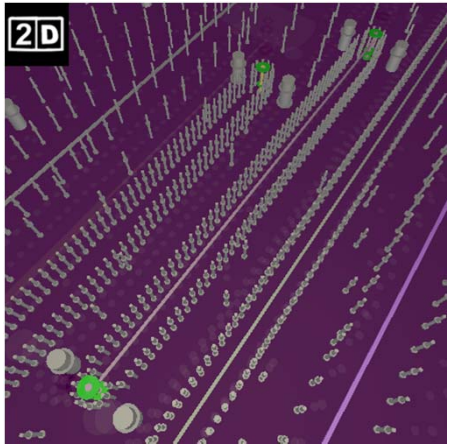
NO.	SPS [0-100]% 35 GHz
1	92.5639
2	91.8262
3	91.7525
4	92.8552
5	91.1739
6	90.8311
7	93.0992
8	93.8351
9	91.087
10	93.0776
11	94.7303
12	95.3771
13	93.3182
14	94.1929
15	88.4187
16	94.4118
17	93.596
18	93.969
19	91.9582
20	93.3429
21	93.9318
22	91.4807
23	91.6811

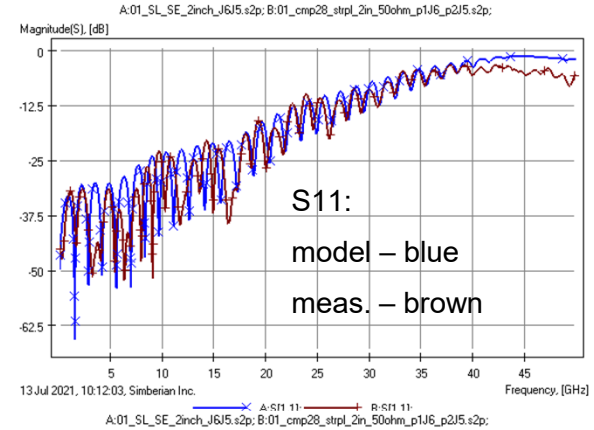
Let's look closer at cases 1, 3, 15, 20…

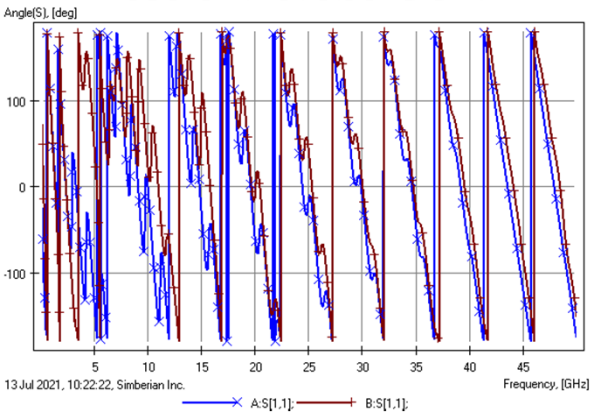
#1 - 2-in Strip – SPS Acceptable

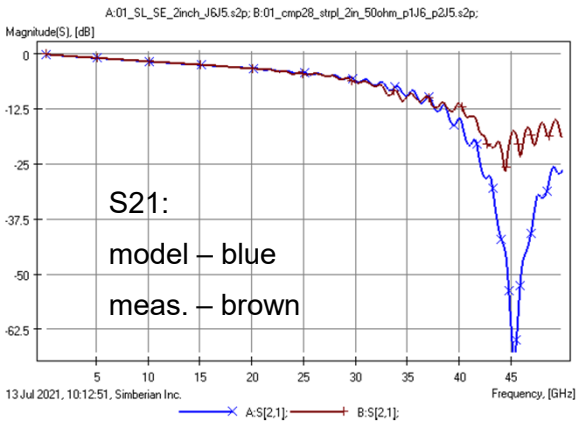
SPS(35)=92.44%

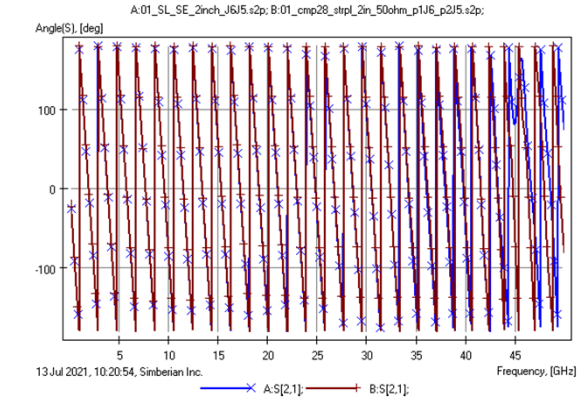
93.7131	98.5223
98.5417	92.4394











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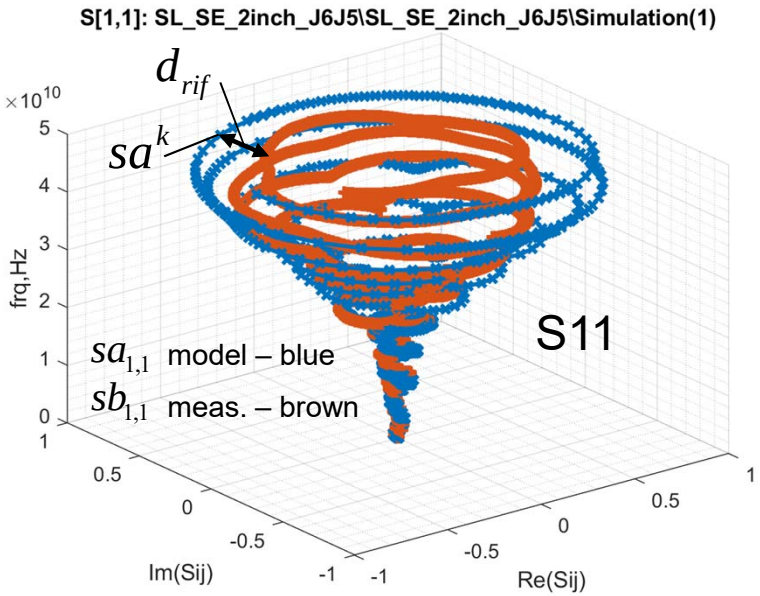
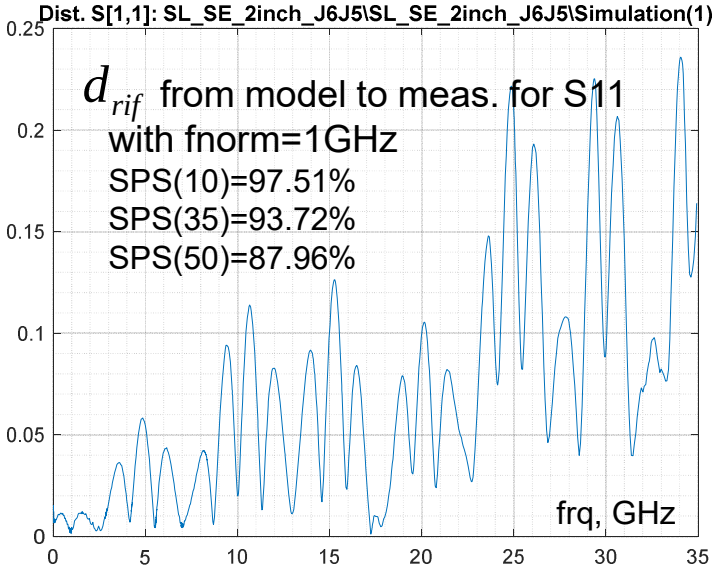
#1 - 2-in Strip - S11 – SPS Acceptable

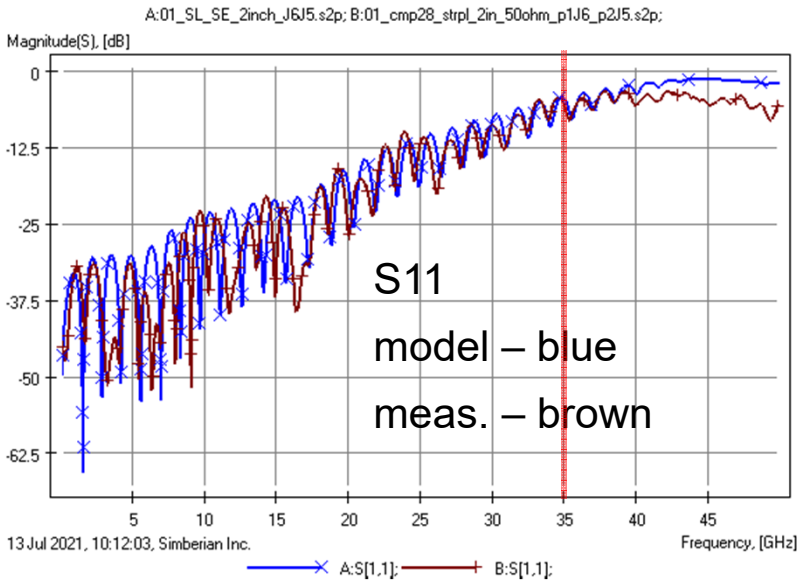


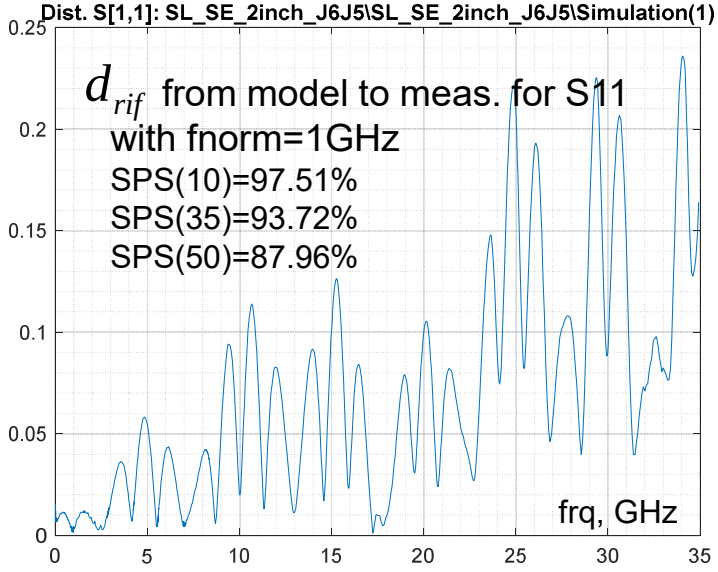


#1 - 2-in Strip - S11 – Fair/Acceptable

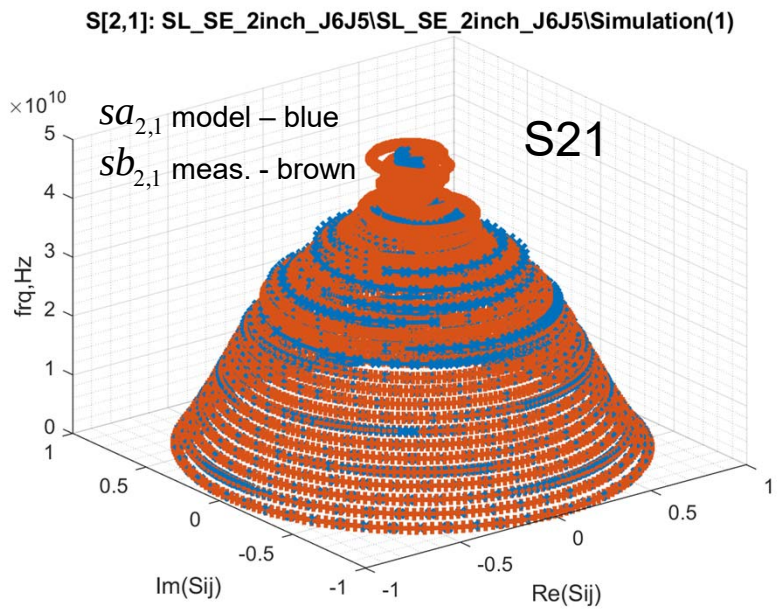
FSV

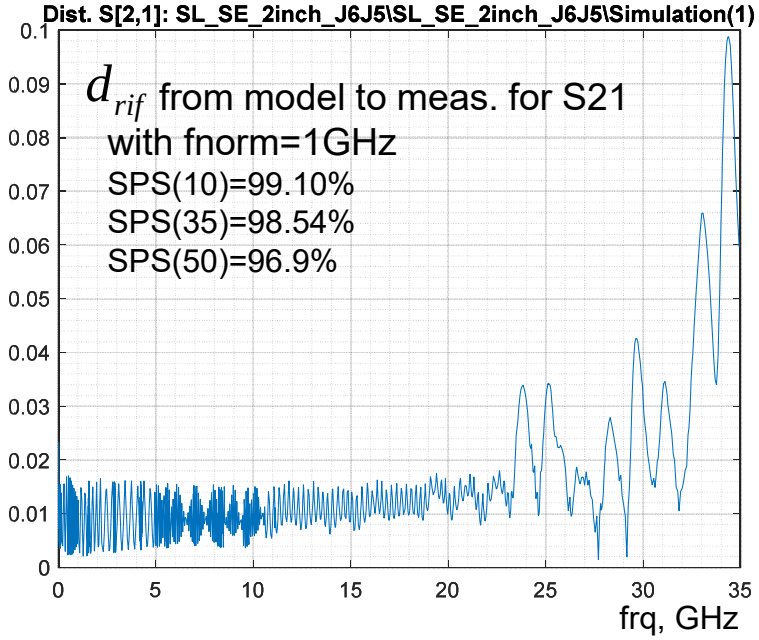
NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
1	0.33	0.43	**0.59**	0.15	0.18	**0.26**	0.43	Fair





#1 - 2-in Strip – S12 – SPS Acceptable

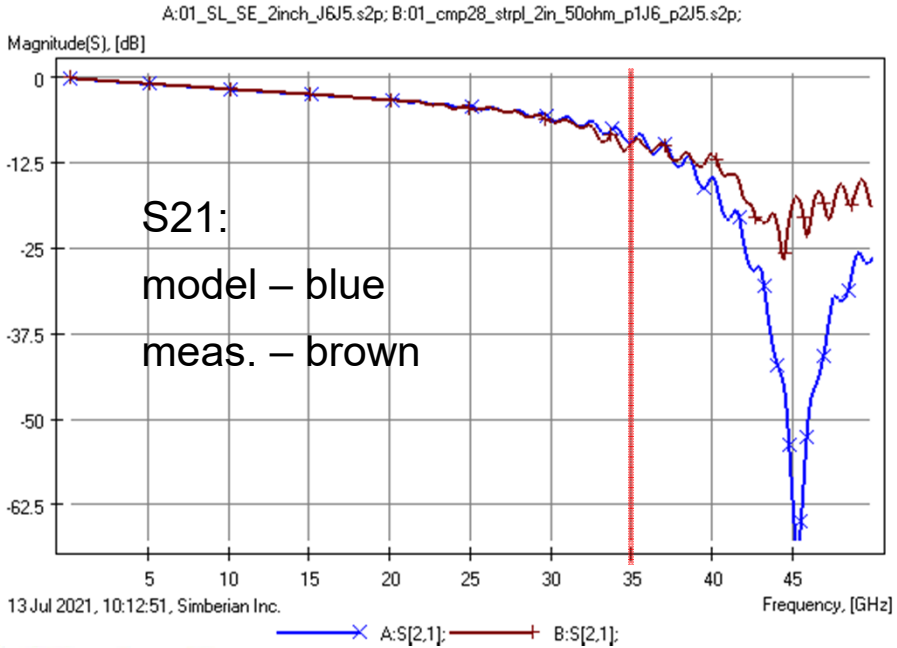


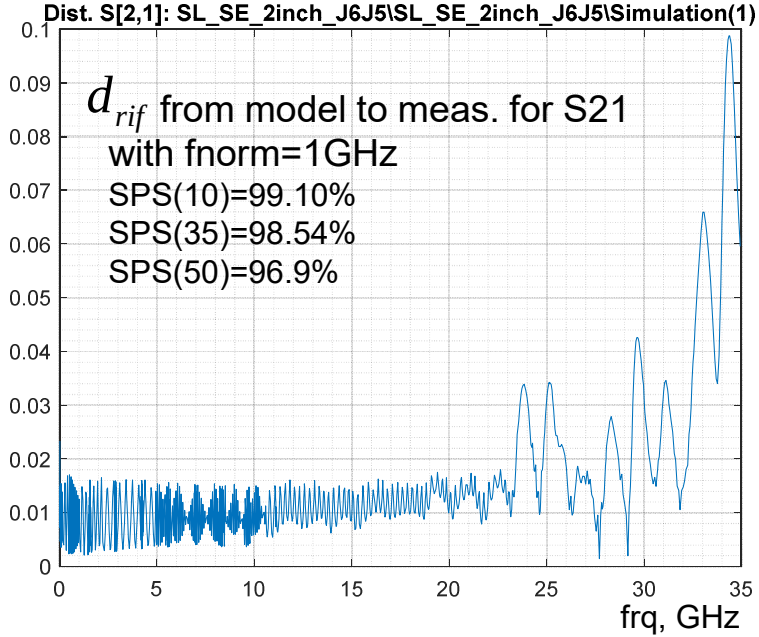


#1 - 2-in Strip – S12 – Good/Acceptable

FSV

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
1	0.33	0.43	**0.59**	0.15	0.18	**0.26**	0.43	Fair

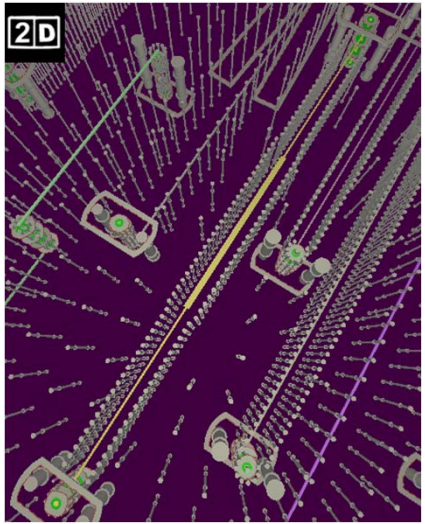


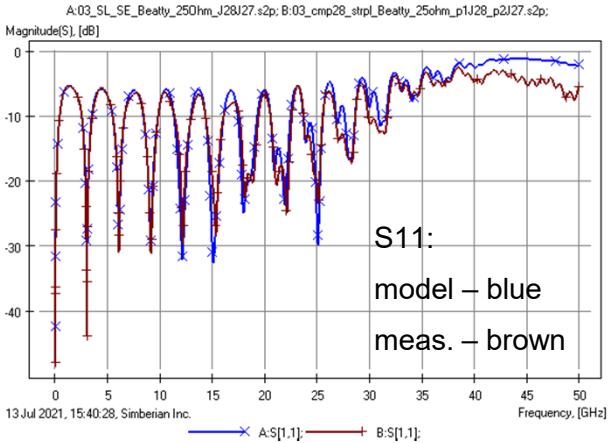


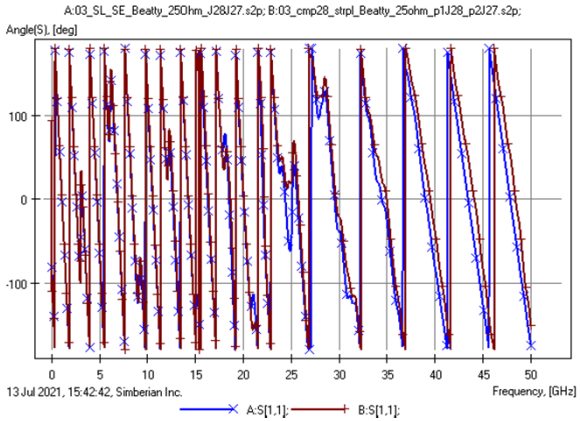
#3 – Strip Beatty – SPS Acceptable

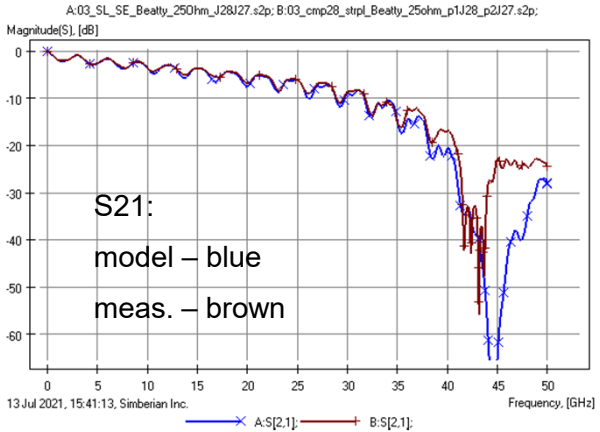
SPS(35)=91.75%

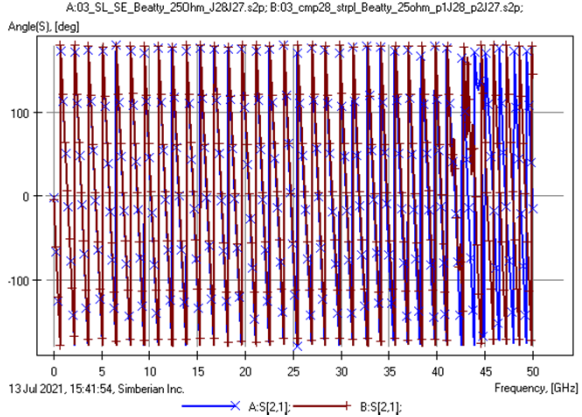
93.8279	96.1705
96.1928	91.7525











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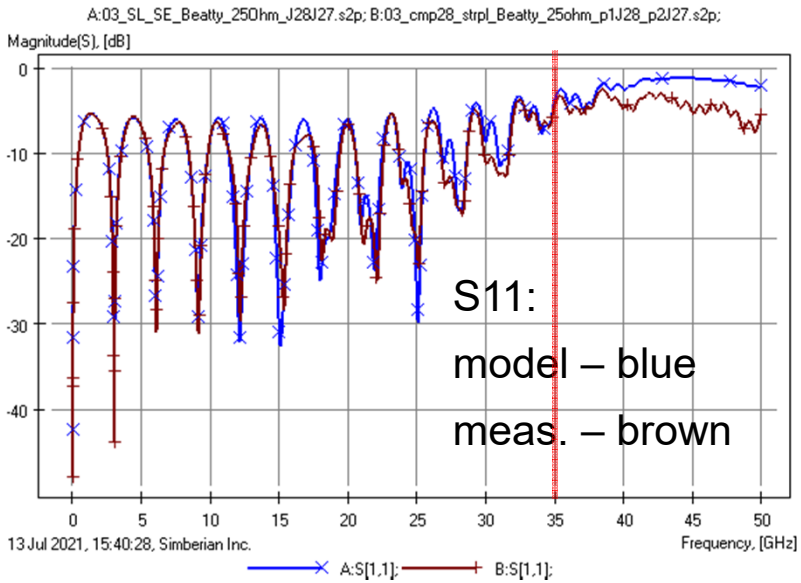
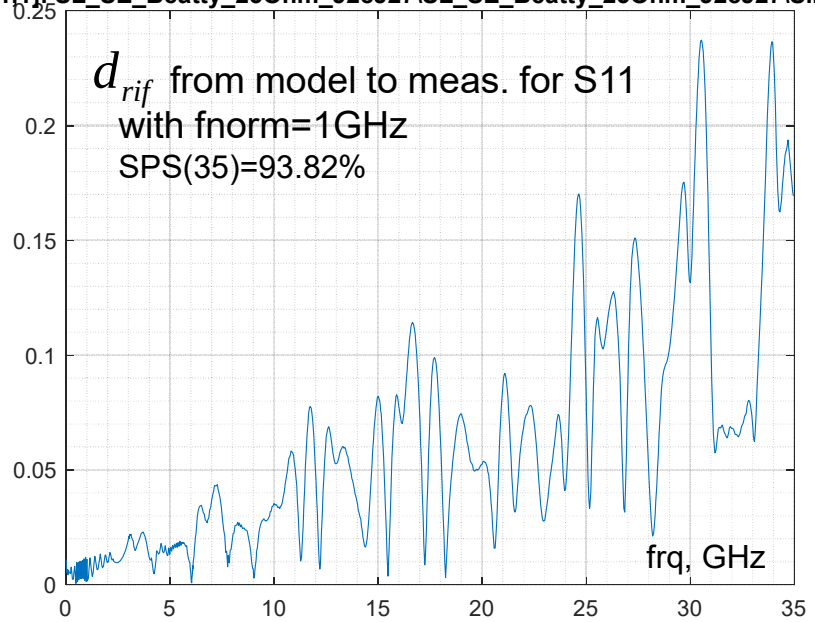
#3 – Strip Beatty - S11 – Good/Acceptable

FSV

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
3	0.16	0.24	**0.33**	0.12	0.13	**0.19**	0.26	Good



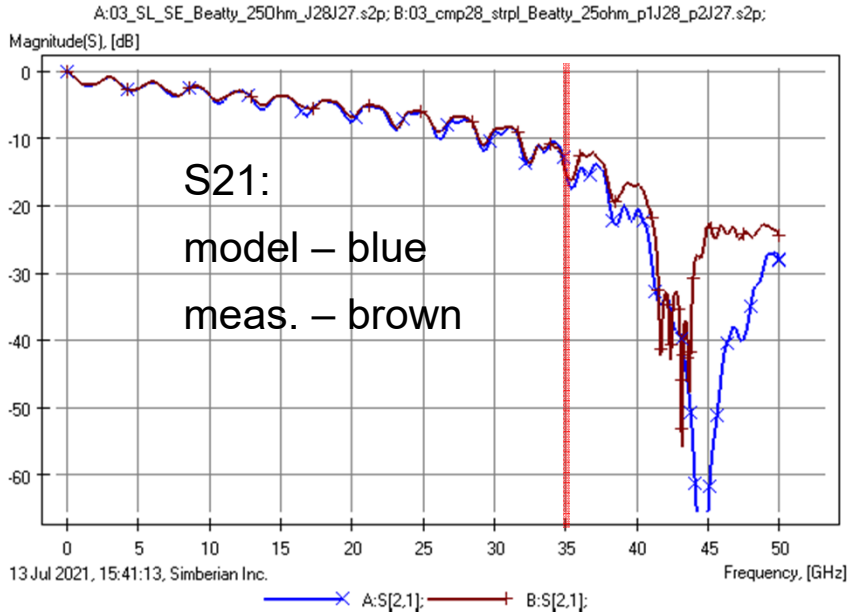


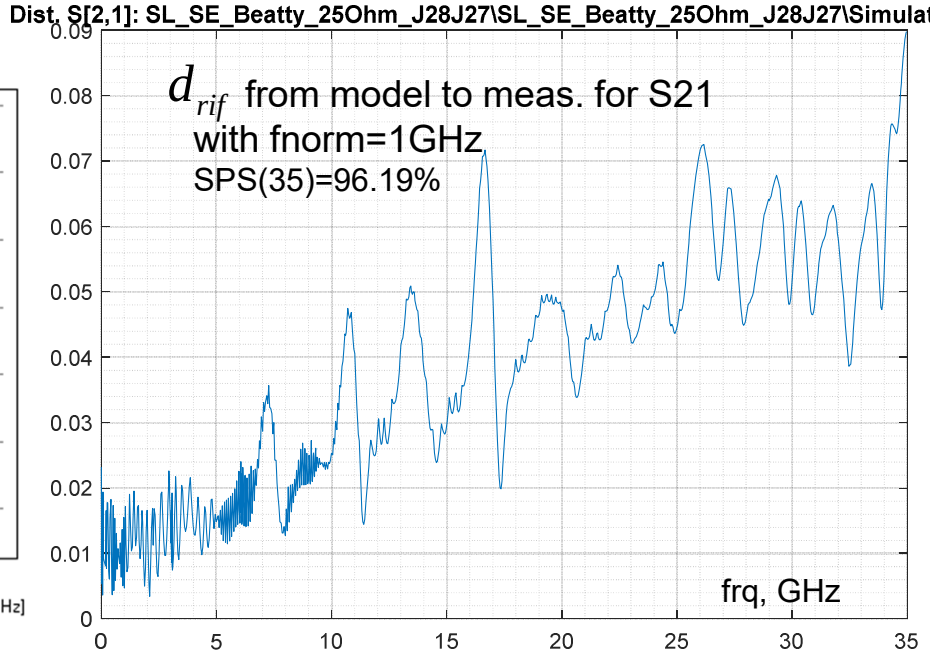
See 3D spiral plots in Appendix…

#3 – Strip Beatty – S21 – Very Good/Acceptable

FSV

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
3	0.16	0.24	**0.33**	0.12	0.13	**0.19**	0.26	Good



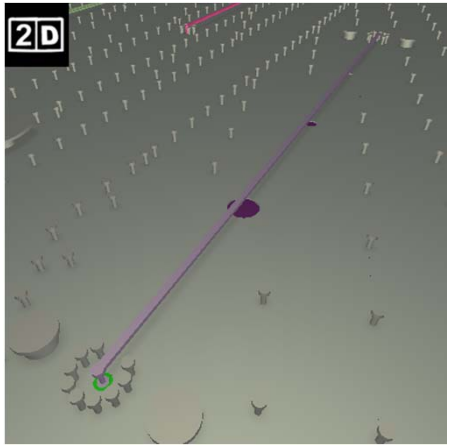


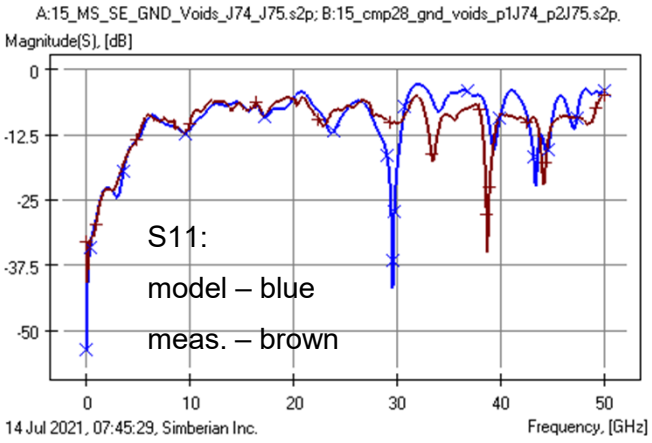
See 3D spiral plots in Appendix…

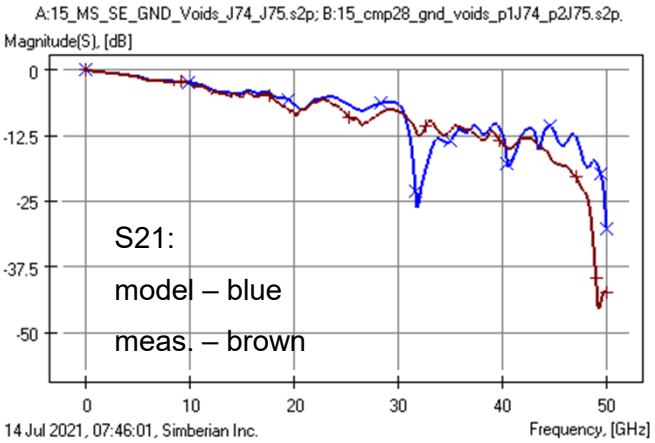
#15 – Voids – SPS Inconclusive

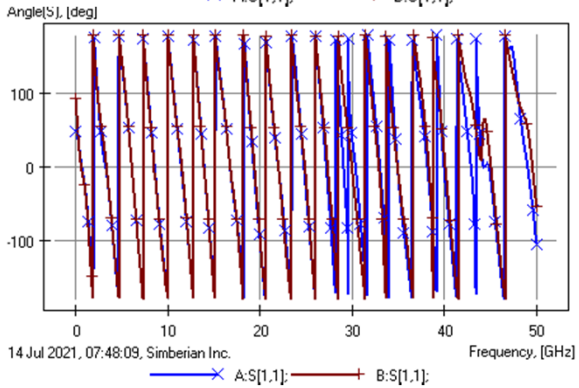
SPS(35)=88.42%

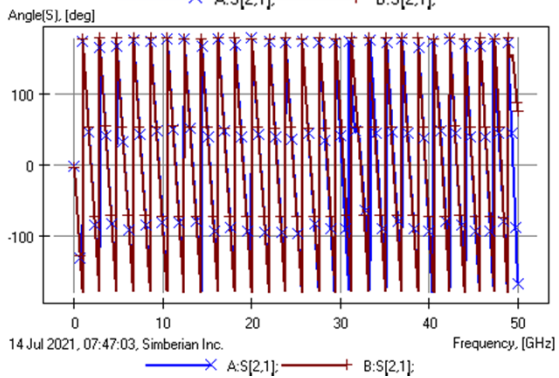
88.4187	92.7228
92.7214	90.6327











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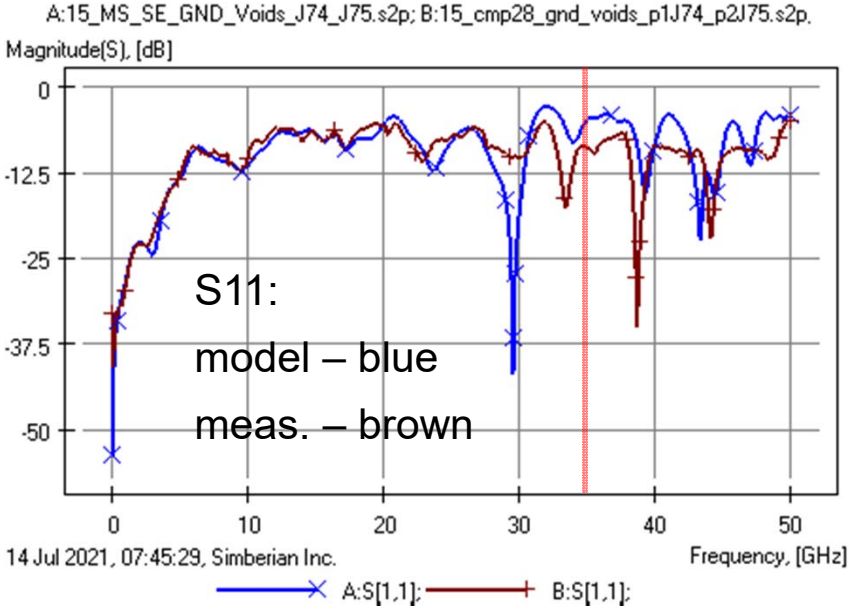
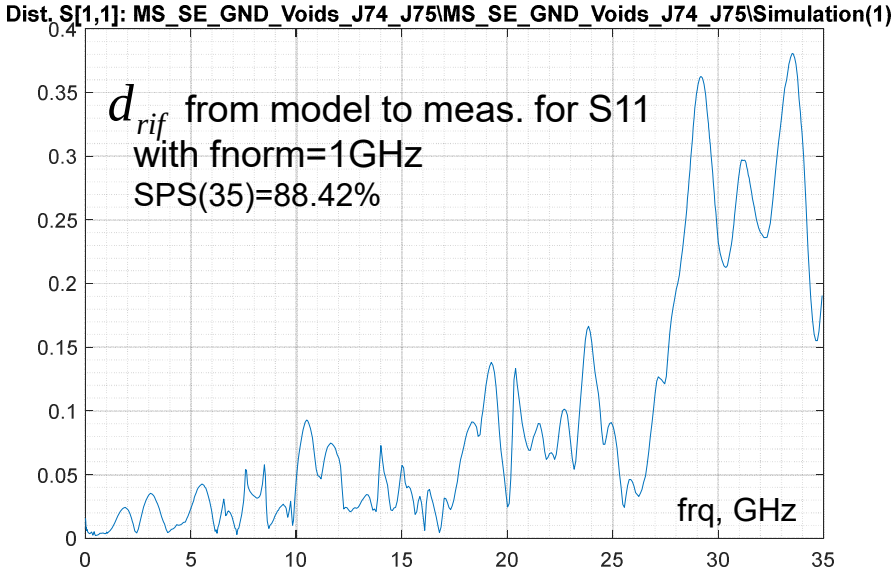
#15 – Voids – S11 – Fair-Poor/Inconclusive

FSV

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
15	0.37	0.55	**0.73**	0.47	0.50	**0.75**	0.74	Fair-Poor



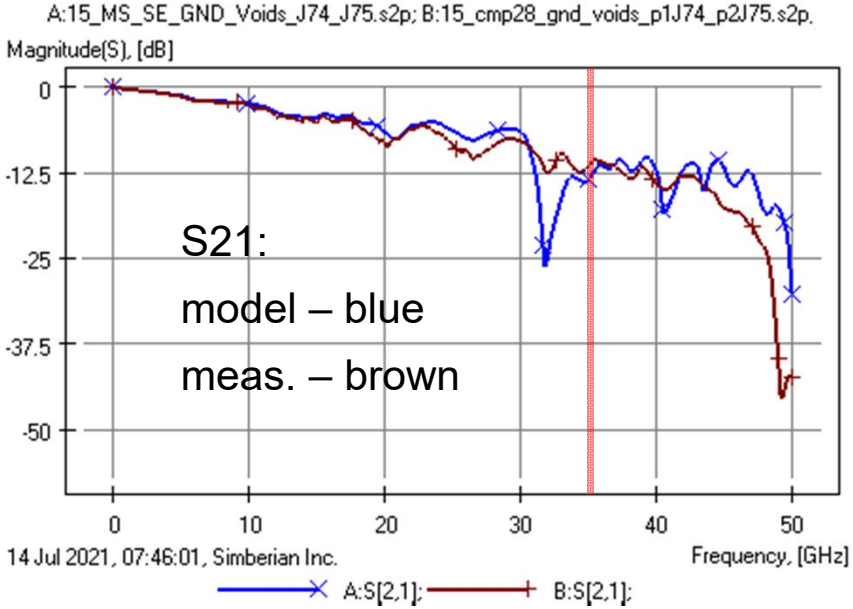


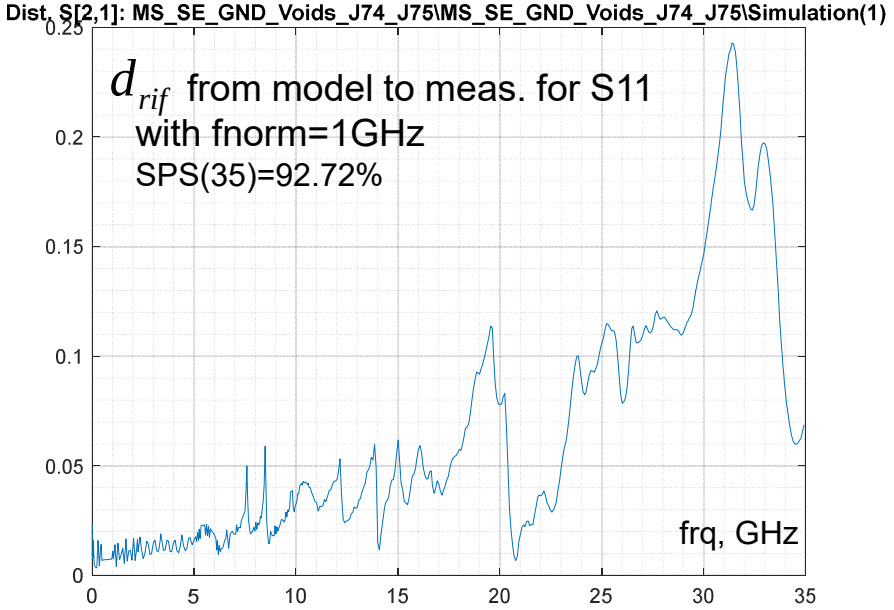
See 3D spiral plots in Appendix…

#15 – Voids – S21 – Fair-Poor/Acceptable

FSV

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
15	0.37	0.55	**0.73**	0.47	0.50	**0.75**	0.74	Fair-Poor



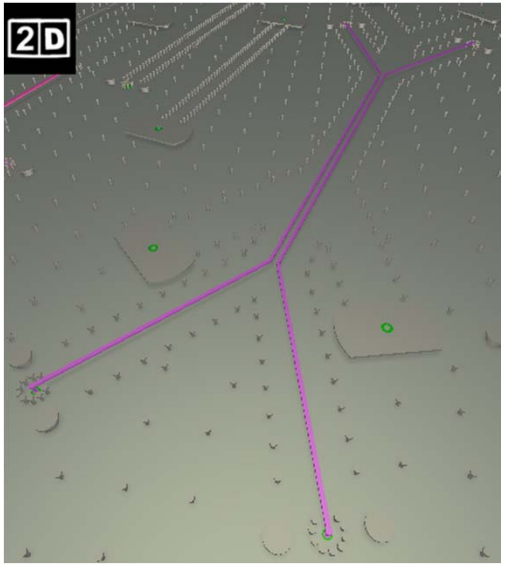


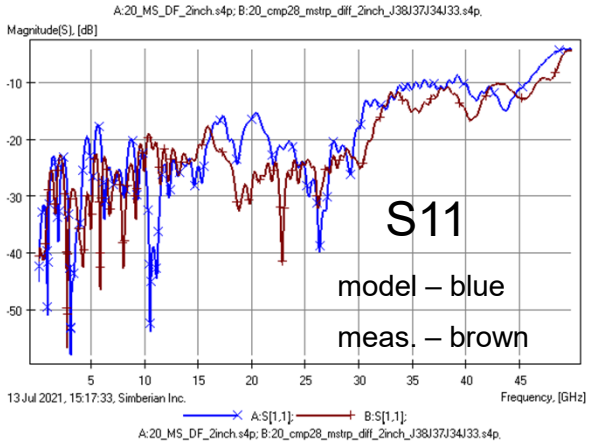
See 3D spiral plots in Appendix…

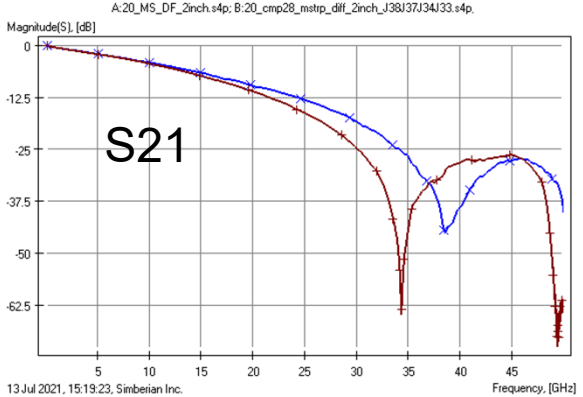
#20 – Diff. 2-in uStrip – SPS Acceptable

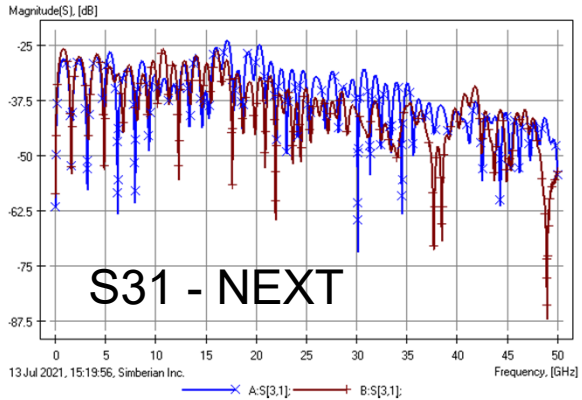
Single-Ended
SPS(35) = 93.34%

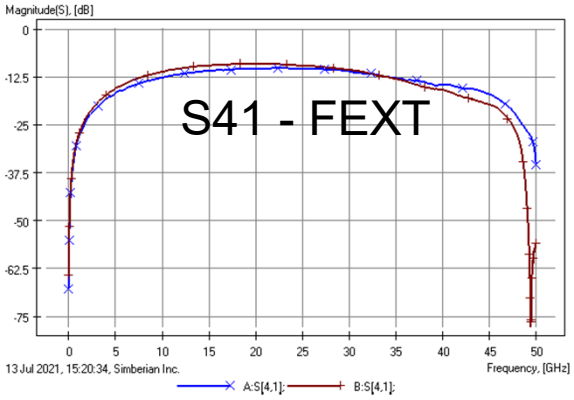
93.6896	96.0340	98.5680	96.8778
96.0421	93.8026	96.5445	98.4246
98.5675	96.5439	93.3429	95.9427
96.8520	98.4240	95.9464	93.4017









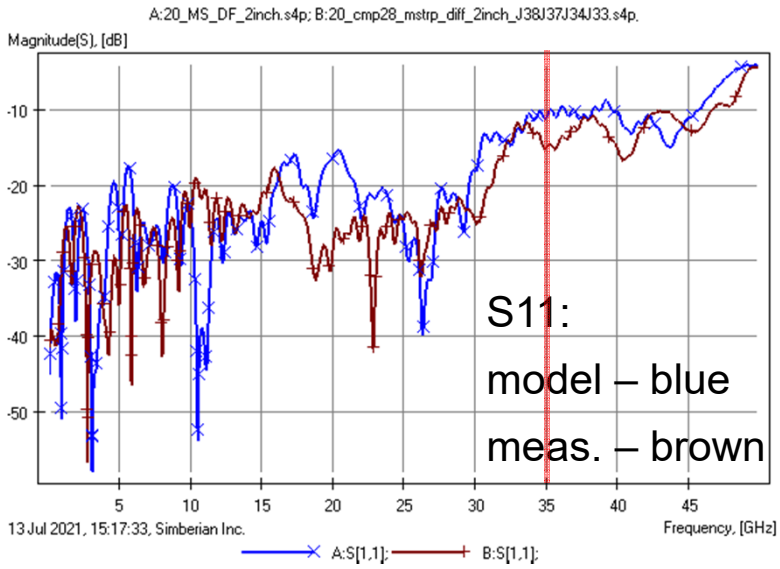


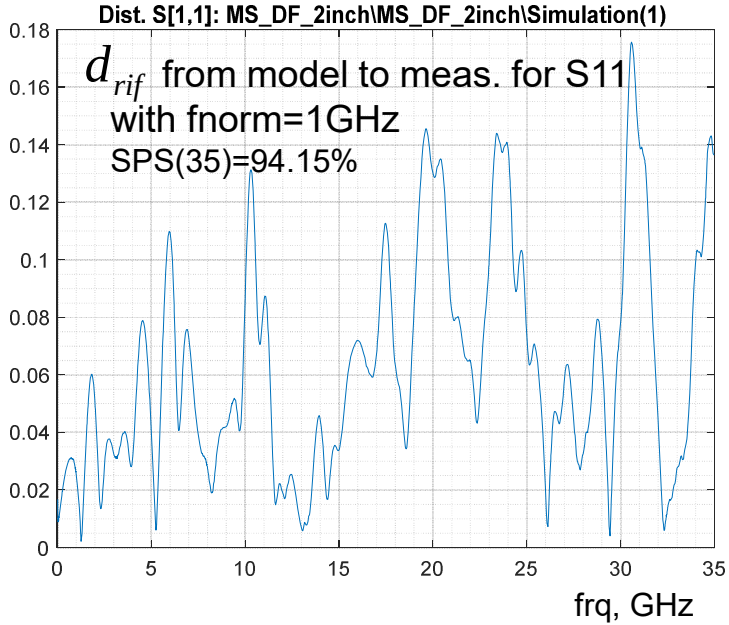
Simberian Electromagnetic Solutions

#20 – Diff. 2-in uStrip – S11 – Poor/Acceptable

FSV

NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
20	0.50	0.56	**0.83**	0.60	0.55	**0.91**	0.87	Poor



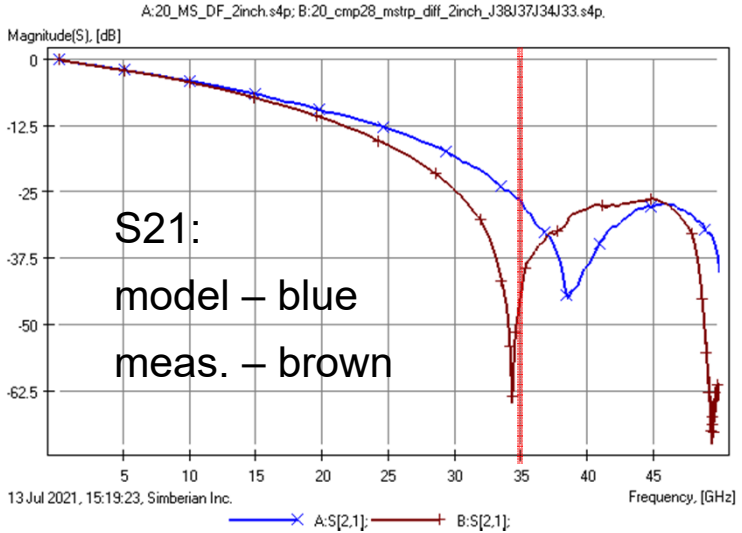


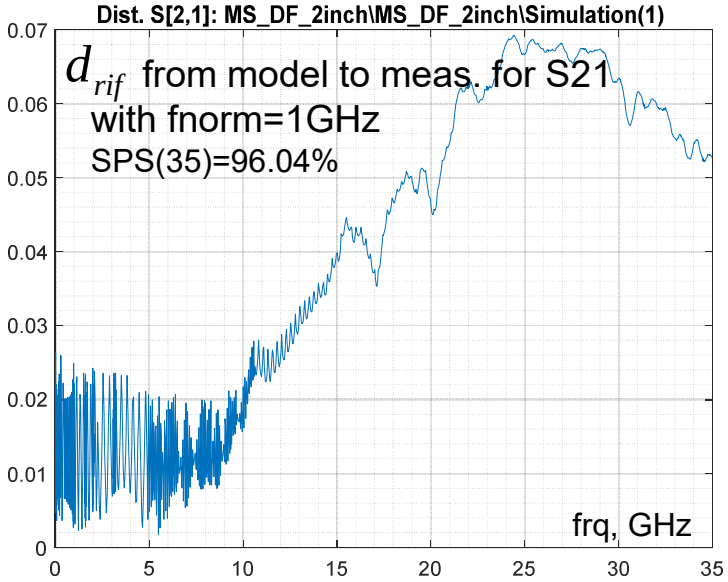
See 3D spiral plots in Appendix…

#20 – Diff. 2-in uStrip – S21 – Poor/Acceptable

FSV

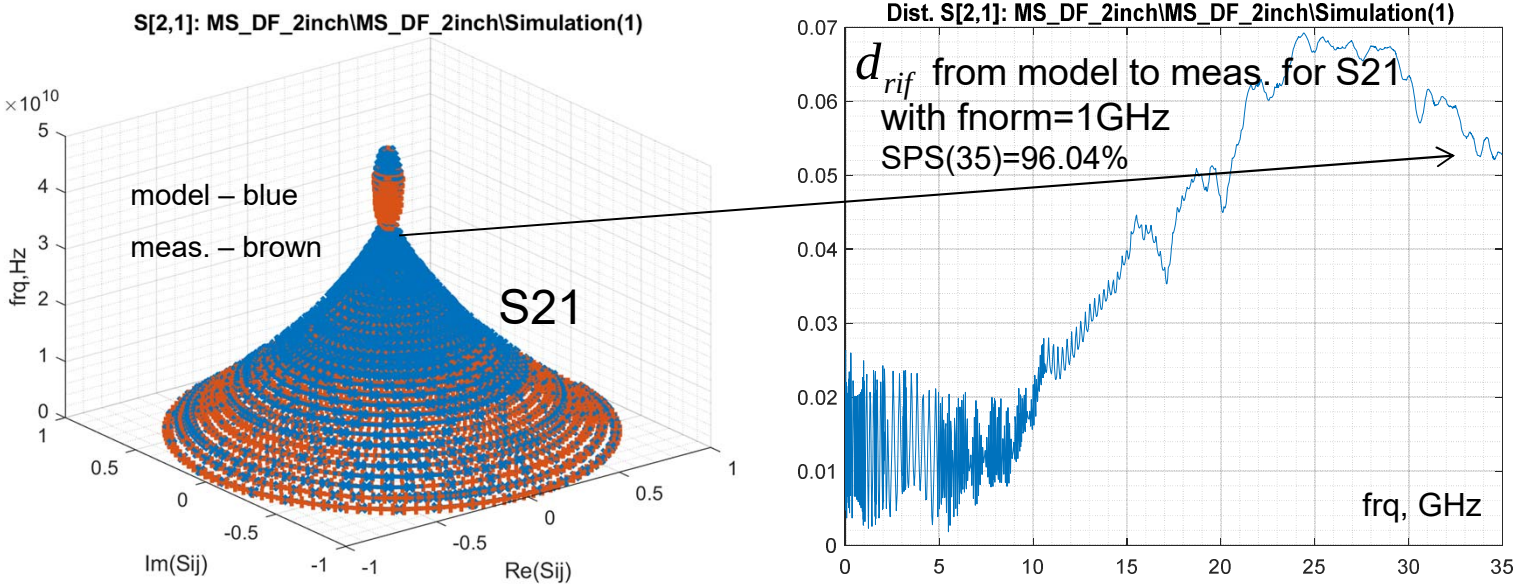
NO.	S11			S21			GDM Average	Qualitative
	ADM	FDM	GDM	ADM	FDM	GDM	(GDM_S11+GDM_S21)/2	
20	0.50	0.56	**0.83**	0.60	0.55	**0.91**	0.87	Poor





SPS is less sensitive to S-parameters with small magnitude

#20 – Diff. 2-in uStrip – S21 – SPS Acceptable



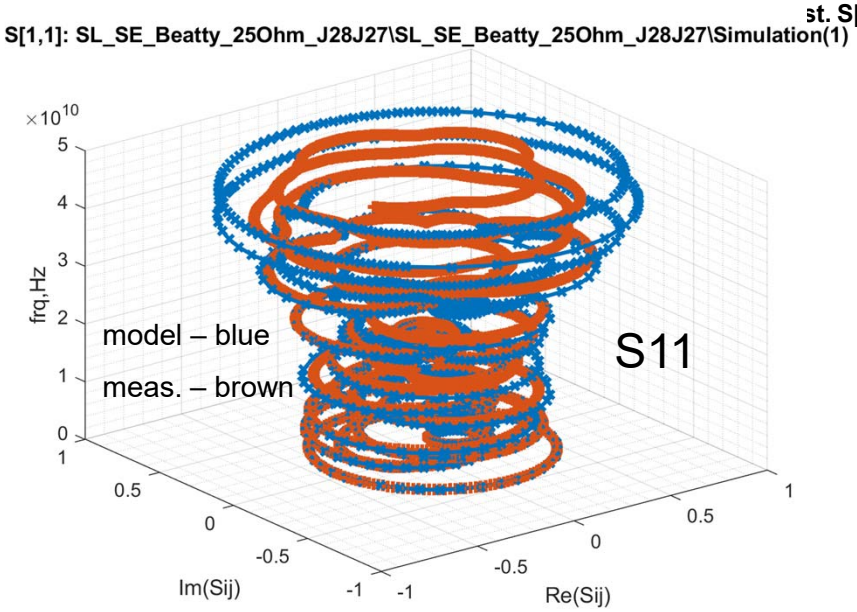
Small magnitude of both S-parameters produces smaller distance

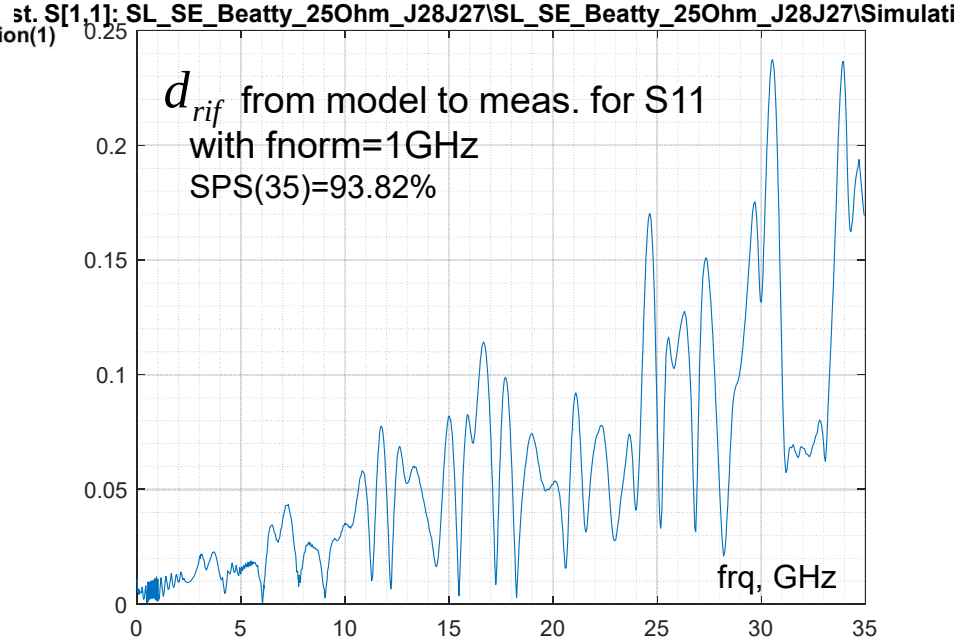
Conclusion

- FSV and SPP metrics are used to compare analysis to measurements for CMP-28 validation platform
- Similar qualitative interpretations are observed on most of the structures
- Differences in SPS and FSV interpretation are observed on S-parameters with very small magnitudes – below 0.1
  - SPS may be not acceptable for comparison of transmission parameters in links with high insertion losses – it needs modification
  - FSV captures the difference quite well – it mirrors the human perception
- SPS is much simpler and may be used for preliminary analysis of large datasets or as complementary to FSV

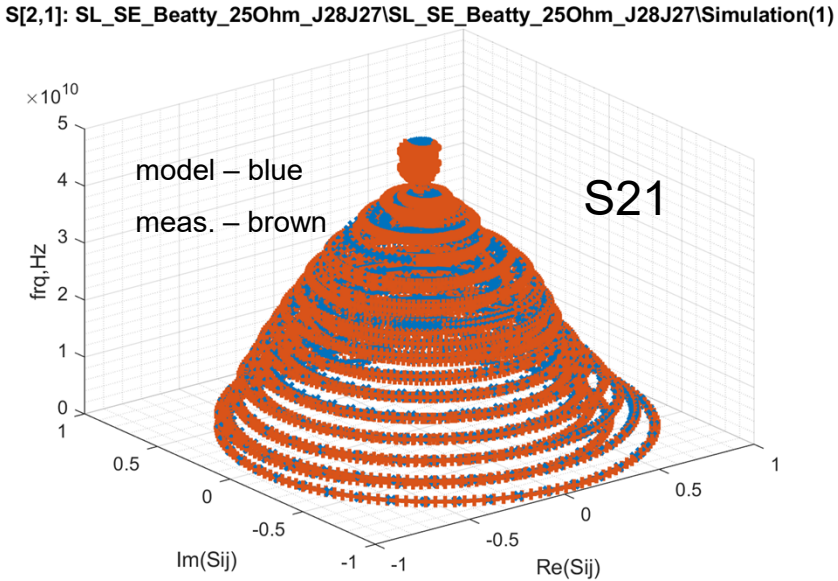
Appendix: Backup Slides

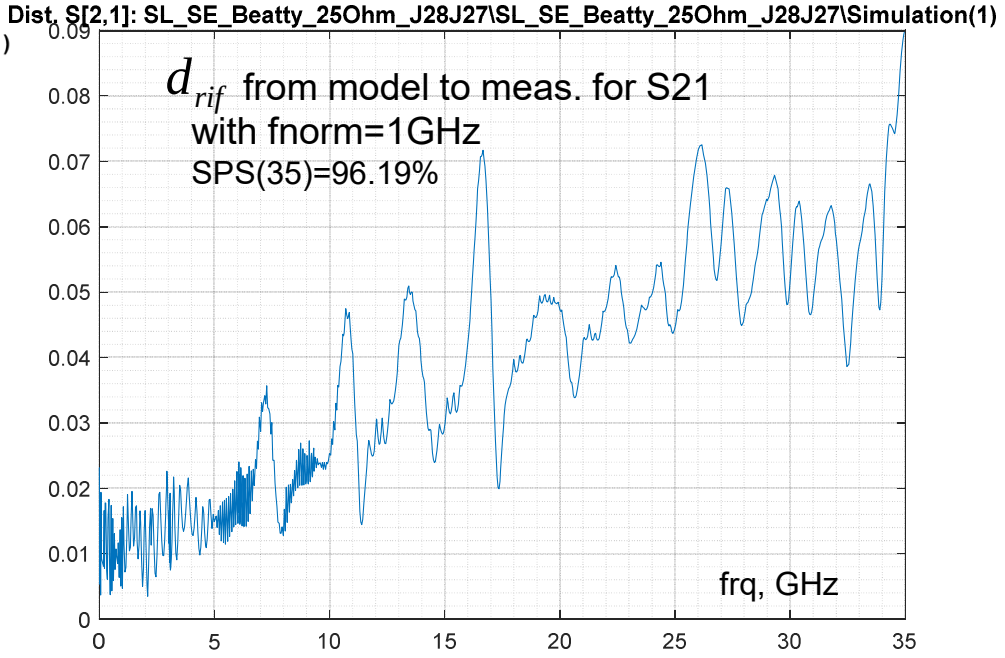
#3 – Strip Beatty – S11 – SPS Acceptable



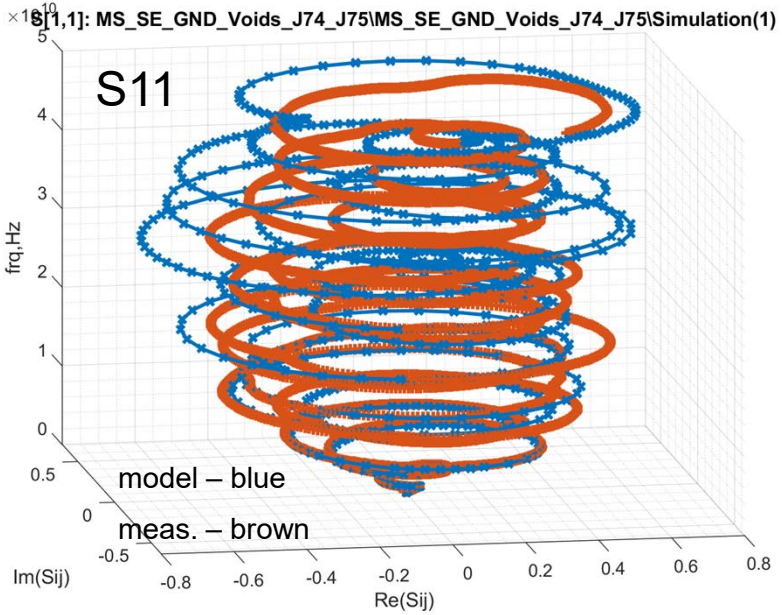


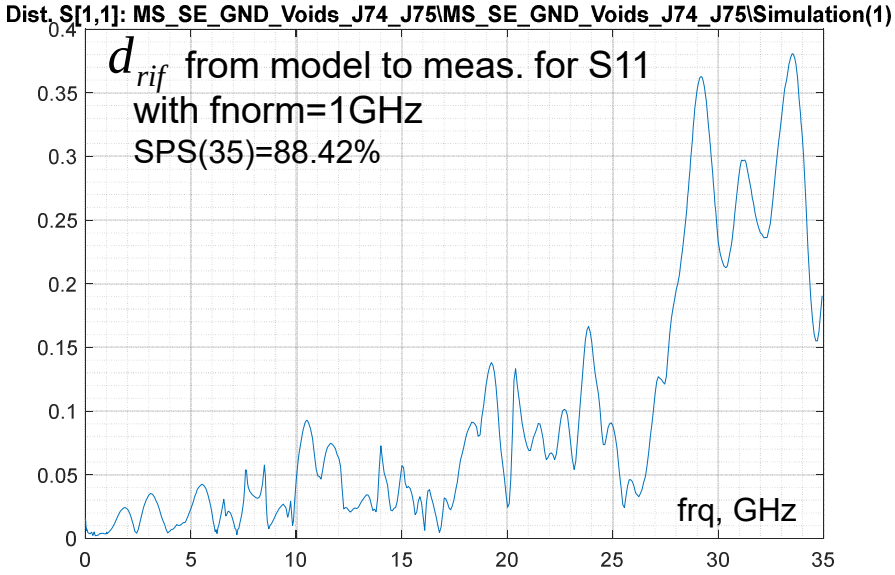
#3 – Strip Beatty – S21 – SPS Acceptable



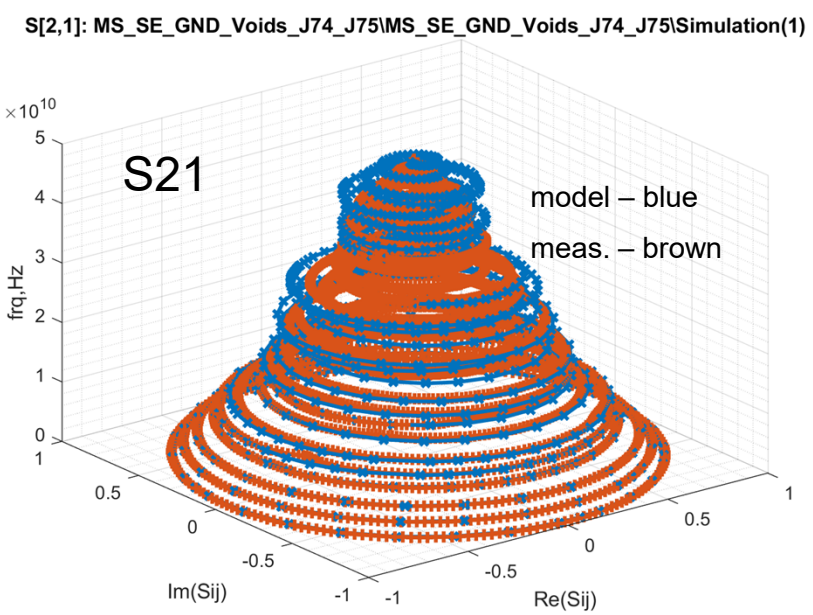


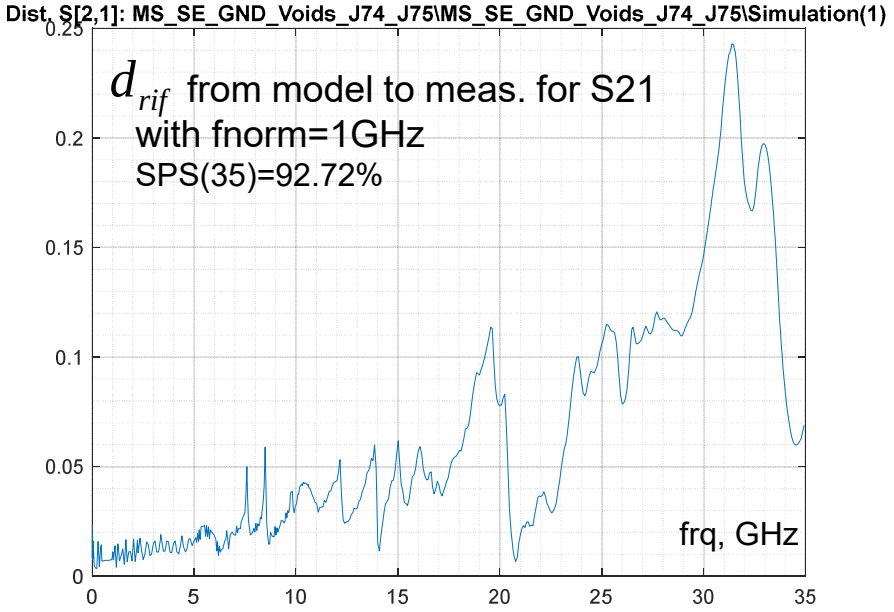
#15 – Voids – S11 – SPS Inconclusive



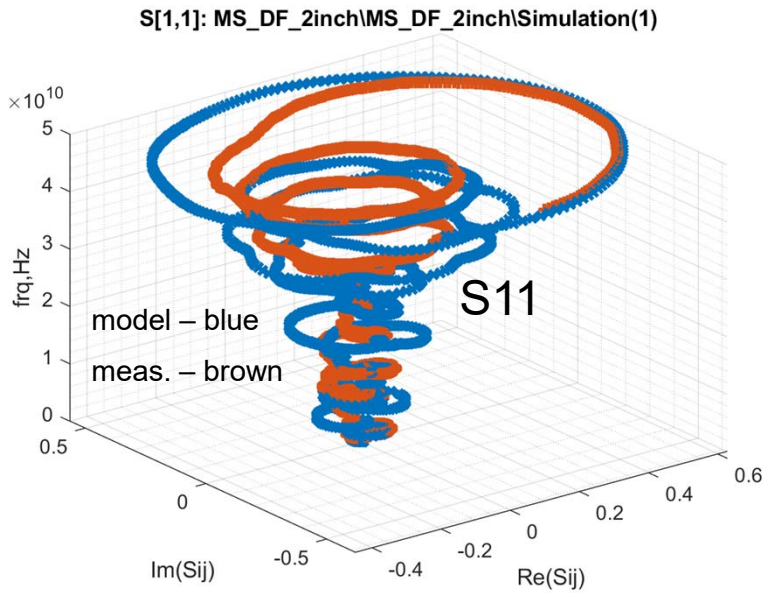


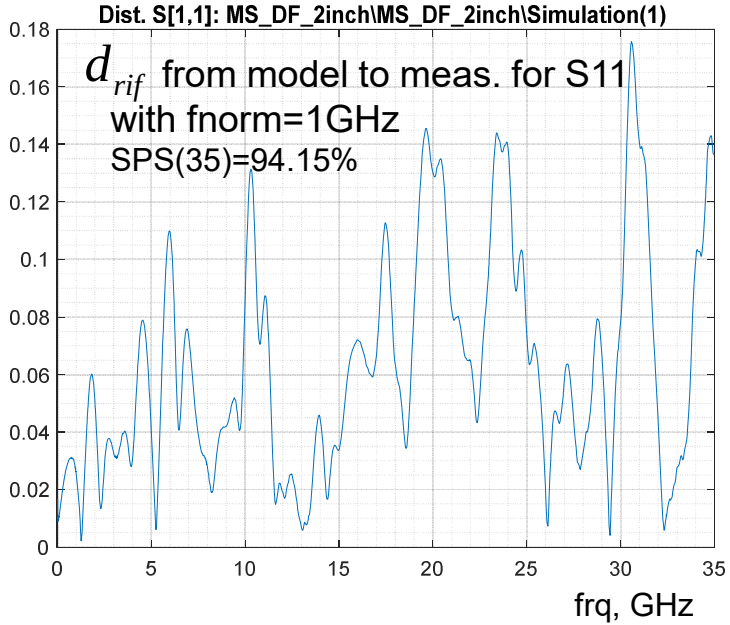
#15 – Voids – S21 – SPS Acceptable



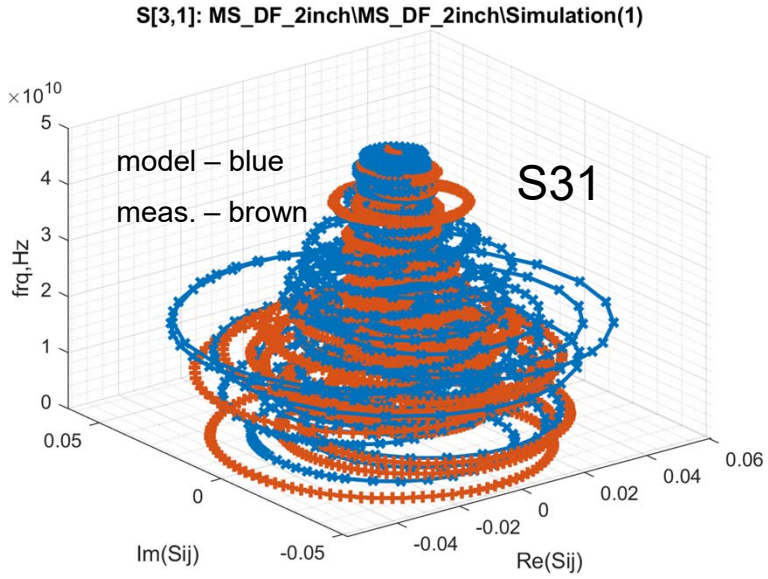


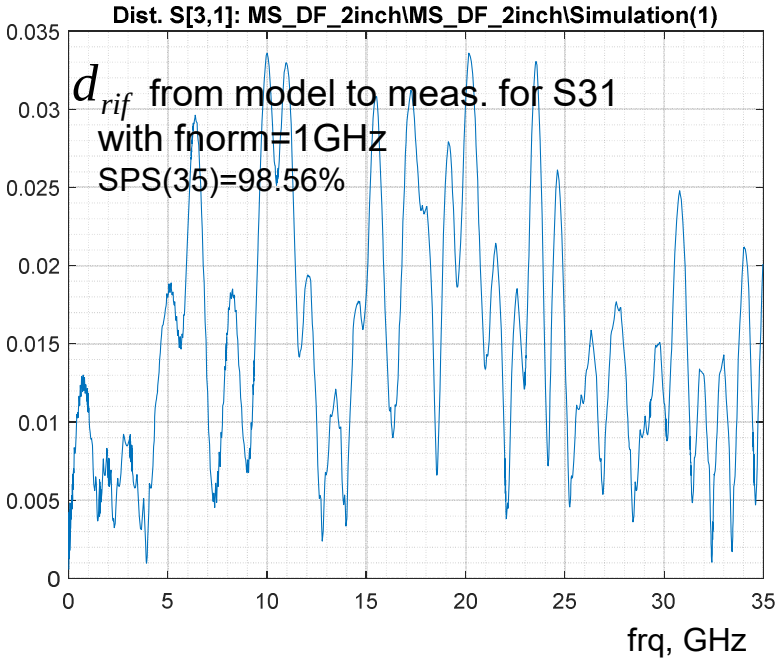
#20 – Diff. 2-in uStrip – S11 – SPS Acceptable





#20 – Diff. 2-in uStrip – S31 – SPS Acceptable





#20 – Diff. 2-in uStrip – S41 – SPS Acceptable