



SOLVER VALIDATION

Validation Report

WaveFEM compared against Ansys HFSS on S-parameters, far-field patterns, adaptive mesh convergence and runtime.

INCLUDED EXAMPLES

Coupled Line Filter

Filter

Hairpin Filter

Filter

Interdigital Bandpass Filter

Filter

L Resonator Notch Filter

Filter

Stepped Impedance Filter

Filter

Dielectric Resonator Antenna

Antenna

Planar Vivaldi

Antenna

Probe Fed Patch

Antenna

Coax to Waveguide Adapter

Transmission Line

Waveguide

Transmission Line

OVERVIEW

Summary of results

Each example is solved in WaveFEM and in Ansys HFSS with the same geometry, adaptive refinement target (maximum delta S) and frequency sweep. Runtimes are wall-clock times from the solver logs; element counts are for the final adaptive pass.

Example	Category	WaveFEM time	HFSS time	WaveFEM elements	HFSS elements	Page
Coupled Line Filter	Filter	00:00:53	00:01:37	28,175	17,994	2
Hairpin Filter	Filter	00:00:21	00:01:03	10,729	4,559	4
Interdigital Bandpass Filter	Filter	00:01:05	00:01:23	30,581	17,344	6
L Resonator Notch Filter	Filter	00:01:17	00:02:32	38,532	39,070	8
Stepped Impedance Filter	Filter	00:00:07	00:00:52	5,521	2,975	10
Dielectric Resonator Antenna	Antenna	00:00:05	00:00:31	5,522	3,191	12
Planar Vivaldi	Antenna	00:01:12	00:01:30	37,095	23,220	15
Probe Fed Patch	Antenna	00:00:40	00:01:16	36,088	19,159	18
Coax to Waveguide Adapter	Transmission Line	00:00:10	00:00:34	8,340	3,420	21
Waveguide	Transmission Line	00:00:04	00:00:41	2,383	5,915	23

FILTER

Coupled Line Filter

A 5.5-7.5 GHz bandpass filter. Using a 1.5 mm substrate with $\epsilon_r=4.3$

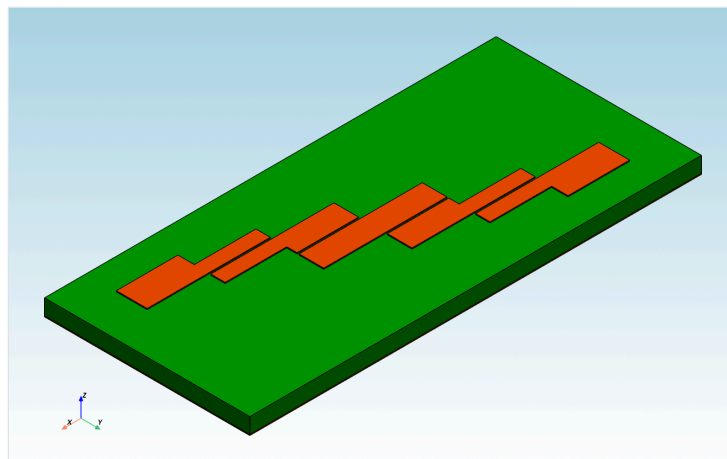
Simulation Setup

Refinement frequency	7 GHz
Delta S	0.02
Frequency range	2 - 10 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:53	00:01:37
Adaptive meshing	00:00:20	00:00:39
Frequency sweep	00:00:28	00:00:54
Adaptive passes	9	10
Final elements	28,175	17,994
Matrix size	160,792	110,368

Geometry



Convergence

Convergence - Coupled Line Filter

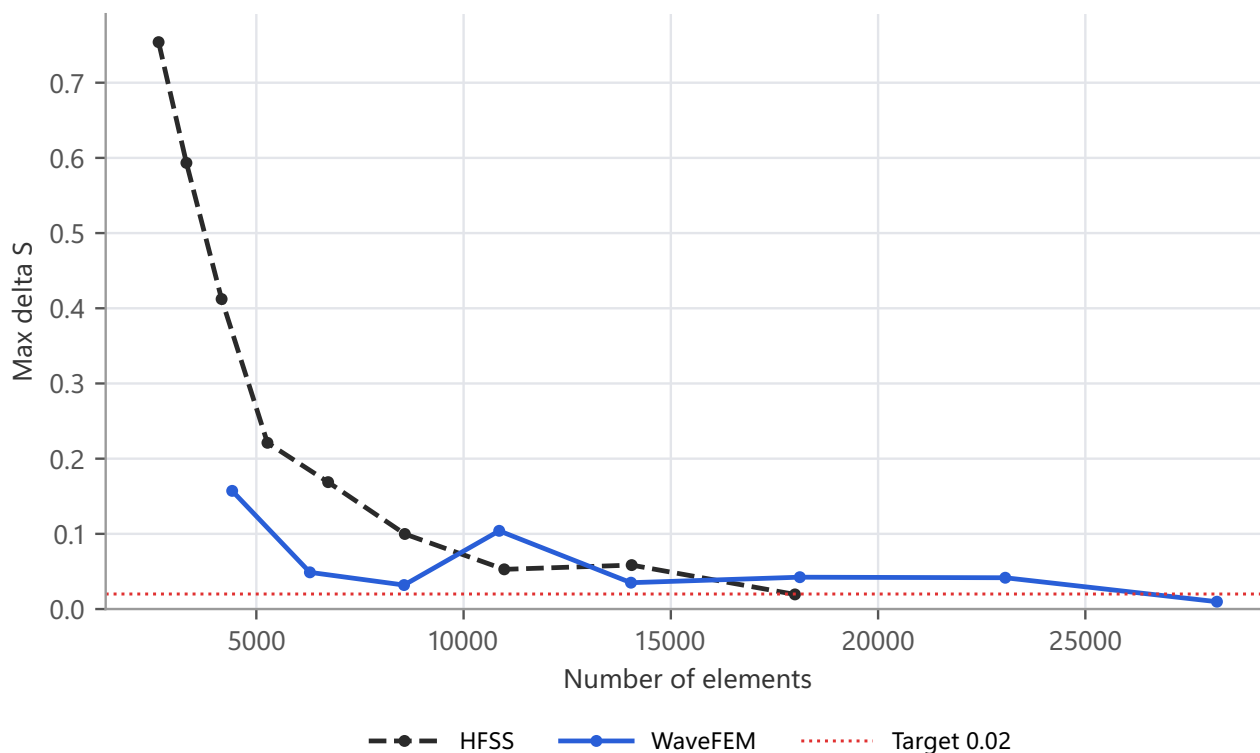


Figure 1 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

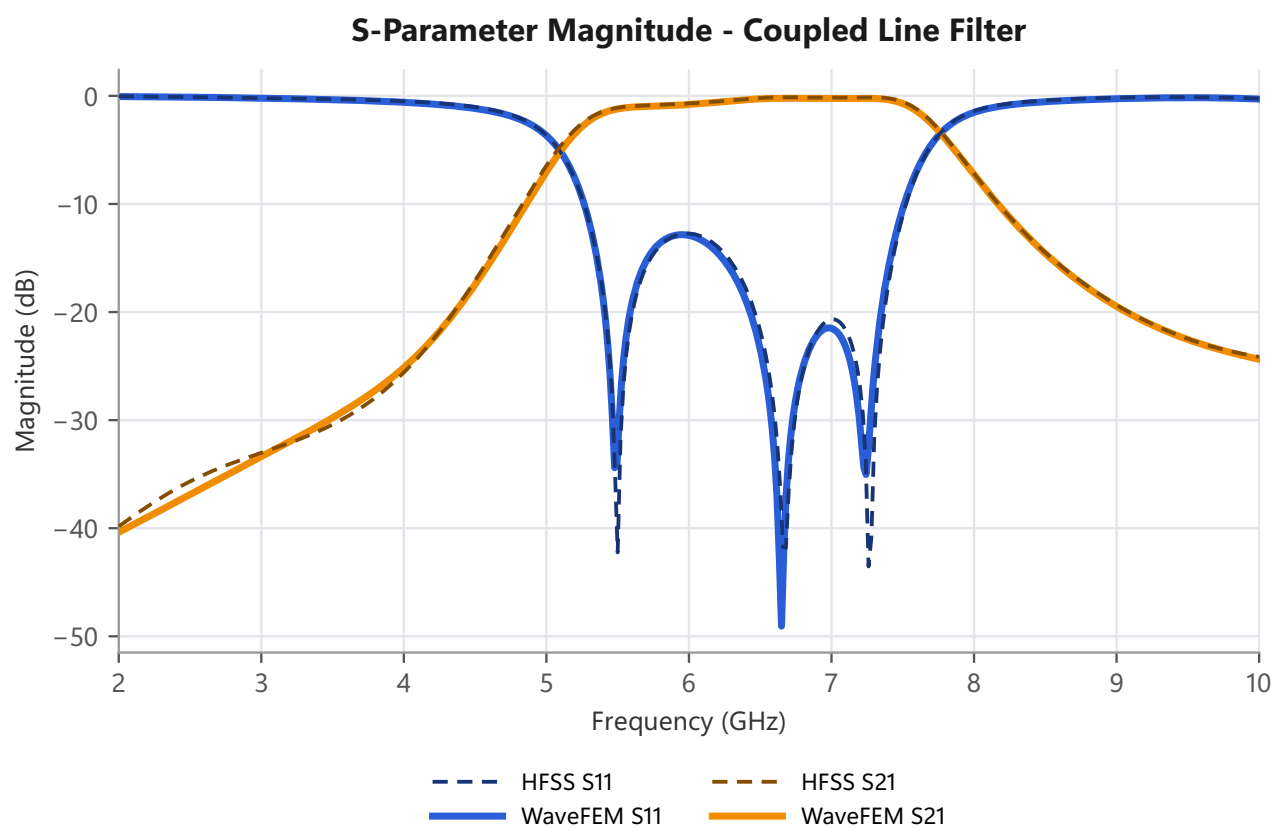


Figure 2 — S-parameter magnitude.

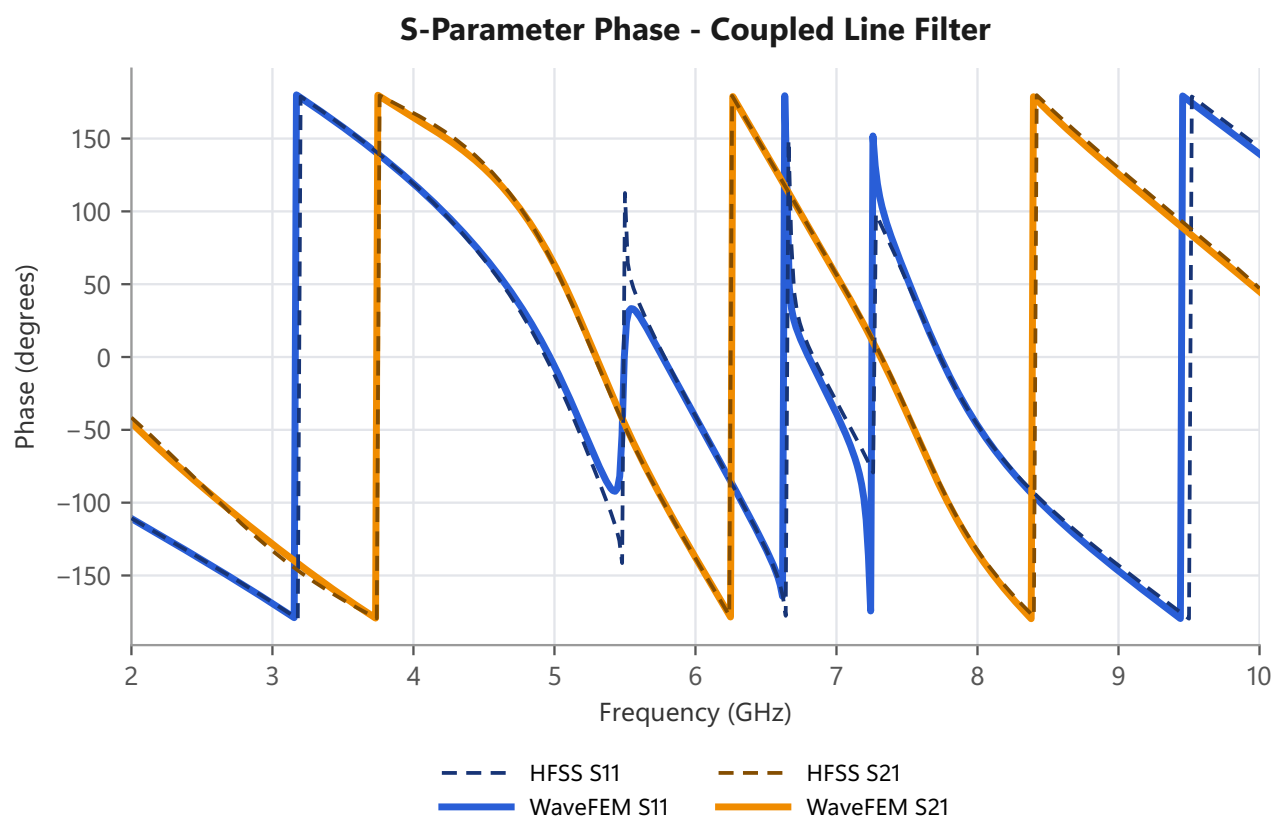


Figure 3 — S-parameter phase.

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FILTER

Hairpin Filter

A 2-4 GHz bandpass hairpin filter. Using a 1.55mm substrate with $\epsilon_r=4.4$ & $\tan\delta=0.01$

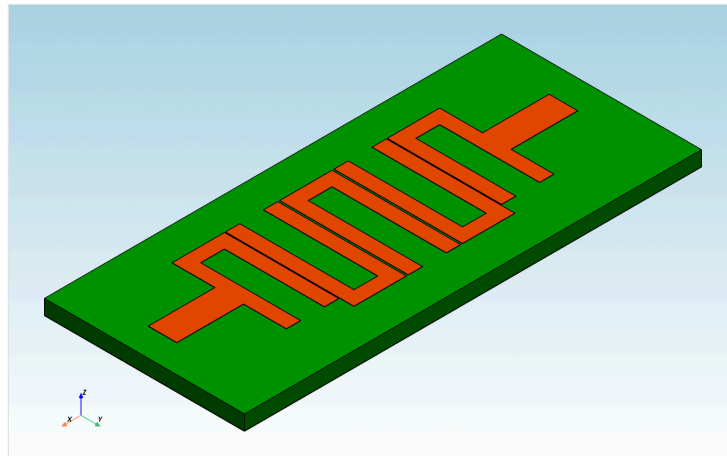
Simulation Setup

Refinement frequency	3.5 GHz
Delta S	0.02
Frequency range	1 - 5 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:21	00:01:03
Adaptive meshing	00:00:08	00:00:28
Frequency sweep	00:00:10	00:00:32
Adaptive passes	7	10
Final elements	10,729	4,559
Matrix size	59,356	26,618

Geometry



Convergence

Convergence - Hairpin Filter

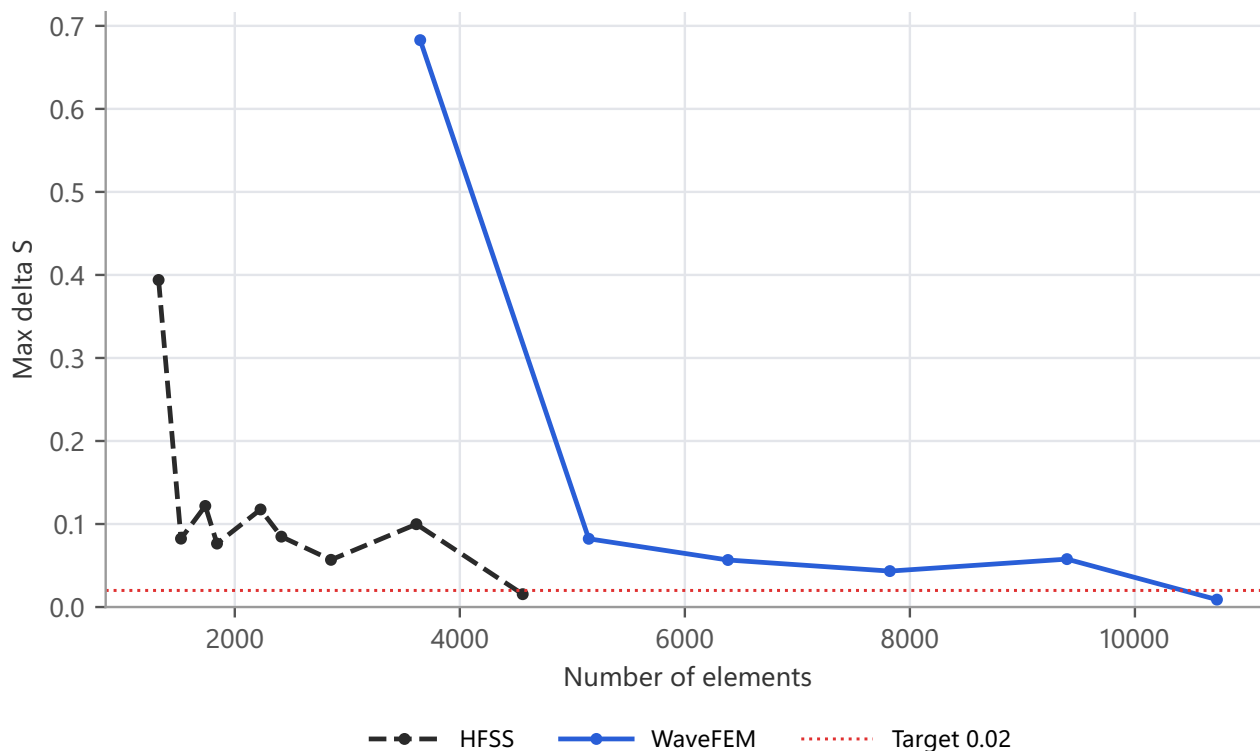


Figure 4 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

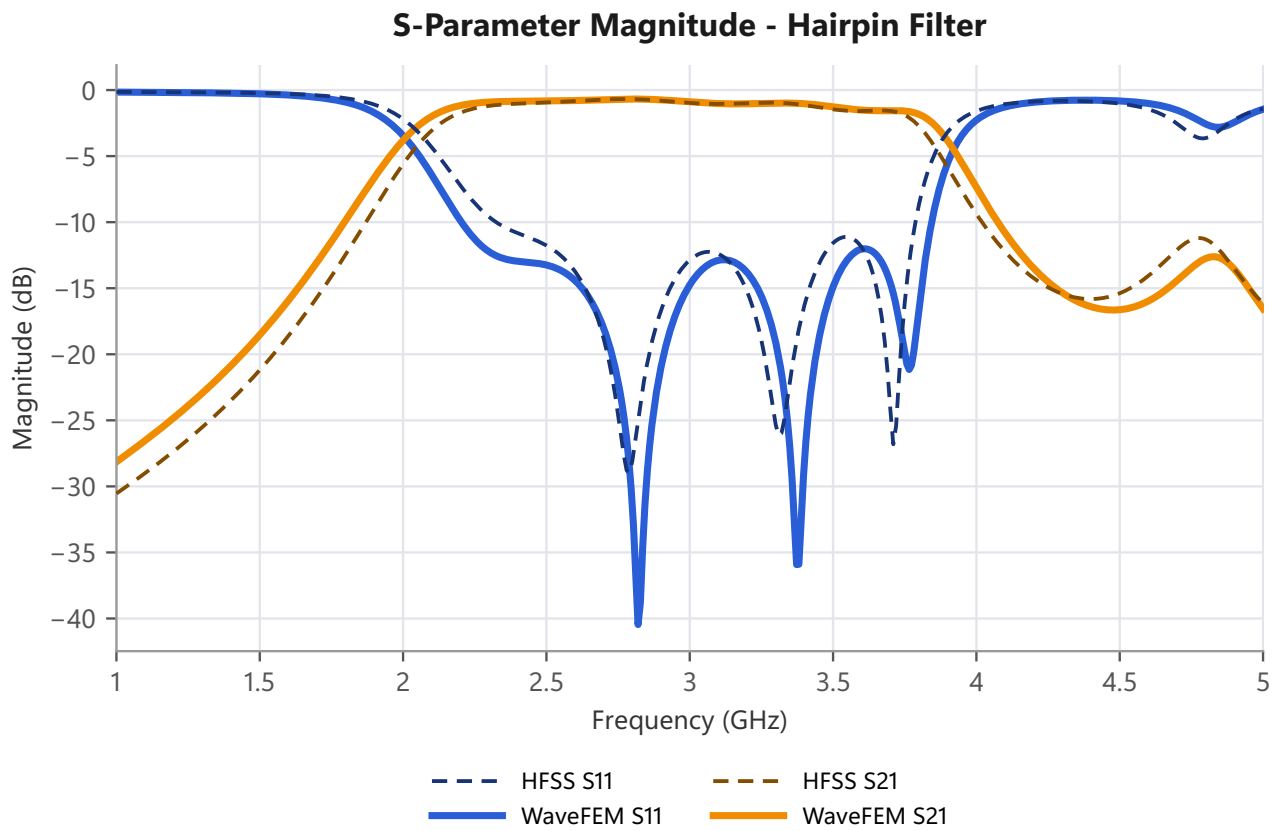


Figure 5 — S-parameter magnitude.

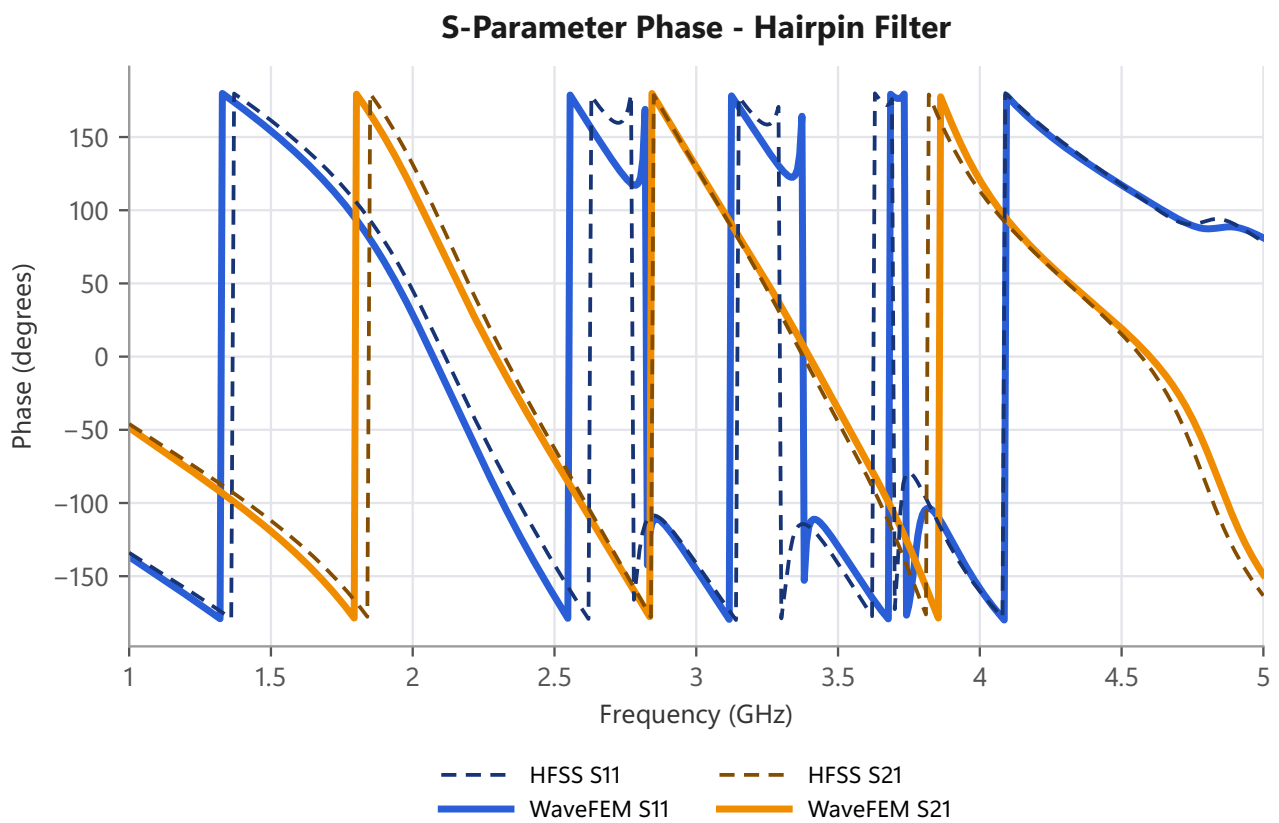


Figure 6 — S-parameter phase.

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FILTER

Interdigital Bandpass Filter

A 7-9 GHz bandpass filter. Using a 0.8mm substrate with $\epsilon_r=3.55$ $\tan\delta=0.0027$

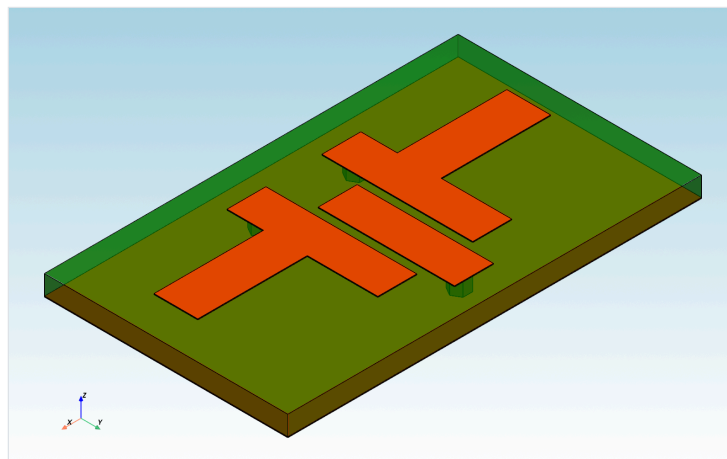
Simulation Setup

Refinement frequency	8 GHz
Delta S	0.02
Frequency range	4 - 12 GHz

Statistics

	WaveFEM	HFSS
Total time	00:01:05	00:01:23
Adaptive meshing	00:00:24	00:00:38
Frequency sweep	00:00:35	00:00:41
Adaptive passes	10	11
Final elements	30,581	17,344
Matrix size	175,800	106,044

Geometry



Convergence

Convergence - Interdigital Bandpass Filter

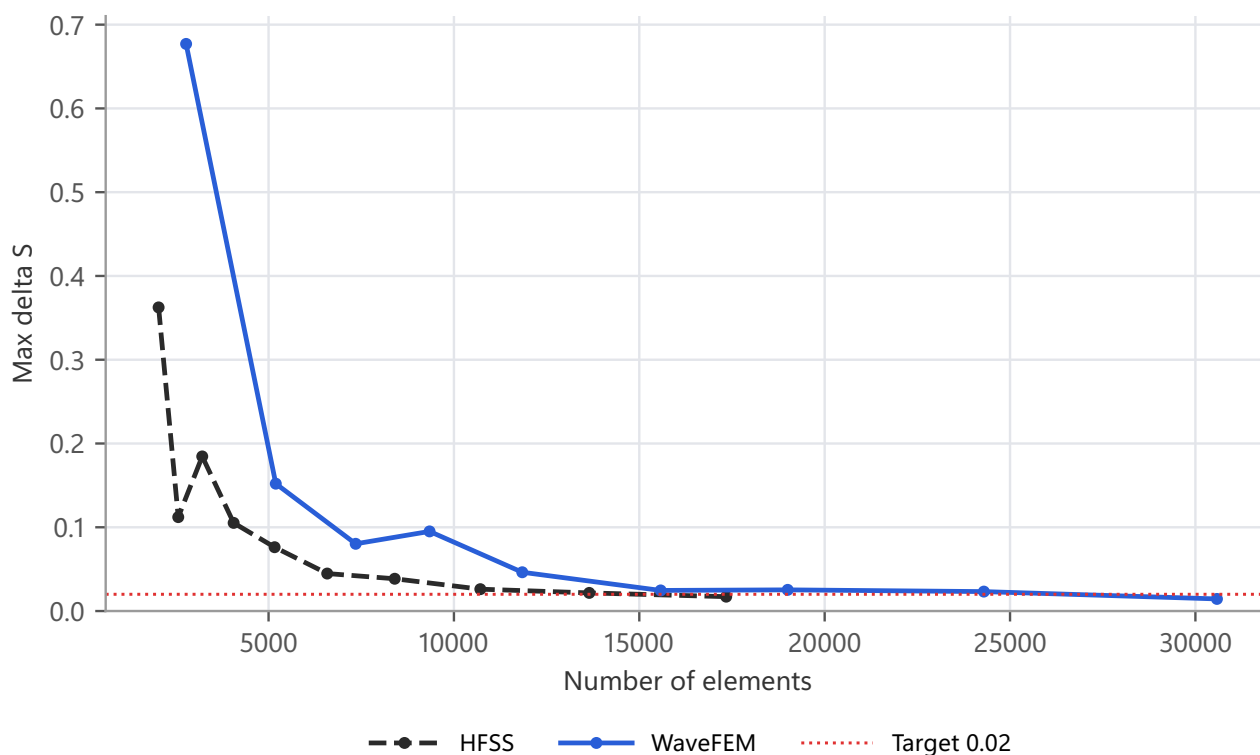


Figure 7 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

S-Parameter Magnitude - Interdigital Bandpass Filter

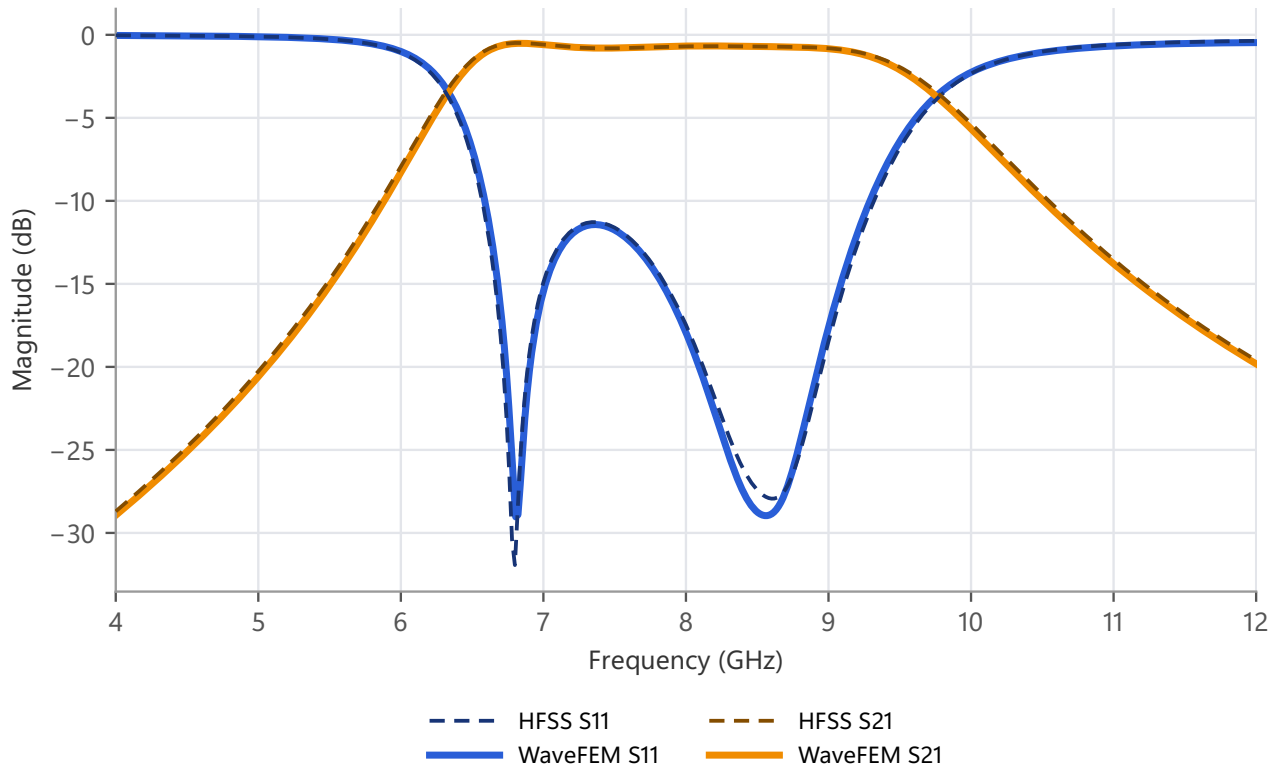


Figure 8 — S-parameter magnitude.

S-Parameter Phase - Interdigital Bandpass Filter

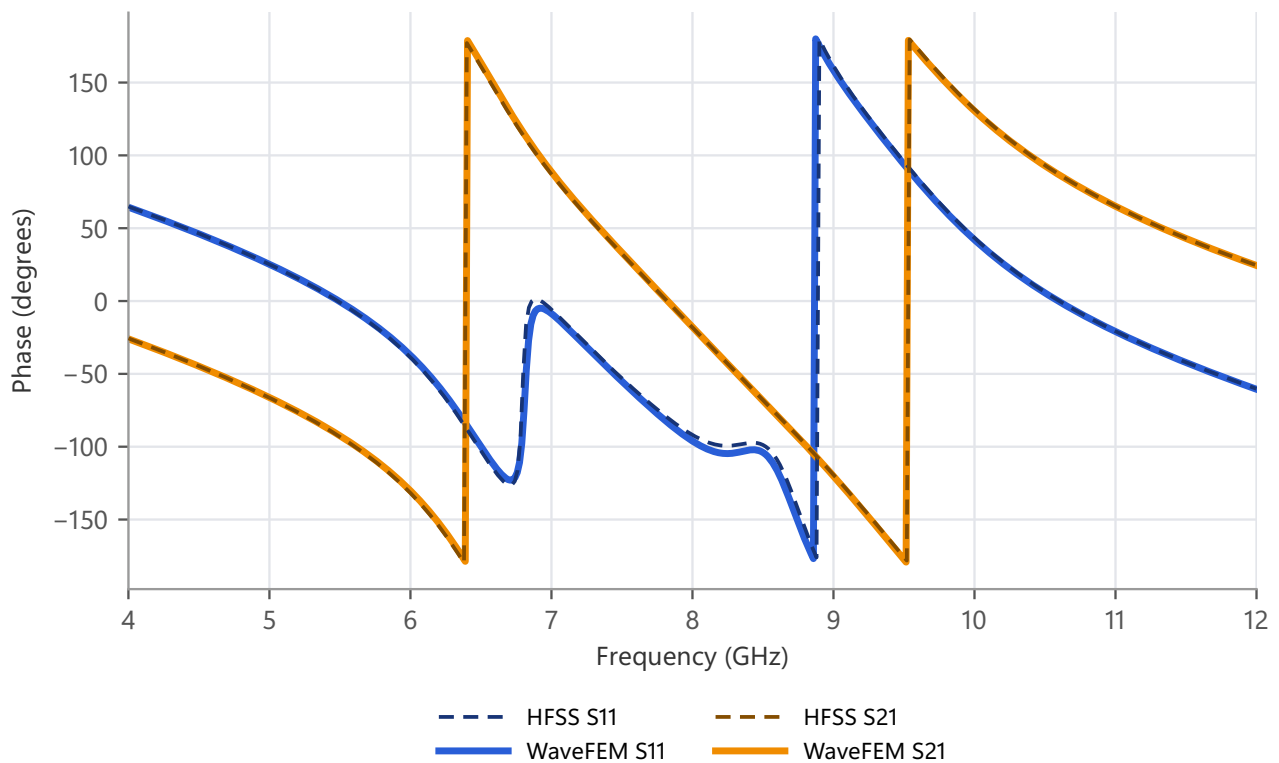


Figure 9 — S-parameter phase.

FILTER

L Resonator Notch Filter

A 3.2 GHz notch filter. Using a 1.27mm substrate with $\epsilon_r=10.8$

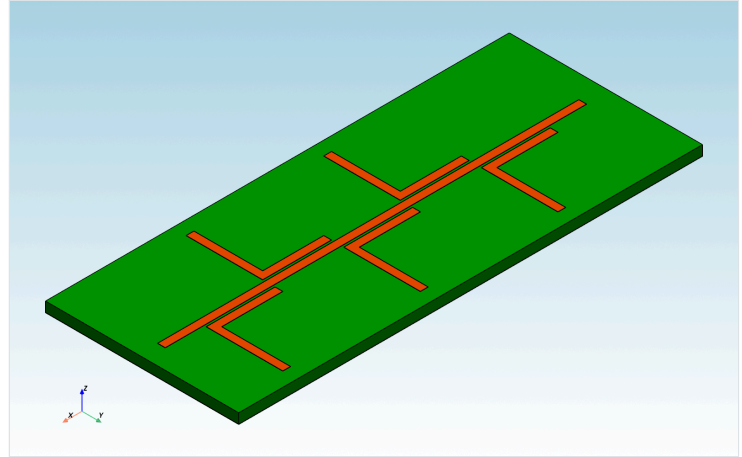
Simulation Setup

Refinement frequency	3.4 GHz
Delta S	0.02
Frequency range	2 - 4 GHz

Statistics

	WaveFEM	HFSS
Total time	00:01:17	00:02:32
Adaptive meshing	00:00:28	00:01:05
Frequency sweep	00:00:42	00:01:25
Adaptive passes	11	15
Final elements	38,532	39,070
Matrix size	218,190	239,094

Geometry



Convergence

Convergence - L Resonator Notch Filter

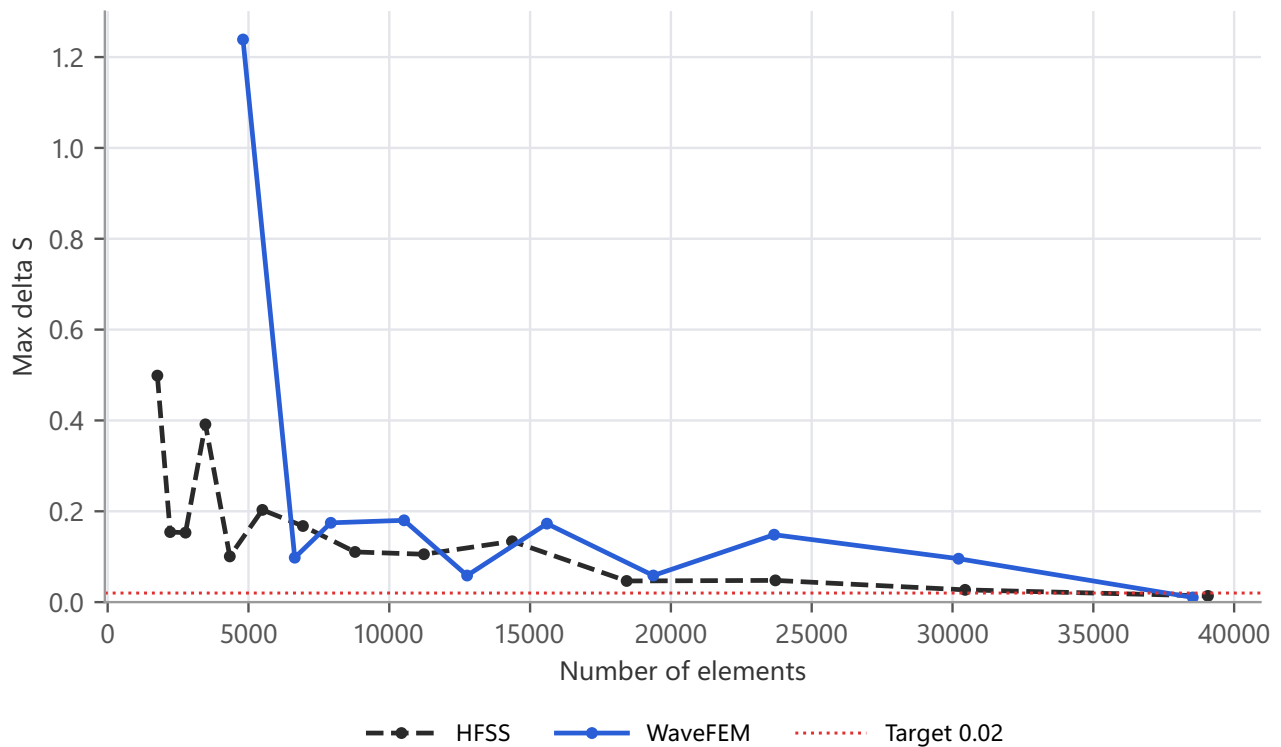


Figure 10 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

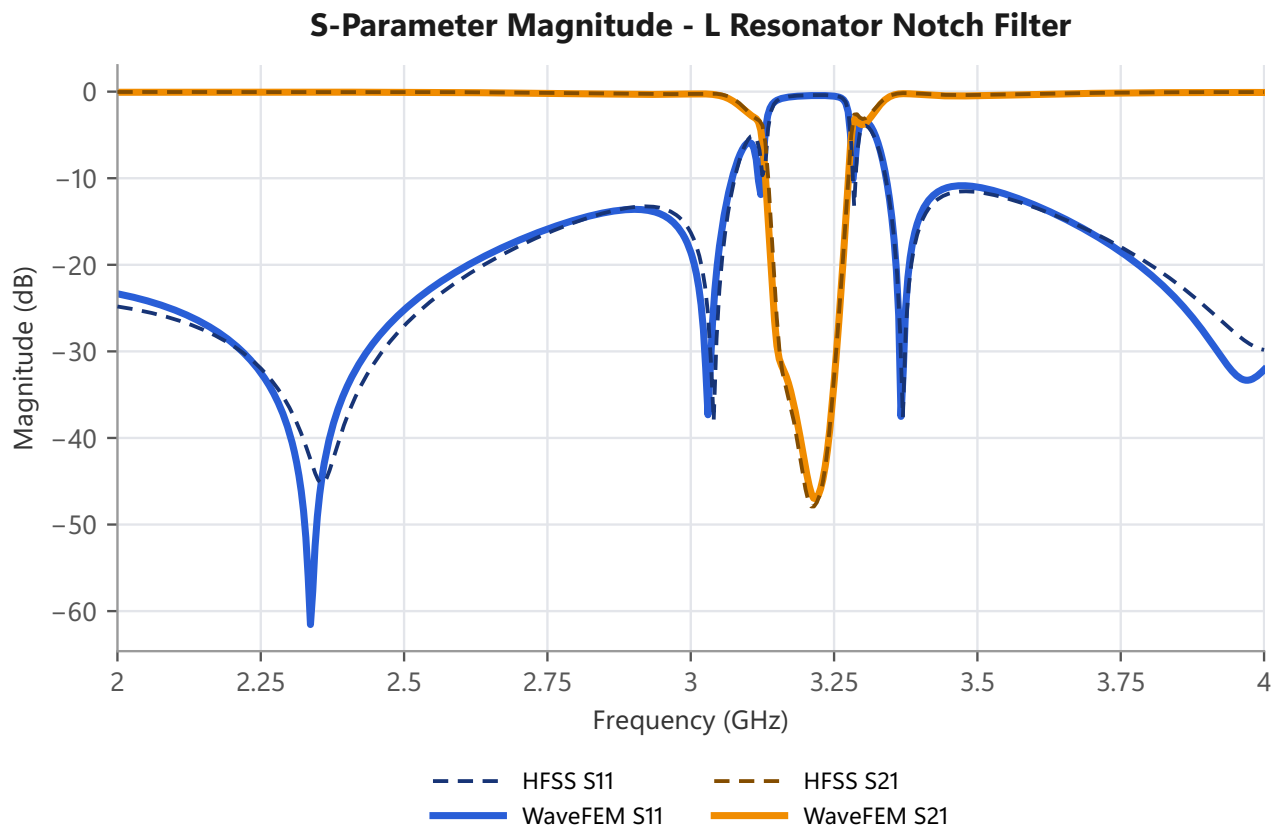


Figure 11 — S-parameter magnitude.

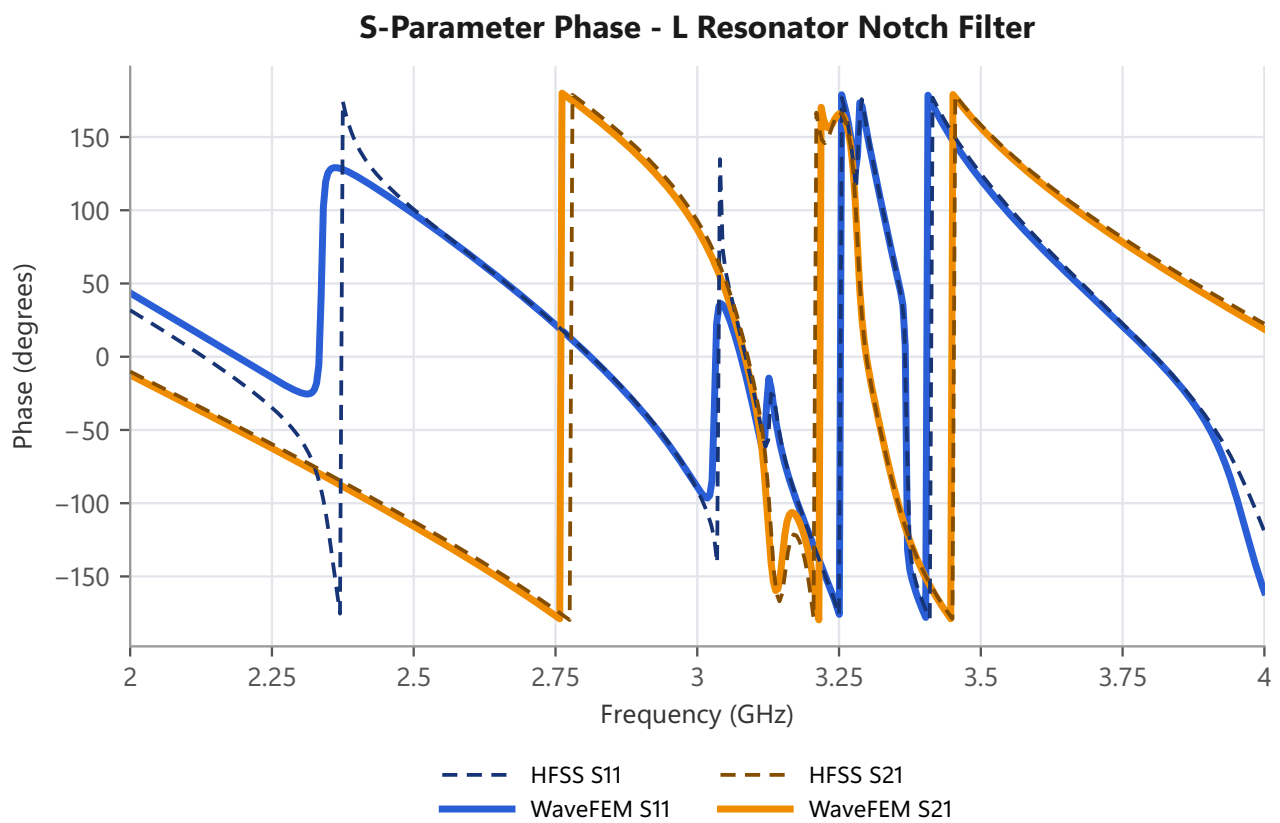


Figure 12 — S-parameter phase.

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FILTER

Stepped Impedance Filter

A 9 GHz lowpass filter. Using a 0.5mm substrate with $\epsilon_r=3.55$ $\tan\delta=0.0027$

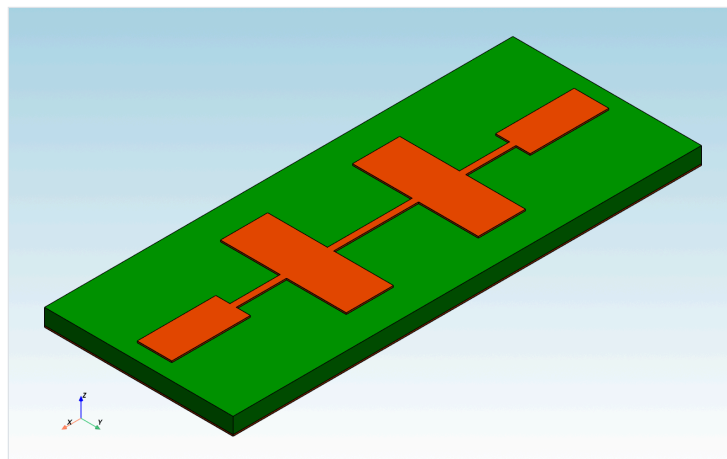
Simulation Setup

Refinement frequency	7 GHz
Delta S	0.02
Frequency range	1e-09 - 20 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:07	00:00:52
Adaptive meshing	00:00:03	00:00:18
Frequency sweep	00:00:04	00:00:32
Adaptive passes	4	7
Final elements	5,521	2,975
Matrix size	31,606	17,656

Geometry



Convergence

Convergence - Stepped Impedance Filter

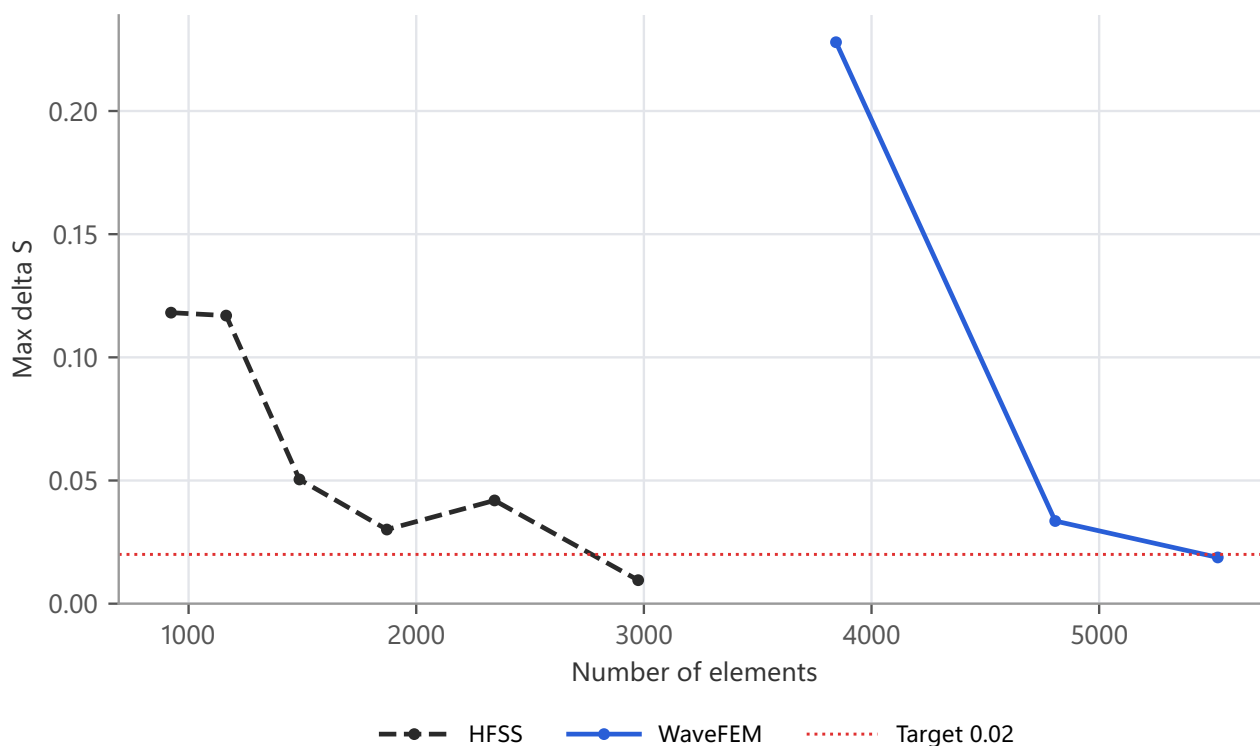


Figure 13 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

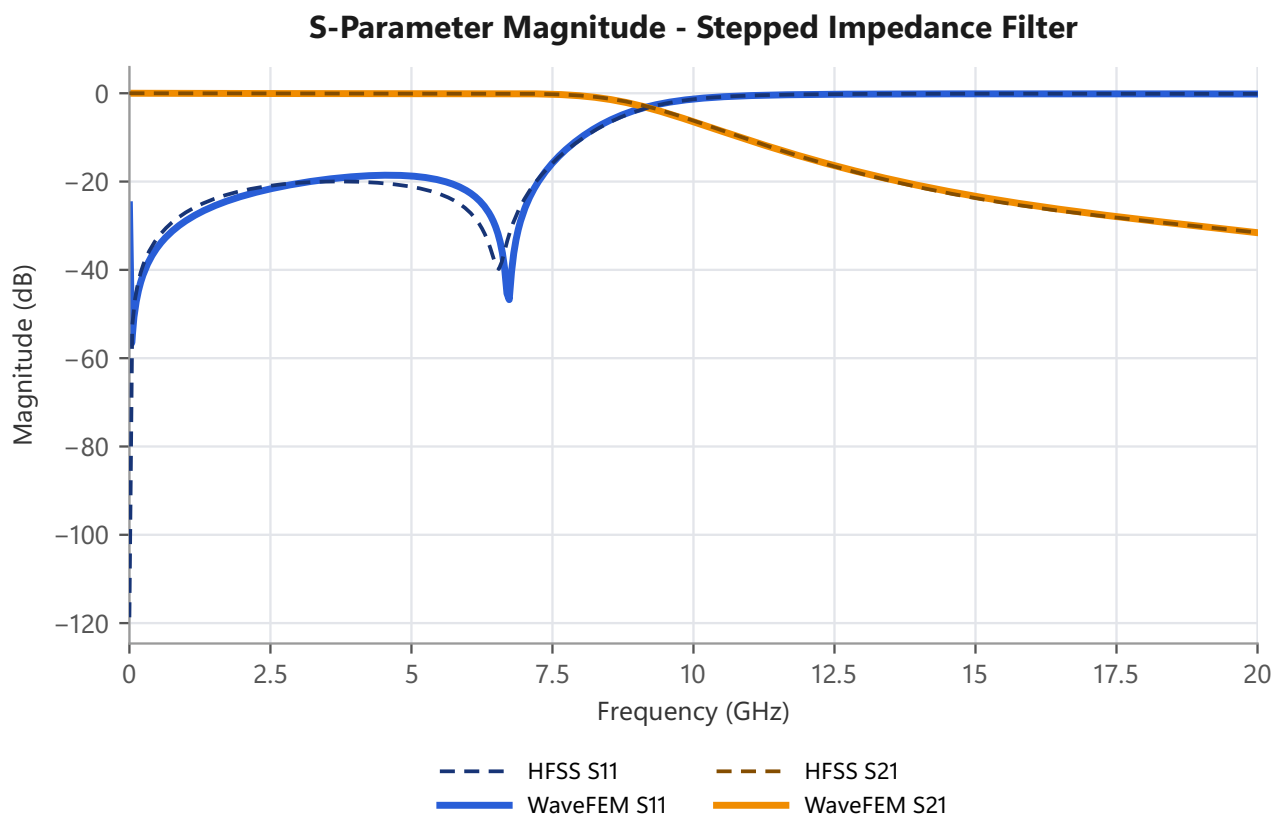


Figure 14 — S-parameter magnitude.

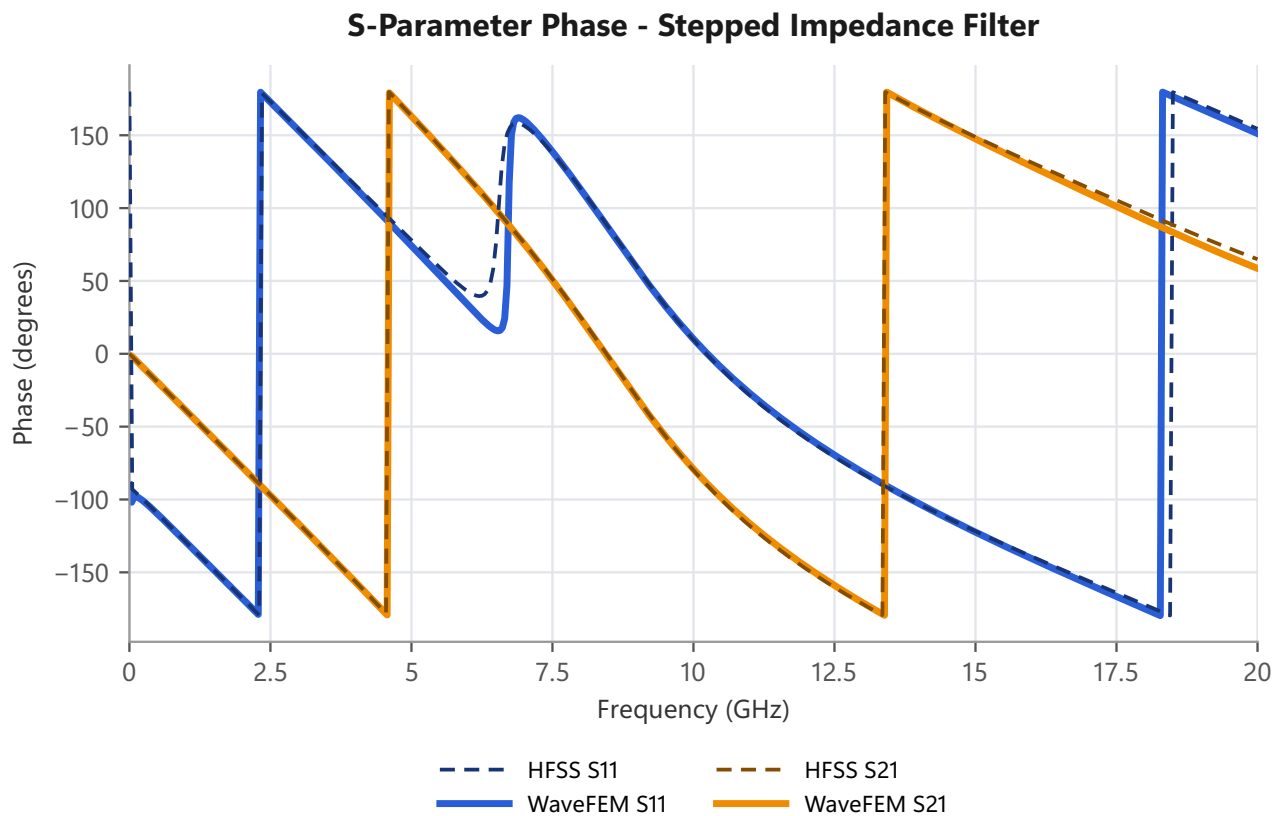


Figure 15 — S-parameter phase.

ANTENNA

Dielectric Resonator Antenna

A 5.6 GHz probe fed dielectric resonator antenna, using ceramic with $\epsilon_r=10$ & $\tan\delta=0.002$

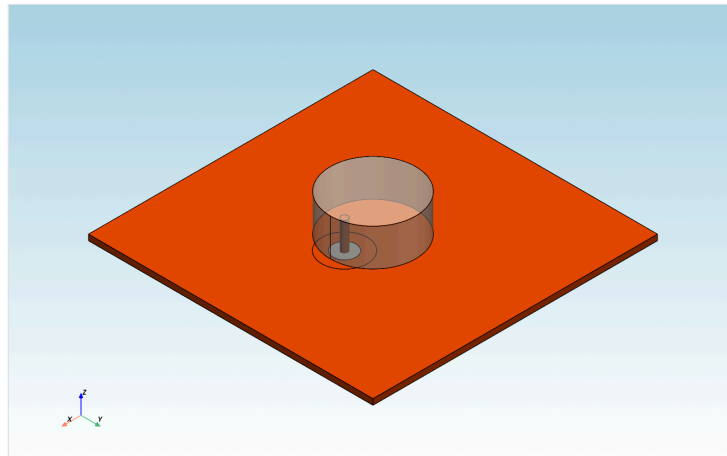
Simulation Setup

Refinement frequency	5.6 GHz
Delta S	0.02
Frequency range	4 - 7 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:05	00:00:31
Adaptive meshing	00:00:03	00:00:07
Frequency sweep	00:00:02	00:00:19
Adaptive passes	4	3
Final elements	5,522	3,191
Matrix size	33,600	18,923

Geometry



Convergence

Convergence - Dielectric Resonator Antenna

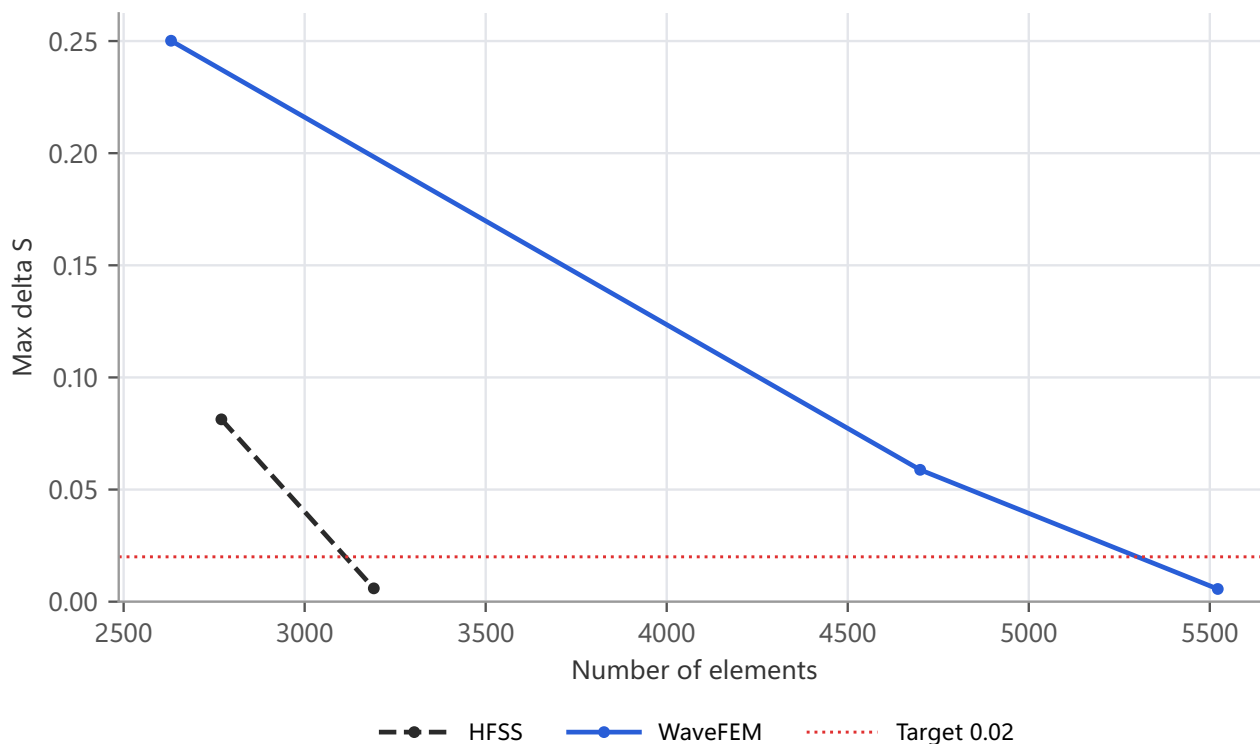


Figure 16 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

S-Parameter Magnitude - Dielectric Resonator Antenna

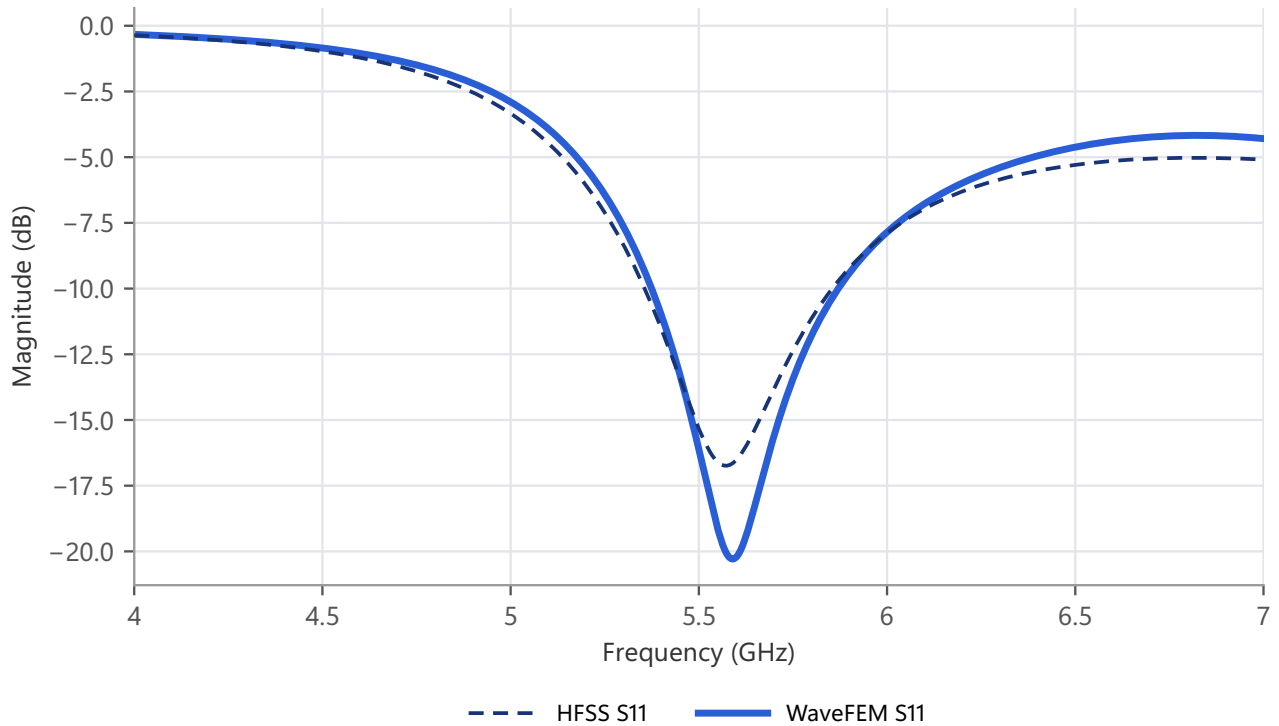


Figure 17 — S-parameter magnitude.

S-Parameter Phase - Dielectric Resonator Antenna

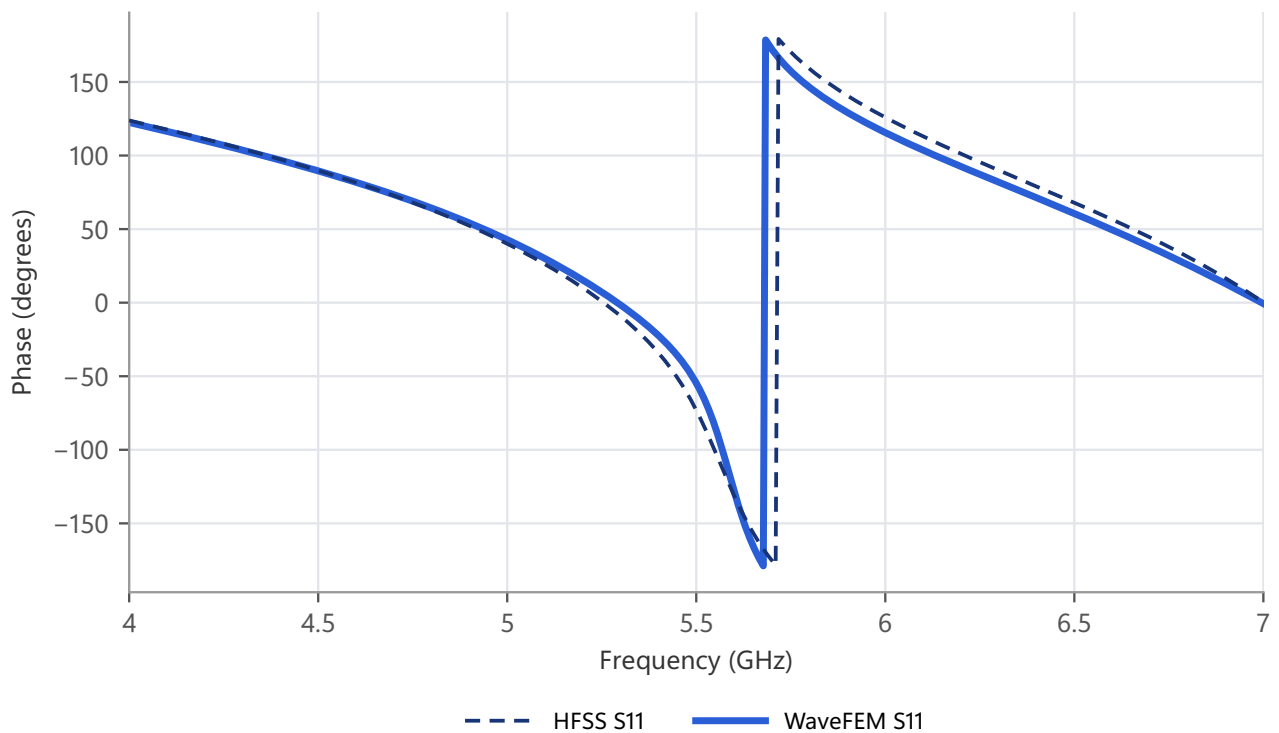


Figure 18 — S-parameter phase.

Far Field

Realized Gain at 5.6 GHz - Dielectric Resonator Antenna

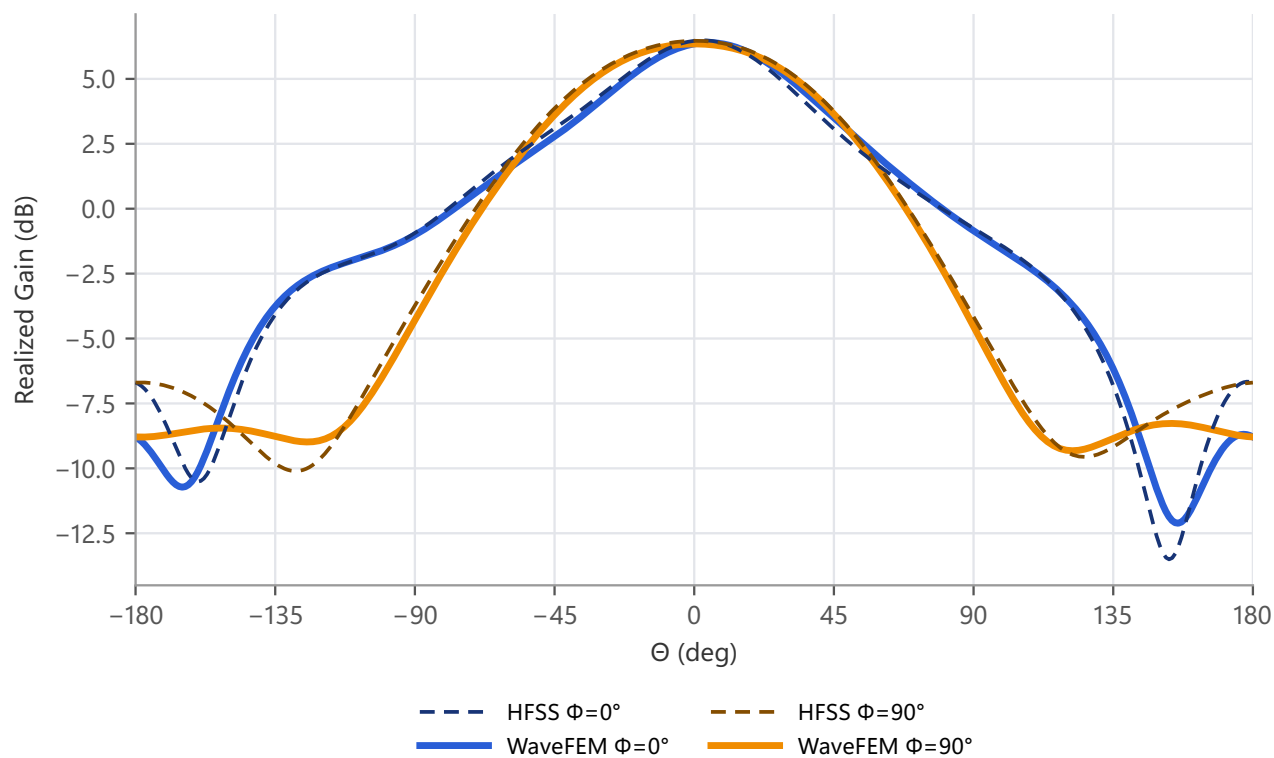


Figure 19 — Total realized gain cuts at 5.6 GHz.

ANTENNA

Planar Vivaldi

A wideband planar Vivaldi antenna, using radiation boundaries to terminate into free space.

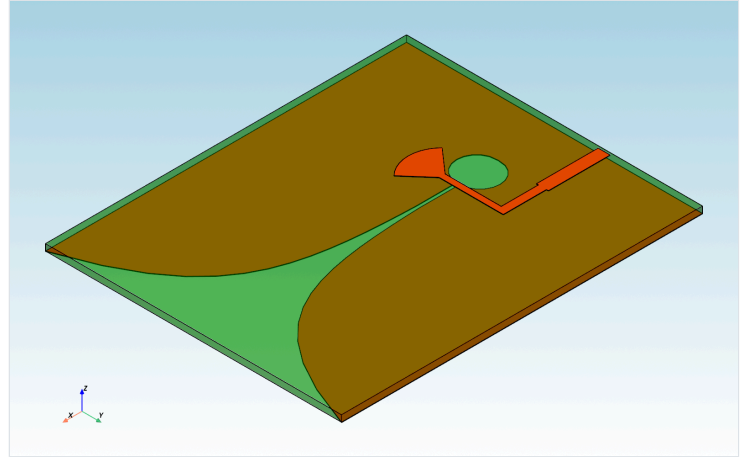
Simulation Setup

Refinement frequency	11 GHz
Delta S	0.02
Frequency range	2 - 11 GHz

Statistics

	WaveFEM	HFSS
Total time	00:01:12	00:01:30
Adaptive meshing	00:00:25	00:00:35
Frequency sweep	00:00:43	00:00:53
Adaptive passes	8	9
Final elements	37,095	23,220
Matrix size	215,510	142,967

Geometry



Convergence

Convergence - Planar Vivaldi

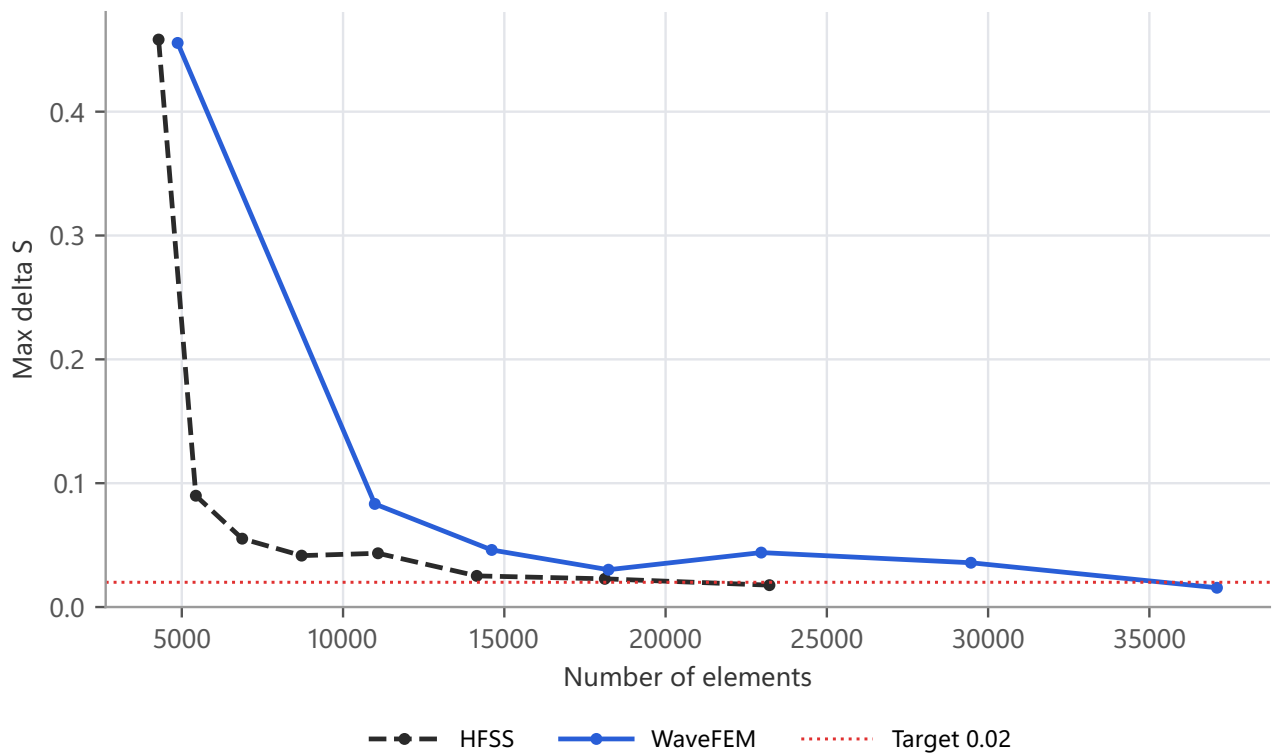


Figure 20 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

S-Parameter Magnitude - Planar Vivaldi

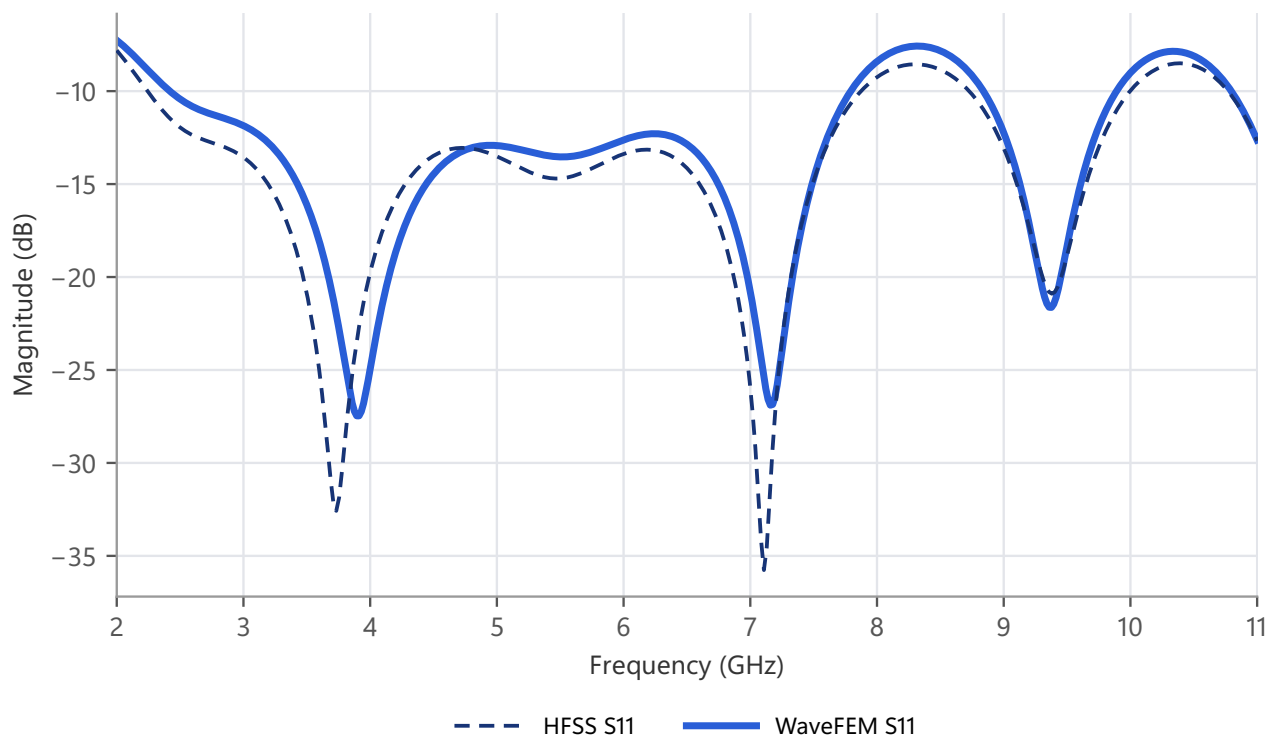


Figure 21 — S-parameter magnitude.

S-Parameter Phase - Planar Vivaldi

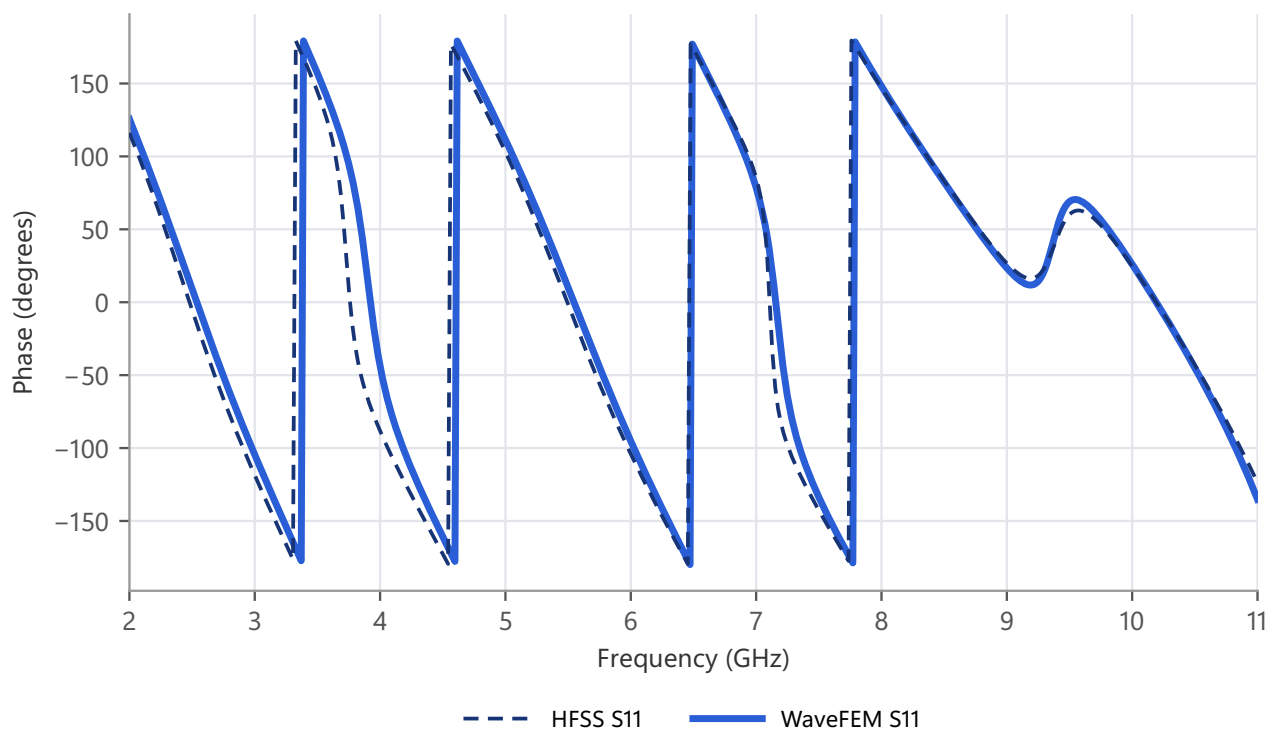
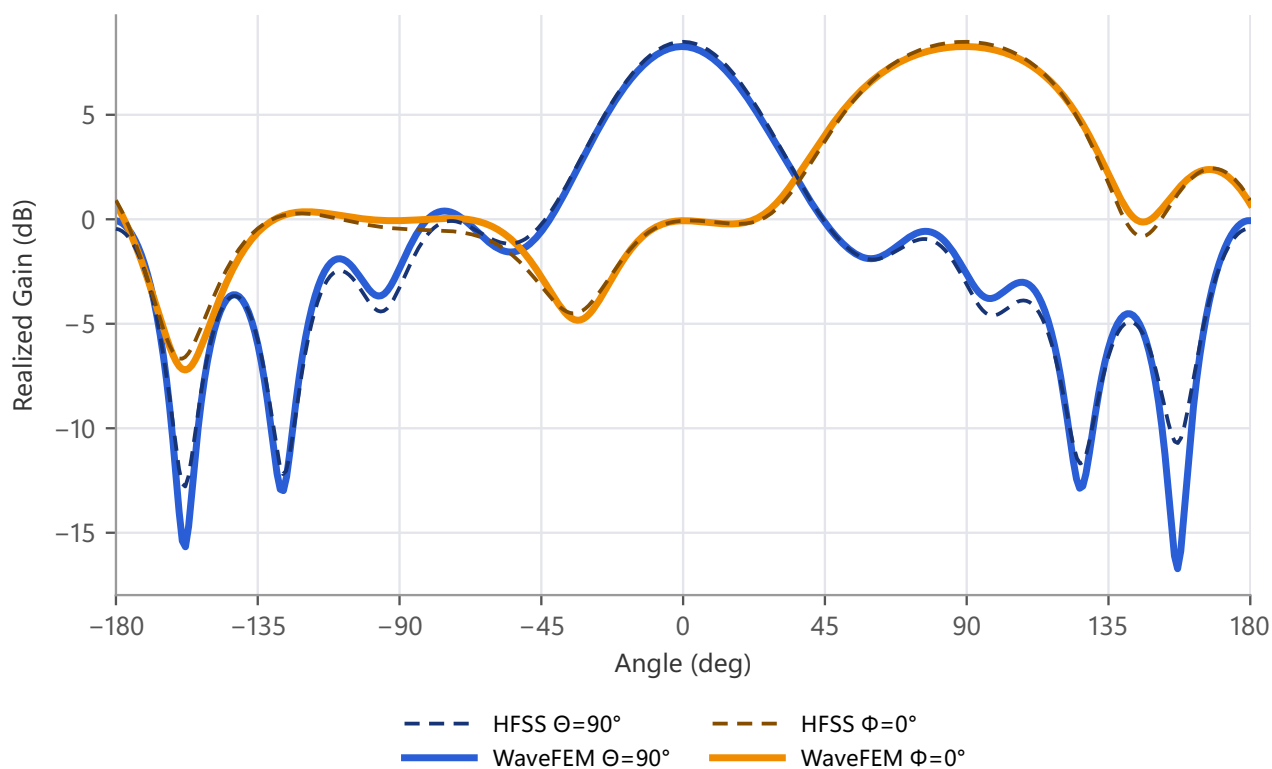
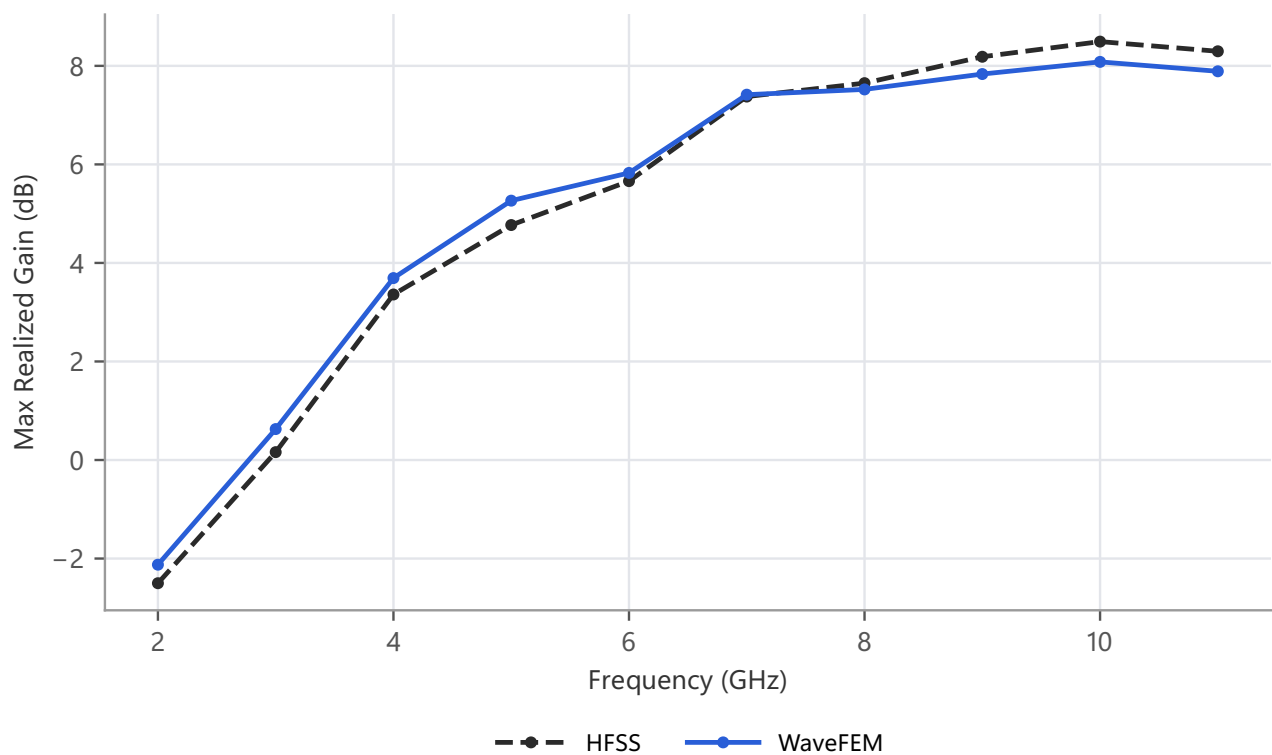


Figure 22 — S-parameter phase.

Far Field**Realized Gain at 10 GHz - Planar Vivaldi****Figure 23** — Total realized gain cuts at 10 GHz.**Max Realized Gain vs Frequency - Planar Vivaldi****Figure 24** — Maximum realized gain against frequency.

ANTENNA

Probe Fed Patch

A coaxial probe fed rectangular patch antenna resonant at 2.4 GHz.

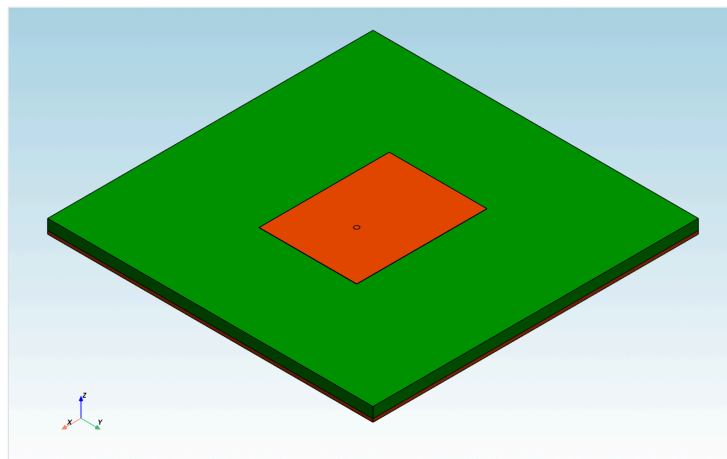
Simulation Setup

Refinement frequency	2.4 GHz
Delta S	0.02
Frequency range	2 - 3 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:40	00:01:16
Adaptive meshing	00:00:23	00:00:46
Frequency sweep	00:00:13	00:00:23
Adaptive passes	11	13
Final elements	36,088	19,159
Matrix size	209,734	115,581

Geometry



Convergence

Convergence - Probe Fed Patch

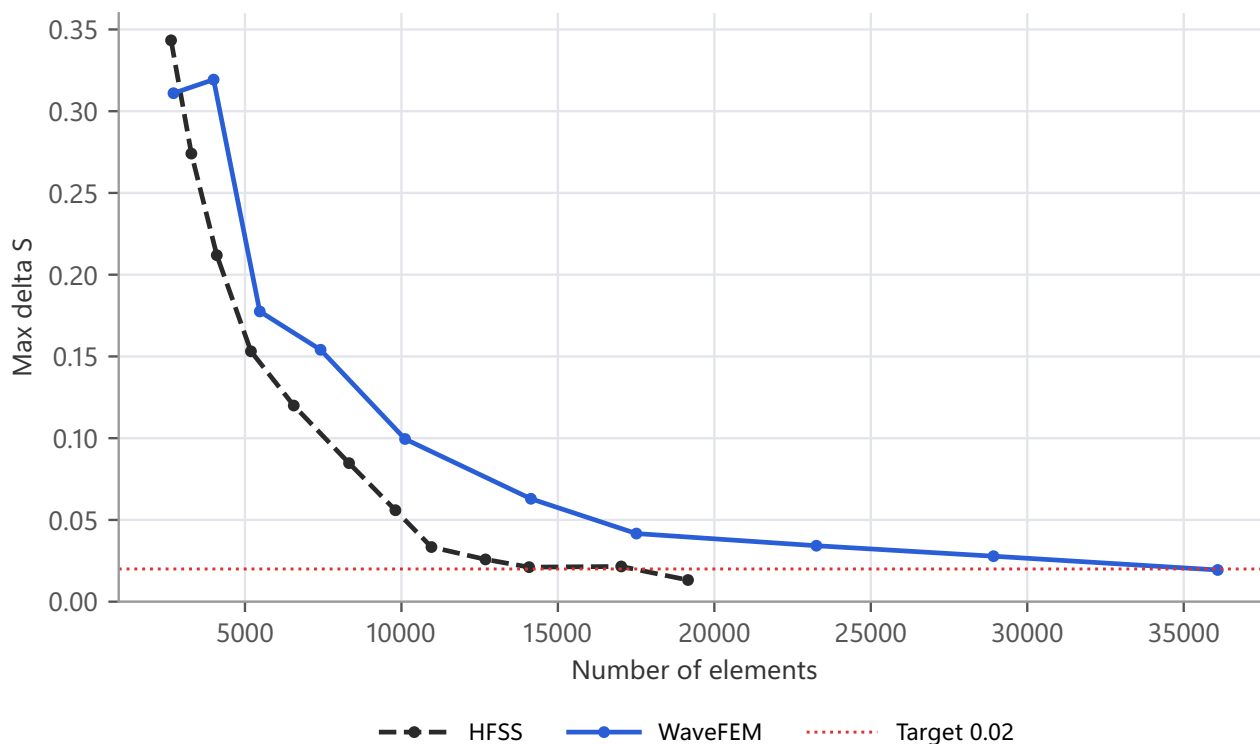


Figure 25 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

S-Parameter Magnitude - Probe Fed Patch

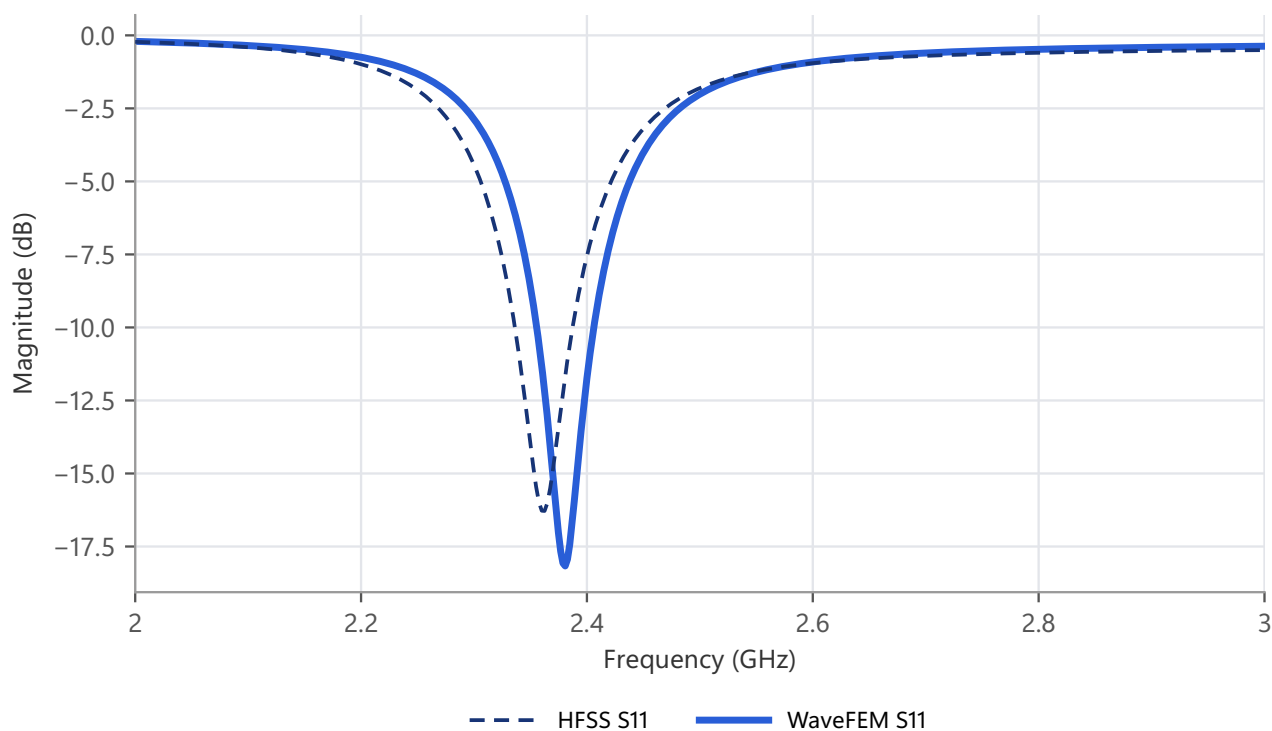


Figure 26 — S-parameter magnitude.

S-Parameter Phase - Probe Fed Patch

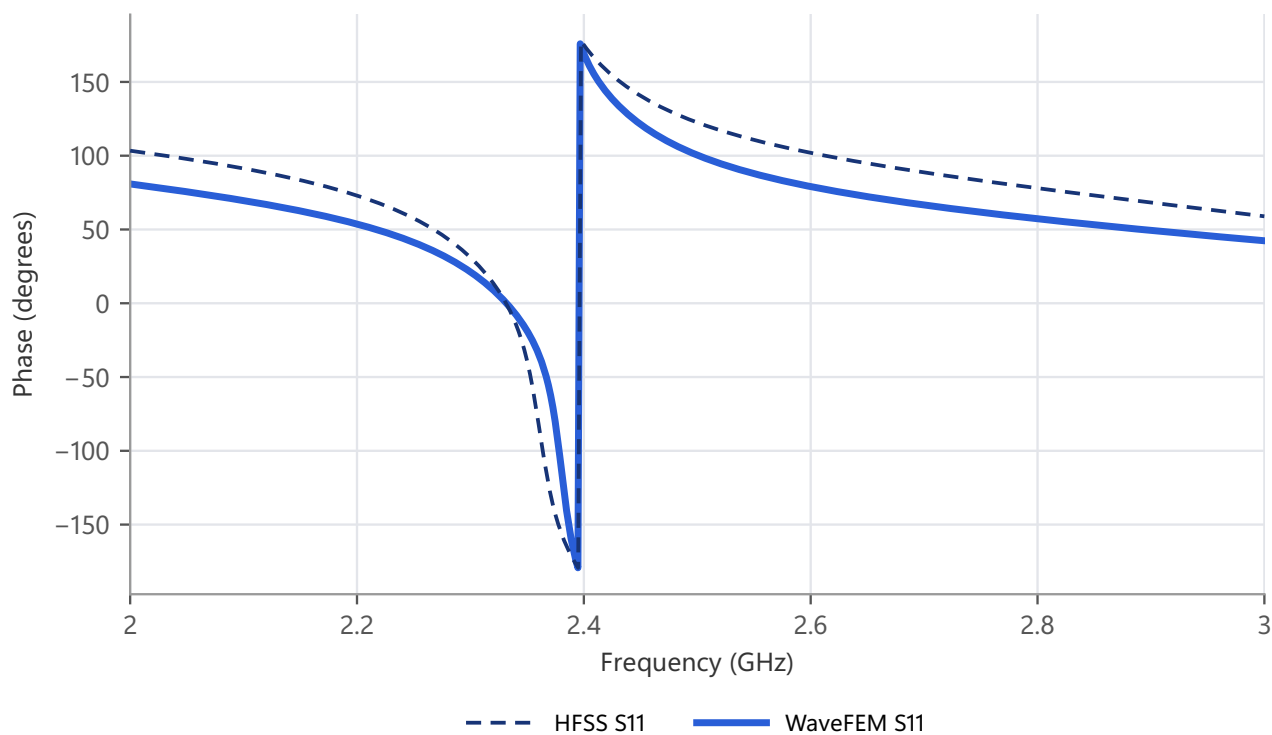


Figure 27 — S-parameter phase.

Far Field

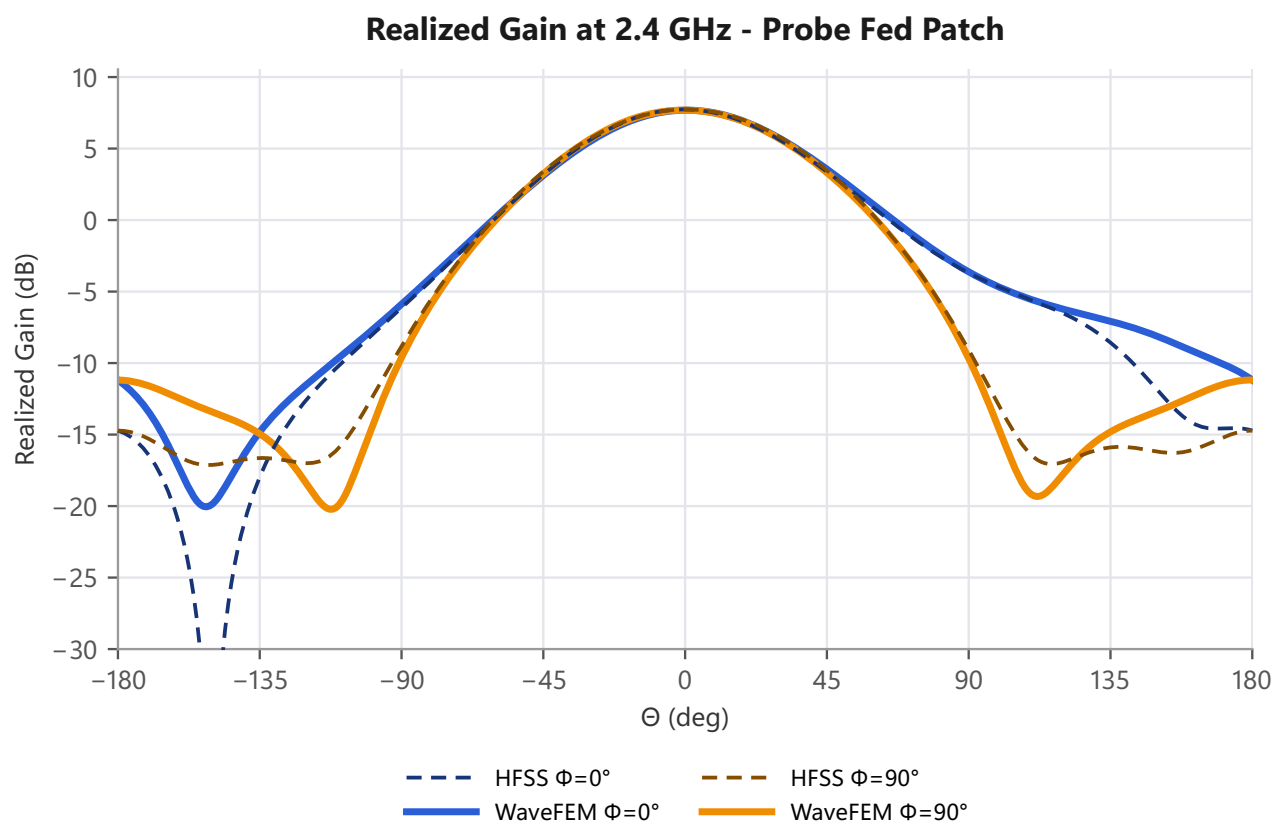


Figure 28 — Total realized gain cuts at 2.4 GHz.

TRANSMISSION LINE

Coax to Waveguide Adapter

A transition between a coaxial cable and a rectangular waveguide, optimised for 9-10 GHz

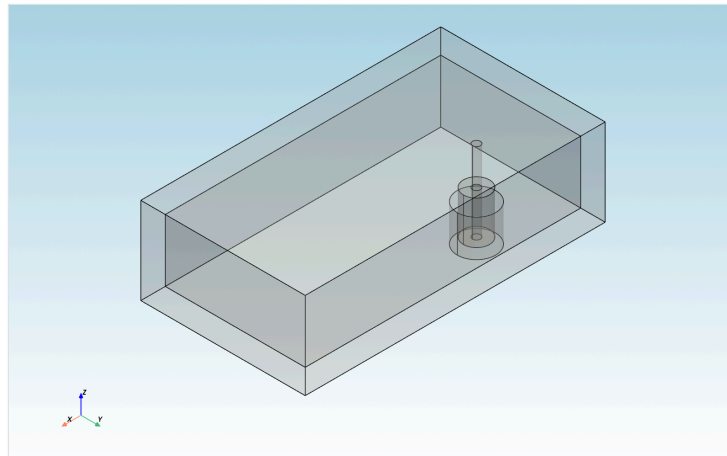
Simulation Setup

Refinement frequency	10 GHz
Delta S	0.02
Frequency range	8 - 13 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:10	00:00:34
Adaptive meshing	00:00:04	00:00:12
Frequency sweep	00:00:06	00:00:19
Adaptive passes	4	5
Final elements	8,340	3,420
Matrix size	47,644	19,512

Geometry



Convergence

Convergence - Coax to Waveguide Adapter

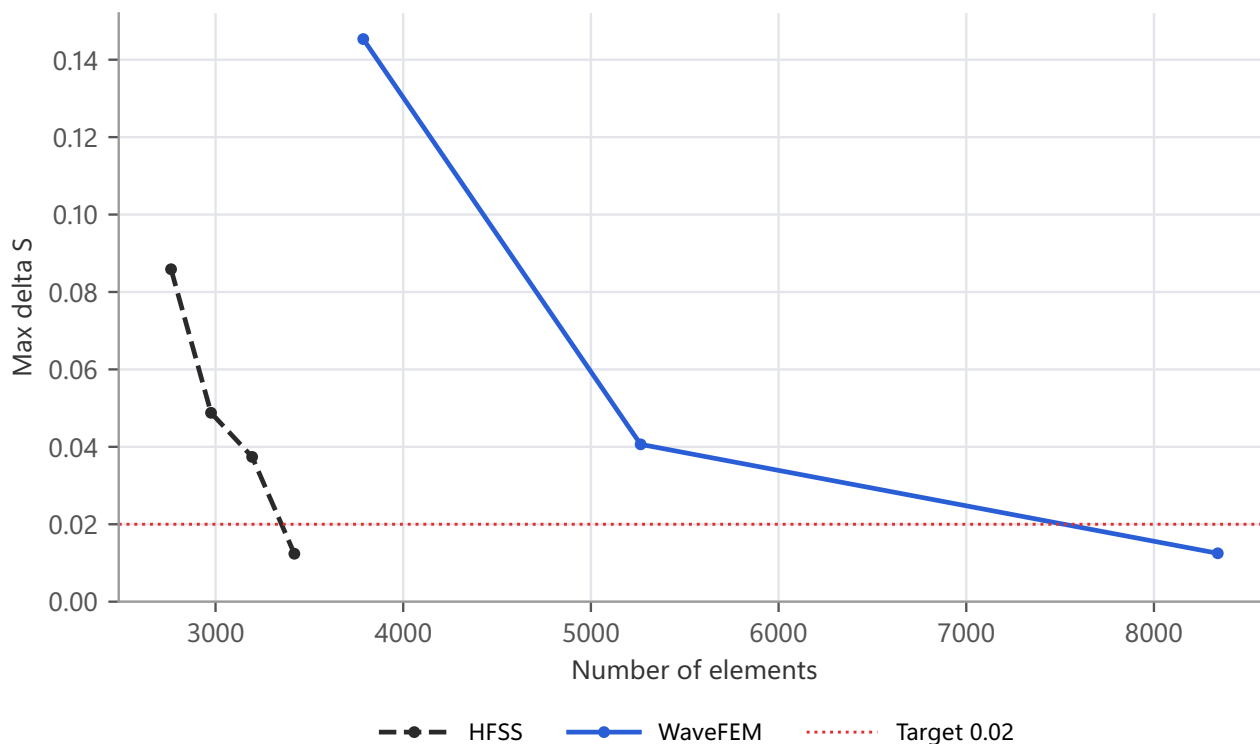


Figure 29 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

S-Parameter Magnitude - Coax to Waveguide Adapter

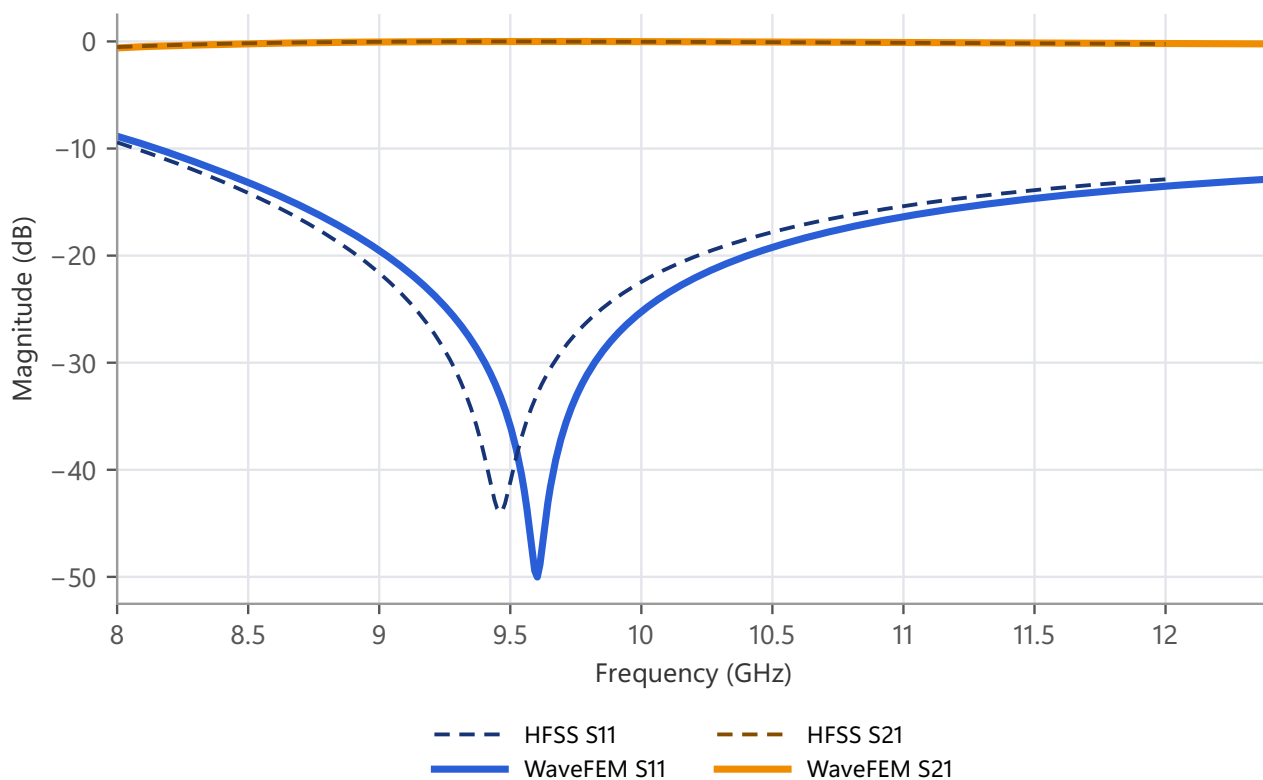


Figure 30 — S-parameter magnitude.

S-Parameter Phase - Coax to Waveguide Adapter

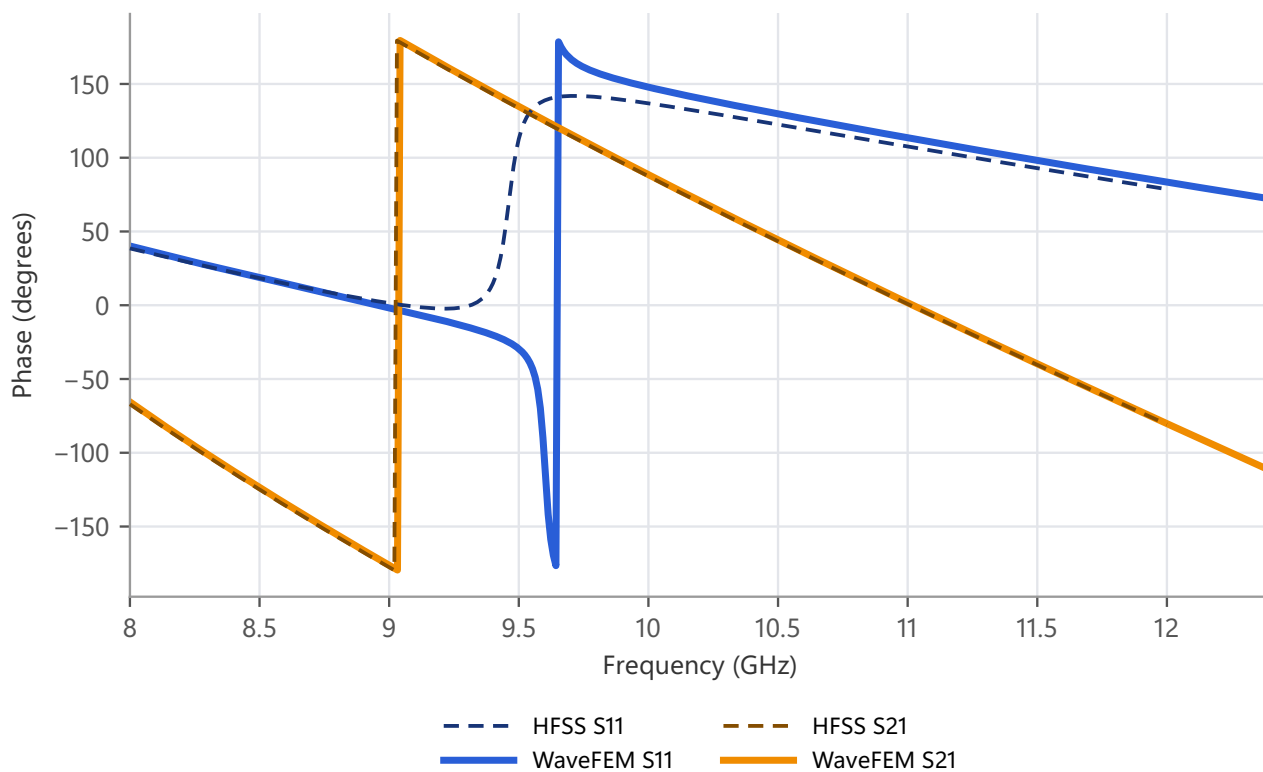


Figure 31 — S-parameter phase.

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TRANSMISSION LINE

Waveguide

A straight WR159 waveguide, 150mm long

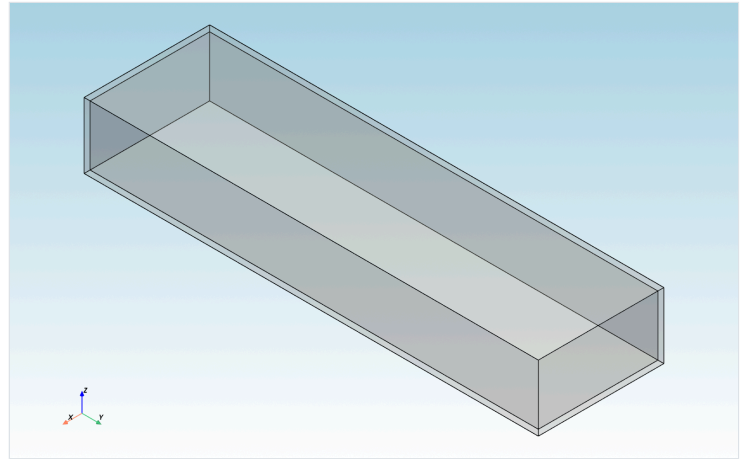
Simulation Setup

Refinement frequency	10 GHz
Delta S	0.02
Frequency range	2 - 10 GHz

Statistics

	WaveFEM	HFSS
Total time	00:00:04	00:00:41
Adaptive meshing	00:00:01	00:00:07
Frequency sweep	00:00:02	00:00:30
Adaptive passes	3	3
Final elements	2,383	5,915
Matrix size	17,794	41,448

Geometry



Convergence

Convergence - Waveguide

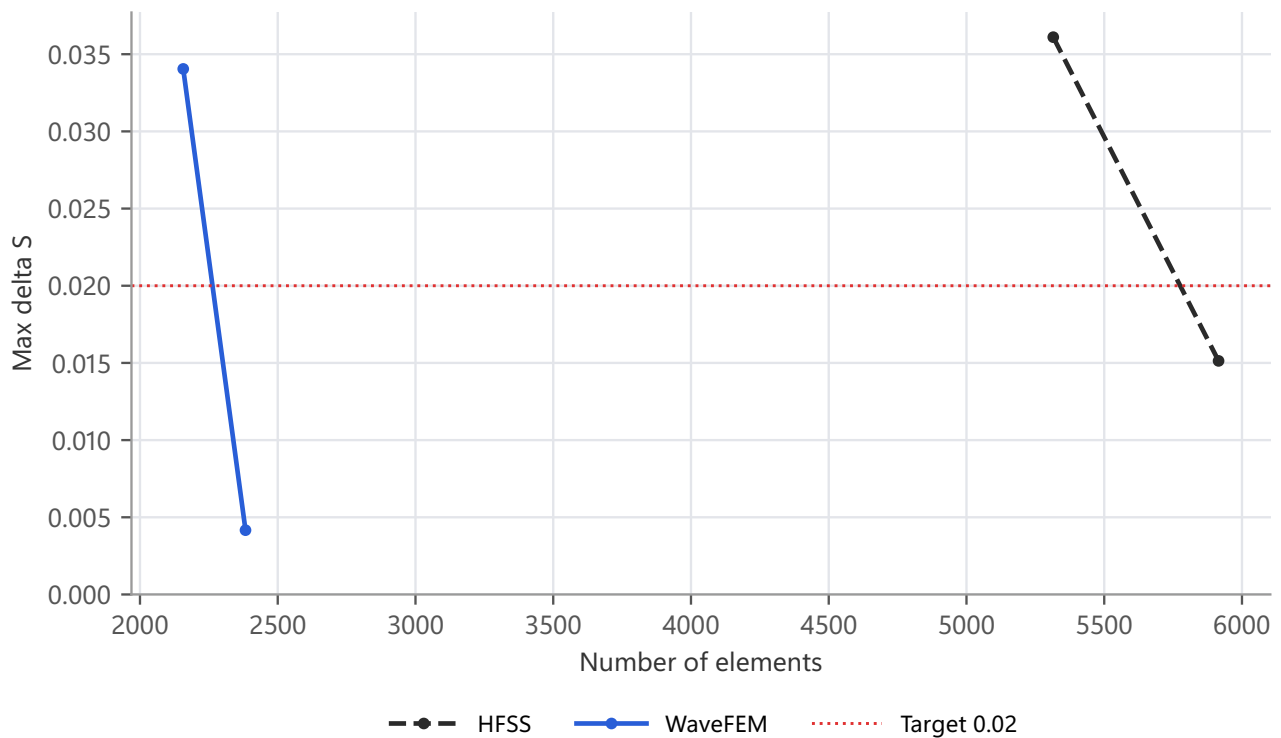


Figure 32 — Adaptive mesh convergence: maximum delta S and solved elements per pass.

S-Parameters

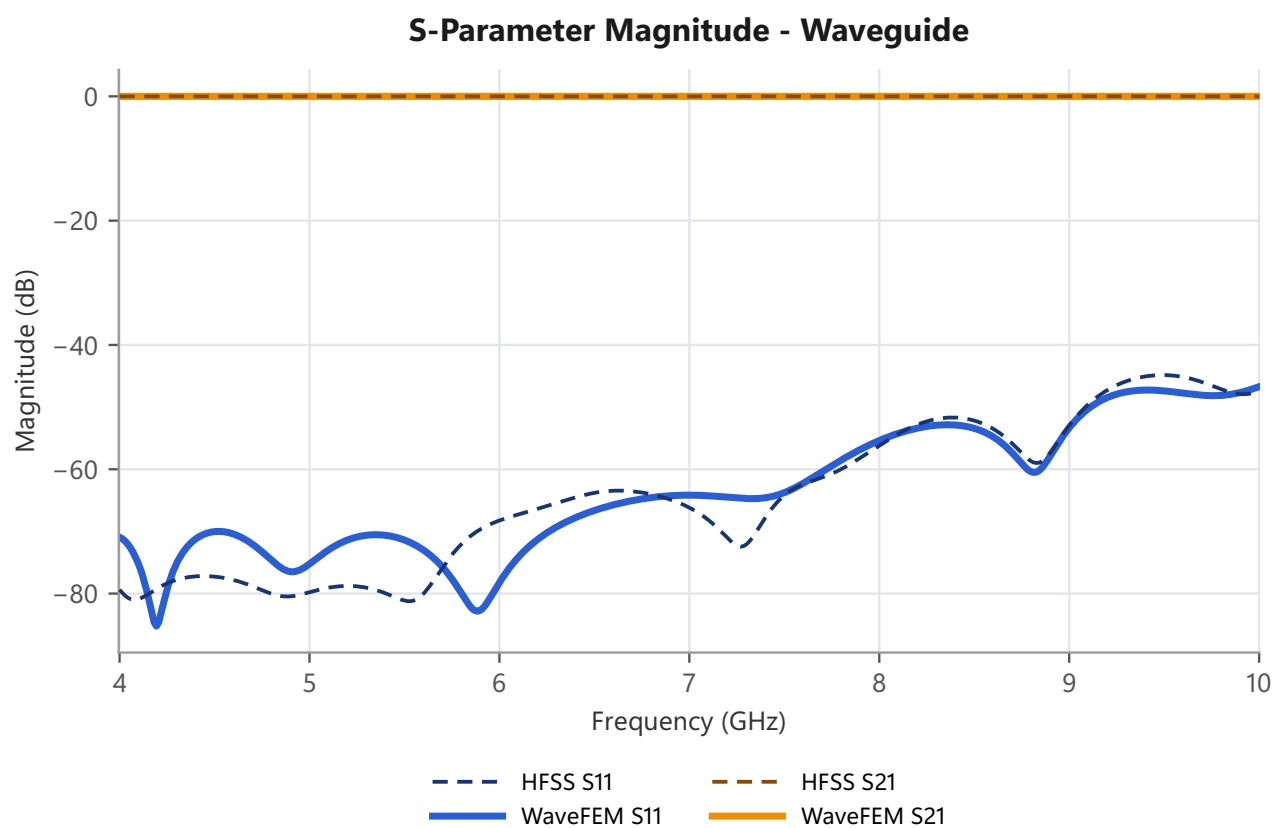


Figure 33 — S-parameter magnitude.

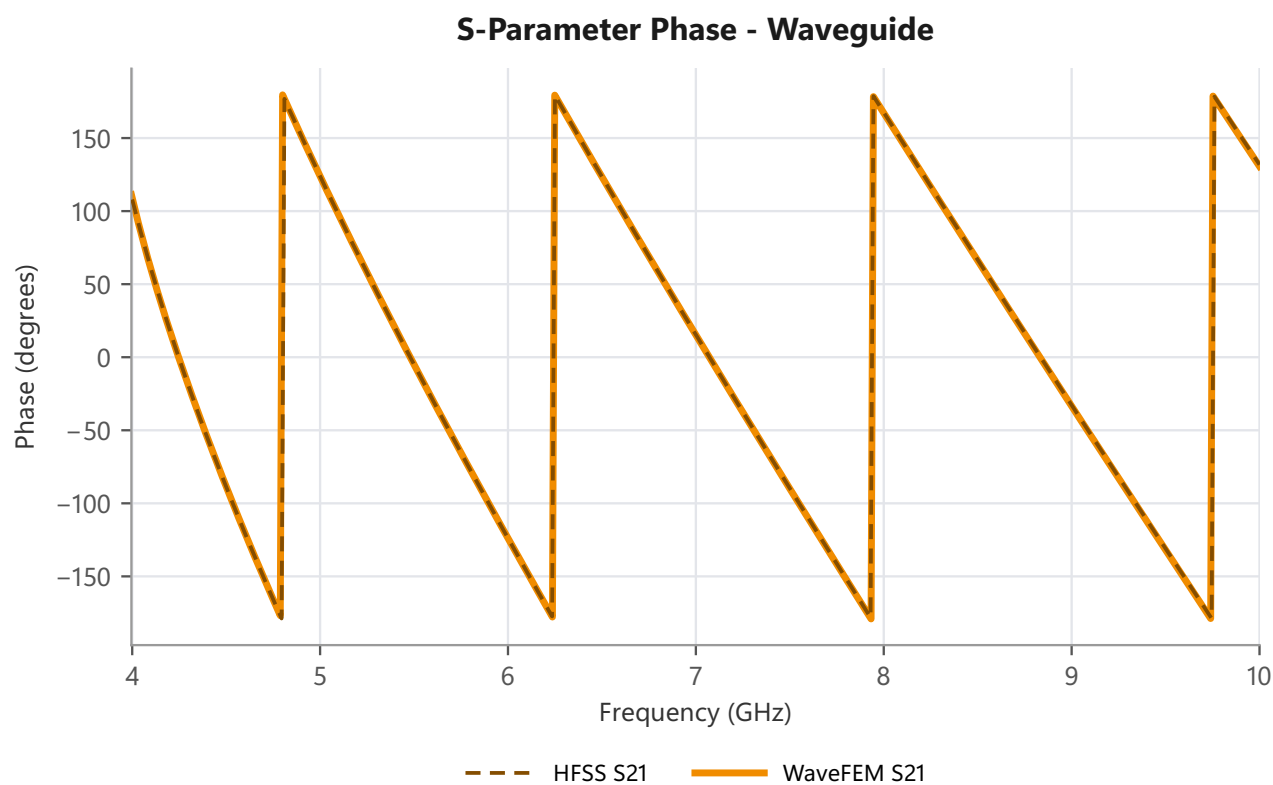


Figure 34 — S-parameter phase.