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Design Smarter Matching Networks

Ampsa Matching Wizards

Powered by Differential Evolution

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Innovative Amplifier Design Tools

Efficiency is critical in power amplifier designs. Higher efficiency reduces transistor stress, energy consumption, failures, and maintenance needs. To improve transistor efficiency, it is essential to control both the fundamental-frequency and the harmonic terminations presented to a transistor. The peak voltages and currents associated with the harmonic control implemented should be within the safe range for the transistor used. Without access to the intrinsic reference plane, these voltages and currents cannot be calculated accurately.

The matching problems to be solved can be defined with

- Load-pull/source-pull hardware (mechanical or active).
- Load pull/source-pull with nonlinear transistor models.
- Clipping theory.

Note: Load-pull without known or controlled harmonic terminations and non-linear models without access to the intrinsic reference plane are of limited use.

Clipping theory for linear power amplifiers has been extended to a fully useful point in the Amplifier Design Wizard (ADW). *S*-parameters and *I*/*V*-curve boundaries are required to setup the required transistor models in the ADW. The ADW models fitted can be fine-tuned by comparing the performance of a designed power amplifier with the measurements, or by using an accurate non-linear model. The external, as well as the intrinsic load terminations can be controlled with the ADW. Only the external terminations can be controlled with the Matching Wizard (MW). The CIL wizard in the ADW can be used to setup power matching problems.

Matching problems can be solved with the ADW or the MW. The artwork of synthesized distributed solutions can be exported as basic scripts, as Sonnet Software (.son) files, or as DXF files for further processing.

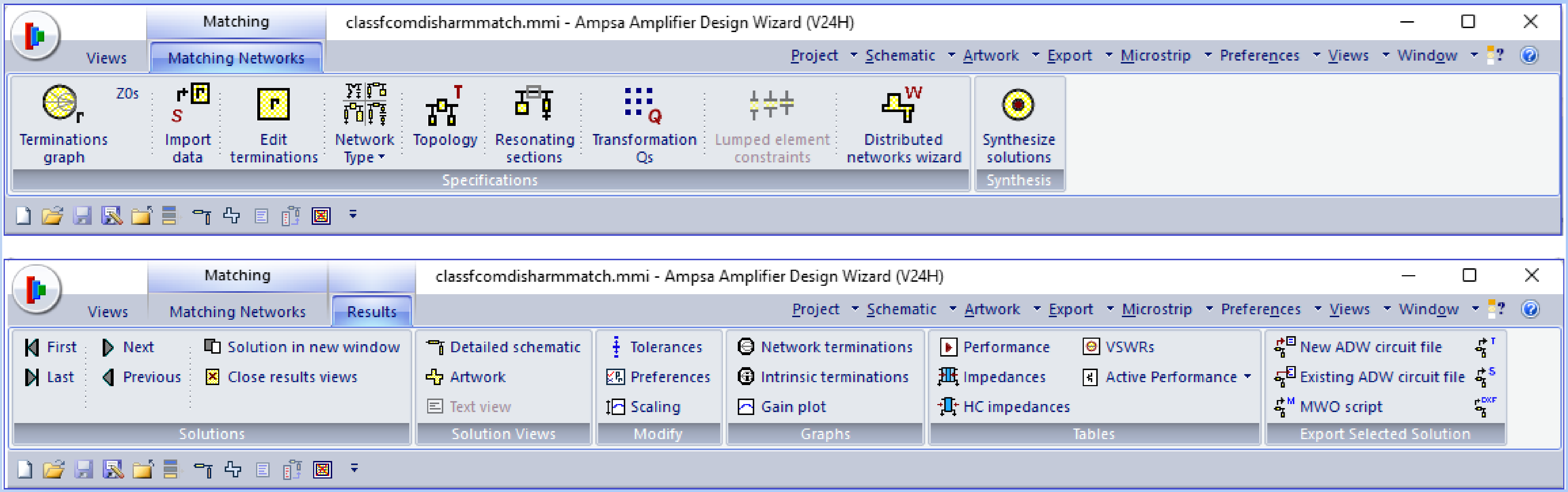
Systematic searches combined with finer searches and optimization were previously used in the ADW to find the best solutions to a matching problem. This approach has been enhanced with differential evolution followed by optimization. Integrating both capabilities in the same tool validates solutions and increases solution diversity, increasing the likelihood that the global optimum is achieved.

The standard evolution algorithm was also modified to provide an alternative evolution approach. The minimum errors obtained with this approach are similar to those obtained with the standard algorithm, but the average errors are worse. Convergence with the modified algorithm is obtained in less generations.

Differential evolution is significantly faster than systematic searches for complex problems requiring more than six elements. Systematic searches establish performance standards for the evolution, and when the evolution results are inferior, adjustments can usually be made to get similar results (larger population, more generations, optimizing more solutions, ...). For matching problems requiring eight or more elements, systematic searches may become impractical due to excessive execution time, making differential evolution the only viable option. The performance with fewer elements and the modified evolution approach can then be used as benchmarks.

These advancements enable faster design cycles, and improved efficiency and reliability in amplifier designs.

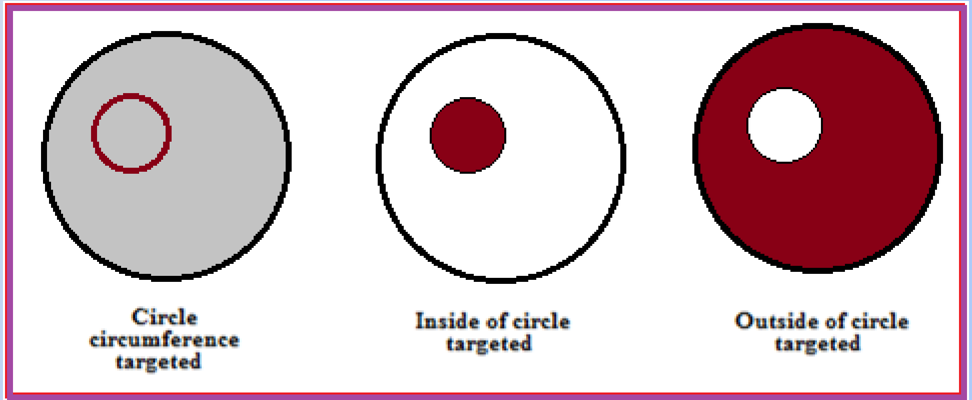
The systematic searches and the evolution operate in *Q*-space. The basic principles will be explained first, after which four detailed examples will be provided to illustrate the design process and the wizard capabilities. Networks will be synthesized using both approaches to compare performance. It will be shown that differential evolution delivers results comparable to systematic searches, but significantly faster. More network elements can also be used with differential evolution. The convergence behavior of the implemented differential evolution algorithm will also be explored.

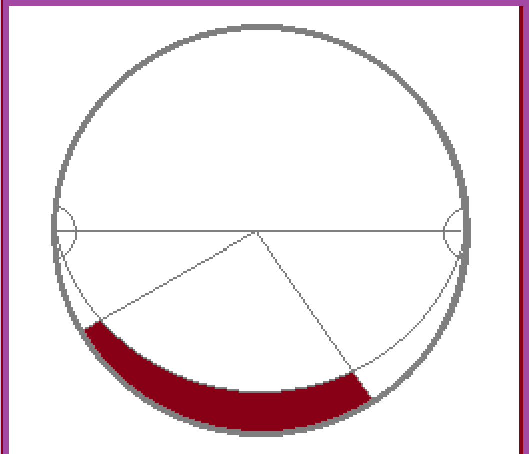


ADW and MW: Ribbon Commands

The Impedance-Matching Wizards in the ADW and MW provide ribbon commands that centralize access to matching functions and offer shortcuts to synthesis, analysis, and export tools.

Note: The Intrinsic Terminations command is not provided in the MW.





Reactive reflection coefficients targeted (Q > Qmin).

Defining the ADW or MW Matching Problem

The ADW or MW can synthesize a wide range of cascade-type lossless networks.

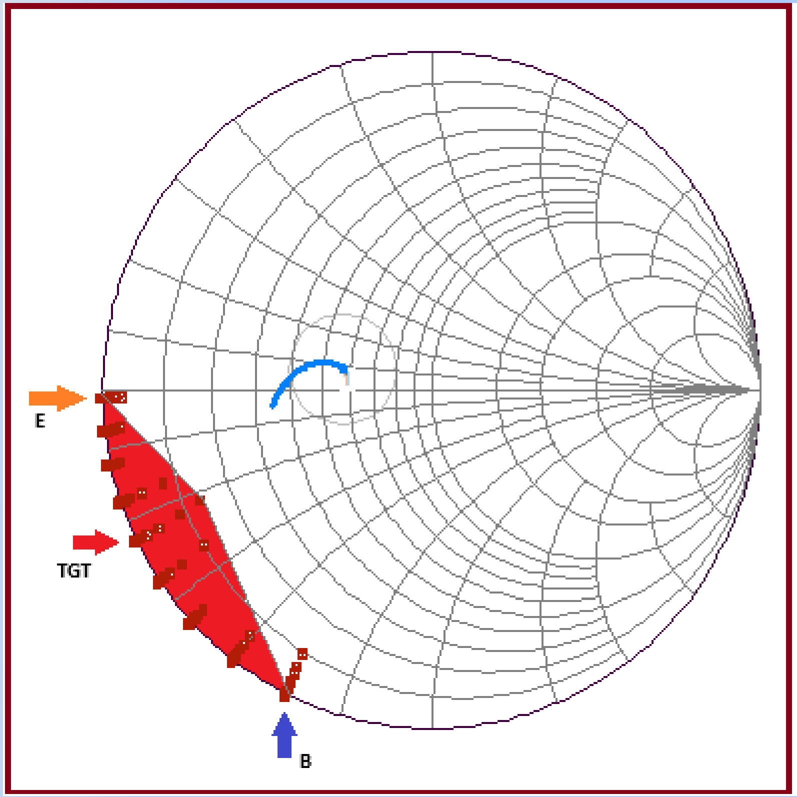
At the fundamental frequencies, specified load terminations can be transformed to:

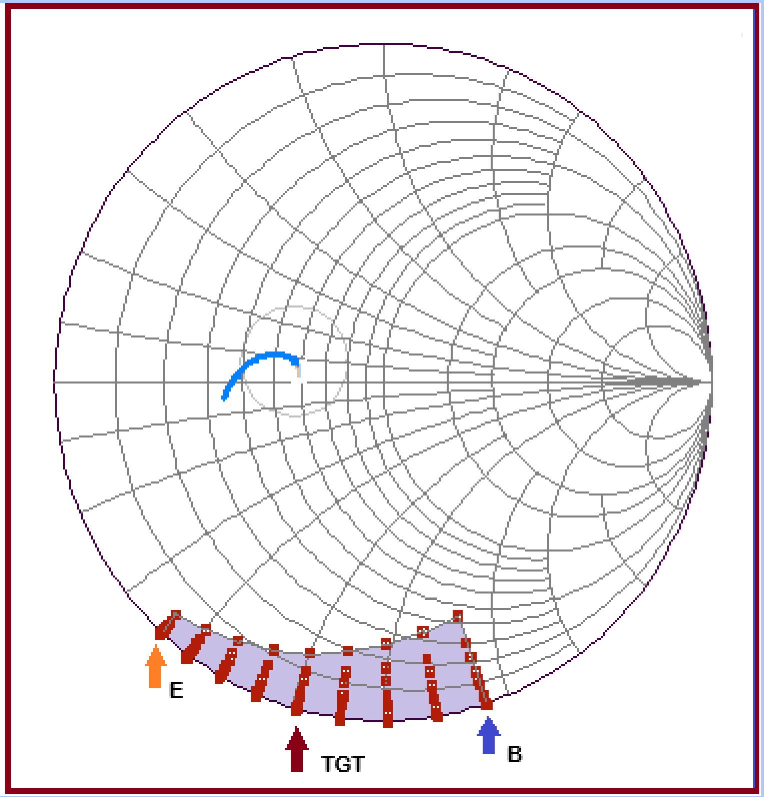
- Match the source terminations specified tightly (if possible).
- Achieve terminations inside, outside or on the circumferences of circles, derived from the transducer power gain specifications (e.g., G_T =1.0 for a conjugate match). The circles relate to power gain, noise figure, power and/or efficiency.

The harmonic targets can be defined by one of the following:

- A range of reactance values (typically high Q).
- A Smith chart sector defined by two intersecting lines and the Smith chart edge, with the intersection inside the Smith chart (local origin sectors).
- A Smith chart sector defined by a reflection coefficient swept linearly over a specified angular range, and the Smith chart edge (reflection sectors).

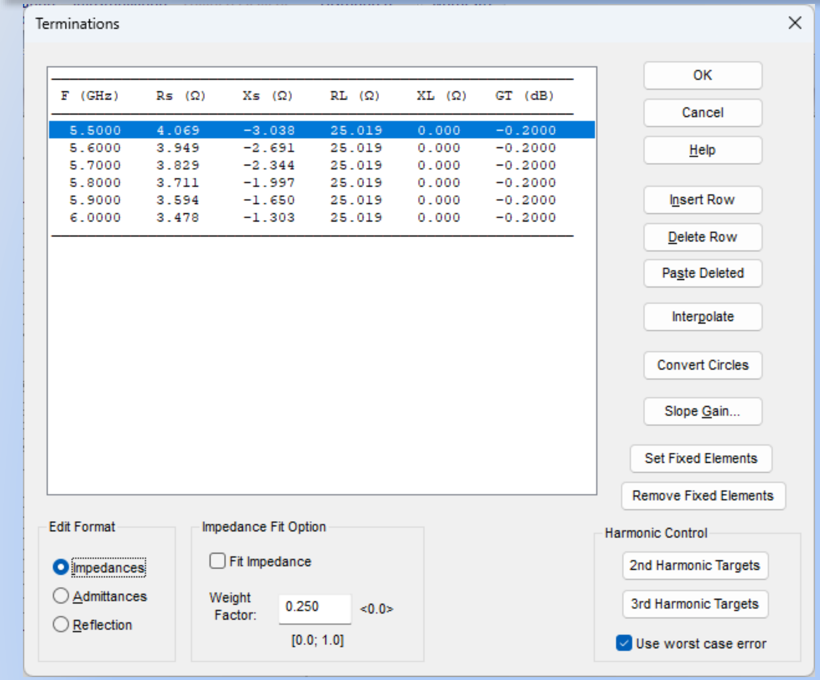
Note: Only one of these harmonic target options can be used for a specific problem.

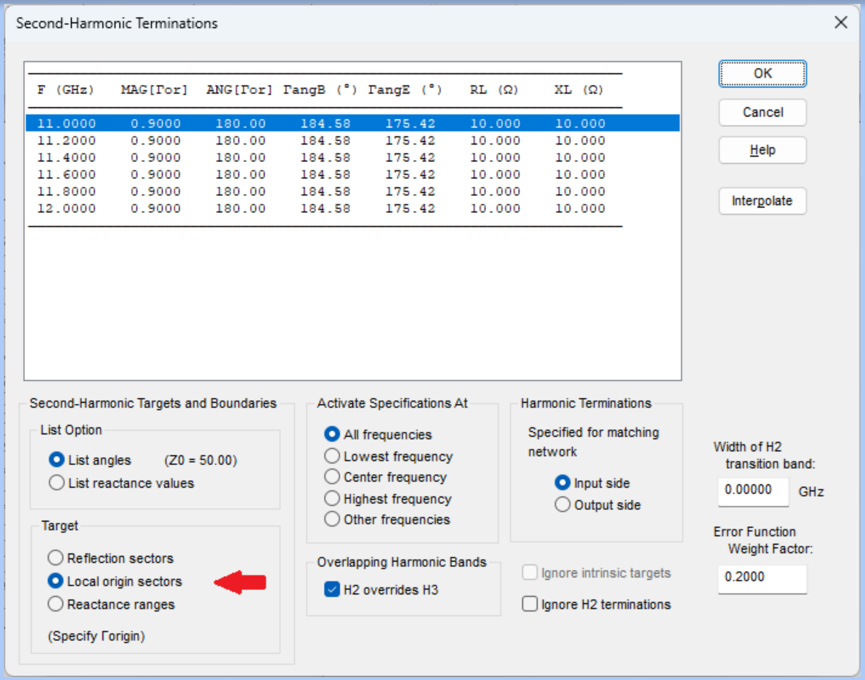




Local Origin and Reflection Sectors

This illustration shows local origin sectors (LHS) and reflection sectors (RHS) used to define the second and third-harmonic reflection coefficients at the input or output of the matching network in the Amplifier Design Wizard (ADW) and Matching Wizard (MW).



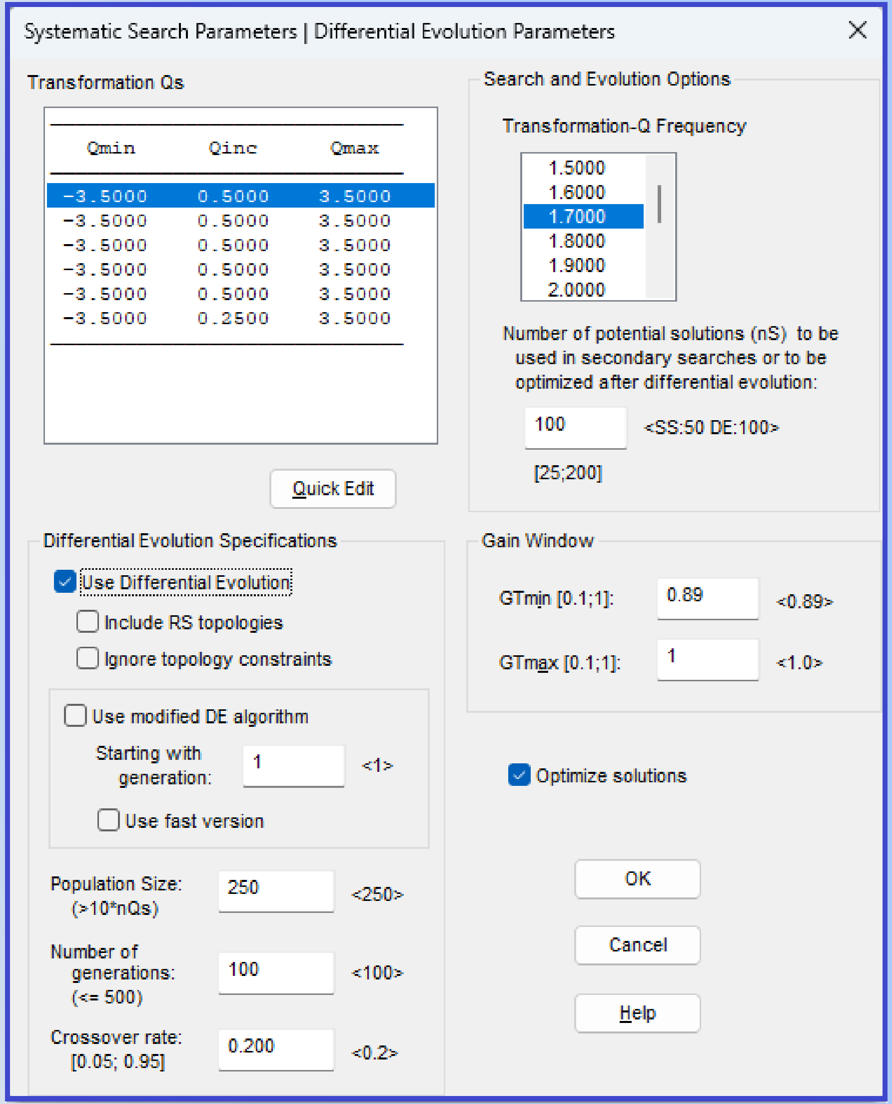


Fundamental and Harmonic Frequency Specifications

Examples of specifications for matching networks in the ADW and MW include:

- **Fundamental-Frequency Targets**: Import from .s1p / .s2p files or specify manually.
- **Harmonic Targets**: Specify manually or use wizards in the ADW Analysis module to automate matching problem setup.

Note: The Analysis module in the MW provides wizards for passive matching problems; ADW provides wizards for both active and passive problems.



Introduction and Principles

Solutions to matching problems can be synthesized using:

- Differential evolution
- Systematic searches combined with finer searches around the best results.

In both approaches, the best results obtained are optimized, though optimization can be deactivated. Topology constraints are ignored during optimization.

Searches and evolution operate in *Q*-space, where a transformation-*Q* is the reactance-to-resistance (*X*/*R*) or susceptance-to-conductance (*B*/*G*) ratio at a network element's input. Each transformation step scales resistance or conductance by a factor $(1+Q_n^2)$.

In the ADW and the MW, *Q*s are numbered from the load side towards the input.

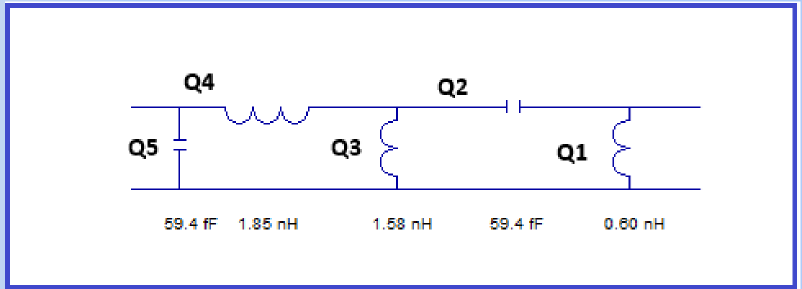
Wideband networks cannot have high *Q*-values. In narrowband networks, the circuit *Q* is approximately half the highest transformation-*Q*. *Q*-values can be positive or negative. The difference between two consecutive *Q*-values decides the element type:

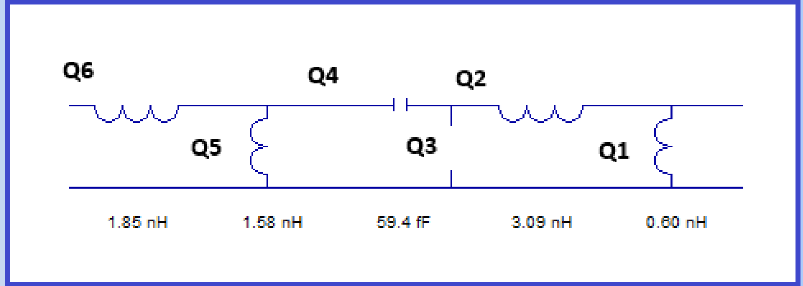
- Positive *Q*-difference: Series inductor or shunt capacitor
- Negative *Q*-difference: Series capacitor or shunt inductor

Note: The Gain Window specifications impose additional constraints on the last two *Q*s, but differential evolution currently considers only the last *Q*'s constraints.

Transformation-Qs are calculated at the highest gain frequency. If the gain targeted for the different passband frequencies are similar, the Qs are calculated at:

- The lowest passband frequency for high pass problems
- The highest passband frequency for lowpass problems
- A frequency near the passband centre for bandpass problems





In a simple series-shunt–series-shunt cascade, Qs correspond 1:1 with network elements. Changing the topology (e.g., series-series, shunt-shunt) increases the number of Qs. The number of unknown variables remains equal to the number of network elements.

A series-series combination can be identified by the missing shunt element in the cascade. Similarly, the missing series element marks the position of a shunt-shunt section. These combinations are called resonating sections. The Q associated with a resonating section is the negative of the Q for the network element to its right.

In systematic searches, the number of network elements are fixed. In differential evolution, the number is fixed if:

- The Fixed topology option is selected in Topology specifications
- The Allow Resonating sections option is enabled when specifying transformation-Qs

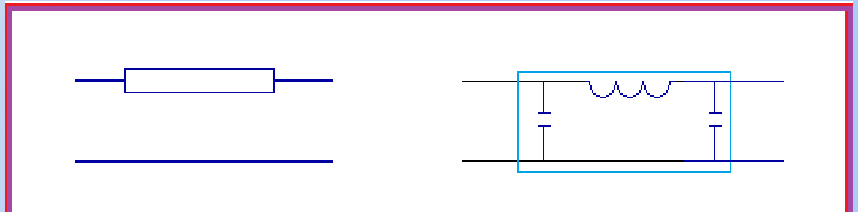
Given the speed of differential evolution, increasing the number of elements is a viable alternative.

Limits:

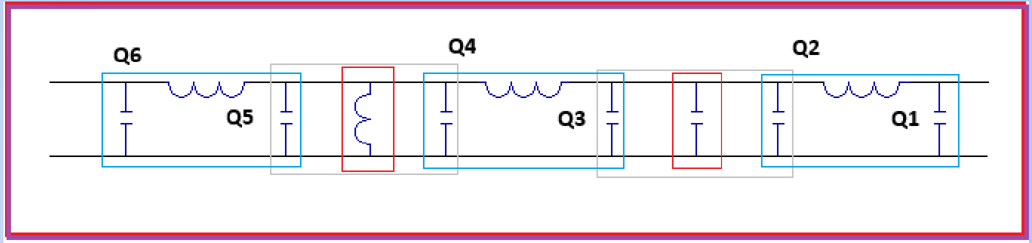
- Differential evolution: Up to 12 elements
- Systematic search: 2 – 8 elements

Example:

An example of defining the Qs for a network with series transmission lines and shunt lumped components is provided here. Shunt capacitors associated with each series connected transmission line are combined with the relevant shunt components.



A Narrow Band Lumped Equivalent Circuit for a Transmission Line



Allowed Components in ADW and MW Matching Networks:

- Series lines
- Open-ended stubs
- Shorted stubs
- Capacitors and inductors (with or without pads)
- Open-ended shunt branch with two cascaded lines (Stepped Impedance Resonator, SIR)

Note: With fixed pad dimensions, a lumped element with pads can be represented by a single *Q*-value.

Mapping Transformation Qs to Network Types

Transformation Qs can be mapped to:

- Lumped element networks
- Commensurate distributed network
- Non-commensurate distributed network
- Mixed lumped/distributed networks

Commensurate Networks:

- User-specified line lengths for series lines, open-ended stubs, and shorted stubs.
- Characteristic impedances are the variables (constrained or unconstrained)
- Systematic search to optimize series line lengths
- Open-ended stubs can be transformed into equivalent main-line sections

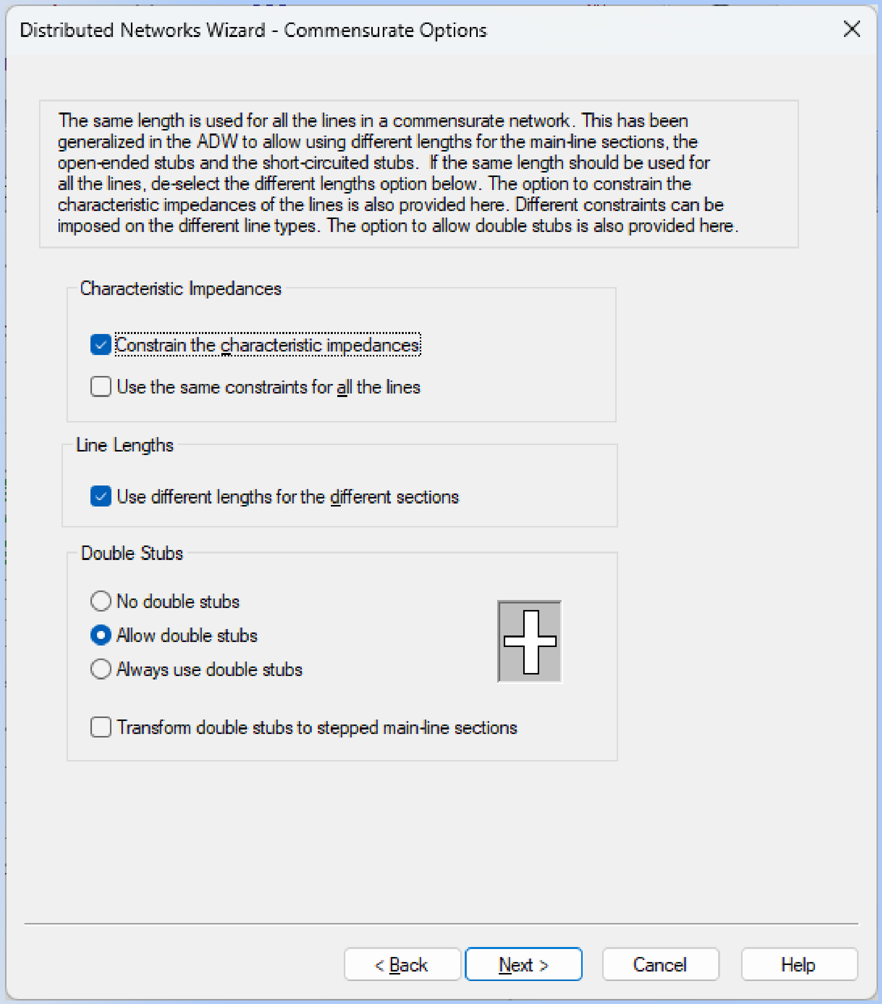
Non-commensurate networks:

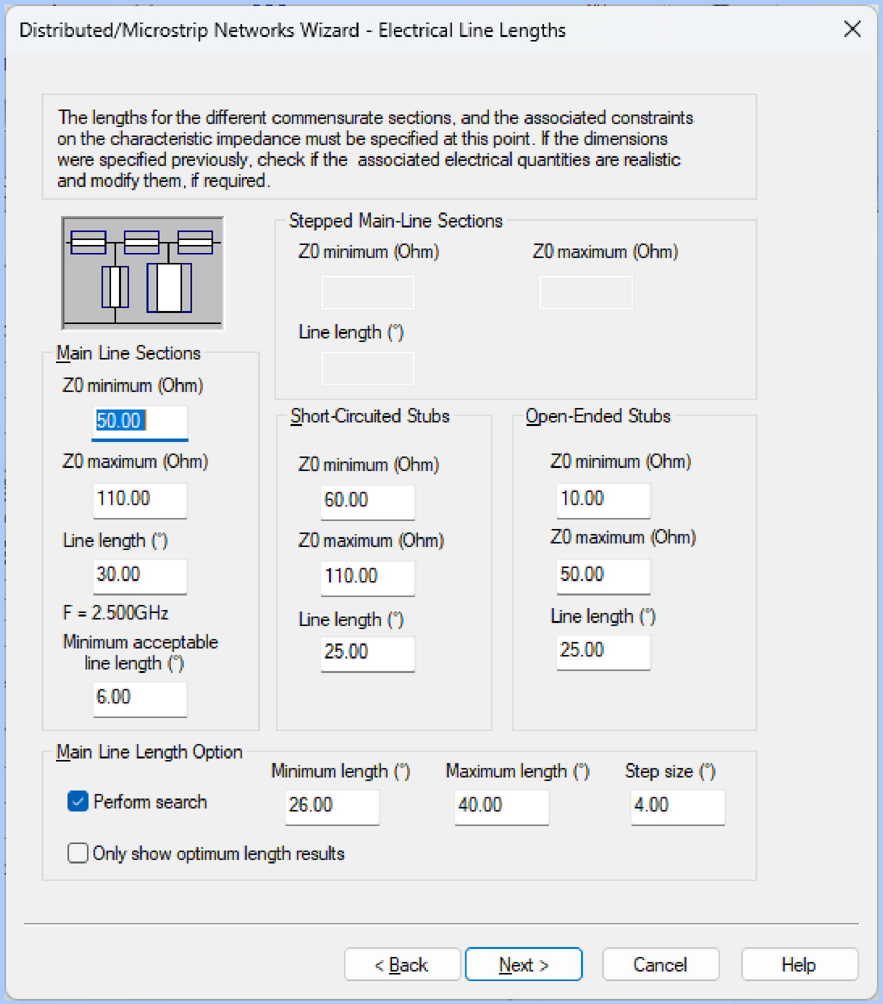
- User-specified characteristic impedances for series lines, open-ended stubs, and shorted stubs
- Line lengths can be constrained
- Systematic search to optimize series line characteristic impedances
- Open-ended stubs can be transformed into main-line sections or replaced with Stepped Impedance Resonators (SIRs) to provide transmission nulls at a specified frequency while maintaining required shunt admittance

Mixed lumped/distributed networks:

- Lumped components reduce network size
- Options to shorten series lines, open-ended stubs or shorted stubs
- Parasitic inductance for capacitors and parasitic capacitance for inductors can be specified
- Additional inductance for shunt capacitors to create transmission nulls at a specified trap frequency
- Additional capacitance for inductors to provide series-connected opens at a specified trap frequency

Note: The Distributed Networks Wizard is used to specify the distributed network parameters





Distributed Network Specifications

This slide shows specifications for commensurate networks configured using the Distributed Networks Wizard in the ADW and MW.

- **Double Stub Transformation**: Option to convert double stubs into equivalent main-line sections.
- **Purpose**: Replaces an open-ended stub with a short, low-impedance series transmission line to eliminate resonant behavior.

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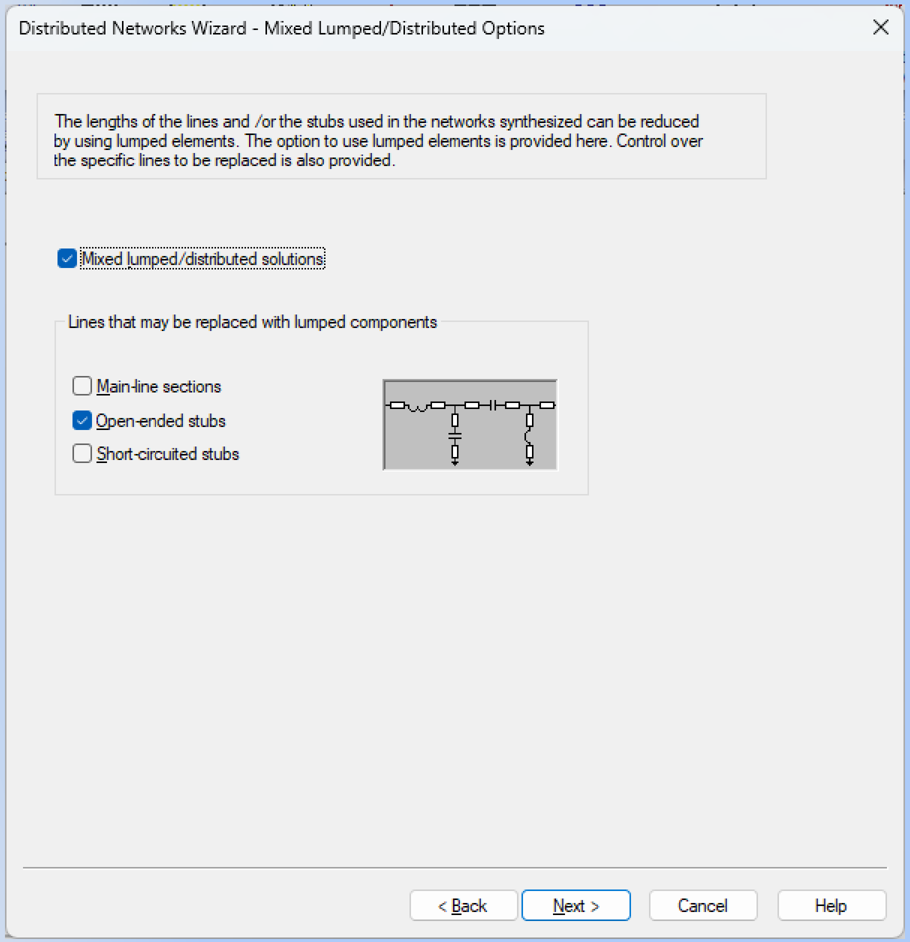
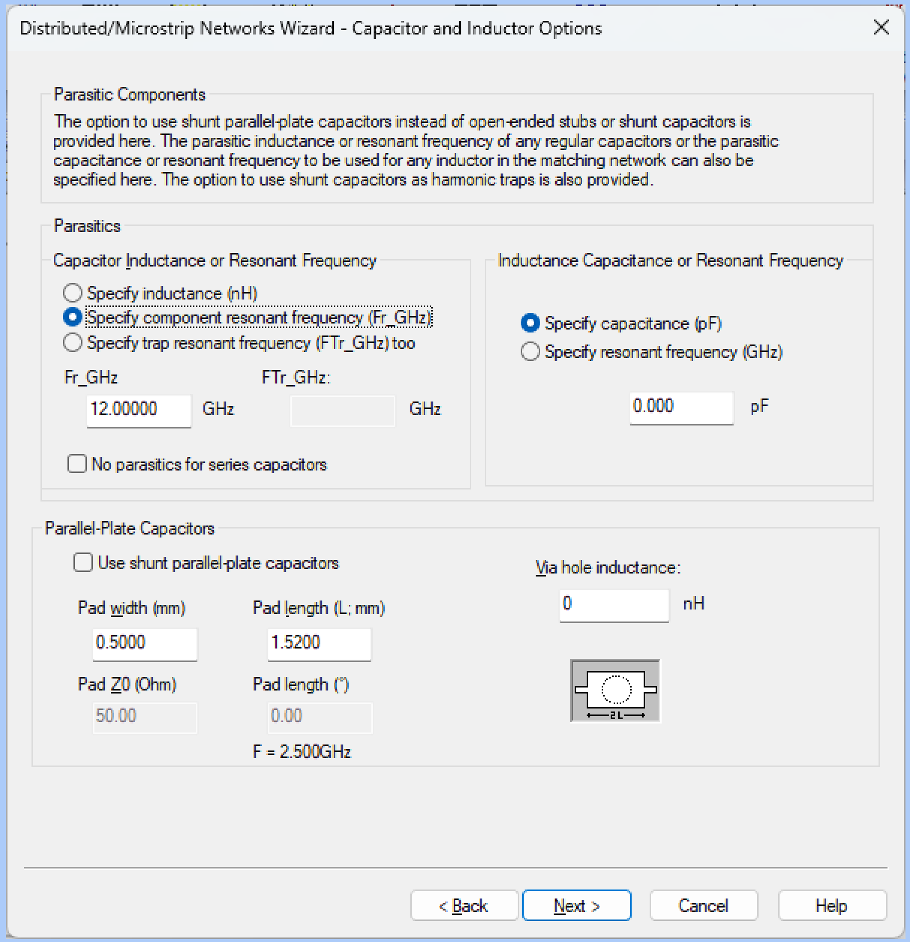
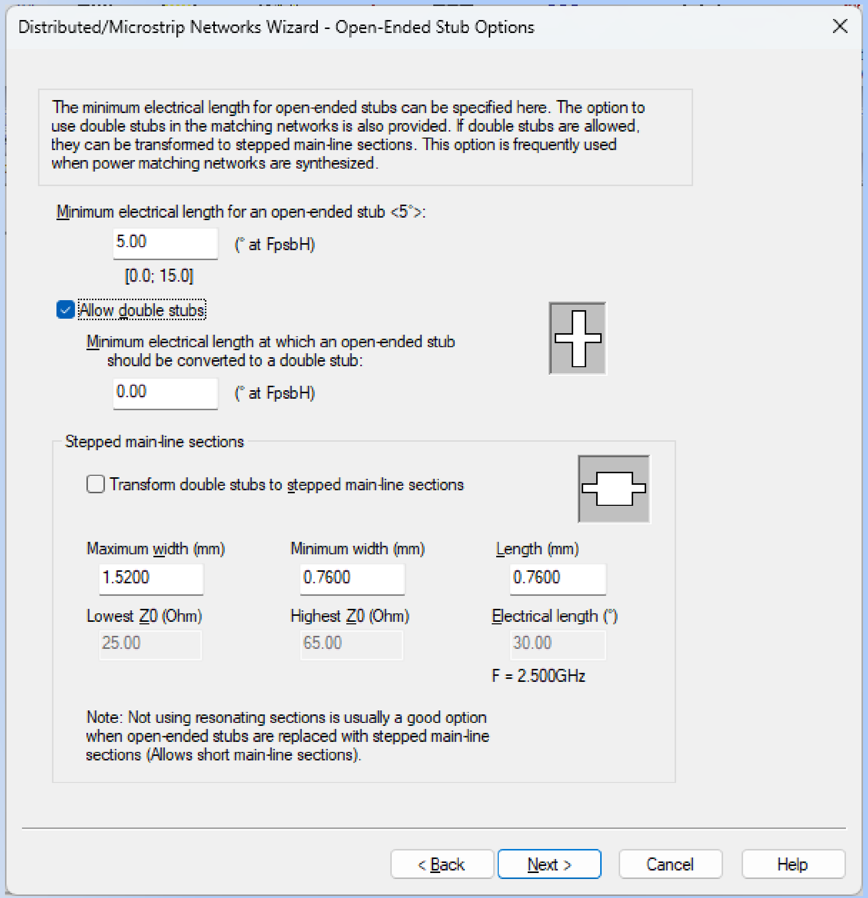


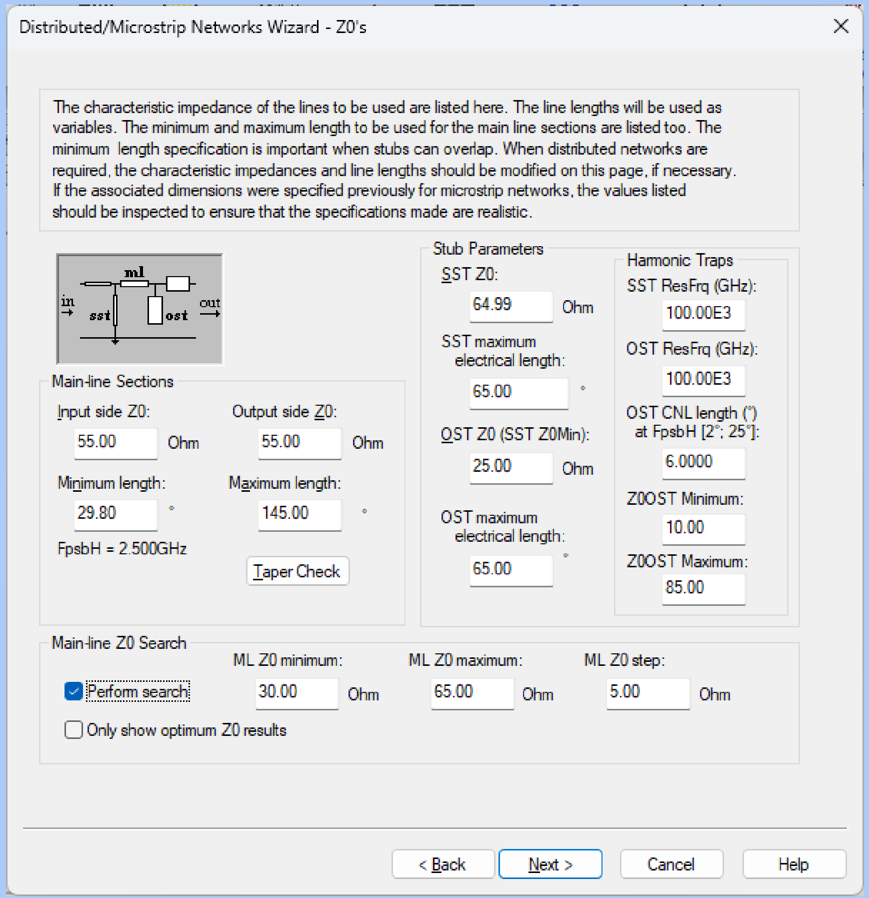


Non-Commensurate Network Specifications

This slide presents specifications for non-commensurate networks configured using the Distributed Networks Wizard in the ADW and MW.

Note: Adjustments to parasitic values enable targeted frequency suppression (transmission nulls) in non-commensurate networks.





Additional Non-Commensurate Network Specifications

This slide presents additional specifications for non-commensurate networks.

- **Double Stub Transformation**: Convert open-ended double stubs to equivalent main-line sections when enabled.
- **Harmonic Traps**: Specify harmonic trap options for shorted and open-ended stubs to suppress targeted frequencies.

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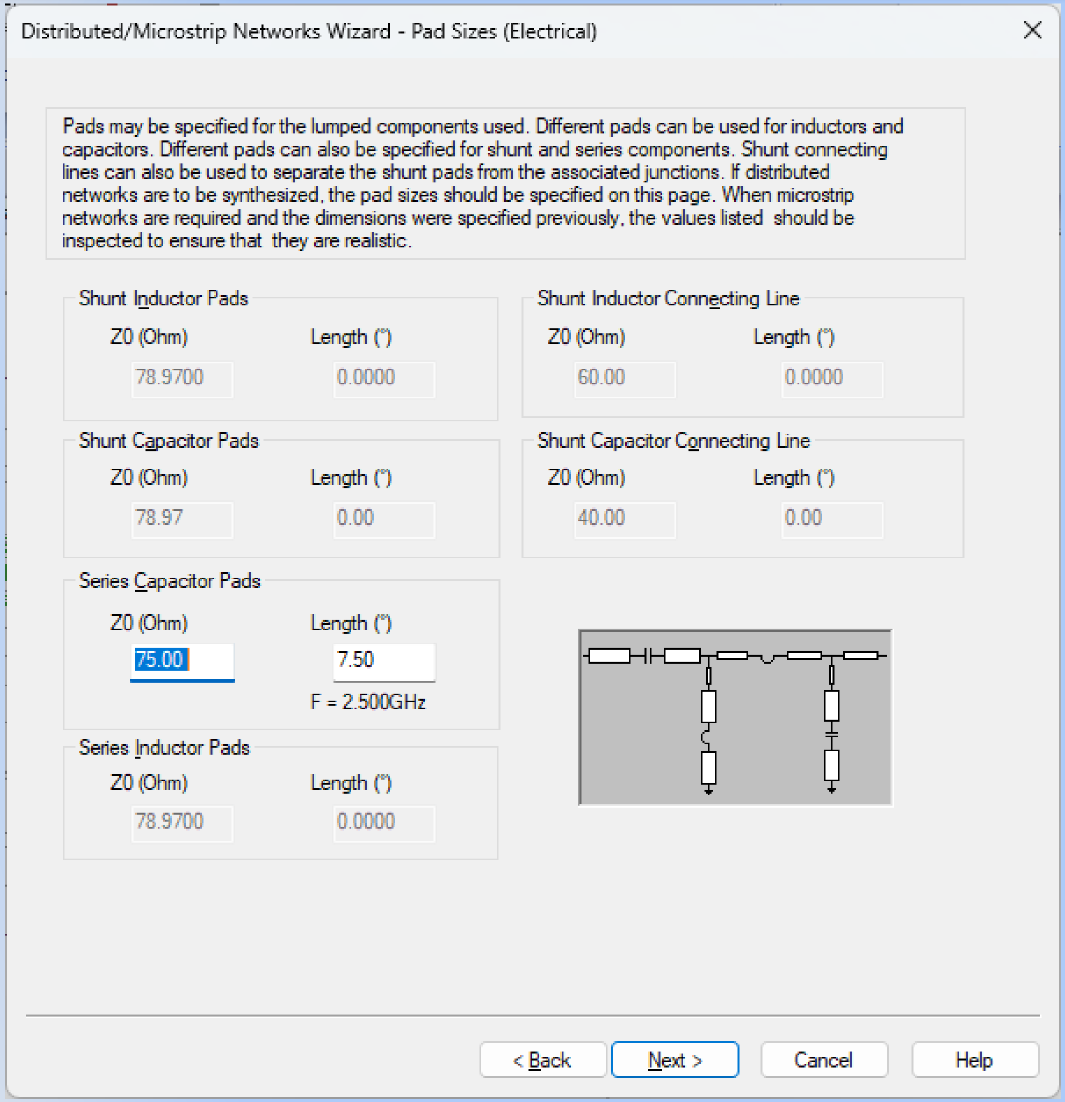
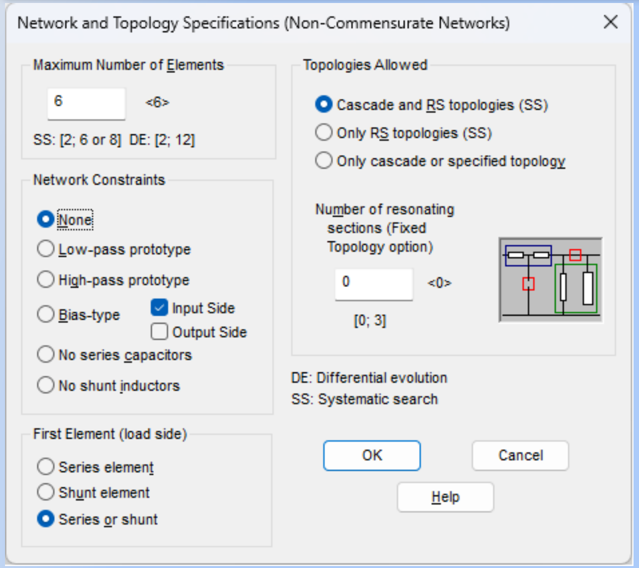
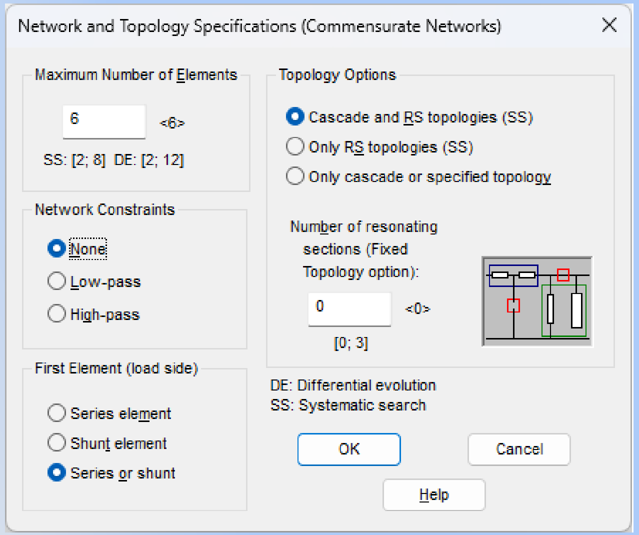


Lumped-Element Pad Sizes in Non-Commensurate Networks

The pad sizes for lumped elements can be specified on the wizard page shown. Only series capacitors are allowed in this example.

Note: The pads for the series capacitors must also provide separation between adjacent junctions and stubs.





Topology Constraints for Matching Networks

This slide presents topology specifications for commensurate and non-commensurate networks in the ADW and MW.

Number or Elements: The maximum number of network elements allowed must be specified.

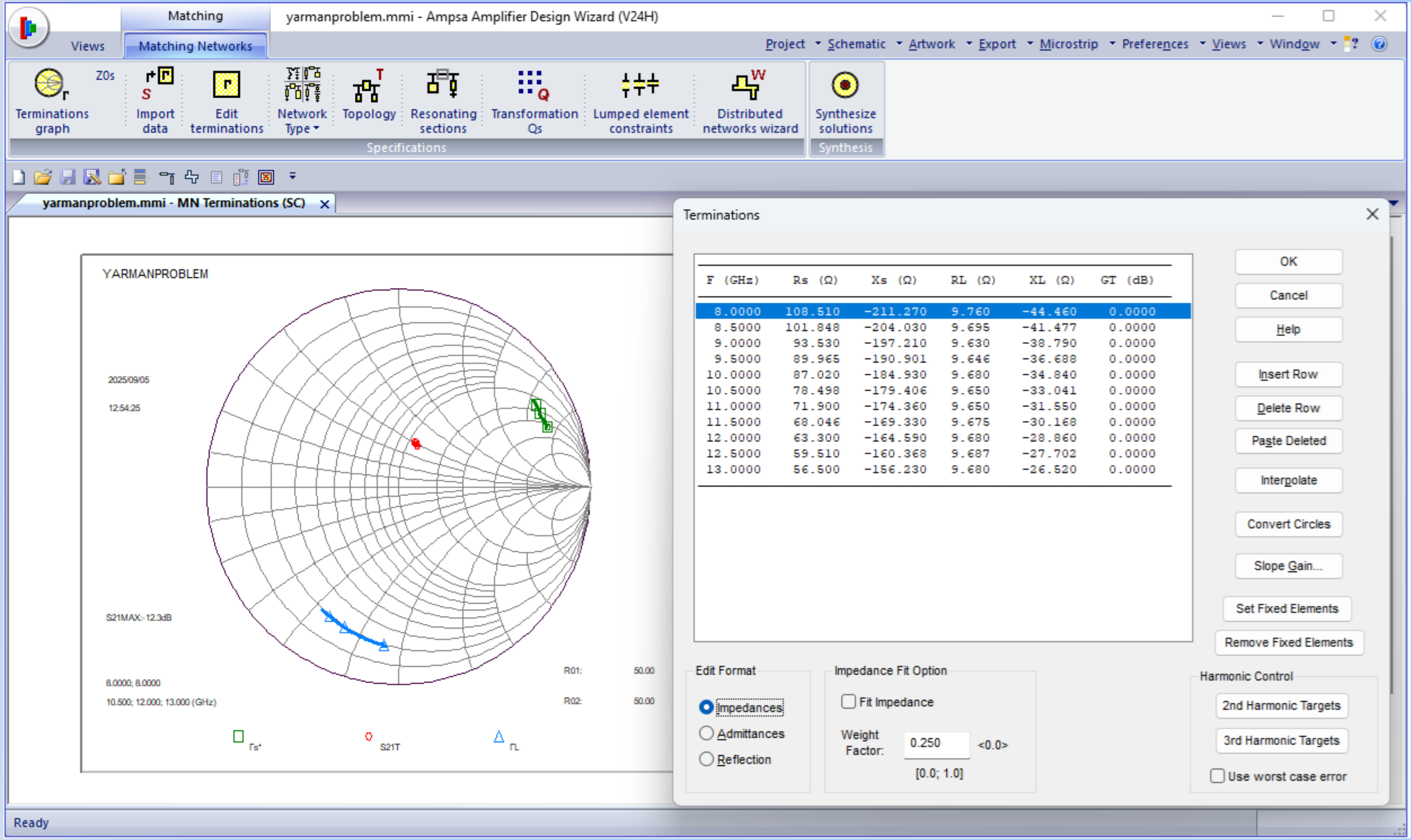
Note: The actual number of elements in a synthesized network could be less (out-of-range shunt elements will be removed from the networks synthesized), or in special cases more (differential evolution).

Network Constraints: The networks to be synthesized can be unconstrained or can be constrained to be lowpass or high pass networks, to be suitable for biasing purposes, to have no series capacitors or to have no shunt inductors.

Standard Cascade and Resonating Section Topologies

The search or the evolution can be limited to a single topology (the standard series-shunt-series-shunt cascade topology or the specified topology) or resonating section topologies can be included in the search or evolution. For systematic searches, the maximum number of elements will be as specified. If the Include Resonating Section Topologies option provided in the Transformation-Qs dialog box is selected, this will also be the case for differential evolution. If this option and the fixed topology option provided here were not selected, the number of elements will be increased to implicitly allow for resonating sections.

Note: Up to three resonating sections are allowed in the ADW and the MW.

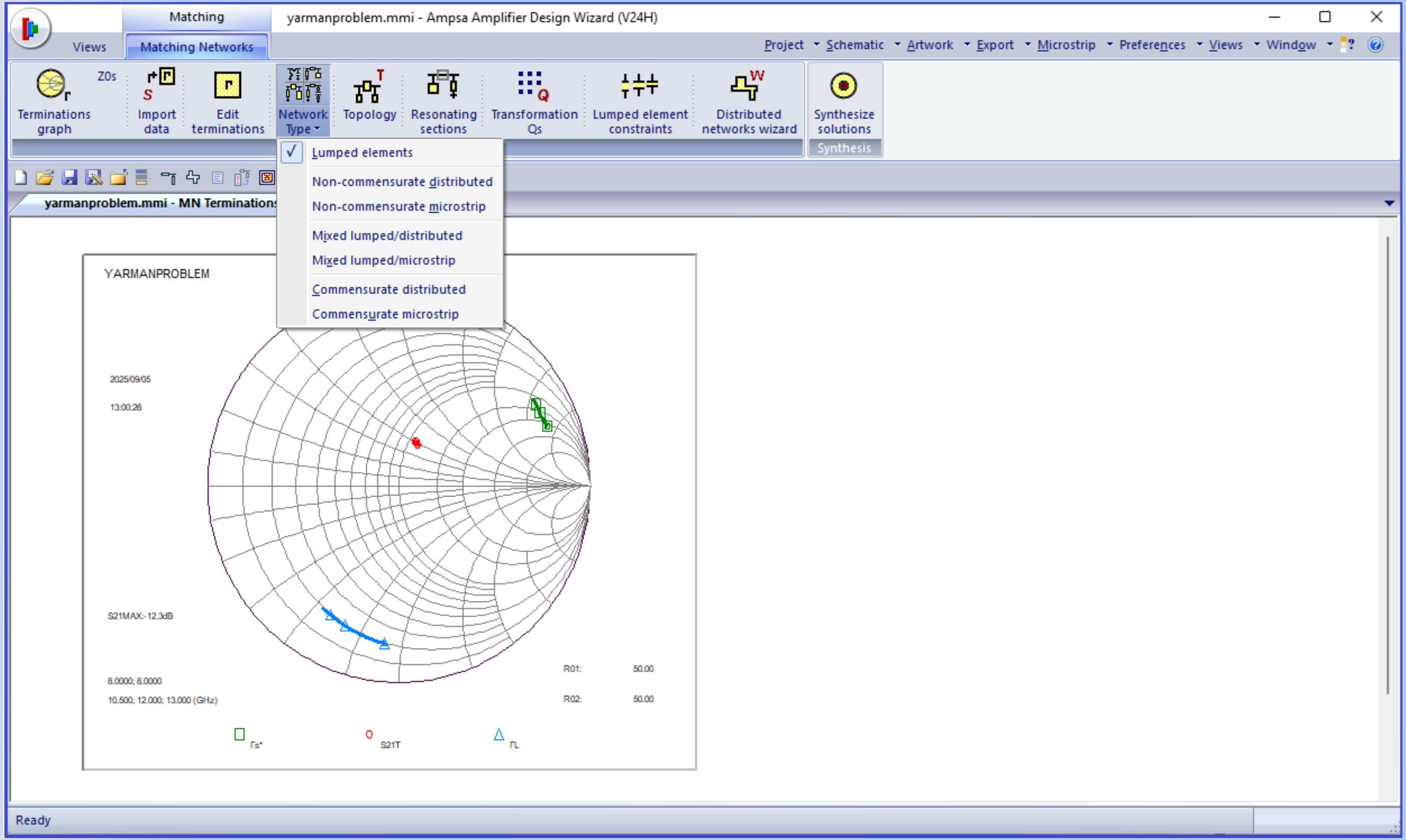


Example 1: Matching Problem Without Harmonic Control

This example demonstrates solving a matching problem using differential evolution and a systematic search. The design flow will be highlighted and the results obtained with the two approaches will be compared.

Goal: Match impedances over the 8.0–13.0 GHz passband.

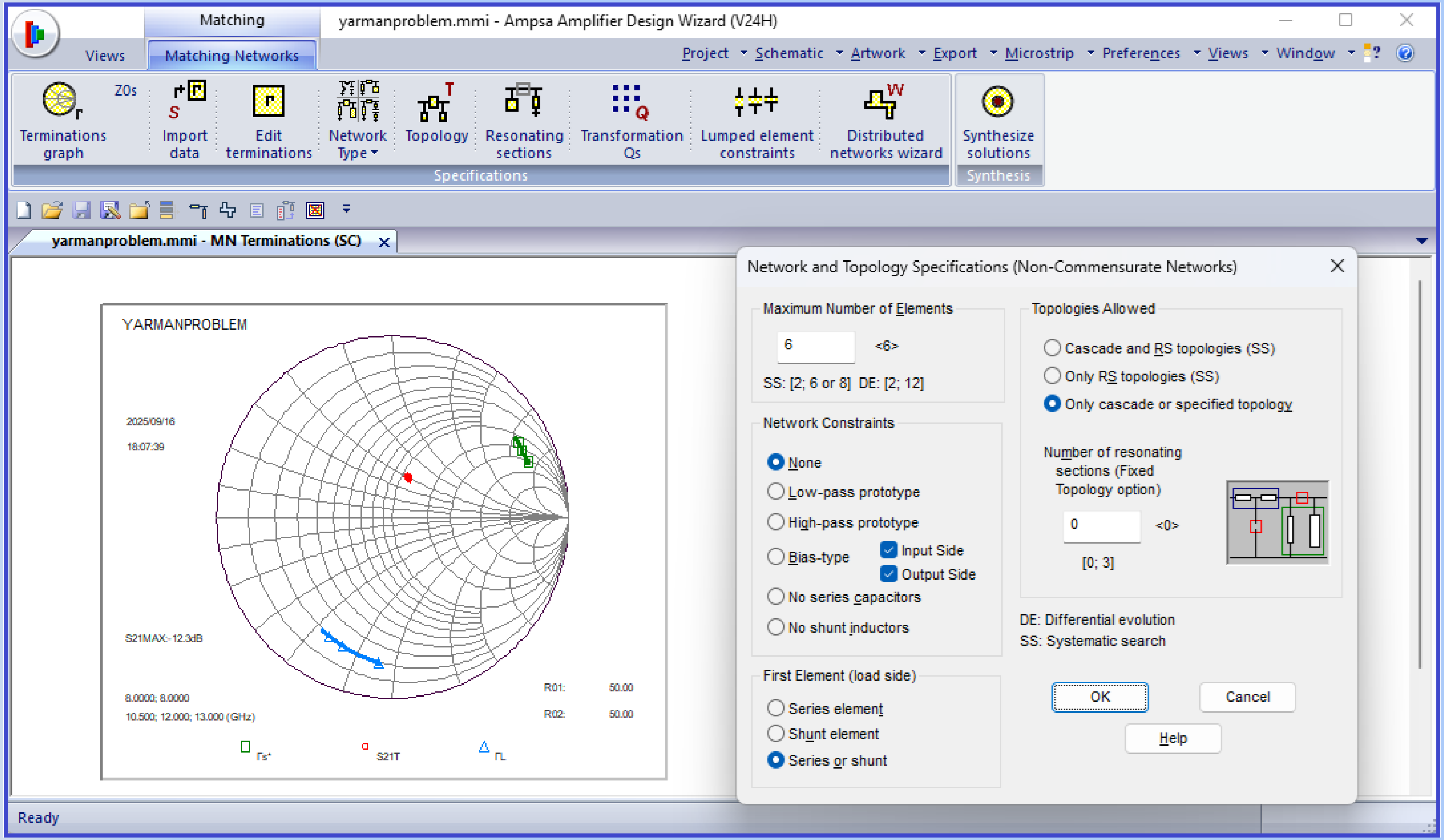
Specifications: Define source and load impedances, admittances, or reflection coefficients manually or import from .s1p/ .s2p Touchstone files.



Example 1: Lumped-Element Matching Constraints

The different network options are shown here. Lumped element will be used in this example.

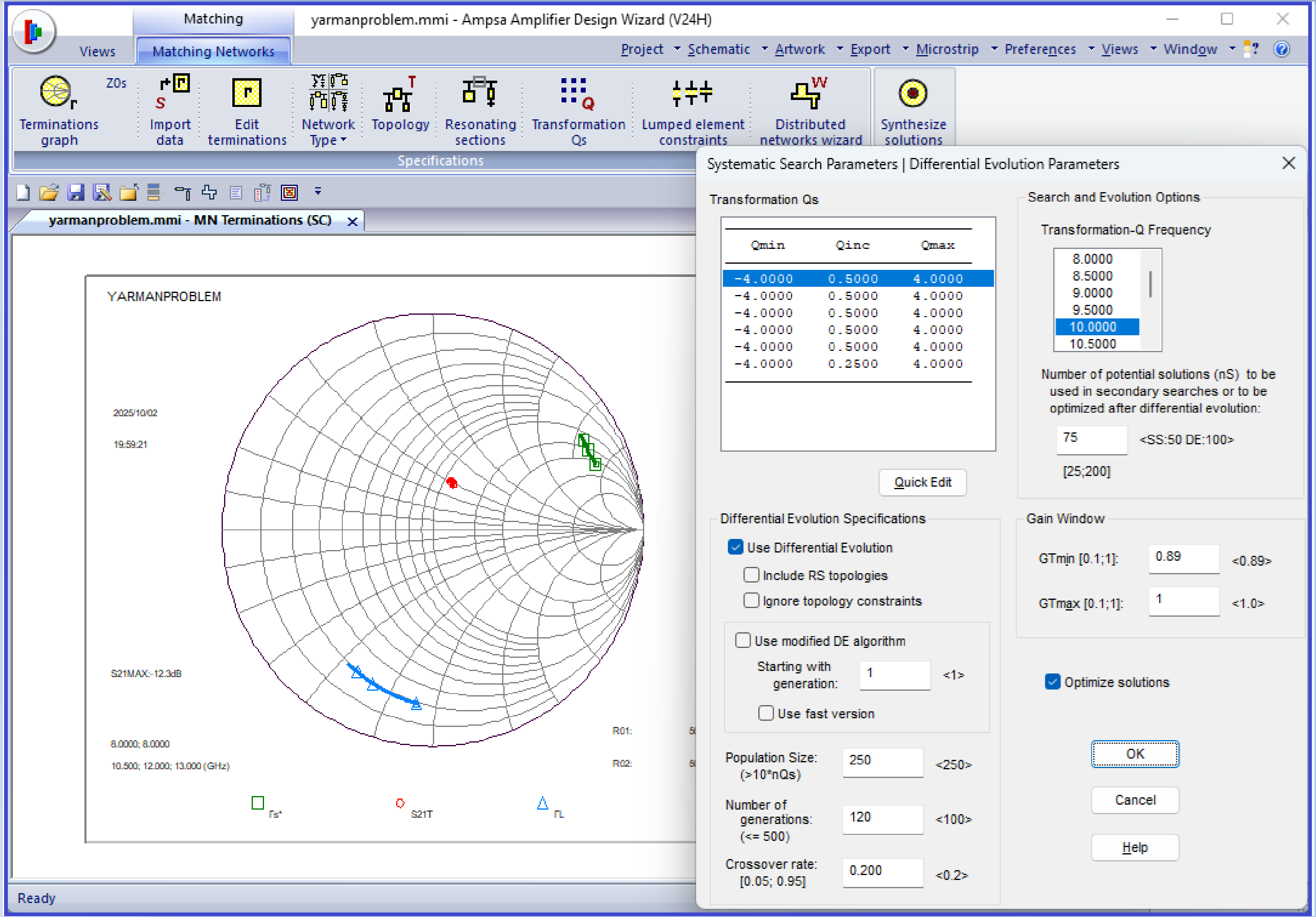
Note: Constraints to lumped-element values can be imposed by using the ribbon command provided. Different constraints can be set for series and shunt components.



Example 1: Network Topology Configuration

This slide shows the topology specifications set for the matching problem.

- **Maximum Element Count**: Use up to six lumped elements.
- **Topologies Allowed**: Maintain fixed topology.
- **Load-Side Configuration**: Allow the first element on the load side to be series or shunt.



Example 1: Differential Evolution Settings

This slide shows the differential evolution specifications for the matching problem. The Transformation Qs ribbon command was used to open this dialog box. The differential evolution option was selected here.

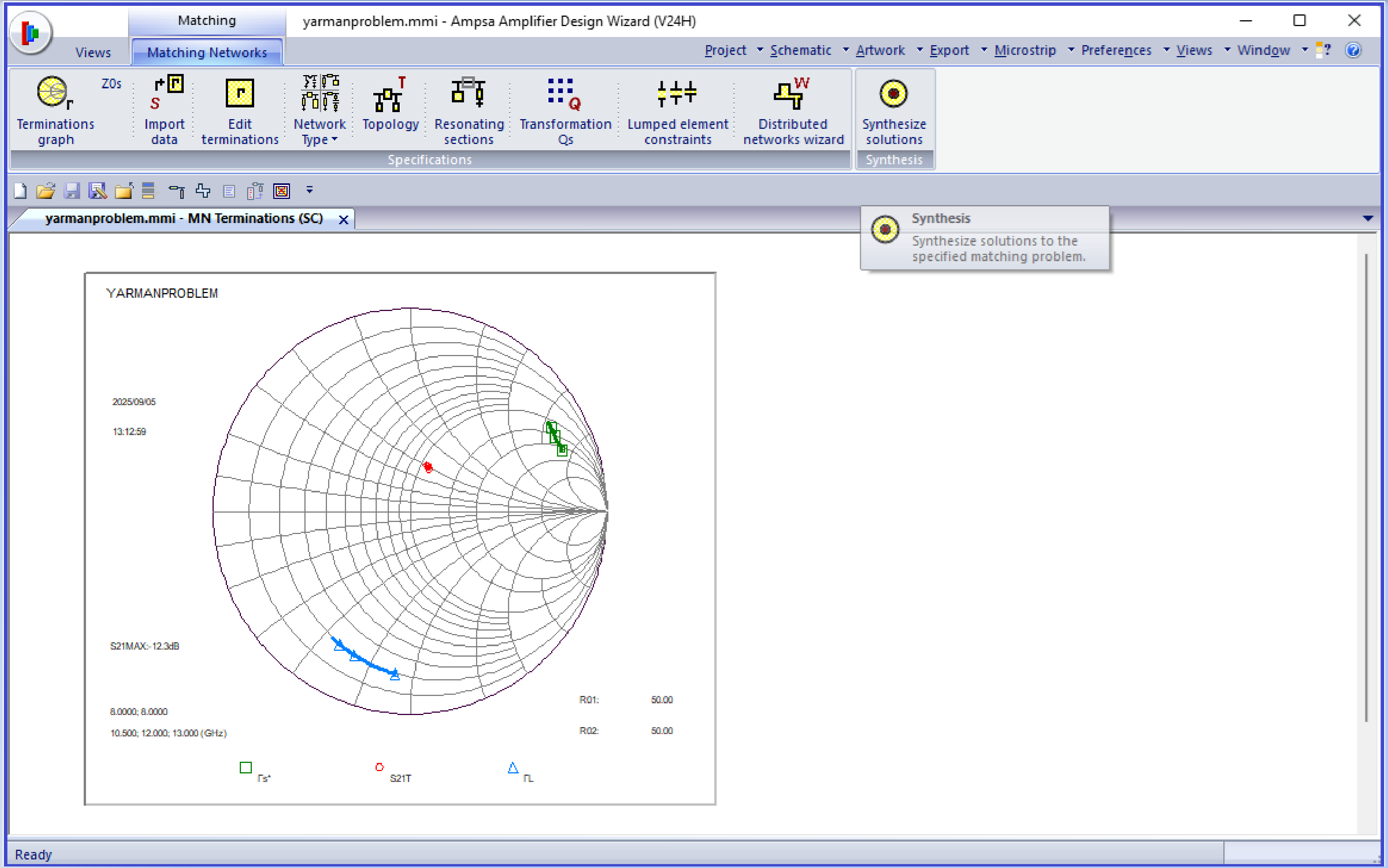
Transformation Qs: The *Q*-range for each element was set to [-4.0; 4.0].

Number of Solutions to be Optimized: 75

Population Size: 250

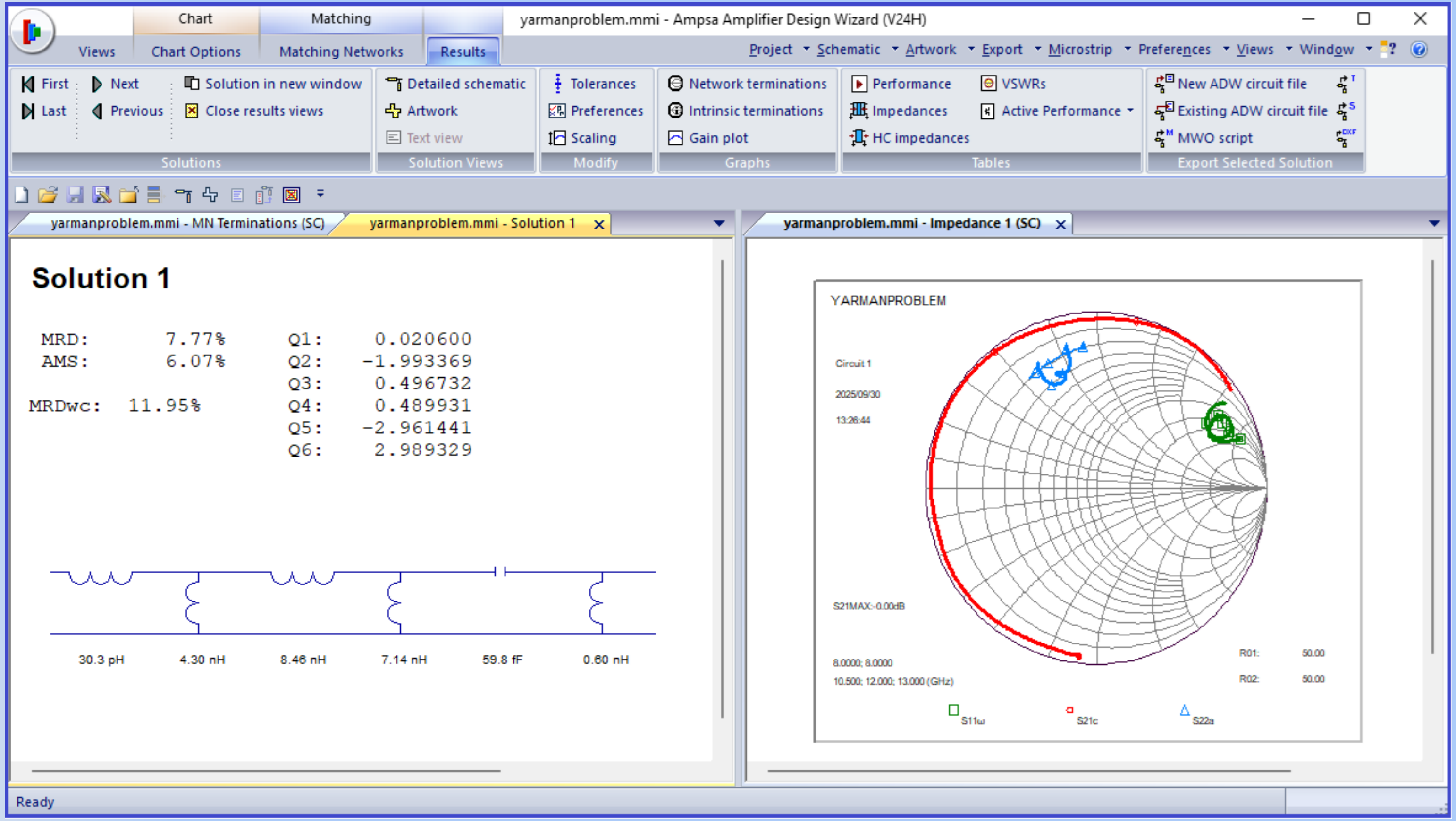
Number of Generations: 120

Note: The standard differential evolution algorithm can be modified after a specified number of generations by using the option shown. Experimentation with the number of generations may be required – Typical values are 1, 20, 35 and 50.



Example 1: Synthesizing Matching Solutions

Use the Synthesis ribbon command to generate solutions for the matching problem.



Example 1: Best Six-Element Solution

This slide presents the best six-element solution for the matching problem using differential evolution.

- **Solution Overview**: Achieves optimal matching with six lumped elements over 8.0–13.0 GHz.
- **Transformation Qs**: Maximum absolute *Q* value of 2.989; reducing range to [-3.5, 3.5] may improve results.
- **Gain Window**: Adjust gain window using transducer power gain at the transformation frequency.
- ***MRDwc***: Worst-case maximum relative deviation (*MRD*) reflects 1% component value tolerances.

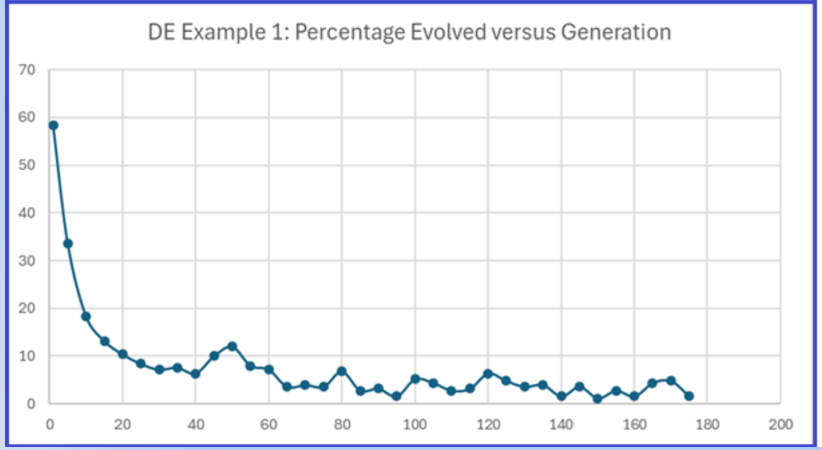
Note: Random numbers are used in differential evolution. The results obtained with the same specifications may differ.

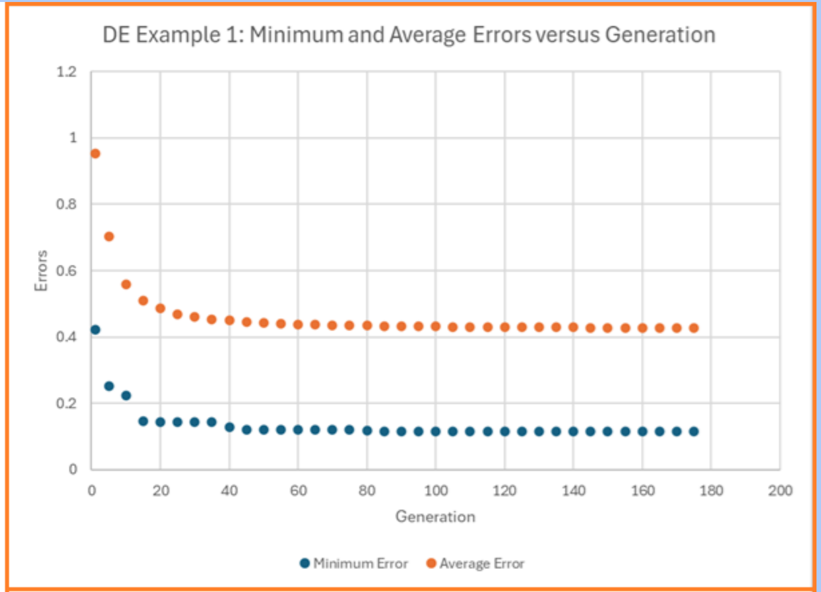
Generation	Minimum Error	Average Error	Maximum Error	Evolved (%)
1	0.5915	0.9592	1.0000	46.00
5	0.3624	0.8687	0.9984	33.20
10	0.2029	0.7695	0.9800	20.40
15	0.2029	0.7093	0.9746	11.60
20	0.2029	0.6555	0.9505	11.60
25	0.2029	0.6145	0.9276	11.20
30	0.1647	0.5673	0.9276	10.80
35	0.1647	0.5390	0.8981	6.80
40	0.1647	0.5119	0.8633	4.40
45	0.1647	0.4894	0.8292	6.00
50	0.1647	0.4760	0.8279	4.00
55	0.1647	0.4605	0.8227	4.80
60	0.1647	0.4461	0.8227	4.00
65	0.1647	0.4301	0.8227	4.40
70	0.1647	0.4188	0.7828	2.40
75	0.1252	0.4094	0.7828	6.00
80	0.1252	0.3989	0.7517	4.40
85	0.1252	0.3869	0.7469	4.80
90	0.1252	0.3766	0.7469	4.00
95	0.1252	0.3694	0.7469	3.60
100	0.1252	0.3621	0.7469	3.60
105	0.1252	0.3551	0.7469	2.40
110	0.1252	0.3497	0.7469	3.60
115	0.1252	0.3391	0.7469	3.60
120	0.1252	0.3347	0.7469	2.40
125	0.1252	0.3290	0.7469	1.20
130	0.1252	0.3211	0.7469	1.60
135	0.1252	0.3160	0.7401	2.80
140	0.1252	0.3121	0.7401	2.40
145	0.1252	0.3070	0.5603	2.00
150	0.1252	0.3026	0.5603	2.40
155	0.1252	0.2986	0.5603	3.20
160	0.1066	0.2967	0.5603	2.80
165	0.1066	0.2929	0.5603	2.80
170	0.1066	0.2899	0.5603	2.80
175	0.1066	0.2876	0.5603	1.60

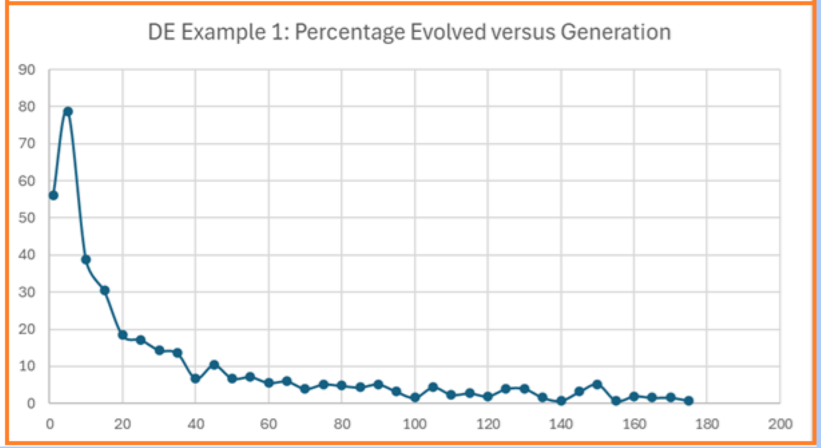
Example 1: Population Fitness Improvement

This slide lists fitness improvements for population members across generations in the differential evolution process.

- **Metrics Defined**:
  - Minimum Error: Lowest error in the generation.
  - Average Error: Average error for the generation.
  - Maximum Error: Difference between best and worst errors.
  - Evolved: Percentage of population that evolved in the generation.
- **Optimization Impact**: The minimum error improved from 10.66% to 7.77%.
- **Data Source**: Metrics are from the .out file associated with the solved matching problem.



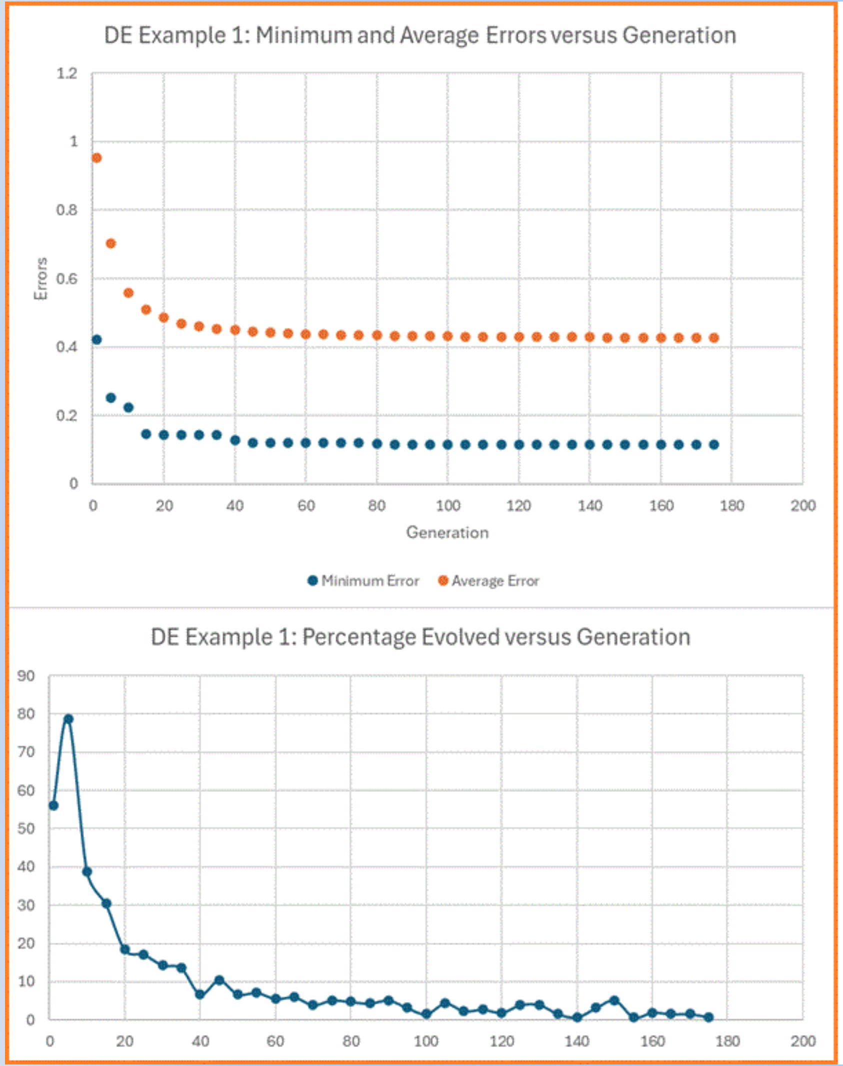


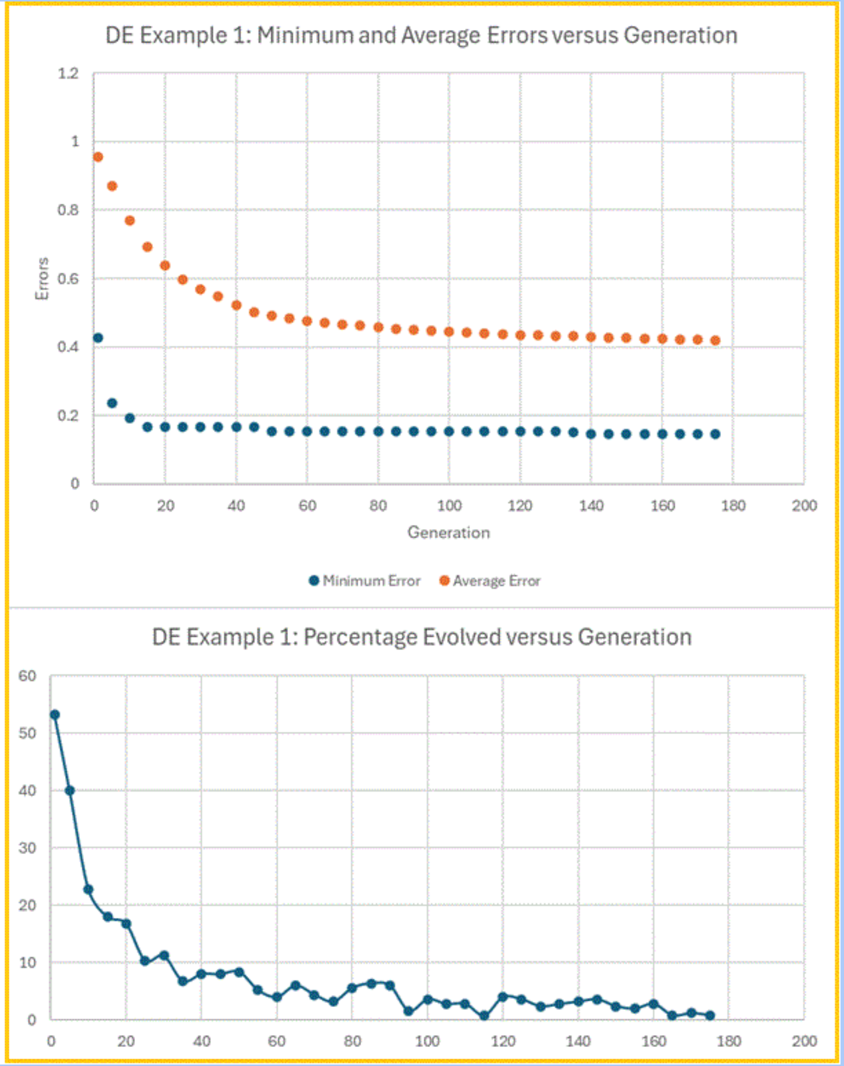


Example 1: Population Fitness Improvement

The minimum and average errors and the percentage of the population that evolved in each generation were plotted in the graphs shown here. The fitness improvements with the standard DE algorithm is shown on the left. The graphs on the rights apply to the modified DE algorithm.

The minimum errors obtained are similar, but the average errors associated with the standard algorithm are significantly better. The performance with the modified algorithm stabilized sooner.

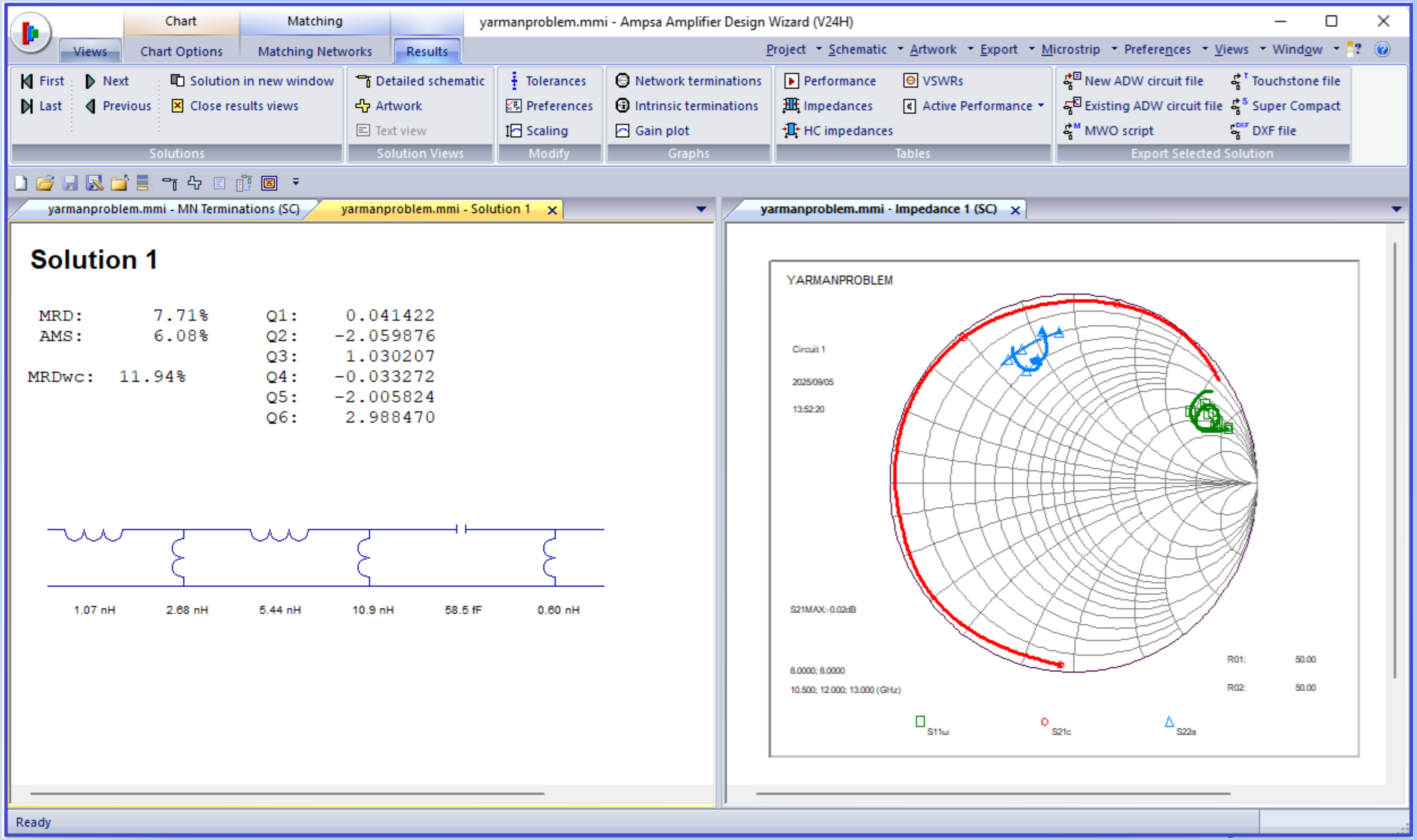




Example 1: Population Fitness Improvement for the Modified DE Algorithm

The performances of the modified algorithm without (LHS) and with the fast option selected (RHS) are compared here. The performance with the fast option is poorer than that without, but the run-time is shorter for the same number of generations.

If the run-time is not a factor, the best algorithm is the standard algorithm, and the second best is the modified algorithm without the fast option.



Example 1: Systematic Search Solution

The best six-element solution obtained with a systematic search is shown here. The performance is like that of the best solution obtained differential evolution.

Note: Differential evolution is significantly faster than systematic search.

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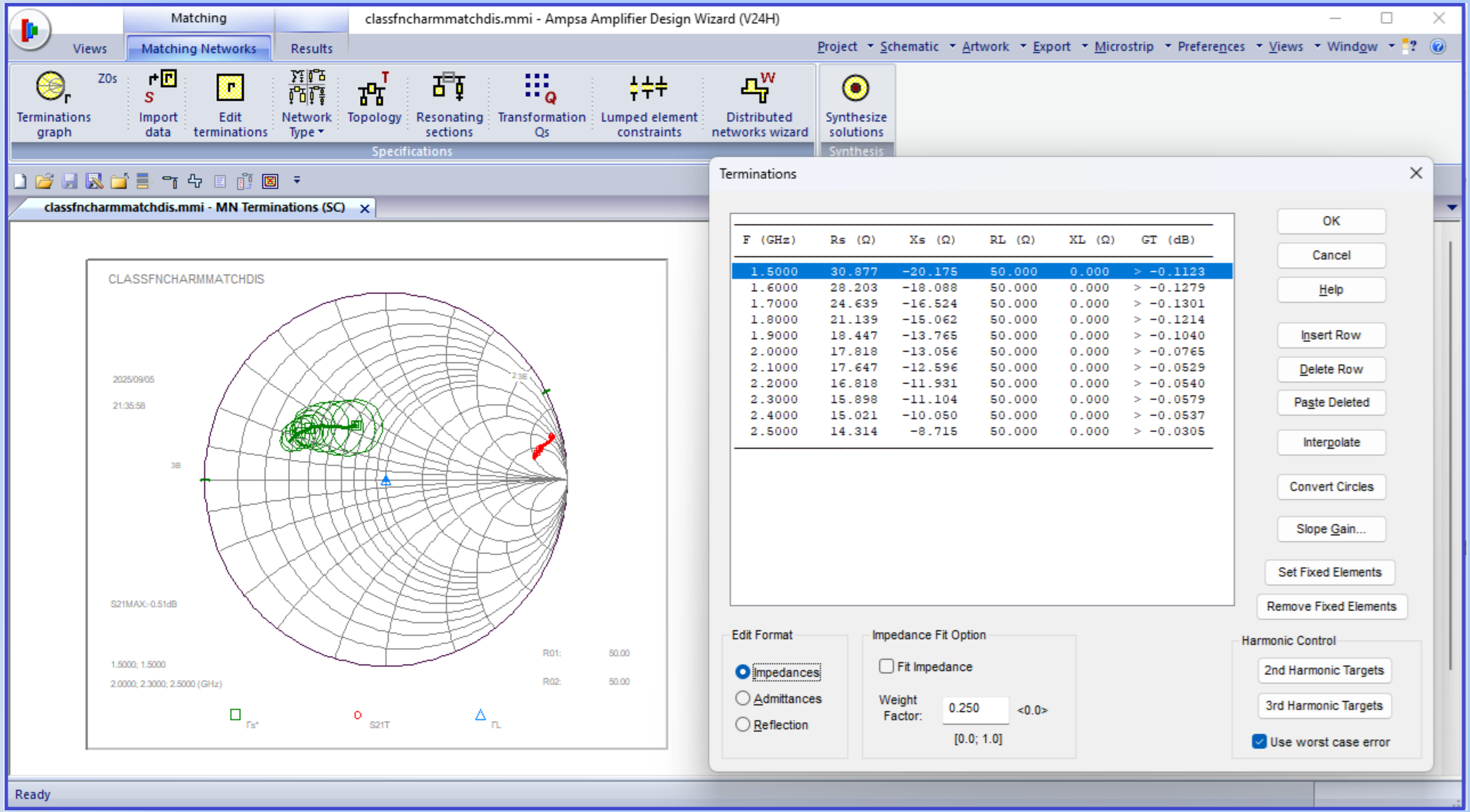
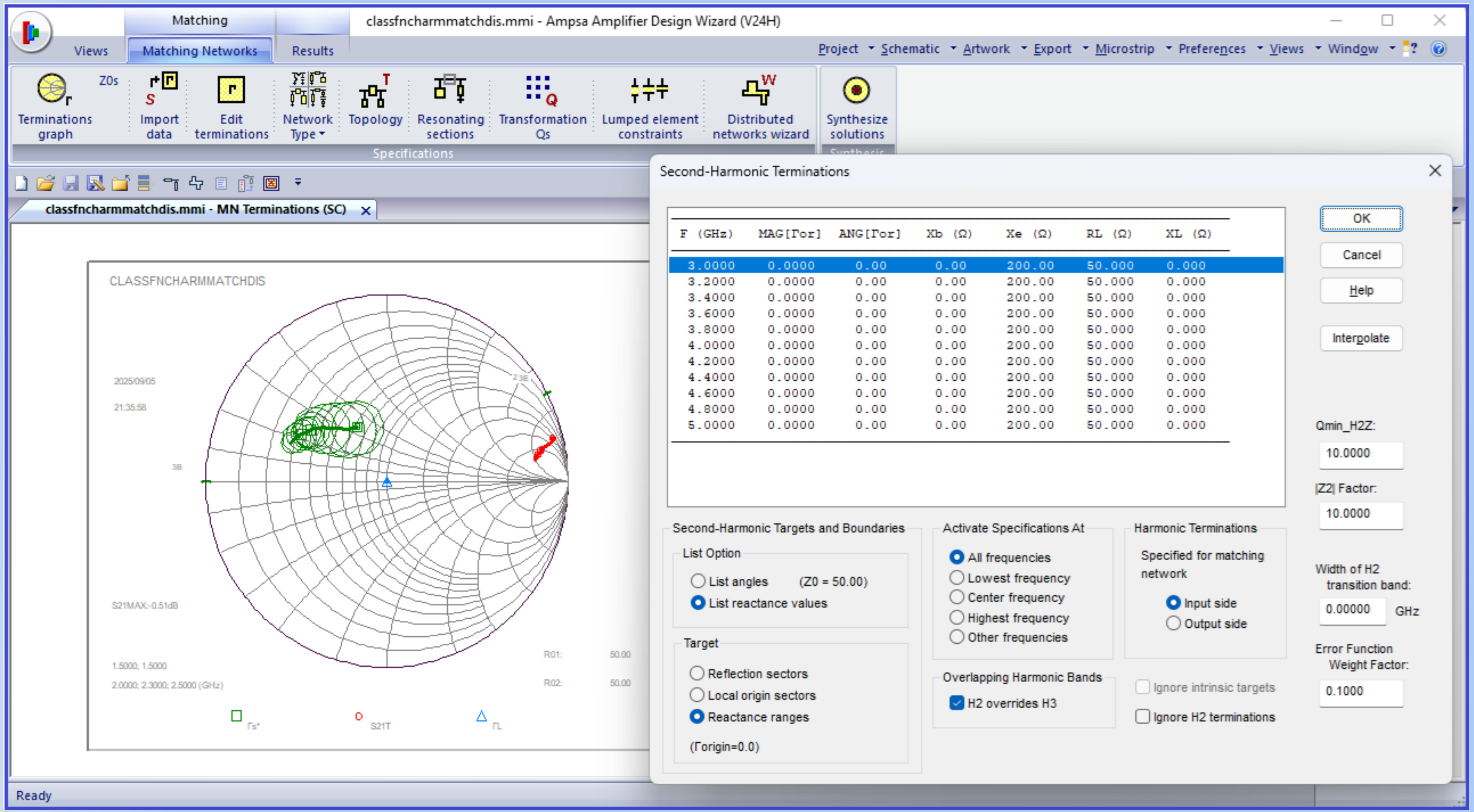


Example 2: Harmonic Control Matching with Non-Commensurate Networks

This slide introduces a matching problem with harmonic control using non-commensurate networks in the ADW and the MW.

- **Passband Specifications**: Terminations must lie within specified circles over the 1.5–2.5 GHz passband.
- **Harmonic Terminations**: Required to be in the first and second quadrants of the Smith chart (inductive impedances).
- **Fundamental Frequency**: Specifications defined for 1.5–2.5 GHz passband.



Example 2: Second-Harmonic Reactance Targets

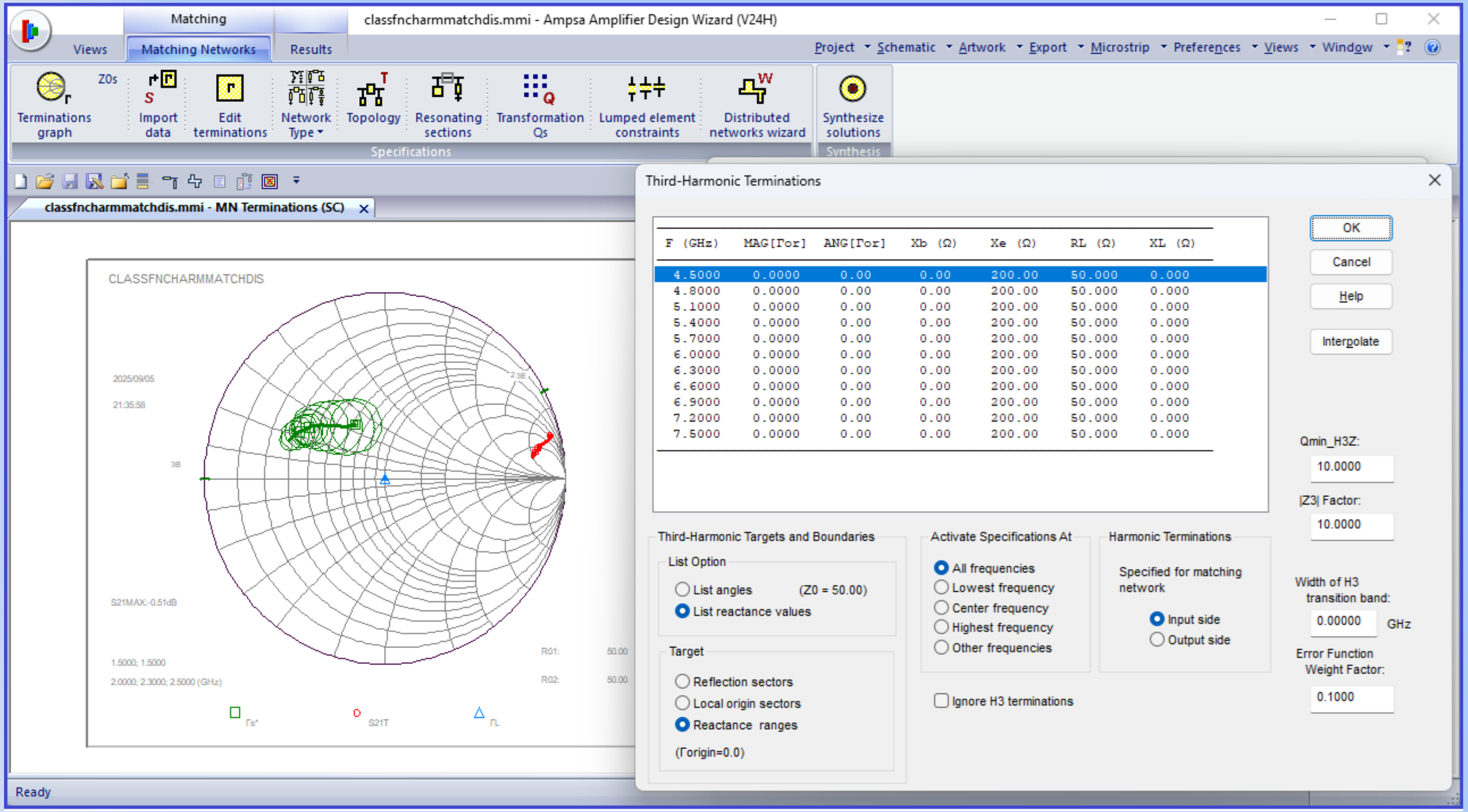
This slide shows the second-harmonic reactance targets for the harmonic control matching problem to be solved.

Reactance Targets:

- Values rotate clockwise from X_b to X_e on the Smith chart at each frequency.
- Minimum Q-value: 10.0 for second-harmonic impedances.
- Minimum Z-factor ($|R_1/Z_2|$ or $|G_1/Y_2|$): 10.0 for second-harmonic impedances.

Error Function Weight:

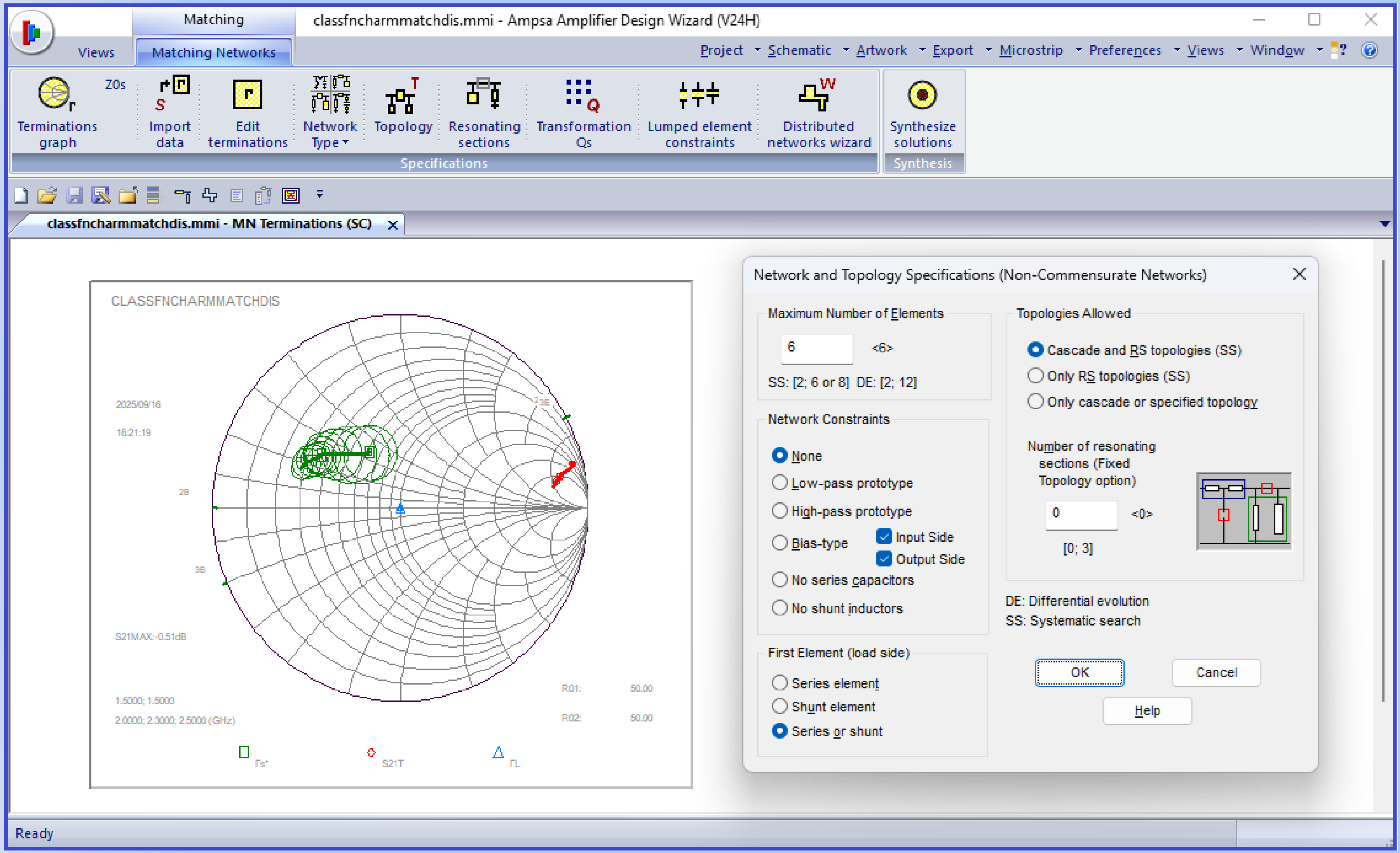
Adjust the weight to get the required compromise between the fundamental-frequency match and the harmonic terminations.



Example 2: Third-Harmonic Reactance Targets

This slide shows the third-harmonic reactance targets for the matching problem.

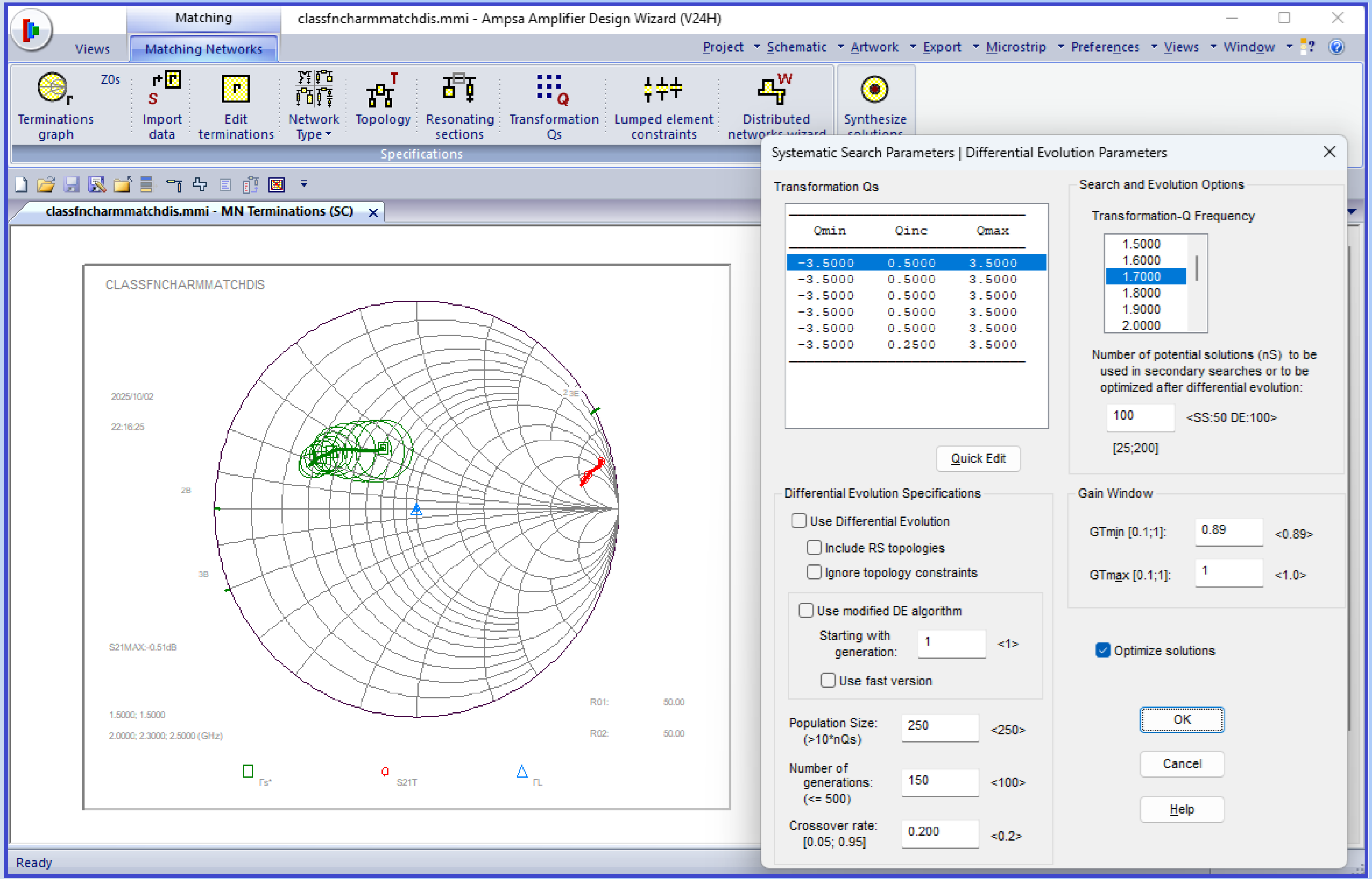
Note that targets were set for all third-harmonic frequencies. If the results are suboptimal, target specific third-harmonic frequencies, ignoring the harmonic control errors at others.



Example 2: Topology Constraints

This slide shows the topology specifications made for the matching problem.

- **Network Configuration**: Networks with up to six elements will be synthesized to meet the passband and harmonic termination requirements. No constraints were imposed on the network elements.
- **Topologies Allowed**: The search or evolution will be done over the standard cascade topology and the resonating section topologies.
- **First Element**: The first element on the load side can be a series or a shunt element.



Example 2: Transformation-Q Specifications

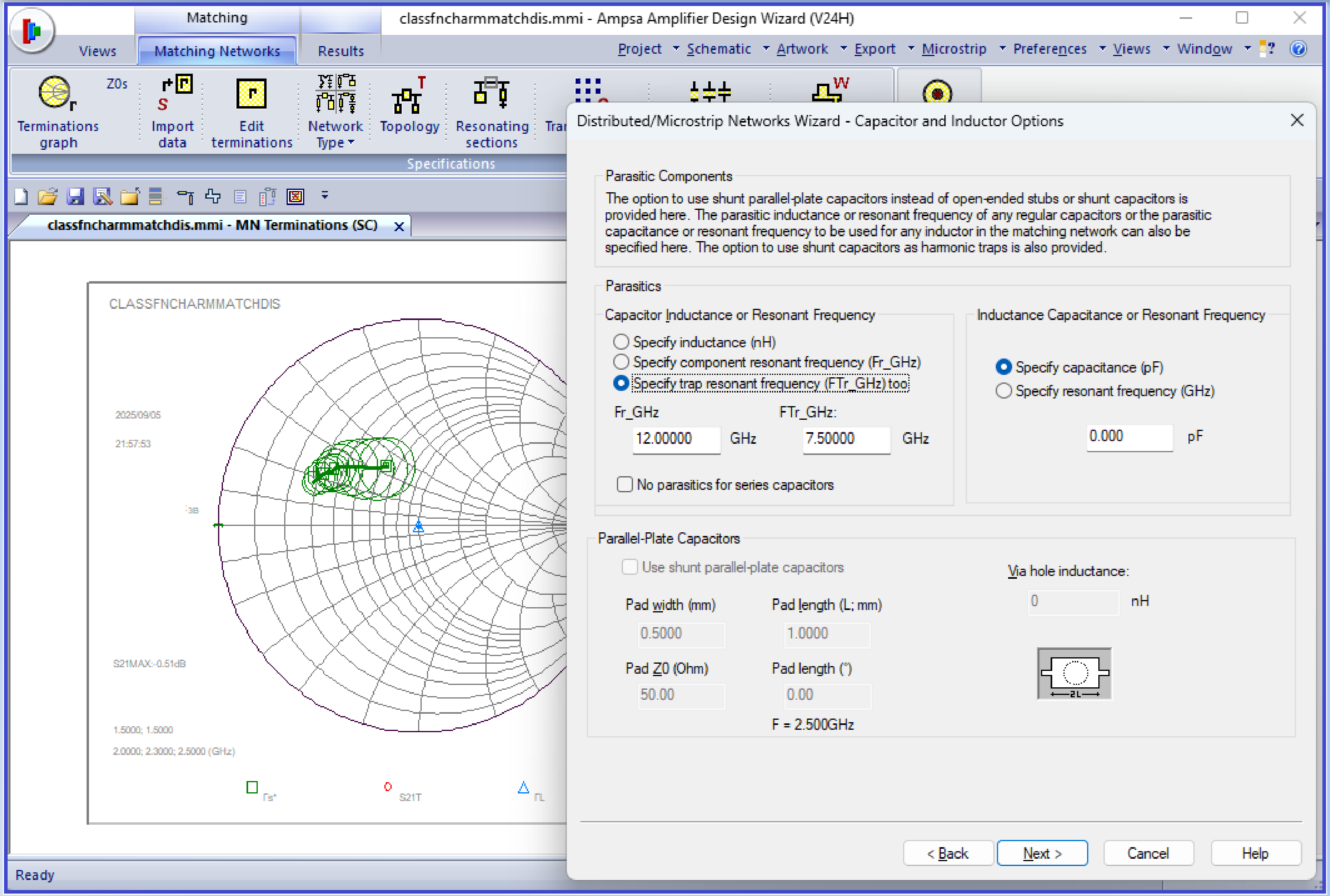
This slide shows the specifications made on the Transformation-Qs page. Solutions will first be synthesized with a systematic search.

Qs: The range for each transformation-Q was set to [-3.5; 3.5]. The *Q*-increment is 0.5.

Gain Window: The gain window is set to [0.89; 1.0].

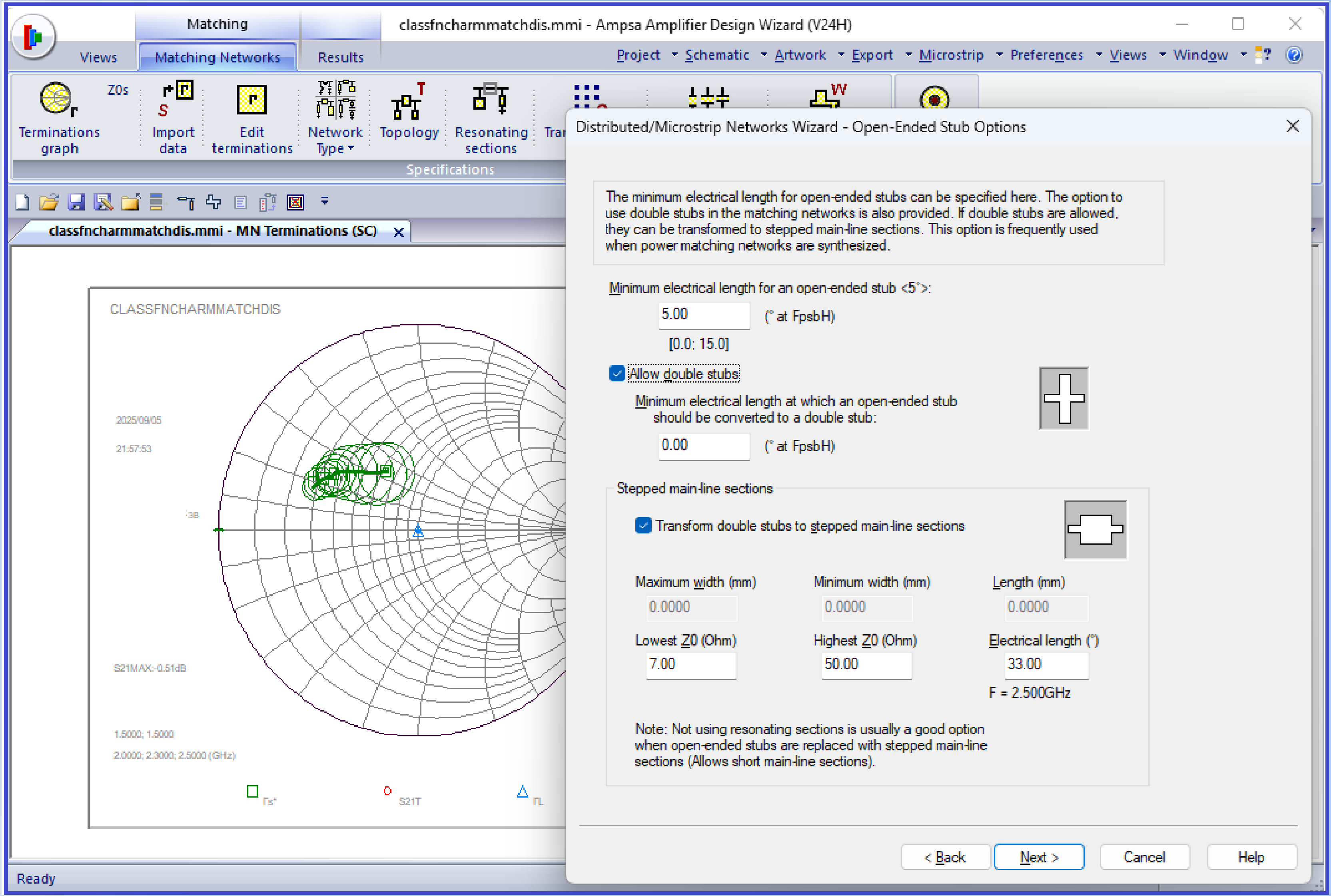
Finer Searches: Finer searches will be performed on the best 100 solutions obtained in the main search.

Optimization: The best solution obtained in each finer search will be optimized.



Example 2: Lumped-element Parasitics and Traps

The resonating frequency (12 GHz) for any lumped capacitors were specified here. When possible, extra inductance will be added to the shunt capacitors to provide transmission nulls at 7.5 GHz.



Example 2: Open-ended Stub Options

Various options for open-ended stubs are provided on this page.

Minimum Length: Open-ended stubs shorter than 5° at the highest passband frequency will be removed from the networks synthesized.

Double Stubs: Double stubs will be allowed in this example. The option to transform these stubs to stepped main-line sections was selected.

Stepped Sections: The range of characteristic impedances for the stepped sections is [7Ω; 50Ω]. Note the line length specified for the stepped sections. Good results are usually obtained with lengths in the range [30°; 45°].

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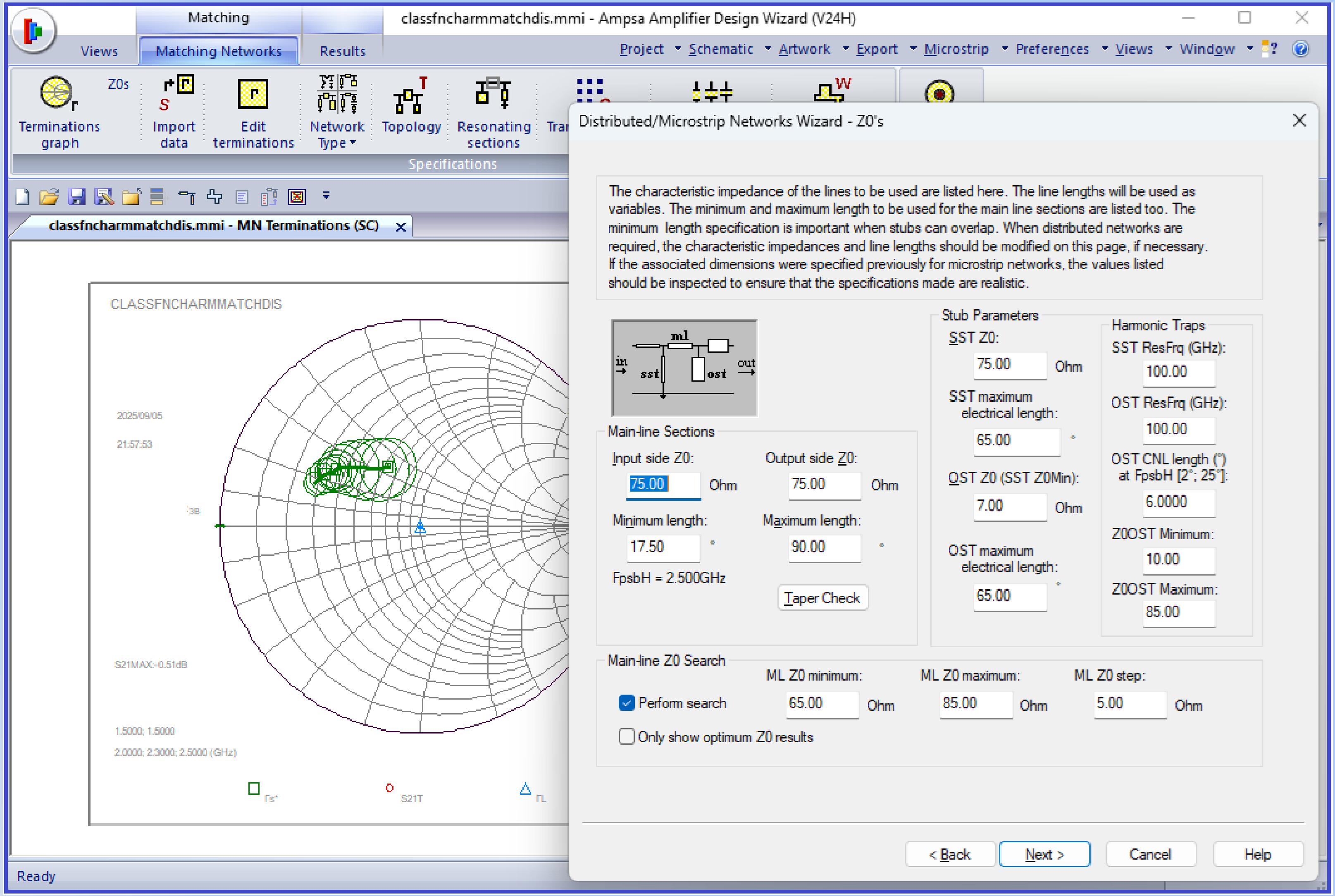


Example 2: Main-Line and Stub Specifications

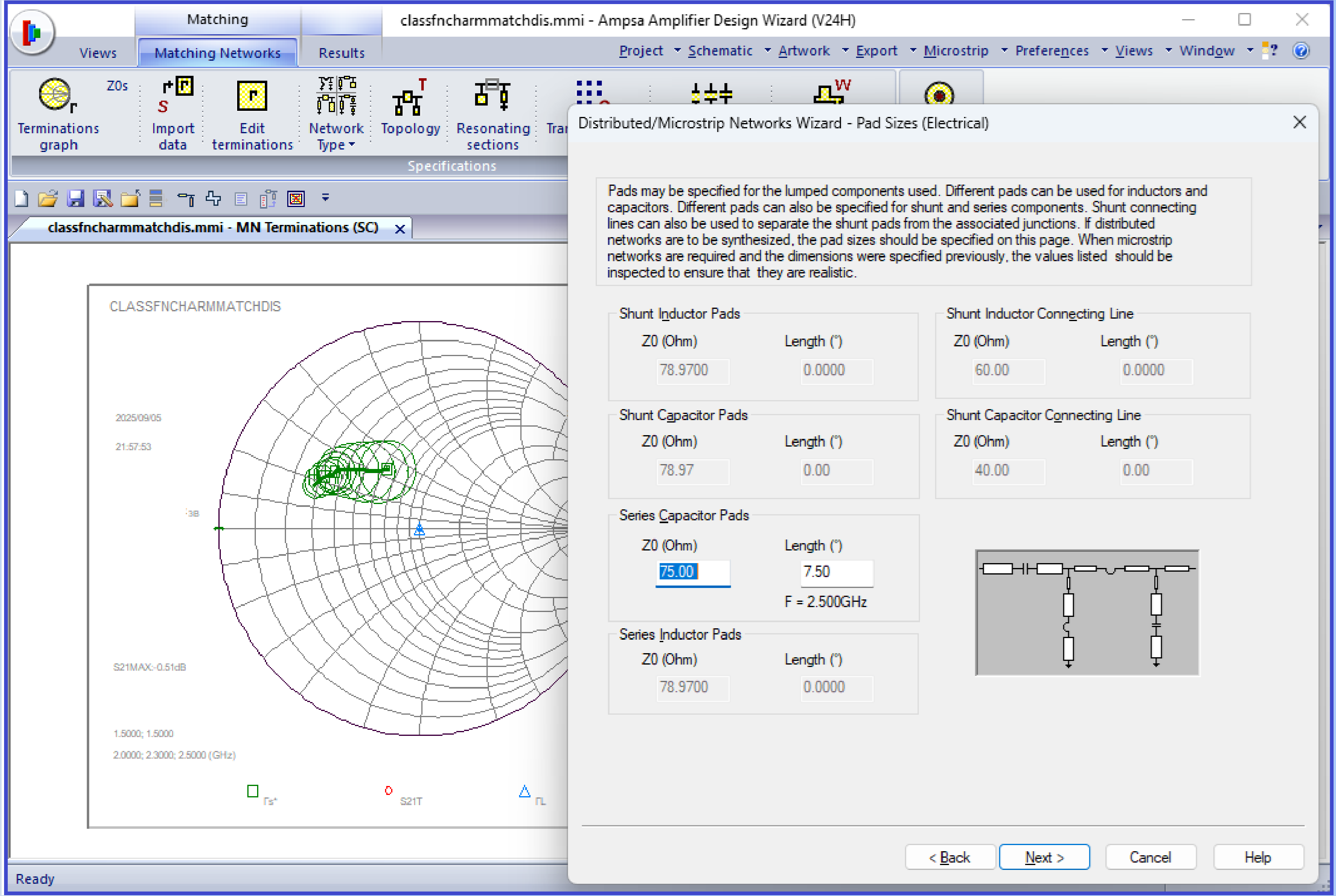
The characteristic impedances and line lengths to be used are specified on this page.

Z0s: The characteristic impedances to be used for the main-line sections and the shorted and open-ended stubs must be specified here. If different Z0s are specified for its input and output side, the main-line will be tapered.

Lengths: Constraints can be imposed on the line lengths. The minimum length for the main-line sections is important. It ensures sufficient separation between consecutive junctions.

Search: The option to search for the best main-line characteristic impedance was selected and the range and step size for this search was set.

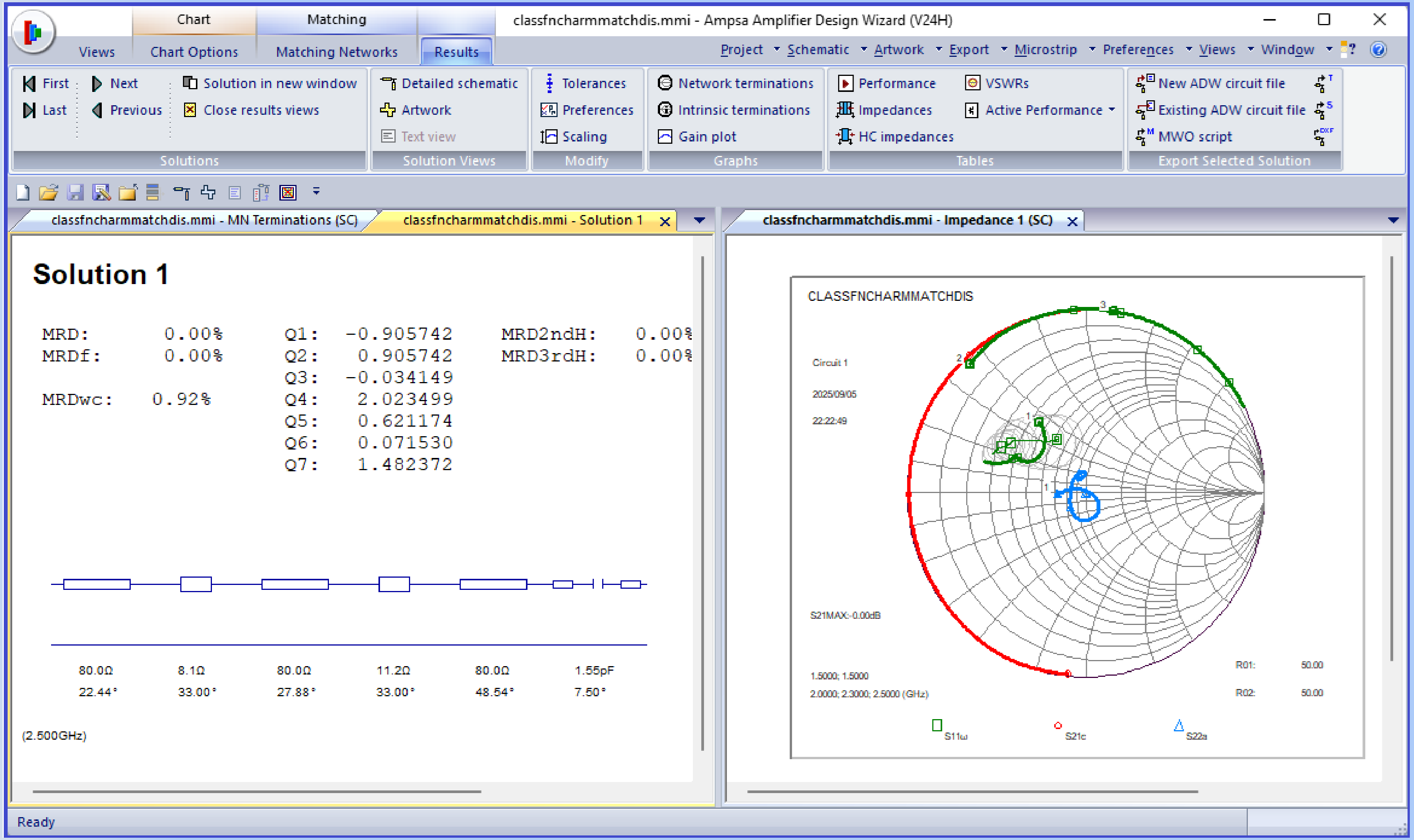
Traps: The stubs will not be used to provide transmission nulls in this example.



Example 2: Lumped-Element Pad Sizes

The pad sizes for lumped elements must be specified on this wizard page. Only series capacitors are allowed in this example.

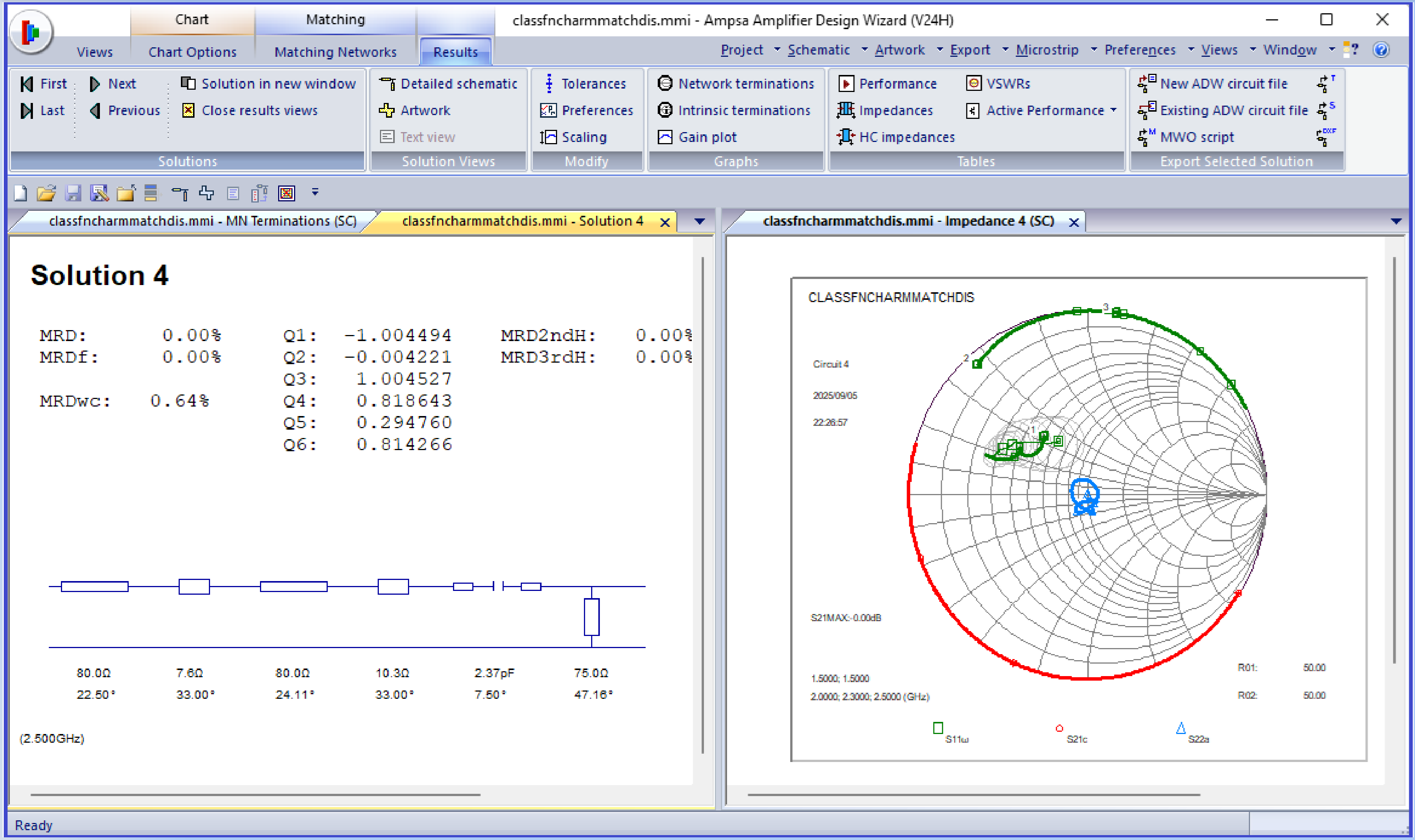
Note: The length specified for the series capacitor pads must ensure sufficient separation between adjacent stubs.



Example 2: Best Six-Element Solution

The first solution obtained with the systematic search is shown here.

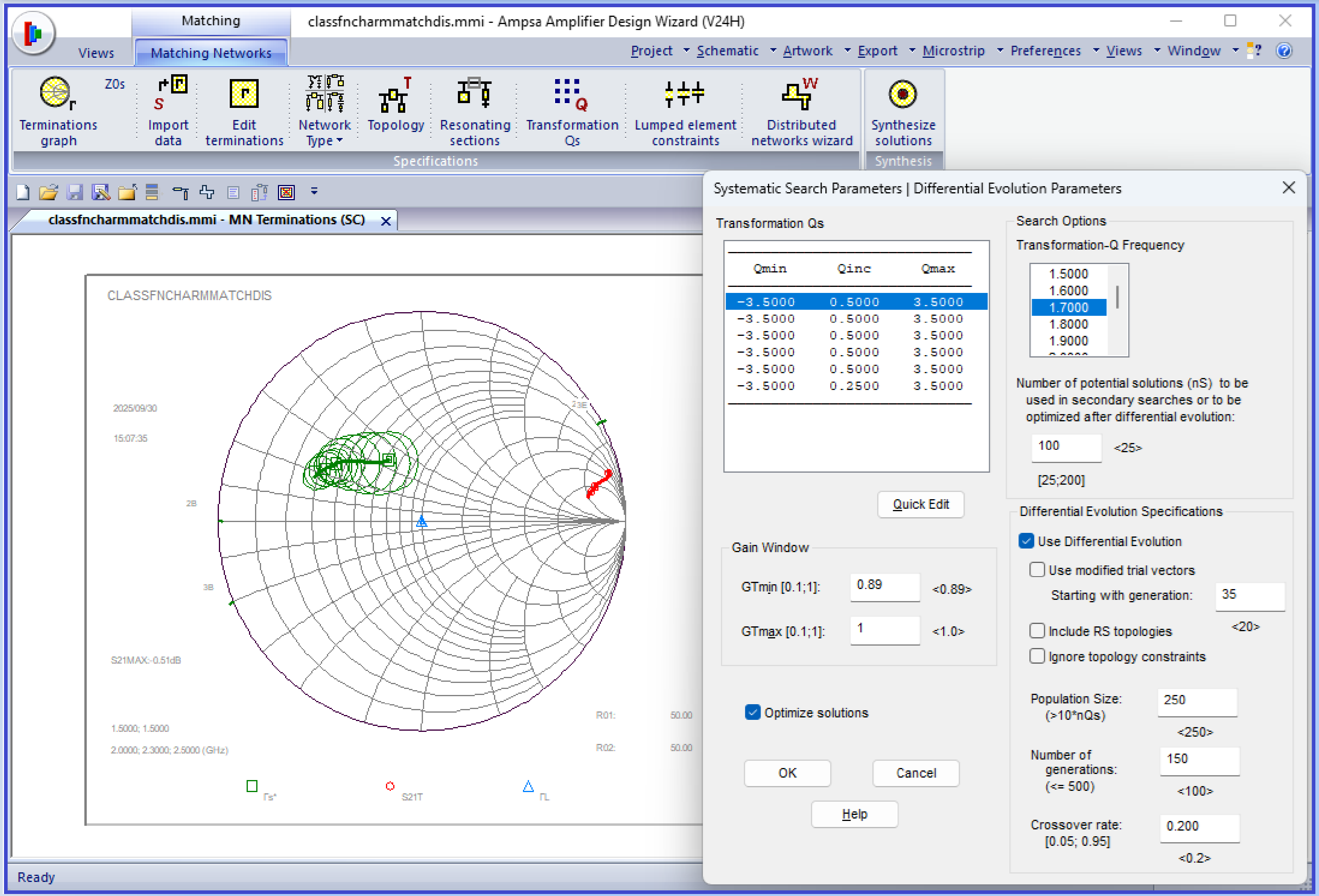
Note that several good solutions were obtained to this problem.



Example 2: Fourth Six-Element Solution

The fourth solution obtained with the systematic search is shown here.

The topology differs from those obtained previously.



Example 2: Differential Evolution Solutions

Solutions will be synthesized next by using differential evolution. The specifications made on the Transformation-Qs page are shown here.

Resonating Sections: Resonating sections will be allowed.

Note: The main-line impedance was fixed to 80 Ω (Line and Stub specifications) but searching for the best characteristic impedance is also allowed with differential evolution.

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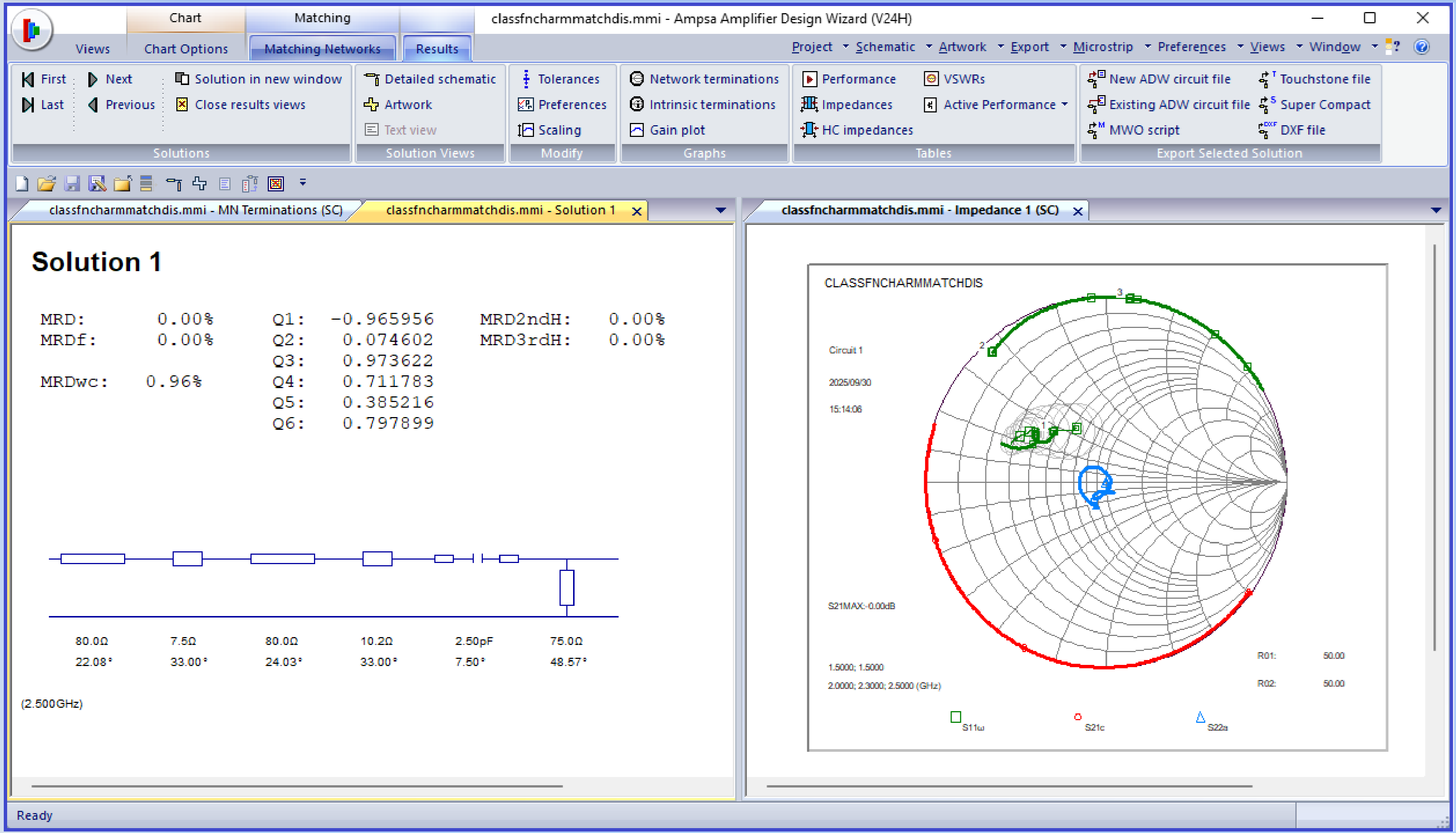

Example 2: Best Six-Element DE Solution

The first solution obtained with differential evolution is shown here.

The topology is like that of the fourth solution obtained with the systematic search and the performance is similar.

Generation	Minimum Error	Average Error	Maximum Error	Evolved (%)
1	0.2174	0.8297	1.0073	40.00
5	0.2012	0.6634	1.0000	27.60
10	0.1679	0.5338	1.0000	19.20
15	0.1679	0.4504	1.0000	16.00
20	0.1453	0.4121	1.0000	12.40
25	0.0695	0.3819	1.0000	14.00
30	0.0536	0.3604	0.7984	14.40
35	0.0536	0.3387	0.7690	13.20
40	0.0497	0.3288	0.7690	10.40
45	0.0497	0.3160	0.7690	8.80
50	0.0497	0.3065	0.7690	6.80
55	0.0497	0.2988	0.7534	5.60
60	0.0497	0.2924	0.6365	5.60
65	0.0497	0.2882	0.6365	4.40
70	0.0497	0.2810	0.6365	6.40
75	0.0497	0.2742	0.6365	4.40
80	0.0497	0.2661	0.6365	4.80
85	0.0497	0.2590	0.6365	4.40
90	0.0437	0.2510	0.6365	7.20
95	0.0144	0.2465	0.6365	4.00
100	0.0144	0.2420	0.5219	2.80
105	0.0144	0.2372	0.5053	2.80
110	0.0144	0.2289	0.5053	5.20
115	0.0144	0.2237	0.5053	2.80
120	0.0144	0.2181	0.4563	4.40
125	0.0131	0.2116	0.3804	3.20
130	0.0131	0.2074	0.3804	2.40
135	0.0131	0.2016	0.3804	2.40
140	0.0131	0.1986	0.3804	2.40
145	0.0131	0.1947	0.3706	2.00
150	0.0131	0.1872	0.3706	3.20

Example 2: Population Fitness Improvement

This slide lists fitness improvements for population members across generations in the differential evolution process.

Optimization Impact: The minimum error improved from 1.31% to 0.0%.

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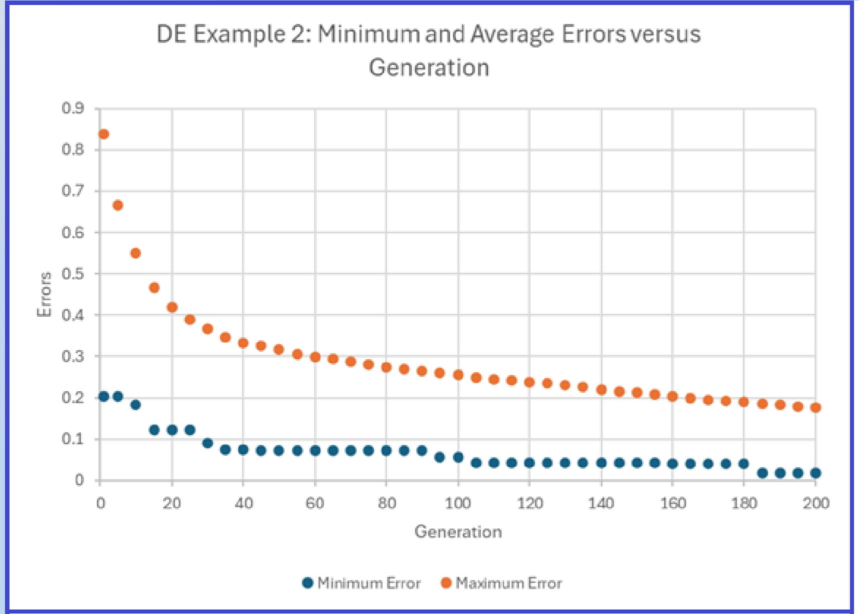
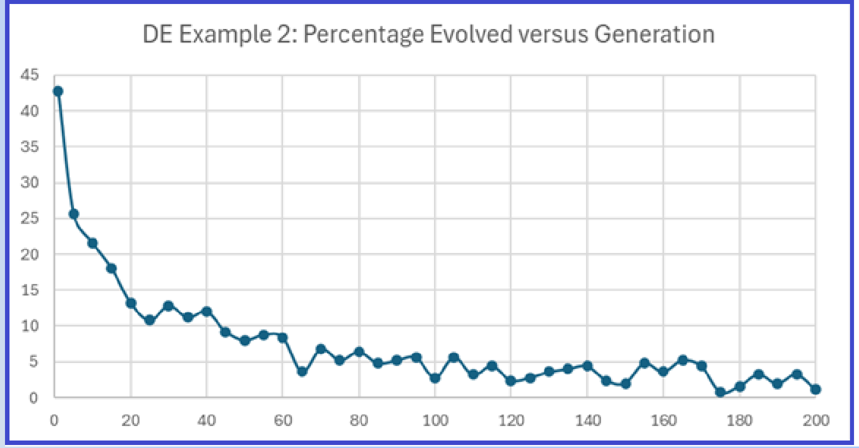
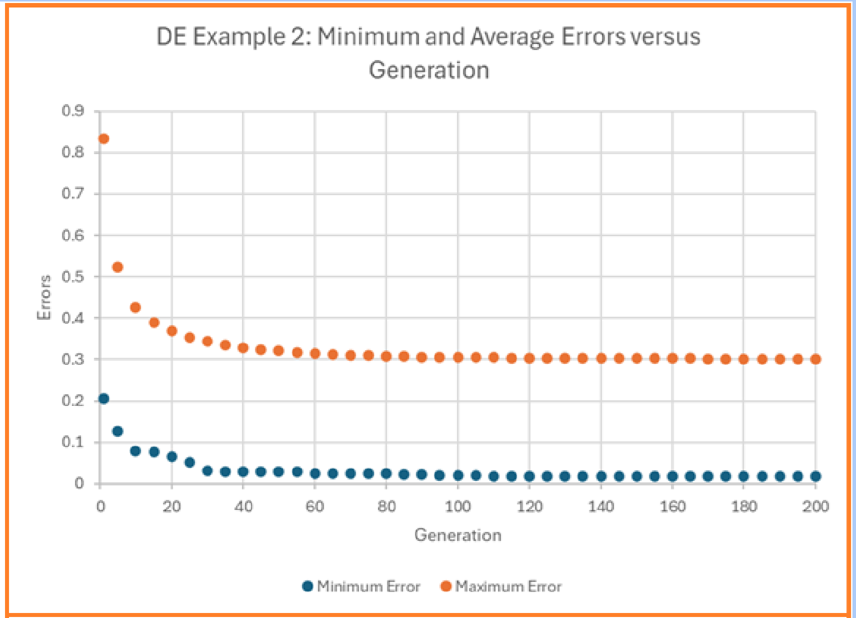
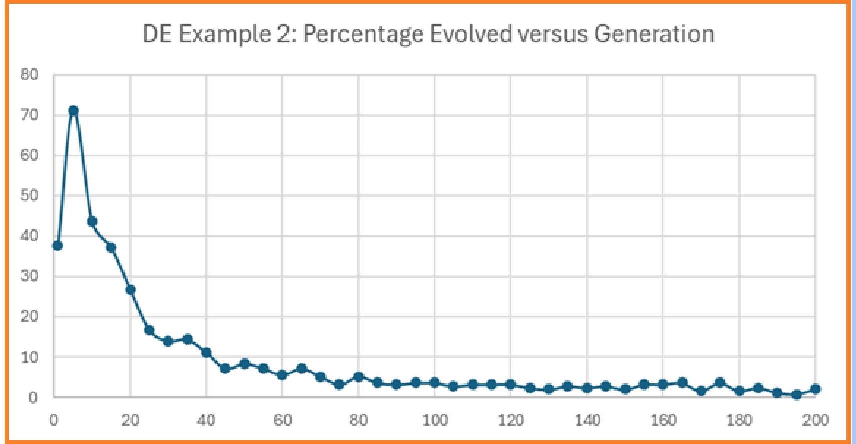






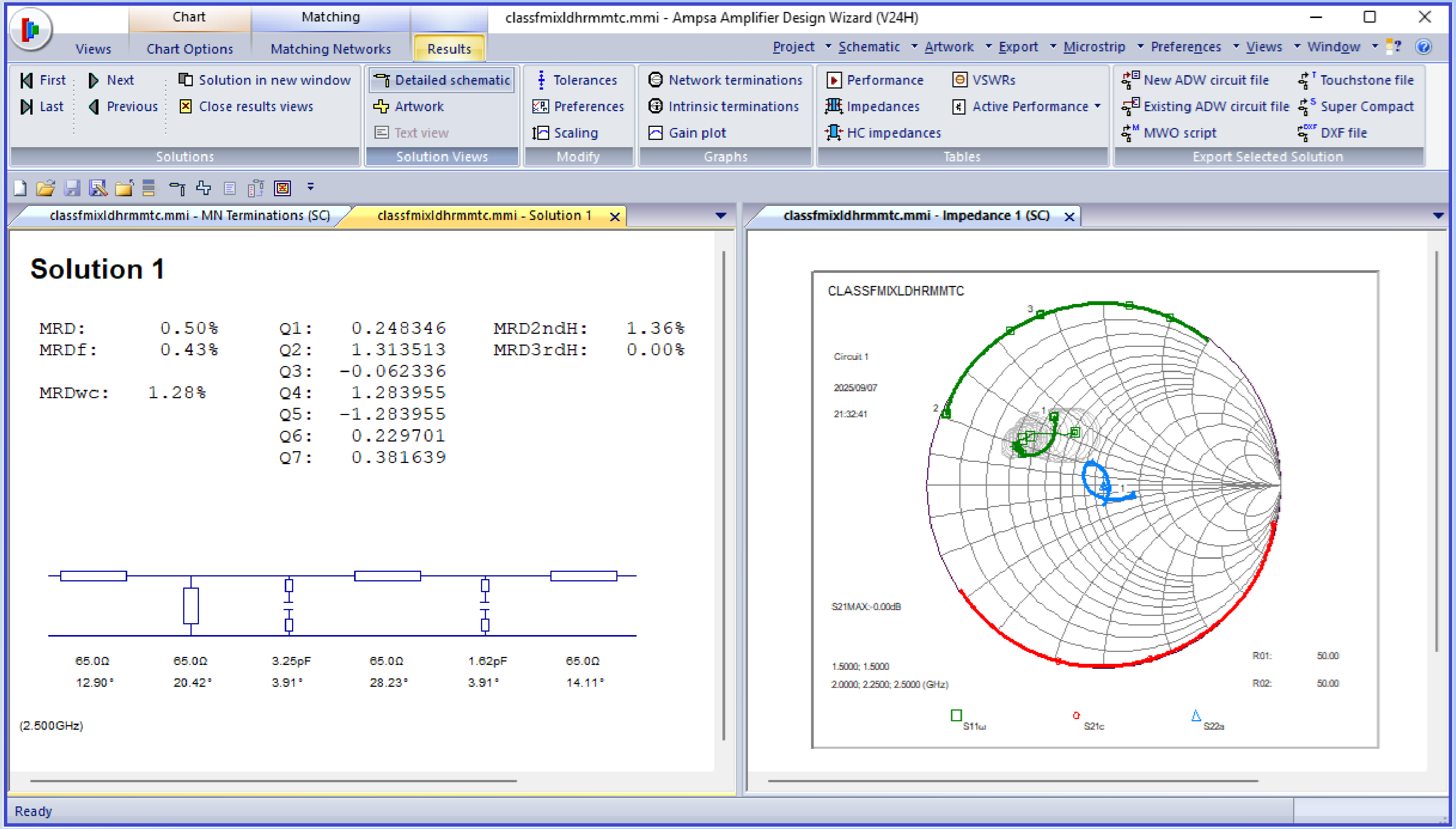


Example 2: Population Fitness Improvement

The minimum and average errors and the percentage of the population that evolved in each generation were plotted in the graphs shown here. The evolution was for seven elements and a fixed topology.

The fitness improvements with the standard DE algorithm is shown on the left. The graphs on the rights apply to the modified DE algorithm.

The minimum errors obtained are similar, but the average errors associated with the standard algorithm are significantly better. The performance with the modified algorithm stabilized much sooner.

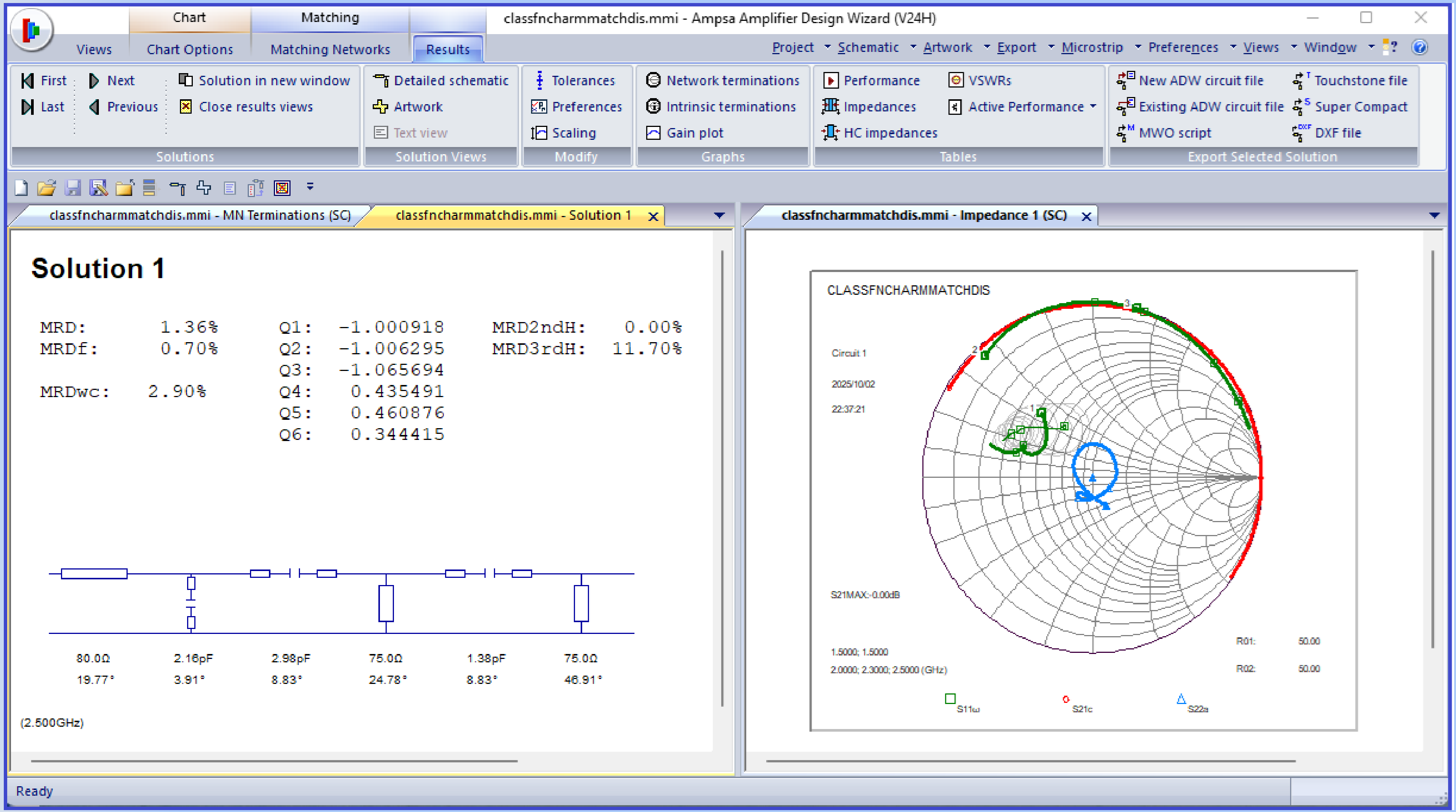


Example 2: Mixed Lumped/Distributed Solutions

The specifications were changed to synthesize mixed lumped/distributed solutions to the problem (Open stubs replaced with padded capacitors).

Resonating sections were allowed in the systematic search.

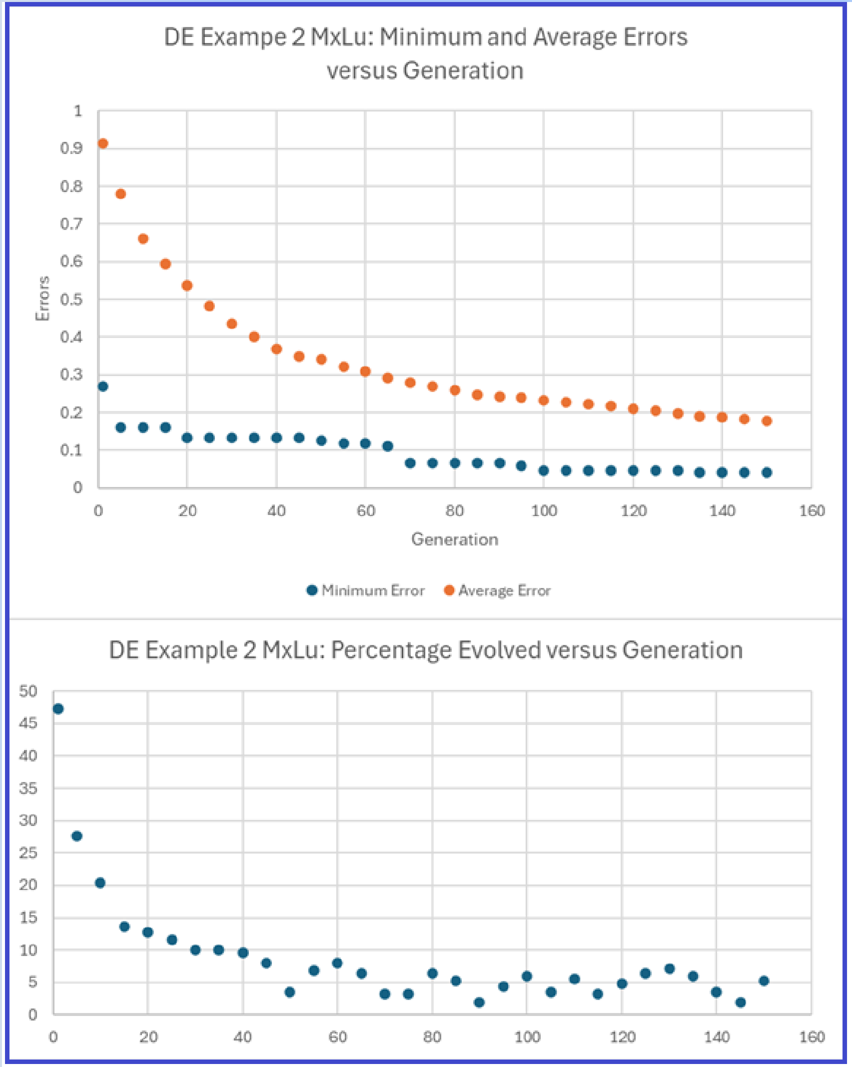
Systematic search: The first solution obtained with a systematic search is shown here. The performance is like those of the solutions presented earlier.

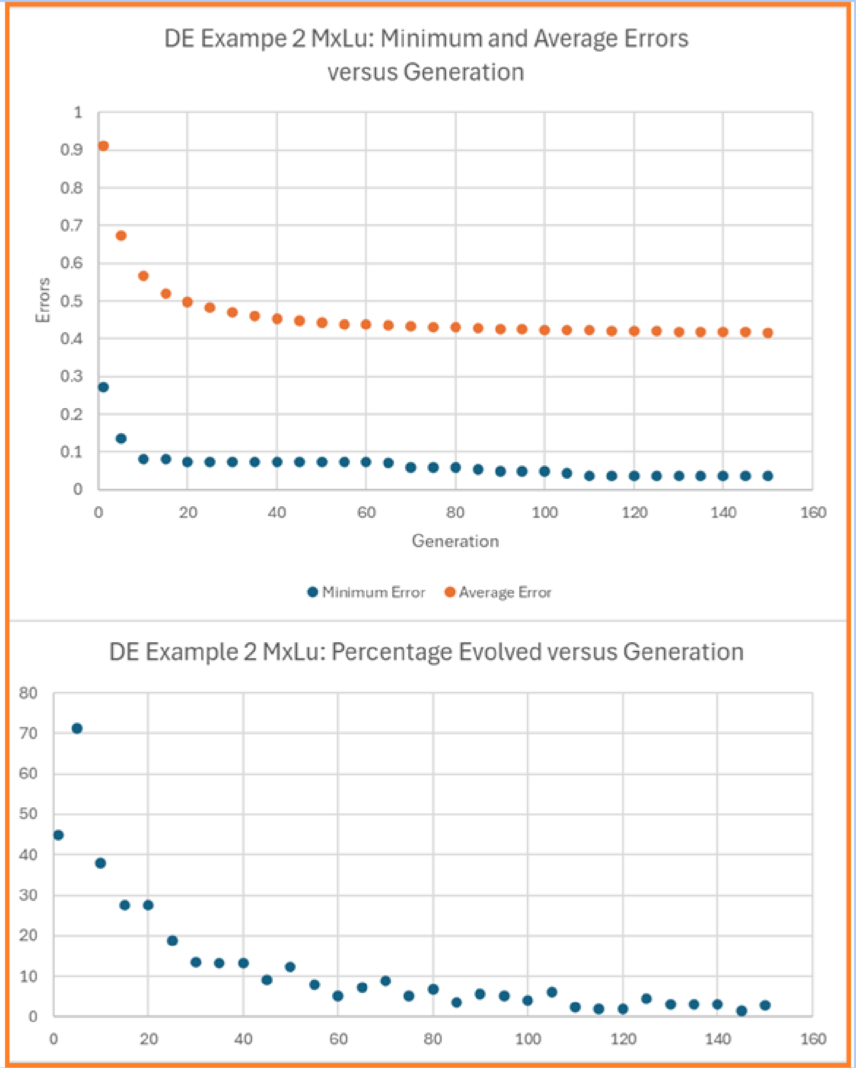


Example 2: Mixed Lumped/Distributed DE Solutions

The first mixed lumped/distributed solution obtained with differential evolution is shown here.

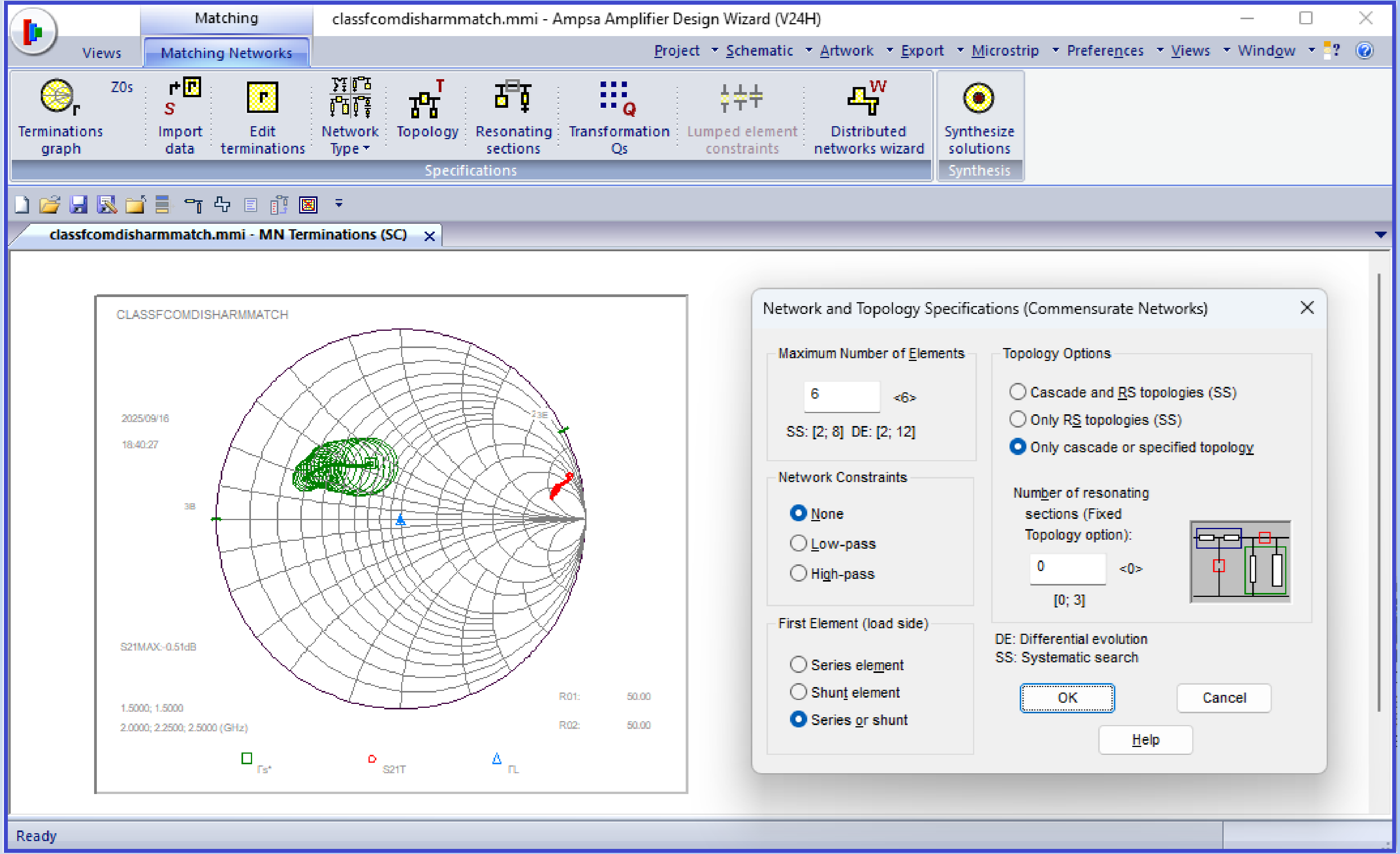
Resonating sections were not allowed, and the number of elements was set to six.





Example 2: Population Fitness Improvement

The minimum and average errors and the percentage of the population that evolved in each generation were plotted in the graphs shown here. The fitness improvements with the standard DE algorithm is shown on the left. The graphs on the rights apply to the modified DE algorithm.

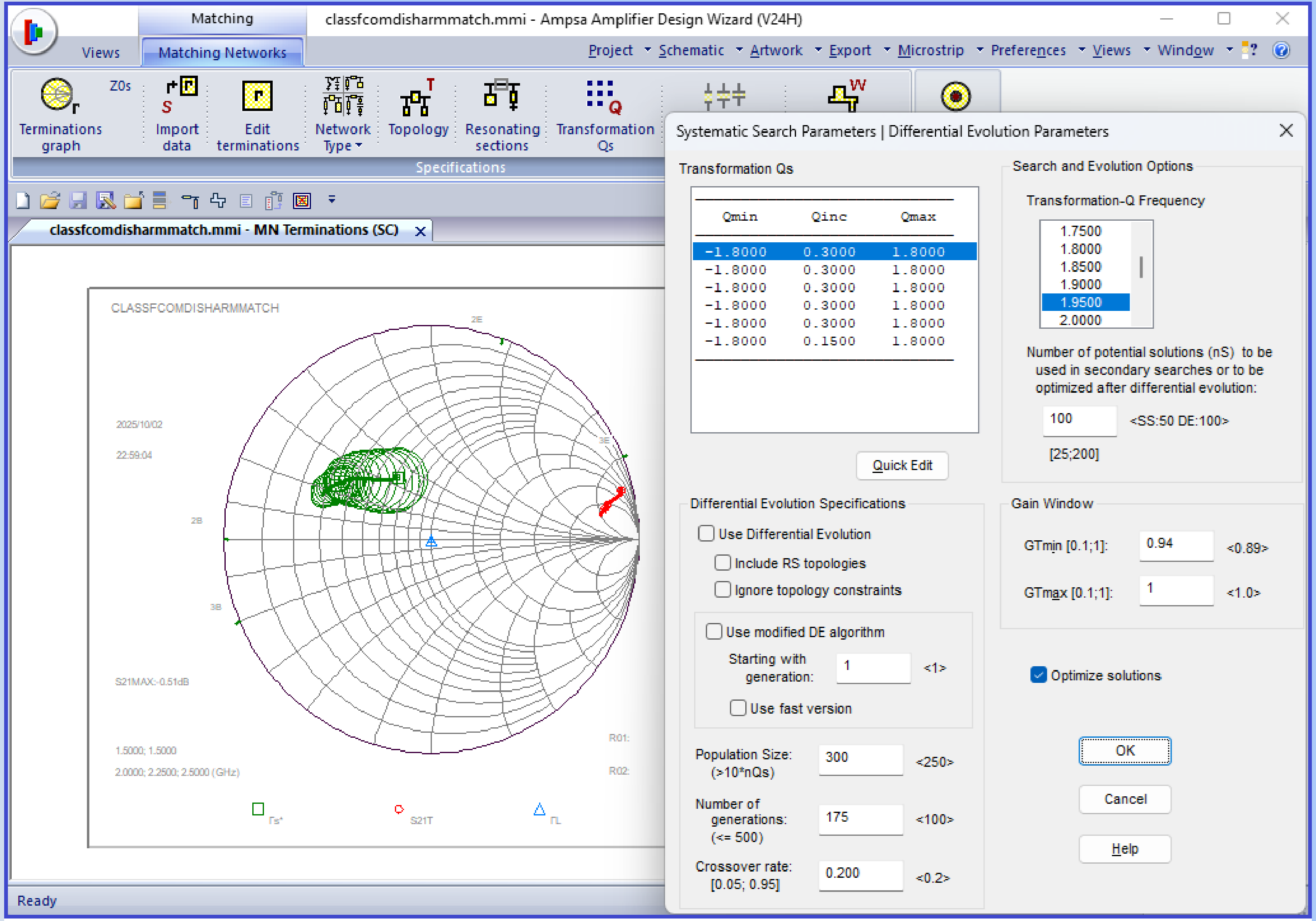


Example 3 – Harmonic Control Matching With Commensurate Networks

The problem in Example 2 will be solved with commensurate networks in this example.

Networks with up to six elements will be synthesized. No constraints will be imposed on the element types. The first element on the load side could be series or shunt.

The resonation section topologies will not be included in the search.



EXAMPLE 3 – Transformation-Q Specifications

This slide shows the specifications made on the Transformation-Qs page. Solutions will first be synthesized with a systematic search.

Qs: Based on the results obtained in a previous synthesis cycle, the range for each transformation-Q *was* reduced to [-1.8; 1.8].

Gain Window: [0.94; 1.0].

Number of Main-Search Solutions to be Refined with Secondary Searches: 100.

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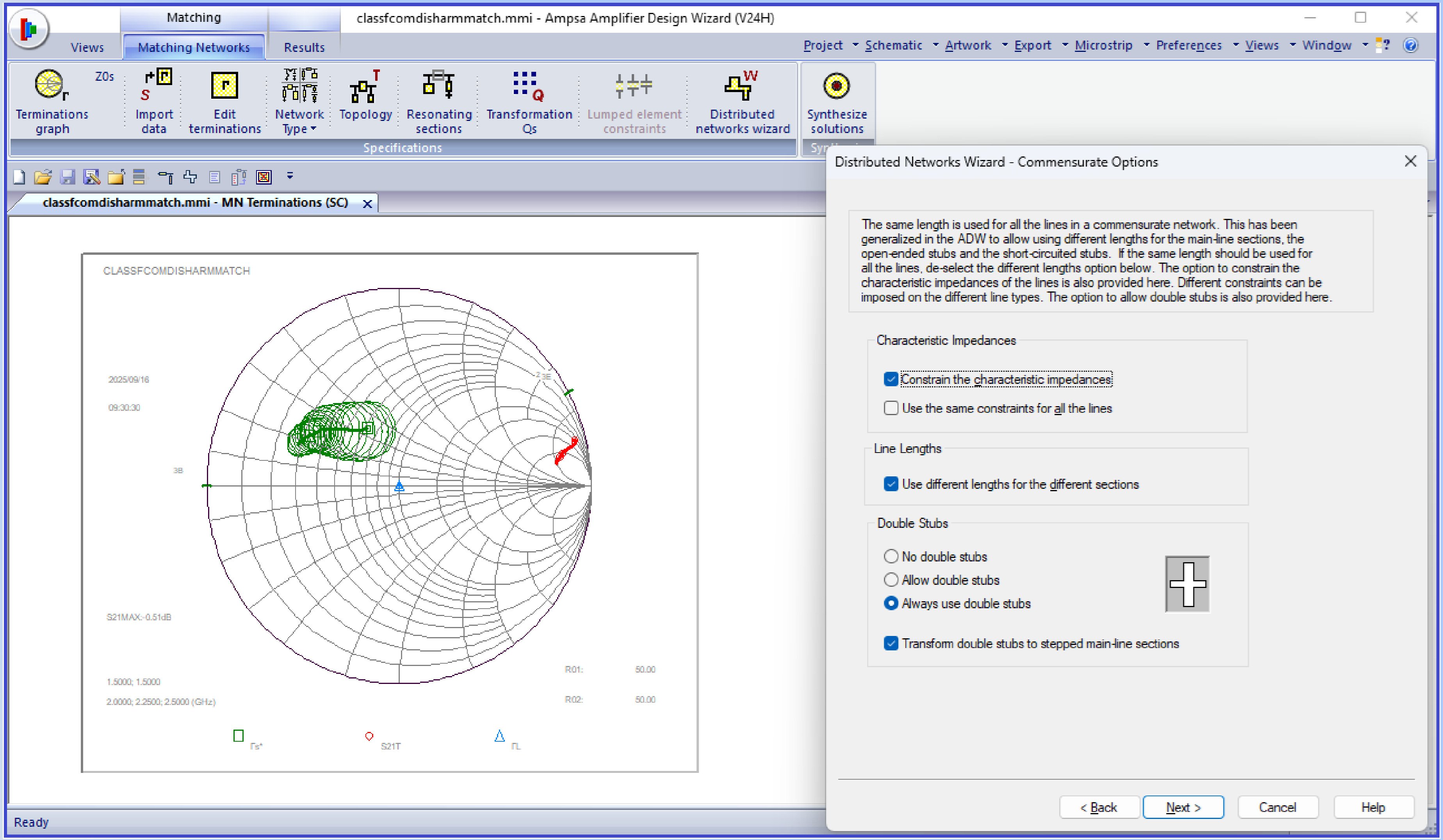
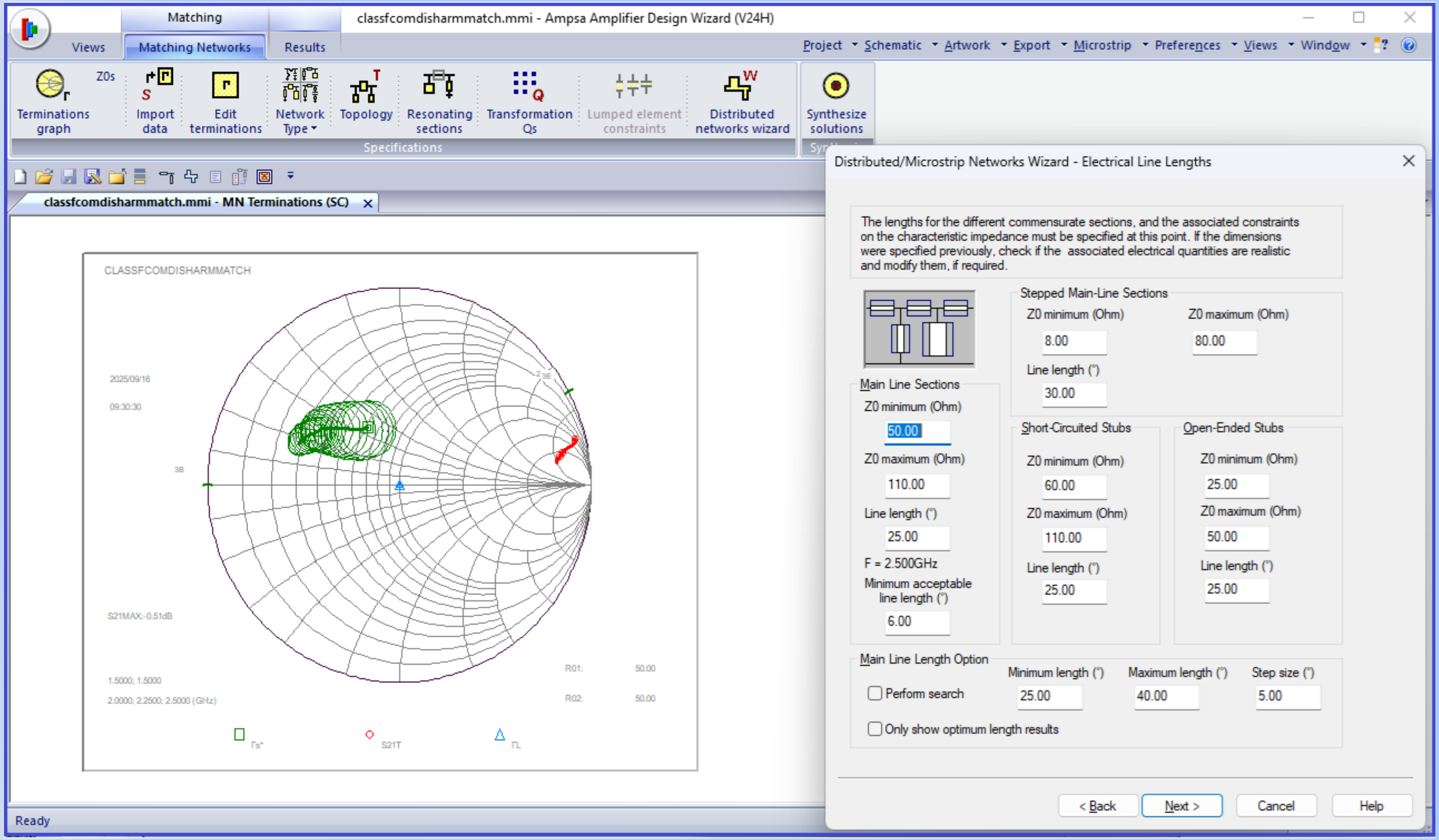


Example 3 – Constraints and Double-Stub Options

Z0s: The characteristic impedances will be constrained. Different constraints will be used for the main-line sections and the shorted and open-ended stubs.

Line Length: Different lengths will be used for the main-line sections, the open-ended stubs, the shorted stubs and the equivalent main-line sections.

Double Stubs: The option to transform double stubs to stepped main-line sections was selected here. The double stubs will be transformed to stepped main-line sections.



Example 3 – Main-Line and Stub Specifications

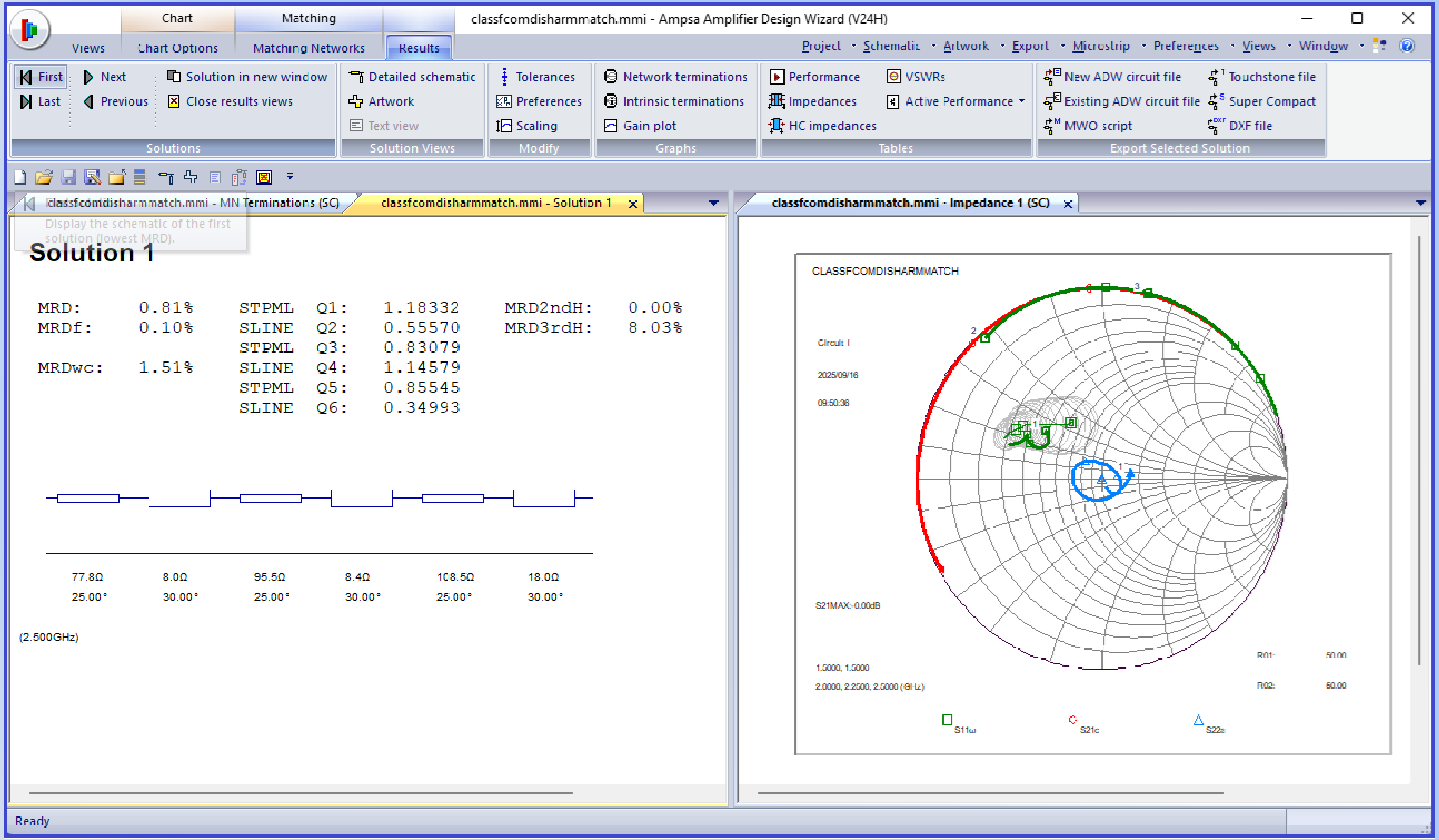
The line lengths and the range of characteristic impedances allowed for the different element types are shown here.

Main-Line Length: The search option can be used to find the optimum length for the main-line sections.

Stepped Sections Length: Experimentation with the length of the stepped sections is also required.

The specifications shown (25°; 30°) yielded good results.

Note: Short lines and stubs will yield results like lumped networks if the characteristic impedances are not constrained.



Example 3 – Best Six- Element Systematic Search Solution

The best solution obtained with the systematic search is shown here.

Note: The wide lines are the main-line equivalents for the open-ended stubs.

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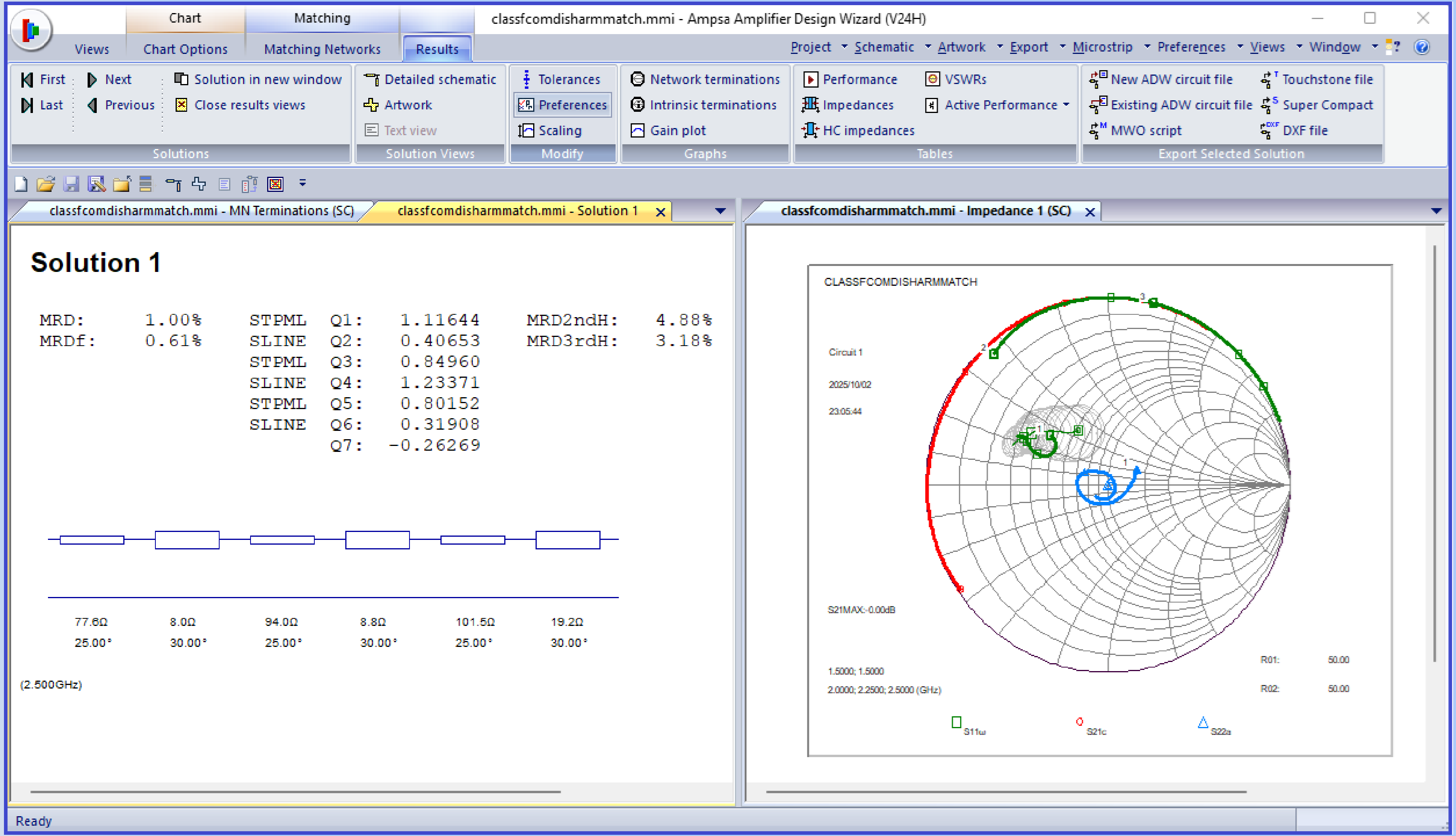


Example 3 – Best Six-Element DE Solution

The best differential evolution solution obtained is shown in this slide. The performance of this solution is like that obtained with the systematic search (*MRD*: 1.00% vs 0.81%).

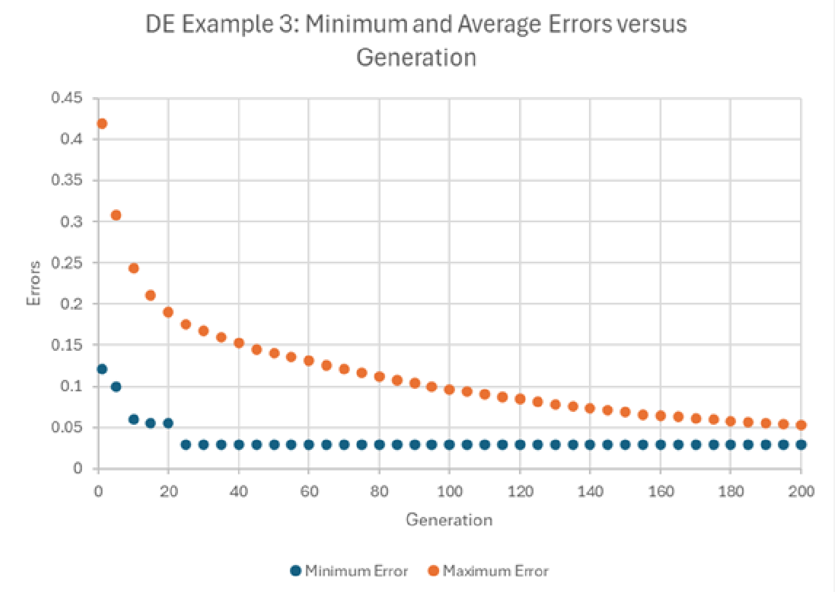
Specifications: The number of elements was increased to seven and the topology was fixed (no explicit resonating sections). The number of solutions to be optimized was also increased to 150 and the number of generations was set to 200.

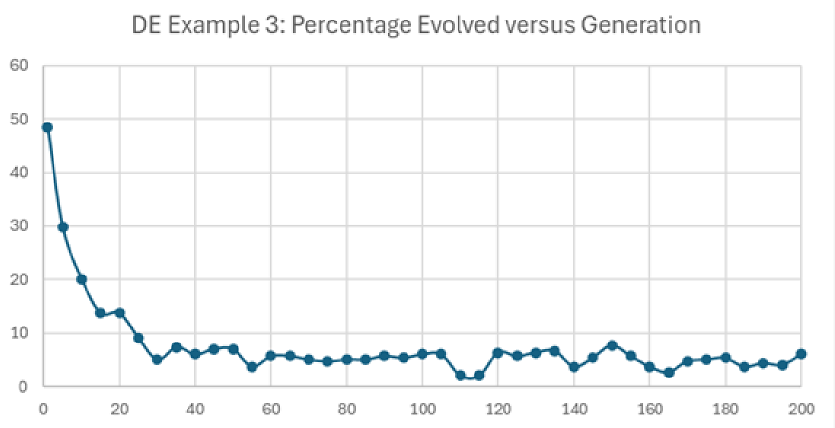
Generation	Minimum Error	Average Error	Maximum Error	Evolved (%)
1	0.1208	0.4186	0.7490	48.49
5	0.0993	0.3084	0.6682	29.77
10	0.0598	0.2430	0.6672	20.07
15	0.0550	0.2110	0.4540	13.71
20	0.0550	0.1906	0.4163	13.71
25	0.0296	0.1752	0.4024	9.03
30	0.0296	0.1672	0.3888	5.02
35	0.0296	0.1590	0.3709	7.36
40	0.0296	0.1523	0.3709	6.02
45	0.0296	0.1452	0.3709	7.02
50	0.0296	0.1405	0.3709	7.02
55	0.0296	0.1355	0.3709	3.68
60	0.0296	0.1311	0.3709	5.69
65	0.0296	0.1251	0.3279	5.69
70	0.0296	0.1210	0.3279	5.02
75	0.0296	0.1163	0.2781	4.68
80	0.0296	0.1115	0.2757	5.02
85	0.0296	0.1073	0.2757	5.02
90	0.0296	0.1037	0.2592	5.69
95	0.0296	0.0997	0.2538	5.35
100	0.0296	0.0961	0.2538	6.02
105	0.0296	0.0933	0.2538	6.02
110	0.0296	0.0901	0.2538	2.01
115	0.0296	0.0870	0.2538	2.01
120	0.0296	0.0847	0.2538	6.35
125	0.0296	0.0813	0.2538	5.69
130	0.0296	0.0783	0.2538	6.35
135	0.0296	0.0754	0.2538	6.69
140	0.0296	0.0738	0.2538	3.68
145	0.0296	0.0710	0.2538	5.35
150	0.0296	0.0686	0.2538	7.69
155	0.0296	0.0660	0.2538	5.69
160	0.0296	0.0642	0.2538	3.68
165	0.0296	0.0627	0.2538	2.68
170	0.0296	0.0612	0.2477	4.68
175	0.0296	0.0595	0.1962	5.02
180	0.0296	0.0574	0.1962	5.35
185	0.0296	0.0562	0.1962	3.68
190	0.0296	0.0548	0.1962	4.35
195	0.0296	0.0539	0.1962	4.01
200	0.0296	0.0531	0.1893	6.02

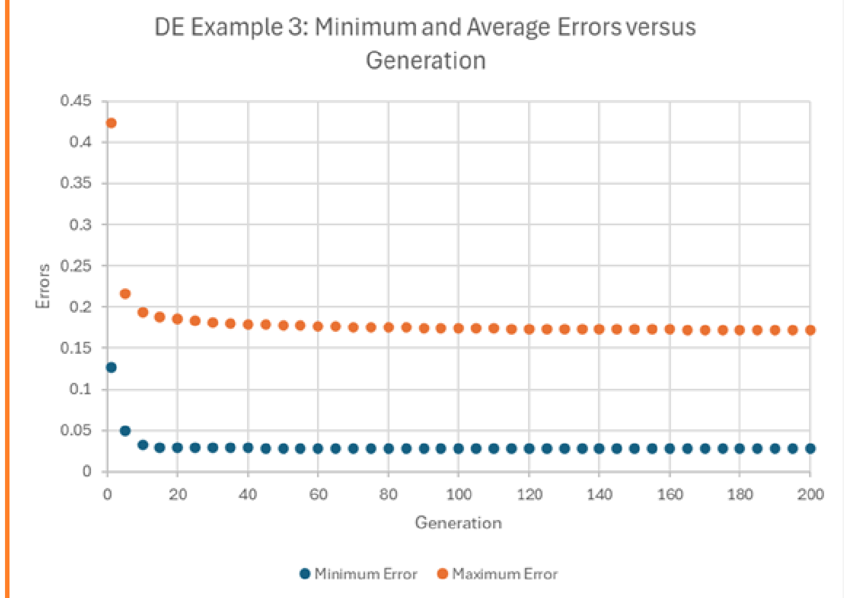
Example 3: Population Fitness Improvement

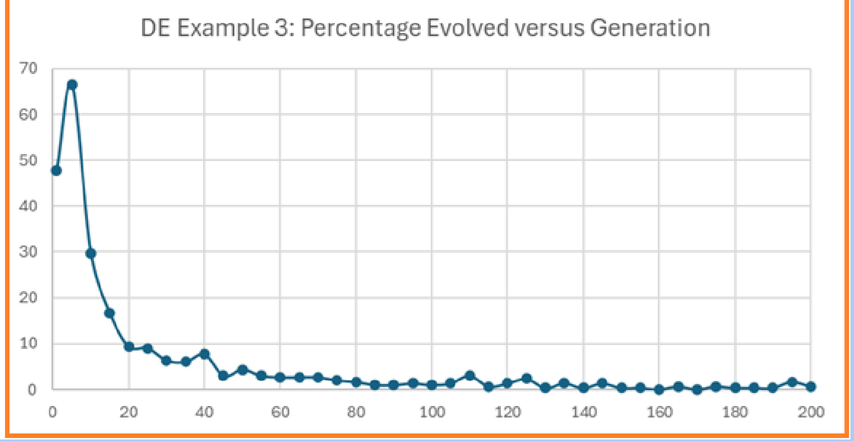
This slide lists fitness improvements for population members across generations in the differential evolution process.

Optimization Impact: The minimum error improved significantly from 2.96% to 1.0%.



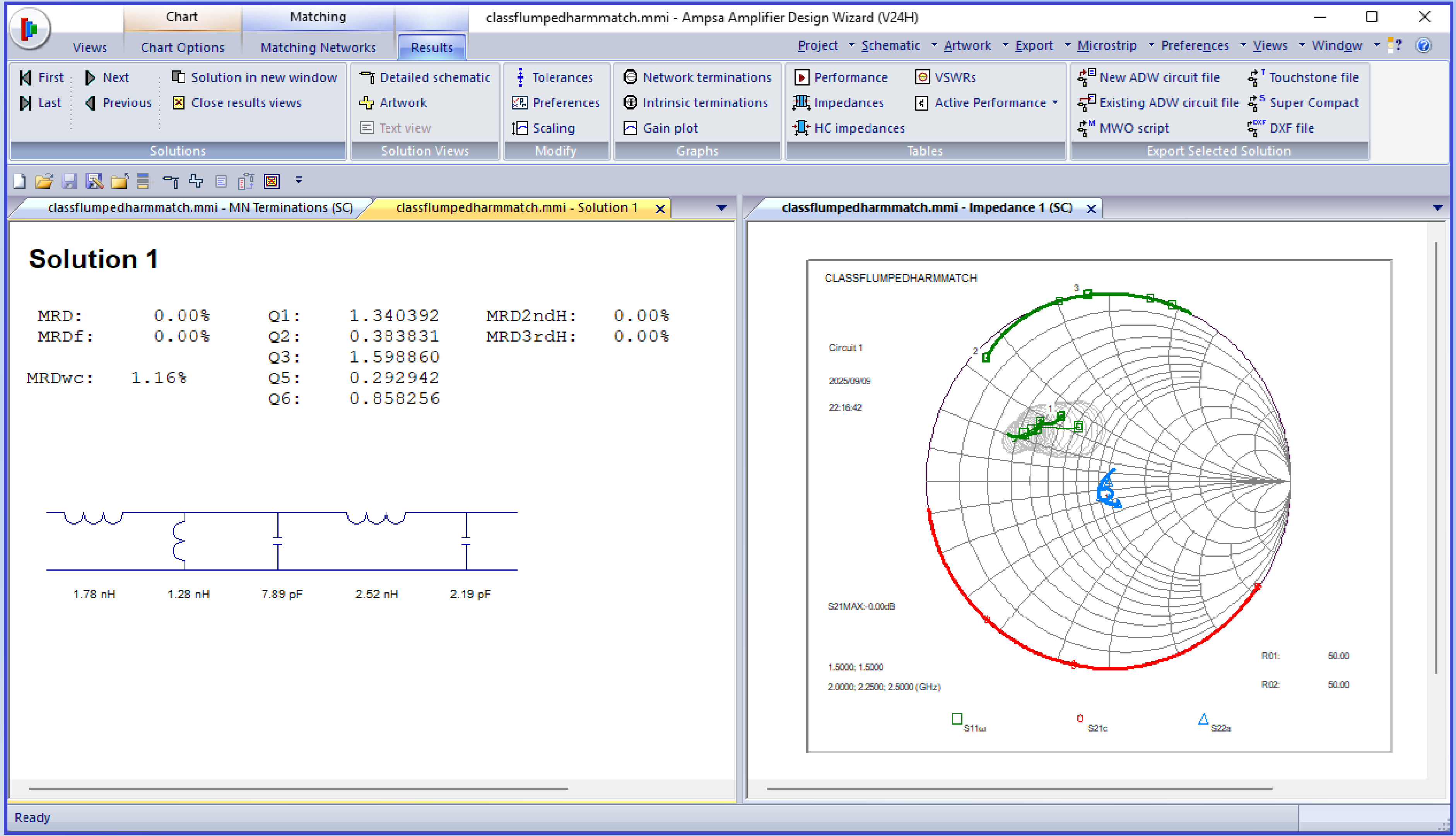






Example 3: Population Fitness Improvement

The minimum and average errors and the percentage of the population that evolved in each generation were plotted in the graphs shown here. The fitness improvements with the standard DE algorithm is shown on the left. The graphs on the rights apply to the modified DE algorithm.



Example 3 – Best Five-Element Lumped Solution

The best five-element lumped-element solution obtained with a systematic search is shown here to provide an idea of what could be done with lumped elements.

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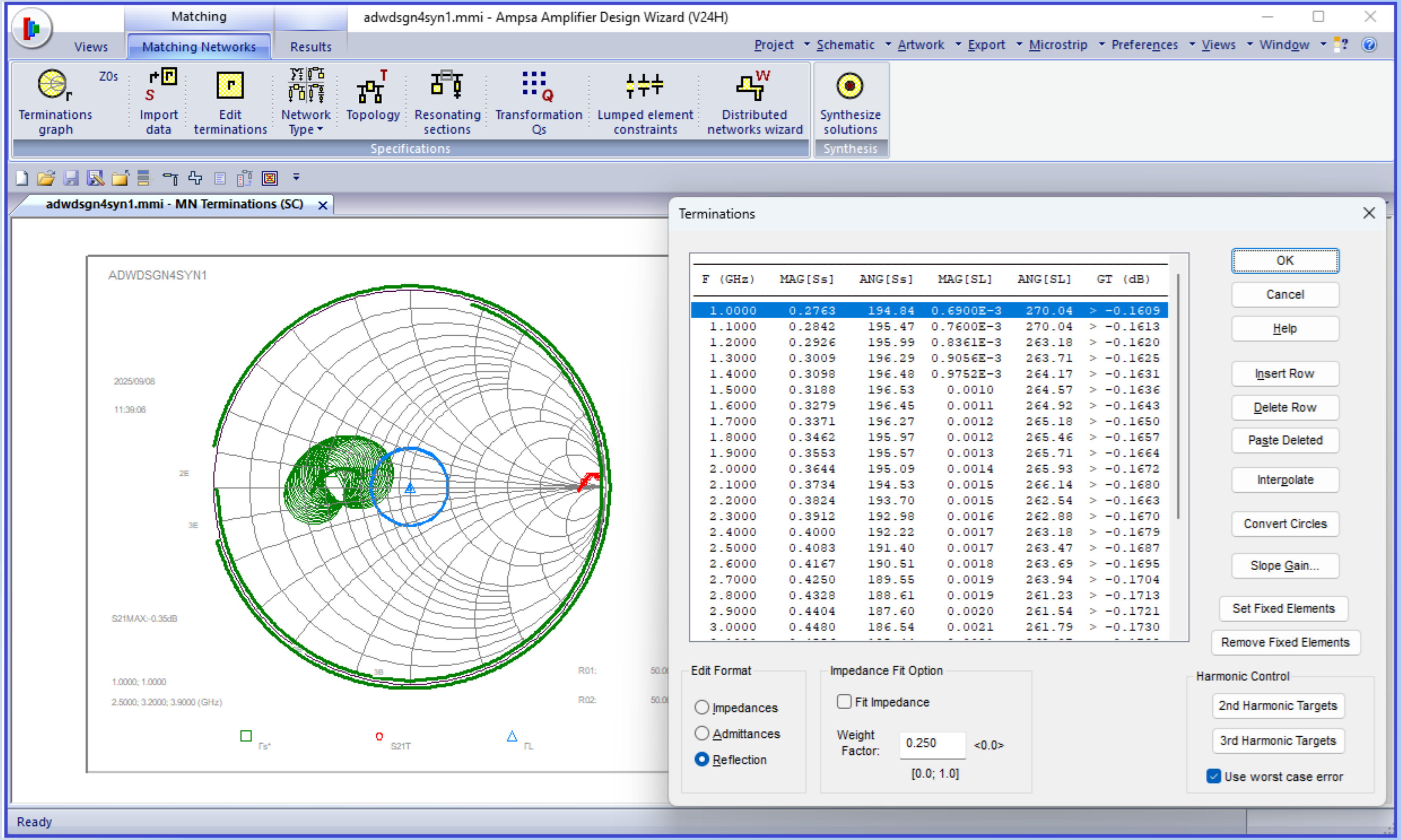


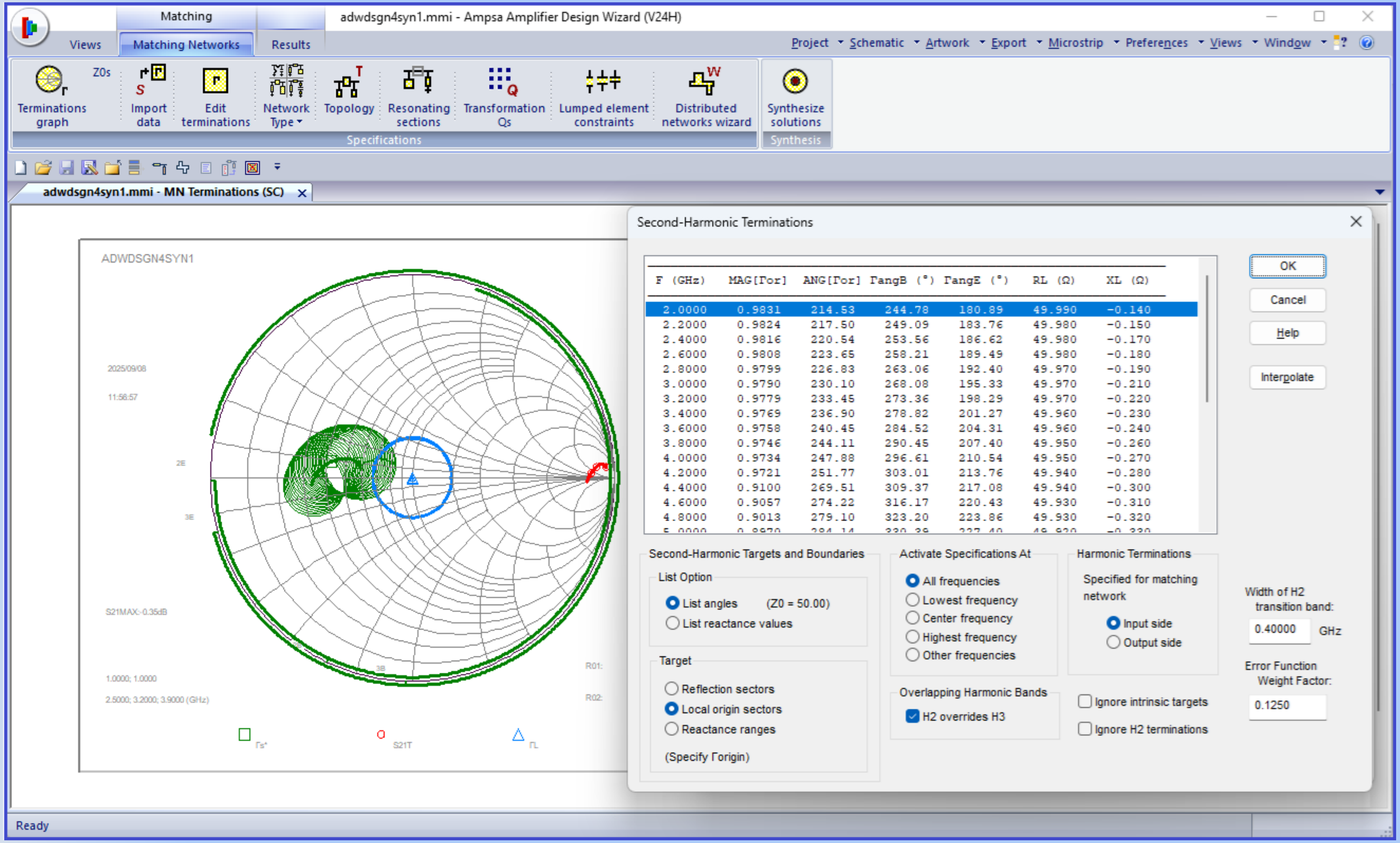
Example 4 – Controlling Intrinsic Harmonic Impedances Directly With The ADW

A wideband matching problem will be solved next. The intrinsic harmonic impedances presented to a 10W GaN transistor will be targeted in this example. The bandwidth is 1.0 – 3.9 GHz.

The specifications for this problem was set up by using the CIL wizard provided in the ADW.

Intrinsic Targets: The matching problem can be defined at the insertion point for the matching network as was done before, but using the intrinsic targets for the harmonics yields better results. The results are also easier to interpret.

Note: Control over the intrinsic terminations is not provided in the MW.



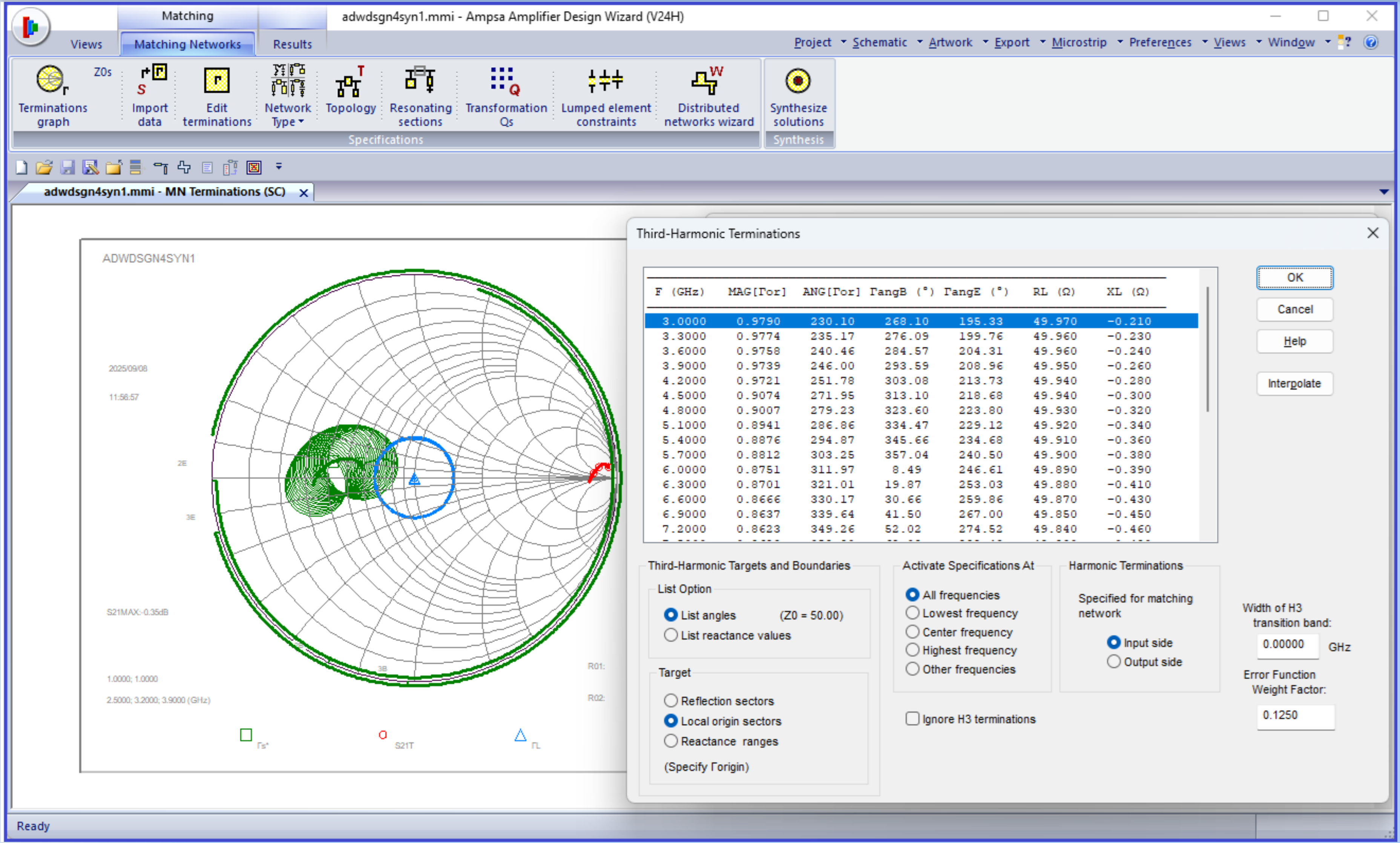
Example 4 – Second-Harmonic Sectors

Local origin sectors were used for the harmonics in this example.

Specifications: The local origin and the angles for the two intersecting lines must be specified on this page. The rotation around the local origin must be clockwise from point *B* to point *E*. Points *B* and *E* are the intersections with the Smith chart edge.

Transition Band: Because of the overlap with the fundamental frequencies, a transition band is required. The second harmonic errors in the passband and in the transition band are ignored.

Note: Experimentation with the transition band and the weight factor may be required.



Example 4 – Third-Harmonic Sectors

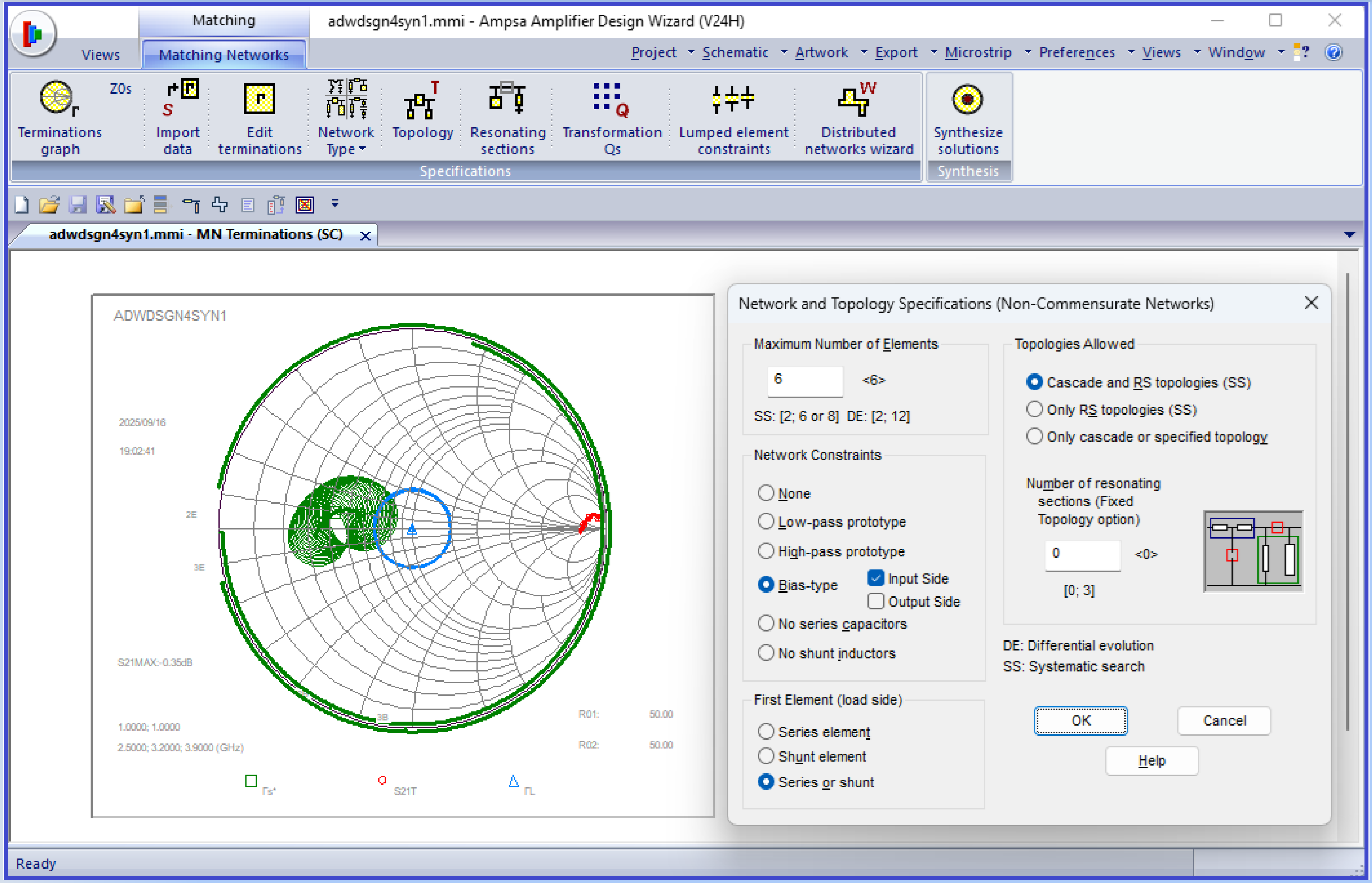
The specifications for the third harmonics are shown here.

Specifications: The local origins and the angles associated with the intersecting sector lines must be specified here.

Transition Band: Because low intrinsic impedances are required for the second and the third harmonics, no transition band is required here.

The third harmonic errors are ignored in the second harmonic band and in the transition band.

Note: Experimentation with the weight factor may be required.

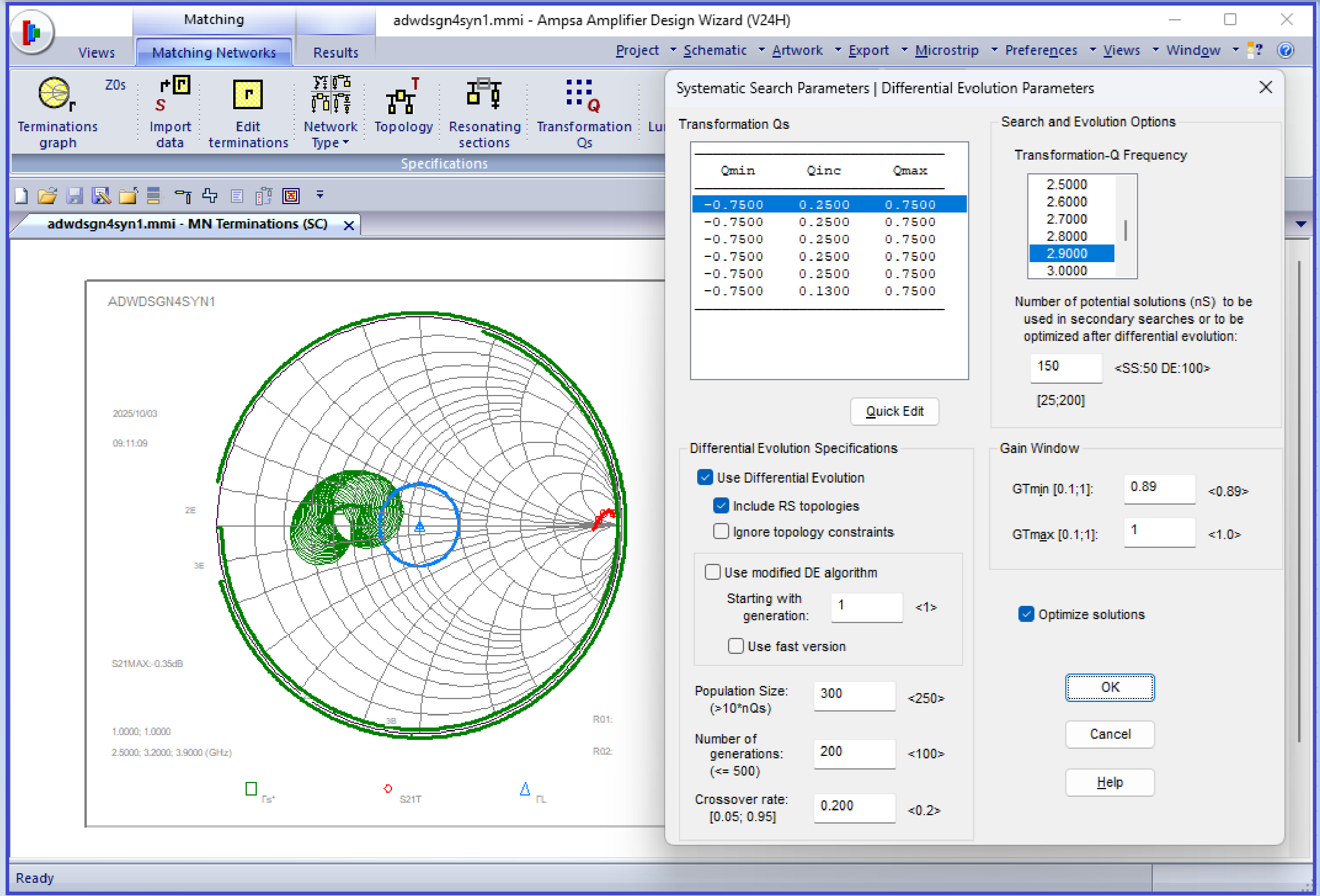


Example 4 – Network and Topology Constraints

The topology constraints to be imposed are shown here.

Specifications:

- Networks with up to six-elements will be synthesized.
- Resonating section topologies will be included in the search and evolution.
- The networks synthesized must be suitable for *dc* biasing on the input side.
- The first element on the load side can be series or shunt.



Example 4 – Differential Evolution Specifications

The specifications made for differential evolution are shown here.

Transformation-Qs: The range specified for each element is [-0.75; 0.75].

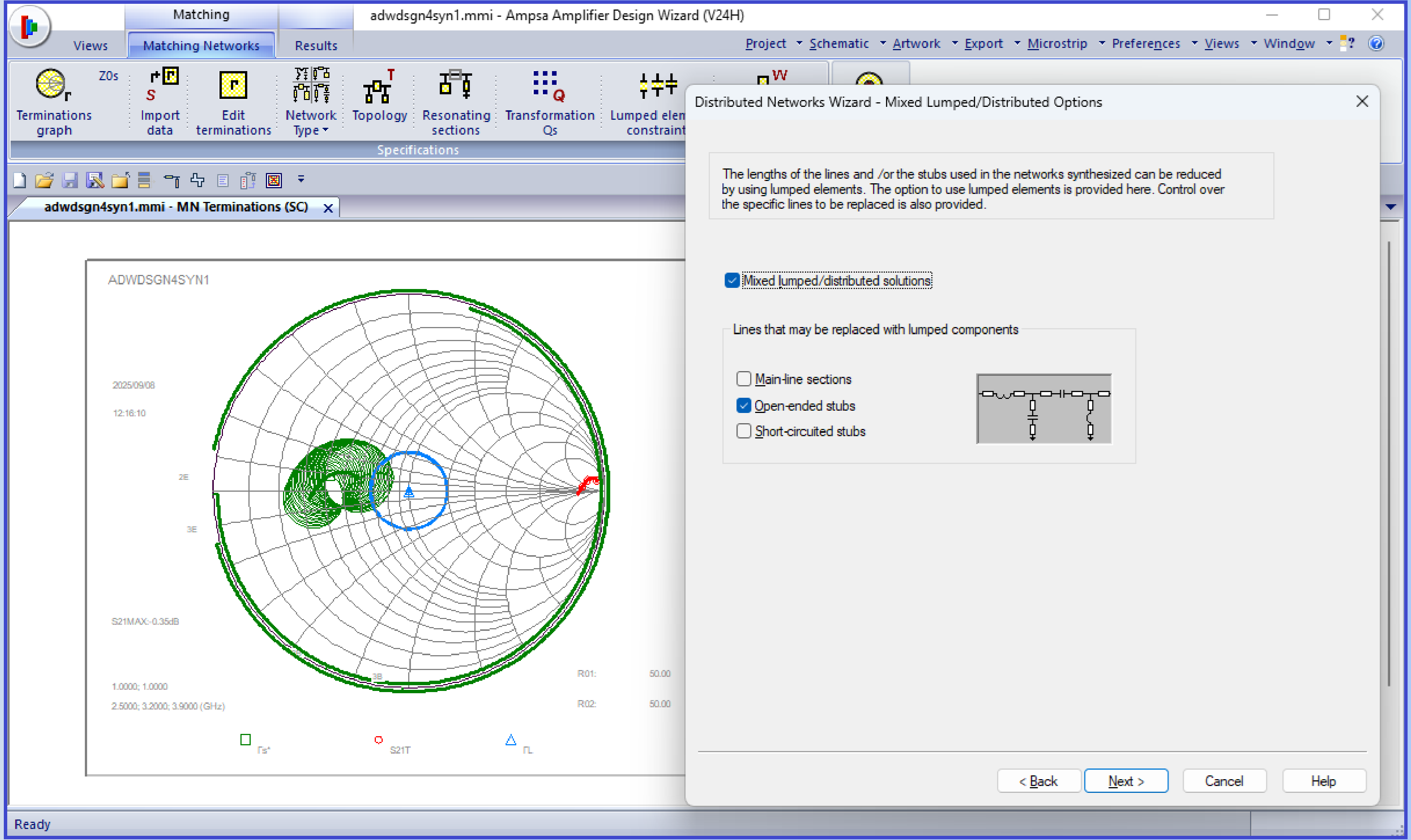
Gain Window: The gain window was set to [0.89; 1.0].

Resonating Sections: The evolution will be done over the different topologies associated with six elements.

Number of solutions to Optimize: 100 of the fittest population members will be optimized.

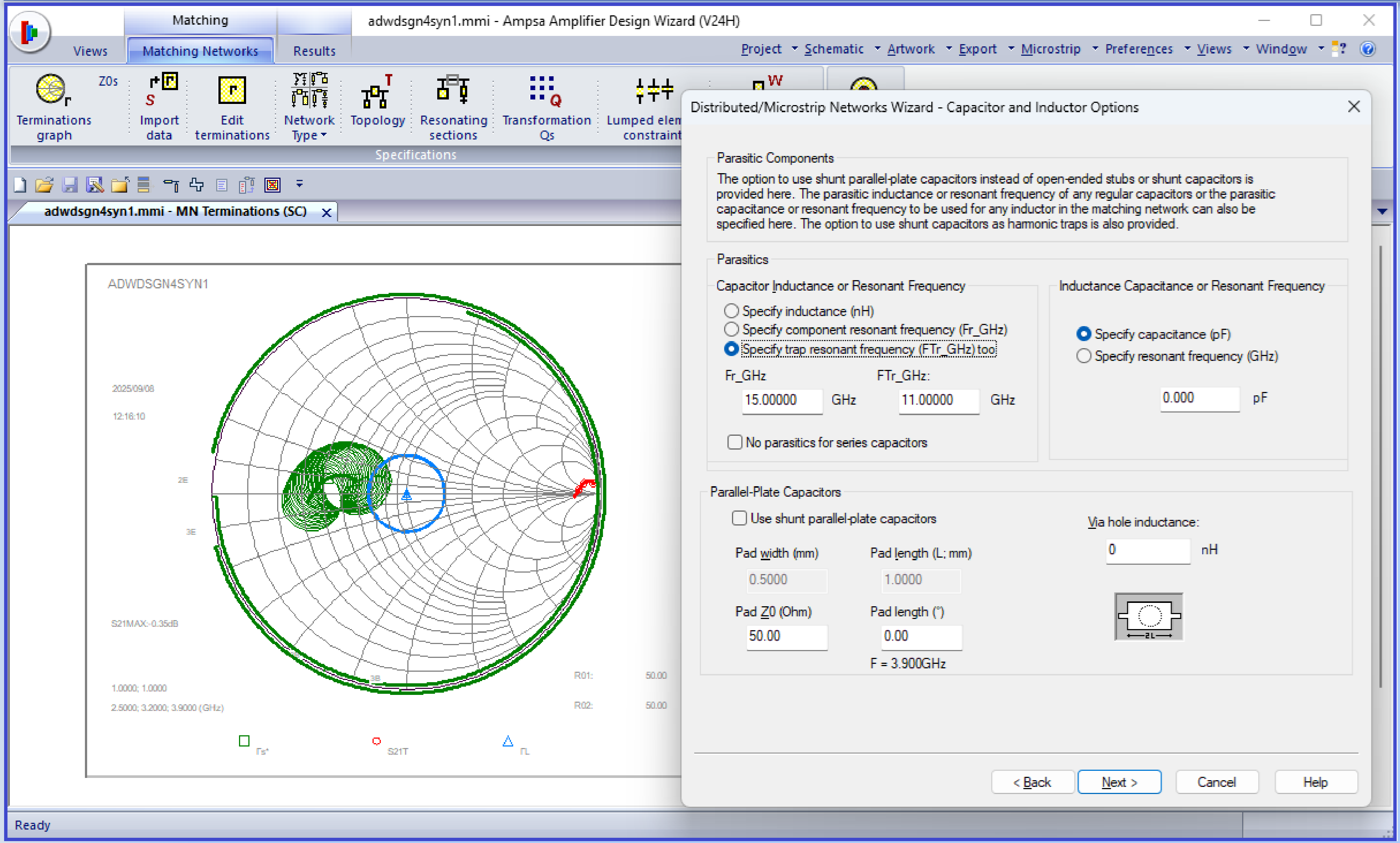
Population Size: 500

Number of Generations: 120



Example 4 - Mixed Lumped/Distributed Options

The option to replace open-ended stubs with padded capacitors was selected.



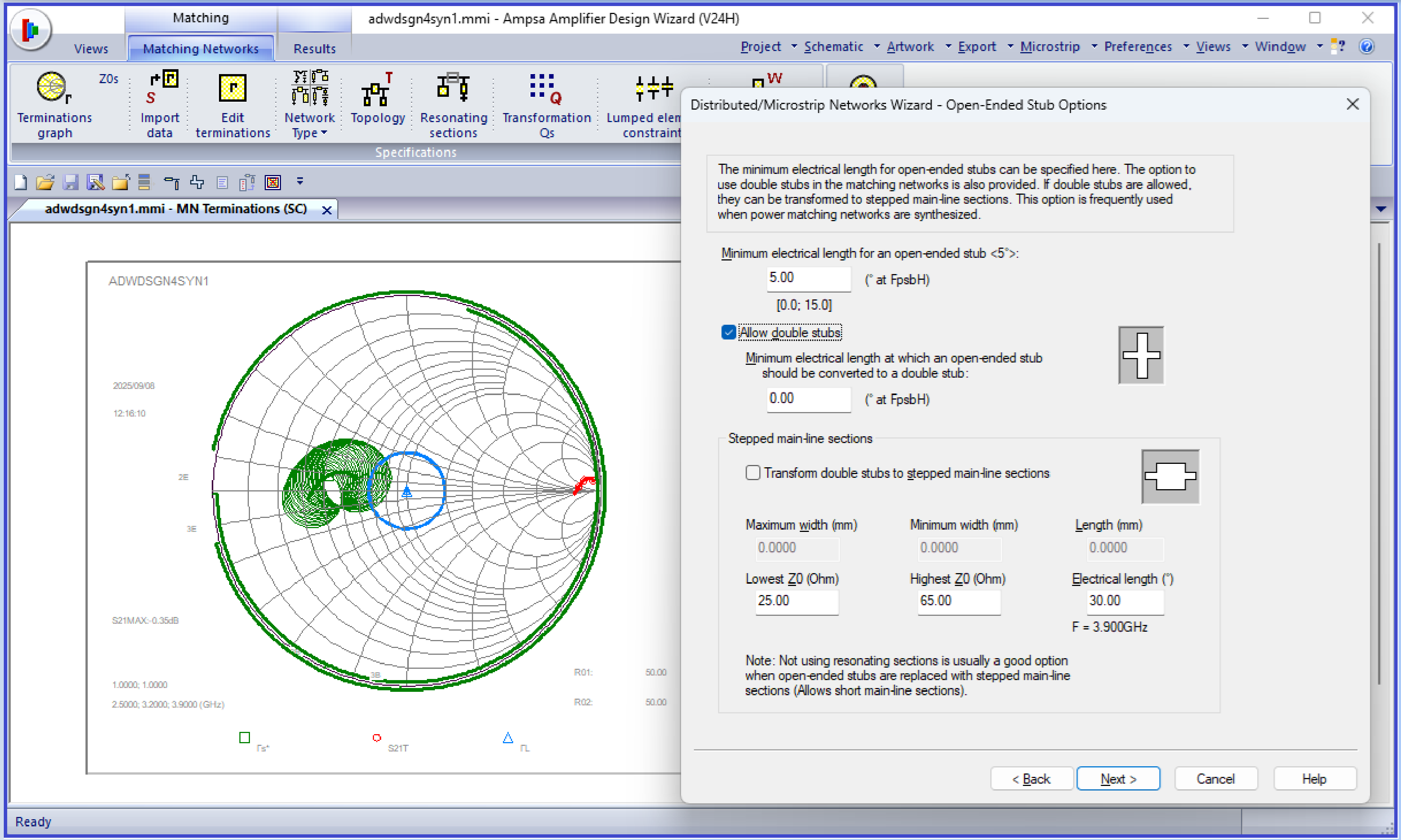
Example 4 – Lumped-Element Parasitics and Traps

The specifications made for the lumped-element parasitic components are shown here.

Note: The parasitic inductance associated with shunt capacitors can be increased to provide transmission nulls at the trap frequency specified.

Resonant Frequency: 15GHz

Trap Frequency: 11GHz

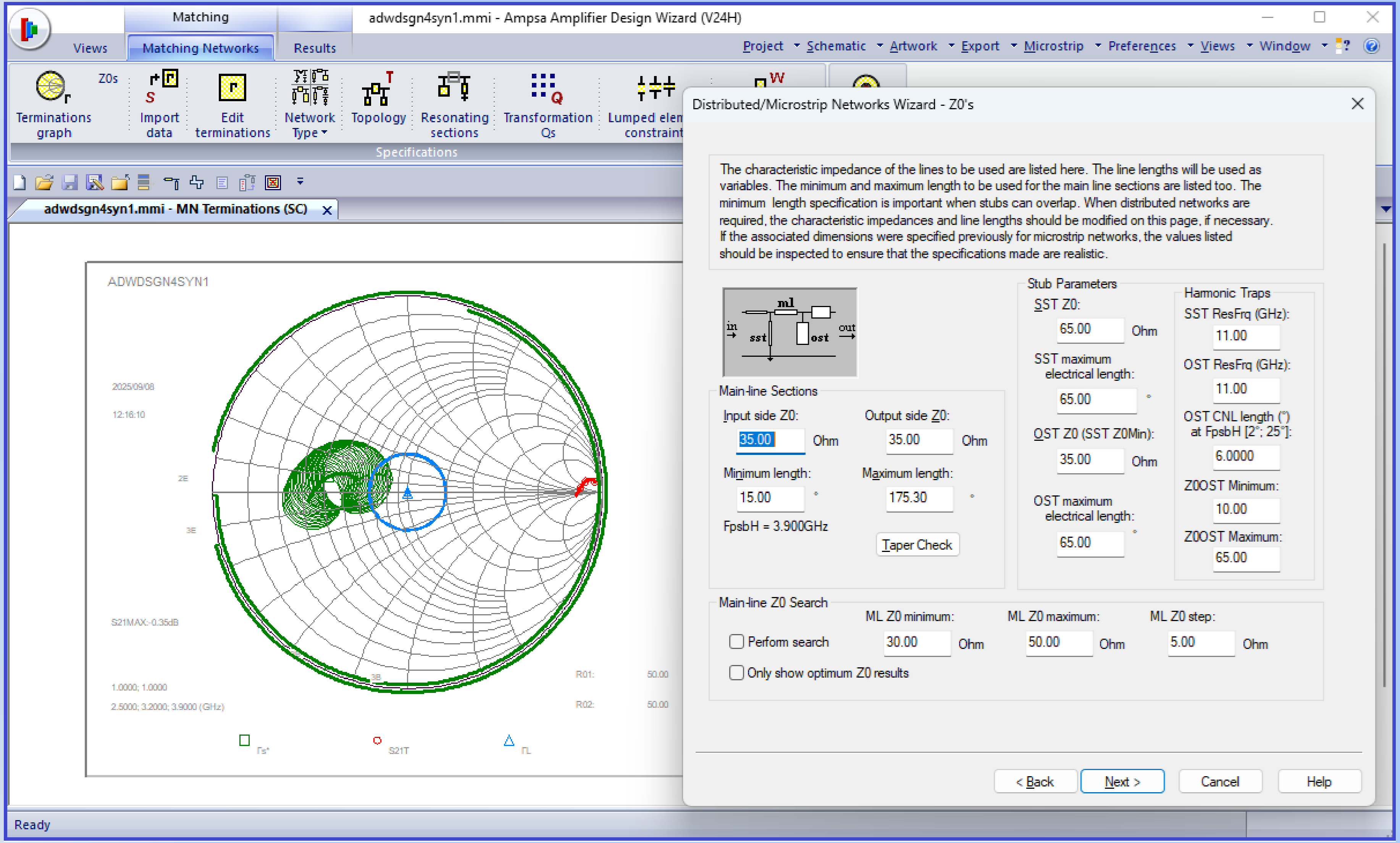


Example 4 – Open-ended Stub Options

Various options are provided on this page for open-ended stubs.

Specifications:

- Open-ended stubs shorter than 5° at the highest passband frequency will be removed.
- Double stubs will be allowed.
- Double stubs will not be transformed to equivalent main-line sections.



Example 4 – Main-Line and Stub Specifications

The specifications made for the characteristic impedances and the constraints on the line lengths are shown here.

Note: An open-ended stub (OST) can be replaced with an open-ended branch consisting of two cascaded lines (SIR) to create a trap. The dimensions of the section connected to the main-line (CNL) is fixed In the ADW and the MW. The characteristic impedance and the electrical length of the open-ended stub are the variables. The characteristic impedance must be in the range specified.

SIR Specifications:

CNL: (35 Ω, 6°); Z0: [10Ω; 65Ω].

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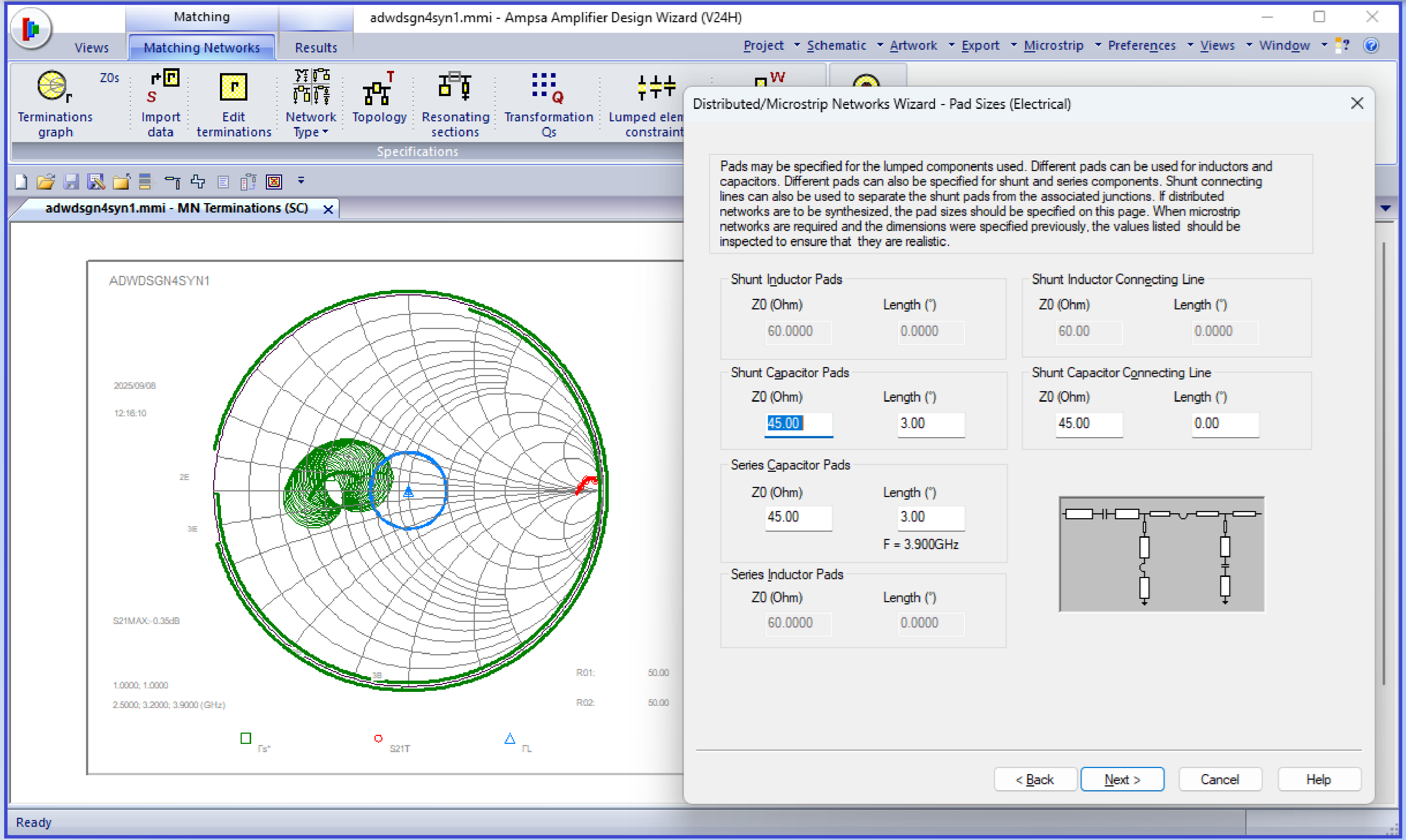
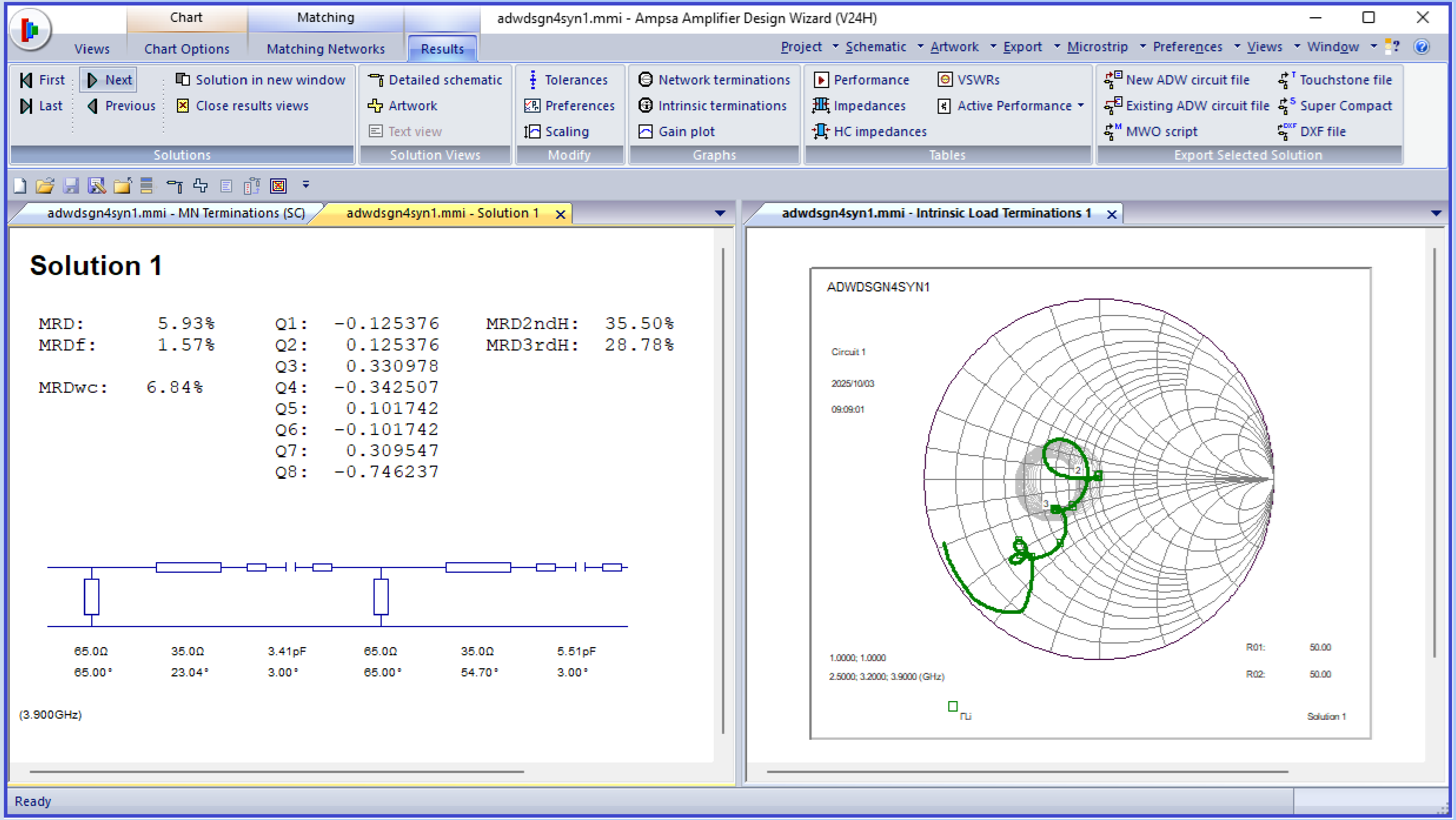


Example 4 – Lumped-Element Pad Specifications

The characteristic impedances and electrical line lengths for the pads to be used for the lumped components are shown here.

A connecting line is allowed with the pads for shunt capacitors and inductors.

Note: The series pads must also provide separation between the associated stubs and junctions.

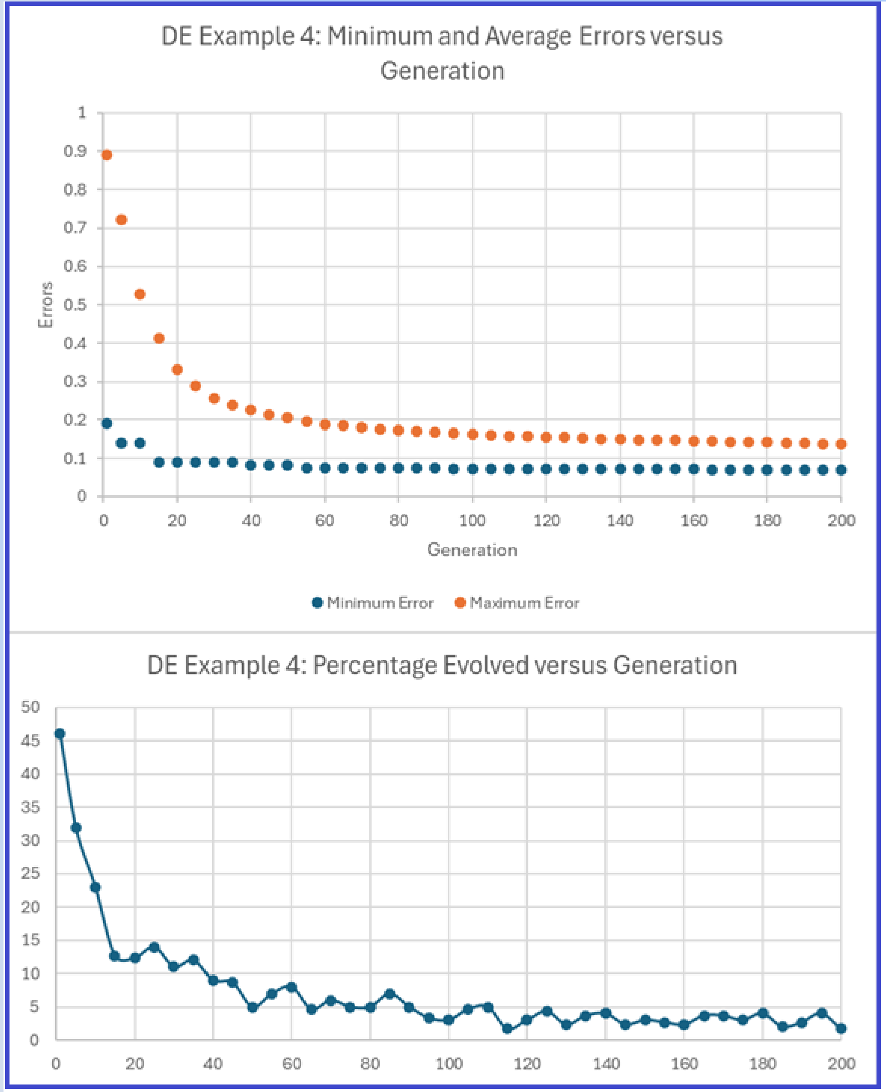


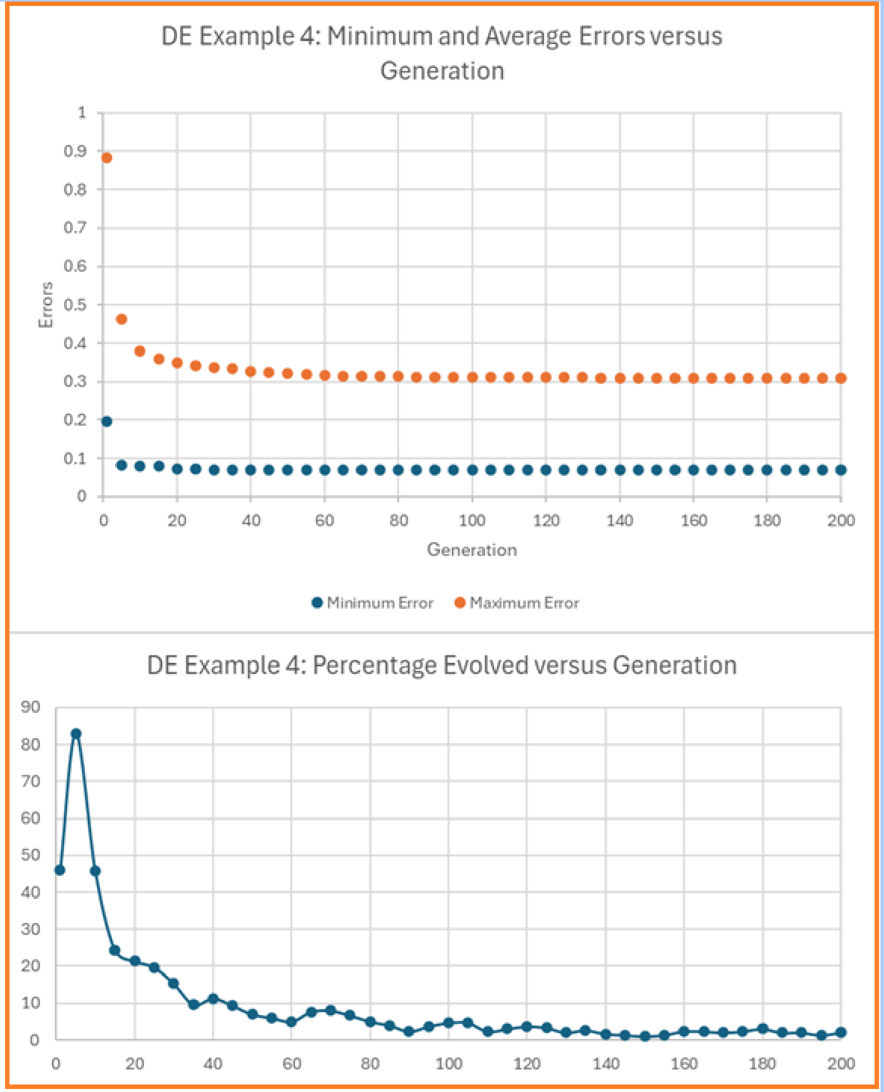
Example 4 – Differential Evolution Solution

The first solution obtained with differential evolution is shown here with the intrinsic load reflection coefficients presented to the transistor at the fundamental and harmonic frequencies.

The circular areas are the intrinsic targets at the fundamental frequencies.

Note: The *dc* ground associated for the stub on the left can be transformed to an *ac* ground to allow for biasing the transistor.

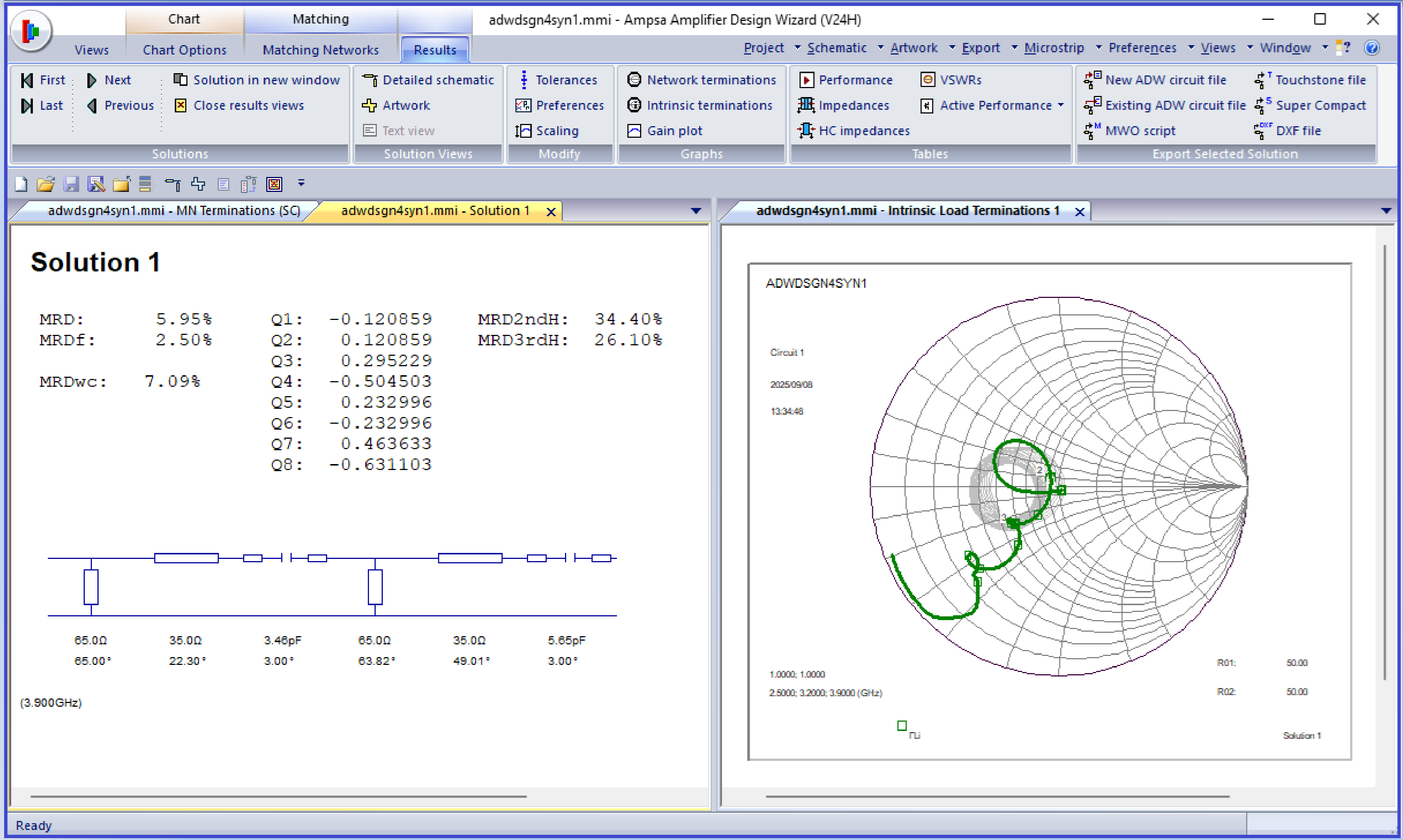




Example 4: Population Fitness Improvement

When resonating sections are used, the evolution is done for each of the topologies. To evaluate the fitness performance, eight-element solutions with the topology fixed were synthesized.

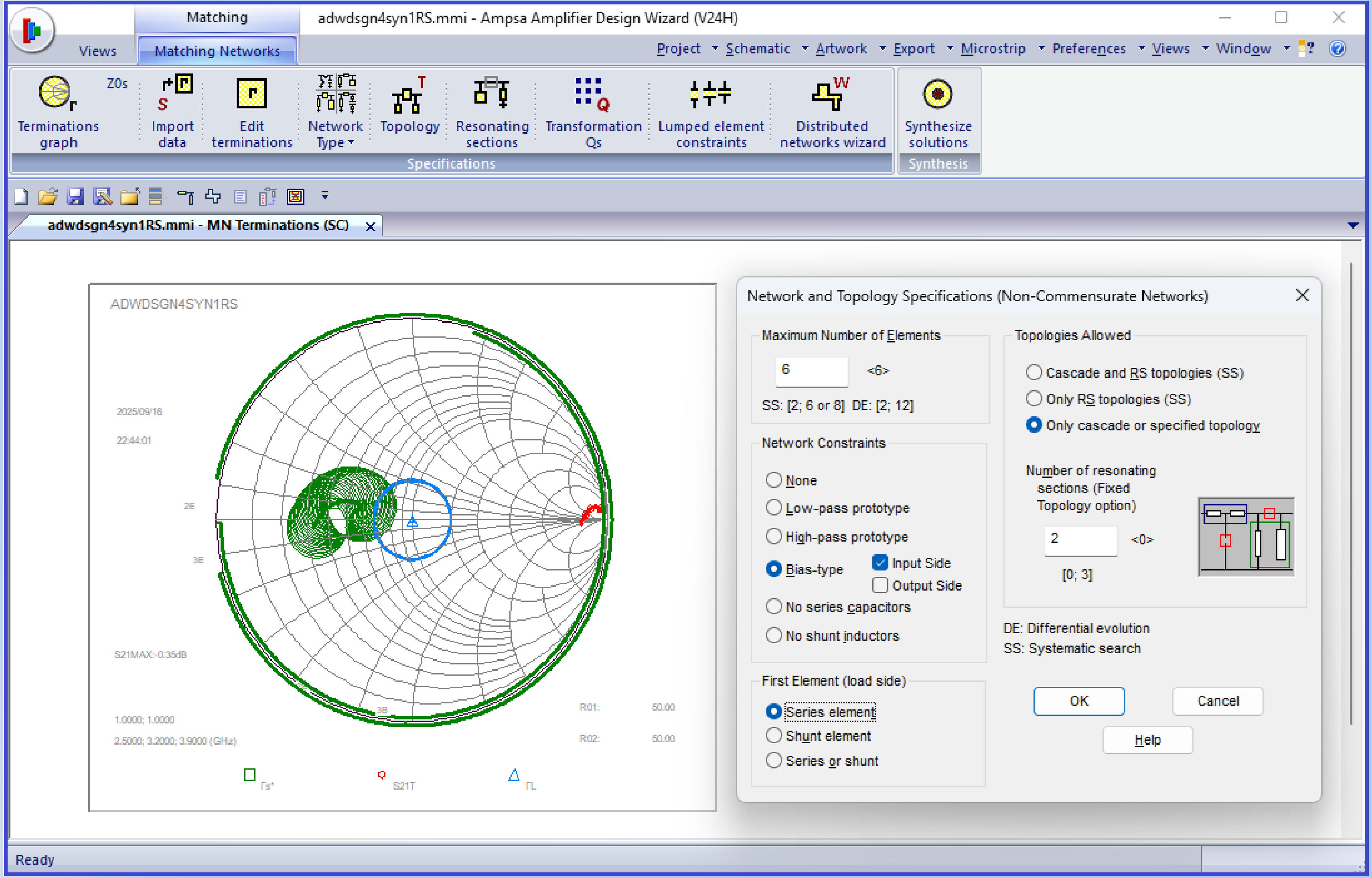
The minimum and average errors and the percentage of the population that evolved in each generation were plotted in the graphs shown here. The fitness improvements with the standard DE algorithm is shown on the left. The graphs on the rights apply to the modified DE algorithm.



Example 4 – Systematic Search Solution

The first solution obtained with a systematic search is shown here.

The topology is the same as that obtained with differential evolution and the performance is similar.

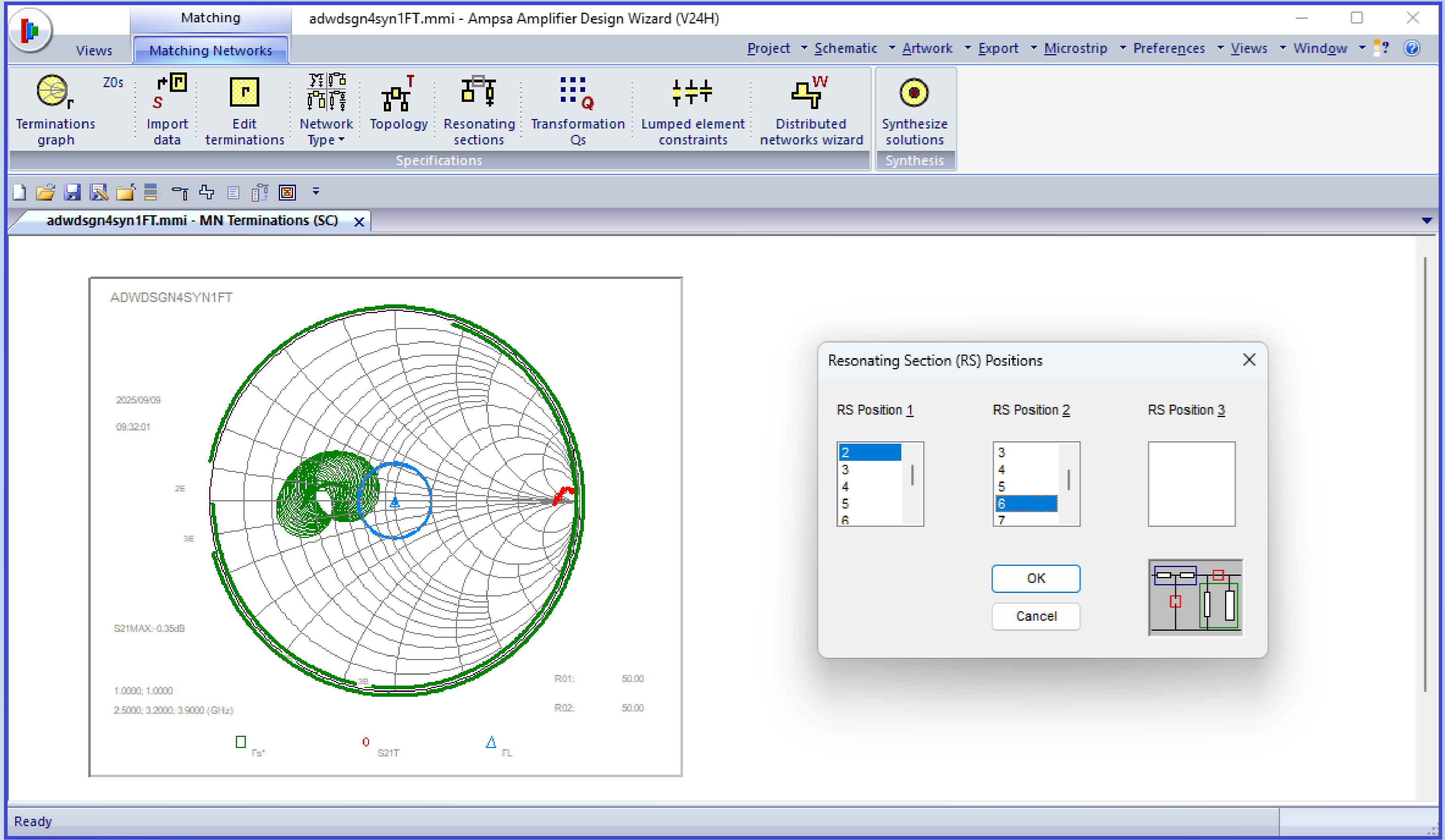


Example 4 – Exploring Solutions With a Specific Topology

The evolution or systematic search can be restricted to a specific topology. The topologies of the two solutions shown are identical. The topology is defined by missing elements 2 and 6 in an eight-element series-shunt cascade. The maximum number of elements remains six.

The SaveAs command was used to rename the original impedance-matching data file, and the topology specifications were then changed as shown here. The fixed topology option was selected, and the number of resonating section was specified to be 2.

Note that the first element on the load side was restricted to be a series element.



Example 4 – Resonating Section Positions in the Fixed Topology

The Resonating Sections ribbon command was used to specify the positions of the two resonating sections in the eight-element series-shunt cascade network.

Specifications: The shunt elements in positions 2 and 6 are absent in the eight- element series-shunt cascade network.

Note: The elements are counted from the load side towards the input.

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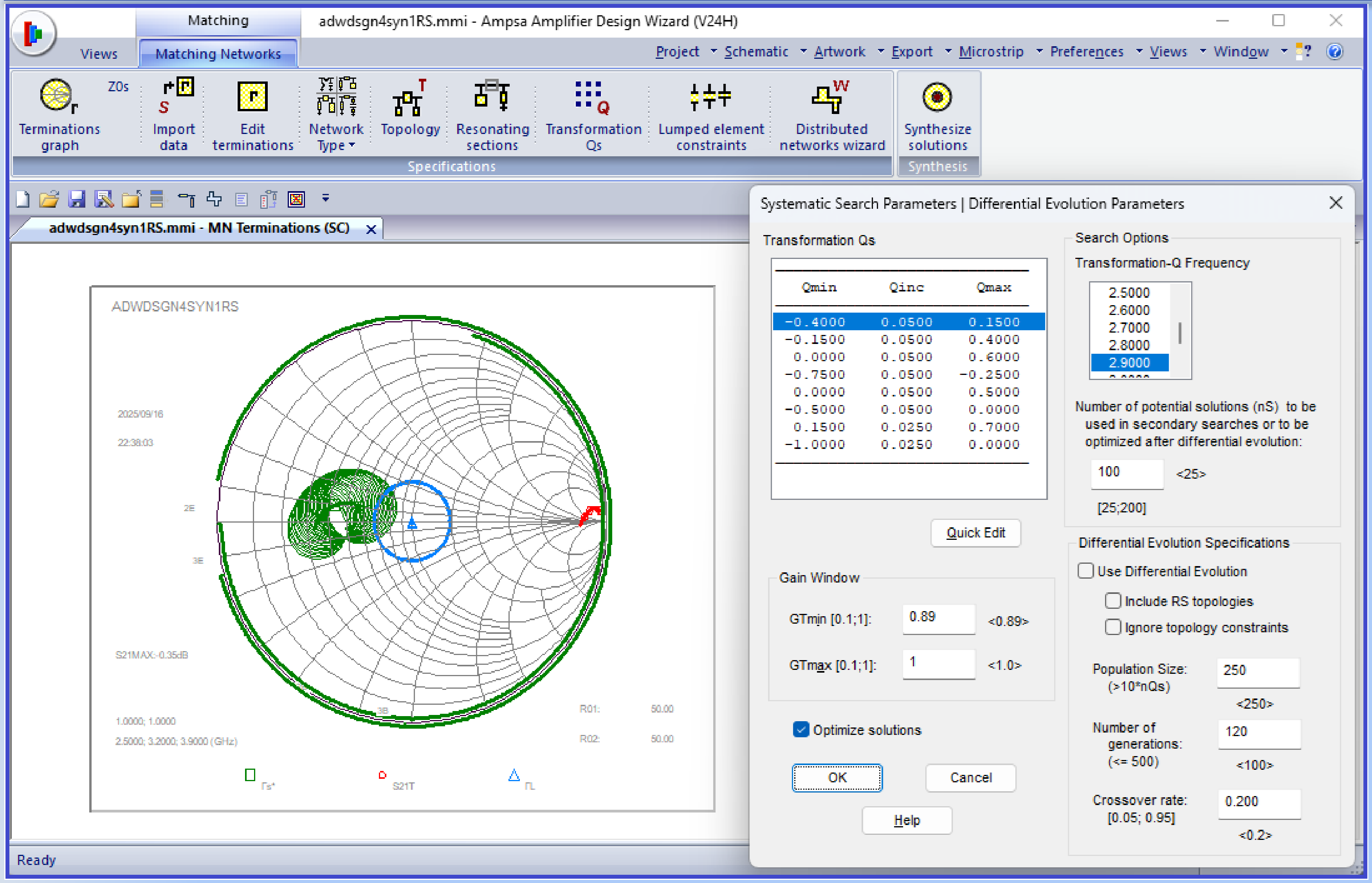
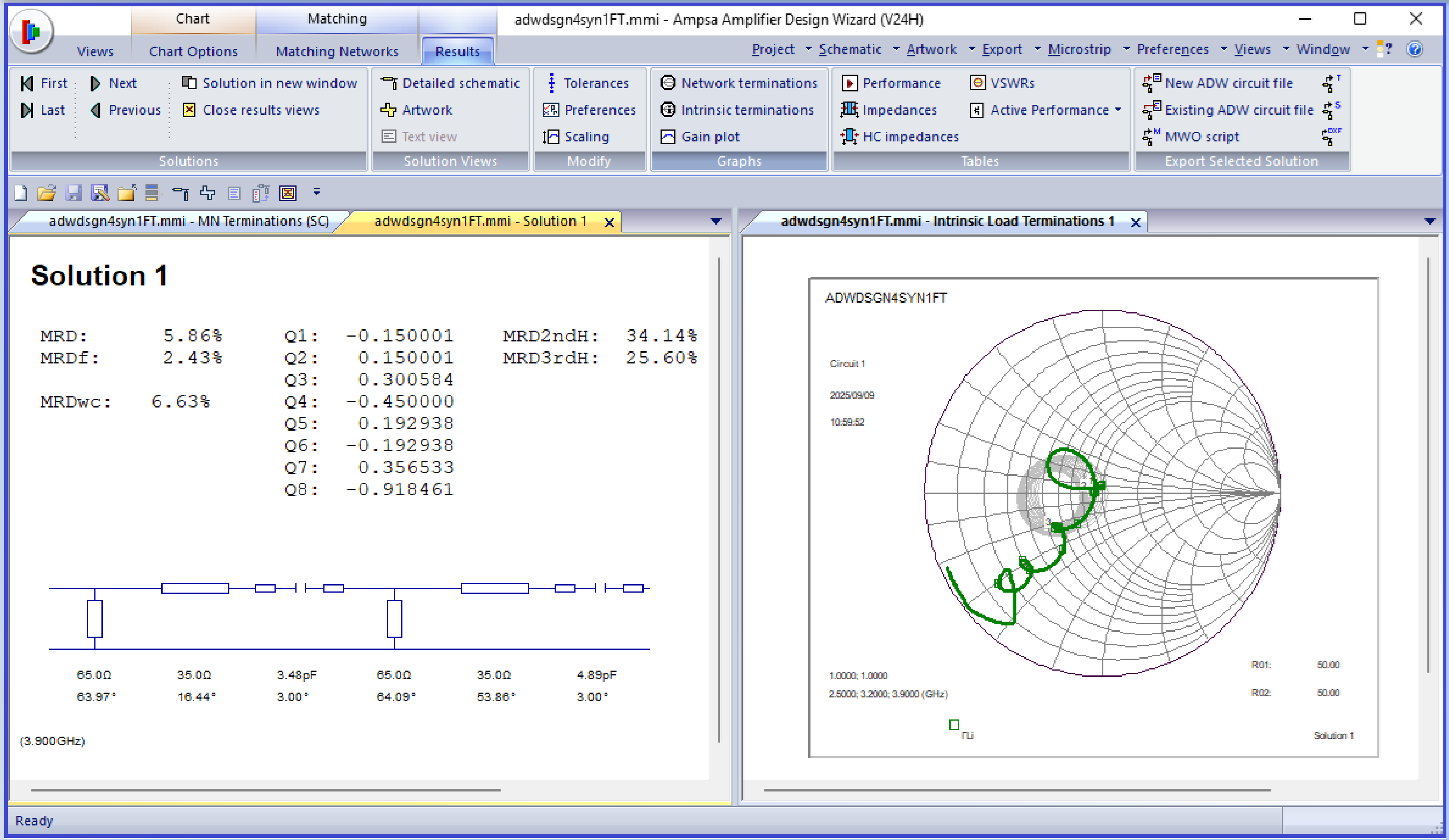


Example 4 – Transformation-*Q* Specifications

The *Q*-space was adjusted by using the *Q*-values of the first solutions obtained with differential evolution and the systematic search. The range for each *Q*-value was reduced to approximately 2 × 0.25 (twice the increment used before).

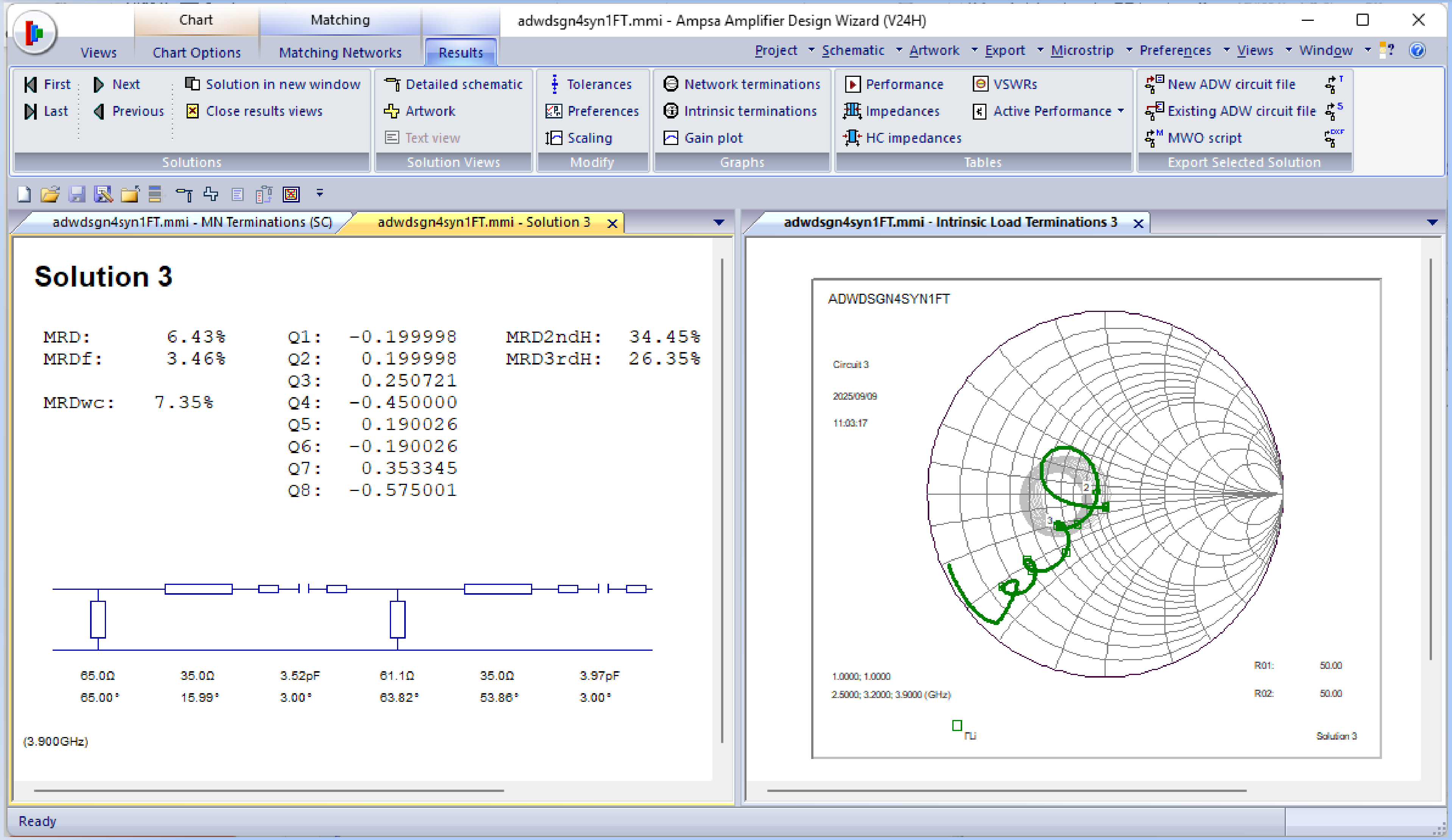
Note: The increment for each *Q*-value should be scaled with the same factor as the range to keep the execution time for the systematic search similar. In this example, the increment was decreased to 0.05.



Example 4 – Best Systematic Search Solution

The first solution obtained with the systematic search is shown here.

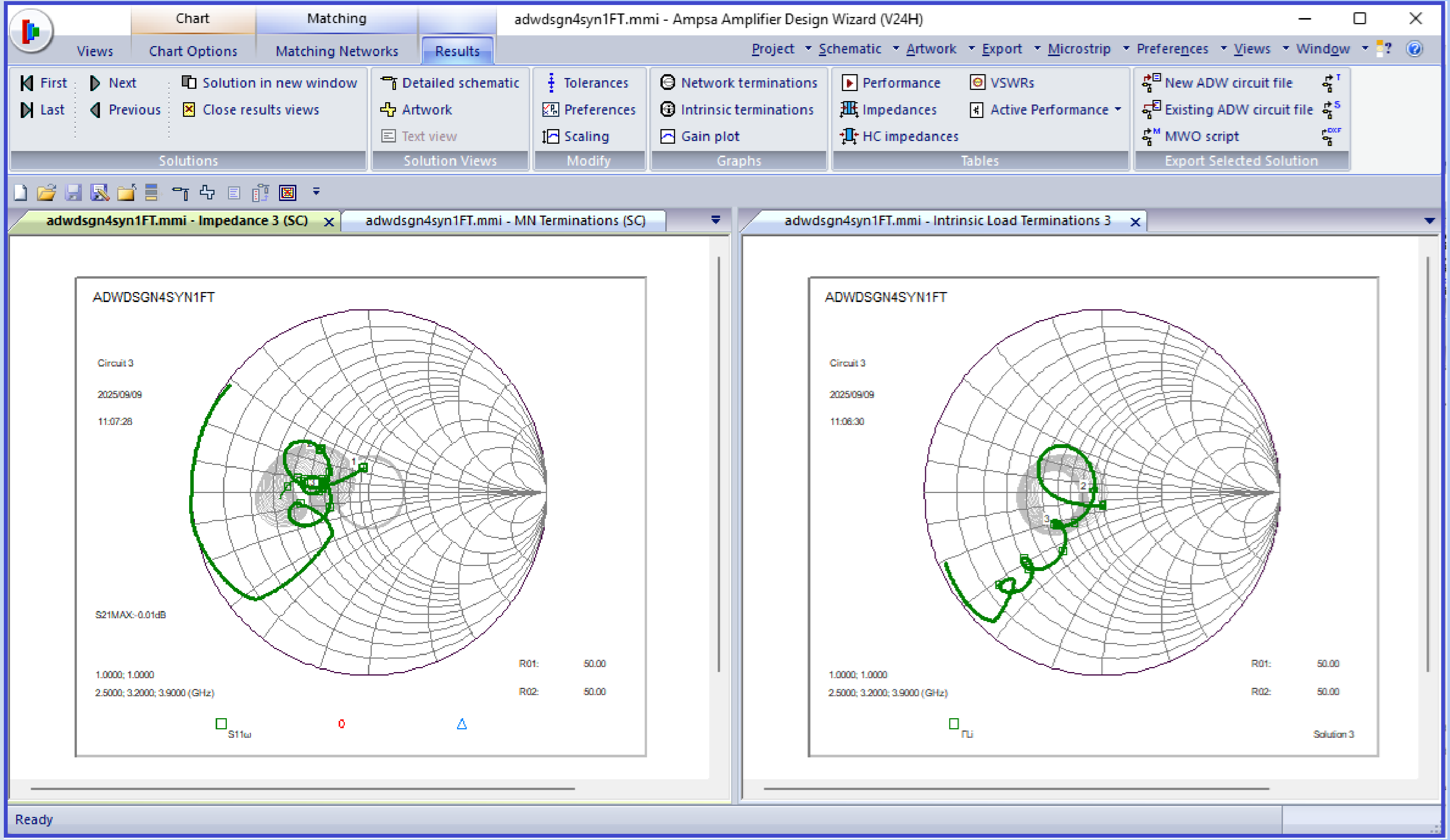
The performance is like that obtained before.



Example 4 - Alternative Systematic Search Solution

The third solution obtained with the systematic search is shown here.

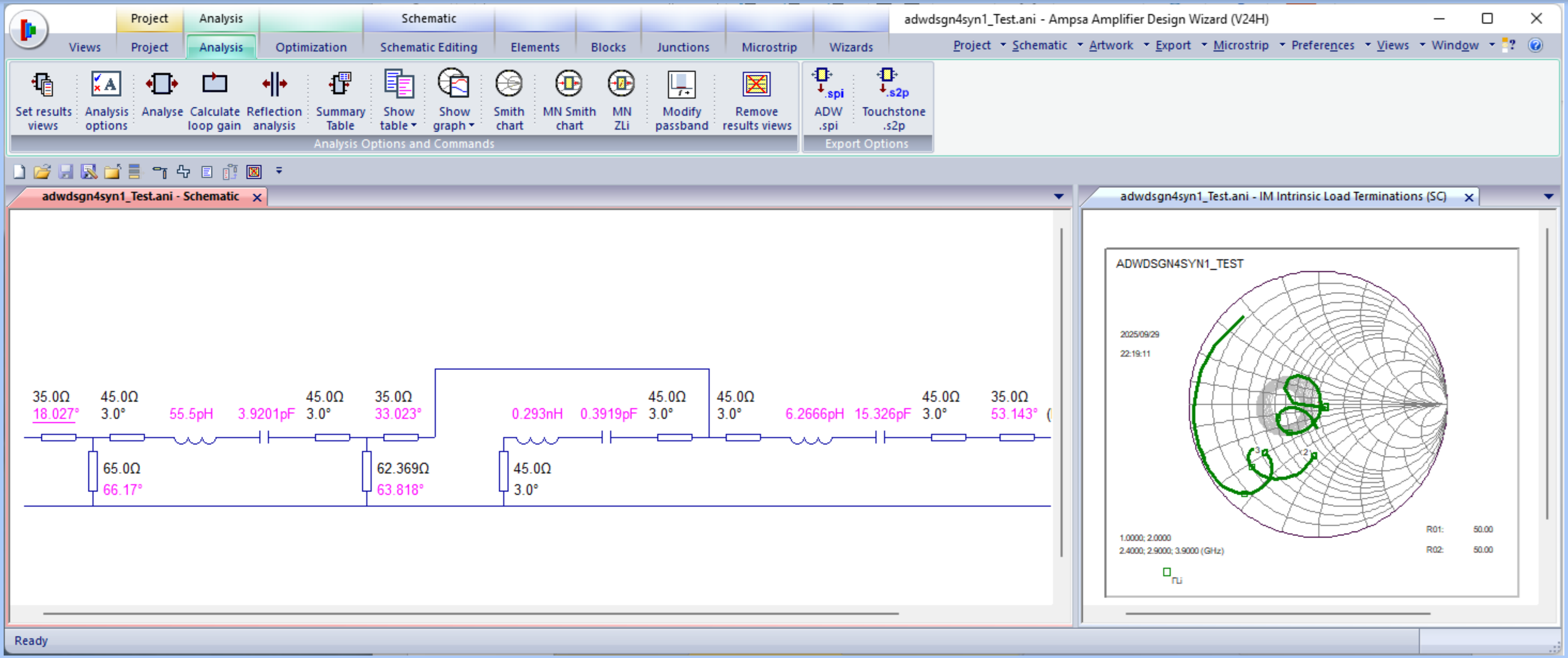
The passband performance is slightly worse than that of the first solution, but the harmonic reflection coefficients are better behaved.



Example 4 – Comparison of External and Intrinsic Terminations

The external and intrinsic input reflection coefficients presented by the last solution are compared here.

Note that the resonance behavior is very different at the two reference points.



Example 4 – The intrinsic load terminations presented by a matching network after minor tuning in the Analysis Module

The path of the intrinsic terminations of the solution shown here differs from those of the previous solutions shown. This solution was tuned to remove a resonance spike in the intrinsic harmonic reflection coefficients. The spike did not show up during synthesis. (The network was analyzed at more frequencies in the Analysis module.)

Note: Instead of adding extra inductance to a capacitor, the pad lengths can be increased.

Thank you!

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