Exploring Matching or Pre-Matching with Phase-Controlled Matching Networks

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When one of the impedance-matching wizards is used to set up a matching problem in the Analysis module of the Amplifier Design Wizard (ADW) or the Matching Wizard (MW), the matching problem defined is usually solved by using the Impedance-Matching module. The option (Explore Pre-match) is now provided to bypass this module and to solve the matching problem with basic networks designed to provide a specific transmission phase shift and a conjugate match [1] at a selected frequency in the passband (CMA networks).

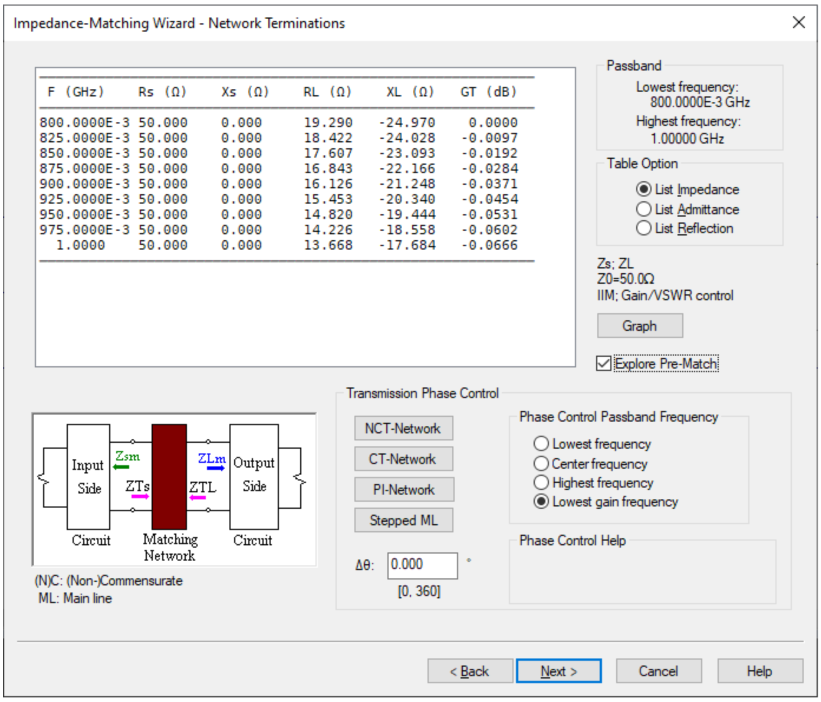

Figure 1. The Explore Pre-Match option provided to solve a matching problem with a CMA network instead of the Impedance-Matching Module.

The topologies of the CMA networks are derived from T- or PI-networks. The main-line components are transmission lines, while the shunt components can be stubs or lumped components with pads. The pad sizes can be specified by the user (different pads can be used for inductors and capacitors). When a stub (open-ended or shorted) will be used in a shunt section, the characteristic impedance or line length of the stub can be fixed. The line lengths are usually fixed when the harmonic control is also required.

Parallel shunt components are also allowed in these networks. The two parallel branches can be identical or can form a resonating section (partial resonance - the effective shunt susceptance is not changed; refer to Figure 2). When resonating sections are allowed, the shunt susceptance required can be obtained from an open-ended stub in parallel with a shorted stub, or an inductor in parallel with a capacitor. The resonating section components are calculated by using a resonating section factor *RS*. When *RS* is zero, the susceptance provided by the extra shunt component will be zero (that is, no extra shunt element will be used). When *RS* is 1.0, the magnitude of the susceptance provided by the extra component will be equal to the magnitude of the susceptance provided by the shunt component when a resonating section is not used. The range allowed for *RS* is [0.0, 1.0].

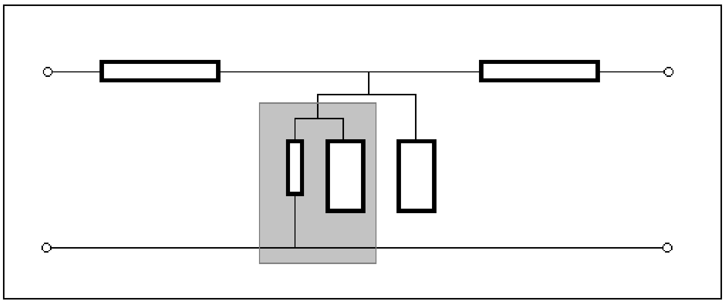

Figure 2. Partial resonance in a CMA T-network.

Parallel stubs will decrease the degrading effect of the associated main-line junction (that is, if a smaller junction is used), or may decrease the stub lengths when open-ended stubs are used. When capacitors are used, parallel capacitors may decrease the degrading effect of the parasitic inductance (smaller capacitor).

Note that the characteristic impedances of the lines used in a CMA network can be constrained. Networks with out-of-range characteristic impedances will be ignored.

The CMA network types allowed in the ADW, or the MW are

1. Non-commensurate T-networks. The same characteristic impedances (Z_{om}) are used for the two main-line sections. Z_{om} can be specified by the user. The transmission phase shift required and Z_{om} are the main design parameters. The susceptance of the shunt section(s) can be set to be capacitive or inductive. If a specific option is not required, both options should be explored.

2. Commensurate T-networks. The same electrical lengths are used for the two main-line sections. The length can be specified by the user. The phase shift and the length are the main design parameters.

3. PI-Networks. The main-line characteristic impedance can be specified by the user. The phase shift and the characteristic impedance are the two main design parameters. There are two solutions for each main-line length. The option to use the solution with the shorter line is provided. (If not selected, the solution with the longer line will be used.)

4. Stepped main lines. The electrical lengths of the two lines are the same and can be specified by the user. The phase shift and the length are the two main design parameters. There may be two options for the characteristic impedance of the line on the output side of the network. (The ratio of the characteristic impedances of the two lines in the network are fixed by the line length.) The option to use the solution with the higher characteristic impedances is provided. (If not selected, the solution with the lower characteristic impedances will be used.) Both options are explored when a systematic search is performed on the main design parameters.

The different networks allowed are shown in Figures 3 through 12 below.

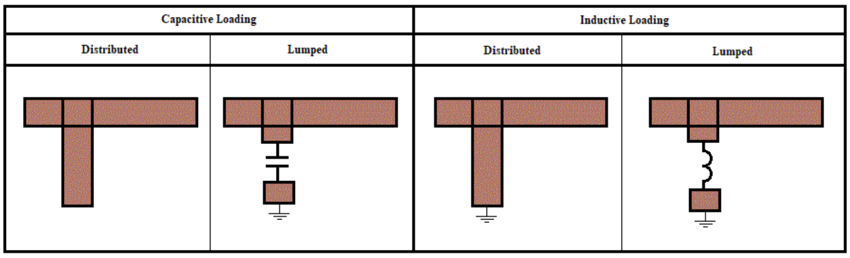

Figure 3. The main line of a non-commensurate CMA T-network can be loaded with an open-ended stub, a shorted stub, or a lumped equivalent.

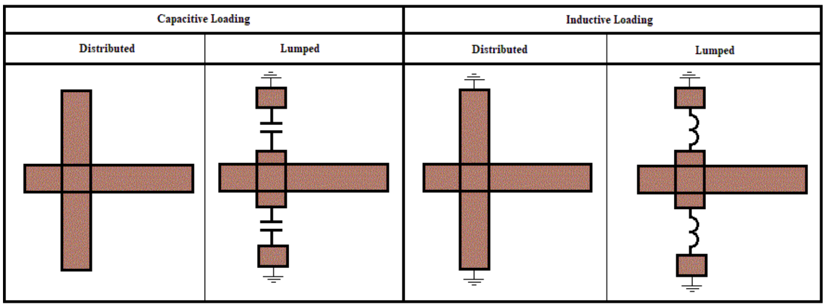

Figure 4. The non-commensurate T-network topologies associated with the Parallel Shunt Elements option.

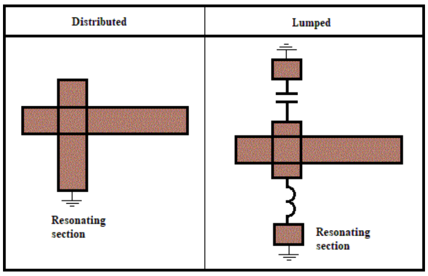

Figure 5. Non-commensurate CMA T-network topologies associated with the Resonating Sections option.

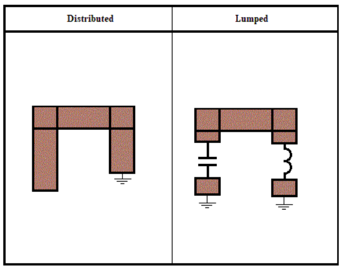

Figure 6. The main line of a CMA PI-network can be loaded with open-ended or shorted stubs or lumped equivalents.

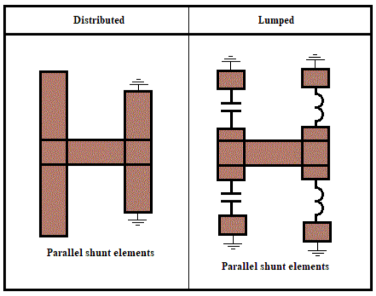

Figure 7. Some CMA PI-network topologies associated with the Parallel Shunt Elements option.

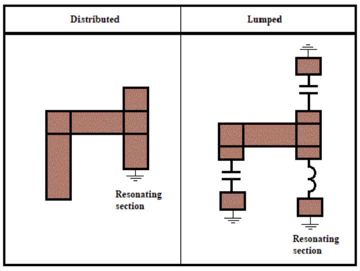

Figure 8. CMA PI-network topologies associated with the Resonating Sections option.

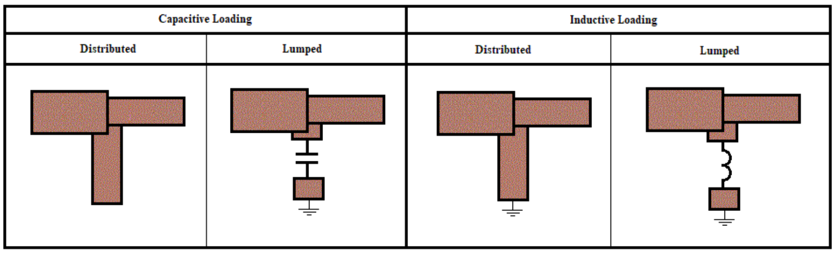

Figure 9. The main line of a commensurate CMA T-network loaded with an open-ended stub, a shorted stub, or a lumped equivalent.

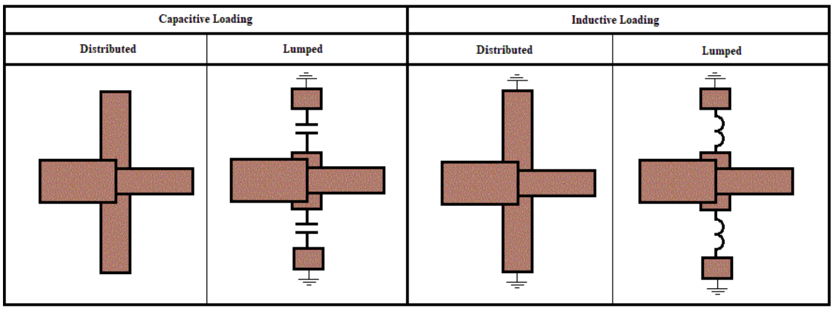

Figure 10. The commensurate CMA T-network topologies associated with the Parallel Shunt Elements option.

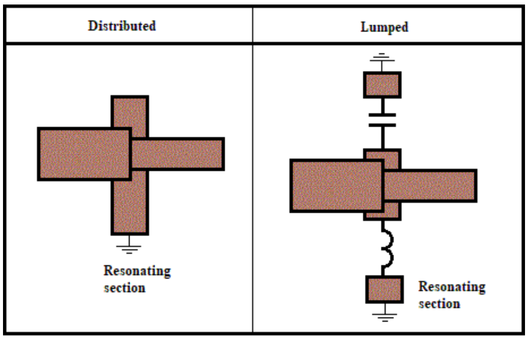

Figure 11. Commensurate CMA T-network topologies associated with the Resonating Sections option.

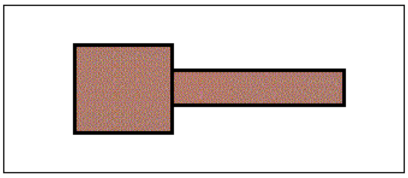

Figure 12. An example of a stepped main lines CMA network.

An example of controlling the transmission phase shift of an amplifier is provided in Figure 13. In this example, T-networks were designed to provide phase shifts of 0°, 52°, 90° and 180° at the centre frequency. Note the change in the bandwidth and the input reflection coefficients with the different phase shifts.

The CMA networks are synthesized to provide a conjugate match and the desired phase shift at a specified passband frequency [1]. This frequency could be the lowest passband frequency, the centre frequency, the highest passband frequency, or the lowest gain frequency (default option). The performance over the passband is evaluated by calculating the worst-case VSWR for the network synthesized. When a gain circle is targeted instead of a conjugate match, the equivalent VSWR is derived from the relative gain obtained. (The VSWR is set to zero when the gain is higher or equal to the gain targeted.)

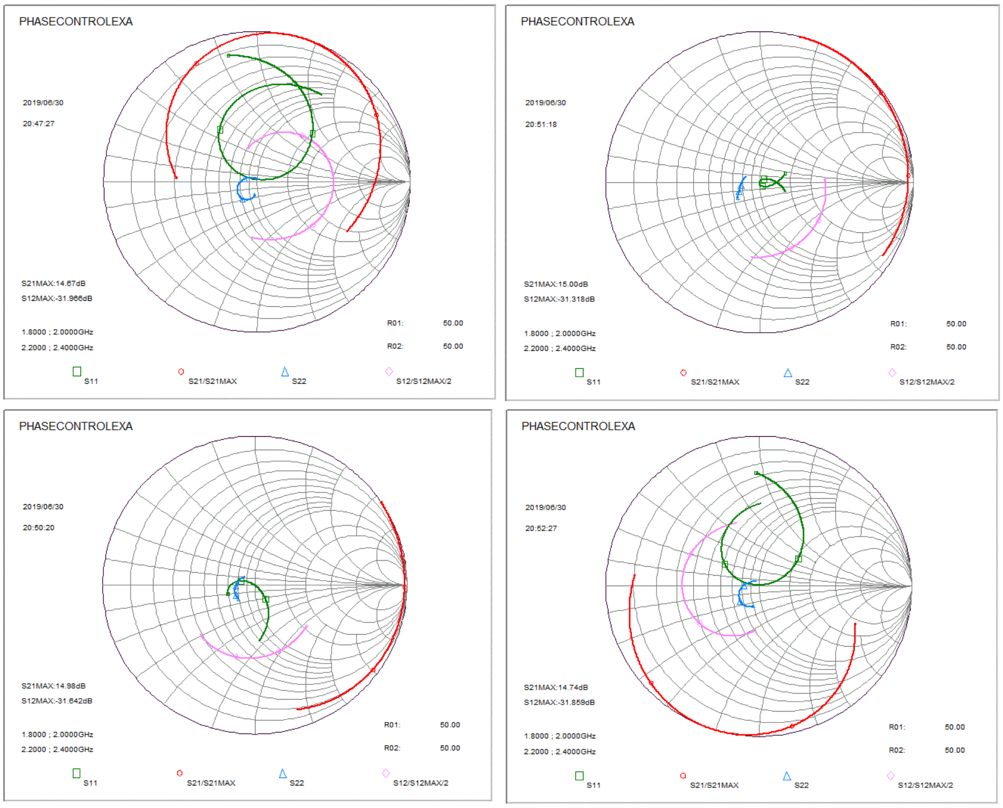

Figure 13. The *S*-parameters of an amplifier with the input network designed for different transmission phase shifts and a conjugate match at the centre frequency. The phase shifts selected were 0°, 52°, 90° and 180°.

When a specific worst-case VSWR is targeted over the passband of interest, the performance required cannot be obtained with arbitrary phase shifts. The phase shifts for which solutions can be synthesized will be constrained to specific phase-shift bands. These bands are listed in the ADW or the MW when a systematic search for potential solutions is performed. Note that, except for non-commensurate T-networks, there are transmission phase shifts for each network type for which no network can be synthesized. These phase shifts are also calculated, and phase targets close to these values will not be accepted.

A systematic search can be done for each CMA network type to find the main design parameters which will provide the best performance (lowest worst-case VSWR, ...) over the passband targeted. Guidance is also provided on the solution with the shortest main-line length or the smallest area with the passband VSWRs lower than the target specified. The area is listed in square millimetres or square degrees. The latter option is used when no substrate has been specified. The network length is listed in millimetres or degrees.

The step size for the phase shift angle in the systematic search is 1°. The step size for the main-line characteristic impedance is 1Ω, while that for the main-line electrical length is 1°. The number of phase angles values with acceptable worst-case passband VSWRs (*nPha*) is listed at the end of the range of phase shift values listed, with the total number of acceptable solutions (*nSol*) obtained in the search.

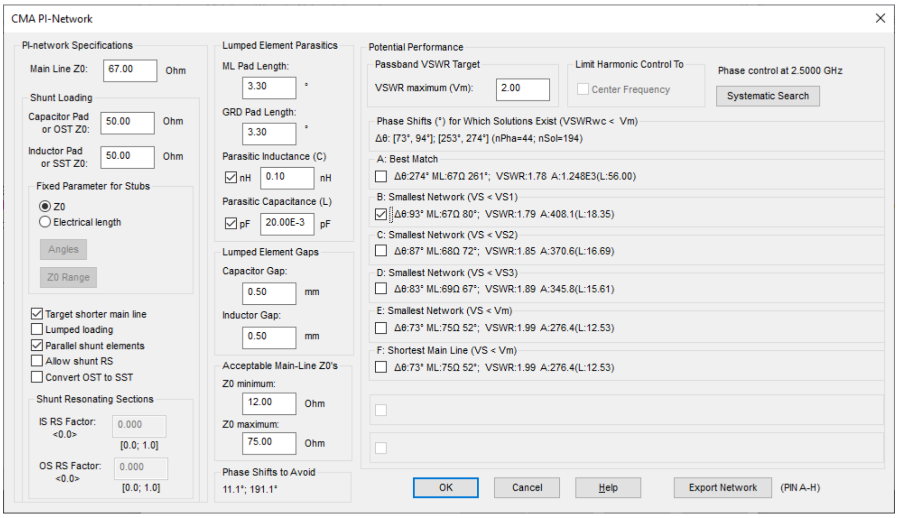

Figure 14. The specifications to be made for a CMA PI-network, with the results of a systematic search.

When resonating sections are allowed, a search for the best resonating-section factor is also done, that is, if the resonating-section factor (*RS*) is specified as zero. The two-dimensional search then becomes three-dimensional. If the specified resonating-section factor is non-zero, a resonating-section with the *RS* factor specified will be assumed to be in place and no search will be done for the best resonating-section factor. The resonating-section factors considered in a search are [0.0, 1.0] in steps of 0.1.

An example of the specifications to be made for a CMA PI-network is provided in Figure 14. A systematic search was done in this example to find the best solutions and Solution B was selected. (Note the difference in the areas of solutions A and B.) Experimentation with the fixed stub parameter is advisable.

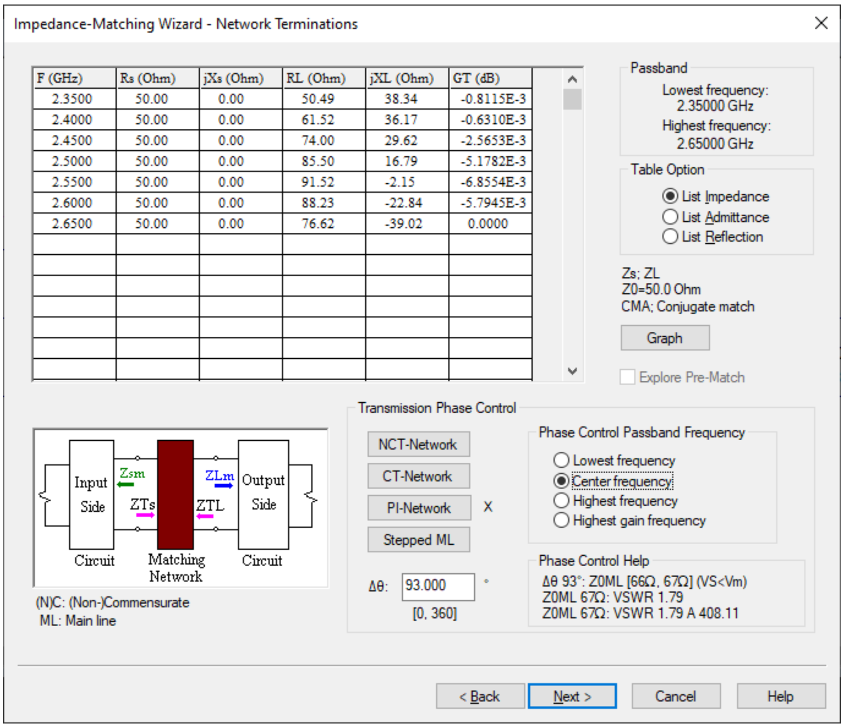

Figure 15. The Terminations page of the IIM wizard. The phase control help (lower RHS corner) is provided after tabbing out of the *Δθ* field.

If one of the listed solutions is not selected, the Main Line Z_0 specified will be used. The phase shift ($\Delta\theta$) required can be specified (after closing the CMA network dialog box) on the IIM Terminations page (see Figure 15). The phase shift is set automatically when one of the listed solutions was selected.

Note the Phase Control Help provided in Figure 15 (Lower RHS corner). This help is provided after tabbing out of the $\Delta\theta$ field. The passband performance depends on the transmission phase shift targeted and the main-line parameter specified (characteristic impedance or electrical length). The range of main-line parameters with acceptable worst-case passband VSWRs ($VS < V_m$) will be displayed for the transmission phase shift specified. The main-line parameters associated with the lowest worst-case passband VSWR and the smallest network (with acceptable passband VSWRs) will also be displayed. When no solutions with acceptable worst-case passband VSWRs can be obtained with the transmission phase shift targeted, the range of phase shift values with acceptable performance is displayed. The information displayed is generated when the Systematic Search command on the specifications page for the CMA network of interest is selected.

Note the X marker next to the PI-network command in Figure 15. This indicates that a PI-network was selected to solve the matching problem. When a solution has been selected and has been inserted into the schematic (complete the steps provided by the wizard), the ADW | MW optimization features can be used to improve the performance.

Harmonic Control

In the ADW or the MW, point matches or circular areas can be targeted at the fundamental frequencies, while harmonic sectors can be targeted at the harmonic frequencies. (A harmonic sector is defined by two intersecting line segments and the Smith chart edge – See Figure 16.) In narrowband problems the harmonic sectors are usually selected for optimum performance. In wideband problems, the sectors should be selected to avoid poor performance. The sectors for wideband performance generally define much larger areas than those associated with optimum performance.

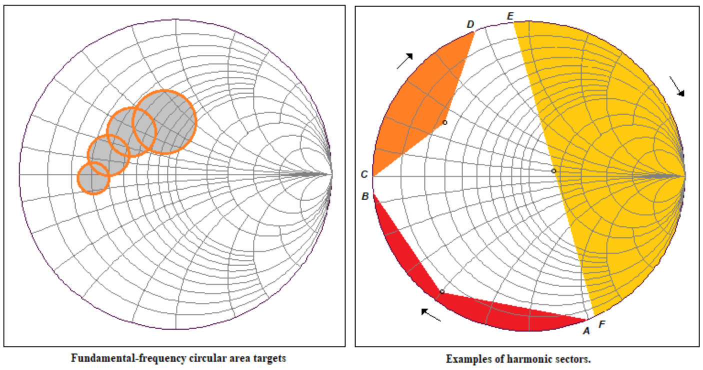

Figure 16. In the ADW or the MW, circular areas can be targeted at the fundamental frequencies, while harmonic sectors can be targeted at the harmonic frequencies.

The systematic search results for a matching problem with harmonic control are shown in Figure 17. The VSWR values listed apply to the fundamental frequencies, while the H_2 error values apply to the second-harmonic sectors and the H_3 error values to the third-harmonic sectors. The number of passband frequencies at which the fundamental-frequency reflection coefficients are inside the circles targeted, the number of second-harmonic frequencies with reflection coefficients inside the second-harmonic sectors and the number of third-harmonic frequencies with reflection coefficients inside the third-harmonic sectors are also listed, in that order. (Example: F: 7 5 2.) When a circle is targeted at a fundamental frequency, an equivalent VSWR based on the network gain relative to the gain associated with the circle targeted is used instead of the actual VSWR.

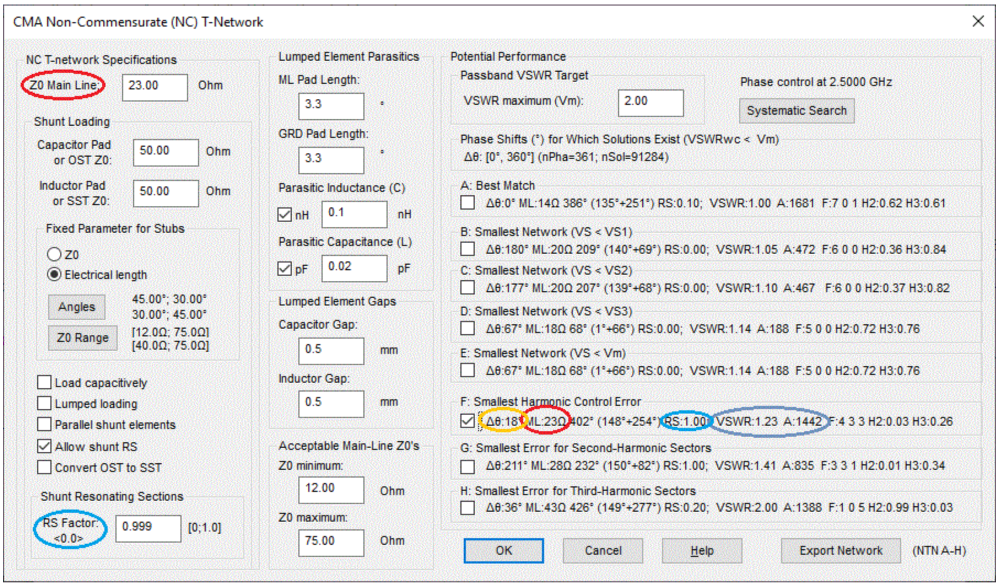

Figure 17. The specifications and results for a harmonic control matching problem.

Targets for an ADW / MW harmonic control problem are usually set at all the second and/or third harmonic frequencies specified. The Limit Harmonic Control option (see Figure 14) can be used to limit control to the centre frequency only. Try both options.

Solution *F* was selected in Figure 17. The fundamental-frequency and harmonic terminations associated with this solution are shown in Figure 18 with the fundamental-frequency circles and the harmonic markers targeted (harmonic sectors were fitted automatically to the harmonic markers by the CIL wizard). (Press the "I" key while viewing the graph to de-activate the graphics interpolation.) The intrinsic load terminations associated with the solution is shown in Figure 19 and the amplifier designed is shown in Figure 20.

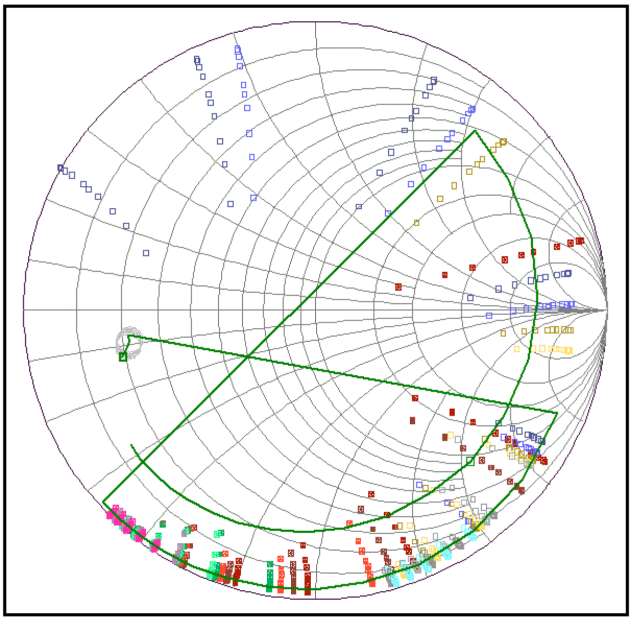

Figure 18. Comparison of the performance of a synthesized commensurate T-network with the targets set (Fundamental-frequency circles and second-harmonic and third-harmonic markers).

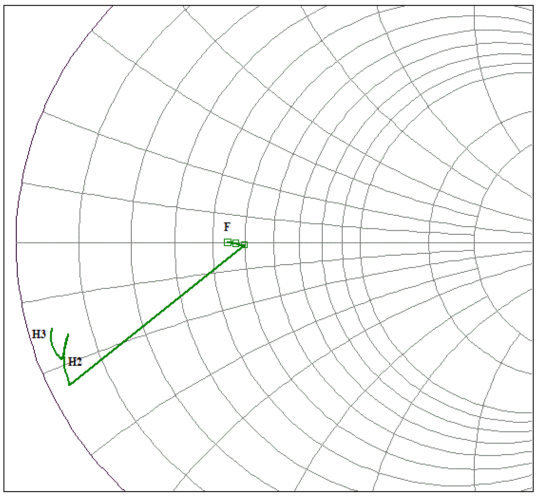

Figure 19. The intrinsic load terminations associated with the CMA network synthesized.

If the performance obtained with CMA networks are not good enough, better solutions can usually be obtained with the ADW / MW Impedance-Matching module. The information gained in synthesizing CMA networks can speed up the synthesis process in the Impedance-Matching module. The main-line characteristic impedance associated with the best-match CMA network is usually a good choice for the main-line characteristic impedance when non-commensurate solutions are synthesized with the Impedance-Matching module. The transformation *Q*s of the best CMA networks also provide an idea of the range of *Q*-values for which good solutions may be obtained. The transformation *Q*s of a CMA network are listed just before the network is inserted into the ADW or MW circuit.

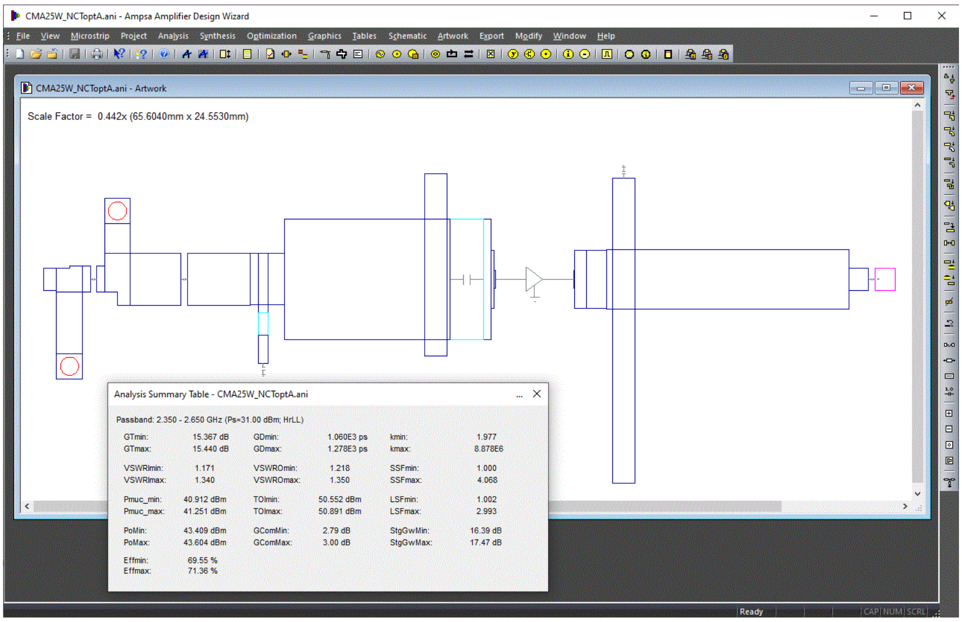

Figure 20. An ADW amplifier designed by using CMA networks.

Note that a CMA network inserted into an ADW / MW circuit can be removed by using the Undo command. The reflection analysis command can be used to calculate the input reflection coefficients presented by the network at the fundamental and the harmonic frequencies (see Figure 18). The intrinsic terminations (Figure 19) can by calculated by using the standard analysis command.

The ADW / MW procedure for designing a CMA network when one of the impedance-matching wizards is used to define the matching problem to be solved is summarized below:

1. Select the insertion point for the required matching network in the schematic and launch the wizard to be used.
2. Select the Explore Pre-Match option on the relevant wizard page (see Figure 1) to bypass solving the defined problem with the Impedance-Matching module.
3. Select the synthesis frequency. The lowest gain frequency in the passband is the default selection.
4. Select one of the CMA-network options (NCT, CT, PI or Stepped ML).
5. Specify the network parameters, the lumped-element parasitics and pads, as well as the range of characteristic impedance values or line lengths to be allowed for the main line (see Figure 14).
6. Set the target for the worst-case VSWR over the passband of interest and then use the Systematic Search option to explore the potential performance with the network selected and the specifications made.
7. A list of potential solutions will be provided. If the performance is acceptable, select one of the solutions listed.

   If several solutions are acceptable, each of these solutions can be selected and exported to an ADW / MW circuit file (Export Network command in Figure 14). The original circuit can be copied and renamed at a later stage to replace the selected solution with one of the saved solutions.

   The solution selected when the dialog box is closed (OK command) will be inserted in the active ADW circuit file. If no solution has been selected, it will be necessary to specify the transmission phase shift required for the solution to be synthesized.
8. Experiment with different specifications and different CMA networks. (Note the tick next to the active CMA network type on the Terminations wizard page.)
9. With a solution selected or with the transmission phase shift specified, use the Next command (see Figure 1) to proceed to inserting the solution into the active circuit file.

   The transformation-*Q*s associated with the solution will be listed with the main-line characteristic impedance or electrical length on the next page of the wizard. This information will be useful if the Impedance-Matching module will be used to solve the problem.
10. When the solution has been inserted in the ADW / MW circuit file, the optimization features can be used to optimize the network.

Reference

[1] Rakesh Sinha and Arijit De, "*Theory on Matching Network in Viewpoint of Transmission Phase Shift*", IEEE Trans. Microwave Theory and Techniques, Vol. 64, No. 6, June 2016.

