

Microwave Circuits and Devices

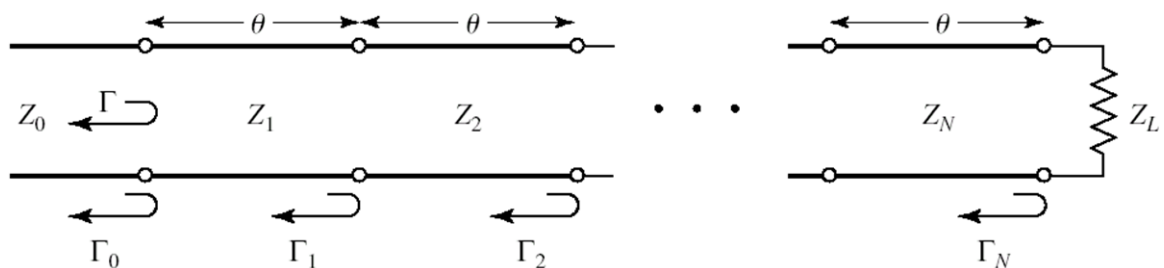
Laboratory no. 1

Note: Even if an image contains more information than 1000 words, the "little black things" between the pictures have their purpose in the current document.

Design of the multisection impedance matching transformers

Load mismatch, with its associated power loss, appears when there is an impedance mismatch between the source and the load. The impedance mismatch can be corrected in several ways, the most simple and often used being the placement of a transmission line with a physical length equal to $\lambda/4$ **at the operating frequency** (quarter-wave transformer) and a characteristic impedance half-way (geometric mean) between the source and load impedance. Instead of an abrupt change in impedance between the source and the load we achieve a gradual change (increase or decrease) in impedance, improving the power transfer **at the operating frequency**.

The main drawback of the quarter-wave transformer consists of its relatively narrow passband (the frequency band where a "good enough" impedance match is achieved). A wider passband can be achieved inserting more sections of transmission line, all having a physical length equal to $\lambda/4$ **at the operating frequency** (commensurate lines), the goal being the same, achieving a gradual change in impedance between the source and the load. As a consequence, the values of the characteristic impedances must increase or decrease monotonically across the multisection transformer.



The first step consists in the design of the multisection transformer starting from your **individual data**. For design relation you must read lecture 3/4 (2020/2021). In the lab we use quick design sheets for binomial and Chebyshev transformers design. The two transformers differ in the way the power loss limit is allowed across the passband (only at the edge of the passband for the binomial one, at multiple frequencies inside the passband and on the edges for the Chebyshev one).

Suppose your individual data requests that you design a binomial transformer to match an 110Ω load to a 50Ω source at 3 GHz, maximum allowable reflection $|\Gamma| = 0.15$. This will give a ratio $Z_L/Z_0 \approx 2$. From the binomial quick design sheet we use the line corresponding to $Z_L/Z_0 = 2$ for the 3 sections transformer ($N=3$). In this particular case we will use for Z_0 the source impedance $Z_0 = 50\Omega$

$$Z_1/Z_0 = 1.0907, Z_1=54.53 \Omega; \quad Z_2/Z_0 = 1.4142, Z_2=70.71 \Omega; \quad Z_3/Z_0 = 1.8337, Z_3=91.68 \Omega$$

Even if the quick design sheets give results only for $Z_L/Z_0 > 1$, they can be used to achieve a match even if the source has higher impedance than the load. As in previous example, matching a 50Ω source to an 110Ω load generates a impedance succession (increasingly) $50\Omega, 54.53\Omega, 70.71\Omega, 91.68\Omega, 110\Omega$. The same values, but **in reverse order** (decreasingly) can be used to match an 110Ω source to a 50Ω load: $110\Omega, 91.68\Omega, 70.71\Omega, 54.53\Omega, 50\Omega$. As a consequence, for both quick design sheets we will use Z_0 as the lower

and Z_L as the higher of the two values received in your individual data (source/load). Z_1 will be placed next to Z_0 , and Z_3 will be placed next to Z_L .

Initial values for the Chebyshev transformers will come from the second quick design sheet, with an extra parameter: the maximum allowable reflection coefficient (in this case $|\Gamma| = 0.15 \approx 0.20$).

Binomial multisection matching transformers

Z_L/Z_0	$N = 2$		$N = 3$			$N = 4$			
	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1067	1.3554	1.0520	1.2247	1.4259	1.0257	1.1351	1.3215	1.4624
2.0	1.1892	1.6818	1.0907	1.4142	1.8337	1.0444	1.2421	1.6102	1.9150
3.0	1.3161	2.2795	1.1479	1.7321	2.6135	1.0718	1.4105	2.1269	2.7990
4.0	1.4142	2.8285	1.1907	2.0000	3.3594	1.0919	1.5442	2.5903	3.6633
6.0	1.5651	3.8336	1.2544	2.4495	4.7832	1.1215	1.7553	3.4182	5.3500
8.0	1.6818	4.7568	1.3022	2.8284	6.1434	1.1436	1.9232	4.1597	6.9955
10.0	1.7783	5.6233	1.3409	3.1623	7.4577	1.1613	2.0651	4.8424	8.6110

Z_L/Z_0	$N = 5$					$N = 6$					
	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_6/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0128	1.0790	1.2247	1.3902	1.4810	1.0064	1.0454	1.1496	1.3048	1.4349	1.4905
2.0	1.0220	1.1391	1.4142	1.7558	1.9569	1.0110	1.0790	1.2693	1.5757	1.8536	1.9782
3.0	1.0354	1.2300	1.7321	2.4390	2.8974	1.0176	1.1288	1.4599	2.0549	2.6577	2.9481
4.0	1.0452	1.2995	2.0000	3.0781	3.8270	1.0225	1.1661	1.6129	2.4800	3.4302	3.9120
6.0	1.0596	1.4055	2.4495	4.2689	5.6625	1.0296	1.2219	1.8573	3.2305	4.9104	5.8275
8.0	1.0703	1.4870	2.8284	5.3800	7.4745	1.0349	1.2640	2.0539	3.8950	6.3291	7.7302
10.0	1.0789	1.5541	3.1623	6.4346	9.2687	1.0392	1.2982	2.2215	4.5015	7.7030	9.6228

Chebyshev multisection matching transformers

Z_L/Z_0	$N = 2$				$N = 3$					
	$\Gamma_m = 0.05$		$\Gamma_m = 0.20$		$\Gamma_m = 0.05$			$\Gamma_m = 0.20$		
	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1347	1.3219	1.2247	1.2247	1.1029	1.2247	1.3601	1.2247	1.2247	1.2247
2.0	1.2193	1.6402	1.3161	1.5197	1.1473	1.4142	1.7429	1.2855	1.4142	1.5558
3.0	1.3494	2.2232	1.4565	2.0598	1.2171	1.7321	2.4649	1.3743	1.7321	2.1829
4.0	1.4500	2.7585	1.5651	2.5558	1.2662	2.0000	3.1591	1.4333	2.0000	2.7908
6.0	1.6047	3.7389	1.7321	3.4641	1.3383	2.4495	4.4833	1.5193	2.4495	3.9492
8.0	1.7244	4.6393	1.8612	4.2983	1.3944	2.8284	5.7372	1.5766	2.8284	5.0742
10.0	1.8233	5.4845	1.9680	5.0813	1.4385	3.1623	6.9517	1.6415	3.1623	6.0920

Z_L/Z_0	$\Gamma_m = 0.05$				$\Gamma_m = 0.20$			
	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0892	1.1742	1.2775	1.3772	1.2247	1.2247	1.2247	1.2247
2.0	1.1201	1.2979	1.5409	1.7855	1.2727	1.3634	1.4669	1.5715
3.0	1.1586	1.4876	2.0167	2.5893	1.4879	1.5819	1.8965	2.0163
4.0	1.1906	1.6414	2.4369	3.3597	1.3692	1.7490	2.2870	2.9214
6.0	1.2290	1.8773	3.1961	4.8820	1.4415	2.0231	2.9657	4.1623
8.0	1.2583	2.0657	3.8728	6.3578	1.4914	2.2428	3.5670	5.3641
10.0	1.2832	2.2268	4.4907	7.7930	1.5163	2.4210	4.1305	6.5950

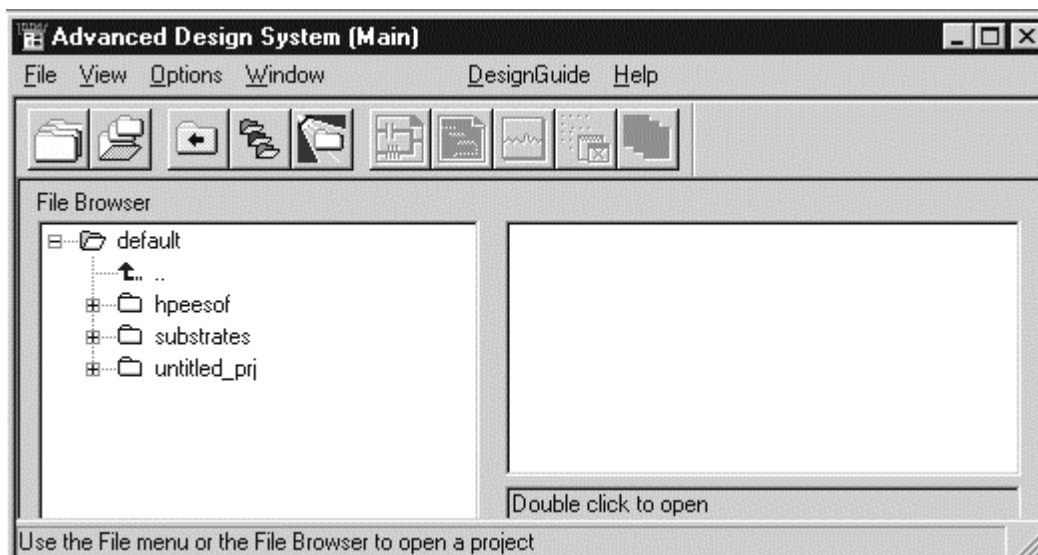
Starting ADS

In the lab we use Advanced Design System, produced by Agilent Technologies (company splitted from Hewlett Packard). The software is installed on Windows XP Professional. In the lab you find this system on a virtual machine. Find on your desktop the icon that starts VMware Player. In the main interface detect a virtual machine entitled "RF XP Professional" or choose "Open a Virtual Machine" and search for the VM in the folder (typically) D:\DCMR\WXP_CIM.

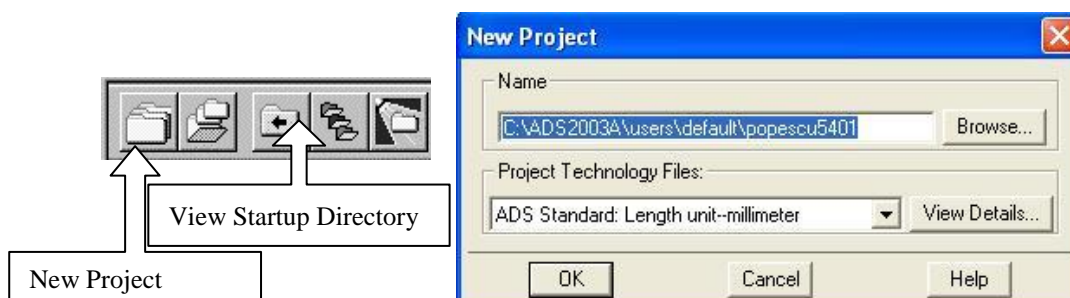
To start the software click the Start button in Windows XP and choose the commands succession **Start > All Programs > Advanced Design System 2003A > Advanced Design System**.





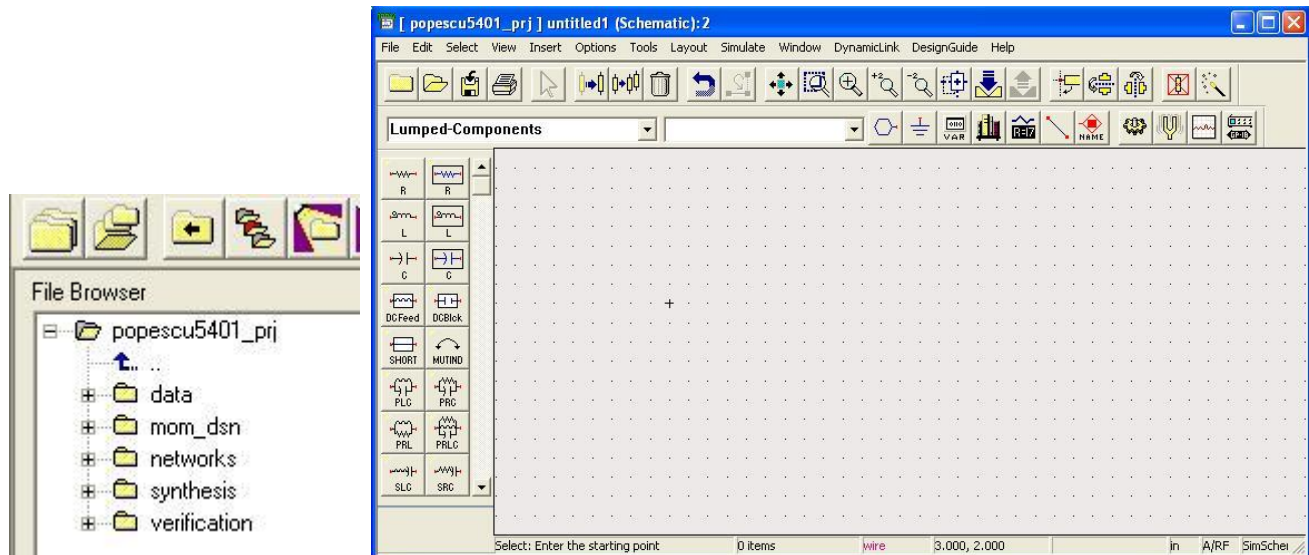
The main program window - **Advanced Design System (Main)** allows project management (creation, deletion, archiving – useful for moving a project to another computer, a zip archiving method is used, resulting in a file with the "zap" extension which stores the project's directory structure), and access to individual project files. Each project will be stored in its own folder with the name "chosen_name" + "_prj", implicitly found by default at "C:\ADS2003A\users\default\" but the path can be modified upon creating a new project.



It is recommended that you choose **View > Startup** to get to the default followed by the **File > New Project** command to create a new project. The same commands can be given by the icons. In the next window insert the desired name after the path already present there "C:\ADS2003A\users\default\" without "_prj" ending, this will be added by the software upon project creation. Example: **C:\ADS2003A\users\default\popescu5401**

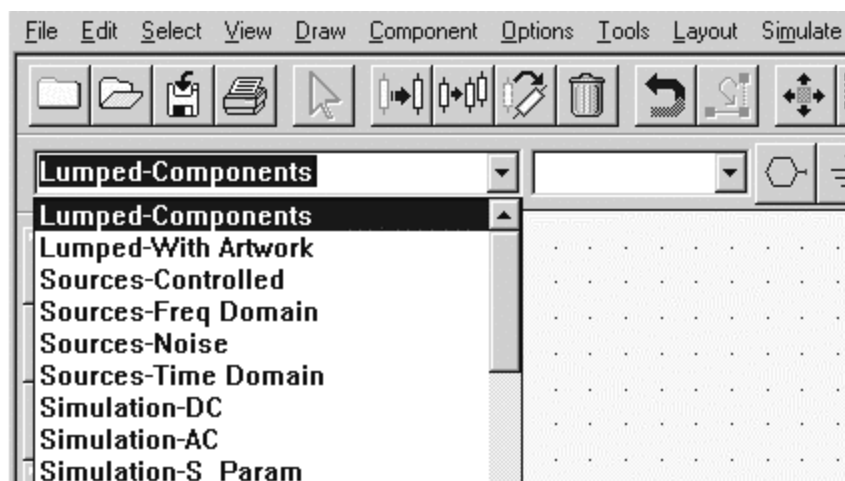


The new project is created and is automatically opened. By default a new schematic is created in a new window. If this is not the case choose the  icon to create a new schematic or the **File > New Design** command from the menu. Save this schematic (the window [popescu5401_prj] untitled1)  with a recognizable name. After saving it the schematic can be found in the **networks** section of the project structure (main program window - Main) if you close it by mistake.

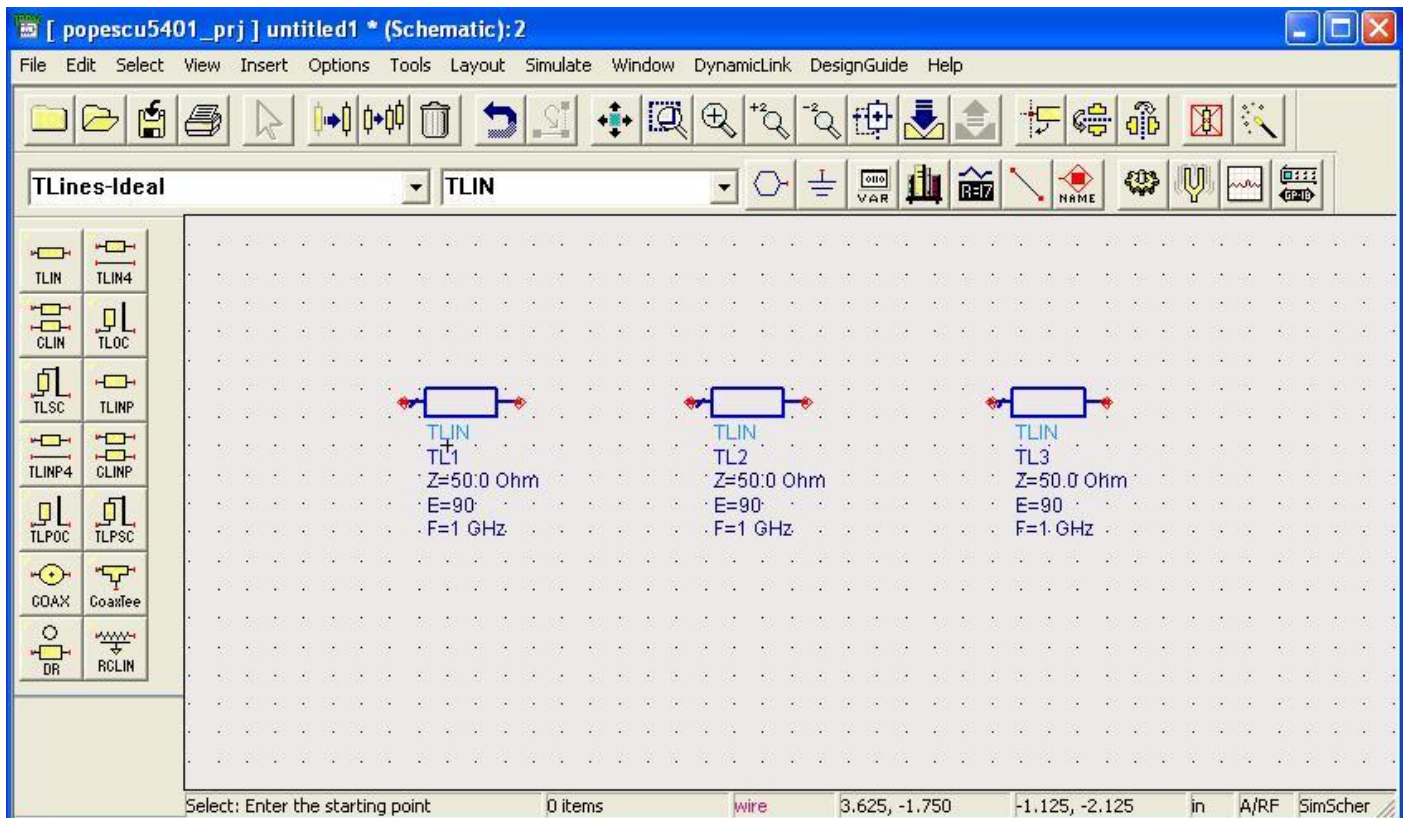


Simulation of the impedance transformer

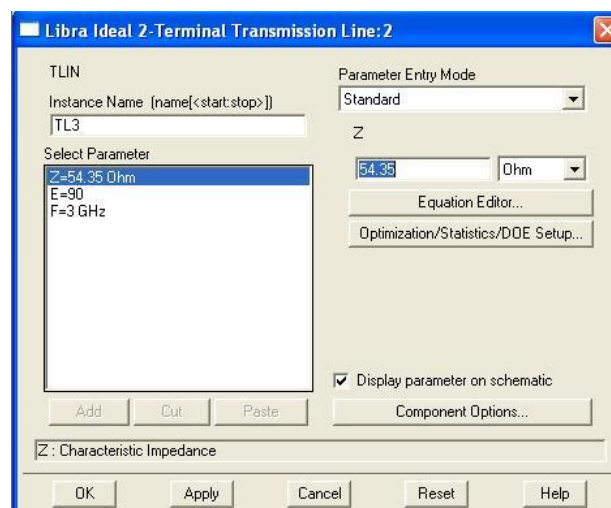
In the schematic created in the previous step you will draw the multisection transformer calculated for your own data. For this, access the component palette where all the available schematic symbols are conveniently divided into palettes, each containing similar items. By default, the **Lumped-Components** palette is opened. You will need to change to **TLines-Ideal** where ideal models for transmission line reside. The element to be entered is the first in the list called TLIN, the ideal transmission line model where all structural and material elements are absent.



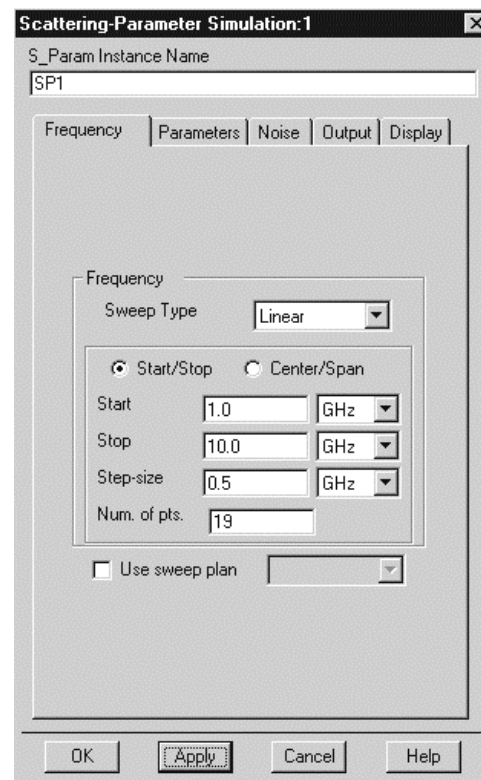
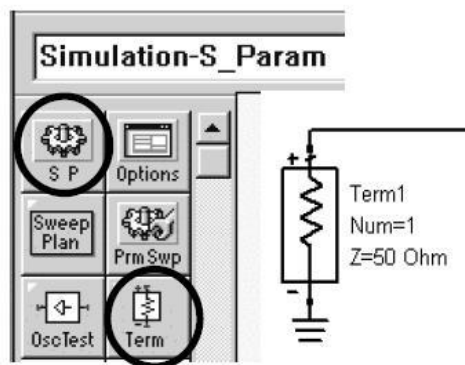
Insert 3 transmission line sections in the schematic by clicking on the item icon in the palette then clicking the desired place on the schematic. You will notice that the default impedance is 50Ohm, the electrical length ($E = \beta l$) is 90° at a frequency of 1GHz.



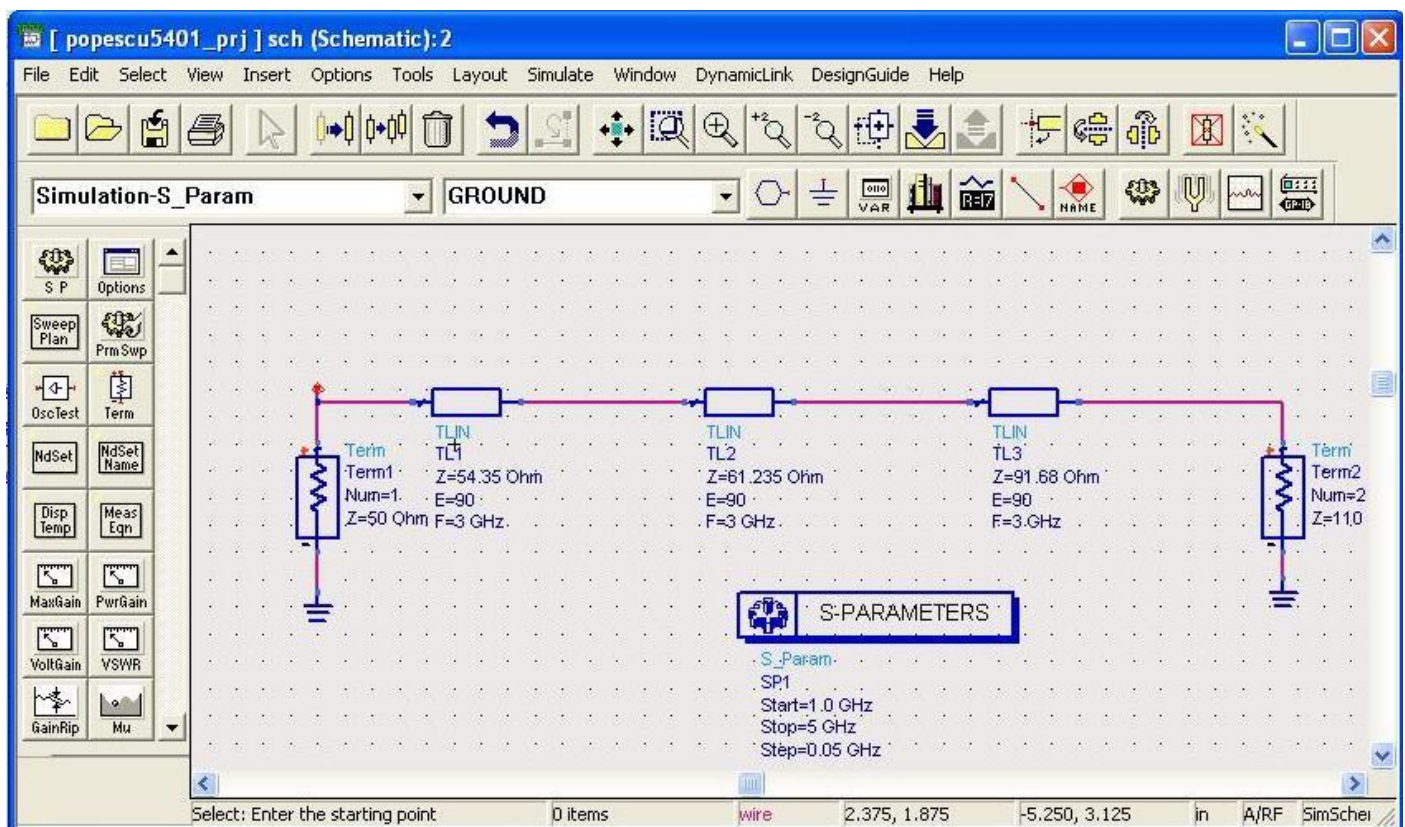
You will need to change these values. Double-clicking an item opens the **Edit Instance Parameters** window where these parameters can be changed. The parameters in this window correspond to the particular parameters of that item. Even if changes can be made clicking on the schematic directly, the parameters window is the preferable way to change any item, because **not all parameters are visible on the schematic**.




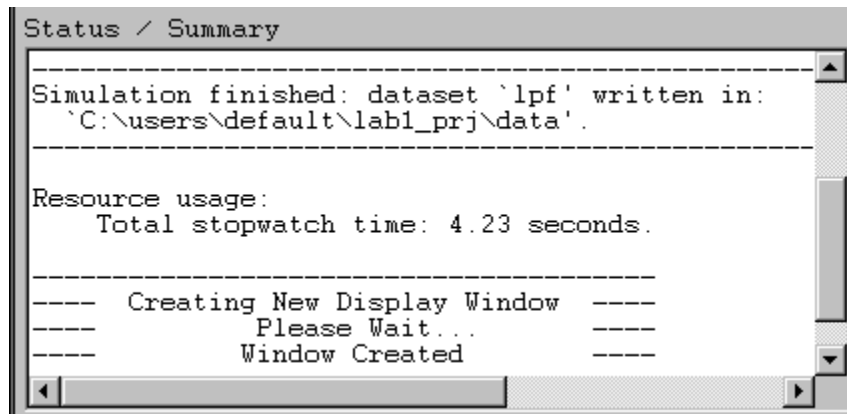
The simulation that will reveal the quality of the match will be a S parameters simulation. A particular schematic can be analyzed with multiple methods (circuit/electromagnetic, linear/non-linear), often in the same time. To indicate the simulations to be performed for the schematic, one or more simulation controllers must be inserted. In this case the **S-Parameters** controller can be found in the **Simulation-S_Param** palette. Insert the items denoted in next image: a simulation controller (**S P**) and two terminators (**Term**) that will be the two ports: source and load. For the example, we are interested in the input terminator (traditionally Num=1) having an impedance of 50 Ω and the output terminator (Num=2) 110 Ω . Also, the simulation should be done in a band **around** the 3 GHz frequency, for example in the 1÷5GHz band with a 0.05GHz step. Do not forget to change the simulation controller parameters according to **the individual data** you received. Also, terminator impedances should be changed to match the values of the source and load in the individual data.



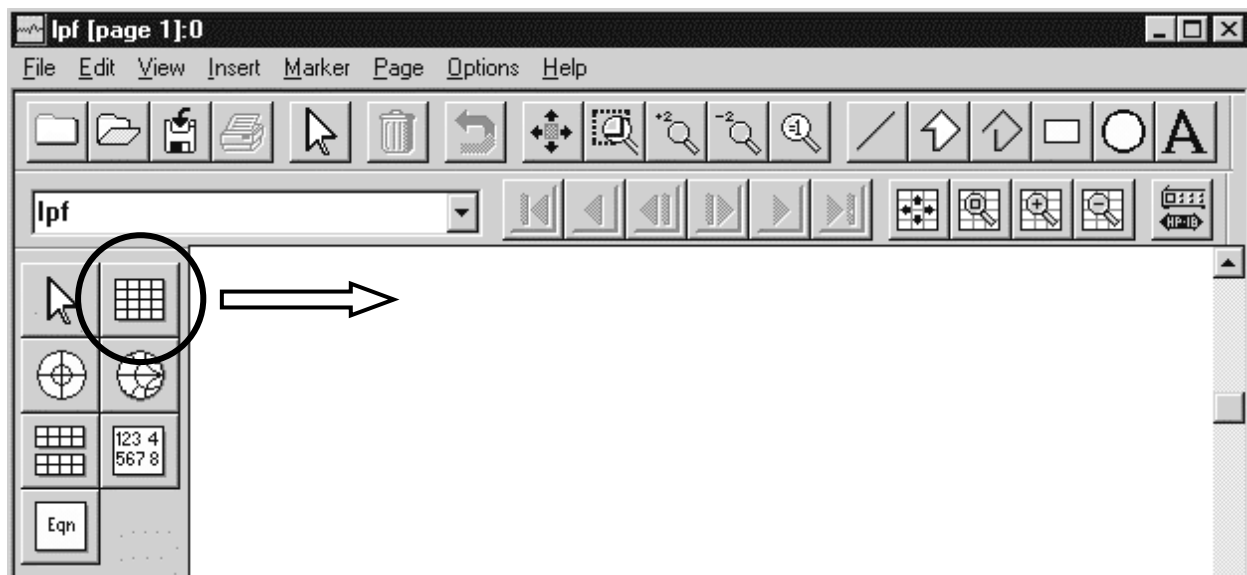
Use wires , ground , and rotate  from the button bar to finish the schematic.



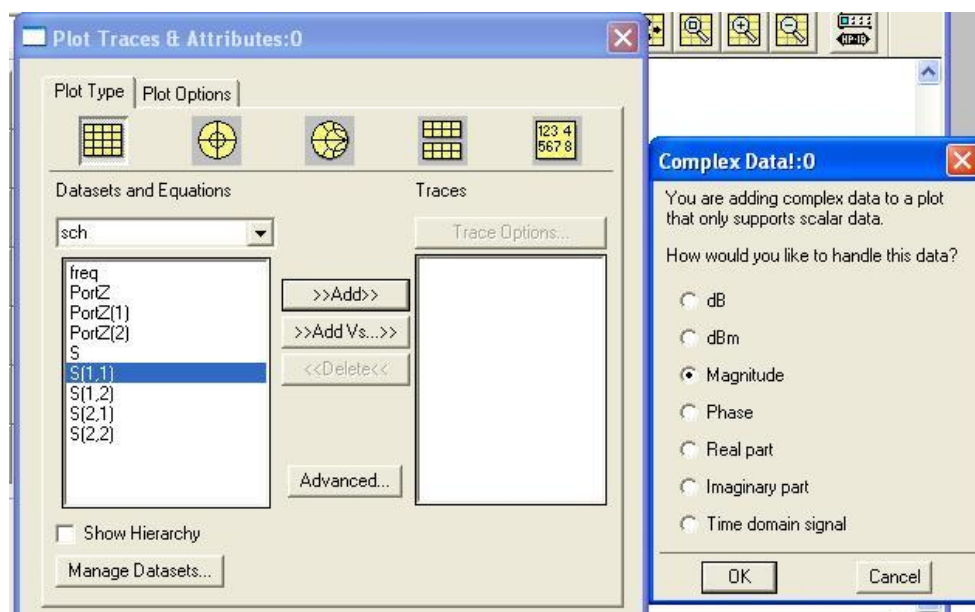
Start the simulation: , or **F7** or menu commands **Simulate > Simulate**. Because it's a circuit simulation with ideal models, you can expect the simulation to finish briefly, in seconds. The simulator window shown below remains open. Track messages to identify a possible error message in the "Simulation Messages" section. If necessary, try to interpret and correct the error, in case of failure call the teacher's help.

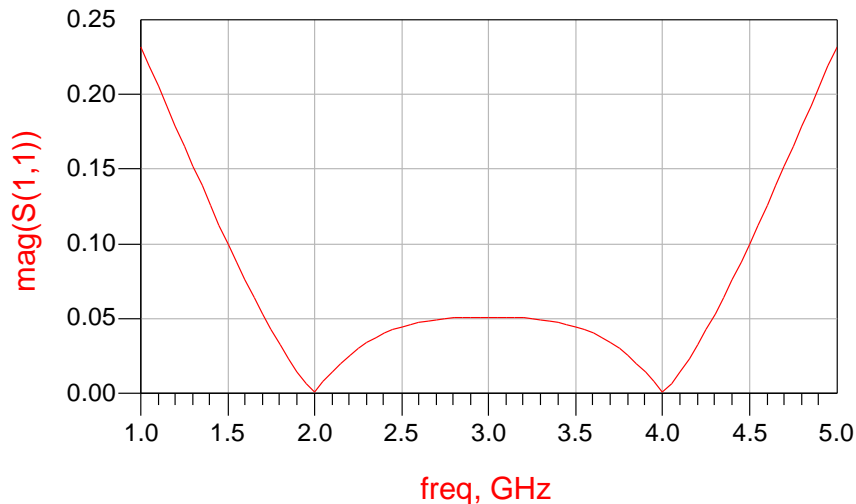



Once the analysis has finished **successfully**, the Data Display window will open automatically. If this doesn't happen, check in menu **Simulate > Simulation Settings** if the checkbox "Open Data Display when simulation ends" is checked.

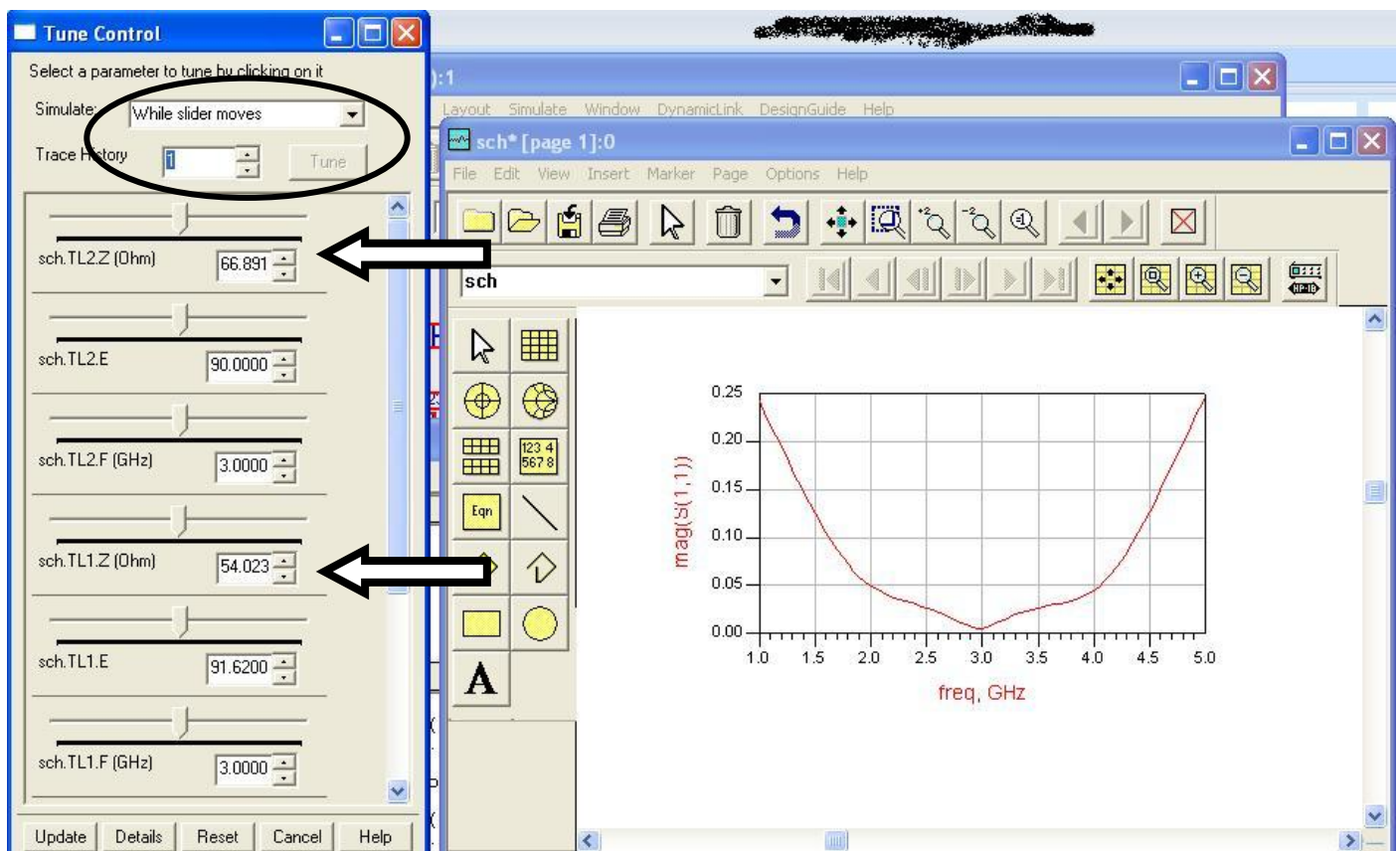


You are interested in representing the amplitude of the reflection coefficient $|\Gamma|$, so click the rectangular graph icon then click on the data display window. In the next window that appears choose to plot the input reflection coefficient S (1,1) then Add, then choose to represent the modulus of the complex number (Magnitude).



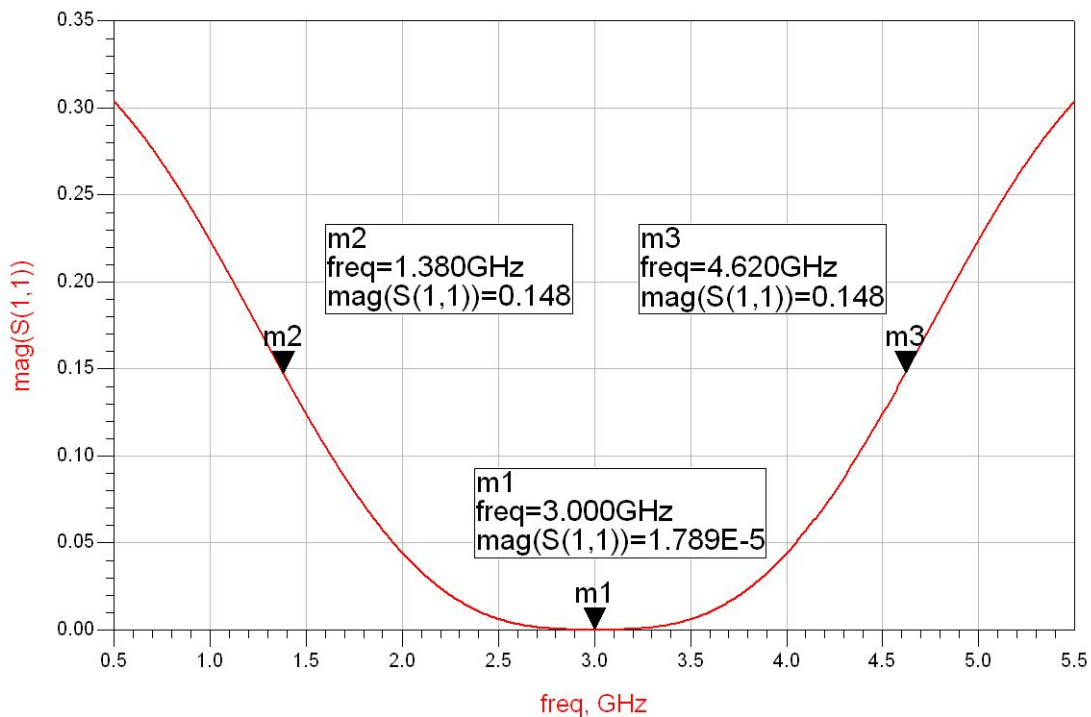


The result that will show the quality of the impedance matching at a particular frequency is the representation of the S parameters resulting in a null or "almost null" reflection coefficient at that frequency. The initial match is not perfect (intentionally) because Z_L/Z_0 ratio is not exactly equal to 2. You will need to **select the elements** you need to tune (TL1, TL2 and TL3 in this case) then press  to start the **Tune** tool.

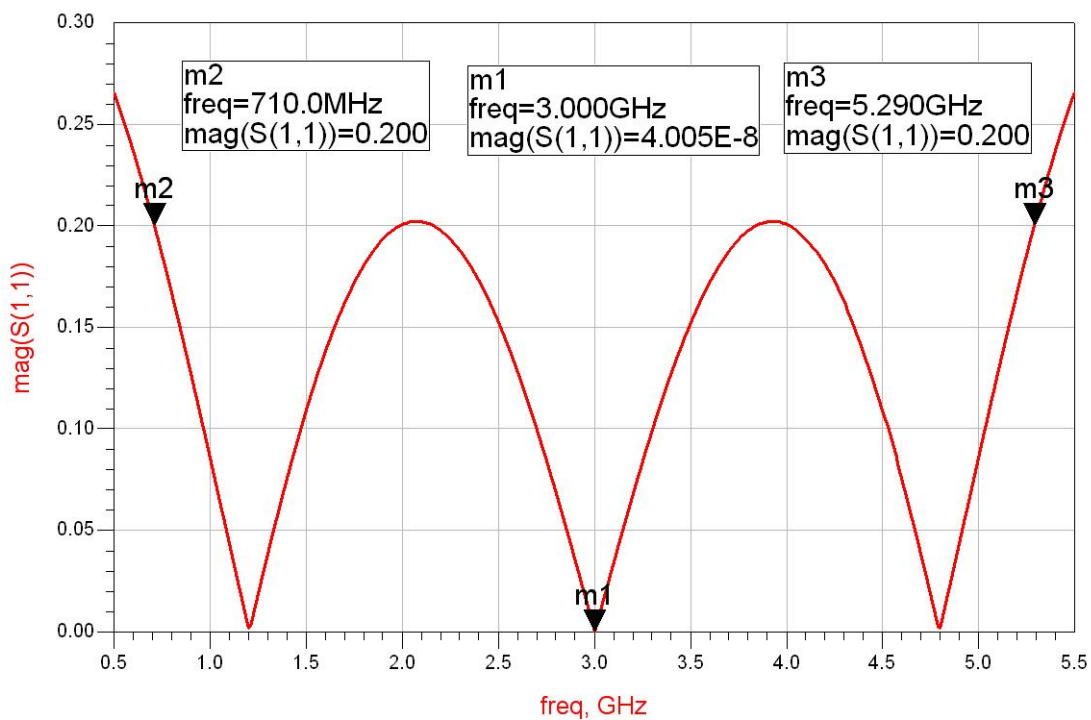


You may need to change (if it is convenient for you) the selection in the **Simulate** and **Trace History** sections (in this particular schematic a simulation finishes fast enough that "While Slider Moves" permits real time changing of the graph). Press **Details** to change at your convenience Min/Max/Step values (remember that **all three** characteristic impedances **must lie between** the source and load impedance values and **increase or decrease monotonically**). The characteristic impedances of the three transmission lines will be changed with the slider or up/down buttons to achieve the desired result (remember that all impedances have a length $\lambda/4$ at 3GHz so neither E or F **must not** be tuned). Use 1-2 markers (**Marker** > **New**) view exact value of the reflection coefficient at a particular frequency (during tune and for results submission).

Final results should look similar to the next two images.



For the binomial multisection matching transformer your graph should reach 0 (or very close) at the operating frequency, should have a maximally flat shape and have the largest possible passband in this conditions.



For the Chebyshev multisection matching transformer your graph should reach 0 (or very close) at **three** frequencies (one of which should be the operating frequency) and the two maxima between them should reach the maximum allowable reflection $|\Gamma|$ from your individual data.

In both cases use 2 markers (or one marker that you move around) to detect the two lateral frequencies where the maximum allowable reflection $|\Gamma|$ is found.

(Most important) Note: At the end of the lab, the **final tuned** parameters must be handed over to the teacher/submitted to the server, not the initial computed ones.