

Design Project #1: Matching Transformers

In this project you will design and test **three** matching networks:

- a) A Quarter-wave transformer
- b) A 4-section Binomial transformer
- c) A 4-section Chebychev transformer

PROJECT SCOPE

In this design, we will attempt to match a real load of $R_L = 120\Omega$ to a transmission line with a 50Ω characteristic impedance at a frequency of 4.0 GHz.

The **bandwidth** of the 4-section transformers is defined by $\Gamma_m = 0.2$.

Assume TEM wave propagation in the transmission lines, and the transmission line dielectric constant is $\epsilon_r = 16.0$.

PROJECT TASKS

1) **Design** each of the three matching networks, determining both the **characteristic impedance** and **physical length** (in cm) of each section.

2) Use the design equations in your notes/book to **determine** the **expected bandwidth** for each design.

3) **Implement** each design on **ADS** software. **Analyze** the circuit by evaluating $\Gamma_{in}(\omega)$ from **0 to 8 GHz**. **Display** the results as (make sure you use **enough frequency points—at least 100—in the analysis!**):

- a) a Smith Chart plot of $\Gamma_{in}(\omega)$. Note this is a **parametric** plot of reflection coefficient Γ_{in} as a function of **frequency**—not as a function position (i.e., **not** $\Gamma(z)$!).

b) a Cartesian plot of $|\Gamma_{in}(\omega)|$ versus frequency (i.e., linear scale).

c) a Cartesian plot of $10\log_{10} |\Gamma_{in}(\omega)|^2$ versus frequency (i.e., dB scale). Make sure that you use a **log scale** that makes sense (e.g., 50 dB from top to bottom).

Q1: Do the plots indicate that your designs are correct? Explain why you think so. Give specific numerical examples.

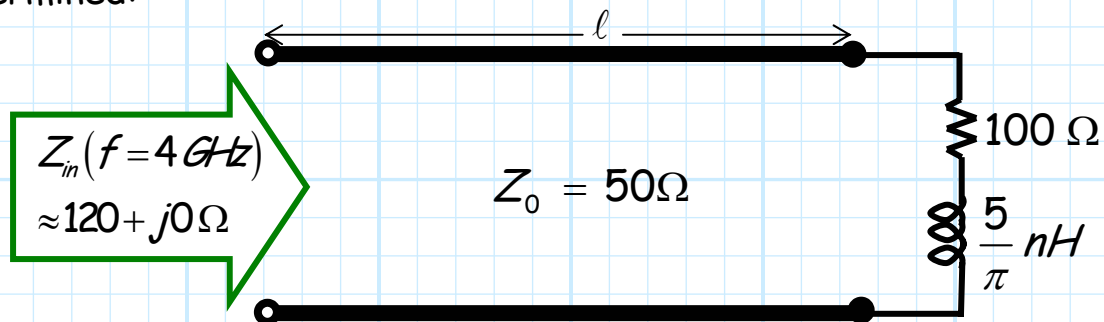
Q2: Observe the parametric plot $\Gamma_{in}(\omega)$ on the Smith Chart. Use the adjustable markers to determine at what frequencies the curve is far from the center of the chart, and at what frequencies the curve is near the center. Explain why this result makes sense.

Q3: Likewise determine the frequencies at which the parametric Smith Chart plot of $\Gamma_{in}(\omega)$ is precisely at the center of the chart (i.e., the curve intersects the center point). Explain why this result makes sense. Locate these same frequencies on the Cartesian plots. What are the values of $|\Gamma_{in}(\omega)|$ and $10\log_{10} |\Gamma_{in}(\omega)|^2$ at these frequencies? Explain why this result makes sense.

4) Use the adjustable markers on the plots to determine the bandwidth of each design.

Q4: You will find that the bandwidths of your design will not be exactly the bandwidths predicted by the design equations. Explain why that is. Hint: It is not because "ADS has errors"!

5) You will find that at $f = 4 \text{ GHz}$, the following device has an input impedance of approximately $Z_{in} \approx 120 + j0 \Omega$ if the length ℓ is properly determined:



6) **Determine** the proper value for line length ℓ . Now **replace** the 120Ω resistor with this 120Ω "load" shown above, and **reanalyze** (with ADS) each matching transformer design.

7) **Display** the results of this new load on the same three plots (with the same scale!) as described in step 3.

Q5: *Compare and contrast these results with the 120 Ohm resistor plots. How are the results different? Determine the frequencies where the value of $\Gamma_{in}(\omega)$ is precisely the same for the two cases. Explain why is this true.*

PROJECT REPORT

1. You basically should view the project report as a **lab report**. **Show how** and why the design parameters were determined. "Construct" the circuits in ADS, and then "measure" the circuits in ADS. Provide the results of these "measurements" in report. **Discuss** your results, and include the answers to the questions posed earlier (put particular emphasis on the answers to questions with the word "why"!).

2. Assume your audience is a **knowledgeable microwave engineer** (i.e., **me!**) Thus, you do not need to provide a long (or even short) discussion about what matching networks are, or why they are so great, or what their general characteristics are, or a multiple reflection analysis of

them, etc. I assume you know the material that has been presented in class. What I don't know is if you can take that material and: 1) **design** a matching network that works and; 2) explain the behavior of that design when analyzed on ADS.

3. Thus, I am looking for **quality** over quantity. I do not want this to be a massive report requiring tons of writing. Make the points that you want to make in a clear and complete manner, and then **stop** writing! However, do not confuse the word "**why**" with the word "**what**". I have frequently asked you to explain **why** an observation is true, or **why** something happened, or **why** an observation makes sense. Students often instead just tell me **what** is observed, or **what** happened when something was changed—do **not** do this!

For example:

Me: Explain **why** water appears on the outside of a cold glass on a humid day.

Bad student response: "Because the outside of the glass slowly becomes wet".

4. You must describe the synthesis process you used to design the matching networks. I require that your **computations** be presented in your report. I must be able to see **where** the error was made if your results or design are erroneous. I want to see all the **general equations** used, and then the **values** used for the **variables** in the equations, and **then** the numeric results of the equation.

You may put **detailed computations** in one or more **organized appendices**. These appendices can be **handwritten**. However, do not destroy the flow or organization of your report by providing **fundamental** information in the appendix **only**. In other words, I do not want to have to search through the appendix to find fundamental design parameters (e.g., the

characteristic impedances, bandwidth, etc.)—the appendix is for computation **details**.

5. Moreover, the report should flow from one section to another as one continuous document. Often I receive a set of independent pieces, stacked together and called a report—do not do this! To this end, figures, tables, and appendices should be labeled, number, and titled and referred to in the report. For example, "Figure 2 provides the parametric plot of $\Gamma_{in}(\omega)$ for...", or "The details of the computation can be found on page 3 of Appendix 2".

Likewise, the titles of each figure must be **descriptive**.

A descriptive title: Parametric plot of $\Gamma_{in}(\omega)$ for Binomial transformer design and resistive load.

A non-descriptive title: Plot of $\Gamma_{in}(\omega)$

GRADING AND EVALUATION

1. Each student team (2 people max.) must work alone on this project—the design and analysis must represent each team's effort and knowledge only. Working with other teams will be considered academic misconduct and **all** students involved will receive a **zero grade**. You are **forbidden** from viewing the report of other project teams—**past** or present.

2. However, you may ask your colleagues about how to operate or in any way use **ADS**.

3. Likewise, you may confer with fellow students about any **general** questions about the theory of wideband, multi-section matching networks. However, these questions must be **general**!

4. A report that receives a top grade will exhibit three characteristics:

a) **Accurate** - the designs and the analyses are correctly done.

b) **Professional** - the results are clearly, completely, and unambiguously presented.

c) **Insightful** - the report convinces me that you understand what you have done and why the result appear the way they do. In other words, after reading your report, I wish to be **impressed** with your knowledge and insight.

5. You may **extend** this project beyond what is called for in the project description. If done correctly, this will likely impress me and help me conclude that you are a very motivated, knowledgeable, and professional microwave engineer! Your grade will thus reflect this favorable opinion.

However, this does **not** mean that an extension of the project scope is **required**—you will get full credit with a well-done report that addresses only the project scope described earlier.

EECS 723 Project #1 Evaluation

Authors: _____

1. **Report organization clarity and professionalism** - Was the report well written and organized? Was it easy to understand and follow? Did the authors appear to take the assignment seriously and work hard to produce a professional product? Did the report include all the required elements?

/25

2. **Design effectiveness** - Is the design effective and accurate? Does it appear to be designed by a knowledgeable microwave engineer? Does it meet the technical specifications of the project?

/20

3. **Design synthesis** - Does the report describe well the synthesis of the design? Are the design equations and calculations clearly, completely, and unambiguously stated?

/15

4. **Design analysis** - Is the analysis of the design and its observed behavior complete and unambiguous? Is the analysis correct? Were all questions satisfactorily answered? Did the author's appear to know **why** their observations and measurements were correct? Did the authors show sufficient insight in the analysis?

/40

Comments:

/100

ADS INFORMATION

1. You will find on the website an ADS Overview (Parts 1 and 2). It will give you a quick tutorial on the general operation of the software. Further assistance can be found in the help file of ADS. Of particular interest is the "Quick Tour", which can be found by selecting *Help -> Topics and Index*.
2. There are several types of analyses that can be performed by ADS. The overview provides examples for "DC" and "Transient" analyses. However, this project will require only the **S-Parameter** analysis (i.e., *Simulations_S-Param*).
3. The only circuit elements you will need for this project are:
 - a) Port Termination (*Term*) - This device is an element of the *Simulations_S-Param* category. This device is used to define the ports of a multi-port network for S-parameter analysis. Its design parameter is the port impedance (i.e., Z_0).
For this project, we will need only one of these devices, connected to the input of the matching network. As such, the simulation will determine only S_{11} (port 1 being the input to the matching network). Note that this means that $S_{11} = \Gamma_{in}$ if the port impedance is $Z_0 = 50\Omega$.
 - b) Ideal Transmission Line (*TLIN*) - This device is simply a length of ideal transmission line. Its design parameters are characteristic impedance and electrical length (at a specific design frequency). This device is an element of the *TLines-Ideal* category.

c) Resistor (R) - This device is simply an ideal resistor. Its design parameter is simply its resistance in Ohms. It is an element of the *Lumped-Components* category.

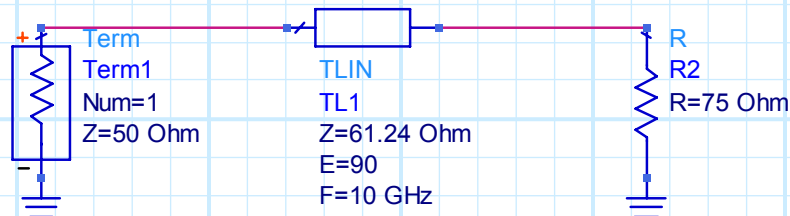
d) Inductor (L) - This device is simply an ideal inductor. Its design parameter is simply its inductance in Henries. It is an element of the *Lumped-Components* category.

4. I have made available on the web two files, a design file and a display file. You can open up the design file and then save it under a name of your own choosing. However:

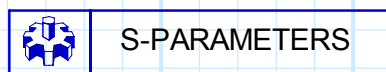
a) Do not leave any spaces in the file name (ADS gets VERY upset when you do this).

b) Save these files to a floppy or to your own disk space. If you save it to a general directory of the computer that you are working on, it may not be there when you return!

5. The design file will open a schematic for a quarter wave transformer that is matched to a 75 Ohm load at 10 GHz:



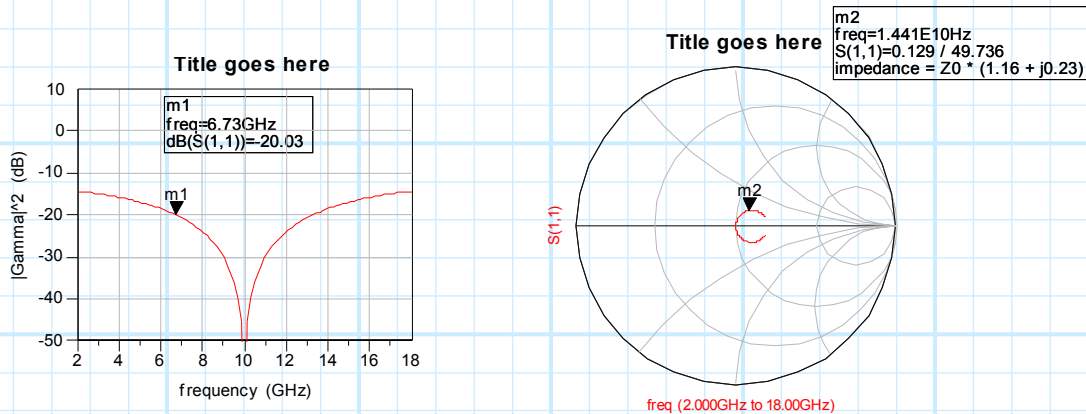
Note ground elements!



S_Param
SP1
Start=2.0 GHz
Stop=18.0 GHz
Step=

Note that this schematic contains all of the required devices except the inductor. You will obviously need to add several more sections of transmission line for your designs. You can simply modify this design, or start from scratch with a new design file.

6. The display file contains formatted Cartesian and Smith Chart plots:



Again, you should save the display file to your own disk space, using a name of your choosing. You may (in fact are encouraged) to modify or add to the display formats in any way. These two files are provided as an aid to you; you may ignore them completely if you wish.

Note that the markers can be moved in ADS by "clicking and dragging" them to a new point on the graph. Likewise, double-clicking on the plots launches a window that allows you to format the graphs in any way you see fit.

Finally, use a vertical log scale that makes sense. Typically, 40 to 60 dB of vertical scale is all that is required (i.e., do **not** give me a 200 dB log scale!).

7. Note that you can copy all graphics from ADS by selecting the graphics and typing "Ctrl-C", and then pasting into a MS document.