

Microwave Circuit Design: Lab 5

1. Introduction

This lab investigates how trade-offs between gain and noise figure affect the design of an amplifier.

2. Design Specifications

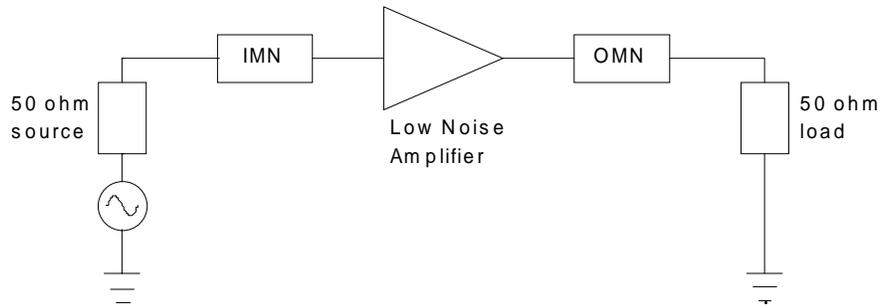


Figure 1: Block diagram of an amplifier

You are to design a single-stage amplifier that has a noise figure (NF) of 1.8 dB and an available gain (G_a) of 20 dB. The design frequency is $f = 1$ GHz.

The core of the schematic is a special low noise amplifier (LNA) subcircuit. MDS supplies a pre-built LNA subcircuit (called `LS_amplifier`) as part of its demo files. You still have to add a few extra components to the `LS_amplifier` subcircuit to create the final LNA subcircuit.

There is a $50\ \Omega$ source impedance on the input side of the LNA and a $50\ \Omega$ load on its output. To keep things simple, use ell circuits (i.e., capacitors and inductors) instead of microstrip for the input and output matching networks. You may also ignore coupling capacitors.

3. Accessing the Pre-built LNA Subcircuit

If you already have both the `samplelib` and `Learn_amp` icons on your main MDS screen, then you may skip the following procedures. If you do not have those icons visible, then perform the following procedures to load the necessary MDS library files:

Loading `samplelib`:

Activate the file browser utility either by choosing `[MB:TOOLS/BROWSE-OPEN]` or by clicking `[SUI:Browse/Open]`. The 'Browse/Open' dialog window appears. At the top of the window, click `[Unix System]` to view your Unix directories. Next click `[Browsing Options...]`. When the 'Browsing Options...' window appears, click `[Libraries]` to view only MDS libraries and then click `[OK]` to exit.

In the center of the 'Browse/Open' window, you should now see a scrollable list of available MDS libraries. Scroll down the list, select the `samplelib` library, and click `[OK]`. The 'samplelib: FILE' window will appear. Close that window.

Loading Learn_amp:

Activate the file browser utility again. In the 'Browse/Open' dialog window, click [Browsing Options...]. Click [Working] to view your current working directory and then click [OK] to exit.

In the center of the 'Browse/Open' window is an input box labeled *Directory path*, which shows the name of your current directory. Below that is a scrollable list of directories and files that you can click on to navigate the directory system. Erase whatever text is in the input box and type /pkgs (i.e., a forward slash character followed by the directory name pkgs) In the scrollable list area, successively click on directory names in this order:

hp_hfds-7.0/ → mds_b.07.00/ → hp85150/ → demos/

Once you are in the demos/ directory, scroll down the list, select the Learn_amp file, and click [OK]. The 'Learn_amp: FILE' window will appear. Open the LS_amplifier icon and examine the low noise amplifier schematic. When you are done, close the open windows.

4. Creating the Final LNA Subcircuit

4.1 Assignment

Create the LNA subcircuit that contains both the LS_amplifier subcircuit and its DC power supply.

4.2 Circuit construction

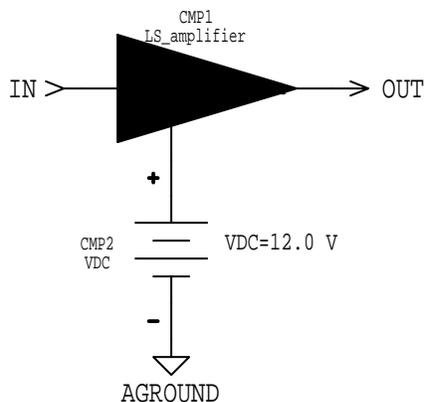


Figure 2: LNA subcircuit (LS_amplifier + power supply)

- Construct the subcircuit shown in Figure 2. To access the LS_amplifier subcircuit, click [MB:INSERT/COMPONENT/BY LABEL]. The 'Label of Design Icon to be used as a Component:' window appears. In the input box, type Learn_amp/LS_amplifier. Click [OK] and then place the LS_amplifier symbol onto the circuit page.
- Add the +12.0 volt DC power supply and the input and output connectors to LS_amplifier. To finish the LNA subcircuit, remember to create a symbol and add the reference block (i.e., use [MB:WINDOW/CHANGE PAGE/SYMBOL 2], [MB:PERFORM/CREATE SYMBOL], and [MB:INSERT/REF-NAME-LABEL]). When done, close the LNA subcircuit window.

5. LNA Noise Characteristics

5.1 Assignment

You will determine the noise figure characteristics of the LNA subcircuit.

5.2 Circuit construction

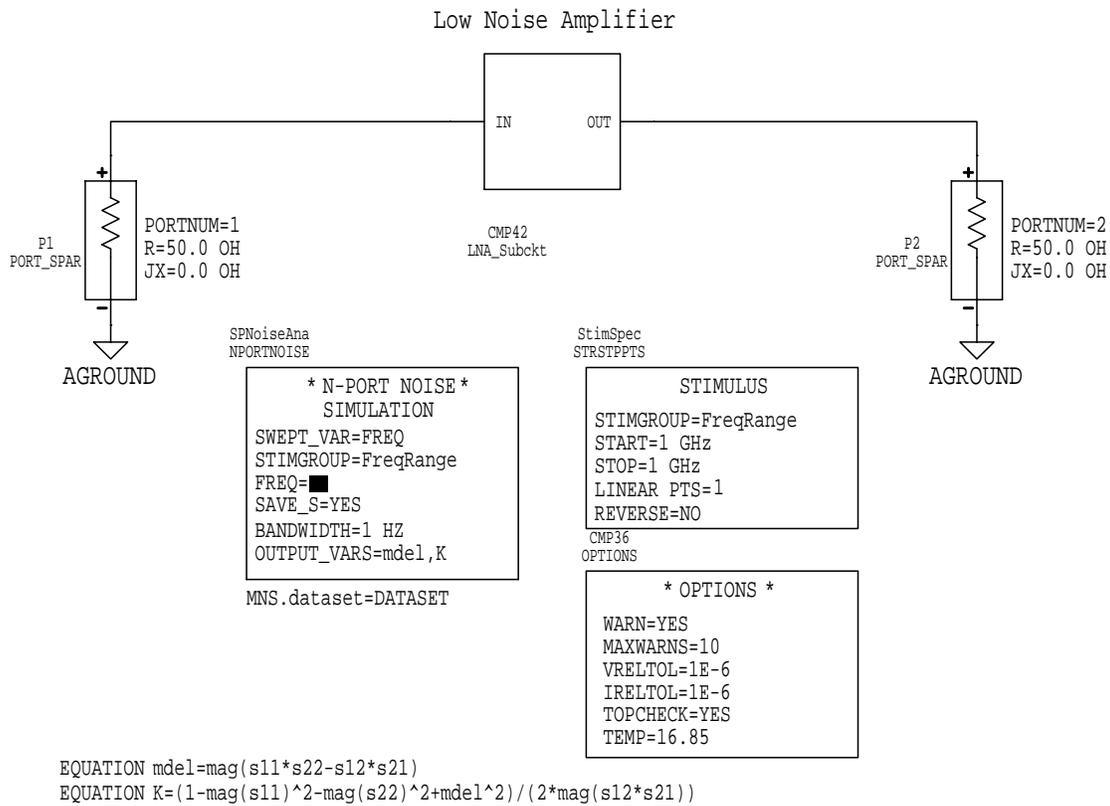


Figure 3: LNA test circuit

NOTE: The circuit in Figure 3 was created using a template that has all the necessary noise and stimulus controls pre-configured. Do not try to build the circuit using your standard construction techniques. Perform the following steps instead.

- Create a new circuit page.
- Select [MB:INSERT/TEMPLATE/templatelib/S_Parameters/Noise_vs_freq]. An outline of an entire test circuit tags along with the mouse pointer. Click the mouse button to drop the noise vs. freq test circuit onto the circuit page.
- Delete the text on the circuit page that says [CONNECT YOUR CIRCUIT HERE]. Insert your LNA subcircuit in the spot where the deleted text used to be.
- Add the two equations to the circuit page.

- The line that says $MNS.dataset=DATASET$ tells MDS to use the name **DATASET** when saving the data from the simulation run. It is not a simple line of text. Choose [MB:INSERT/MNS/DATASET NAME]. Position the mouse pointer where you want the $MNS.dataset=$ line to appear and click the mouse button to drop the line onto the circuit page. You can change the dataset name to something else if you wish, as long as you **remember to use the same name on your presentation pages**.

5.3 Simulation

NOTE: Instead of using the standard ‘Simulation Setup’ dialog window to configure the simulation, you will edit the parameters of the noise and stimulus control boxes that reside on the circuit page.

- In the control box labeled *STIMULUS*, make the following changes:
 $START=1$ GHz, $STOP=1$ GHz, $LINEAR PTS=1$

This sets the frequency sweep to a single point at 1 GHz.

- In the control box labeled *N-PORT NOISE SIMULATION*, make this change:
 $OUTPUT_VARS=mdel,K$

This declares the equation variables *mdel* and *K* as output variables.

- To actually run the simulation, first highlight the *N-PORT NOISE SIMULATION* control box by clicking inside that box. On the left side of the circuit page window is a column of command buttons. Click the [S] button to start the simulation.

5.4 Output

- When the simulation is done, create a new presentation page. Be sure the *Dataset=* line at the top of the presentation page has the correct dataset name.
- Choose [MB:INSERT/TEMPLATE/templatelib/S_Parameters/Noise_vs_freq]. A very large outline of several output plots tags along with the mouse pointer. Click the mouse button to drop the plots onto the presentation page.
- Carefully examine each of the plots and note the significance of the various parameter values.

5.5 Items to turn in

- Turn in printouts of the LNA subcircuit (see Figure 2) and the LNA test circuit (see Figure 3).
- Submit a printout of the presentation page containing the noise figure plots.

5.6 Questions

1. According to the noise figure plots, what is the minimum noise figure NF_{min} ? ($NFmin$ in the plot)
2. What is the equivalent unnormalized noise resistance R_n ? (RN in the plot)
3. What is the stability of the LNA subcircuit at 1 GHz? Explain how the stability regions of the LNA subcircuit might affect your choice of source and load reflection coefficients.

6. Matching Network Design

6.1 Assignment

The amplifier design requirements are $NF = 1.8$ dB and $G_A = 20$ dB at $f = 1$ GHz. Find the source and load reflection coefficients that will accomplish this goal. Design the corresponding input and output matching networks using ell circuits.

NOTE: This is a paper design only. You do not need to construct and simulate the IMN and OMN.

6.2 Design considerations

One way to approach this design is to plot the 1.8 dB noise figure circle and the 20 dB available gain circle on the same Smith chart. The intersection points between the two circles will tell you the required source reflection coefficient.

- Create a new presentation page. Instead of plotting a Smith chart the standard way, choose [MB:INSERT/PLOT/Z-SMITH]. Next, define a rectangular area on the presentation page where the chart should be drawn. To do this, click and drag the mouse from the upper left corner to the lower right corner of the rectangular area. When you release the mouse button, MDS will draw a blank Smith chart inside the area you just defined.
- To draw the noise figure circle on the blank Smith chart, you first have to insert a noise figure circle equation on the presentation page. Choose [MB:INSERT/EQUATION/CIRCLES/SOURCE MISMATCH NOISE]. An outline of the equation tags along with the mouse pointer. Position the pointer outside the frame that surrounds the Smith chart and click the mouse button to drop the equation onto the presentation page. Note that this only defines the noise figure circle setup conditions but does not actually draw the circle on the chart (that is a separate step).

The equation you see on the presentation page is $Ns = NScircle(Sopt, rn/real(portZ[1]), nfmin)$. The full syntax of the noise figure circle equation (where braces indicate optional parameters) is:

$$Ns = NScircle(Sopt, rn/real(portZ[1]), nfmin\{, StartValue, StepSize, NumCircles, PointsPerCircle\})$$

$Sopt$ is the optimal source matching that produces the minimum noise figure. $rn/real(portZ[1])$ is the normalized noise resistance. $nfmin$ is the minimum noise figure. These three parameters are output variables from the simulation in the previous section. Hence, their values are already computed, so you do not have to set them yourself (i.e., do not edit them).

$StartValue$ is the initial noise figure circle (dB) to compute. $StepSize$ indicates the interval (dB) between successive noise figure circles. $NumCircles$ tells how many noise figure circles to compute. $PointsPerCircle$ determines the number of evaluated points per circle. The computed noise figure circle data is stored in Ns .

For example, if you wanted to plot three noise figure circles starting at 1.5 dB with a 0.25 dB separation between circles, you would use $Ns = NScircle(Sopt, rn/real(portZ[1]), nfmin, 1.5, 0.25, 3)$.

- Click inside the $Ns = NScircle(...)$ equation to edit it. Enter values for the $StartValue$, $StepSize$, and $NumCircles$ parameters to compute a single 1.8 dB noise figure circle. To get smoother circles, you can include the $PointsPerCircle$ parameter to increase the number of plotted points (default = 51).
- Choose [MB:INSERT/TRACE ON PLOT]. The 'Messages' window asks you to select a plot for inserting the trace. Select the blank Smith chart with the mouse.

- The 'Expression Error' dialog window appears. In the input box, type $Ns[1, *, *]$ and press RETURN (or click [OK]). MDS now draws the 1.8 dB noise figure circle on the Smith chart.

What did that expression do? Ns has the syntax $Ns[FrequencyIndex, CircleIndex, Angle]$. The first parameter determines which frequency to plot noise figure circles for (* = include all frequencies in the frequency sweep). The second parameter indicates which of the computed noise figure circles to plot at a given frequency (* = include all circles). The third parameter determines the angle on the circle for plotting a data point (* = include all angles, i.e., a full circle).

Hence, $Ns[1, *, *]$ causes MDS to draw all noise figure circles that correspond to the first frequency in the frequency sweep. For this lab, the sweep was just the single frequency at 1 GHz.

- Adding the 20 dB available gain circle to the Smith chart is performed in a similar manner. Choose [MB:INSERT/EQUATION/CIRCLES/AVAILABLE GAIN] to place the gain circle equation onto the presentation page.

The equation you see on the presentation page is $Ga=GAcircle(S)$. The full syntax of the available gain circle equation (where braces indicate optional parameters) is:

$$Ga=GAcircle(S\{,StartValue,StepSize,NumCircles,PointsPerCircle\})$$

S is an array that holds the S -parameter data. Its value is stored in your dataset, so don't change it.

- Edit the $Ga=GAcircle(...)$ equation. Enter values for the *StartValue*, *StepSize*, *NumCircles*, and *PointsPerCircle* parameters to compute a single 20 dB gain circle.
- Once again, choose [MB:INSERT/TRACE ON PLOT]. In the input box of the 'Expression Error' dialog window, type $Ga[1, *, *]$. MDS will draw the 20 dB gain circle on the Smith chart.
- Use [MB:INSERT/MARKER ON TRACE] to place a marker on the gain circle. Move the marker to the intersection point that is closest (magnitude-wise) to the center of the Smith chart and read off the value of the source reflection coefficient.
- MDS has several other pre-defined circle types that you can add to the Smith chart. Choose [MB:INSERT/EQUATION/CIRCLES/SOURCE STABILITY] to insert a source stability circle equation. Choose [MB:INSERT/EQUATION/CIRCLES/LOAD STABILITY] to insert a load stability circle equation. In the input box of the 'Expression Error' dialog window, type either $Stab_S$ or $Stab_L$ for source stability or load stability, respectively.

6.3 Items to turn in

- Turn in the Smith chart plot with the noise figure, available gain, and stability circles.
- Submit the Smith charts you used to design the ell circuits of the IMN and OMN. Briefly outline your design decisions.
- Turn in a sketch or drawing of the completed amplifier (LNA subcircuit + matching networks). Be sure to label the component values of the capacitors and inductors.

6.4 Questions

1. What are the values for Γ_s and Γ_L (in magnitude & phase format) that fulfill the design requirements of $NF = 1.8$ dB and $G_A = 20$ dB at 1 GHz?
2. If you were to redesign the amplifier circuit 7 Tji/ cha N