ECE424 – Radio System Design

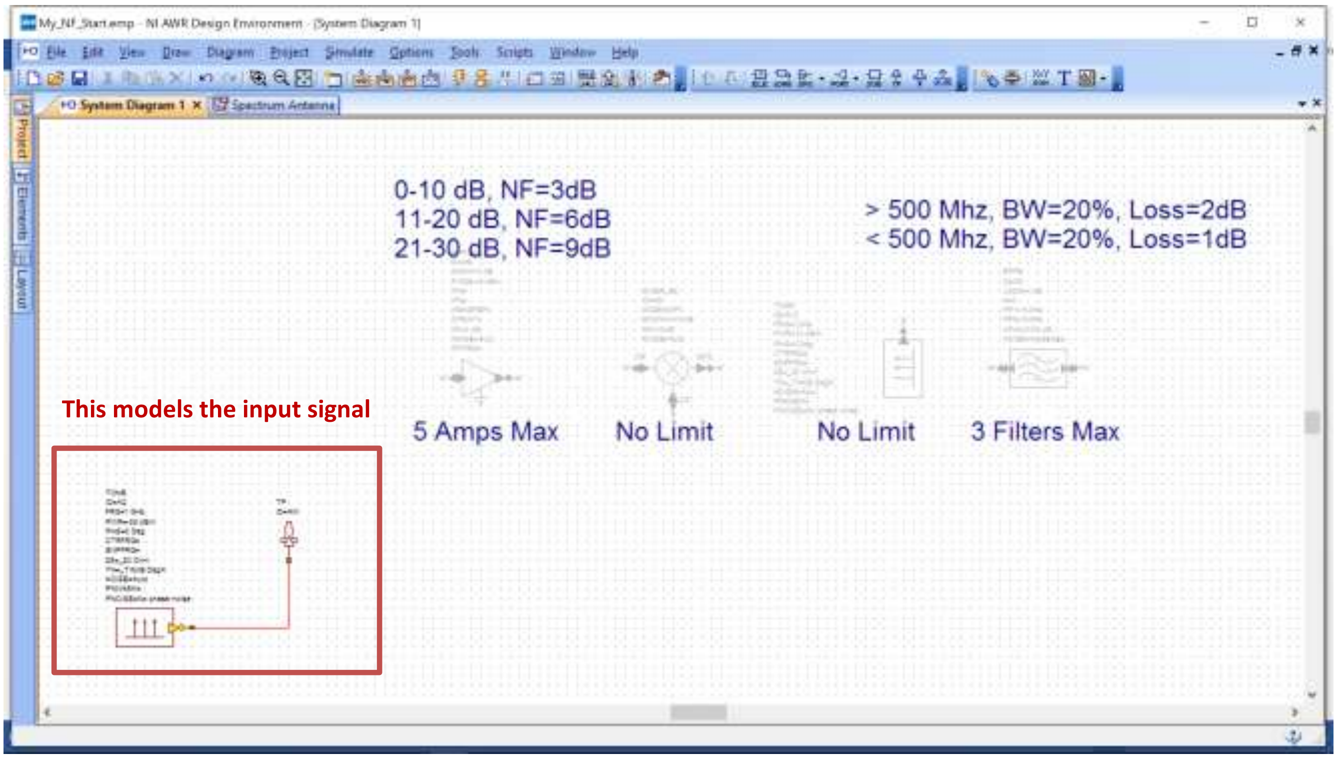
LAB 07 – NOISE FIGURE AND SNR
45 PTS POSSIBLE

By:
David S. Ricketts (david.ricketts@ncsu.edu)

This lab is different from previous labs in that it is not a step-by-step experiment, but rather a design project.

Please download the AWR file called "MY_NF_Start."

The system diagram looks like this:



Part 1: Input Noise

In the calculation of noise figure, we made an assumption about the input noise. This assumption is often overlooked, so let's take a moment to look at the noise at the **Ant** input.

The input noise used to calculate NF is ***defined as the noise from an impedance matched resistor at room temperature***. For most systems this is 50 ohms. Thus the noise voltage of the source is:

$$v_n^2 = 4kTR = 4 \cdot 1.38 \cdot 10^{-23} \cdot 293 \cdot 50 \left[\frac{\mathrm{V}^2}{\mathrm{Hz}} \right]$$

This voltage source is then divided between the source 50 Ohms and the input 50 Ohms of the system (by definition we are impedance matched). The voltage transfer function is:

$$v_{in} = v_n \cdot \frac{R}{R+R} = v_n \frac{R}{2R}$$

So the noise power delivered to the receiver is:

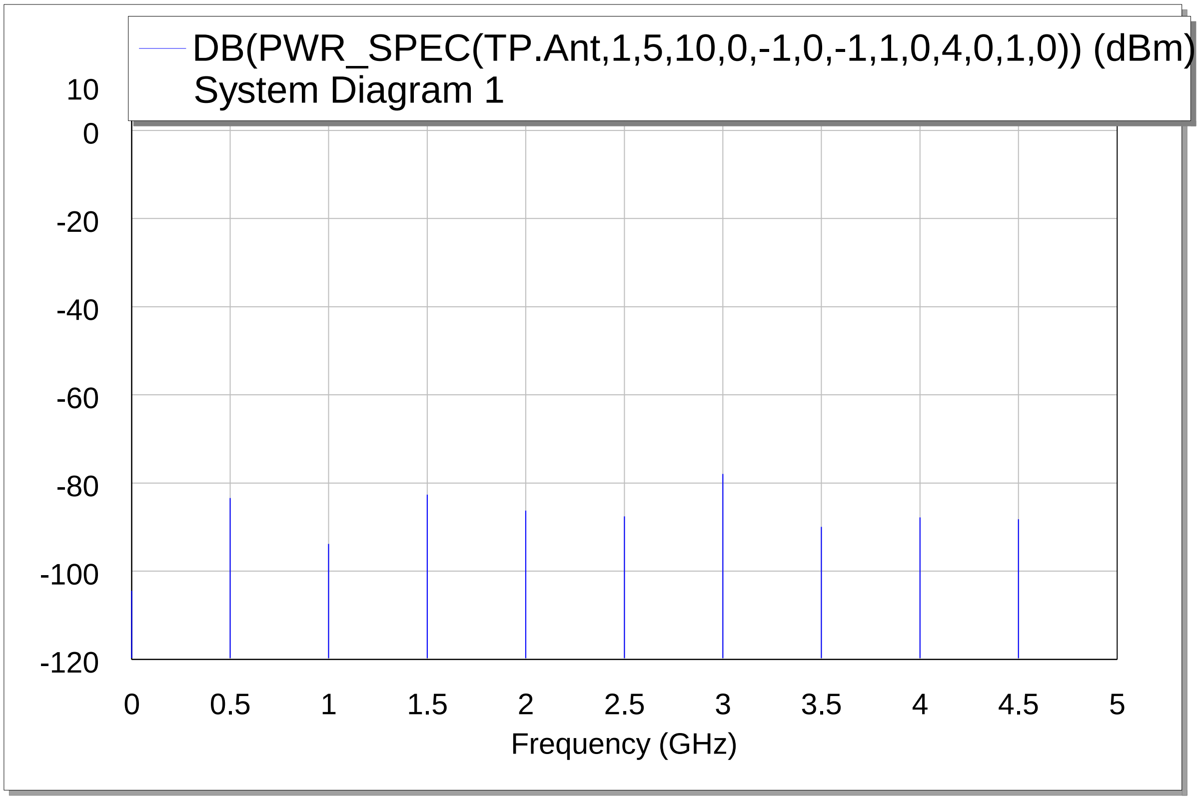
$$P_{in} = \frac{v_n^2 \cdot \left(\frac{R}{2R} \right)^2}{R} = \frac{4kT}{1} \frac{R^2}{2R^2} = kT = 1.38 \cdot 10^{-23} \cdot 293 = 4 \cdot 10^{-21} \left[\frac{\mathrm{W}}{\mathrm{Hz}} \right]$$

$$P_{in} = -204dB \left[\frac{1}{\mathrm{Hz}} \right] = -174dBm \left[\frac{1}{\mathrm{Hz}} \right]$$

The input noise of an impedance matched, passive system, is always *kT*!

Assignment: (3 pts)

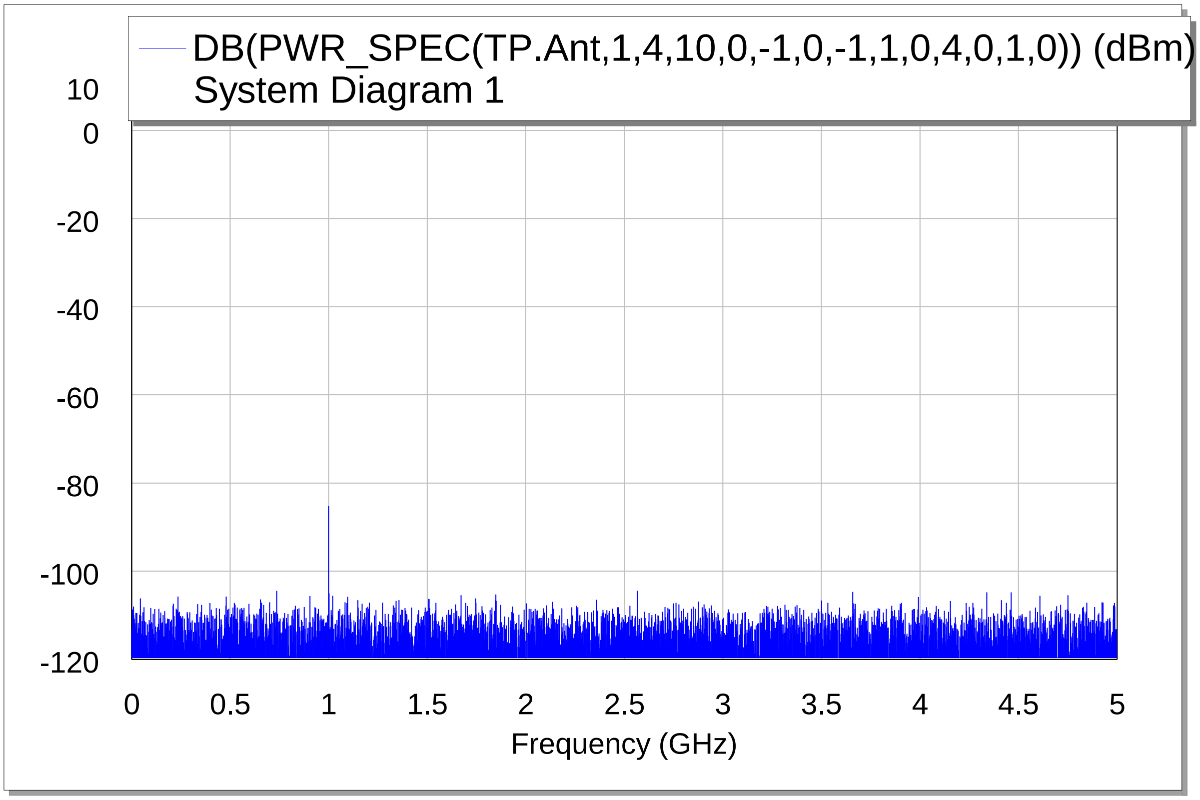
- **Plot the spectrum of Ant. (1 pt)**



-
- **Is it at -174 dBm? If not why? (1 pt)**

It is not, the RBW for the circuit is 1 GHz. Pnoise = -174 + BW (dB).

- **Change the RBW in the measurement setup to 1 Mhz. Is it at -174 dBm now? Why? (1pt)**



Still not at -174 dBm. Pnoise = -174 dBm + 60 dB = -114 dBm
1MHz = 60 dB.

A spectrum analyzer is simple a heterodyne receiver. The spectrum analyzer's antenna is its input port. It amplifies the signal and then sweeps the LO across the desired frequency span. At each LO value, it calculates the TOTAL POWER out of the filter. In the case of a SA, it is a BPF. The SA then plots that TOTAL POWER on the screed for the LO frequency. It then goes to the next LO. Every signal in the BPF BW gets integrated, signals, interferers, noise, etc. Thus, the point you see on a spectrum analyzer is not necessarily your actual signal. By making the filter BW narrower, you exclude other signals and reduce the total noise power. This filter is called a Resolution Bandwidth Filter (RBW) as it sets the *resolution* of your measurement.

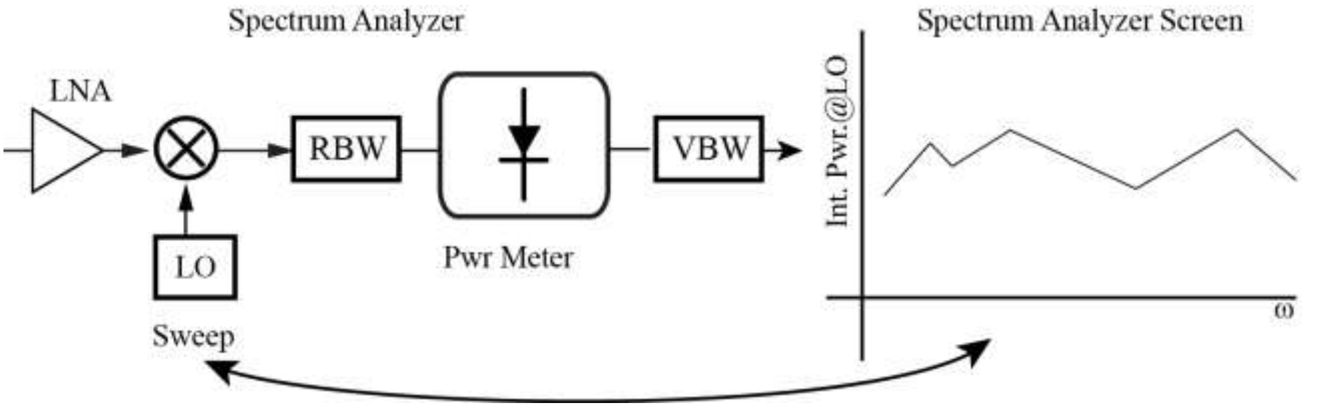


Figure 1: Block Diagram for a spectrum analyzer. RBW and VBW are KNOBS on the SA. Screen of SA plots the *integrated power* over the RBW @ single LO, then increases LO to next frequency.

In your spectrum plot above, the RBW was 1 GHz (by default in the setup file). Change the RBW of your Spectrum Antenna graph from 1 GHz to 1 MHz. Now, note that the noise power (P_n) is per Hertz, so at 1 MHz it should be 10^6 times the noise PSD we calculated – that was per Hz – thus it will be 60 dB above that value..

Assignment: (2 pts)

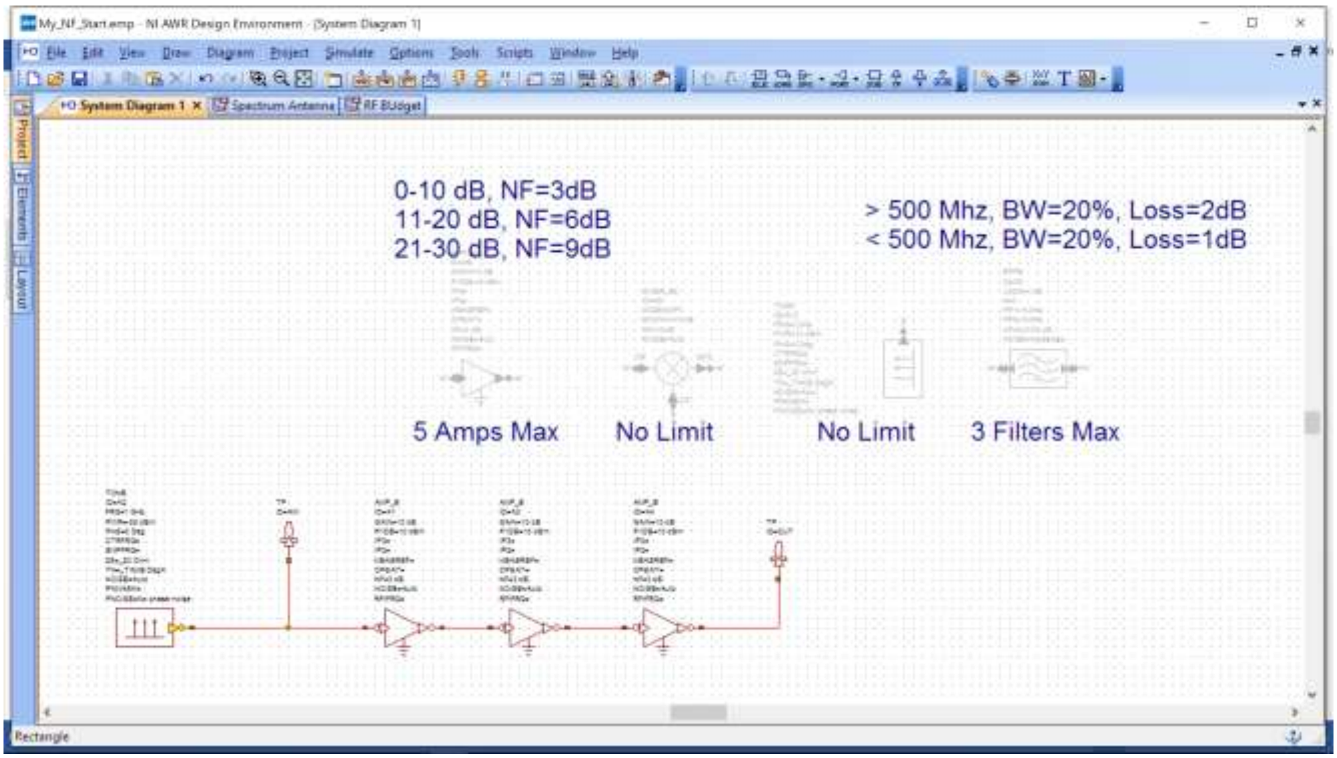
- **What is the level of the noise with the RBW=1 MHz? Is it -174+60=114dB? (2 pts)**
  Yes, 114 dBm. Since we know that Pnoise = kT + BW. (dBm).

You may still seem some fluctuations on the screen, which can be removed by the Video Bandwidth Filter, which is a filter that comes after the power meter. It is just a LPF of what is on the screen. Averaging of the plot would do the same function. You can adjust the VBW also in AWR, but it slows down your measurements too.

Part 2: NF

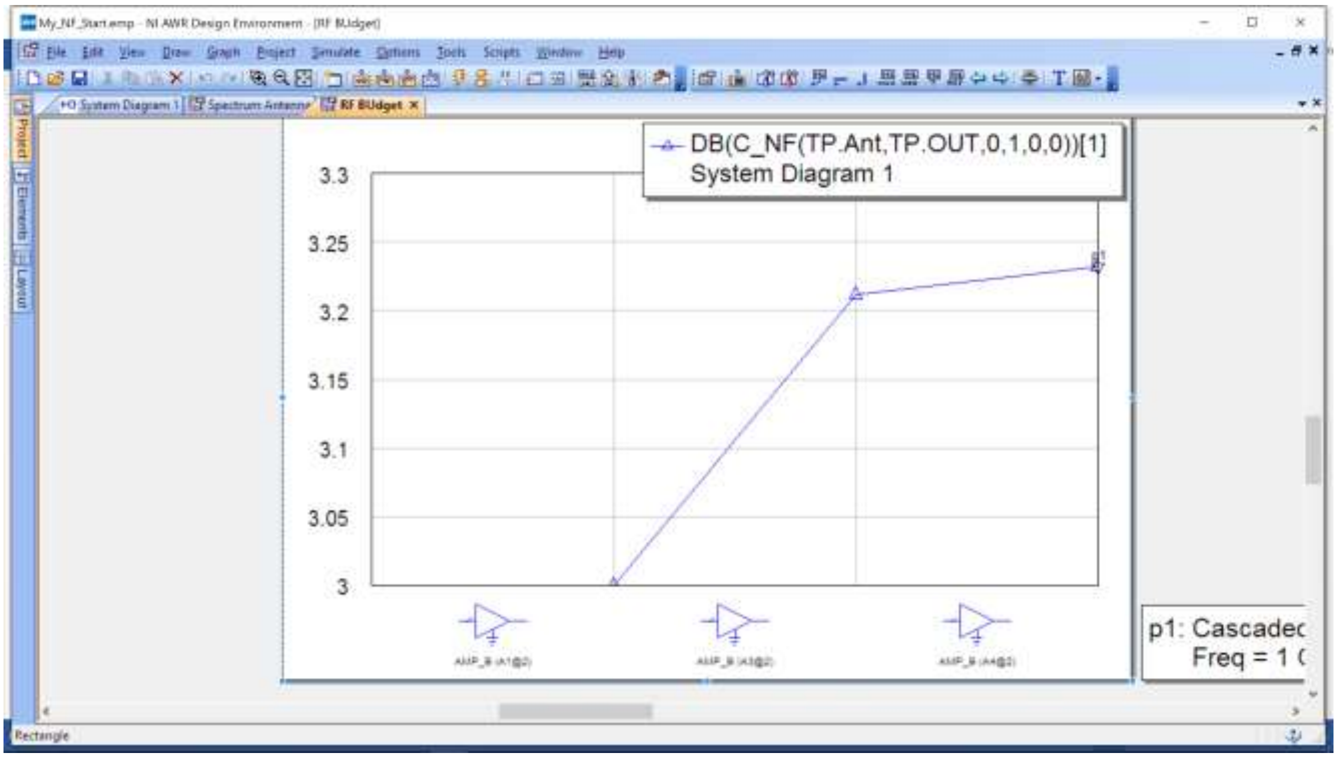
In this part of the lab you will design your system for the lowest NF. Your goal is to get a NF below 4dB.

Using the cumulative NF equation from lecture, you can calculate the NF resulting from a given series of components. AWR has a very handy built in **RF Budget Analysis** as a measurement. To see how this works, please place a series of three amplifiers as shown below:



Now add a rectangular graph, then **Add New Measurement->System->RF Budget** then select **C_NF** (cumulative NF). You have to select the start point and end point for the analysis on the upper right side of the measurement setup window. In this example, it would be **Ant** and **Out**.

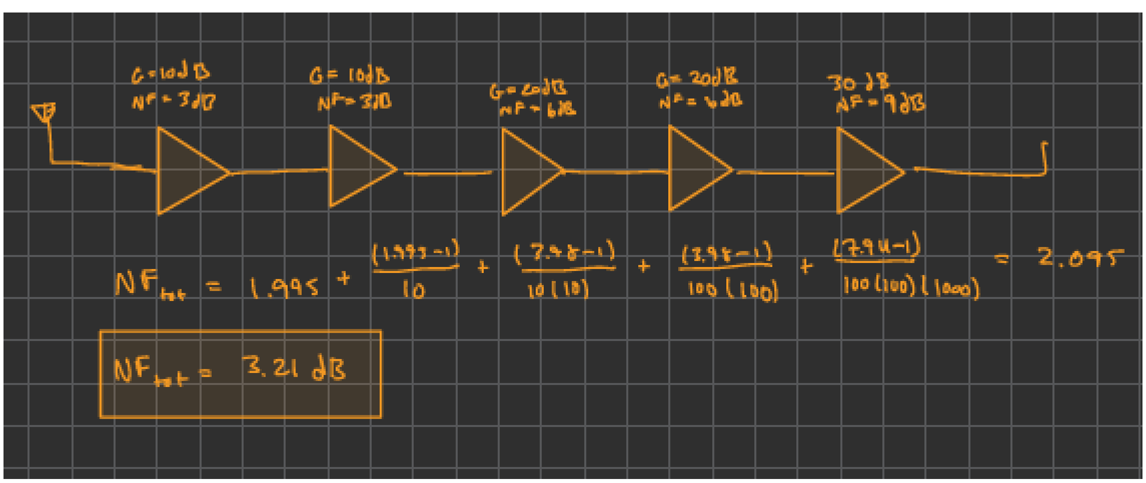
When you run the simulation the graph will change – an image of the components will be added to the bottom and the NF plotted:



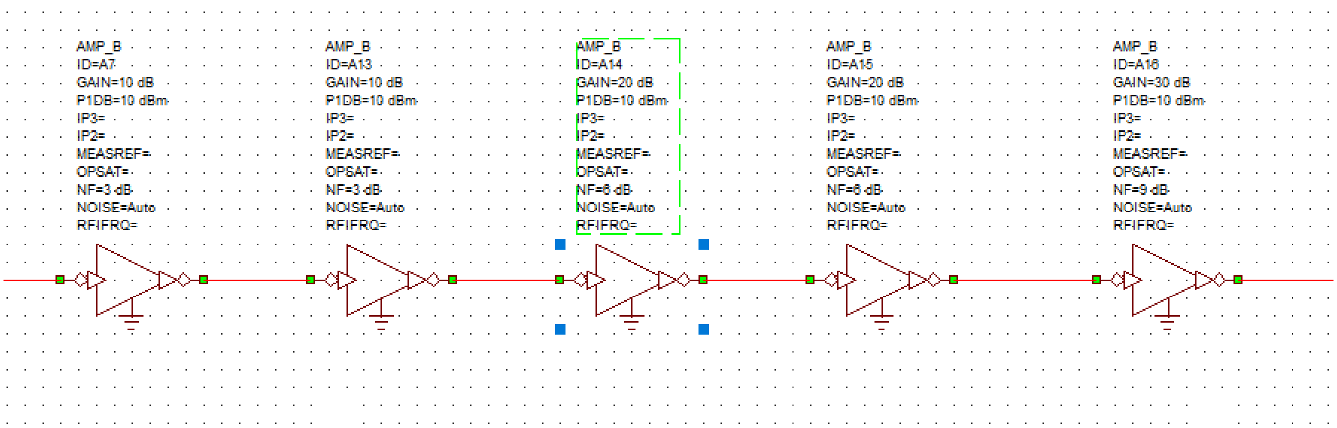
This is a good way to check your hand calculations.

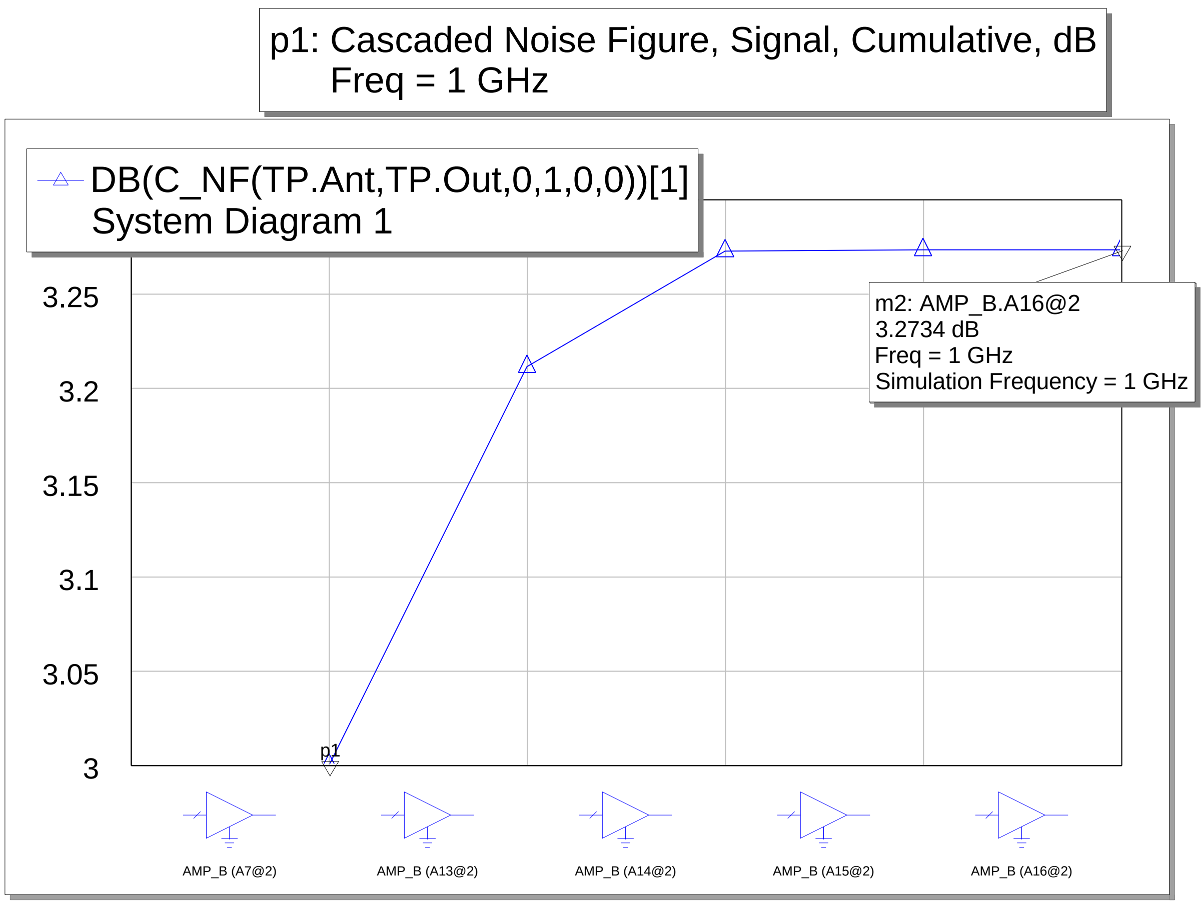
Assignment: Design receiver chain with a total NF< 3.4 dB and an output signal power of 0 dBm at 1GHz. You receiver must contain a maximum of 5 amplifiers. Note that NF of amplifiers vary with their gain according to the information provided on the schematic (10 pts)

- **Show your hand calculation of your NF (4 pts)**



- **Insert the schematic of your solution and also the C_NF plot. (6 pts)**





Part 3: SNR

In the previous section you found the configuration for a low NF. This minimizes the ***added noise*** not the absolute noise. The absolute noise is highly dependent on the receiver design, in particular the BW of the receiver.

GOAL: You have to design a receiver that has an output power level of 0 dBm and SNR > 9 dB.

Challenge: Choose amplifiers and filters that have the following restrictions:

- Amplifiers – **≤ 5 total.**
- Amplifier NF/Gain (max gain is 30 dB from single amplifier)
  - 0-10 dB Gain, NF=3dB
  - 11-20 dB Gain, NF=6dB
  - 21-30 dB Gain, NF=9dB
- Amplifiers – P1dB =10 dBm
  - The signal will not reach this level, but spurious tones might. Make sure to filter any large, unwanted tones so as not to saturate the amplifiers.
- Filters – **≤ 3 total**
- Filter specs
  - > 500 MHz, BW=20%, insertion loss=2dB
  - < 500 MHz, BW=20% insertion loss=1 dB
- Mixer – use the provided mixer with NF=10 and do not adjust any other parameters, e.g. conversion gain, LO Feedthrough. You may change the LO power, however the output signal will also be affected.

As in any engineering task, there will be trade-offs and you should clearly motivate your choice of frequencies. NOTE that there is no unique "Right" or 'Wrong" solution to this assignment. If your answer fulfills the requirements, it is obviously a correct design. Bonus credit for the highest SNR achieved (492 and 592).

Please download the AWR file called "MY_NF_Start."

The node "Ant" is the signal received from the antenna. You need to downconvert that to below 100 MHz and amplify to meet the specs listed.

To calculate the SNR you will need to calculate the total noise, which is the integral of the noise over the bandwidth. In AWR, you can create a **Tabular** graph and then create a measurement **SYSTEM-POWER->PWR-MTR**. It integrates all of the signals in the BW specified. In your start file this auto selects the center frequency and sets the BW=f_s, which is the sampling frequency and is set in System Options. In your file it is set to 10 GHz (1 Ghz Symbol rate and 10x oversampling). An example of the measurement is in your startup file.

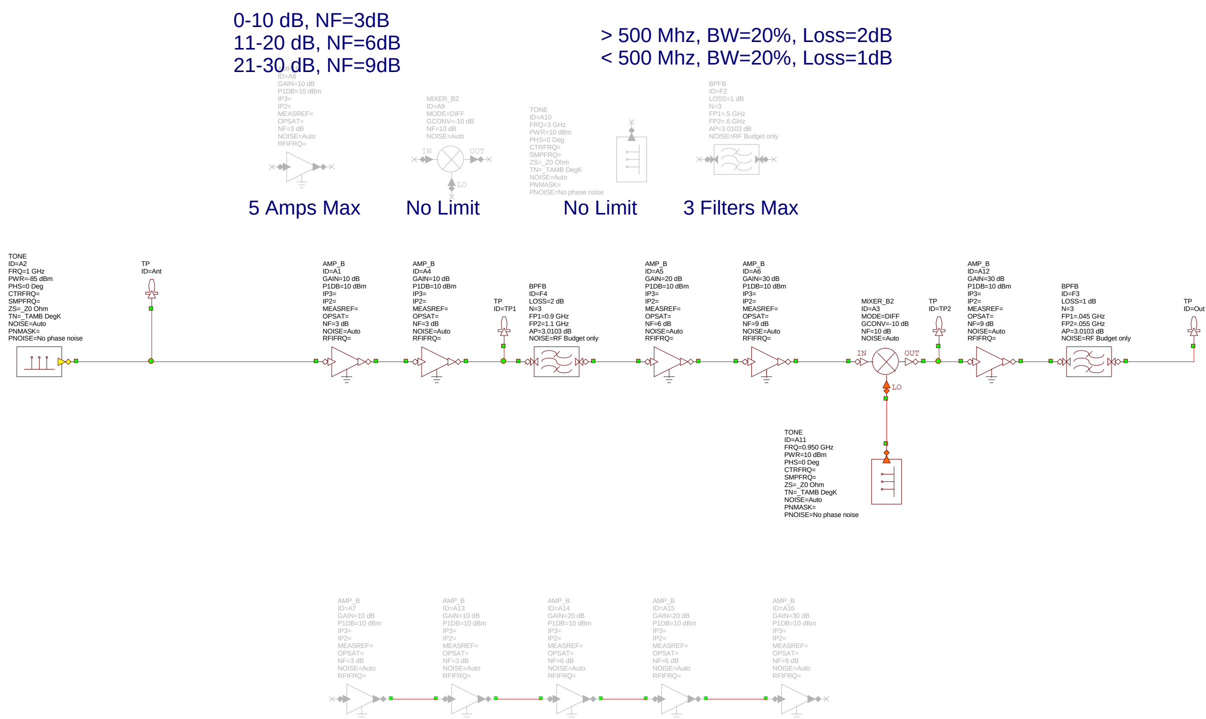
The power of your signal can be calculated from the spectrum plot with a marker.
NOTE: the power of the noise cannot be determined directly from the plot, as the spectrum analyzer integrates the noise over the RBW (as described in Part 1) and plots the integral of the noise over the RBW, not the actual noise PSD. Note the RBW is different than your receiver BW or any other BW, it is actually a knob on a spectrum analyzer, so you can change it to change the spectrum analyzer's accuracy. The signal power can be directly taken from the plot because it dominates the integral over the RBW, so the value of the integrated spectrum where the signal is is simply the signal.

To illustrate the point of this part of the lab. Measure the signal power at the **Ant** node (start with a frewsh MY_NF_Start). Then measure the total noise power over a 1 GHz BW (in Pwr-Mtr setup). This is a very realistic scenario if you were to hook an oscilloscope with a 1 GHz BW up to your antenna and measure the input. It would see all noise from 0 to 1 GHz. Calculate the SNR (in linear scale). **It will be less than 1!** Why? The total noise integrated over 1 GHz is huge! No radio would every operate with such a large BW (well, most would not).

The key to radio sensitivity is their ability to reduce the BW so that the integrated noise become less than the signal power – this is how your cell phone receives 10 pW of signal successfully!!!

Assignment (30 pts):

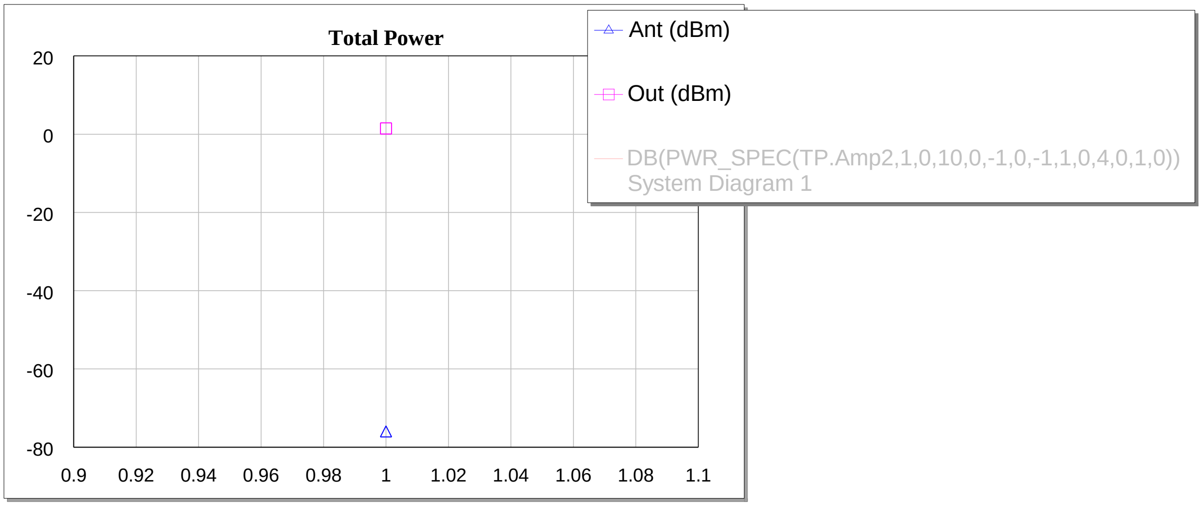
- **Insert a schematic of your final design such that all paraemters are visable (2 pts).**



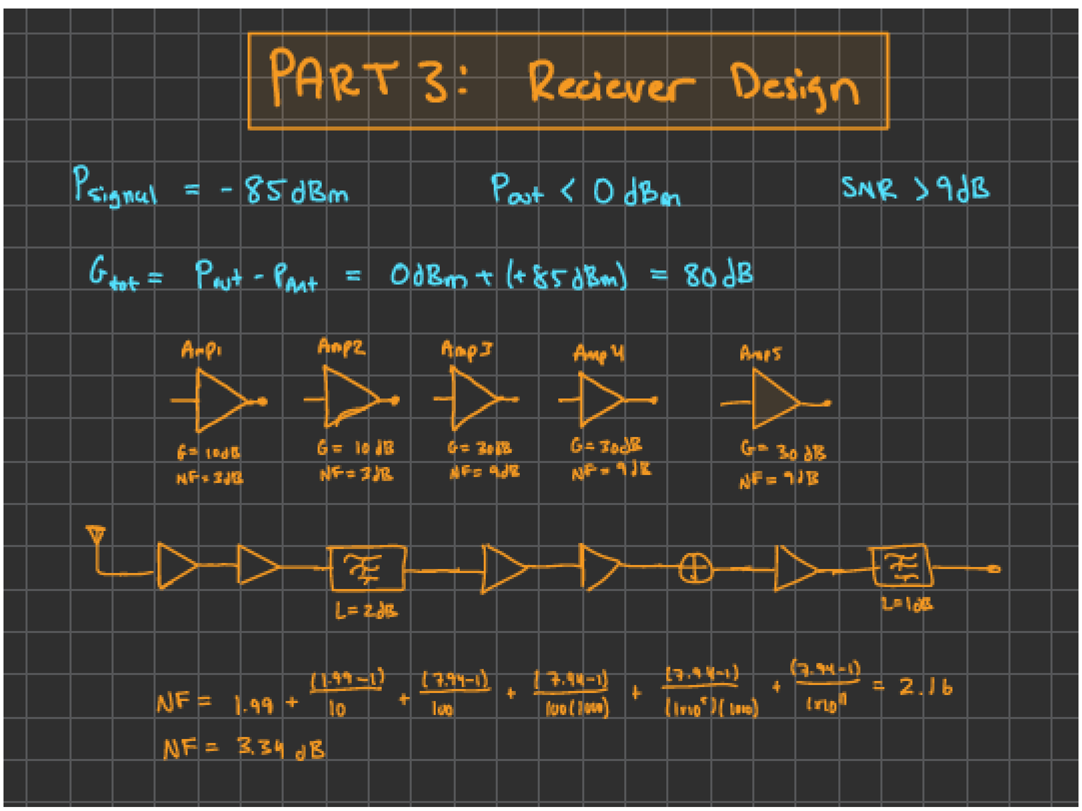
- **Write 1-2 paragraphs about how you optimized your design. What methodology did you use, what were the tradeoffs, etc. (10 pts)**

I first started with a super-heterodyne reciever (not shown) but results were very poor. The mixers introduce a lot of noise. I moved initial filter to after the first two amplifiers. I cascaded 2 amplifiers with small gain instead 1 large one to avoid an increase in noise. I made the last 3 amplifiers to have the largest gain to help reach the requirements for the ouput.

- **Plot the signal power and total noise power at each node of your schematic. You may do this by calculating them in AWR and then using Excel to plot. You may also investigate options in AWR that may do this for you (check by hand to make sure it is calculating what you think) (6 pts).**

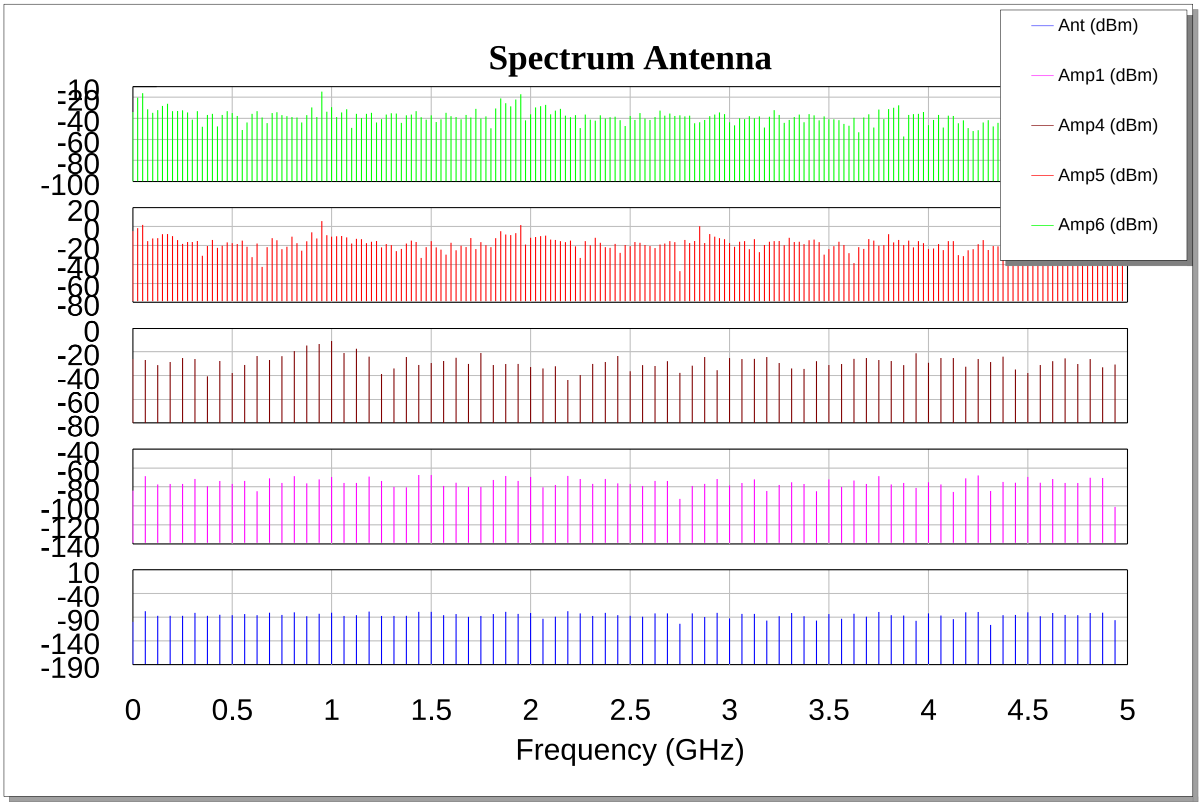


- **Calculate the SNR at each point. Is it increasing or decreasing? (2 pts)**
- **Calculate by hand the NF of your final receiver. (2 pts)**

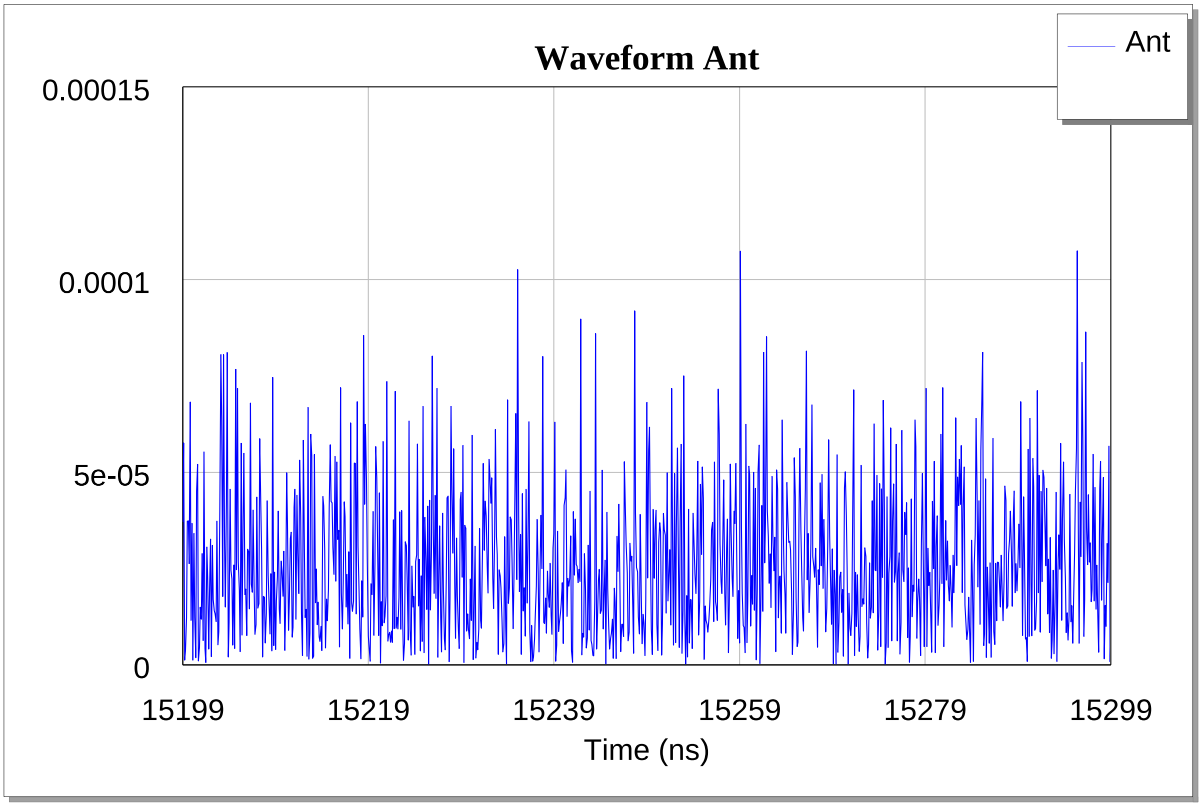


- **Plot the frequency spectrum of your signal at each point where you change circuit element. For example after an amp and before a filter. But not, between two amps (same element). Plot signals of like frequency on the same graph, but separate each axis to make**

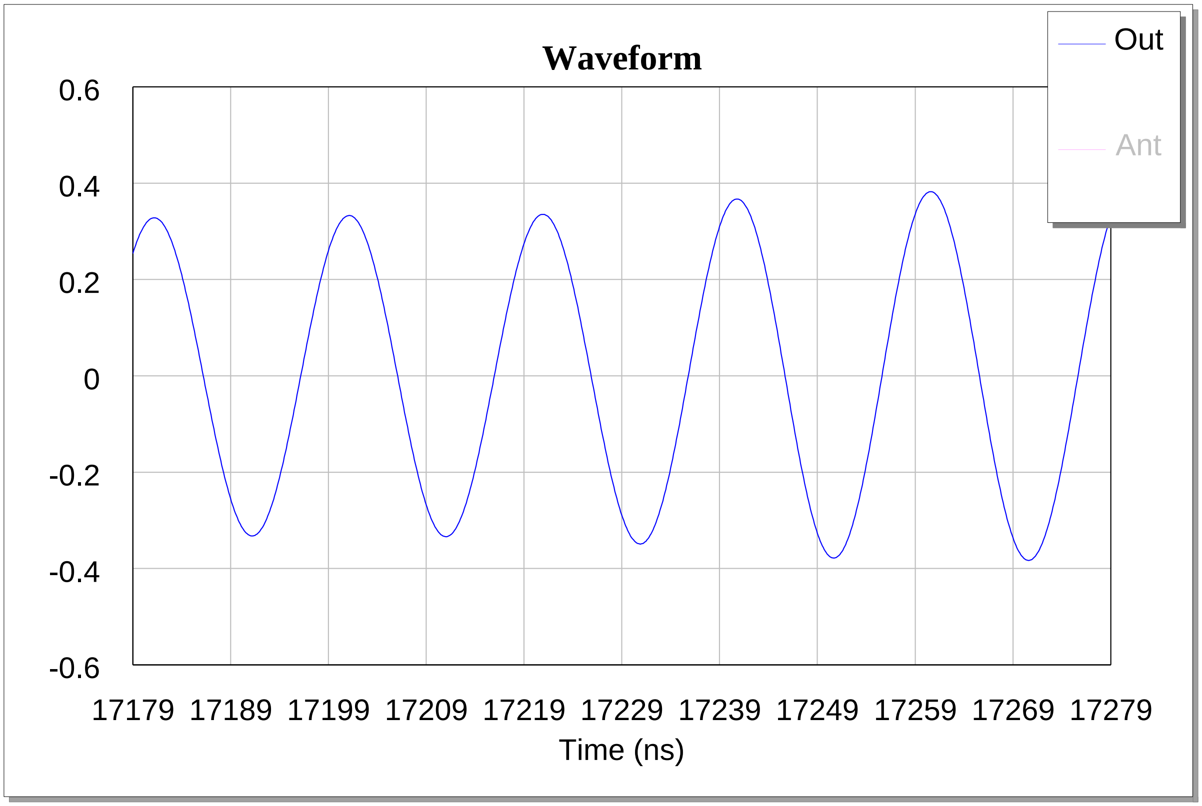
signals clear. (4 pts)



- **Plot the time domain waveform at the antenna. Can you see your signal? (2 pts)**



- **Plot the time domain waveform at the output. Can you see your signal? (2 pts)**


Waveform
Out
Ant
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
17179 17189 17199 17209 17219 17229 17239 17249 17259 17269 17279
Time (ns)