ECE 166- Microwave Circuits
Summary of Amplifier Design

The design of low noise or high gain amplifiers follows a well determined path. It is a "cookbook" approach since most of the work has been done by the device group (bless their heart). They have built the transistors, and determined the bias conditions and S-parameters for low noise and high gain bias conditions. They have also measured the noise parameters and determined Gamma(opt) and the optimum noise figure. Basically, our job is to design of the input and output matching networks, check for stability, and include the input and output biasing networks (and their effect on the amplifier performance).

<u>High-Gain Amplifier Design:</u>

High-gain amplifiers are used at the second stage of a typical amplifier chain, or at the transmit side of a circuit. They do not offer the best noise figure, but the highest gain that can be achieved using a single-stage design. Choose a transistor which has the gain that you need, a decently low noise figure, and S11, S22 which are not so close to 1. In many cases, you have no choice in S11 and S22 (GaAs high frequency amplifiers).

1) Determine the S-parameter table that you need (typically high current bias).
    a. Determine the maximum available gain that can be achieved using this transistor (vs. frequency).
    b. Look at S11 and S22 of the transistor. Typically, the closer they are to 1, the harder it will be to match the transistor.
2) Plot U vs. frequency. The smaller the U, the better is the unilateral approximation.
3) If U=0.1 or less, you can do a unilateral design. In this case, you are guaranteed that the actual measured gain will not vary by more than 0.9-1.1Gu (or Gerror=+/-0.5 dB).
    a. For the unilateral design, the input reflection coefficient is S11 and the output reflection coefficient is S22.
    b. Design input and output matching networks which transform the 50 Ohm loads to a conjugate match for S11 and S22.
4) Check for stability at all frequencies (not only at the design frequency).
    a. Calculate K. At frequencies where K>1, then the transistor is unconditionally stable (i.e, stable for all Gamma(in) and Gamma(out)). At frequencies where K<1, then the transistor will oscillate IF Gamma(in) and Gamma(out) are inside the input and output stability circles. Therefore, plot the stability circles and make sure that Gamma(in) and Gamma(out) do not pass by these regions.
    b. If the amplifier is not stable at certain frequencies, then you need to add circuits at the input and/or output ports in order to reduce the gain at these un-stable frequencies.
    c. Checking for stability is important because the amplifier may work well at 2 GHz, but still oscillate at 400 MHz or 3 GHz. You can "see" this in the lab by a slight drop in the gain (not so much, but a slight drop), and mainly by a large increase in the noise figure of the amplifier. This is why, in a practical circuit, it is important to check the output of an amplifier on a spectrum analyzer from 100 KHz to 10 GHz (or wherever it does not have gain anymore) to make sure that it is not oscillating at any frequency.
5) Include the bias networks (which should have no affect at all at the design frequency since they should appear as open circuits at fo, but could have a bad effect at other frequencies).
6) Re-simulate the S-parameters and re-check for stability.
7) If U>0.1, then you need to use a Bilateral Conjugate Match Design.
    a. Calculate Gamma(in) an Gamma(out) using the equations in the book (or notes). This is only possible for K>1. Also, ADS or any software will calculate them for you.

    b. Design input and output matching networks which transform the 50 Ohm loads to a conjugate match for S11 and S22.

8) Redo (4), (5), (6) above.
9) a. If K<1, then you need to plot the stability circles and design for Gamma(s) and Gamma(l) to avoid coming close to these areas. Notice that Gamma(s) and Gamma(l) may not be the complex conjugate of Gamma(in) and Gamma(out) and therefore, you are not guaranteed a good input and output match. However, you at least do not have an oscillator on your hands ! In general, you need to do several iterations here since the location of Gamma(s) and Gamma(l) is generally quite broad on the Smith Chart, and you need to choose a certain area which gives you a decent gain, and a decent match (around –10 dB or so).
   b. Redo (4), (5), (6) above.
10) The high-gain design is complete.

The challenge in high-gain amplifier design is not the design at a single frequency (as you are currently doing), but the design of well-matched (S11, S22 < -10 dB) flat-gain (G+/-1 dB) amplifiers over a wide bandwidth (+/-30-50%). This could be done using mismatched amplifiers, or using a feedback or a shunt load which is frequency sensitive. If you want to use a resistive load to ground (to reduce the gain), then it is best to put it at the output of the transistor so as not to increase the noise figure a lot.

Low-Noise Amplifier Design:

Low noise amplifiers are used as the first stage of a receiver chain, and will determine the ultimate noise figure of system. Typically, one must design a low noise amplifier with at least 8-10 dB of gain so as to reduce the noise of the second-stage amplifier, or mixer, etc.. Choose a transistor which has the NF that you need and a good associated gain at this frequency (Ga). Also, look at the power consumption of this amplifier. Sometimes, you want low noise but also very low power consumption. This can only be achieved with GaAs or SiGe.

1) Determine the S-parameter table that you need (typically low current bias).
    a. Determine Gamma(opt) that you need to achieve the low noise figure (NF(opt)).
    b. Determine the associated gain that can be achieved at the frequency of interest.
2) Determine the Gamma(out) using the standard two-port equations. If S12=0 (Unilateral), then Gamma(out)=S22.
3) Design an input and output matching networks which transform 50 Ohm loads to Gamma(opt) and Gamma(out). *Notice that Gamma(opt) is defined in a different "looking" direction than Gamma(in).*
4) For stability, do (4), (5), (6) above.
5) Calculate the input match of the amplifier as seen from the 50 Ohm load input port. It is typically not well matched and there is nothing that you can about this (except using a balanced design). Also, calculate the output match as seen from the output 50 Ohm load. It should be well matched.
6) The low-noise design is complete.

The challenge in low-noise amplifier design is not the design at a single frequency (as you are currently doing), but the design of low-noise amplifiers over a wide bandwidth. Typically, you have to design an input matching network which "tracks" Gamma(opt) vs. frequency. You take whatever gain and input match you get, but you should be able to design an output matching network for a good output match over a wide frequency range.

In this class, we are only looking at single-stage designs and we are only scratching the surface of amplifier design. There are also multi-stage amplifier design with their inter-stage matching networks, wideband amplifiers, distributed amplifiers (1-18 GHz), and high-power amplifiers. Still, we know enough now about transistors to be able to design low-noise amplifiers with a NF < 3.0 dB all the way to 120 GHz (using GaAs or silicon transistors, depending on the frequency)!