

Pre-Work for Knowledge Integration 5 Spring 2020

(Due April 15, 2020)

Here is a list of pre-work questions for KI5. **You are required to submit answers individually to the questions using the assignment submission page on Canvas.**

1. The receiver portion of a radio system is shown in Figure 1 in the green shaded box. Using the knowledge, you learned from the prior KI modules and from the junior level courses (ECE312/332/342), briefly describe the functions of each component in the receiver portion of a radio system in terms of how each component transforms the receiving signal from the antenna to the input of the A/D converter for further processing and storage.

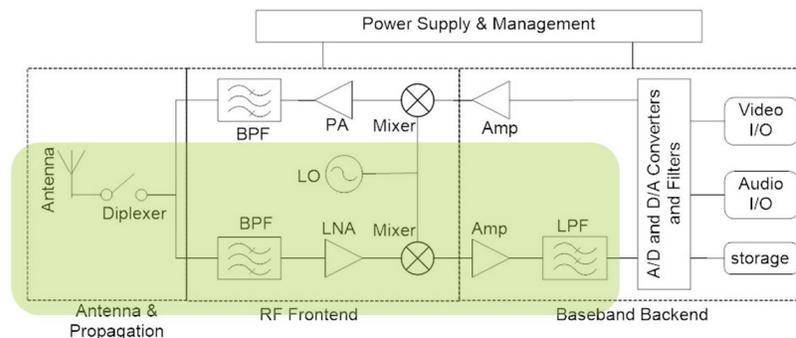


Figure 1. The top-level block diagram of a radio system

2. Amplifiers are extensively used in the baseband portion of a radio receiver system to condition the baseband signal to produce an output signal ready for digital sampling and storage. Some of the key design features of baseband amplifiers include
 - i. DC gain,
 - ii. output swing,
 - iii. power consumption, and
 - iv. bandwidth.

If you were to use a simple single-ended MOSFET common source amplifier for the baseband signal, consider the following design scenarios and choose the correct answer(s) for the required tradeoffs.

- i. To increase DC gain of the amplifier, you would expect (circle all that apply)
 - a) Increase in power consumption
 - b) Decrease in bandwidth
 - c) Decrease in output swing
 - d) All of the above

- ii. For the choice(s) you made above, identify one component characteristics (R_D , I_{ds} , W , L , V_{sat} , V_{dd} , V_{out_DC}) that you will use to increase DC gain and to cause changes in other specs.
- iii. To increase bandwidth of the amplifier, you would expect (circle all that apply)
 - a) Increase in power consumption
 - b) Decrease in DC gain
 - c) Decrease in output swing
 - d) All of the above
- iv. For the choice(s) you made above, identify one component characteristics (R_D , I_{ds} , W , L , V_{sat} , V_{dd} , V_{out_DC}) that you will use to increase bandwidth and to cause changes in other specs.

3. Consider the op-amp circuit shown in Figure 2, which connects two impedances Z_f and Z_i in a closed-loop inverting-amplifier configuration:

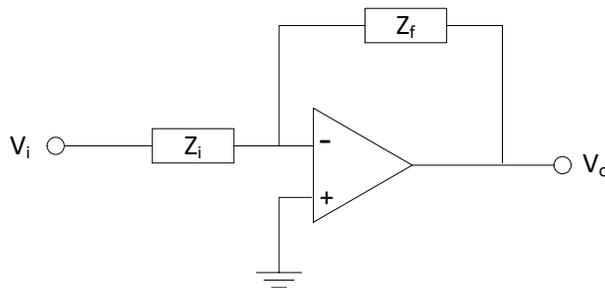


Figure 2. General Inverting Amplifier Configuration

You may assume the op-amp has very large input-impedance, so that essentially zero current flows into the op-amp (+,-) inputs. The operational amplifier provides an open-loop gain as (here V_+ and V_- denote the input terminal voltages):

$$V_o = A(s)(V_+ - V_-)$$

Calculate the closed-loop transfer function (from V_i to V_o) of this circuit for the following two cases (for $A(s)$):

- i. For an ideal op-amp you may assume a constant open-loop gain:

$$A(s) = A$$

You may also assume that this gain is very large, and hence to a very good approximation $\frac{V_o}{V_i}$ should be independent of A .

- ii. For a non-ideal op-amp assume an open-loop transfer function of the form:

$$A(s) = \frac{A}{1 + sT}$$

You may assume that the DC gain A is very large, and hence to a good approximation $\frac{V_o}{V_i}$ should look like the answer from part i multiplied by a first-order transfer function.

4. Now consider the circuit shown in Figure 3, and note that this is a special case of the circuit you analyzed in question 4.

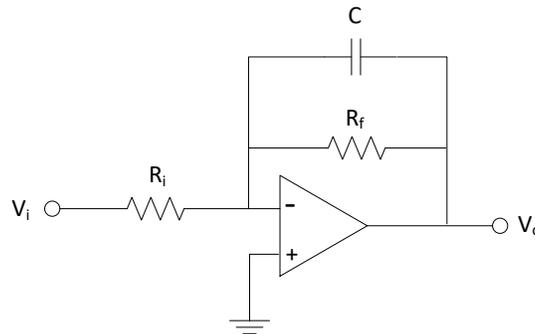


Figure 3. Simple Filter Circuit

- i. Use the results from question 4 to calculate the closed-loop transfer function (from V_i to V_o) of this circuit for the following two cases:
 - a) Ideal op-amp assumption (open loop gain A).
 - b) Non-ideal op-amp assumption (open loop gain $A(s)$).
- ii. Consider the following values for the components:

$$R_f = 10k\Omega, \quad R_i = 1k\Omega, \quad C = 100nF$$

Calculate the Bode plot (using Matlab) for this filter in the ideal op-amp case ($A(s)=A$). Answer the following (compare the theoretical answers to the Matlab Bode plot):

- a) What kind of filter is it?
 - b) Where is the cutoff frequency?
 - c) What is the closed-loop DC gain?
- iii. Consider the non-ideal op amp case and assume the following op-amp parameters for $A(s)$:

$$A = 10^4, \quad T = 0.1\text{sec}$$
 Repeat the analysis from part ii and compare the results. Consider also the open-loop rolloff pole at $s = -\frac{1}{T}$ and answer the following (again compare theoretical answers to Bode plot).
 - a) What is the cutoff frequency for the open-loop op-amp pole?
 - b) What is the cutoff frequency for this pole in the closed-loop circuit?
 - iv. Is the low frequency roll-off pole in the non-ideal op-amp (transfer function $A(s)$) a major issue for the closed-loop circuit (explain)?
 - v. Why do we need such a large open loop gain for the op-amp (e.g., 10^4 or higher) when the closed loop circuit only implements a modest gain (e.g., 10)?

- vi. This circuit implements a generic first order transfer function. Could you cascade these circuits to build any (higher order) transfer function (explain)?
5. Figure 5 depicts the receiver board from Silicon Lab. In the schematic different parts of the circuit can be distinguished.
- The RF circuit and matching network
 - A printed balun that plays the role to equalize the signals in both branches of the antenna
 - The antenna built in the multi plane PCB with vias that generates the 3D structure shown in the lower scheme
 - A PCB transmission line that connects the RF circuit with the antenna

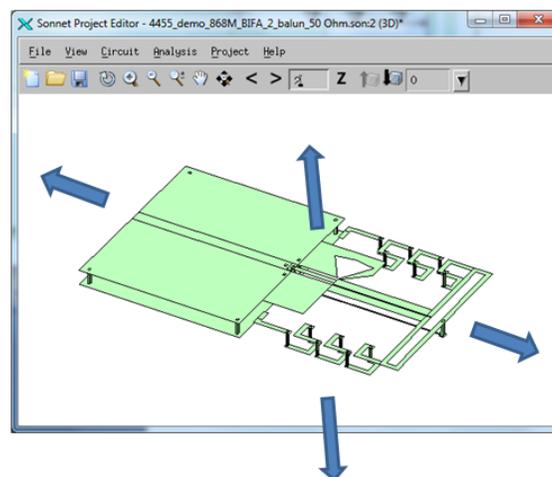
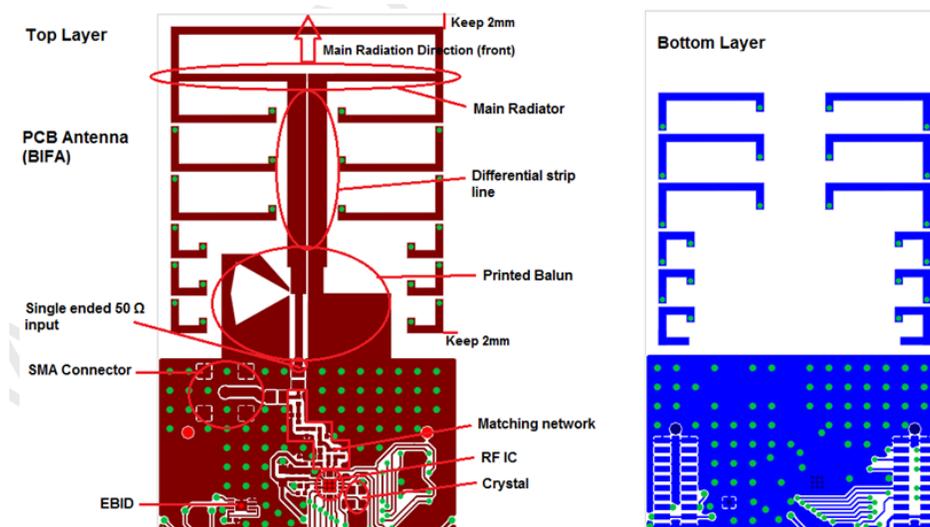


Figure 5. Receiver board from Silicon Lab

With this information in Figure 5, answer the following questions:

- i. What is the function of the matching network? (Hint: Think in terms of circuit theory, assuming that the antenna is the load to the RF circuit)
- ii. Assume that the PCB material has a relative permittivity of 4.2 and a thickness of 1mm. The circuit operates at 315 MHz. How does compare the dimensions of the antenna and transmission line with the wavelength?
(Hint: use the circuit diagram at the end of this document to approximately evaluate the electric length of the antenna circuit.)
Explain
- iii. The RF circuit and the antenna are connected through a transmission line printed in the circuit board. What is the approximate impedance of the transmission line using the dimensions of the transmission line shown in Figure 6 below?
 - a) The approximate value is 50 Ω
 - b) The approximate value is 75 Ω
 - c) The approximate value is 90 Ω
 - d) The approximate value is 120 Ω
 - e) None of the above
- iv. The arrows in Figure 5 indicate the direction of maximum radiation power. Based on the antenna layout, can you justify this pattern with simple concepts?

