LABORATORY REPORT - CHAPTER 4

v7.2

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Total Grade	/100

Record all your measurements and write all your answers in the boxes provided.

Preliminary Work

1. First IF Amplifier

1. An RF amplifier can be built using a BJT. Refer to the circuit given in Fig. 1. TRC-11 uses two of such amplifiers. The values of the resistors and capacitors should be calculated as described below.

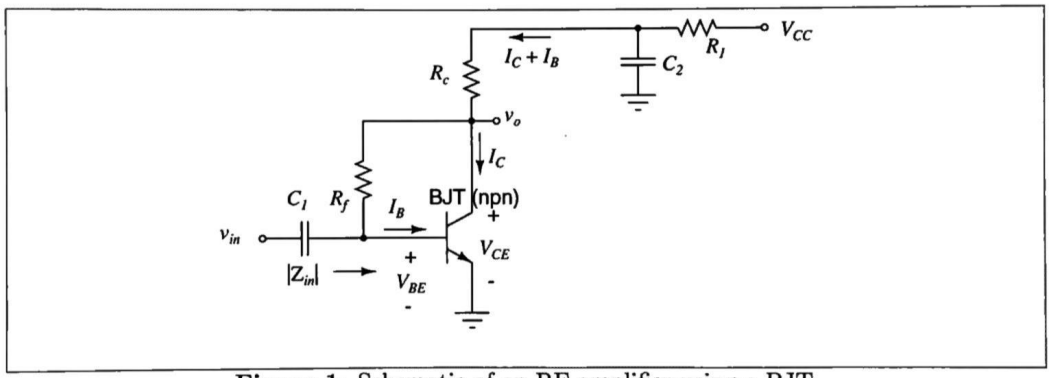

Figure 1: Schematic of an RF amplifier using a BJT.

2. BJT to be used is KSP10, an NPN transistor. Take a look at its datasheet given in 344. It is a high-frequency transistor. β (or h_{FE}) of the transistor is a minimum of 60. Once the operating point (collector current, I_C, and the collector-emitter voltage, V_{CE}) is set, the values of the bias resistors can be calculated as follows:

$$R_c + R_1 = \frac{V_{CC} - V_{CE}}{I_C + I_B} \approx \frac{V_{CC} - V_{CE}}{I_C} \approx \frac{6}{I_C} \quad (1)$$

$$R_f = \frac{V_{CE} - V_{BE}}{I_B} \approx \beta \frac{V_{CE} - 0.8}{I_C} \sim 110 \frac{5.2}{I_C} \quad (2)$$

where we assumed $V_{BE} \approx 0.8$. For the first amplifier, calculate the values of resistors, $R_{50} = R_f$ and $R_{51} + R_{52} = R_c + R_1$, choosing a DC operating point of I_C a value in the

$I_C = 10mA \Rightarrow R_c + R_1 = 600\,\Omega$ ($560\,\Omega$, $39\,\Omega$)

$R_f = 57.2K \Rightarrow 56K\Omega$

$I_C = 5mA \Rightarrow R_c + R_1 = \frac{6}{5 \times 10^{-3}} = 1.2k\Omega$

$\Rightarrow R_f = 110\frac{5.2}{5} = 114.4\,k\Omega \rightarrow$ take

$R_c = 1.2k - R_1 = 1161 \rightarrow 1.2k\Omega$ (R_1: 39)

6 V

range 2 mA to 8 mA and V_{CE}=V_{CC}/2. The operating voltage V_{CE} is chosen to be half the supply voltage to provide a maximum voltage swing at the collector. Choose V_{CC}=12 V. Take β=110 for the purpose of this calculation. Choose $R_{52} = R_1$ in the range 22 to 56 Ω. Select the resistors using among the closest standard resistor values: 1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, and 8.2. $R_1 = 39\ \Omega$

3. The DC block capacitor, C_1, at the input is used to block DC voltages from affecting the base voltage of the transistor. It value should be large enough so that there is no AC voltage drop across it. Its value can be found from

$$C_1 > \frac{10}{2\pi f_0 |Z_{in}|} \simeq 2.12 \times 10^{-9} \rightarrow 10\text{nF} \quad (3)$$

where f_0 is the operating frequency of 15 MHz. Assume $|Z_{in}|$=50 Ω and choose C_{50}=C_1 using the standard capacitor values: 1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, and 8.2.

4. The power supply bypass capacitor, C_2, and the resistor, R_1, forms a low-pass-filter. They are used to to provide a clean power supply voltage to the amplifier. Choose a corner frequency f_1 at least 100 times smaller than f_0.

$f_1 = 10\text{kHz}$ $\qquad C_2 \approx \frac{1}{2\pi f_1 R_1} = 4.08 \times 10^{-7} \rightarrow 390\text{nF}$ (4)

Choose C_{51}=C_2 using the standard capacitor values.

5. Repeat the procedure for the second IF amplifier. For the second amplifier, choose I_C in the range 5 mA to 10 mA (higher than the first). $I_{C_2} = 10\text{mA}$

First amplifier: I_C= 5 mA V_{CE}= 6V
R_{50}= 120 kΩ R_{51}= 1.2 kΩ R_{52}= 39 Ω

C_{50}= 10 nF C_{51}= 390 nF

Second amplifier: I_C= 10 mA V_{CE}= 6V
R_{60}= 56 kΩ R_{61}= 560 Ω R_{62}= 39 Ω

C_{60}= 10 nF C_{61}= 390 nF

1.5. GRADE:

6. The gain of the BJT amplifiers can be calculated using LTSpice. SPICE model of the KSP10 is given as

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.model KSP10TA NPN(IS=1E-11 ISE=70e-11 NE=2.5 VAF=100 BF=110
+ NF=1.3 IKF=0.065 NK=0.45 XTB=0 BR=3 CJC=1.56E-12
+ CJE=2E-12 TR=50e-9 TF=1.85E-10 ITF=0 VTF=0 XTF=0
+ RB=42 RC=.3 RE=.2 Vceo=25 Icrating=100m mfg=OnSemi)
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Place these lines in LTSpice as a SPICE directive. Define the NPN transistor's "Value" (seen after CTRL-right click on the transistor) as KSP10TA (the same label used in the model statement). Enter the schematic of the first amplifier in LTSpice using the calculated values of components. Determine the DC voltages V_{CE} and V_{BE} using "DC opt pnt" analysis.

7. Determine $|Z_{in}|_1$ of the first amplifier at 15 MHz by connecting an AC *current* source of unity magnitude and performing a small-signal AC analysis. The voltage of the current source gives the input impedance, $|Z_{in}|$. Change the default display of the y-axis to "Bode/linear" to read the magnitude of the impedance (specified in V). Refer to Appendix on LTSpice Tutorial on page 399.

8. Determine the small-signal gain, $|v_o/v_{in}|_1$, in dB at 15 MHz also by using small-signal AC analysis. You should define an AC *voltage* source of unity magnitude at the input with a series source resistance of 50 Ω. (The signal generators at the lab has an internal source resistance of 50 Ω.) Place a 20 pF capacitor to ground at the output to simulate the probe capacitance of the oscilloscope (to be compared with measurements later). Set the y-axis to its default: "Bode/decibel" to read the gain in dB.

V_{CE1}=7.19 V V_{BE1}=0.667V
$|Z_{in1}|$=107.78Ω $|v_{o1}/v_{in1}|_{dB}$=30.673 dB

1.8. GRADE:

2. The second IF Amplifier

1. Repeat the LTSpice simulations for the second amplifier.

V_{CE2}=6.9 V V_{BE2}=0.699V
$|Z_{in2}|$=94.191Ω $|v_{o2}/v_{in2}|_{dB}$=32.949 dB

2.1. GRADE:

2. Connect the second amplifier's input to the first amplifier's output. Determine the input impedance, the gain of the first amplifier and the overall gain in dB at 15 MHz. Note that the input impedance and the gain of the first amplifier is not the same as that determined when the amplifier is stand-alone. The reason is that the output load impedance of the first amplifier is changed. The input of the second amplifier is loading the output of the first amplifier, reducing the gain of the first amplifier and also changing the input impedance. The input impedance of a BJT is influenced by the load impedance at the output, especially at high frequencies. At very low frequencies, the input impedance does not get affected by the output load.

$|Z_{in1}|$=336.06Ω $|v_{o1}/v_{in1}|_{dB}$=18.840 dB
Overall gain: $|v_{o2}/v_{in1}|_{dB}$=56.732 dB

3. 2.3. GRADE:

Experimental Work

1. IF Amplifiers

1. The first RF amplifier circuit to be built is the first IF amplifier.

   A schematic diagram of the first IF amplifier is given in Fig. 1. Mount the three leads of

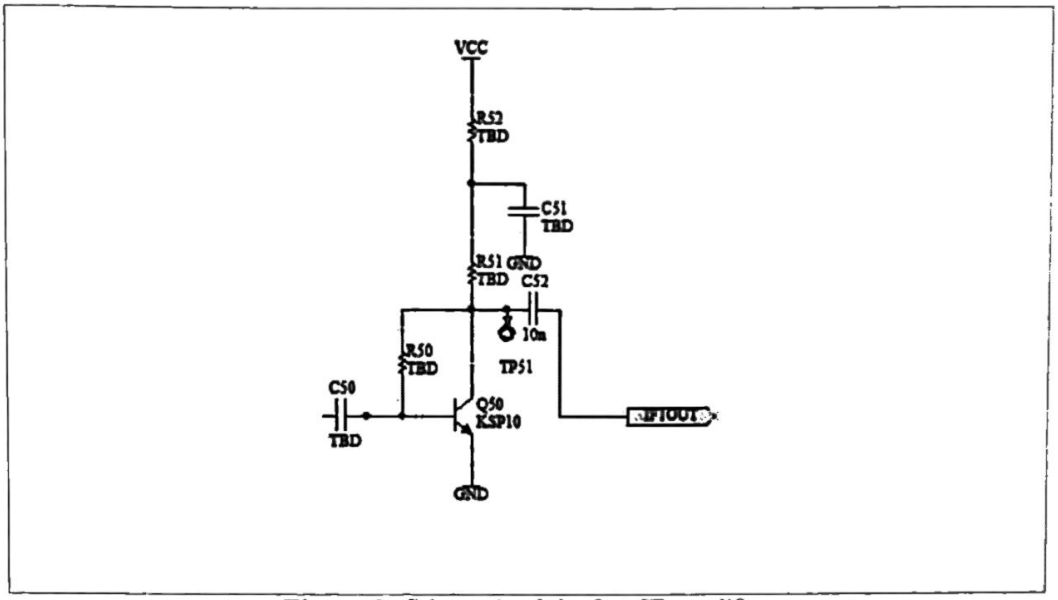

Figure 2: Schematic of the first IF amplifier.

Designator	Comment	Description
C52	10 nF	Capacitor, ceramic disc, 50V
C53	10 nF	Capacitor, ceramic disc, 50V
Q50	KSP10	NPN Bipolar transistor

Figure 3: Bill of materials for the first IF amplifier

   the transistor Q50 (KSP10) watching the orientation on the PCB (e: Emitter, b: Base, c: Collector) and solder it. Do not push the transistor too hard into the holes. Clip the extra leads at the back side.

2. Mount and solder C53. This is a supply bypass capacitor.

3. Using the chosen values collect the resistors R50, R51, R52, and the capacitors, C50, C51. Measure the resistors and capacitors before you mount them. Mount the resistors and the capacitors. Solder them and clip the leads on the back side. Do not mount C52 yet.

4. Solder a clipped resistor lead between the GND terminals (at the right of C50) for convenient connection later.

5. Solder bent resistor leads at the test points, TP50 and TP51.

6. Second IF amplifier is to be mounted next. A schematic diagram of the second IF amplifier is given in Fig. 6.

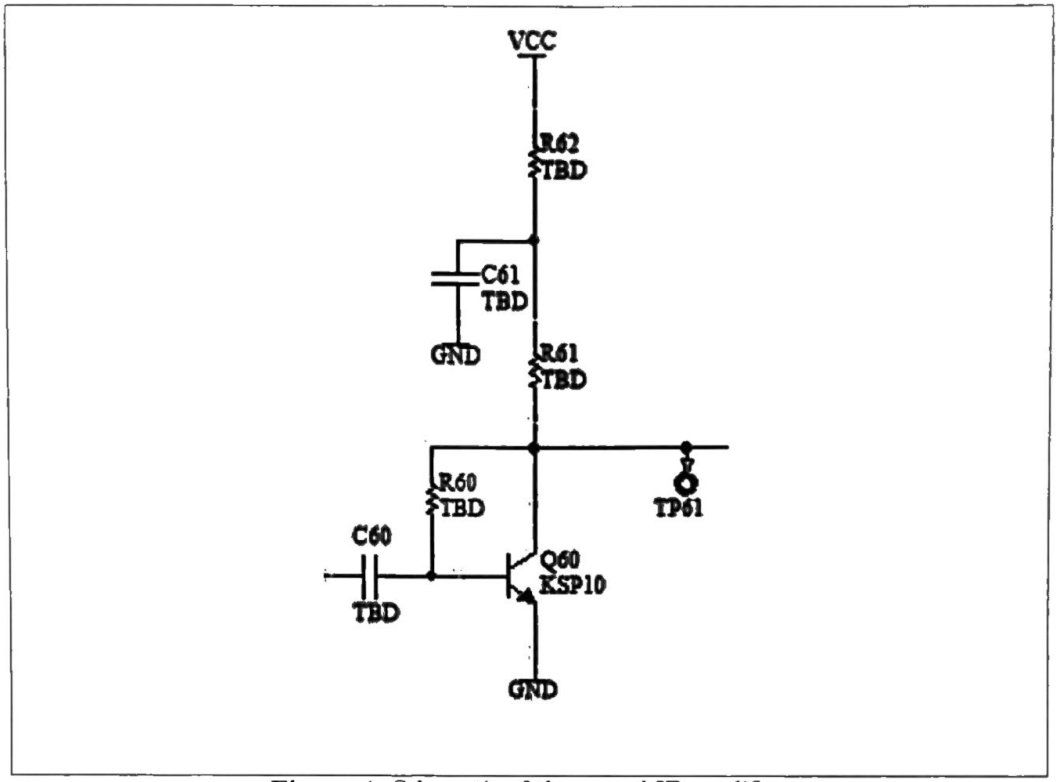

Figure 4: Schematic of the second IF amplifier.

Designator	Comment	Description
C66	10 nF	Capacitor, ceramic disc, 50V
Q60	KSP10	NPN Bipolar transistor

Figure 5: Bill of materials for the second IF amplifier

7. Mount the components of the second IF amplifier: Mount and solder C66. This is a supply bypass capacitor.

8. Mount and solder Q60 (KSP10) watching the orientation of the transistor on the PCB.

9. Collect the resistors R60, R61, R62, and the capacitors, C60 and C61. Measure the resistors and capacitors before you mount them. Solder all components.

10. Solder a clipped resistor lead between the GND terminals (near C65) for convenient connection later.

11. Solder bent resistor leads at the test points, TP60 and TP61.

12. Apply the supply voltage using the adapter. Measure the DC voltages, V_{CE} (between TP51 and GND for Q50; between TP61 and GND for Q60) at the collectors of BJTs for both amplifiers. Measure the base to emitter voltages, V_{BE}, for both transistors. Using the measured values of resistors, and voltage measurements calculate the actual β of the transistors:

$$I_C + I_B = \frac{V_{CC} - V_{CE}}{R_{51} + R_{52}} \tag{5}$$

$$I_B = \frac{V_{CE} - V_{BE}}{R_{50}} \tag{6}$$

$$\beta = \frac{I_C}{I_B} \tag{7}$$

First amplifier: Measured values of resistors

R_{50}= 118.7kΩ R_{51}=1.182kΩ R_{52}= 39.2Ω

Measured V_{BE1}= 0.765V Measured V_{CE1}= 5.62V

Calculated I_{C1}=5.183mA I_{B1}= 0.041mA β_1=126.42

Second amplifier: Measured values of resistors

R_{60}=55.2kΩ R_{61}= 557Ω R_{62}= 39.0Ω

Measured V_{BE2}=0.776V Measured V_{CE2}= 5.64V

Calculated I_{C2}=10.583mA I_{B2}= 0.088mA β_2= 120.26

1.12. GRADE:

13. Set the signal generator to 15 MHz, 50 mVpp sinusoidal signal between TP50 and GND (connect the black lead to GND). Most high frequency signal generators assume that the load resistance is equal to their source resistance of 50 Ω, and hence their display shows half the internal voltage value. That means we are actually using a 100 mVpp voltage source in series with 50 Ω resistance. Measure the peak-to-peak input voltage, v_{in1}, at TP50. You may use ACQUIRE, Average option of the oscilloscope to get a noise-free signal. Use the MEASURE, Pk-Pk option to read the value. Calculate the input resistance, R_{in}, of the amplifier assuming that the input impedance is purely real and using the resistive voltage divider formula:

$$v_{in1} = \frac{R_{in}}{R_{in} + 50} 0.100 \tag{8}$$

Note this value. You need this value in the preliminary part of Lab 6 experiment.

14. Measure the peak-to-peak output voltage, v_{o1}, at TP51. Make sure that the output voltage is purely sinusoidal and that it is not distorted. Determine the voltage gain $|v_{o1}/v_{in1}|_{dB}$ in dB ($20\log_{10}()$). Compare it with the simulated result.

TP50, Measured v_{in1}(pp)= 51.2 mV TP51, measured v_{o1}(pp)= 3.84 V

R_{in1}= 52.46 Ω $|v_{o1}/v_{in1}|_{dB}$= 37.50 dB

Comparison: The measured gain was ≈7dB higher. Possible reasons behind this result are, actual β of the transistor being higher, 20 pf capacitor that we connected in LTspice was not an accurate representation of the probe and the oscilloscope, and other inaccuracies of components and measurements. But most importantly, my V_{in} measurements was lower than expected (≈50 mV instead of 100 mV) because of the oscilloscope and the probe interfering with the measurement.

1.14. GRADE:

15. Connect the signal generator to TP60. Measure the peak-to-peak voltage at TP60 (v_{in2}) and TP61 (v_{o2}). Determine the voltage gain $|v_{o2}/v_{in2}|_{dB}$ in dB. Compare it with the simulated result.

TP60, Measured v_{in2}(pp)= 46.4 mV TP61, measured v_{o2}(pp)= 4.76 V

R_{in2}= 43.28 Ω $|v_{o2}/v_{in2}|_{dB}$= 40.22 dB

Comparison: Similar to the 1.14, the measured gain was ≈7dB higher than the simulated one because of the same reasons given in 1.14.

1.15. GRADE:

16. Mount and solder C52 (10 nF) that connects the output of the first amplifier to the input of the second amplifier.

IF amplifier mounting is now finished. The testing of the combined IF amplifiers will be done later.

CHECK POINT: