LABORATORY REPORT - CHAPTER 5

Lastname, Firstname	Defne Yaz Kılıç
Student ID	22102167
Date	23. 11. 22

Total Grade	/100

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

Preliminary Work

1. Transmitter Amplifier

1. A tuned RF amplifier that acts as the transmitter amplifier of TRC-11 can be built using a BJT, Q30. BJT to be used is a more powerful NPN transistor, 2N2222. Inspect the datasheet given in 368. It can handle currents up to 600 mA and voltages up to 40 V. It can dissipate up to 625 mW power at room temperature. These values are considerably high compared to KSP10 used earlier. Refer to the circuit given in Fig. 1. It is a Class-A power amplifier intended to drive an antenna. R_L is the load to be driven (it is actually the real part of the antenna impedance to be discovered later). The power delivered to R_L is the transmitted RF power into the air when the antenna is used. Actually, the output power is intentionally kept low, not the violate local RF transmission limits in this frequency band. C_{31} is a DC block capacitor. L_1, L_2 and C_{37} form a impedance transformation network, that transforms R_L into an optimal impedance for the transistor.

   The supply voltage, V_S, of this is to be varied to according to the audio signal to be transmitted. When the supply voltage is changed the RF signal output voltage is also changed accordingly. To change the supply voltage we utilize another BJT, Q31, forming the modulation amplifier. Q31 is a PNP transistor. The base bias resistors, R37 and R38 of this transistor is selected so as to keep the voltage V_S at 7 V. This choice allows the supply voltage to be varied between 7±5=2 V to 12 V, when a time varying signal is applied to the base of Q31.

   A DC analysis of the transmitter and modulation amplifier can be made using the schematic shown in Fig. 2, obtained by short-circuiting inductors and open circuiting capacitors. Biasing resistors, R_{30}, R_{31}, R_{32}, R_{37}, and R_{38} can be calculated after deciding on the DC operating point of the transistors, Q30 and Q31, while considering the variations in β's of the transistors. To find the values of resistors, we set the operating point as V_S=7 V and V_{E1}=2 V with V_{DD}=12 V. We note that now V_{CE1}=$-V_{CE2}$=5 V. This choice allows V_S to vary between 2 V to 12 V with equal 5 V swing in both directions. We also set I_{C1}=I_{C2} in the 20 mA to 40 mA range. In idle conditions DC power dissipations on Q30 and Q31 are $V_{CE1}I_{C1}$=$-V_{CE2}I_{C2}$ is in the range 100 mW to 200 mW, within the allowed range of the transistors.

   $V_{CE_1} = -V_{CE_2} = 5V$

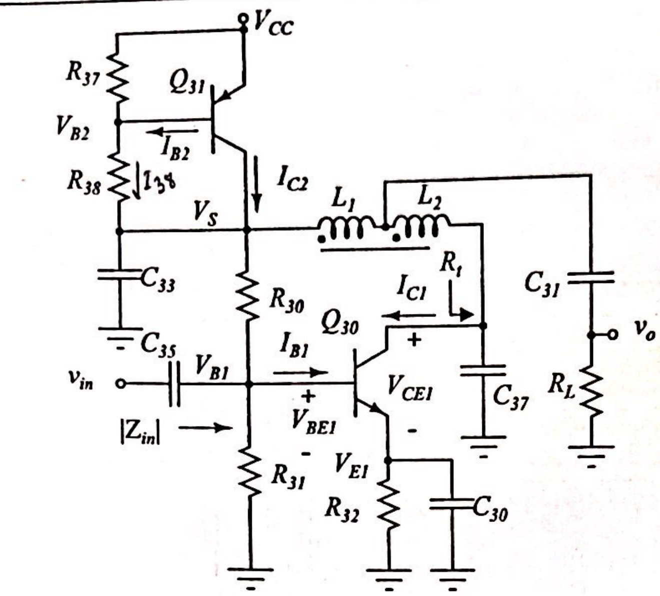

Figure 1: Schematic of transmitter amplifier.

Since β of transistors may vary from device to device, we need to design with a little dependence on β variations. For this purpose, it is a good idea to choose $I_{30}=I_{38}$ about 10 to 20 times smaller than $I_{C1}=I_{C2}$. Let us choose $I_{30}=I_{38}$=1.3 mA. Assuming the base-emitter voltages of transistors are approximately 0.75 V, we have $V_{B1}=V_{E1}+0.75$=2.75 V, and $V_{B2}=V_{CC}-0.75$=11.25 V. We can now find the values of resistors:

$V_{B2} = V_{cc} - 0.75$
$V_{cc} - V_{B2} = 0.75$

$$R_{38} = \frac{V_{B2} - V_S}{I_{38}} = \frac{11.25 - 7}{1.3} = \frac{4.25}{1.3} = 3.27\ K\Omega \tag{1}$$

We choose the closest standard value of R_{38}=3.3 KΩ. Similarly, R_{30} can be found from

$$R_{30} = \frac{V_S - V_{B1}}{I_{30}} = \frac{7 - 2.75}{1.3} = \frac{4.25}{1.3} = 3.27\ K\Omega \tag{2}$$

Hence we choose R_{30}=3.3 KΩ as well. From the datasheet of BC556B, we see that $\beta=h_{FE}$ can vary between 180 to 460. We choose a typical value of β_2=320. The current in R_{37} is

$$I_{37} = I_{38} - I_{B2} = I_{38} - \frac{I_{C2}}{\beta_2} \Rightarrow \tag{3}$$

The resistance R_{37} can be found from

$$R_{37} = \frac{V_{CC} - V_{B2}}{I_{37}} \Rightarrow \text{value} \quad \frac{0.75}{1.22\,mA} \tag{4}$$

Similarly, the resistance R_{31} can be found from

$$R_{31} = \frac{V_{B1}}{I_{31}} = \frac{V_{B1}}{I_{30} - I_{C1}/\beta_1} \Rightarrow \frac{2.75}{1.3\,mA - \frac{25\,mA}{200}} \tag{5}$$

$V_{B1} = 2.75V$, $I_{30} = 1.3mA$, $\beta_1 = 200$

with a typical β_1=200, since its β can be anywhere between 75 to 325.

The emitter resistance of Q30 can be found from

$$R_{32} = \frac{V_{E1}}{I_{C1}} = \frac{2\,V}{25\,mA} \tag{6}$$

$V_{B1} = V_{E1} + 0.75$
$2.75 = V_{E1} + 0.75$

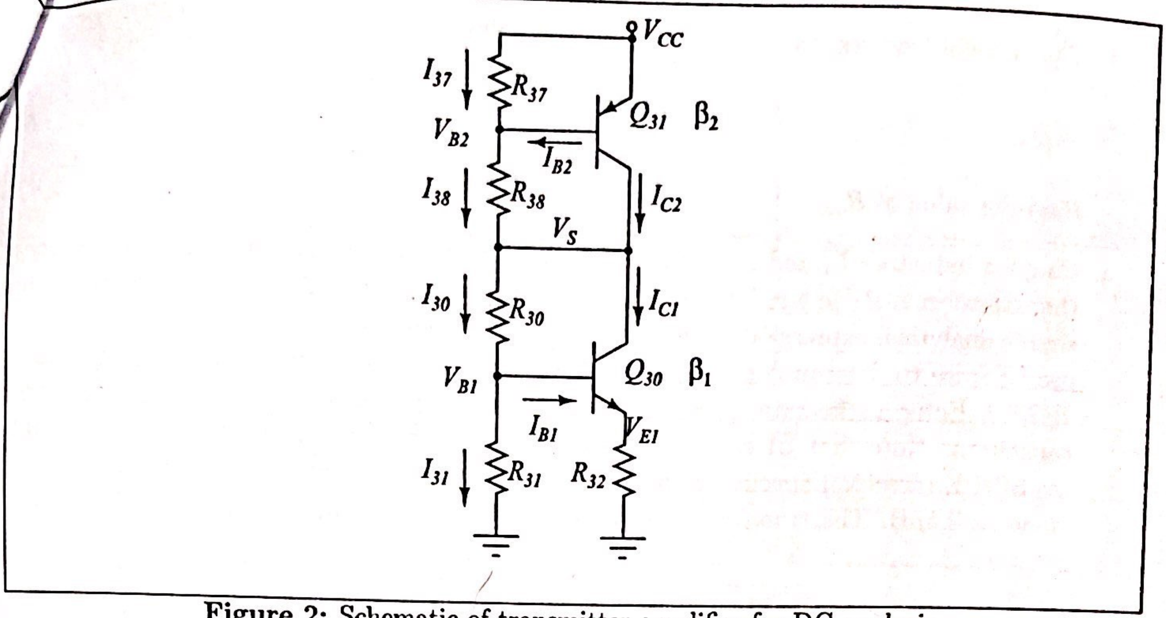

Figure 2: Schematic of transmitter amplifier for DC analysis.

Choose I_{C1}=I_{C2} in the 20 mA to 40 mA range and calculate the values of R_{31}, R_{37}, and R_{32}. Choose the closest standard values.

$\dfrac{2.75}{\frac{1.3}{10^3} - \frac{30}{200 \cdot 10^3}}$

Transmitter amplifier: I_{C1}=I_{C2}= 25mA

= R_{31}= 2340Ω ≈ 2.2kΩ R_{37}= 614.75 Ω ∼ 680 Ω R_{32}= 80Ω ∼ 82 Ω

1.1. GRADE:

2. The value of the capacitor, C_{30}, can be determined by

$C_{30} > 718$ pF

$$C_{30} > \frac{10}{2\pi f_0 R_{32}} \qquad \frac{10}{2\pi \cdot 27 \cdot 10^6 \cdot 82\,\Omega} \tag{7}$$

since this bypass capacitor is supposed to short-circuit R_{32} at the operating frequency of f_0=27 MHz. It is a good idea to choose a capacitor close to this limit, but not much higher. Choose the closest standard value. The value of the decoupling capacitor, C_{33}, can be determined from

$C_{33} > 58.9$ nF

$$C_{33} > \frac{10}{2\pi f_0 |Z_d|} \qquad \frac{10}{2\pi \cdot 27 \cdot 10^6} \tag{8}$$

where Z_d is the required impedance of V_S, approximately 1 Ω.

Transmitter amplifier: C_{30}=718 pF ∼ 820pF C_{33}= 58.9 nF ∼ 68 nF

1.2. GRADE:

3. The optimal load resistance for the transistor, Q30, is given by

$$R_{opt} = \frac{V_{CE1}}{I_{C1}} \quad \frac{5\,V}{25\,mA} = 200\,\Omega \tag{9}$$

Find the value of R_{opt}.

4. Coupled inductors L_1 and L_2 along with C_{37} form an impedance transformation network that transforms R_L to a resistance R_t close to the optimal resistance, R_{opt}. Unfortunately, simple analytical expressions to find the component values do not exist. Instead, one can use LTSpice to determine the values. LTSpice already has the model for the transistor, 2N2222. Enter a schematic as shown in Fig. 3 using the calculated values of resistors and capacitors. Note that L1 and L2 are coupled inductors with "K L1 L2 0.4" statement (as SPICE directive) specifying the coupling coefficient of k=0.4 between them. Set L_1 value as 2.5μH. The transformation ratio can be found using AC analysis in LTSpice.

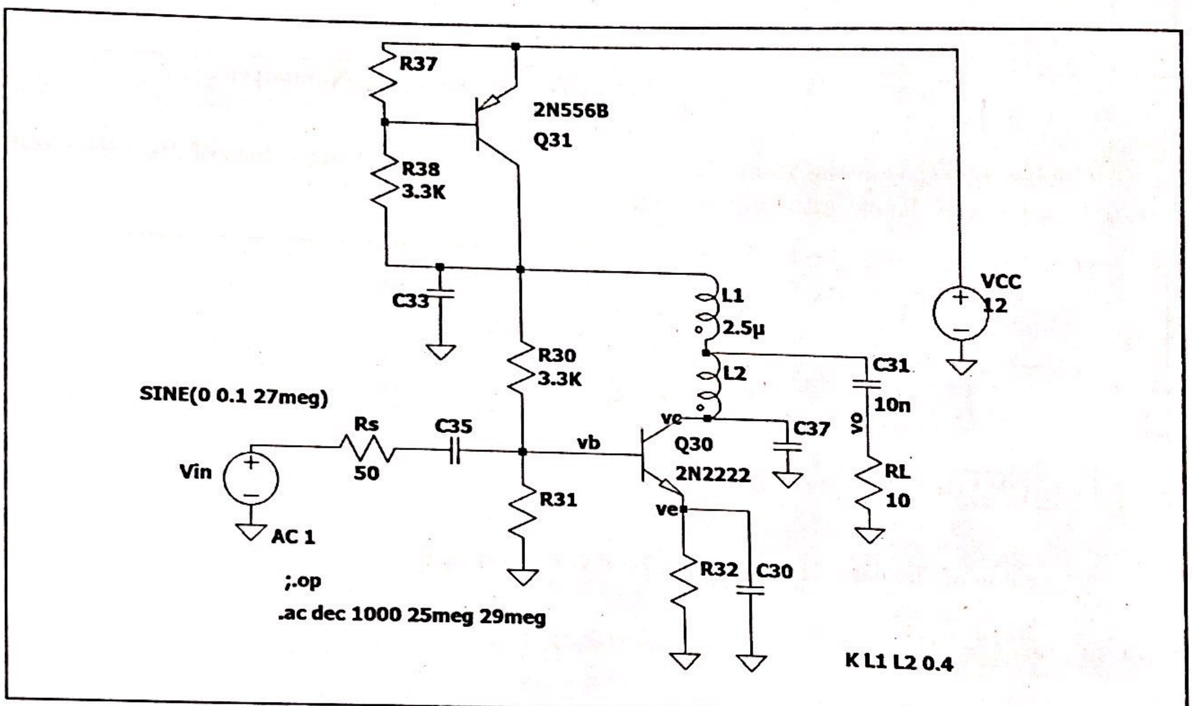

Figure 3: LTSpice schematic of transmitter RF amplifier.

One can find the load impedance as a function of frequency by plotting $-$V(vc)/Ic(Q1) on a linear scale (not dB). L2 and C37 value should be adjusted so that the phase of the load impedance is zero (so that it is resistance) at 27 MHz. The value of the transformed resistance, R_t, can be read as the magnitude of $-$V(vc)/Ic(Q1). The results of a number of such simulations are shown in the Table 1. Choose most suitable values of L_2 and C_{37} from the table so that $R_{opt} \approx R_t$. Use these values in the LTSpice. Perform a transient analysis to find the voltage across R_L. Set the input voltage to 0.1 V peak sinusoid at 27 MHz. Increase the sinusoidal input voltage, v_{in}, until a distortion at the collector voltage starts. In LTSpice simulation, make sure that the collector voltage, v_C, can span most of the range from V_E to $2V_{CC} - V_E$ without distortion. The collector current should be able to span between 0 to $2I_C$ in a nearly sinusoidal manner. There may be some distortion in the current waveform. Record the maximum peak-to-peak voltage, v_{opp}, across R_L.

L_2 (nH)	C_{37} (pF)	R_t (Ω)
729	56	757
595	68	524
490	82	368
395	100	250
322	120	173
248	150	110

Table 1: Values of transformation network at 27 MHz for L_1=3 μH and k=0.4.

R_{opt}= 200Ω L_2= 322nH C_{37}= 120pF

R_t = 173 Ω v_{opp}= 2,1 V

5. 1.5. GRADE:

6. Determine the number of turns, n_2, of L_2 from the following table

n_2	L_2 (nH)
3	260
4	310
5	320
6	380
7	450
8	540
9	680

Table 2: Number of turns using 0.35 mm enameled wire on T37-7 toroid, corresponding inductor values.

7. Determine the power delivered to the load resistance using

at 30mW → Vopp 1.54 V
at 300 mW → Vopp 2.82 V

$$55mW \quad P_L = \frac{v_{opp}^2}{8R_L} \rightarrow 10 \quad (10)$$

It is expected to get P_L between 30 mW to 100 mW.

8. The efficiency, η, of the amplifier can be calculated by dividing the output power to the DC power of the amplifier:

$$\eta = \frac{P_L}{V_{CC}I_C} \Rightarrow \frac{55\,mW}{12 \cdot 25 \cdot 10^{-3}} = 0.18 \quad (11)$$

n_2= 5 P_L= 55mW η= 0.18

1.8. GRADE:

9. Refer to the datasheet of the relay in p. 417. Find the maximum current the relay contacts can carry. Find the nominal current of the solenoid with 12 V excitation.

I_{max}= 15A $I_{solenoid}$= 30mA η= 0.18

1.9. GRADE:

Experimental Work

1. Transmitter amplifier

1. The tuned RF amplifier to be mounted is the transmitter (TX) amplifier operating at 27 MHz. This circuit is given in Fig. 5. L30 is a tapped inductance. The number of turns of L2 is determined in the preliminary work. It is supposed to transform the impedance of 10 Ω to the optimum load resistance of the transistor. Cut 40 cm of 0.35 mm *enameled* wire to wind L1 and L2 on the T37-7 toroid. T37-7 is a core with an outer diameter of 0.37 inches or 9.4 mm (see p. 402). The windings should be single-layer without scrambles. Randomly wound coils do not perform well. The increased capacitance between the windings has a detrimental effect on the inductance performance. Count the turns of L1 carefully. It is very easy to end up with one turn more. The number of turns is the number of times the wire *passes through the toroid.* When the windings of L1 are finished, bend and twist the wire for the tap of 1 cm long. Continue winding in the same direction to complete L2. Windings should be similar to the example tapped inductor shown in the photo of Fig. 4. Cut the extra wires at both ends. Scrape the enamel off with a knife at

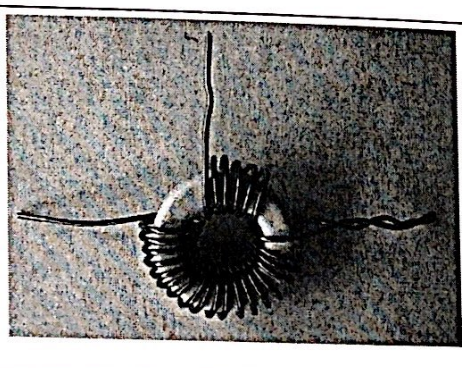

Figure 4: A photo of properly wound tapped inductor example.

each end for about 3mm length without nicking the wire. If you do not strip it properly, you may have a bad solder connection, and your circuit may work only intermittently.