

# LABORATORY REPORT - CHAPTER 6

v7.1

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Total Grade	/100

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

## Preliminary Work

### 1. Crystals

- Intermediate frequency (IF) of TRC-11 is at 15 MHz. Quartz crystals at this frequency can be found abundantly in all component suppliers. Suppose we set up the following network to characterize a quartz crystal. We first find the frequency corresponding to

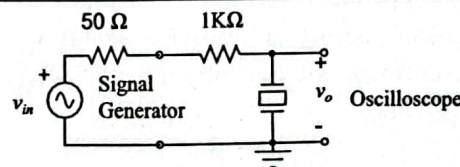


Figure 1: Quartz crystal measurement setup.

the smallest voltage,  $v_{omin}$ , across the crystal. This is the resonant frequency,  $f_s$ , of the crystal. At this frequency, the quartz crystal is equivalent to a resistor,  $r_s$ . We can determine the value of the resistor,  $r_s$ , from

$$v_o r_s + 1050 v_o = v_{in} r_s \quad (1)$$

$$r_s (v_o - v_{in}) = -1050 v_o$$

$$\Rightarrow \frac{v_{omin}}{v_{in}} = \frac{r_s}{r_s + 1050}$$

We also find the frequencies,  $f_1$  and  $f_2$ , at which  $v_o = \sqrt{2} v_{omin}$ . These two frequencies correspond to the situation where the reactance of the crystal is equal to  $r_s$ , hence the difference between them is -3 dB BW. From these frequencies, one can determine the quality factor,  $Q$ , of the circuit shown.

$$r_s = \frac{-1050 v_o}{v_o - v_{in}}$$

$$= 6.467$$

$$Q = \frac{f_s}{f_2 - f_1} = 0.00075 \text{ MHz}$$

We can calculate  $L_s$  and  $C_s$  from  $f_s$ ,  $r_s$ , and  $Q$ :

$$L_s = \frac{Q r_s}{2\pi f_s} \text{ and } C_s (\text{pF}) = \frac{25330}{f_s (\text{MHz})^2 L_s (\mu\text{H})} \quad (2)$$

Assume that  $v_{in}=10$  V,  $v_{omin}=80$  mV at  $f_s=14.995$  MHz. Suppose that  $v_o=113$  mV at  $f_1=14.994870$  MHz and  $f_2=14.995120$  MHz. Find the inductor parameters,  $r_s$ ,  $Q$ ,  $L_s$ , and  $C_s$ .

2. It is possible to shift the resonant frequency of a quartz crystal toward higher frequencies using a series capacitor,  $C_1$ . The shift in the frequency can be found from

$$\delta f(\text{MHz}) = \frac{1}{2f_s(\text{MHz})} \frac{25330}{L_s(\mu\text{H})C_1(\text{pF})}$$

Determine  $\delta f$  for  $C_1=33$  pF.

$$r_s = 2.47 \Omega \quad Q = 51980 \quad L_s = 0.005392 \text{ H} \quad C_s = 21 \text{ pF} \quad \delta f = 4747 \text{ MHz}$$

1.2. GRADE:

## 2. IF Filter

1. We can make a second-order band-pass-filter using two such crystals. To make a filter of bandwidth  $\Delta f$ , we calculate the termination impedance,  $R_o$ , and inverter impedance,  $X$ , using Eq. 6.48 in 270:

$$X = R_o + r_s = \frac{2\pi \Delta f L_s}{1.4142} \quad (4)$$

Choose a bandwidth,  $\Delta f$ , in the range of 4 to 5 KHz. Find  $X$  and  $R_o$  for this bandwidth. Find the value of the capacitor to implement the inverter.

$$C = \frac{1}{2\pi f_s X} \quad (5)$$

$$\Delta f = 4.5 \text{ KHz} \quad X = 107.8 \quad R_o = 99.33 \quad C = 198 \text{ pF}$$

2.1. GRADE:

## 3. IF Transformer

1. The receiver mixer is a SA602A (or SA612A) IC. The output impedance of this chip is approximately  $1.5 \text{ k}\Omega$  (see page 401). It has two  $180^\circ$  out of phase outputs. We use both outputs of this chip constructively to get twice the voltage or four times the power. Therefore, the total output impedance is  $3 \text{ k}\Omega$ .

Consider the equivalent circuit in Fig. 2. The function of the transformer T40 is to convert the output impedance of  $3 \text{ k}\Omega$  to  $R_o$  as needed by the IF filter. This is necessary for maximum power transfer between the mixer and the IF filter. This requirement sets the transformer ratio to

$$\frac{n_1}{n_2} = \sqrt{\frac{3000}{R_o}}$$



In this circuit, out of phase outputs of the mixer chip are modeled as two voltage sources  $V_{o1}$  and  $-V_{o1}$ , with  $1.5\text{ k}\Omega$  source resistances. With  $V_1 = 2V_{o1}$ , the two outputs are constructively added at the transformer primary terminals.

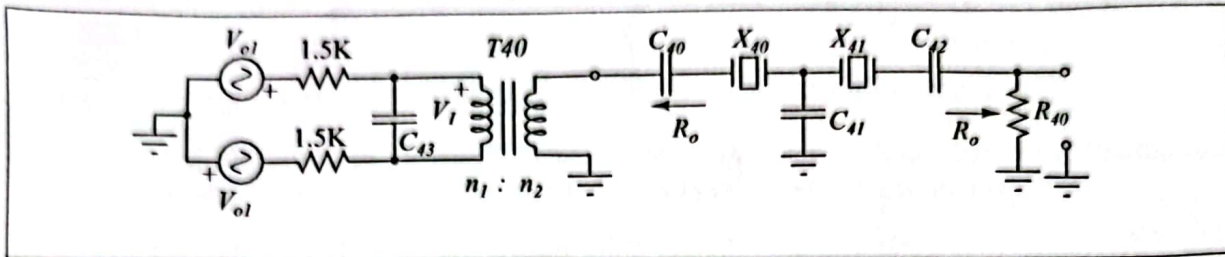


Figure 2: Impedance matching between receiver mixer and IF filter.

The core for the IF transformer is a T38-8/90 toroid produced by Micrometals (see page 420). T38 core has an outer diameter of 0.38 inch (or 9.53mm), and 8/90 signifies the iron powder material type. The core materials for transformer applications must have a permeability as high as possible to keep most of the flux within the core. This material has a relative permeability  $\mu_r$  of 35 and yields an  $A_L = 26\text{ nH/turn}^2$  when windings are tightly wound.

Use a turns ratio of  $n_1/n_2$  to transform  $3\text{ k}\Omega$  to  $R_o$  value. Since the coupling between the windings of the transformer is not perfect, we need to increase the number of turns of the secondary winding to get the required transformation. We use  $n_1=19$  for the primary and  $n_2=6$  turns for secondary winding.

If the winding is tight, the inductance observed at the primary terminals is  $n_1^2 \times 26\text{ nH}$ . With windings spread out, the inductance can be lower. Find the value of the capacitor C43 to tune out this inductance at 15 MHz. Choose the closest standard value.

$$C_{43} = 1.199 \times 10^{-11}$$

$$1.199 \times 10^{-12}$$

$$12\text{ pF}$$

3.1. GRADE:

$$\omega = \frac{1}{\sqrt{LC}}$$

$$\omega^2 = \frac{1}{LC}$$

$$C = \frac{1}{\omega^2 L}$$

## Experimental Work

### 1. Crystals

1. We measure  $f_s$  and  $Q$  of both crystals in this exercise and then characterize the relevant crystal parameters. The measurement setup is given in Fig. 1.

Solder one end of the first crystal (X40) to a  $1\text{ k}\Omega$  resistor. Connect the signal generator cable and the oscilloscope probe, making sure that the ground is common at the crystal side.

Adjust the signal generator to deliver  $5\text{ V}_{pp}$  sine wave at 15 MHz (recall that with a high-impedance load it delivers,  $10\text{ V}_{pp}$ ), and set it up so that you can change the frequency at 1 kHz intervals. Connect the external sync of the oscilloscope to the SYNC output of the signal generator to be able to measure more accurately. Scan the frequency range between 14.990 MHz and 15.005 MHz. As we change the frequency, we should observe a

minimum on the voltage across the crystal because the crystal has a series resonance. At the frequency where you observe a dip in the voltage, decrease the scan step to 10 Hz. Find the frequency,  $f_s$ , of the minimum voltage. Use averaging feature of the oscilloscope for more accurate measurements. Measure and record this frequency and this minimum peak-to-peak voltage,  $v_{omin}$ .

- Determine the series resistance of the crystal using Eq. 1 with  $v_o = 10 \text{ mV}$ .
- Shift the frequency in 20 Hz steps and observe that the voltage increases. Record the frequencies,  $f_1$ , and  $f_2$ , on both sides of  $f_s$ , where the voltage is  $\sqrt{2} v_{omin}$ .
- Calculate  $Q$ ,  $L_s$  and  $C_s$  of the crystal using Eqs. 2.
- Find the value of the series capacitor,  $C_1$ , to shift the resonant frequency to exactly 15.000 MHz using Eq. 3 (If the resonant frequency is already higher than 15.001 MHz, ask for a different crystal from the technician). Choose the nearest standard capacitor value. Solder this capacitor in series with the crystal. Measure the shifted resonant frequency,  $f'_s$ . If the resonant frequency is not between 14.999 and 15.001 MHz try another capacitor of the same value or the next smaller or larger standard capacitor value. Once the resonant frequency is correct, keep them soldered together to preserve the association.

First crystal (X40):

$$f_s = 14.994 \text{ MHz} \quad r_s = 8.46 \Omega$$

$$\delta f = 0.006 \text{ MHz}$$

$$C_s = 20 \text{ pF}$$

$$L_s = 5.38 \times 10^{-3} \text{ H} \quad Q = 5997.6$$

$$C_1 = C_{40} = 18 \text{ pF} \quad f'_s = 14.9997 \text{ MHz}$$

#### 1.5. GRADE:

- Repeat the steps above to find the center frequency of the second (X41) 15 MHz crystal and the necessary capacitance ( $C_{42}$ ) to shift the center frequency to very close to 15.000 MHz. Measure the shifted center frequency of the second crystal.

Second crystal (X41):

$$f_s = 14.9944 \text{ MHz} \quad r_s = 8.35 \Omega$$

$$\delta f = 0.0056 \text{ MHz}$$

$$L_s = 5.31 \times 10^{-3} \text{ H} \quad Q = 5977.6$$

$$C'_1 = C_{42} = 18 \text{ pF} \quad f'_s = 14.99910 \text{ MHz}$$

#### 1.6. GRADE:

- Using Eq. 4 find the value of the inverter impedance  $X$  and the corresponding termination impedance,  $R_o$ , to make a second-order band-pass-filter with your chosen bandwidth,  $\Delta f$ .



Since  $L_s$  for two crystals may be slightly different, use the average value of  $L_s$  for  $X$  calculation. Find the nearest standard capacitor value,  $C_{41}=C$ , for the inverter using Eq. 5.

$$X = 107.56 \quad R_o = 79.10$$

#### 1.7. GRADE:

### 2. IF Filter

Designator	Comment	Description
R41	2.7 K	Resistor, carbon film, axial leaded, 1/4W
T40	T38-8/90	Toroidal core
X40,X41	15MHz	Crystal

Figure 3: Bill of materials for IF filter

1. The IF filter of TRC-11 is given in Fig. 4. Start building the filter by placing the crystal X40 and its corresponding series capacitor C40 in their places. Solder them.
2. Place and solder the crystal X41 and its series capacitor C42.
3. Mount and solder the resistor, R40.
4. Solder a looped wire to the test point, TP50.

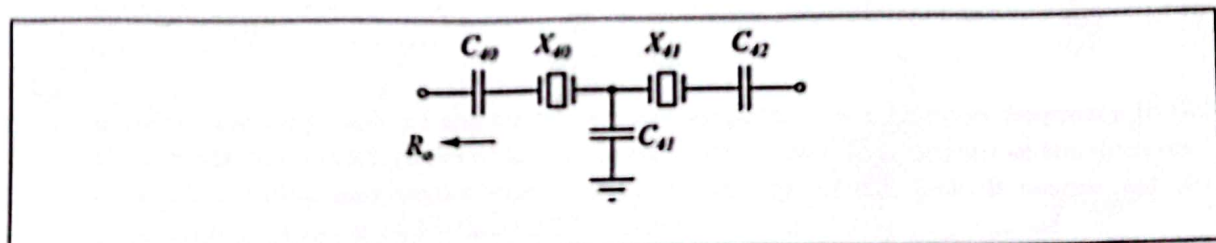


Figure 4: IF Filter schematic.

5. Mount and solder C<sub>41</sub>=C as the inverter capacitance, whose reactance is equal to  $X$ . The termination impedance for this filter is given as  $R_o$ .

### 3. IF Transformer

1. First, wind the primary using 35 cm long 0.35mm enameled wire. Wind 19 tight turns on T38 8/90 toroid. Do not stretch the windings to cover the toroid, keep them tight together. This is useful for minimizing the leakage flux since we have a small number of turns in the secondary winding. Wind six tight turns of secondary next to the secondary winding. Use about 14 cm of 0.35 mm wire. Trim all four leads leaving about 1 cm, strip the enamel, and cover with solder.

2. Install the transformer T40, paying attention to the correct placement of the primary and secondary pairs of leads. Solder the leads. Install and solder the capacitor C43 with the value you calculated.
3. Place and solder the test resistor R41. This resistor should be removed after testing.
4. Solder a looped wire to TP40.

#### 4. Testing the IF amplifier

1. The IF amplifier with two stages is already built. Now, we are ready to test it along with the IF filter. Connect the oscilloscope probe (10× setting) between the output of the IF amplifier at TP61 and GND. Turn on the power.

Set the signal generator output to 10 mVpp sine wave (with a high-impedance load, it delivers 20 mVpp). Connect it between TP40 and GND. Vary the frequency over the passband of IF filter around 15 MHz in very small steps and find and set it to the frequency where the amplitude of the amplifier output is maximized. This frequency is the center frequency of the IF filter. Record it. Calculate the gain of the system at the center frequency in dB. You should use

$$G(\text{dB}) = 20 \log_{10} \frac{v_o}{v_{in}} \quad \text{5.43 V}$$

where  $v_o$  is the peak-to-peak voltage at the output (TP61), and  $v_{in}=20$  mV is the (doubled) peak-to-peak voltage at the terminals of the signal generator (between TP40 and GND). If the gain is lower than 35 dB, you have something wrong with your circuit.

Center frequency (MHz) = 15 MHz  
Gain at center freq (dB) = 48.62 dB

##### 4.1. GRADE:

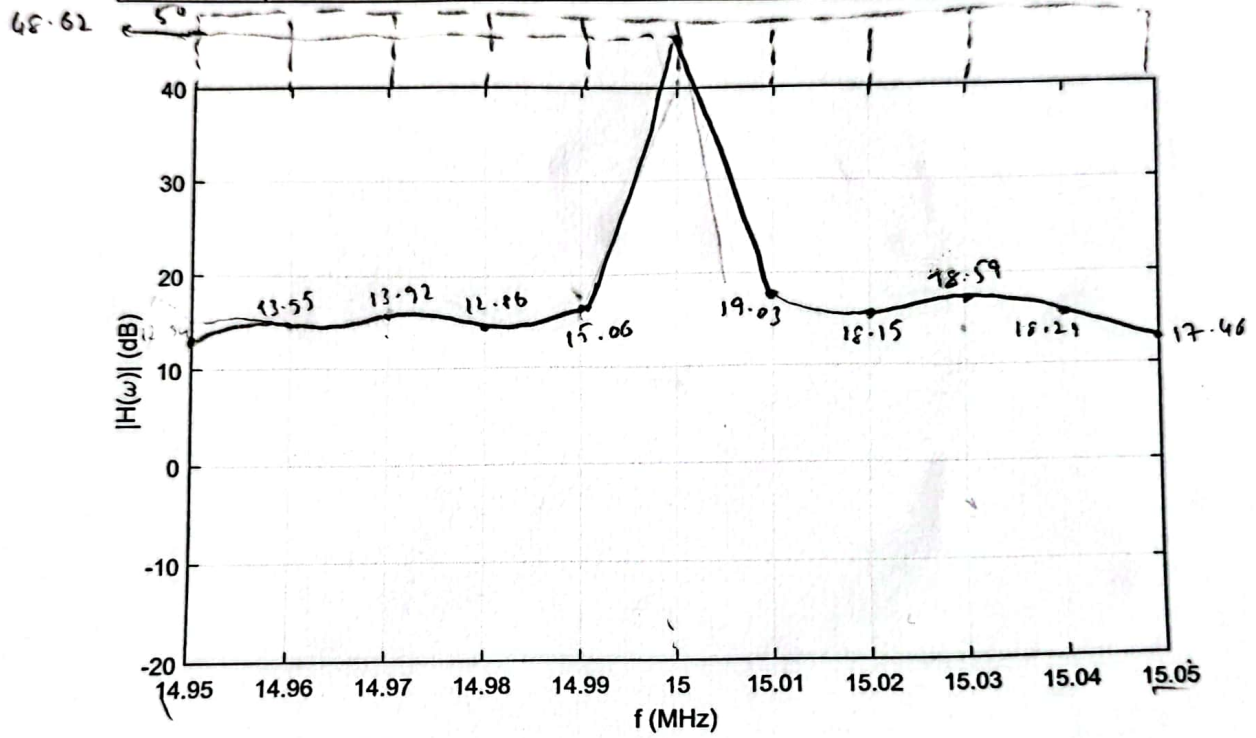
2. Measure the magnitude of the output voltage amplitude as a function frequency to determine the bandwidth (BW) of the IF filter. Recall that BW is defined as the difference between two frequency points where the gain drops by -3 dB. (-3 dB means that the gain drops by a factor of  $1/\sqrt{2}=0.707$ ). Record it.

Bandwidth (kHz) = 3.5 kHz

##### 4.2. GRADE:

3. **CHECK POINT:** Plot the gain in decibels as a function of frequency in a 100 kHz range.

$f$ (MHz)	$ H(\omega) $ (dB)	$f$ (MHz)	$ H(\omega) $ (dB)	$f$ (MHz)	$ H(\omega) $ (dB)
14.95	17.46	15.00	48.62 dB	15.05	17.46
14.96	13.55	15.01	19.03		
14.97	13.92	15.02	18.15		
14.98	12.46	15.03	18.59		
14.99	15.06	15.04	18.29		



4.3. GRADE: