

LABORATORY REPORT - CHAPTER 6

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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

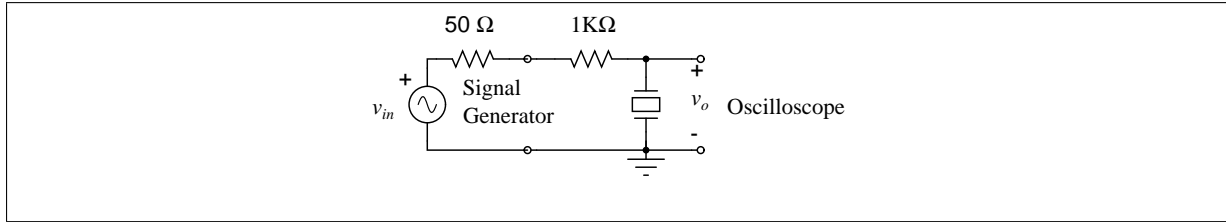


Figure 1: Quartz crystal measurement setup.

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

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

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.

$$Q = \frac{f_s}{f_2 - f_1}$$

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

$$\delta f(\text{MHz}) = \frac{1}{2f_s(\text{MHz})} \frac{25330}{L_s(\mu\text{H})C_1(\text{pF})} \quad (3)$$

Determine δf for $C_1=33$ pF.

$r_s = 8.47\Omega$	$Q = 59980$	
$L_s = 5.39\text{mH}$	$C_s = 20.9\text{nF}$	$\delta f = 4.75\text{kHz}$

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 Δf , we calculate the termination impedance, R_o , and inverter impedance, X , using Eq. 6.48 in 235:

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

Choose a bandwidth, Δf , in the range of 3 to 4 KHz. Find X and R_o for this bandwidth. Find the value of the capacitor to implement the inverter.

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

$\Delta f = 3.6\text{kHz}$	$X = 86.21\Omega$	$R_o = 77.74\Omega$	$C = 123.12\text{pF}$
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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 k Ω (see page 390). It has two 180° 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 k Ω .

Consider the equivalent circuit in Fig. 2. The function of the transformer T40 is to convert the output impedance of 3 k Ω 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.

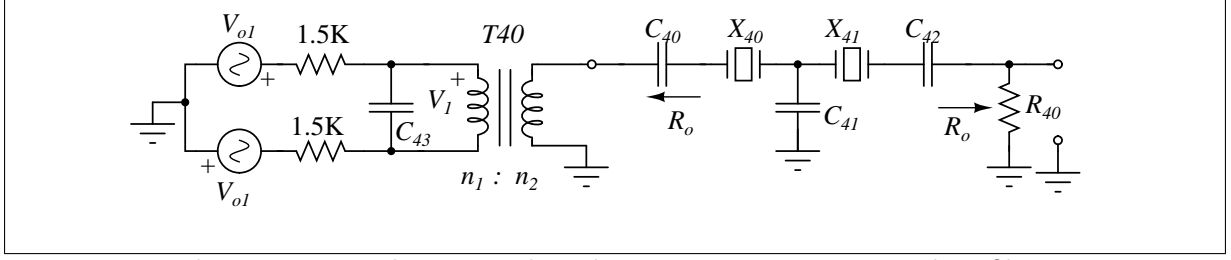


Figure 2: Impedance matching between receiver mixer and IF filter.

The core for the IF transformer is a T38-8/90 toroid produced by Micrometals (see page 406). 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 μ_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 C_{43} to tune out this inductance at 15 MHz . Choose the closest standard value.

$$C_{43} = 12\text{ pF}$$

3.1. GRADE:

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 V_{pp} sine wave at 15 MHz (recall that with a high-impedance load it delivers, 10 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} .

2. Determine the series resistance of the crystal using Eq. 1.
3. Solder a $C_1=5.6$ pF capacitor in series with the crystal as shown in Fig. 3. Determine the resonance frequency, f_{s1} , of the new circuit within 10 Hz. Find the difference, δf , between the resonance frequencies with and without 5.6 pF capacitor in series. Note that the minimum voltage observed in this measurement is higher than that in the measurement without the capacitor, since the capacitor, C_1 , also has a finite series resistance of its own.

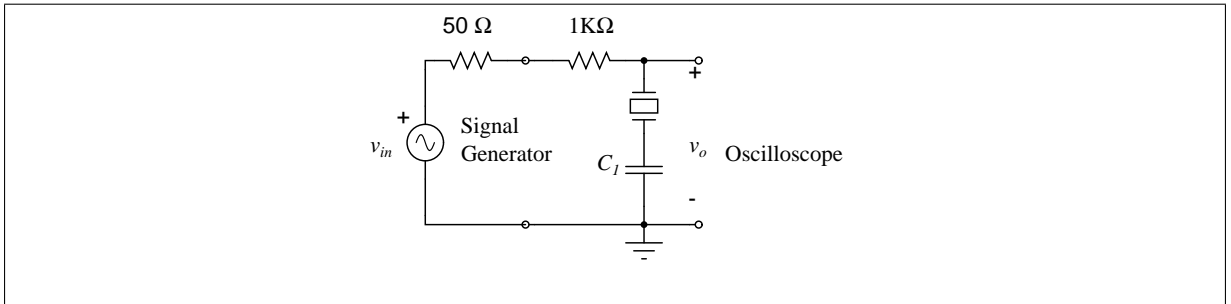


Figure 3: Quartz crystal measurement setup with a series capacitor.

4. Determine the series inductance, L_s , of the crystal using the equation

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

This method gives a better accuracy compared to measuring f_2 and f_1 .

5. Determine the quality factor, Q , of the crystal using Eq. 2.
6. 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):

$$f_s = 14994410\text{Hz} \quad r_s = 13.18\Omega \quad \Delta f = 5.83\text{KHz}$$

$$L_s = 13.31\text{mH} \quad Q = 95134.3$$

$$C'_1 = C_{40} = 11.35\text{pF} \quad f'_s = 15000240\text{Hz}$$

1.6. GRADE:

- Repeat the steps above to find the center frequency of the second (X41) 15 MHz crystal and the necessary capacitance (C42) to shift the center frequency to very close to 15.000 MHz. Measure the shifted center frequency of the second crystal.

Second crystal (X41):

$$f_s = 14994100\text{Hz} \quad r_s = 12.3\Omega \quad \Delta f = 5.84\text{KHz}$$

$$L_s = 12.67\text{mH} \quad Q = 96902.6$$

$$C'_1 = C_{42} = 11.29\text{pF} \quad f'_s = 15000250\text{Hz}$$

1.7. 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, Δf . 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.

$$X = 336.5\Omega \quad R_o = 324.24\Omega$$

1.8. GRADE:

2. IF Filter

Designator	Comment	Description
C40, C41, C42	TBD	Capacitor, 50V
R41	2.7K	Resistor
T40	T38-8/90	Toroidal Core
X40, X41	15MHz	Crystal

Figure 4: Bill of materials for IF filter

- The IF filter of TRC-11 is given in Fig. 5. Start building the filter by placing the crystal X40 and its corresponding series capacitor C40 in their places. Solder them.
- Place and solder the crystal X41 and its series capacitor C42.
- Mount and solder the resistor, R40.

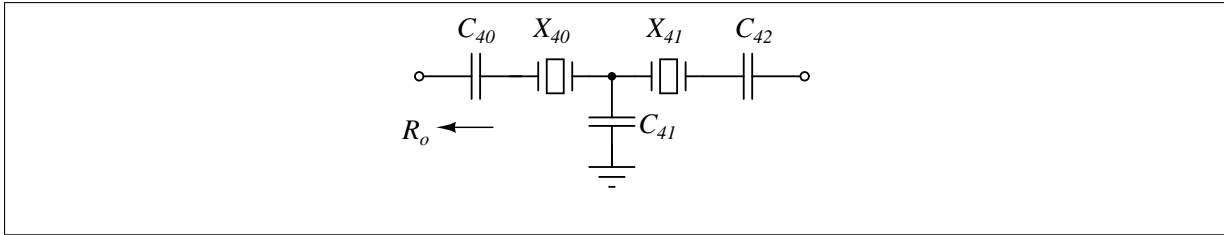


Figure 5: IF Filter schematic.

4. Solder a looped wire to the test point, TP50.
5. Mount and solder $C_{41}=C$ 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 ($10\times$ 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

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

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)= 15.0002MHz
Gain at center freq (dB)= 43.2dB

4.1. GRADE:

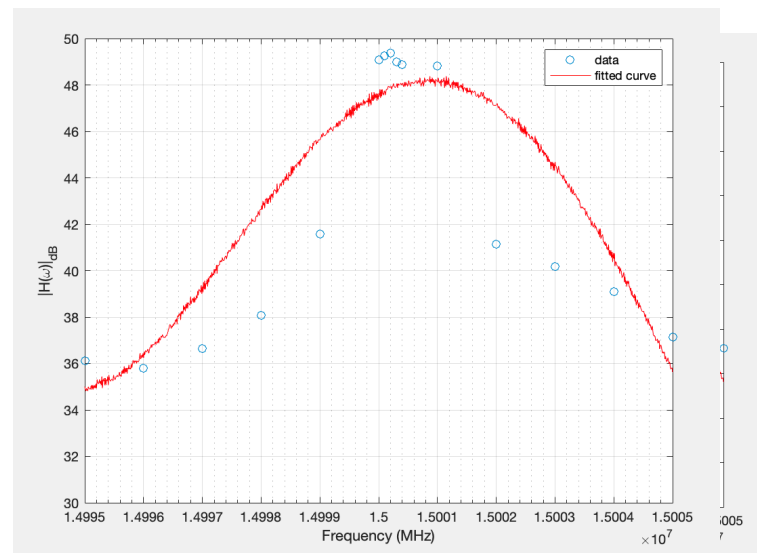
2. Measure the magnitude of the output voltage amplitude as a function frequency to determine the bandwidth (BW) of the IF filter. Recall that BW is defined as the difference between two frequency points where the gain drops by -3 dB. (-3 dB means that the gain drops by a factor of $1/\sqrt{2}=0.707$).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

Bandwidth (kHz)= 4KHz

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)
14.999MHz	41.58dB	15MHz	49.09dB	15.0001Mhz	49.24dB
14.998MHz	38.06dB	15.001MHz	48.81dB	15.0002Mhz	49.36dB
14.997MHz	36.63dB	15.002MHz	41.13dB	15.0003Mhz	49.00dB
14.996MHz	35.79dB	15.003MHz	40.17dB	15.0004Mhz	48.88dB
14.995MHz	36.12dB	15.004MHz	39.08dB	15.005Mhz	37.14dB



4.3. GRADE: