Lab Exercise 3
Prototype Design of a SONAR Transmitter

Objective

The objective of this lab assignments is to learn how to

a. Read a datasheet for finding out the key information relevant to a design
b. Develop a prototype of a Sonar transmitter on a breadboard and test its desired outcome

Description

The system level configuration of the ultrasonic narrow band Doppler sensor is shown in Fig.1. The system consists of transmitter and receiver circuits. The transmitter consists of a crystal oscillator that generates a 2MHz sinusoidal signal. The frequency divider divides the 2MHz signal by a factor of 50 to generate a 40KHz (f_o) output signal. A low pass filter is used to remove any higher order harmonics that may be generated. The filter may be designed as an active filter to provide voltage amplification to the transmitted signal. The signal may be amplified and conveyed to the acoustic transducer where the electrical signal is converted to acoustic signal and transmitted as shown in the equation below.

$$S_{tx}(t)=A_{tx}\cos(2\pi f_o t) \qquad \text{-------------------(1)}$$

In this lab we will design the Tx part of the SONAR, where we will be designing each block of the transmitter circuit as indicated in the below figure, and cascading them to achieve the desired output. We will see that the final output signal after the LPF block practically differs from the exact sinusoid as indicated in Eq 1.

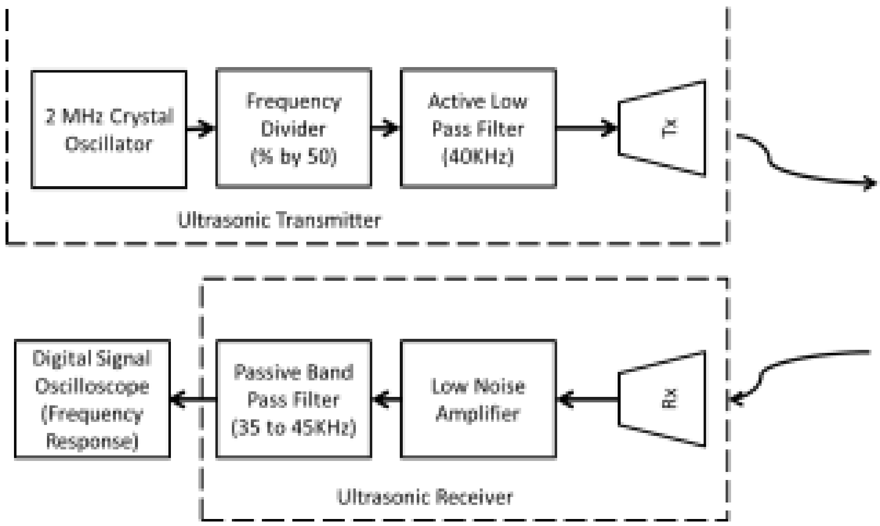


Fig. 1. Ultrasonic narrow band Doppler sensor

Oscillator Design

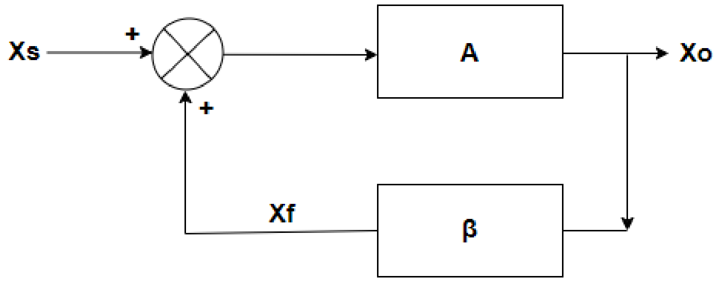


Fig. 2: Oscillator Block Diagram

The basic structure of a sinusoidal oscillator consists of an amplifier and a frequency-selective network connected in a positive-feedback loop, such as that shown in block diagram form in Fig. 2. Although no input signal will be present in an actual oscillator circuit, we include an input signal here to help explain the principle of operation. It is important to note that, here the feedback signal Xf is summed with a positive sign. Thus the gain-with-feedback is given by

$$Af(s) = \frac{A(s)}{1-A(s)\beta(s)} \text{ (where s = j}\omega\text{)} \qquad \text{------------(2)}$$

where we note the negative sign in the denominator. The loop gain L(s) is given by $L(s) \equiv A(s)\beta(s)$.

If at a specific frequency of the loop gain $A\beta$ is equal to unity, it follows from Eq. 2 that Af will be infinite. That is, at this frequency the circuit will have a finite output for zero input signal. Such a circuit is by definition an oscillator. Thus the condition for the feedback loop of Fig. 2 to provide sinusoidal oscillations of frequency ωo is $L(j\omega o) \equiv A(j\omega o)\beta(j\omega o) = 1$. That is, at ωo the phase of the loop gain should be zero and the magnitude of the loop gain should be unity. This is known as the Barkhausen criterion. Note that for the circuit to oscillate at one frequency, the oscillation criterion should be satisfied only at one frequency (i.e., ωo); otherwise the resulting waveform will not be a simple sinusoid.

Quartz Crystal

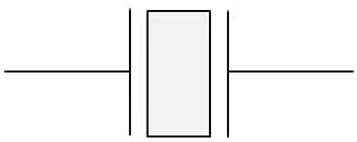


Fig.3 (i) Quartz Crystal

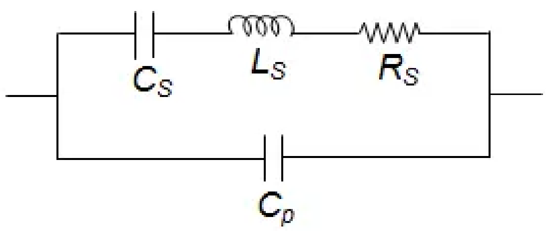


Fig.3 (ii) Equivalent Circuit

Crystal oscillators operate on the principle of inverse piezoelectric effect in which an alternating voltage applied across the crystal surfaces causes it to vibrate at its natural frequency. It is these vibrations which eventually get converted into oscillations.

Fig.3 (i) shows a quartz crystal & Fig.3 (ii) shows its equivalent circuit which consists of series RLC circuit in parallel with capacitance of its electrodes Cp.

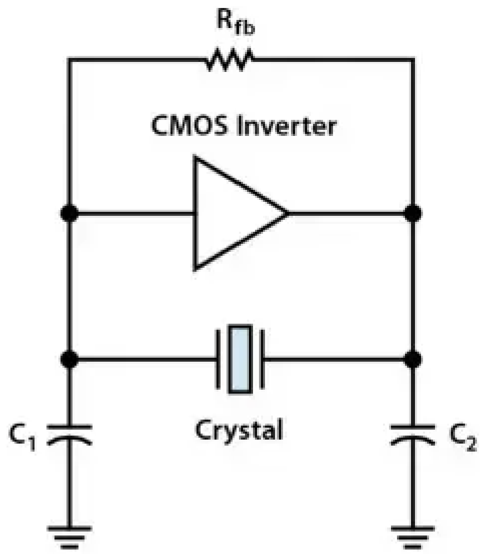
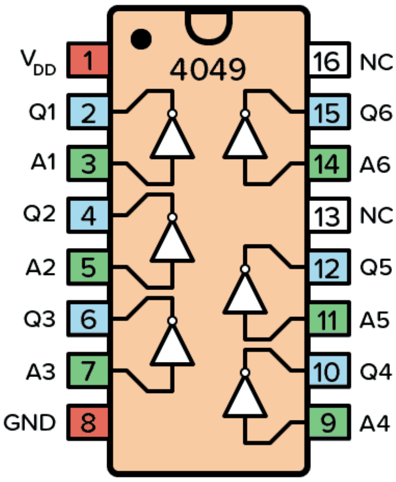


Fig.4 Connections for Crystal Oscillator to achieve 0^0 phase shift

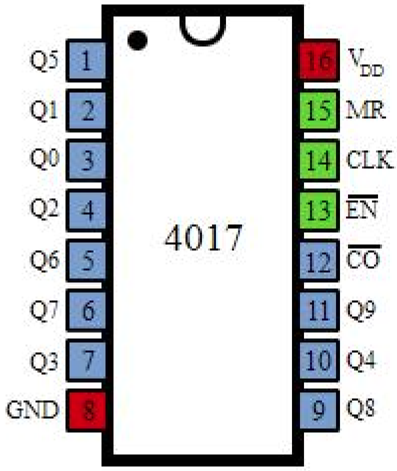
Components Utilized in the Tx Section of the SONAR:

Components Part Number	Type	Purpose	Link for the Datasheet
HC-49U	Crystal Oscillator	Generate 2MHz signal	Link1 / Link2
TL072	Low Noise Amplifier	Amplify received signal without introducing too much noise	Link
CD4017BE	Frequency Divider	Convert 2MHz signal to 40KHz signal	Link
CD4049	Buffer Amplifier	Allows for impedance transformation and protects circuits from fluctuations in currents. This IC can also be used with an oscillator.	Link
MCUSD16A40S12R0	Piezoelectric Transducer	Convert electrical to ultrasonic signal and back (Transmitter and Receiver)	Link
	R, L, C	Resistors, inductors, capacitors	

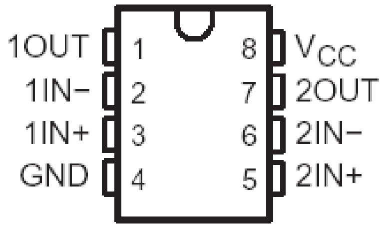
IC Pin Diagram



IC 4049 pinout



IC 4017 pinout



IC TL072 pinout

Circuit Diagram of the Tx Section:

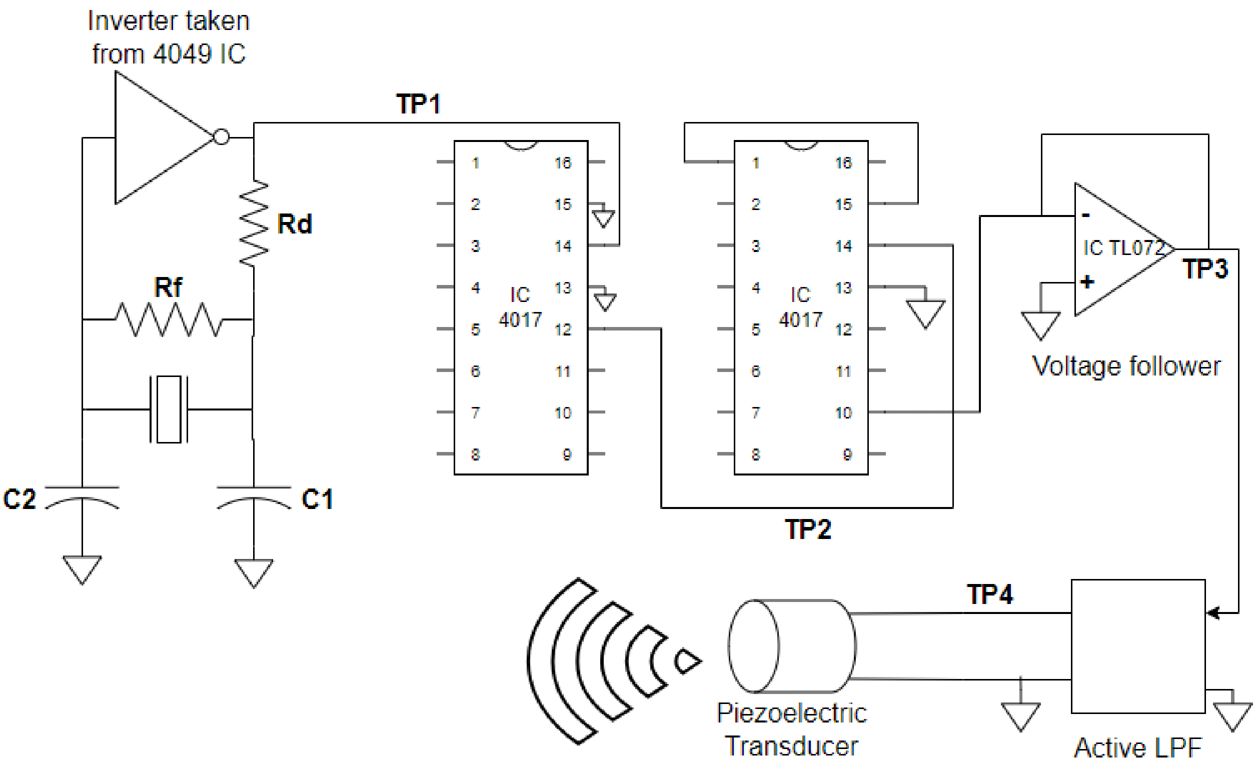


Fig.5 SONAR Transmitter

In the Tx circuit indicated above, the selection of Rf, C1, and C2 depends of the desired frequency of oscillations. The capacitors C1 and C2 are called load capacitors and their frequency mapping is given in the table below:

Frequency Range	Load
0 - 5 MHz	33pf
5 - 10 MHz	18pf
10 - 15 MHz	16pf
15 - 20 MHz	14pf
20 - 30 MHz	12pf
30 - 40 MHz	10pf

Since, we are going to use a crystal of 2MHz, the respective range of load capacitor will be 33pf. The typical value of Rf for such a case will be taken as 1 Mohm.

Lab Exercise:

In the circuit designed on the breadboard for the SONAR Tx, as indicated in Fig.5.

1. ***Check the response at the node marked by TP1 in DSO. This will form the oscillator output. Take a potentiometer of 10Kohm and connect it in place of Rd, check the effect on the output peak to peak by changing the pot from min to max.***

   2 marks, no partial marking

2. ***Check the response at TP2, here we should get the oscillating signal of 200KHz.***

   2 marks, no partial marking

3. ***Check the response at TP3, the outcome of TP3 shall be 40kHz oscillating wave.***

   2 marks, no partial marking

4. **The signal at TP3 will be passed through the active LPF block. This block needs to be implemented by utilizing the knowledge of the filter design which was experimentally verified in the previous lab. The filter cutoff frequency should be 40 KHz.** ***Check the response at TP4, and look at the frequency information of this signal by using the FFT feature of the DSO, mark the frequency which is having the highest peak.***

   2 marks: 1+1 (plot+FFT)

5. ***Correct circuit & file submission***

   2 marks: 1+1 (Circuit+File Submission)