

7. Bandpass Filter

Chapter 7 Goals

- Introduce the tank circuit as a bandpass filter
- Become familiar with bandwidth and Q of a resonant circuit
- Analyze the filter with LTspice
- Breadboard and test filters

Many frequency components are contained in the output of the mixer. It is preferred that we filter out the unwanted components, otherwise we will waste power amplifying them. These unwanted frequency components can also cause noise in the output, and can even result in more noise due to mixing in nonlinear devices in the circuit.

Filters can be made using Op Amps (so called active filters), or can be made using inductors and capacitors (passive filters). The 4 categories of filter are low pass, high pass, band pass and band stop. Here we are interested in bandpass filters (abbreviated BPF).

7.1 The Tank Circuit

A simple and very useful bandpass filter, termed a *tank* circuit, is shown in Figure 7.1. The parallel inductor and capacitor combination will store energy at a resonance frequency, hence the term tank (storage tank). The impedance, Z , looking into the tank circuit (including the load resistance, R_L) is

$$Z = \frac{j\omega R_L L}{R_L(1 - \omega^2 LC) + j\omega L} \quad (7.1)$$

At resonance, the term $(1 - \omega^2 LC) = 0$, or

$$\omega_{res} = \frac{1}{\sqrt{LC}} = 2\pi f_{res} \quad (7.2)$$

It is easy to show that at the resonance frequency the impedance will be equal to R_L . At values away from the resonance frequency, the impedance drops. This is shown in Figure 7.2 for a pair of tank circuits with a common resonance frequency but with different LC combinations. We observe that the lower value of inductance gives us a narrower bandwidth. For resonant circuits, we employ the term “Q” or “resonator Q” to define the quality of the resonant circuit. Note that this “Q” has nothing

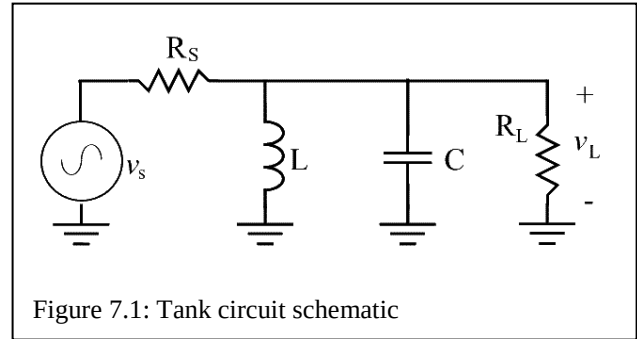


Figure 7.1: Tank circuit schematic

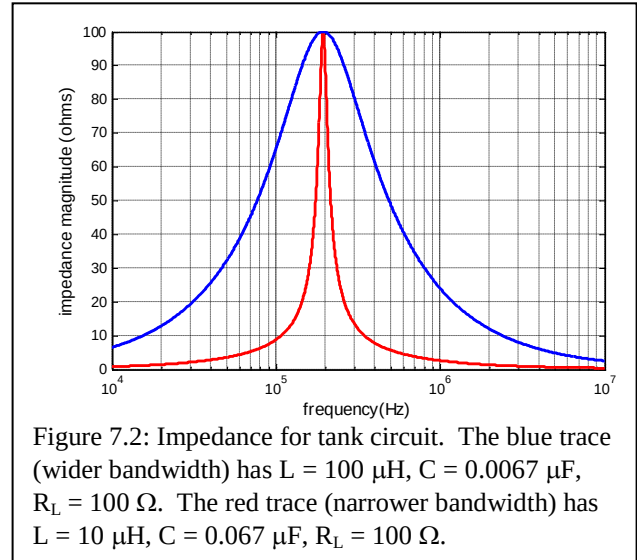


Figure 7.2: Impedance for tank circuit. The blue trace (wider bandwidth) has $L = 100 \mu\text{H}$, $C = 0.0067 \mu\text{F}$, $R_L = 100 \Omega$. The red trace (narrower bandwidth) has $L = 10 \mu\text{H}$, $C = 0.067 \mu\text{F}$, $R_L = 100 \Omega$.

to do with the “Q” of “Q-point”. For a tank circuit, it can be shown that

$$Q = \frac{R_L}{\omega_{res} L} = \omega_{res} R_L C \quad (7.3)$$

Experimentally, we can measure the resonant Q by dividing the resonance frequency by the 3 dB bandwidth:

$$Q = \frac{f_{res}}{BW} \quad (7.4)$$

Thus the narrower bandwidth result in Figure 7.2 has a higher value of Q than the broader bandwidth result.

Exercise 7.1: Derive (7.1).

Exercise 7.2: Suppose $L = 1 \mu\text{H}$ and $R_L = 1 \text{ k}\Omega$ for your tank circuit. Design the circuit to have a 600 kHz resonance frequency. What is the Q for this tank circuit?

7.1a LTspice Simulation

- Build the default circuit in LTspice shown in Figure 7.3 with $L_{f1} = 10 \mu\text{H}$, $C_{f1} = 0.069 \mu\text{F}$, $R_L = 100 \Omega$ And $R_S = 100 \Omega$. For the voltage source, set the Small signal AC analysis values to 2V for AC Amplitude and an AC Phase of 0.
- Calculate the resonant frequency and resonator Q for this configuration:

$$f_{\text{res}} = \underline{\hspace{2cm}} \quad Q = \underline{\hspace{2cm}}$$

- Calculate the maximum possible value for the output voltage amplitude. This is found by removing L_{f1} and C_{f1} .

$$V_{\text{outmax}} = \underline{\hspace{2cm}}$$

- Now, in the Simulate menu, select Edit Simulation Command with the following settings:

Type of Sweep:	Decade
Number of points per decade:	101
Start Frequency:	1e3
Stop Frequency:	1e7

- In order to get voltage in dB, in step 1 we set the AC amplitude to 2 V and then the maximum possible output amplitude for the circuit will be 1 V, corresponding to 0 dB.
 - After simulation, your output should appear as in Figure 7.4.
- To better see the resonance and Q, zoom in on the peak, for instance changing the start and stop frequency range to 100 kHz and 1 MHz. Use display information about the cursor location to fill in Table 7.1.

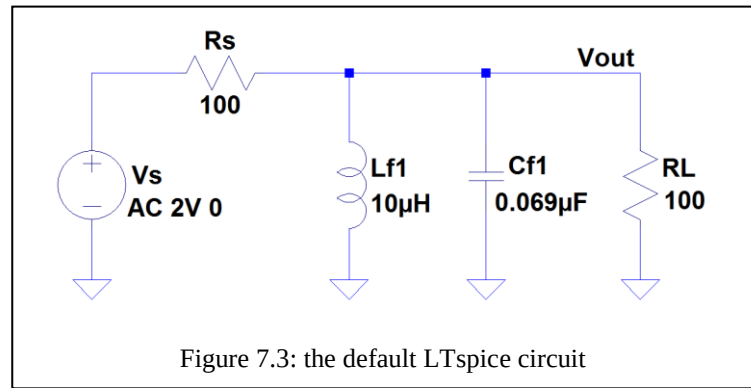


Figure 7.3: the default LTspice circuit

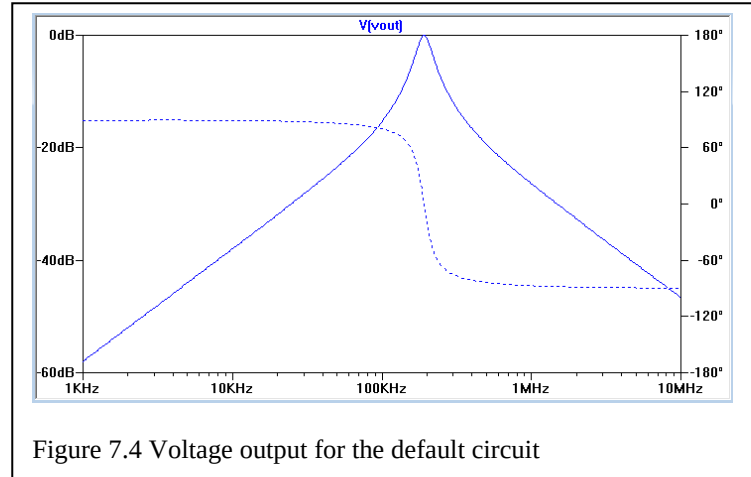


Figure 7.4 Voltage output for the default circuit

- Run another AC Sweep and collect the data for the case where $L_{f1} = 100 \mu\text{H}$, $C_{f1} = 0.0069 \mu\text{F}$, $R_L = 100 \Omega$ and $R_S = 100 \Omega$. Change the Start Frequency to 10 kHz for this simulation. Record the data in Table 7.1.
- Return to the default circuit. Change R_L and R_S to 10Ω and run an AC sweep to find data for Table 7.1. Repeat for R_L and R_S equal to $1 \text{ k}\Omega$. For these runs, adjust the simulation frequency as needed. How does Q vary with the changes in resistance?

Table 7.1 – LTspice AC sweep data

L_{f1}	10 μH	100 μH	10 μH	10 μH
C_{f1}	0.069 μF	0.0069 μF	0.069 μF	0.069 μF
R_L, R_S	100 Ω	100 Ω	10 Ω	1 $\text{k}\Omega$
f_{res}				
$\text{vdB}(@ f_{\text{res}})$				
$f_{(-3 \text{ dB, low})}$				
$f_{(-3 \text{ dB, high})}$				
BW				
$Q = f_{\text{res}}/\text{BW}$				

Table 7.2 – measurement data

L_{f1}	10 μH	10 μH		
C_{f1}	0.069 μF	0.069 μF		
R_L, R_S	100 Ω	1 k Ω		
f_{res}				
$f_{(-3 \text{ dB, low})}$				
$f_{(-3 \text{ dB, high})}$				
BW				
$Q = f_{\text{res}}/\text{BW}$				

7.1b Assemble the Circuit

1. Assemble the default circuit of Figure 7.3 ($L = 10 \mu\text{H}$, $C = 0.069 \mu\text{F}$, $R_L = 100 \Omega$ and $R_S = 100 \Omega$). Here you will use a parallel combination of capacitors, a 0.047 μF and a 0.022 μF , to achieve 0.069 μF .
2. Use the generator to provide a variable frequency input signal, and use the dual trace feature of your oscilloscope to observe the input and output signals simultaneously. Maintain constant amplitude on the input signal. Use Table 7.2 to assist your calculations and record your results for f_{res} and Q .

Comment: Rather than performing a manual sweep of frequency, a network analyzer may be used to automatically sweep frequency and can display an output similar to what is observed in Figures 7.2 and 7.4 (the output in this case is a transmission parameter, termed S_{21} , a topic beyond our present expertise). One limitation is that network analyzers typically have fixed 50 Ω impedance terminations, which would be the values of R_S and R_L .

3. Replace R_S and R_L with 1 k Ω . Find the new f_{res} and Q for Table 7.2.

7.2 Additional Filter Projects**7.2a Op Amp Filter**

A low pass filter can be realized using an Op Amp, and this can have the benefit of sharper rolloff and even amplification of the signal. Care must be taken to find a high speed Op Amp if the intent is to build a filter that will operate at RF frequencies. A good resource is Richard Jaeger's Microelectronics Circuit Design.

7.2b Chebyshev, Butterworth, T or pi filter

Filters using more than two elements can be constructed which will have sharper rolloff. T and pi filters have three elements. Chebyshev and Butterworth filters can have many elements.