Physics 4L Lab 7 (2026)

7.1 Subharmonic generation

Our experimental system is a series L-C-R circuit with a series diode. This leads to interesting behavior indeed. The circuit is driven by a sinusoidal oscillator. It is described by

$$L\, d^2Q/dt^2 + R\, dQ/dt + V_D = V_0\, sin(2\,\pi\, f\, t),$$

where V_D is the voltage across the diode with $V_D = (k_B T/e) \log[d(Q/I_0)/dt + 1]$ where I_0 is the reverse bias current. Under reverse bias voltage the p-n junction in the diode is swept free of charge and functions as a capacitor to pass an alternating current, with $C(V) \sim C_J(0)/\sqrt{(1-V_D/V_I)}$ where $C_J(0)$ is the junctional bias at zero voltage and V_I is the junction potential. Under forward bias the diode will conduct and functions as a resistor.

For our realization, we use a 1N4004 diode, with $C(0) \sim 20$ pF and $V_I = 0.6$ V. Each coil has a nominal inductance of 10 mH and a nominal resistance of 150 Ω, yielding L = 20 mH and R = 300 Ω. At low values of applied voltage, i.e., $V_0 << k_B T/e = 25$ mV, the system behaves like a resonant circuit. As V_0 is increased, C(V) decreases and the resonant frequency shifts upward.

It is not our intention to study the intractable non-linear differential equations for this system. Rather we will make measurements to study bifurcations to period doubling, tripling, etc.

Build the circuit (Figure 7.1) and record V_{in} and V_{out}.

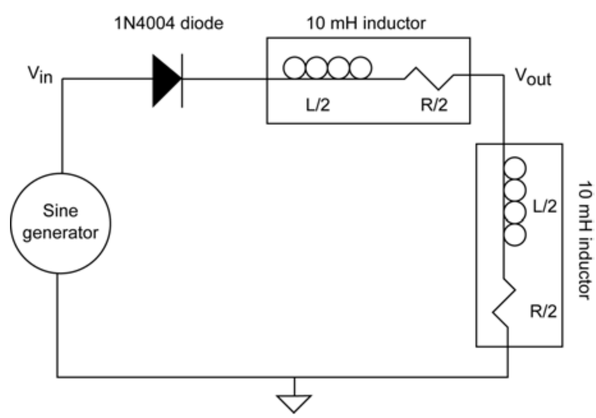


Figure 7.1. A circuit to generate subharmonics. Check that the sine generator is on "high impedance" output.

To shake out the basic circuit dynamics, use the "Acquire" function on the oscilloscope to shift the display of the oscilloscope between "X-Y", i.e., V_{out} versus V_{in}, and "X-T", i.e., the usual V_{in} versus time and V_{out} versus time. Set the frequency to about 1.15 f_0 and slowly ramp up the voltage.

Note 1: Transitions occur abruptly with changes in V_0 as small as a few milliVolts.

Note 2: You will need to adjust the gains on the channels as V_{in} changes; there is a lot of "back and forth" with controls on the oscilloscope with this exercise.

Q.1 Determine the resonance frequency, denoted f_0, for the circuit using $V_0 = 10$ mV; compare with $1/\sqrt{LC(0)}$. Take a SCREENSHOT to justify your answer.

Q.2 What is the expected phase-shift between V_{in} and V_{out} at resonance?

Switch to the use of the DAC board to record the data and analyze it in Matlab.

Q.3 Document the transitions to frequency doubling, tripling, quadrupling, and quintupling as "X-Y" and "X-T" plots. Figure 7.2 supplies examples from one experiment, but your details will differ.

Q.4 Take and report the power spectrum for the case of the lowest subharmonics that you can generate. Label all features.

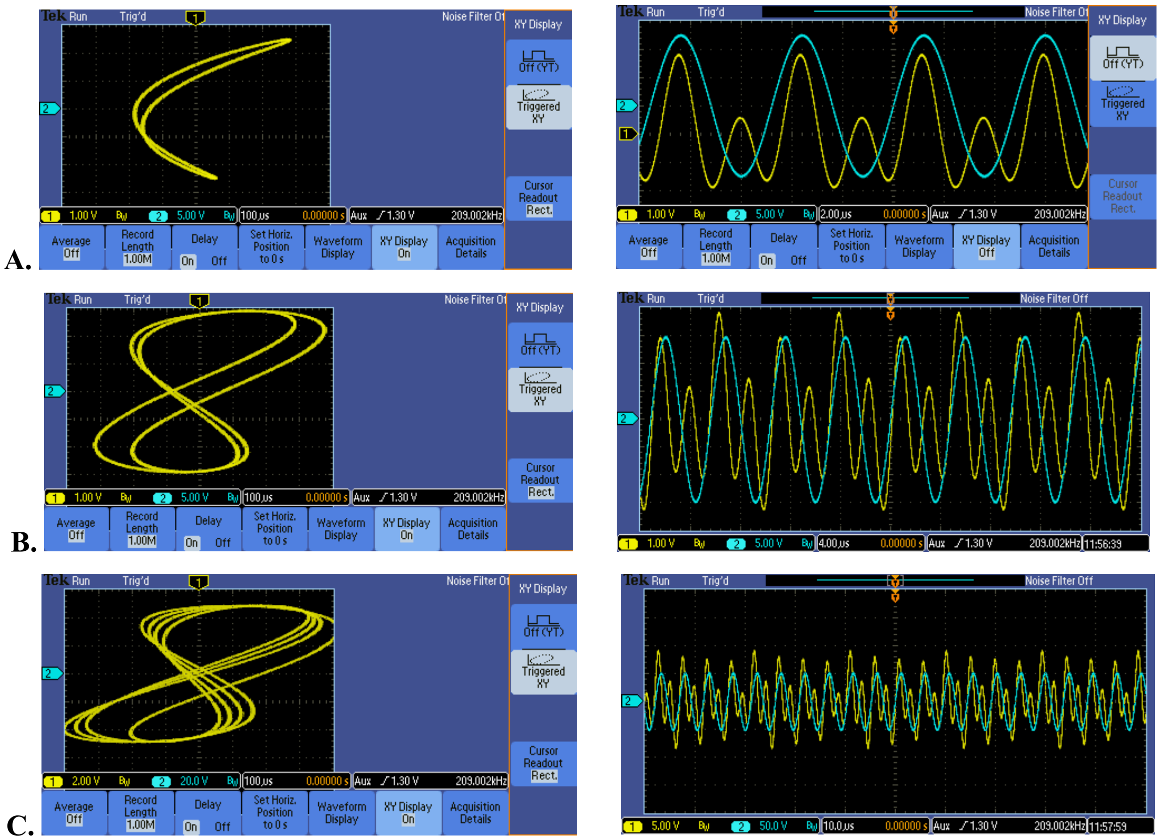


Figure 7.2. Examples of data for V_{in} and V_{out}, plotted as "X-Y" and "X-T" (blue trace is V_{in} and yellow trace is V_{out}) when the fundamental of V_{out} occurs at **(A)** f, **(B)** $f/2$, and **(C)** $f/4$. Resonance was at f_0 = 179 kHz. We used f = 208 kHz, and found V_0 = 2.50, 5.78, 9.70, and 14.93 V at the transitions to the 2^{nd} through 5^{th} subharmonics.

7.2 Spectral analysis of human voice

Hook an electret microphone to the input to the DAC (Figure 7.3). We are going to record your voice - speaking, singing, etc., and analyze the frequency content.

The electret sound sensor is capacitive; sound pressure varies the spacing (d) and thus capacitance (C) between two plates, the charge on the plates is held nearly constant, so the output voltage of the capacitor changes with sound pressure according to $V = Q/C$ so $\Delta V \propto \Delta d \propto \Delta(\text{pressure})$ for small deviations. It includes a FET buffer within the microphone package; think of the FET as an infinite resistance input to maintain the charge on the sound sensor. The FET's output current is converted to a voltage by the 2.2 kΩ pull-up resistor, so the output impedance of the microphone is just 2.2 kΩ.

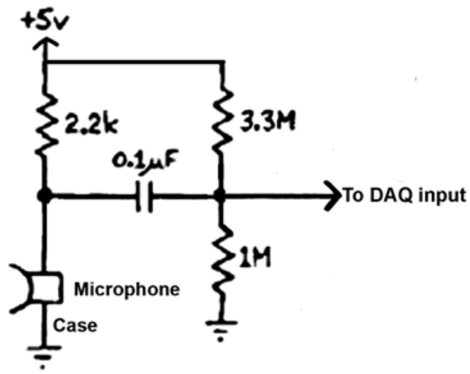
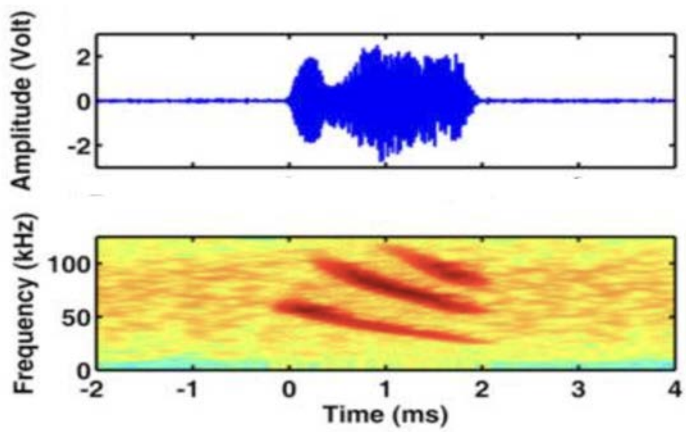


Figure 7.2: The microphone has a polarity; the case, connected to one of the pins with a tab, is grounded.

Record a clip of your voice, the time-series, using an acquisition rate of 50 kHz.

Q.4 Compute the spectrogram - the continuous short-time FFT - of the chirped phonemes "da", "Ba", and "Ga" recorded over a 5 s time-series Provide plots. What do you see?



Q.5 Provide 10 to 20 s plots of recordings of continuous speech and the associated spectrogram. What do you see?

Q.6 Compute the envelope of the previous recording, defined through a short-time root-mean-square estimate of the time -series - or choose to use a fancy, e.g., Hilbert transform, method. Then take the power of the spectrum, i.e., the second spectrum. What do you see?