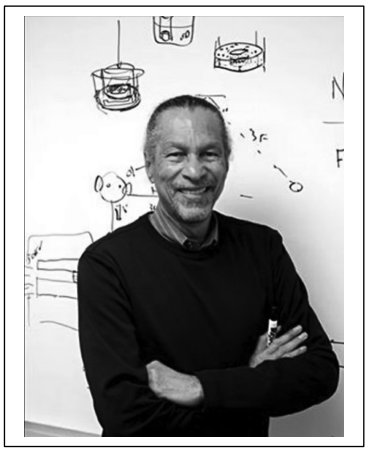
Physics 4L Lab 7 (2026)

We continue to gain expertise with data acquisition and analysis

7.1 Spectral analysis of human voice



Hook an electret microphone to the input to the DAC (Figure 7.1). We are going to record your voice - whistling, maybe singing - 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. The output current is converted to a voltage by the 2.2 kΩ pull-up resistor. the 0.1 μF capaciter acts with the input resistor R ~ 100 kΩ (smaller than the 1 MΩ input impednance of the oscilloscope probe or the DAQ) as a high-pass filter with $f = 1/(2\pi RC) \sim 20$ Hz, the lower limit of human hearing

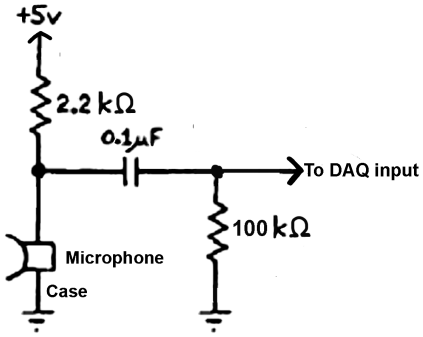
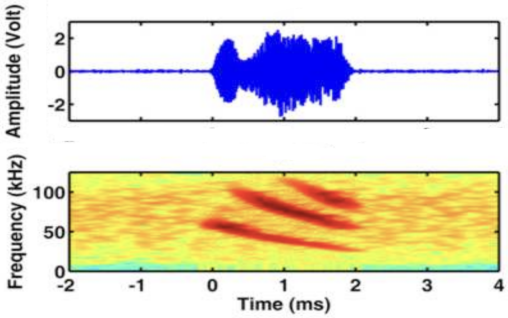


Figure 7.1: The microphone has a polarity; the case, connected to one of the pins with a tab, is grounded.

Test your set-up with the oscilloscope. Start with the most senstive gain setting. Record a clip of your whistling, or spesking or singing, the time-series, using the DAQ and a single channel acquisition rate of 200 kHz.

Q.1 Using MATLAB, compute the spectrogram - the continuous short-time Fourier Transform (STFT) - of a chirped whistle recorded over a 4 s time-series. Provide plots of the time series and the spectrogram. What do you see?



Record 20 individual, 5 s time series of recordings of the same chirped whistle - or song - by the same laboratory partner.

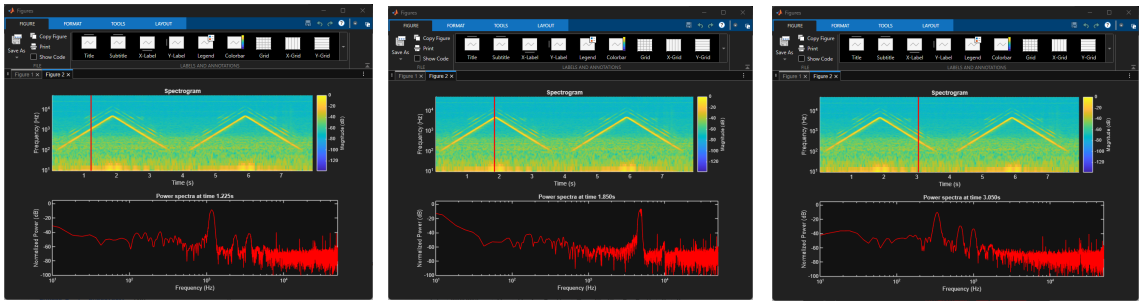
Q.2 Average all 20 of the time series together. Show a plot of one example and the average. What do you get? Why was this a bad idea in terms of learning about trial-to-trial variation?

Compute the spectral power of each of the previous 5 s time series of recordings of the same chirped whistle - or song. Inspect each trial to ensure that each has a complete record and redo any poor records. Compute the trial-averaged spectrum, S(f); be sure to average the individual spectra and *not* take the spectum of the average Fourier transform. Compute the standard deviation at each frequency, σ(f).

Q.3 Plot together, on log-log scales, S(f), S(f)+σ(f), and S(f)-σ(f). What do you get? Why is this a good idea in terms of learning about trial-to-trial variation?

Repeat the acquisition of the 20 individual, 5 s time series of recordings of the same chirped whistle - or song - by the second laboratory partner.

Q.4. Compute and plot together, as for Q.3, S(f), S(f)+σ(f), and S(f)-σ(f). What features are similar and what features are different between the two examples?



For a taste of nonlinear physics and a reminder that electrical circuits are more than linear differential equations (!), we consider the example of subharmonic generation, i.e., bifurcations to period doubling, tripling, etc.

7.2 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 15 mH and a nominal resistance of 30 Ω, yielding L = 30 mH and R = 60 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.

Build the circuit (Figure 7.2) and record V_{in} and V_{out}.

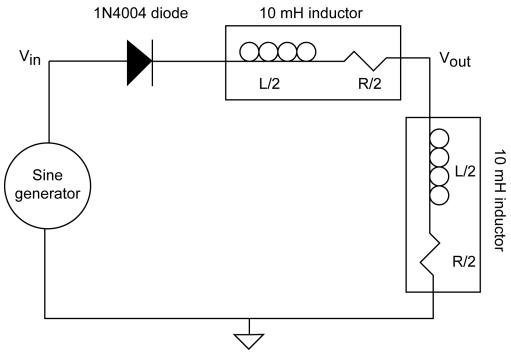


Figure 7.2. A circuit to generate subharmonics. Check that the sine generator is on "high impedance" output.

To shake out the basic circuit dynamics, use the "Acquire" function on the oscilloscope to shift the display between "X-Y", i.e., V_{out} (channel Y) versus V_{in} (Channel X) and "X-T", i.e., the usual V_{in} versus time and V_{out} versus time. Set the frequency to about 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.5 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.6 What is the expected phase-shift between V_{in} and V_{out} at resonance?

Q.7 Document, with SCREENSHOTS, the transitions to frequency doubling, tripling, quadrupling, and quintupling as "X-Y" and "X-T" plots.

Figure 7.3 supplies examples from one experiment, but your details will be difference.

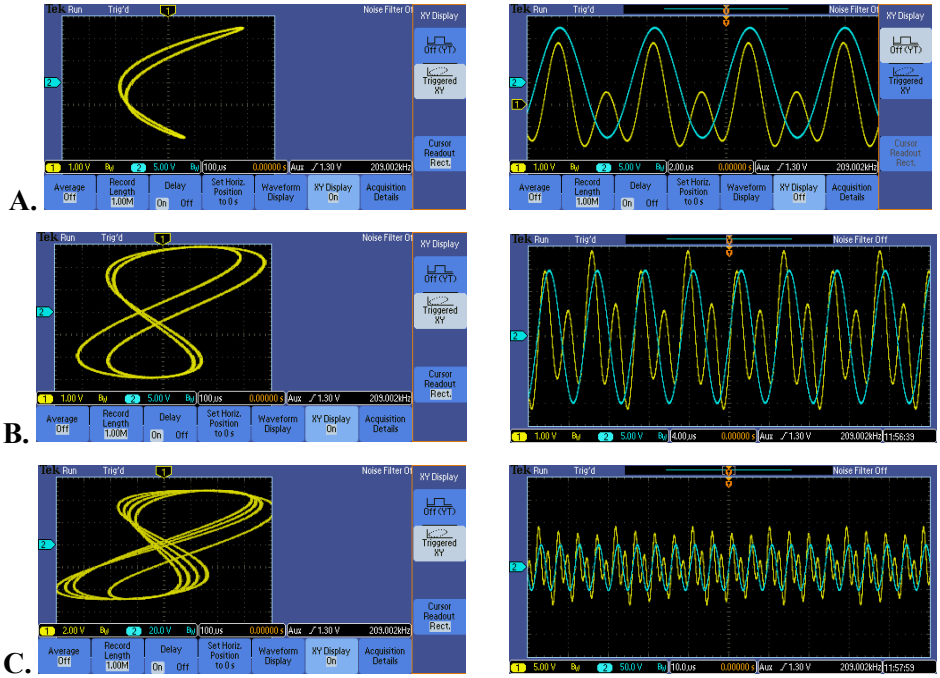


Figure 7.3. Examples of data for V_{in} and V_{out}, plotted as "X-Y" and "X-T" (blue trace is V_{in} and yellow trace is V_{out}) when the fundamental of V_{out} occurs at **(A)** f, **(B)** $f/2$, and **(C)** $f/4$. Resonance was at f_0 = 179 kHz. We used f = 208 kHz, and found V_0 = 2.50, 5.78, 9.70, and 14.93 V at the transitions to the 2nd through 5th subharmonics.