7. Spectra on the YorkU Space Station

In this lab you will apply your recent experience with the Frequency Domain and FFT and experience some new uses for resistors, capacitors, and inductors.

Pre-Lab Exercises

- Read through this manual
- Read the prelab document on Moodle

Equipment

- TBS-1052B digital oscilloscope with probes
- AFG-2005 function generator
- MS8265 digital multimeter with probes
- Prototyping board with wires
- Container of various resistors, capacitors, inductors
- Laptop computer
- BNC-BNC cables
- BNC Tee

7.1 Introduction

Space: the final frontier! You are an engineer on the future YorkU Space Station, and you are responsible for running scientific experiments. When you sent the results of the last experiment to Earth through the downlink transmitter, you were informed by the Earth-based scientific team that the data they received from the station were corrupted. After a Space Station crew brain-storming meeting, it was concluded that the data corruption was due to spurious electrical noise added into the data signals from two noise sources: high frequency noise from the communication downlink transmitter, and lower frequency noise from the power system. As the onboard engineer, you have been assigned the task to filter the noise and leave the data frequency untouched. To solve this problem, you will need to design two different filter circuits: one to reject low-frequency noise signals and another to reject high-frequency noise signals. But there are a limited number of parts on the Space Station to build such circuits. You only have enough parts to build four filter circuits. You'll need to study the characteristics of these four circuits to conclude which one can be used to filter the two types of interference in an optimal way (i.e., reject the most noise and leave your data signal untouched). This is your primary responsibility.

7.2 Filters

In order to remove the unwanted frequency components from the Space Station downlink signal, you will need to pass the signal through a circuit that filters (removes or attenuates) a specific range of frequencies. Filter design could be a course in itself, but here you will study two of the simplest filters: RC (resistor and capacitor) and RL (resistor and inductor). Let's begin with an RC circuit set up as shown in Fig. 7.1. The output signal voltage is the voltage across

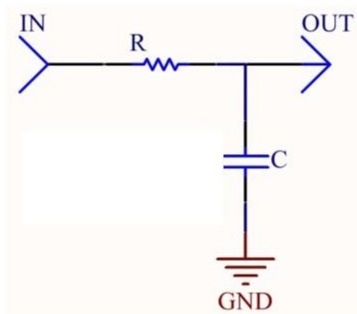

Figure 7.1: RC Low-pass filter

the capacitor. Remember that a capacitor generally blocks DC voltage, and its impedance decreases with increasing AC voltage frequency (such that it is nearly a short-circuit at very high frequencies). So, at low frequencies, the input voltage is blocked by the capacitor, and $V_{capacitor} = V_{input} = V_{output}$. However, as the frequency of the input signal increases, the capacitor acts as a short circuit and has no voltage across it. In this case, V_{output} is small (i.e., V_{input} has been filtered out).

If the placement of the resistor and capacitor were to change, as in Fig. 7.2, the output voltage is the voltage across the resistor. In this circuit, a low-frequency input signal would be blocked by the capacitor such that there would be a small output voltage (i.e., low frequencies are filtered out), but high-frequency input signals pass easily through the capacitor and the resistor such that $V_{resistor} = V_{output} = V_{input}$.

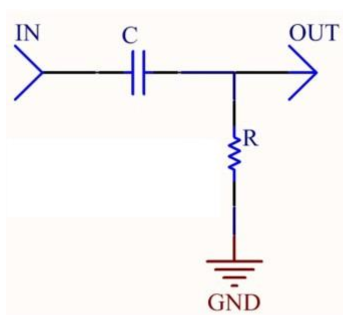

Figure 7.2: RC High-pass filter

Formally, the two circuit elements form a simple voltage divider, where the voltage is split between the capacitor and resistor, depending on their relative impedances (i.e., frequency- dependent resistances). The impedance Z_R of a resistor is just the resistance R . The impedance of a capacitor of capacitance C is $Z_C = {}^{1}/_{i\omega C}$, where $\omega = 2\pi f$ is the angular frequency.
Notice that for large frequencies, ω would be also be large and hence Z_c would be small.
Resistors and inductors together in a circuit can also act as a filter for similar reasons. The impedance of an inductor of inductance L is $Z_L = i\omega L$ and hence for large frequency, Z_L is also large.

7.3 Observing the Effect of the Filters (1.5 Hours)

You will perform these tasks individually, but feel free to discuss as a group. Remember what you learned last lab about the frequency domain.

- Start by setting a sine wave at 100 Hz of amplitude 2.0 V and view the FFT on the oscilloscope. Set a Frequency/Division of 250 Hz for the x-axis. Adjust the frequency of the sine wave in steps of 100 Hz. Collect FFT peak CH1 values dB/V for frequencies: 100, 200, 500, 1000, 2000 Hz. What happens to the height of the FFT peak as the frequency changes?
- The values for the components that you can find on the Space Station to build four filter circuits are generated by running the program: *\desktop\PHYS2211\LAB 7 Space Station Spectra\spectra param generator.exe*. Enter your Group number and Laptop number and run the program by clicking on the white arrow in the top tool bar. A set of four filter parameters (values of R1 and C1 or L1, R2 and C2 or L2, R3 and C3 or L3, R4 and C4 or L4) and configuration (RC, CR, LR, RL) will be chosen for you. Do not stop program and keep it on the Desktop. You will need it to input the measured values after next step.
- Include in your Journal a screen shot of this program after it has generated your values.
- The actual parts can be found in the cells of the parts box. Do not collect them on the desk! Take pair of parts for each filter and place it on the breadboard at position where you plan to assemble the filter circuit. Do not connect any wires. One pair in a time. Measure the resistors and capacitors using the multimeter. Assume the inductor values are as shown on the package (68, 100, 120 mH). Input the measured values on the right column of the spectra param generator program front panel. Press NEXT and wait when Excel file of parameters will appear on the Desktop. Include the table in your journal.
- On the prototyping board, set up the filters as shown in their accompanying configuration schematic. A BNC-Tee is attached to the output of the function generator and goes both to the oscilloscope CH1 and to the middle screw terminal on the prototyping board. A yellow wire attached to this terminal can be used as the input for the particular circuit you are testing.
- The ground connections are already pre-wired for you.
- To connect the output from the filter circuit to CH2 of the scope, the CH2 scope probe is pre-connected to the left terminal of the prototyping board. The associated red wire can be used to connect to the particular filter you are testing.
- Now it's time to measure the filter frequency response ($Gain = {V_{out}}/{V_{in}}$ versus frequency). While looking at the FFT of the filter output (CH2), you can see the spectra line power in dB/V units. It means that Gain in dB units can be expressed as: $Gain_{dB} = V_{out_{dB}} - V_{in_{dB}}$ where $V_{in_{dB}}$was measured at the first step from CH1. You can measure the $V_{out_{dB}}$value for different frequencies by adjusting the frequency of the signal. Make a so call "dry run" by fast changing frequency in the range between 100 Hz and 2500 Hz. What happens to the peak of the FFT as the frequency changes?

Group Discussion: The main characteristic point of the filter frequency response curve is the cutoff frequency where the Gain drops by 0.5 in power or $\sqrt{0.5} = 0.707$ in voltage or -3 dB in dB units. So, to evaluate how your filter is good to pass the scientific data and reject the noise you should find out its cutoff frequency. Discuss in which frequency range you can measure few points and in which one you need more points to catch curve parts of frequency response to measure the cutoff frequency. Do the same to select proper amplitude range and scale.

- •Create a table of FFT peak height (Vout_dB/V) vs input frequency, for frequencies 100 Hz and 2500 Hz
- Repeat for the three other filter types. All fours filters can be mounted on the protoboard at the same time.

7.4 Analyzing the Data (1 Hour)

Calculate the frequency response $Gain_{dB}(f)$Gain_dB (f) for each filter from your measurements. Plot all four responses on the same graph. Add clear legends to know which type of filter belong to which response. Plot -3 dB horizontal line which will cross all responses at cutoff frequencies. Determine cutoff frequencies for each filter and create table. Your scientific data in in the range of 400-700 Hz frequencies and pair of LPF and HPF will filter all frequencies below 400 Hz from solar array noise and above 700 Hz from downlink transmitter. Find out formula for the ideal LPF and HPF frequency responses and make separate plot for them in the same frequency range and proper cutoff frequencies. This is what you would design at the ground where any component values are available. Make vertical lines at these frequencies on your plot for filters you got on the space station. Analyze your plot to find out which pair of the filters permits to bypass the data. Make a table for each selected pair. You can select the pair with small losses (0 - -3dB). But if no one like this you can select pair with large losses in data frequency range with request to add amplifier of certain gain (put add_amp_gain value column in your table). To get the idea how effective your filter pair in filtering low and high frequency noise, measure the gain at double frequencies apart of data one: 200 Hz and 1400 Hz and add solar_array_filtering and downlink_transmitter_filtering columns. Conclude how far your filters from ideal one.

Lab Cleanup (15 Minutes) The space station Commander will be coming by your work area. If the equipment is not left neat, tidy, and organized, you will be sent out to scrub the outside of the station near the waste ejection port (i.e., your Report grade will be reduced by 2/20).

- Leaving all wires in place, remove the resistors, capacitors and inductors from the proto- board and place them back into the appropriate bins of your component box. The digital mulitimeter can help you confirm the values of the capacitors and resistors in case you are unsure.
- Please report to the TA (without penalty or shame) any missing/lost/broken components.
- Press *Default Setup* on the oscilloscope. Turn off the OUTPUT of the function generator, but leave all devices powered on.

7.5 Post-Lab Exercises (at home)

- Ensure the data tables and plot are nicely scaled and labelled.
- Add onto each plot a horizontal line that is 3 dB below the unfiltered peak height.
- Add onto each plot a vertical line that runs from the intersection of the data plot and horizontal 3 dB line down to the frequency axis.
- Determine which filter or combination of filter you should use to filter out the unwanted frequencies from the next downlink data transmission and explain why.

7.6 Appendix. Ideal filter frequency response.

All two element LPF and HPF can be considered as simple divider made from complex impedances Z1 (in series) and Z2 (in parallel). Then the complex divider voltage gain or frequency response is

$$Gain = \frac{Z2}{Z1 + Z2}$$

where Z formulas for resistor, capacitor and inductance are given in 7.2. We are interesting only the absolute voltage value at the filter output and not the phase, then:

$$|Gain| = \frac{|Z2|}{\sqrt{|Z1|^2 + |Z2|^2}}$$

This is the formula for ideal two component filter with ideal capacitor, inductance and resistor.