

## Experiment 8

### Final Project

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## ***Experiment 8***

### **Final Project**

Your final project is the culmination of your efforts to learn some analog electronics and provides you the opportunity to demonstrate your new-found talents by creating something fun of your own design. You will have about ten days to build, test, and refine your circuit before presenting it to the judges — the course instructor and TAs.

Your project grade will be based on your circuit's originality, how well it meets your design specification, and how well you understand its operation and limitations.

## PROJECT SCOPE AND SOME IDEAS

Your project's sophistication should be matched to how much you have come to understand the concepts of analog circuit design and testing: if you pick a project idea that is too simple for you, then you should expect a disappointing grade; if you pick a project that is too difficult, then you won't have enough time to complete it, and you won't have a good understanding of what is happening in the circuit to keep it from working the way you want. Your TA and the course instructor can work with you to decide on a project that you find interesting and that is suited to your current level of understanding.

You will construct the electronic circuit for your project on one or more solderless breadboards provided to you. The breadboard and its circuitry are yours to keep (except for some special components you may need to borrow from the lab). Identify any unique parts you will need for your project early so that the lab has time to acquire them for you — this is particularly important for any sensors, actuators, or special connectors you may want to use.

Sub-circuits of your project system may use designs you have found in books or on the internet, but they should generally involve mainly components and techniques to which you have been introduced as a part of your studies. In any case you must, however, thoroughly understand the design and operation of such circuits and, importantly, why the various resistors and capacitors in the circuit were assigned their particular values. You should always apply some customizations of your own design to the original circuit to complete your project.

You may design parts of your project using ICs which are more sophisticated than what you have studied during your course work, but they must not be *ASICs* (application-specific ICs) which require only a power supply and a speaker, for example, to complete the system. In any case, you must study the IC's data sheet and thoroughly understand what it does, its limitations, and how to use it.

Your circuit may not be connected to the building 120VAC power network unless you use a lab power supply or similar, approved, safe device. 9V batteries and their associated connectors will be available to use with your project, if you wish. Your circuit must not connect to a human or other animal body using a low-impedance contact.

You should not plan to design and build RF oscillators or amplifiers (frequencies over about 2MHz) because the solderless breadboards are not suitable for these high-frequency circuits. Antennas are generally difficult beasts to successfully tame, so make sure you thoroughly discuss your project and any antenna requirements with the course instructor.

### **Project ideas**

Here is a selection of possible project ideas arranged roughly in order of increasing complexity or conceptual difficulty. In all cases they should be constructed only from op-amps, bipolar transistors, and the other component types to which you have been introduced in lab (e.g. no voltage regulator ICs for the voltage converter projects).

#### **Fairly straightforward**

- Electronic stethoscope to amplify and listen to a heartbeat
- A “clapper” for an LED (“clap on... clap off...”)
- Phase-locked oscillator outputting twice the frequency of an input signal
- Touch or proximity sensor to turn an LED on and off
- A gated function generator to produce a repeating tone burst of its output
- A frequency to voltage converter (1V DC output for a 1kHz input frequency)
- A capacitance meter (1V DC output for a 100nF capacitor)
- A 4-quadrant analog divider: divide by negative voltages as well as positive

#### **Moderately challenging**

- Color organ: 3 filter channels with each channel’s LEDs’ intensities varying with sound level
- Generate a synthetic heartbeat waveform
- A dual, tracking voltage regulator producing regulated  $\pm 5V$  from two 9V batteries
- Intersection traffic lights (using red, yellow, green LEDs) with proper light sequencing
- FM signal demodulator using a phase-locked loop
- Send data or audio over an optical data link using an LED and a photodiode
- Metal detector
- A simple Theremin circuit (frequency control only), or include a volume control as well (harder)
- Temperature controller of the glass envelope of a small incandescent light bulb using the bulb filament as the heater and a thermistor as the temperature sensor
- Class-D power amplifier outputting 1W RMS into an 8 ohm speaker from a 5V power supply
- An envelope generator to take a tone burst and vary its attack and decay profiles
- Pulse-stretcher circuit using discrete transistors: 50ns, 5V input to a 10 $\mu$ s, 5V output

*Experiment 8: Project scope and some ideas*

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Plot any general 4<sup>th</sup>-order polynomial on an oscilloscope (using XY mode)

Generate 100V DC from a 9V battery

Diode temperature sensor with linear output of 2.5V for 25°C, etc.

Efficient Class AB transistor power amplifier for an op-amp output with no crossover distortion and over-current protection

*More sophisticated*

Generate  $\pm 12\text{V}$  DC from a single 9V battery

A simple op-amp constructed from discrete transistors (must be DC-coupled)

Add a sine-wave output to the function generator circuit of Experiment 4

Add voltage-controlled symmetry to the function generator circuit of Experiment 4

Chua's chaotic oscillator circuit showing its behavior on an oscilloscope

Analog computer: plot projectile trajectory on an oscilloscope (using XY mode) given initial velocity

Analog computer: Lorenz attractor showing chaotic behavior on an oscilloscope

A PID control loop to maintain the balance of an inverted pendulum

## DEVELOPING THE SYSTEM DESIGN

In this section we work through an example project and its development phases, from initial specification to final, detailed schematics. First, start with a short description of the project. For this example:

*Design a preamplifier for a phonograph cartridge magnetic pickup that includes the proper RIAA frequency response and which has bass and treble tone controls as well.*

From this start, we expand and develop the project idea step by step. First, a more detailed specification of the circuit is required...

### Detailed specification

Starting from the rough project description statement, outline the actual requirements and scope of the project, as was done for the mini-project tasks in [Experiment 7](#). By specifying the actual, detailed purpose of the project and defining its scope, you have something which can serve to focus your effort.

This specification will be the reference against which the level of success of your project will be measured.

For our example phono preamplifier project, we choose to meet the following specifications:

Phono sensor nominal output voltage:	3mV RMS at 1kHz
Preamplifier nominal output voltage:	0.1V RMS at 1kHz
Preamplifier peak output voltage:	10 V peak-peak into a 10k $\Omega$ load
Preamplifier output frequency response:	-3dB 10Hz-30kHz
Tone control boost and cut:	$\pm$ 10dB boost and cut (minimum)
Tone control 3dB corner frequencies:	300Hz (bass), 1.5kHz (treble)
Input impedance:	47k $\Omega$

RIAA equalization (frequency response):  
Poles at 50Hz and 2122Hz; zero at 500Hz

Power supply:  $\pm$ 12V

### System block diagram

With the detailed specification in hand, next sketch out a system block diagram showing the major sub-circuits, how they will be interconnected, and how the signal is modified as it flows through each sub-circuit. You may later decide that you need to change this block diagram as you learn more about the design problems your project entails, but at least you'll have an initial plan from which to deviate! You should go over this block diagram and your

## Experiment 8: Developing the system design

specifications thoroughly with your TA; once this review is finished both you and your TA should be reasonably satisfied that your final project is appropriate for your skill level and that you can successfully complete it on time.

For the example phono preamplifier project, the system block diagram is quite simple (Figure 8-1); for some projects it might be quite complicated.

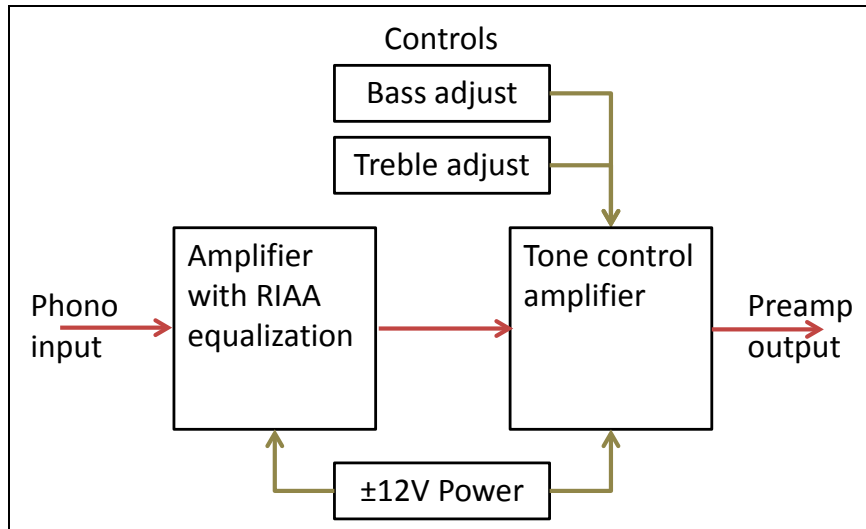


Figure 8-1: A system block diagram for the phono preamp example project.

### Sub-circuit specifications

Using the system block diagram, you then define the detailed specifications of each sub-circuit by describing what its inputs and outputs are and how the signals there are related to each other: for a linear stage, what are its input and output impedance limits and what is its transfer function; for a nonlinear stage, what are its various operating states, what are the inputs required to cause various state transitions, and what are the outputs associated with each state. The required frequency response and/or state transition speed for each sub-circuit should also be determined, as well as its minimum and maximum signal voltage and current requirements.

Identify those blocks or sub-circuits which are likely to give you the most trouble, either because you are unsure how to design a circuit to perform that subtask, or because it involves the use of components with which you are unfamiliar. Make sure that you plan your development and testing schedule to include extra time to figure out and thoroughly test those parts of the project. If necessary, develop a fallback option in case you can't get some section of the project to perform as well as you would like.

Identify the ICs and other more complicated components that may be needed for each sub-circuit. Find and download the manufacturers' *data sheets* for these components and thoroughly read them to make sure that they will meet the requirements of your design. If



necessary, go over the data sheets with the course instructor to make sure you understand the many very technical specifications included in them.

When choosing an unfamiliar IC for your project make sure that it is really suitable!  
In particular, check that:

1. The IC's power supply voltages are compatible with your design.
2. It comes in a package that you can actually make connections to.
3. It is neither too fast (and therefore difficult to keep stable) nor too slow for your application.

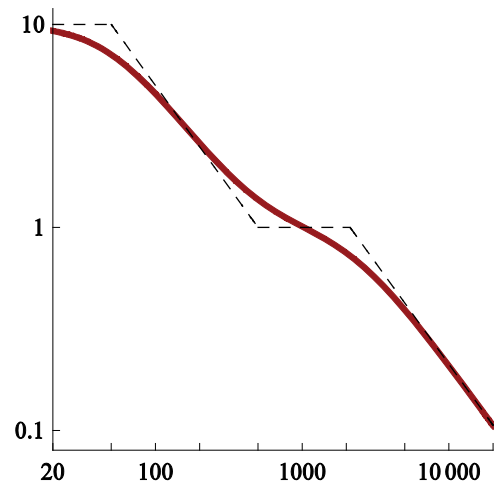
Here are sets of specifications for each of the two amplifier blocks for the example project:

**b) Example: amplifier sub-circuit with RIAA equalization:**

- i) Gain at 1kHz:  $G_0 = 33$
- ii) Input impedance:  $47\text{k}\Omega$
- iii) RIAA equalization gain function and Bode plot:

**Figure 8-2: Gain function and Bode magnitude plot of the RIAA equalization gain plot normalized to 1 at mid frequencies (near 1kHz). The asymptotic response is shown as a dashed line. The first-order corner frequencies are at 50Hz, 500Hz, and 2120Hz.**

$$G(f) = G_0 \frac{(1 + j f / 500\text{Hz}) \times (500\text{Hz} / 50\text{Hz})}{(1 + j f / 50\text{Hz}) \times (1 + j f / 2120\text{Hz})}$$



- iv) Frequency response modifications to the RIAA curve: first-order roll-off at low frequencies with  $-3\text{dB}$  corner at  $10\text{Hz}$ .

**c) Example: tone control amplifier sub-circuit:**

- i) Gain with tone controls centered (no boost or cut): 1
- ii) Frequency response with tone controls centered ( $-3\text{dB}$  corners):  $10\text{Hz}$ ,  $50\text{kHz}$

- iii) Nominal target max boost and cut response curves (note that we target  $\pm 20\text{dB}$  in order to have some leeway to achieve the  $\pm 10\text{dB}$  system specification):

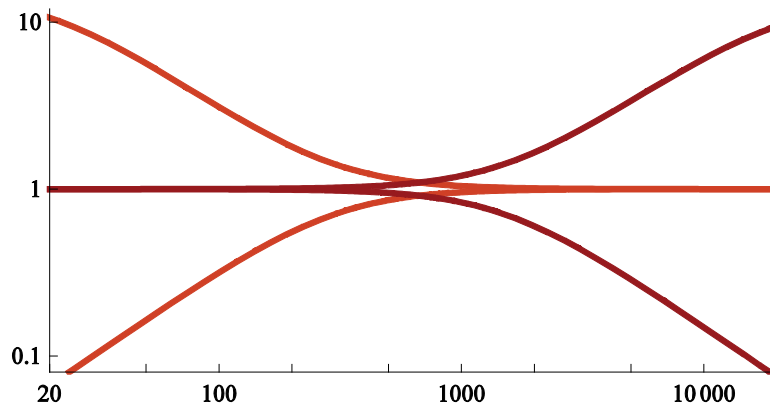


Figure 8-3: Target tone control amplifier gain response at max boost and cut for both bass and treble controls.  $\pm 3\text{dB}$  corners are  $300\text{Hz}$  (bass) and  $1.5\text{kHz}$  (treble).

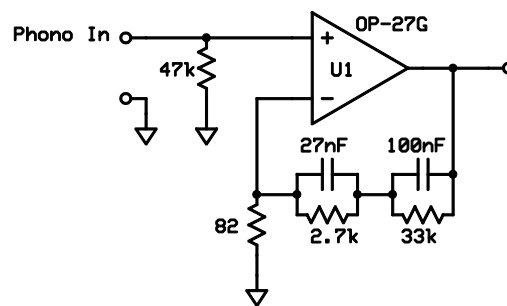
### Detailed sub-circuit schematics

Now you can generate an initial schematic diagram for each sub-circuit and begin to determine its component values.

In some cases you may have to *prototype* a sub-circuit: assemble a preliminary version and check its performance against its specifications in order to finalize its design and determine all of its component values. This effort overlaps that of the next section: *construction and testing*, but it is vital for the success of your project that you use prototyping early on any complicated or subtle section of the design so that you can learn how to make that part work properly!

Continuing our example project, an initial schematic for the RIAA preamplifier sub-circuit is shown in Figure 8-4. The op-amp and one of the capacitor values are both unusual, so a list containing these components must be submitted for parts ordering.

Figure 8-4: Initial schematic for the input amplifier with RIAA equalization sub-circuit. The OP27GP op-amp is a low-noise, high-gain, precision unit particularly suited for this application. It and the  $27\text{nF}$  capacitor may not be available in the lab, so these parts will need to be ordered.



### ***Sensors and actuators***

Many projects require some sort of sensor (such as a microphone) which should be mounted separately from the circuit breadboard. You will need to fashion some sort of cabling and connectors to attach such sensors to the circuit. Get advice and assistance from your TA and the course instructor with this problem. You will probably need to solder some of the connections; the course instructor can show you how to properly solder wires and connectors. Similar issues arise with output actuators such as loudspeakers.

Make sure that you obtain the data sheet or other instructions for properly connecting and using sensors, actuators, or input-output devices; many are easily and permanently damaged if incorrectly connected into a circuit.

### ***Construction and testing***

Once you are fairly confident that your sub-circuit designs are successful, start building up the final, complete circuit by connecting sub-circuits together. If you have many sub-circuits, don't assemble the complete project circuit at first, but start by connecting up independent subsets of the project and determining whether they successfully perform their parts of the overall project task.

You may find that connecting together two sub-circuits substantially degrades the performance of one or the other, possibly because their input and output impedances or signal levels aren't compatible. Adding a voltage follower, voltage divider, or amplifier between them may correct the problem. Maybe the signs of the signals are incompatible; maybe one signal has a DC offset which is too large for a sub-circuit to handle. Recheck your sub-circuit design specifications and try to understand how this interfacing problem arose.

In some cases you may decide that you have misidentified the correct division of your project into sub-circuits, and some part of the system requires a redesign. Make sure you have allotted enough time for this construction and testing phase!

### **PRELAB EXERCISES**

1. Finalize your project's circuit specification.
2. Develop a detailed system block diagram of the signal flow through your circuit and the operation on the signal each sub-circuit must perform. The sub-circuit breakdown should be at the level of individual op-amps or IC functions.
3. Develop a fairly complete schematic diagram of each of your sub-circuits. Label each sub-circuit's inputs and outputs and describe how they will be connected to the other sub-circuits. Present an initial, complete parts list for your circuit, especially of the required ICs, input-output devices, and other components not available in the lab.

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### **LAB PROCEDURE**

Construct and test the circuit you've designed to satisfy the requirements of your chosen project. As was discussed previously, you should build, test, analyze, and fix each sub-circuit independently before connecting various sub-circuits into sub-systems. These sub-systems should in turn be fully tested and working before being connected to complete the final project system. Following this bottom-up assembly and test procedure will improve your chances of success.

Double and triple check the pin number assignments shown on the IC data sheets, especially for the power supply and ground connections. Make sure that any unfamiliar ICs you use are rated for the power supply voltages before you install them!

Practice good component layout techniques when you assemble circuits on your breadboard: add IC pin numbers to your schematic so that you can quickly add components and check your connections; identify the rails you'll use for power supply voltages and ground; determine the most effective positioning of the ICs on the breadboard so that the wiring and component placement will be clean and easy to check; make the power supply and ground connections to each IC before installing other components.

Once the project is working, make sure you collect the data you need to fully document its performance: frequency response sweeps and oscilloscope screen captures, for example. This data will back up your demonstration of the circuit when you present your project.

Double check and update your circuit schematics to reflect the final component values and circuit topology you use during the final presentation.

## **PROJECT PRESENTATION**

Your final project will be demonstrated in the lab to a committee consisting of the course TAs and the lab administrator. At the presentation you must submit the following project documents in support of it:

1. The final detailed specification of the project
2. A comprehensive system block diagram identifying all sub-circuits and their various purposes
3. A complete circuit schematic identifying all component values
4. Data (frequency response plots, o-scope screen shots, etc.) demonstrating that the circuit meets the project specification

You will set up your project circuit at one of the lab stations; you may use the analog trainer power supply, the signal generator, and the oscilloscope, if necessary, to provide a live demonstration of your system.