Physics 120 Lab 9: Negative and Positive Feedback

We begin with a project that combines our previous experiences with both op-amps and transistors, and build a circuit (much like those in audio amplifiers and motor controllers) that can drive significant current. We use this to demonstrate the importance of feedback across the entire circuit, as opposed to just the op-amp sub-circuit.

9.1 Push-pull amplifier and system-wide negative feedback

![PNP and NPN transistors](image)

**Figure 9.1**: NPN and PNP transistors span positive and negative $V_{CE}$, except for $|V_{CE}| < |V_{CE}(sat)|$.

(a) *Op-amp feedback only*

![Amplifier with push-pull buffer](image)

**Figure 9.2**: Amplifier with push-pull buffer

Build the circuit shown above (and make sure to power the LM411 with $\pm 15$V). Drive it first with a sine wave of 100 - 500 Hz ($V_m$). Use scope probes to simultaneously look at the output of the op-amp (point "A") and the output of the push-pull stage ($V_{out}$); make sure you have at least a few volts of output and that the function generator is set for zero DC offset. You should see classic crossover distortion; highlight this on SCREENSHOTS with different output amplitudes.

*Listen* to this waveform on a small speaker. But before you drive the speaker you should determine the maximum safe amplitude, given the following power ratings:

- transistors: 350 mW
- speaker: 250 mW

(b) *With system-wide feedback*

Now reconnect the right side of the 100 kΩ feedback resistor across the full amplifier, *i.e.*, to $V_{out}$ rather than the output the op-amp ("A"), and once again look at the push-pull output. The crossover distortion should be almost eliminated. What should the signal at the output of the op-amp look like? What does it look like? Document your observations with SCREENSHOTS.
Try listening with the speaker again. Better?

(c) With system-wide feedback and feed-through connectivity

The near complete elimination of crossover distortion makes use of a linear feed-through so that the op-amp can directly drive the load when the currents required are very small. Add the 100 Ω resistor as shown below. Is the distortion gone? Document your observation with a SCREENSHOT.

![Figure 9.3: Amplifier with system-wide feedback across push-pull buffer and feed-through resistor](image)

Hook up the output of the modulation circuit that you built for exercise 6.2 - hopefully saved and still operative! - as the input to the push-pull amplifier with full feedback (9.1b). Does the 10 kΩ input resistance of the push-pull amplifier load the output of the modulator circuit? By how much? Document the output with a SCREENSHOT. For fun, try to make your combined device sound like a few bars from the late Keith Emerson (shown below, in his musical prime, with a Moog synthesizer); be careful, too high a gain and you will blow out the transistors and/or the speaker!

![Keith Emerson](image)

9.2 Three Comparators and positive feedback

Comparators work best with positive feedback. But before we show you these good circuits, let’s look at two poor comparator circuits: one using an op amp, the other using a special-purpose comparator chip. These circuits will perform poorly; they will help you to see what’s good about the improved comparator that does use positive feedback.
(a) Open-loop Op Amp as Comparator

You will recognize this as the very first op amp circuit you wired (Lab 4.1), where the point was to highlight the high gain of the device. In that exercise the excessive gain was factored out of the circuit equations and the input/output was linear. Here we view the circuit as a comparator and the very high gain and the “pinned” output are desired.

Drive the circuit with a sine wave with a 100 mV (or less) amplitude at around 100 Hz and notice that the output is close to a "square wave"; document with a SCREENSHOT. Now drive the circuit at 100 kHz, and document with a SCREENSHOT that the “square wave” output is not as square as it was for 100 Hz. Why not?

(b) Special-Purpose Comparator IC

Now substitute a 311 comparator for the 411; the pin-outs are not the same. You will notice that the output stage looks funny: it is not like an op amp’s, which is always a push-pull; instead, two pins are brought out, and these are connected to the collector (pin 7) and emitter (pin 1) of the output transistor, respectively. These pins let the user determine both the top and bottom of the output swing (e.g., one can use +5 V and ground to make the output compatible with standard digital logic).

Here, you will keep the top of the swing at +15 V and set the bottom of the swing to ground. Does the 311 perform better than the 411? How so? Document the improvement in gain(s) with a SCREENSHOT.

A side-effect of the 311’s fast response is its readiness to oscillate when given a small and/or voltage difference between its inputs. Tease your 311 into oscillating near the transition using a sine wave with a gentle slope. You may need to use the "expansion settings" of the oscilloscope. Document your output with a SCREENSHOT that shows rapid transitions near the threshold.
(c) Special-Purpose Comparator IC configured with positive feedback as a Schmitt Trigger

The positive feedback used in the circuit above provides hysteresis that will eliminate the harmful oscillations by shifting the threshold immediately after a transition. Predict the thresholds of the circuit above (see class handout as a guide but derive the expression for this simplified case); they try it out and document your a functioning circuit with a SCREENSHOT.

Notice that triggering stops for sine waves smaller than some critical amplitude. Explain this. Measure and report the hysteresis. Observe the rapid transitions at the output, independent of the input waveform or frequency. Look at both the "-" and "+" comparator terminals and document with a SCREENSHOT of the V. and V+ inputs and the output.

Reconnect the so-called “Ground” pin of the 311 to -15 V; this pin is not necessarily ground, rather it is the emitter of the output transistor. Perhaps you can now see why the chip’s designers brought out this pin, as well as why they provided an open-collector output.

9.3 RC Oscillator

A comparator is used with positive feedback to construct a free-running oscillator. Build the above circuit and show, with a SCREENSHOT, that \( V_{out} \) oscillates. What are the expected and measured frequencies (see, e.g., class notes)? Record from both the output and point "X" and explain, documenting with a SCREENSHOT, what you see. Repeat, including SCREENSHOT, with the 10 kΩ resistor replaced with 1 MΩ.
9-4 **7555 IC Oscillator (square wave)**

The 555 and its derivatives have made the design of moderate-frequency oscillators easy through the use of a monolith device. The 7555 runs up to 500 kHz and its very high input impedances and rail-to-rail output swings can simplify designs.

![7555 relaxation oscillator](image)

**Figure 9.8:** 7555 relaxation oscillator.

Connect a 7555 in the classic relaxation oscillator configuration, as shown above. Look at the output and document with a SCREENSHOT. The frequency is given by:

\[
    f_{\text{oscillation}} = \frac{1.4}{(R_A + 2R_B)C}
\]

Look at the waveform on the capacitor (C). What voltage levels does it run between? Document with a SCREENSHOT. Does this make sense?

Replace \( R_B \) with a short circuit. What do you expect to see at the capacitor? At the output? Document your conclusions with SCREENSHOTS.