Physics 3150, Laboratory 6
FETs and OpAmp basics
February 29 and March 2, 2016

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Last revised 2/25/2016 by Ed Eyler

Purpose:

1. To understand the basics of field-effect transistors both in their linear and saturated regimes.
2. To construct a simple inverting amplifier using an FET-based operational amplifier.

References:

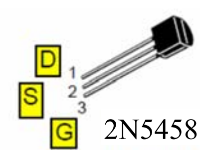
Chapter 5 and Sections 6.1-6.3 of Eggleston. For additional material see Chapter 3 and Sections 4.1-4.2 of Horowitz and Hill, or Sections 5.4 and 6.1–6.3 of Meyer.

Equipment:

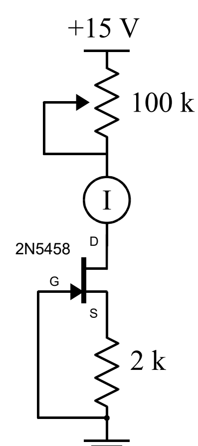
The usual stuff, plus:

1. 2N5458 JFETs (these are n-channel depletion mode junction FETs). A data sheet is available on the course web page.
2. 100 kΩ trimmer potentiometers.
3. LF411 operational amplifiers.
4. Two signal generators (one can be the built-in function generator on a breadboard).
5. A radio.

I. FET current source



1) Build this current source, which operates with V_{DS} in saturation. Vary the resistor and watch the current into the drain, I_D. Measure V_{DS} and I_D for a number of different settings of the 100 k variable resistor.
2) Find the resistance for which the current starts to drop and measure V_{DS} at that point.

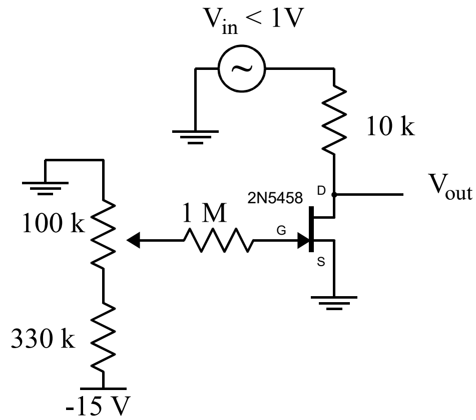


Questions:

1) Plot I_D vs. V_{DS}.
2) The value of V_{DS} at which the current starts to drop markedly is the dividing point between the saturated regime and the linear region of operation. This boundary should occur when V_{DS} is close to $V_{GS}–V_P$, where V_P is the "pinchoff" or "threshold" voltage. Based on this, what is your transistor's V_P? There is huge variability: the specification sheet guarantees only that it is in the range $–7\text{ V} < V_P < –1\text{ V}$.

II. FET as an electronically variable resistor

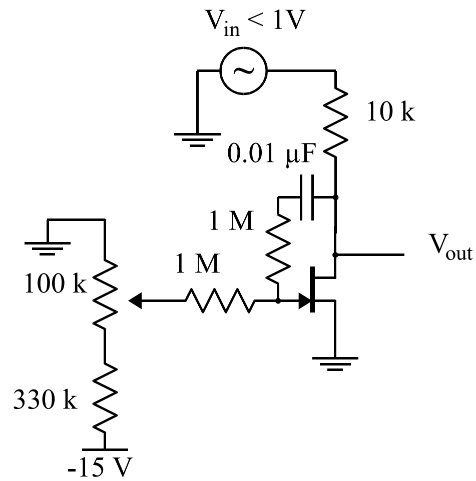
A. Adjustable voltage divider



When V_{DS} is saturated, the FET acts as a current source. However, when V_{DS} is small, I_D becomes proportional to V_{DS} and the FET acts like a resistor, with an effective resistance controlled by V_{GS}. Here, we make a voltage divider with a 10 kΩ resistor and the FET.

1) Apply a 1 kHz triangle wave with $V_{p\text{-}p} \sim 0.3$ V and monitor the output. From the ratio of the output to the input, calculate the FET resistance for several different values of V_{GS}.
2) How well does the output follow a triangle wave? Is there any distortion? (Hint: first set the potentiometer for maximum gain, then watch the output waveform as you reduce the amplitude.)

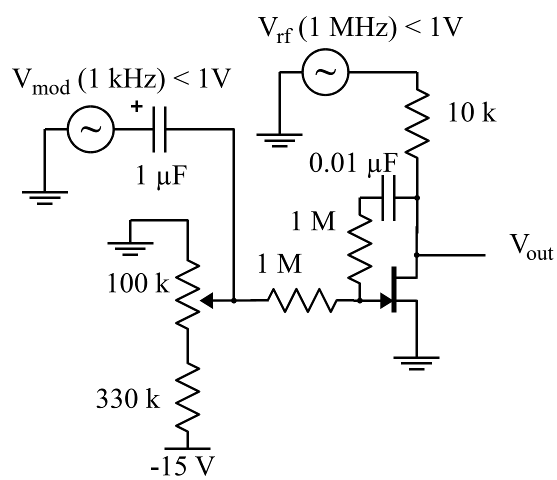
B. Compensated attenuator.



Add a resistor and capacitor to the circuit, as shown at the right. How does this improve the output? For an account of how this works, see Section 3.2.7 of Horowitz and Hill.

C. Amplitude Modulator (AM Radio)

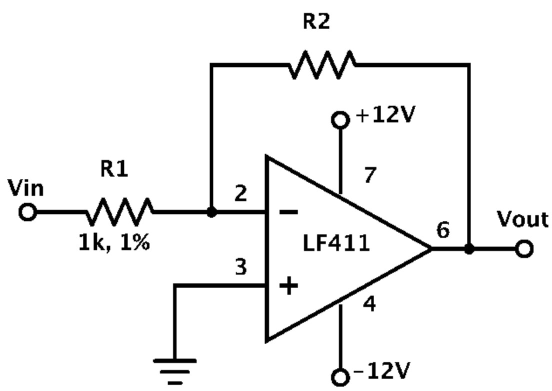
The circuit above can be used as a modulator. In this version, you will drive the input at a high (radio) frequency. Then, by adding a modulation signal with a capacitor, you have an amplitude modulator – the principle behind AM radio transmission.

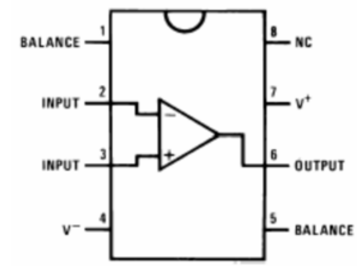


1) Make the necessary modifications to obtain the circuit at the right.
2) First, look at V_{out} on the oscilloscope. There are two very different timescales. If you look on a fast setting, you can see the 1 MHz rf oscillation, the *carrier*. If you look on a slow setting, you will see the audio frequency envelope.
3) Once this looks good, attach a long (1 m) piece of wire to V_{out} and place an AM radio near it. Tune the radio to a region near 1 MHz where there is no broadcast signal. Then, tune the 1 MHz function generator around this frequency until you pick something up on the radio. To verify that you are really hearing your own transmission, vary the audio frequency.

III. Inverting amplifier with an Op Amp

In an operational amplifier (op amp), most of the imperfections of single-transistor amplifiers are overcome by building a multi-stage amplifier into a single integrated circuit chip. Construct an inverting amplifier using an FET-based LF411 op amp as shown in the figure below. Quite often the power pins (in this case pins 4 and 7) are not shown on schematic drawings, so you need to remember to connect them. The op amp will work equally well with ±12 V or ±15 V supplies, so long as you remember that the output swing will be altered correspondingly. Note that pins 1 and 5 (Bal) are not used for this circuit.





1) Use R_1 = 1 kΩ, using a 1% resistor for added accuracy. Choose R_2 to provide a voltage gain of –10, noting that the expected gain is $G = V_{out}/V_{in} = -R_2/R_1$. Measure the gain for several dc input voltage levels. To obtain a variable dc level, you can use the offset voltage from a signal generator with its signal amplitude set as small as possible.

2) Now change R_2 to set the gain to about 100. Does the output behave as expected? At what input and output voltages does the op amp "saturate" to a level that does not increase further?

3) What determines the input impedance of this circuit? (Note that $Z_{in} = V_{in}/I_{in}$, and that the op amp acts to maintain terminal 2 at the same potential as terminal 3.) Confirm your prediction either by adding a 1 kΩ resistor in series with the input, or by measuring the input current through R_1, either directly or indirectly. By the way, the output impedence Z_{out} is too small to measure, so there's no real point in trying.

4) Set the gain back to 10 and apply a SMALL sine wave to the input. Determine the frequency at which the output amplitude drops by a factor of $\sqrt{2}$ relative to its predicted value. What is the approximate phase shift at this 3-dB frequency? Be sure to measure both the input and output voltages, since the signal generator may not produce a constant amplitude as its frequency is adjusted. Is the phase shift similar to that expected of a simple "single-pole" RC low-pass filter (this need not necessarily be the case)?