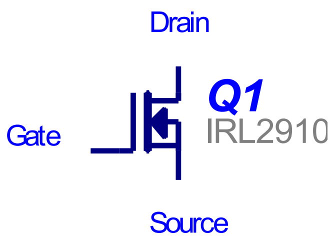
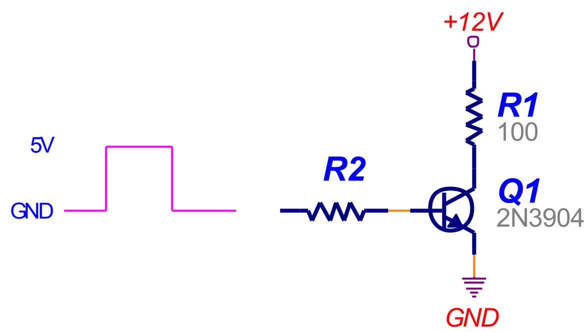
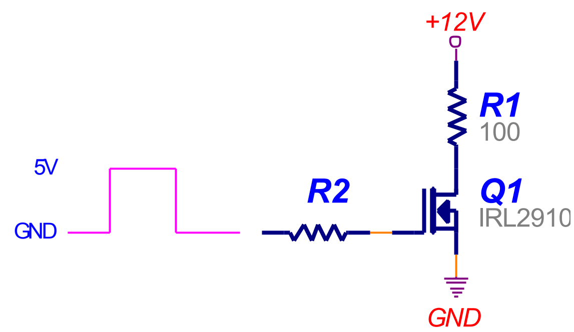
Field Effect Transistors:



FETs (Field Effect Transistors) are similar to the BJTs (Bipolar Junction Transistors) you've used except the output current is controlled by the gate voltage instead of the base current. For this n-channel FET when the gate voltage is high (compared to the source voltage) the resistance between the drain and source decreases allowing current to flow from the drain to the source. The example below shows two similar circuits (one BJT one FET).





When 5V is applied to the gate of the FET it turns on and allows current to flow from the drain to the source. When the gate is at 0V the FET is off (high resistance) and only a small leakage current flows.

Designing with FETs (refer to the IRL2910 datasheet):
http://www.irf.com/product-info/datasheets/data/irl2910.pdf

What gate voltage to you need:
The higher the gate voltage the lower the on-resistance of the FET (at least until the minimum on-resistance is reached). The gate voltage needs to be high enough so that when the FET is switched on the voltage drop across the FET is small compared to the voltage across the load (i.e. it's acting as a switch and not an amplifier). In the datasheet Fig 1 shows the drain-source voltage for different gate voltages and drain currents. Ex: With a gate voltage of 2.5V (lowest curve) the max current is about 2.5A independent of how large the drain source voltage becomes. But, with a gate voltage of 4V the graph is linear until the current reaches 60-70A. Below this current the FET acts like a small resistor (at 4.5A there would be about a 0.1V drop across the switch, at 8.5A, about 0.2V). Note: This is equivalent to a resistance of $R=V/I = 0.2V/8.5A = 0.024\ \Omega$. Raising the gate voltage from 4V to 15V only decreases the on resistance slightly. Note: This FET was chosen because it turns on with a low gate voltage. Many power FETs require 10-15V to turn on fully.

How long will it take to turn on or off:
Once the FET is switched on or off the gate doesn't draw any current (well, almost no current). But switching on or off requires a surge of current to charge or discharge input capacitance. In this case the input capacitance is 3.7nF (see page 2 of the datasheet). If the gate resistor, R2, was 1K and we assume about 5 RC time constants to reach the final voltage it would take about $5*R*C = 5 * 1000\ \Omega * 3.7nF = 18.5us$. It will switch quicker but this is a reasonable estimate. 18us isn't a long time if you're controlling a relay once a second but if you plan to switch on & off a heater 10,000 times a second than you'll need to get more current in & out off the gate faster. Gate driver ICs can provide over 1A of current for a short time to switch the FET in less than 200ns (see the rise/fall times and on/off delay in

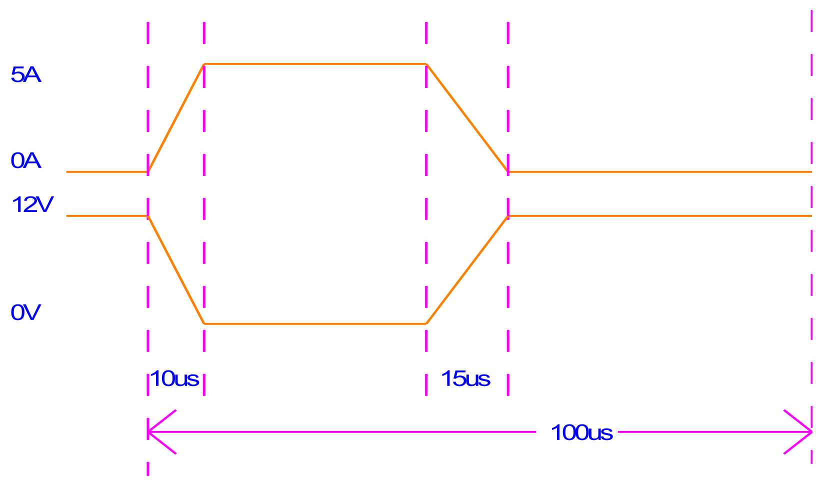
the datasheet for the fastest possible switching times for a particular FET). The MAX4420 is an example of a gate driver.

https://datasheets.maximintegrated.com/en/ds/MAX4420-MXT429.pdf

Power Dissipation:
The power dissipated in the FET when on is I^2*R or I*V. If operating with a gate voltage of 5V and a drain current of 5A the drain-source voltage will be about 0.1V. In this case the FET would dissipate I*V = 5A*0.1V = 0.5W (not much if a small heat sink is used). In the example at the beginning with a 100 Ω load and 12V supply we'll use the current and resistance to estimate the power. Ex: I^2 * R = $(0.12A)^2$ * 0.02 Ω = 0.288mW (basically nothing). Since the current is 40 times less than 5A the power dissipated will be 40^2 = 1600 times smaller.

Note: A floating gate can leave the FET in the on position for a long time. Use a pull up/down resistor on the gate if it's an input. Charging the input capacitance is why low clock rate ICs draw little power and fast ICs draw a lot.

Dynamic power dissipation (i.e. power used while switching on or off):
When switching on & off fast (say 10,000 times a second) a noticeable amount a power is used to switch the FET. If the input capacitance is 3.7nF and it's charged to 5V 10,000 times a second that's I=dQ/dt = C * V * # of times = 3.7nF * 5V * 10,000 = 0.185mA. At 10,000 times a second this is still a small current. But at one million times a second the gate drive current becomes 18mA. Some switching supplies operate at over 1MHz and the more power the FET can handle the larger the input capacitance. Also, when the FET is switching it's in its linear region (i.e. it's not on or off but somewhere in between). When in the linear region the FET could have a large drain source voltage and a large drain current. Energy = V * I * time. Say you're switching 12V@5A 10,000 times a second and it takes 10us for the FET to switch on and 15us to switch off (see figure below).



You can see that power is being dissipated in the FET while switching between on and off. When dealing with high load currents and high switching frequencies it's a good idea to minimize the rise and fall times to limit the time in the linear region. But, at lower switching frequencies the switching time is sometimes made longer to lower the maximum frequency content of the switching noise (i.e. lower EMI).

Note: FETs are also more sensitive to static electricity than BJTs. If the gate is an input that could get zapped it's a good idea to use a resistor in series with the gate to limit the current and possibly save the FET. Ex: You walk across the carpet and touch the input with your finger and see a spark. Thousands of volts just hit the gate of your FET.

Note: The FETs discussed so far have been N-channel FETs. P-channel FETs turn on when the gate to source voltage goes negative and turn off when near zero. We'll use n-channel FETs in class because they have a lower on-resistance