Duke University
Department of Physics

Physics 271 Spring Term 2017

WUN2K FOR LECTURE 17

These are notes summarizing the main concepts you need to understand and be able to apply.

- *Field Effect Transistors* or *FETs* are transistor devices that share many of the properties of bipolar transistors, but operate by somewhat different physical mechanisms. They come in "n-channel" (the type we'll be discussing) and "p-channel" varieties, where the name describes the type of the material of the channel through which current flows. These notes apply to n-channel FETs (p-channel FETs can be treated similarly, with opposite signs of biasing).

- The terminals of a FET have approximate bipolar-transistor equivalents: gate $\leftrightarrow$ base, source $\leftrightarrow$ emitter, drain $\leftrightarrow$ collector. One typically thinks of the gate-source voltage as controlling the drain current (physically, it determines the size of the depletion region inside the channel through which current flows).

- For *Junction Field Effect Transistors (JFETs)*, the majority charge carriers travel through a channel, with amount of depletion controlled by V_{gs}. In normal operation (for n-channel), negative voltage is applied to the gate and the gate-source *pn* junction is reverse-biased. With sufficient reverse bias, the depletion zone fills the whole channel and "pinches off" the current. These transistors have an $I_d - V_{ds}$ curve which turns on linearly ("linear", "resistive", "ohmic" or "nonsaturated" regime) until the amount of current saturates ("saturation" regime where the current $I_{d(\mathrm{sat})}$ is mostly constant). There's a different $I_d - V_{ds}$ curve for each value of V_{gs}.

- FET operation can be described by model equations:

- The saturation voltage is given by $V_{ds(\text{sat})} = V_{gs} - V_t$, where V_t is the threshold voltage for turn-on of current I_d.
- In the linear region where $V_{ds} < V_{ds(\text{sat})}$, $I_d = K(2V_{ds(\text{sat})} - V_{ds})V_{ds}$, where K is a constant.
- In the saturation region where $V_{ds} > V_{ds(\text{sat})}$, we have $I_d = KV^2_{ds(\text{sat})}$.

- *Metal Oxide Field Effect Transistors (MOSFETs)* are a kind of IGFET (Insulated Gate Field Effect Transistor) commonly used in integrated circuits. These have a gate electrically insulated from the drain-source channel, usually by a layer of silicon dioxide. There are many subvarieties of these, tuned to specific applications, but they are generally characterized by very high input impedance and low power consumption. They are very suitable for use as switches. They also tend to be quite sensitive to static. They come in n-channel and p-channel varieties. Because the gate is insulated from the channel, the gate can be made positive with respect to the source. This results in several functional varieties (depending on internal geometry and materials). The common varieties we'll deal with are:
  - *Depletion type (d-mosfet):* V_{gs} controls the current by controlling the size of the depletion region, but it can also go positive, such that (for n-channel) positive carriers are repelled back into the p-type region, freeing negative carriers to carry current in the channel.
  - *Enhancement type (e-mosfet):* V_{gs} controls the current only when it is positive, by freeing negative charges as the (minority) positive carriers are repelled into the p-type material.

- JFETs, d-mosfets and e-mosfets all have similarly-shaped I_d vs V_{gs} curves, and are mostly distinguished by the range of V_{gs} for useful operation (see Fig. 5.8 of Eggleston).

- JFETs, d-mosfets and e-mosfets also all have similarly-shaped I_d vs V_{ds} curves, and are mostly distinguished by the range of V_{gs} values corresponding to the different curves (see Fig. 5.10 of Eggleston).

- FETs work well as switches, with the voltage V_g at the gate controlling whether a current is pulled from the V_{dd} supply. What range of input voltages will turn the switch on or off will depend on the type of FET.