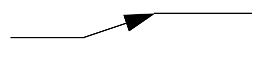
Electronic Switches

Switches

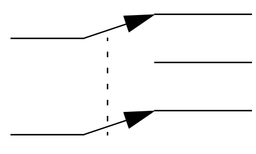
- A switch can be used to allow current to flow (closed) or stop (open).
- A switch can be used to direct current into different circuit paths.

Switches are defined in terms of the number of poles (separate switching elements) and number of throws (number of switch positions).

SPST : Single Pole Single Throw



SPDT : Single Pole Double Throw

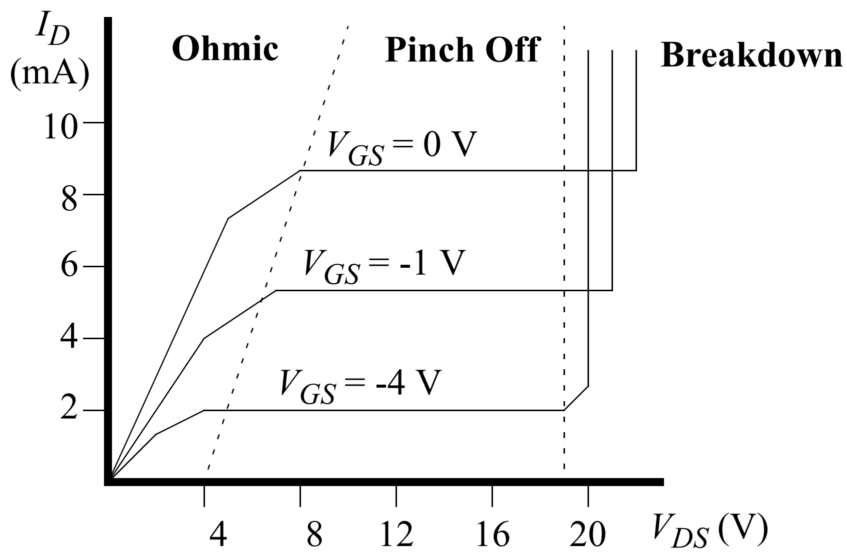


DPST : Double Pole Double Throw

- Mechanical switches will “bounce”. This appears as fluctuations off and on with a period of 1-10 ms.

FET Pinch-off

- FETs operate with two types of behavior: ohmic and pinch-off.



- A JFET is shown above, with a gate threshold of about -5V.
- MOSFETs have positive gate thresholds 1-2 V.

FET Saturation

- At low V_{DS}, $R_{DS} = 1/2k(V_{GS} - V_T)$, V_T is a gate threshold.

$$I_D = \frac{V_{DS}}{R_{DS}(V_{GS})}$$

- Linear region fails as V_{DS} approaches $(V_{GS} - V_T)$
- At $V_{DS} = (V_{GS} - V_T)$:

$$I_D = 2kV_{DS}[(V_{GS} - V_T) - V_{DS}/2]$$

$$I_D = 2k(V_{GS} - V_T)[(V_{GS} - V_T) - (V_{GS} - V_T)/2]$$

$$I_D = 2k[(V_{GS} - V_T)^2/2]$$

$$I_D = k(V_{GS} - V_T)^2$$

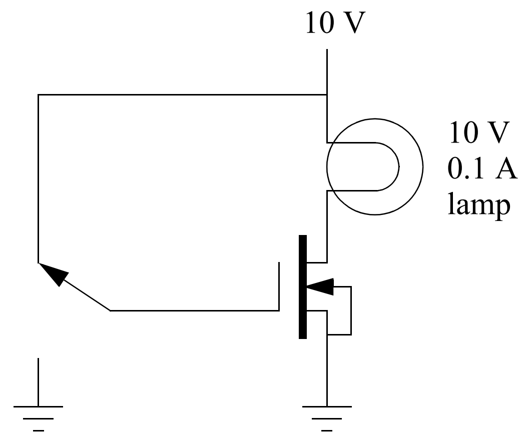
This is the *saturation* region

- In saturation, I_D depends on the square of V_{GS}.

- Saturation occurs when V_{DS} is too large to continue to supply more current through the transistor.

FET Switches

- Single MOSFET Switch

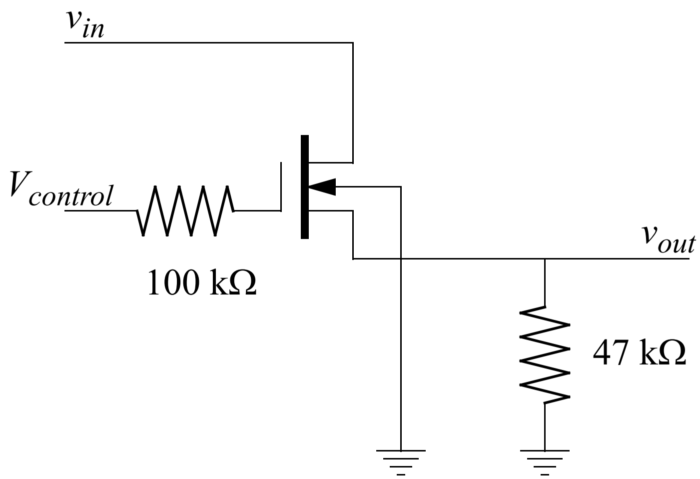


The FET acts like a single-pole single-throw switch.

- Switch at +10 V: $V_{GS} = 10$ V, $R_{DS} = 100\ \Omega$, so $I_D = 50$ mA, and the lamp is on.
- Switch at 0 V: $V_{GS} = 0$ V, $I_D = 0$ mA, and the lamp is off.

Analog Switch

- MOSFET is controlled either ON or OFF



There is a voltage divider with R_{DS} and the 47 kΩ resistor.

When the gate is ground or negative, $R_{DS} > 10^{10}\ \Omega$, $v_{out} < 0.0001 v_{in}$.

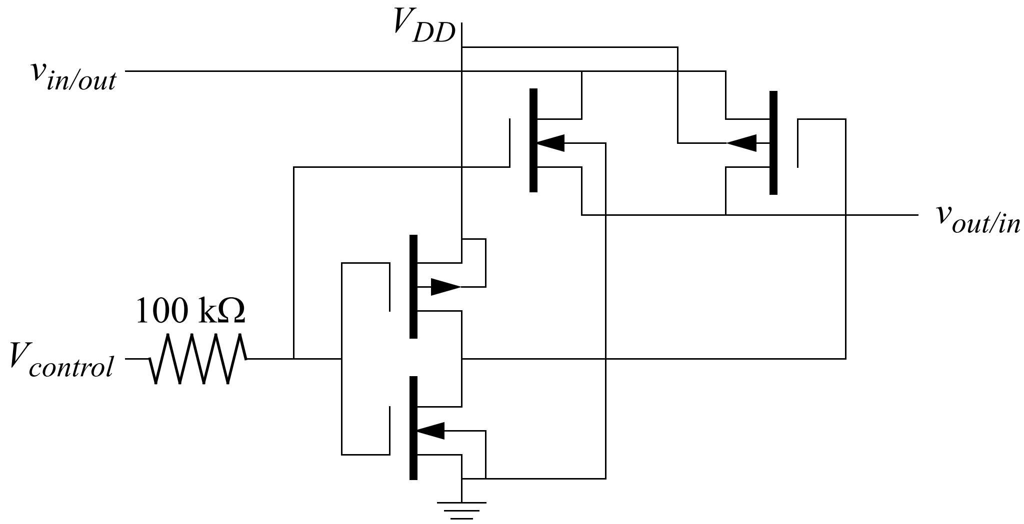
When the gate is + 15 V, $R_{DS} = 100\ \Omega$, $v_{out} = 0.998\ v_{in}$.

- The MOSFET switch is bidirectional, like a mechanical switch

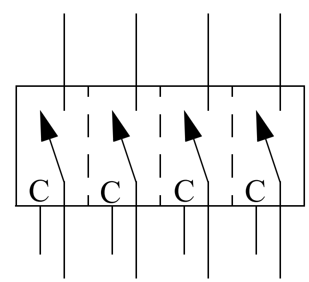
The gate is not fully functional if the signal is near $V_{control}$.

Transmission Gate

- Add a parallel MOSFET of opposite type "complementary MOSFET"
- CMOS Switch



- The extra pair of MOSFETs "invert" the value of $V_{control}$.
- Quad CMOS SPST Integrated Circuit



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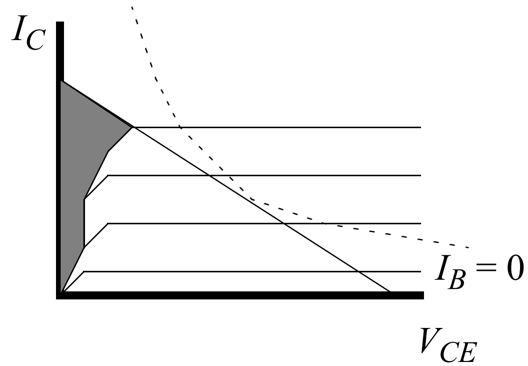
Bipolar Transistor Saturation

- Output (V-I for collector to emitter) looks like a current source



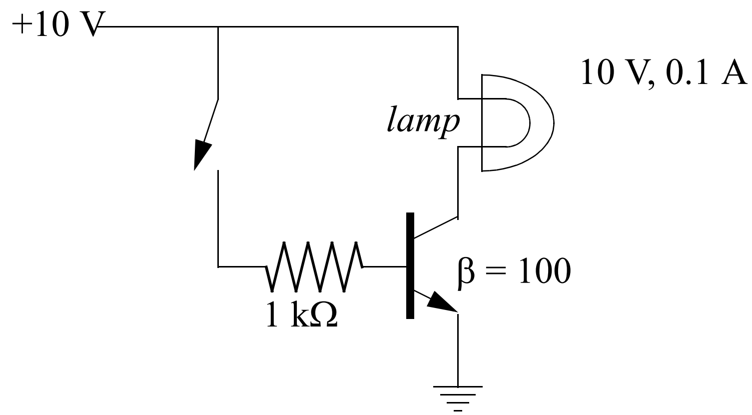
Dashed line is a curve of constant power $I_C V_{CE}$.

Shaded region corresponds to area where V_{CE} may drop no lower for a given I_C.

- Like the FET this is ***saturation.***

Voltages at saturation are typically 0.1 to 0.3 V.

Common Emitter Switch



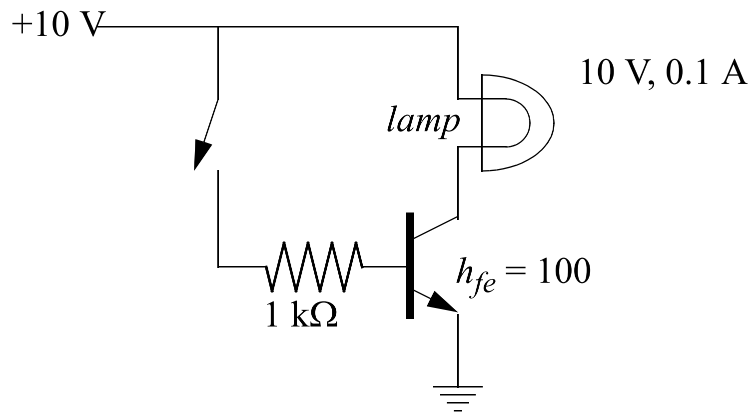
- Switch open: $I_B = 0$ so $I_C = 0$, and the lamp is off.
- Switch closed: $V_B = 0.6$ V, $I_B = 9.4$ mA.

  The rule is $I_C = \beta I_B$ so $I_C = 940$ mA.

  But the lamp will only draw 100 mA at 10 V.

  The collector goes as low as it can (typically 0.1 V) and sinks 100 mA.

Switch Using Transconductance



- Correct gain is $-R_C / r_e = -R_C I_C / 25$ mA-Ω
- At the operating point, R_C = 10 V / 100 mA = 100 Ω
- The gain is (100 Ω)(100 mA) / 25 mA-Ω = –400

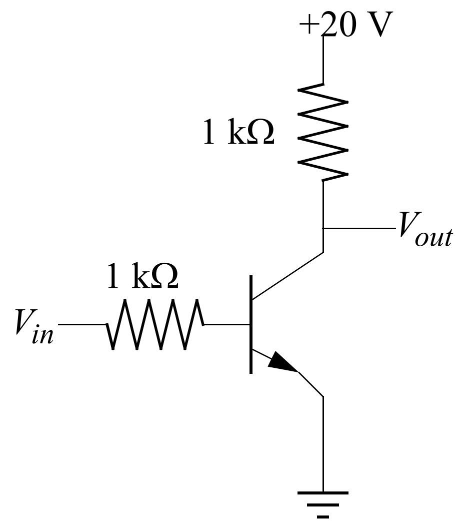
- The base-collector junction is a diode with a diode drop < 0.25 V.
  The reverse current is I_S:

$$I_C = I_S(e^{V_{BE}/V_T} - 1)$$

- The base-emitter voltage is about 0.6 V
- The correct $h_{fe} = I_C / I_B$ = 100 mA / 9.4 mA ≅ 10

Two-state Electronics

- Common Emitter



- When V_{in} = 0 V the transistor switch is open (off) and V_{out} = 20 V.
- As V_{in} increases above 0.6 V then transistor turn on and current begins to flow, lowering V_{out} towards ground.
  The base of the transistor will hold at 0.7 V
  When V_{in} = 0.9 V, I_B = 0.2 mA and $I_C = \beta I_B$ = 20 mA.
  The voltage drop to the collector would now be 20 V and the transistor will be on and V_{out} = 0.2 V.
- With the exception of the range from 0.6 V < V_{in} < 0.8 V, this circuit has only two output states.

LED Driver

- Current should be either on or off.
- Typically a transistor switch, logic gate, or saturated op-amp will drive the LED.
- Use $V_{CC} = +5$ V, $V_{LED} = 1.7$ V, $I_{LED} = 10$ mA.

$$R = \frac{V_{CC} - V_{LED}}{I_{LED}} = 330\Omega$$

- Driving circuit ($V_{in} > 0$, LED is on)