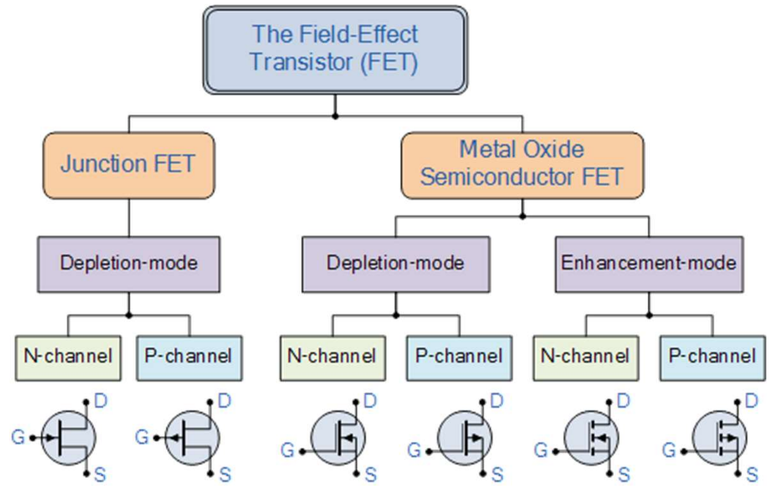
The Field Effect Transistor Chart



Handling Precautions

All MOS devices are subject to damage from electrostatic discharge (ESD). Because the gate of a MOSFET is insulated from the channel, the input resistance is extremely high (ideally infinite). The gate leakage current, I_{GSS}, for a typical MOSFET is in the pA range, whereas the gate reverse current for a typical JFET is in the nA range. The input capacitance results from the insulated gate structure. Excess static charge can be accumulated because the input capacitance combines with the very high input resistance and can result in damage to the device.

To avoid damage from ESD, certain precautions should be taken when handling MOSFETs:

1. Carefully remove MOSFET devices from their packaging. They are shipped in conductive foam or special foil conductive bags. Usually they are shipped with a wire ring around the leads, which is removed just prior to installing the MOSFET in a circuit.

2. All instruments and metal benches used in assembly or test should be connected to earth ground (round or third prong of 110 V wall outlets).

3. The assembler's or handler's wrist should be connected to a commercial grounding strap, which has a high-value series resistor for safety. The resistor prevents accidental contact with voltage from becoming lethal.

4. Never remove a MOS device (or any other device, for that matter) from the circuit while the power is on.

5. Do not apply signals to a MOS device while the dc power supply is off.

JFET vs. MOSFET vs. BJT

Property	BJT	MOSFET	JFET
Gm/I	Best	Worst	Medium
Speed	High	Medium	Low
Noise	Moderate	Worst	Best
Good Switch	No	Yes	Yes
High-Z Gate	No	Yes	Yes
ESD Sensitivity	Less	More	Less

MOSFET BIASING

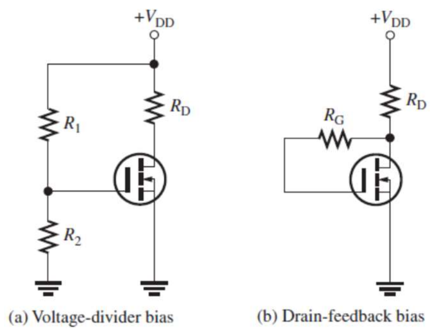


FIGURE 8–46

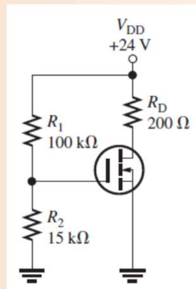
Common E-MOSFET biasing arrangements.

$$V_{GS} = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD}$$

$$V_{DS} = V_{DD} - I_D R_D$$

Determine V_{GS} and V_{DS} for the E-MOSFET circuit in Figure 8–47. Assume this particular MOSFET has minimum values of $I_{D(on)} = 200$ mA at $V_{GS} = 4$ V and $V_{GS(th)} = 2$ V.

▶ FIGURE 8–47



For the E-MOSFET in Figure 8–47, the gate-to-source voltage is

$$V_{GS} = \left(\frac{R_2}{R_1 + R_2}\right)V_{DD} = \left(\frac{15\text{ k}\Omega}{115\text{ k}\Omega}\right)24\text{ V} = \mathbf{3.13\text{ V}}$$

To determine V_{DS}, first find K using the minimum value of $I_{D(on)}$ and the specified voltage values.

$$K = \frac{I_{D(on)}}{(V_{GS} - V_{GS(th)})^2} = \frac{200\text{ mA}}{(4\text{ V} - 2\text{ V})^2} = \frac{200\text{ mA}}{4\text{ V}^2} = 50\text{ mA/V}^2$$

Now calculate I_D for $V_{GS} = 3.13$ V.

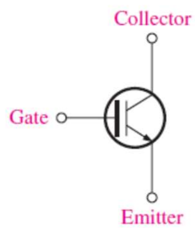
$$I_D = K(V_{GS} - V_{GS(th)})^2 = (50\text{ mA/V}^2)(3.13\text{ V} - 2\text{ V})^2$$
$$= (50\text{ mA/V}^2)(1.13\text{ V})^2 = 63.8\text{ mA}$$

Finally, calculate V_{DS}.

$$V_{DS} = V_{DD} - I_DR_D = 24\text{ V} - (63.8\text{ mA})(200\ \Omega) = \mathbf{11.2\text{ V}}$$

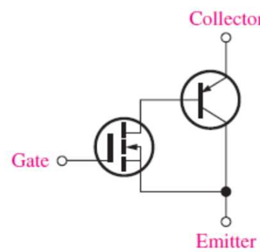
Determine V_{GS} and V_{DS} for the circuit in Figure 8–47 given $I_{D(on)} = 100$ mA at $V_{GS} = 4$ V and $V_{GS(th)} = 3$ V.

The IGBT



▲ FIGURE 8–51

A symbol for the IGBT (insulated-gate bipolar transistor).



▲ FIGURE 8–52

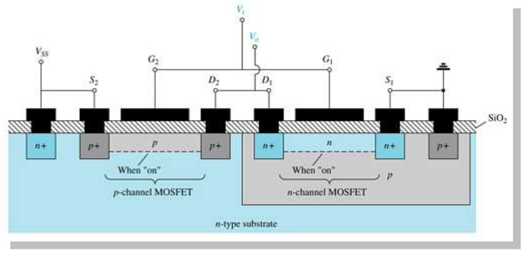
Simplified equivalent circuit for an IGBT.

Comparison of several device features for switching applications

FEATURES	IGBT	MOSFET	BJT
Type of input drive	Voltage	Voltage	Current
Input resistance	High	High	Low
Operating frequency	Medium	High	Low
Switching speed	Medium	Fast (ns)	Slow(uS)
Saturation voltage	Low	High	Low

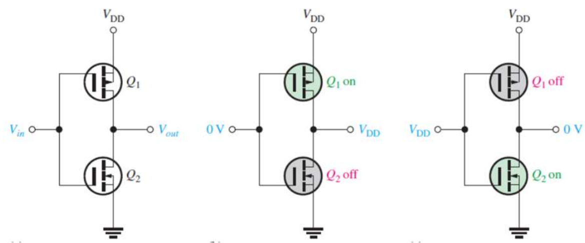
CMOS Devices

CMOS (complementary MOSFET) ใช้ทั้ง *p*-channel และ *n*-channel MOSFET บน substrate เดียวกัน

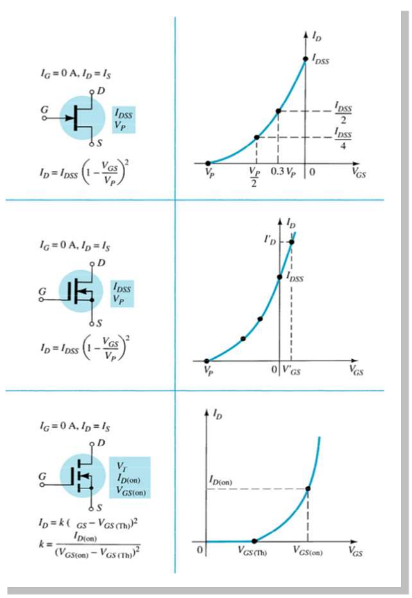


ข้อดี

- มีประโยชน์ในวงจรตรรกะ
- มีอินพุตอิมพีแดนซ์สูง
- ทำงานได้เร็ว
- กินไฟน้อย

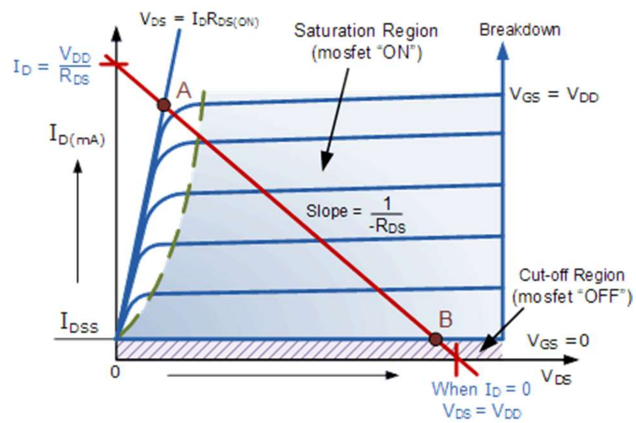


Summary Table

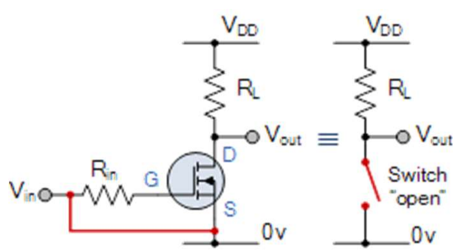


MOSFET Type	$V_{GS} \ll 0$	$V_{GS} = 0$	$V_{GS} \gg 0$
N-channel Enhancement	OFF	OFF	ON
N-channel Depletion	OFF	ON	ON
P-channel Enhancement	ON	OFF	OFF
P-channel Depletion	ON	ON	OFF

MOSFET Characteristics Curves

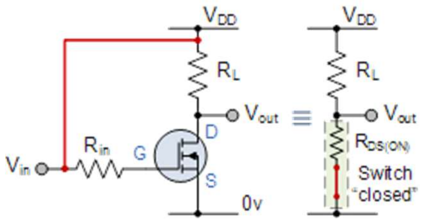


Cut-off Characteristics



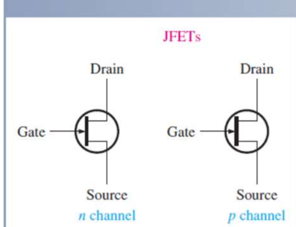
- • The input and Gate are grounded (0V)
- • Gate-source voltage less than threshold voltage $V_{GS} < V_{TH}$
- • MOSFET is "OFF" (Cut-off region)
- • No Drain current flows (I_D = 0 Amps)
- • $V_{OUT} = V_{DS} = V_{DD}$ = "1"
- • MOSFET operates as an "open switch"

Saturation Characteristics



- The input and Gate are connected to V_{DD}
- Gate-source voltage is much greater than threshold voltage $V_{GS} > V_{TH}$
- MOSFET is "ON" (saturation region)
- Max Drain current flows ($I_D = V_{DD} / R_L$)
- V_{DS} = 0V (ideal saturation)
- Min channel resistance $R_{DS(on)} < 0.1\Omega$
- $V_{OUT} = V_{DS} \cong 0.2V$ due to $R_{DS(on)}$
- MOSFET operates as a low resistance "closed switch"

JFETS



- Gate-source *pn* junction must be reverse-biased.
- V_{GS} controls I_D.
- Value of V_{DS} at which I_D becomes constant is the pinch-off voltage.
- Value of V_{GS} at which I_D becomes zero is the cutoff voltage, $V_{GS(off)}$.
- I_{DSS} is drain current when $V_{GS} = 0$.
- Transfer characteristic:

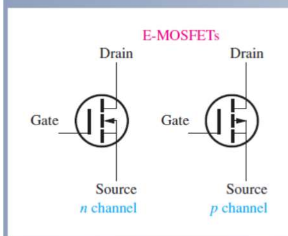
$$I_D \cong I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$$

- Forward transconductance:

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)$$

$$g_{m0} = \frac{2I_{DSS}}{|V_{GS(off)}|}$$

D-MOSFETS



Can be operated in either depletion or enhancement modes. V_{GS} can be either polarity when biased at $V_{GS} = 0$ V.

- *Depletion mode:*

  n channel: V_{GS} negative

  p channel: V_{GS} positive
- *Enhancement mode:*

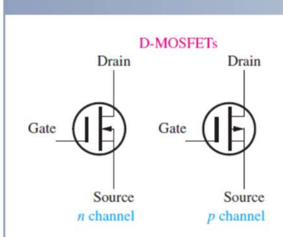
  n channel: V_{GS} positive

  p channel: V_{GS} negative

- V_{GS} controls I_D.
- Value of V_{GS} at which I_D becomes zero is the cutoff voltage, $V_{GS(off)}$.
- I_{DSS} is drain current when $V_{GS} = 0$.
- Transfer characteristic:

$$I_D \cong I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$$

E-MOSFETS



Operates in enhancement mode only.

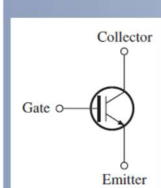
- V_{GS} must exceed $V_{GS(th)}$.
- *Enhancement mode:*

  n channel: V_{GS} positive

  p channel: V_{GS} negative
- V_{GS} controls I_D.
- Value of V_{GS} at which I_D begins is the threshold voltage, $V_{GS(th)}$.
- Transfer characteristic:

  $I_D = K(V_{GS} - V_{GS(th)})^2$
- K in formula can be calculated by substituting datasheet values $I_{D(on)}$ for I_D and V_{GS} at which $I_{D(on)}$ is specified for V_{GS}.

IGBT



- Voltage controlled like a MOSFET
- Output characteristics like a BJT
- Three terminals: gate, collector, emitter