

Transistors: Field-effect transistors

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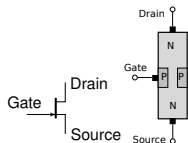


Lecture 08

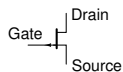
Field-effect transistor (FET)

Junction-FET

NJFET



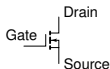
PJFET



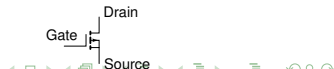
Metal-Oxide-Semiconductor FET (MOSFET)

- gate is truly isolated
- there is a fourth terminal usually connected to source

NMOSFET



PMOSFET



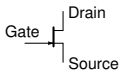
FET pros

- very high input impedance
 - JFET - impedance $10^{12} \Omega$
 - MOSFET - impedance $10^{14} \Omega$
- thus very small current into the base (pA range)
- as result very little power consumption for the biasing network
- can operate bidirectionally

FET cons

- have large parameter spread

Let's focus on NJFET



General notes

- N-channel usually faster due to higher mobility of electrons vs holes
- current goes from drain to source (thus the names)
- drain and source are nearly identical
 - thus sometimes gate is centered on some diagrams



- can be used backwards with almost the same performance
- arrow indicates direction of the PN junction

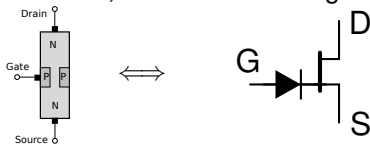


- thus normal operation (low current into the gate) when $V_G < V_S$

NJFET gate voltage rules

V_p : pinch-off voltage (intrinsic parameter), $V_p < 0$ for NJFETs
it is called V_{th} : threshold voltage for MOSFETs

- $V_{gs} < V_p$
 - $I_D = 0$
- $V_{gs} > 0.6 \text{ V}$
 - device fails, remember about gate diode



- $V_p < V_{gs} < 0.6 \text{ V}$
 - normal operation
 - $I_d(V_{gs}, V_{ds})$

I_d vs V_{DS}

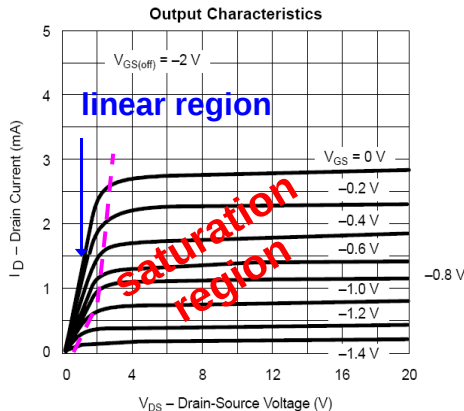
Linear region

- $V_{DS} < V_{GS} - V_p$
- $I_d(V_{DS}, V_{GS}) = k(2(V_{GS} - V_p)V_{DS} - V_{DS}^2)$

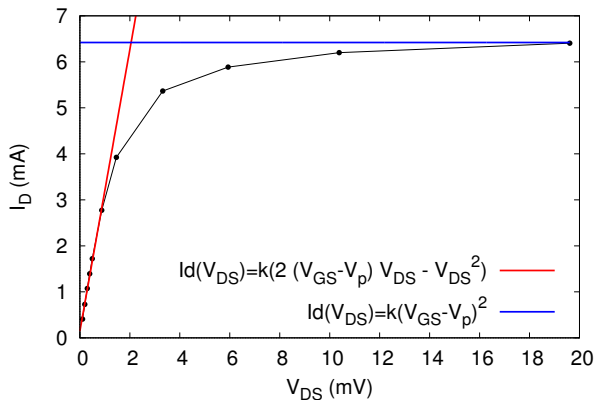
Saturation region

- $V_{DS} > V_{GS} - V_p$
- $I_d(V_{DS}, V_{GS}) = k(V_{GS} - V_p)^2$

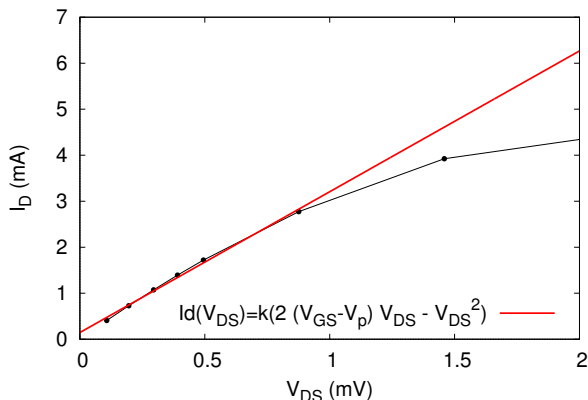
k is a constant



Real I_d vs V_{DS} linear region

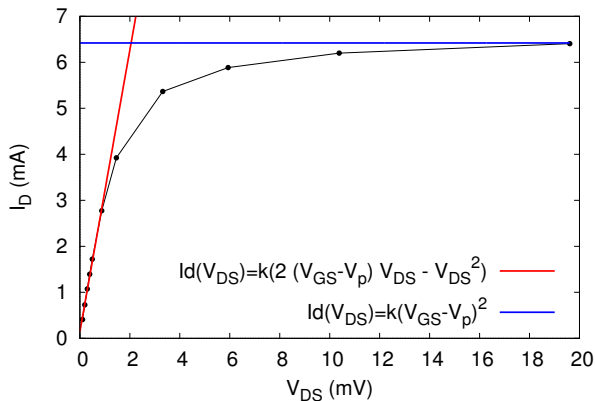


Real I_d vs V_{DS} linear region



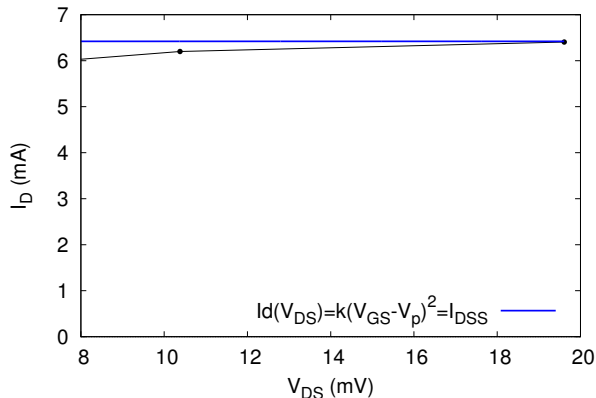
- $V_{DS} < V_{GS} - V_p$
 - $I_D(V_{DS}) = k(2(V_{GS} - V_p)V_{DS} - V_{DS}^2) \approx 2k(V_{GS} - V_p)V_{DS}$

Real I_d vs V_{DS} saturation region



I_{DSS} saturation drain current, depends on V_{GS} and V_p

Real I_d vs V_{DS} saturation region



- $V_{DS} > V_{GS} - V_p$
 - $I_D(V_{DS}) = k(V_{GS} - V_p)^2$

I_{DSS} saturation drain current, depends on V_{GS} and V_p

Reading the specifications

2N3958

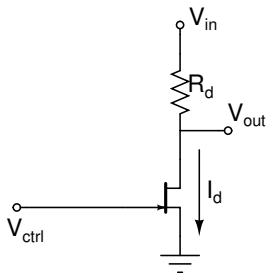
Vishay Siliconix



SPECIFICATIONS ($T_A = 25^\circ\text{C}$ UNLESS OTHERWISE NOTED)						
Parameter	Symbol	Test Conditions	Limits			Unit
			Min	Typ ^a	Max	
Static						
Gate-Source Breakdown Voltage	$V_{(BR)GSS}$	$I_G = -1\ \mu\text{A}, V_{DS} = 0\ \text{V}$	-50	-57		V
Gate-Source Cutoff Voltage	$V_{GS(off)}$	$V_{DS} = 20\ \text{V}, I_D = 1\ \text{nA}$	-1.0	-2	-4.5	
Saturation Drain Current ^b	I_{DSS}	$V_{DS} = 20\ \text{V}, V_{GS} = 0\ \text{V}$	0.5	3	5	mA
Gate Reverse Current	I_{GSS}	$V_{GS} = -30\ \text{V}, V_{DS} = 0\ \text{V}$		-10	-100	pA
		$T_A = 150^\circ\text{C}$		-20	-500	nA
Gate Operating Current	I_G	$V_{DG} = 20\ \text{V}, I_D = 200\ \mu\text{A}$		-5	-50	pA
		$T_A = 125^\circ\text{C}$		-0.8	-250	nA
Gate-Source Voltage	V_{GS}	$V_{DG} = 20\ \text{V}, I_D = 200\ \mu\text{A}$	-0.5	-1.5	-4	V
		$I_D = 50\ \mu\text{A}$			-4.2	
Gate-Source Forward Voltage	$V_{GS(F)}$	$I_G = 1\ \text{mA}, V_{DS} = 0\ \text{V}$			2	
Dynamic						
Common-Source Forward Transconductance	g_{fs}	$V_{DS} = 20\ \text{V}, V_{GS} = 0\ \text{V}$ $f = 1\ \text{kHz}$	1	2.5	3	mS
Common-Source Output Conductance	g_{os}			2	35	μS

$V_{GS(off)}$ is the same as V_p

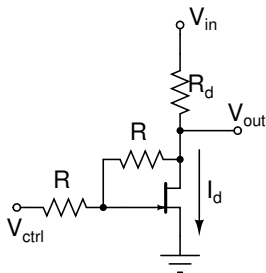
NJFET voltage controlled divider



Transistor in the linear region

$$I_d(V_{DS}, V_{GS}) = k \left(2(V_{GS} - V_p)V_{DS} - V_{DS}^2 \right)$$

NJFET compensated voltage controlled divider



Transistor in the linear region

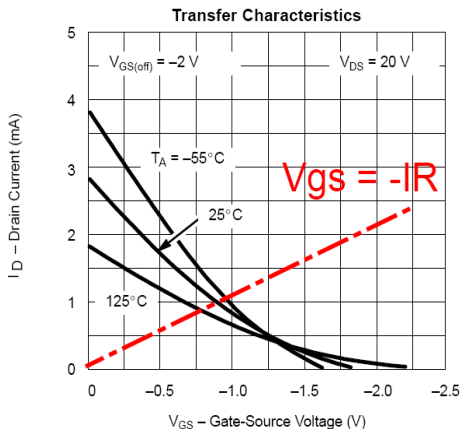
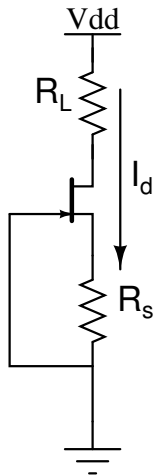
$$I_d(V_{DS}, V_{GS}) = k \left(2(V_{GS} - V_p)V_{DS} - V_{DS}^2 \right)$$

$$V_g = (V_{ds} + V_{ctrl})/2$$

$$R \gg R_d$$

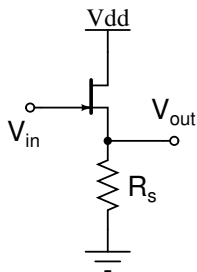
NJFET constant current source

Transistor in the saturation region



FET source follower

Transistor in saturation region

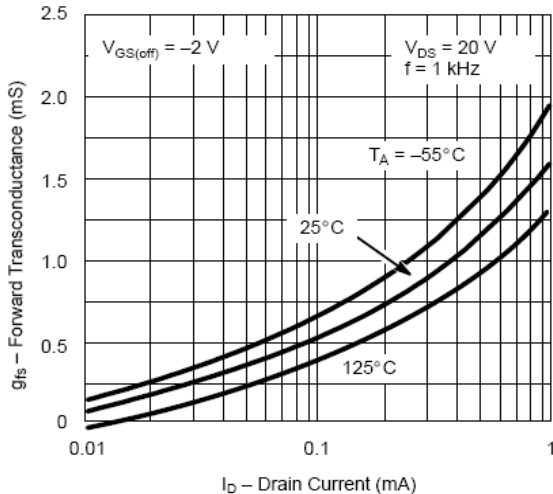


$$V_{out} = \frac{R_s}{R_s + 1/g_m} V_{in}$$

$$r_{th} > 1/g_m$$

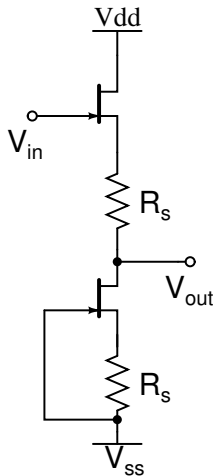
$$V_{out} > V_{in}$$

Common-Source Forward Transconductance vs. Drain Current



FET source follower improved

Transistor in saturation region



Requires **matched** pair of transistors

$$V_{out} = V_{in}$$

$$V_{out} = V_{in}$$

$$R_{th} = R_S$$