

Transistors: Field-effect transistors

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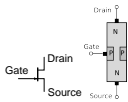
Lecture 08

Notes

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



Notes

FET vs BJT

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)
- can operate bidirectionally
- as result very little power consumption for the biasing network

FET cons

- have large parameter spread

Notes

Let's focus on NJFET



General notes

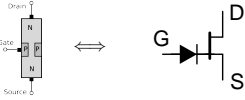
- N-channel usually faster due to higher mobility of electrons vs holes
- current goes from drain to source (thus the names)
- drain and source are nearly identical
 - thus sometimes gate is centered on some diagrams
- can be used backwards with almost the same performance
- arrow indicates direction of the PN junction
- thus normal operation (low current into the gate) when $V_G < V_S$

Notes

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}

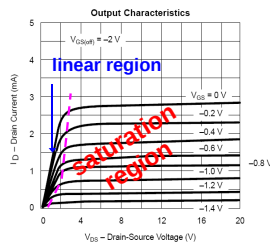
Linear region

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

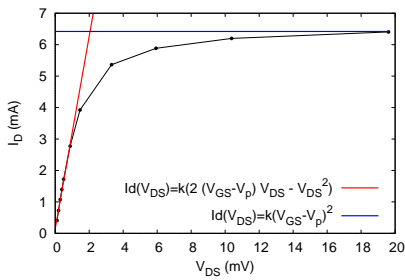
Saturation region

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

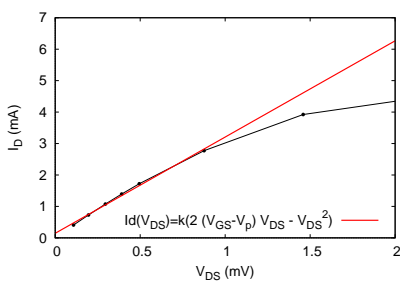
k is a constant



Real I_d vs V_{DS} linear region



Real I_d vs V_{DS} linear region



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

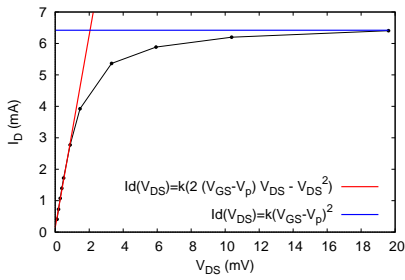
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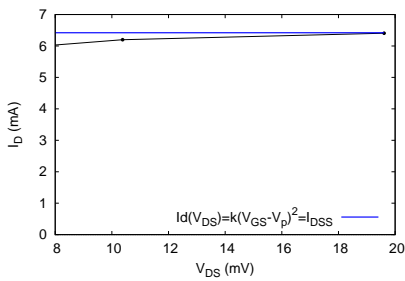
Real I_d vs V_{DS} saturation region



Notes

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

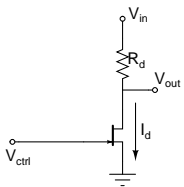


SPECIFICATIONS (T _A = 25 °C UNLESS OTHERWISE NOTED)						
Parameter	Symbol	Test Conditions	Limits			Unit
			Min	Typ ²	Max	
Static						
Gate-Source Breakdown Voltage	V_{BSS}	$I_S = -1 \mu A, V_{GS} = 0 V$	-50	-57		V
Gate-Source Forward Voltage	V_{GS}	$I_D = 10 mA, V_{DS} = 0 V$	0.6	0.7	0.8	V
Saturation Drain Current	I_{DSS}	$V_{GS} = 0 V, V_{DS} = 0 V$	10	15	20	mA
Gate Reverse Current	I_{OSS}	$V_{GS} = -30 V, V_{DS} = 0 V$	-10	-100		μA
Gate Operating Current	I_G	$V_{DS} = 20 V, I_D = 200 mA$	-5	-50		μA
		$T_A = 150^\circ C$	-5	-50		μA
Gate-Source Voltage	V_{GS}	$V_{DS} = 20 V, I_D = 200 mA$	-0.5	-1.5	-4	V
Gate-Source Forward Voltage	$V_{GS(F)}$	$I_D = 50 \mu A$			-4.2	V
		$I_S = 1 mA, V_{GS} = 0 V$			2	V
Dynamic						
Common-Source Forward Transconductance	g_m	$V_{GS} = 20 V, V_{DS} = 0 V$	1	25		mS
Common-Source Output Conductance	g_{os}	$I_D = 1 mA, V_{GS} = 0 V$	2	35		μS

Notes

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

NJFET voltage controlled divider

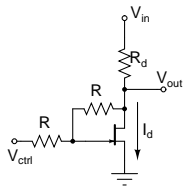


Transistor in the linear region

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

Notes

NJFET compensated voltage controlled divider



Transistor in the linear region

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

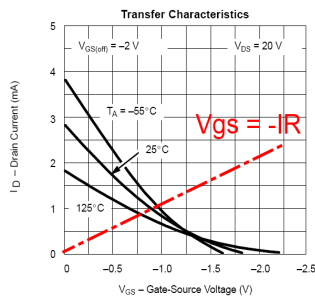
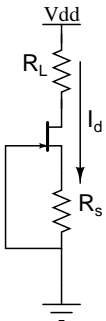
$$V_g = (V_{ds} - V_{ctrl})/2$$

$$R \gg R_d$$

Notes

NJFET constant current source

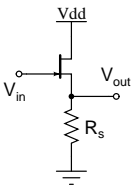
Transistor in the saturation region



Notes

FET source follower

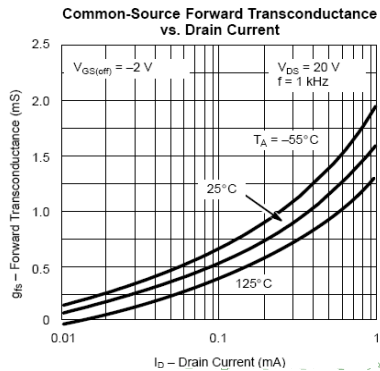
Transistor in saturation region



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

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

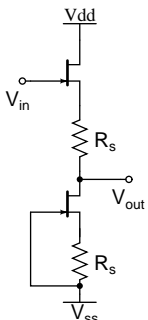
$$V_{out} > V_{in}$$



Notes

FET source follower improved

Transistor in saturation region



Requires **matched** pair of transistors

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

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

$$R_{th} = R_s$$

Notes
