Transistors: Field-effect transistors

Eugeniy E. Mikhailov

The College of William & Mary

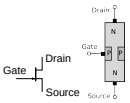
Lecture 08

Notes

Field-effect transistor (FET)

Junction-FET

NJFET



PJFET

Metal-Oxide-Semiconductor FET (MOSFET)

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

NMOSFET

PMOSFET

Notes

FET vs BJT

FET pros

- very high input impedance
  - JFET - impedance 10^{12} Ω
  - MOSFET - impedance 10^{14} Ω
- 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

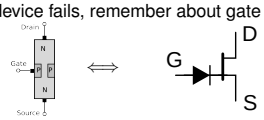
  - thus normal operation (low current into the gate) when $V_G < V_S$

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

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



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

Notes

I_d vs V_{DS}

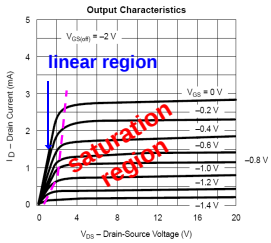
Linear region

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

Saturation region

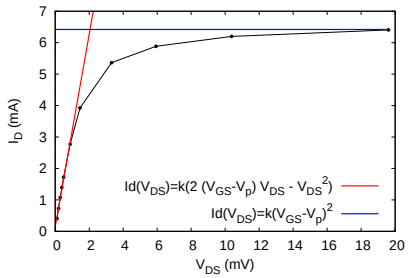
- $V_{DS} > V_{GS} - V_p$
  - $I_d(V_{DS}, V_{GS}) = k(V_{GS} - V_p)^2$

k is a constant



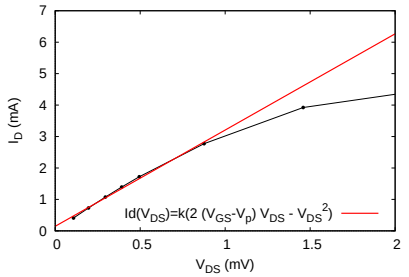
Notes

Real I_d vs V_{DS} linear region



Notes

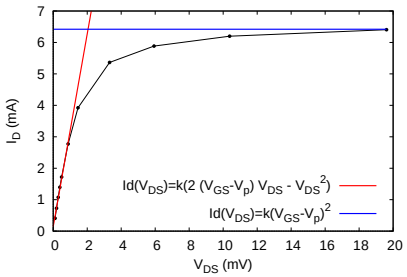
Real I_d vs V_{DS} linear region



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

Notes

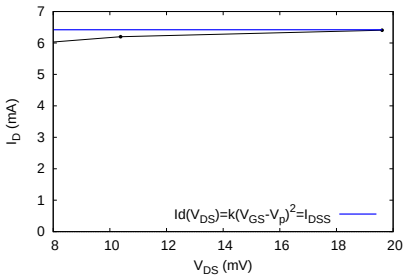
Real I_d vs V_{DS} saturation region



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

Notes

Real I_d vs V_{DS} saturation region



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

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

Notes

Reading the specifications

2N3958
Vishay Siliconix

VISHAY

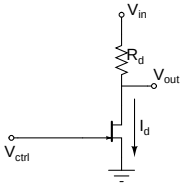
SPECIFICATIONS (T_A = 25°C UNLESS OTHERWISE NOTED)

Parameter	Symbol	Test Conditions	Limits Min	Typ[a]	Max	Unit
Static						
Gate-Source Breakdown Voltage	$V_{(BR)GSS}$	I_G = −1 µA, V_{DS} = 0 V	−50	−57		V
Gate-Source Cutoff Voltage	$V_{GS(off)}$	V_{DS} = 20 V, I_D = 1 nA	−1.0	−2	−4.0	
Saturation Drain Current[b]	I_{DSS}	V_{DS} = 20 V, V_{GS} = 0 V	0.5	3	9	mA
Gate Reverse Current	I_{GSS}	V_{GS} = −30 V, V_{DS} = 0 V		−10	−100	pA
		T_A = 150°C		−20	−500	nA
Gate Operating Current	I_G	V_{DG} = 20 V, I_D = 200 µA		−5	−50	pA
		T_A = 125°C		−0.8	−250	nA
Gate-Source Voltage	V_{GS}	V_{DG} = 20 V, I_D = 200 µA	−0.5	−1.5	−4	V
		I_D = 50 µA			−4.2	
Gate-Source Forward Voltage	$V_{GS(F)}$	I_G = 1 mA, V_{DS} = 0 V			2	
Dynamic						
Common-Source Forward Transconductance	g_{fs}	V_{DS} = 20 V, V_{GS} = 0 V, f = 1 kHz	1	2.5	5	mS
Common-Source Output Conductance	g_{os}			2	35	µS

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

Notes

NJFET voltage controlled divider

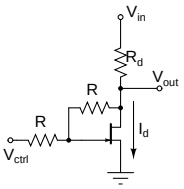


Transistor in the linear region

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

Notes

NJFET compensated voltage controlled divider



Transistor in the linear region

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

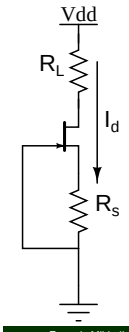
$$V_g = (V_{ds} - V_{ctrl})/2$$

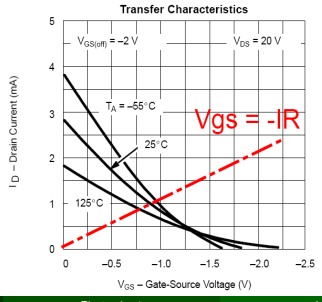
$$R >> R_d$$

Notes

NJFET constant current source

Transistor in the saturation region

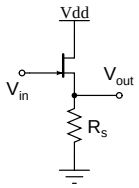




Notes

FET source follower

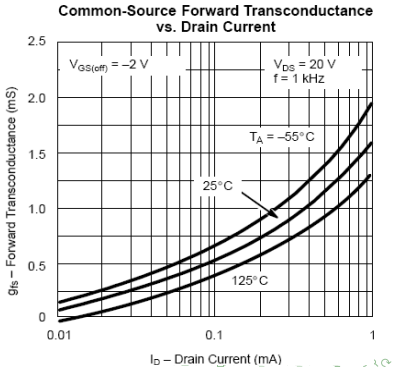
Transistor in saturation region



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

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

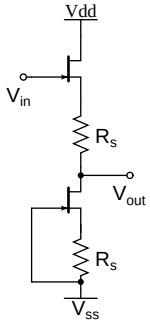
$$V_{out} > V_{in}$$



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