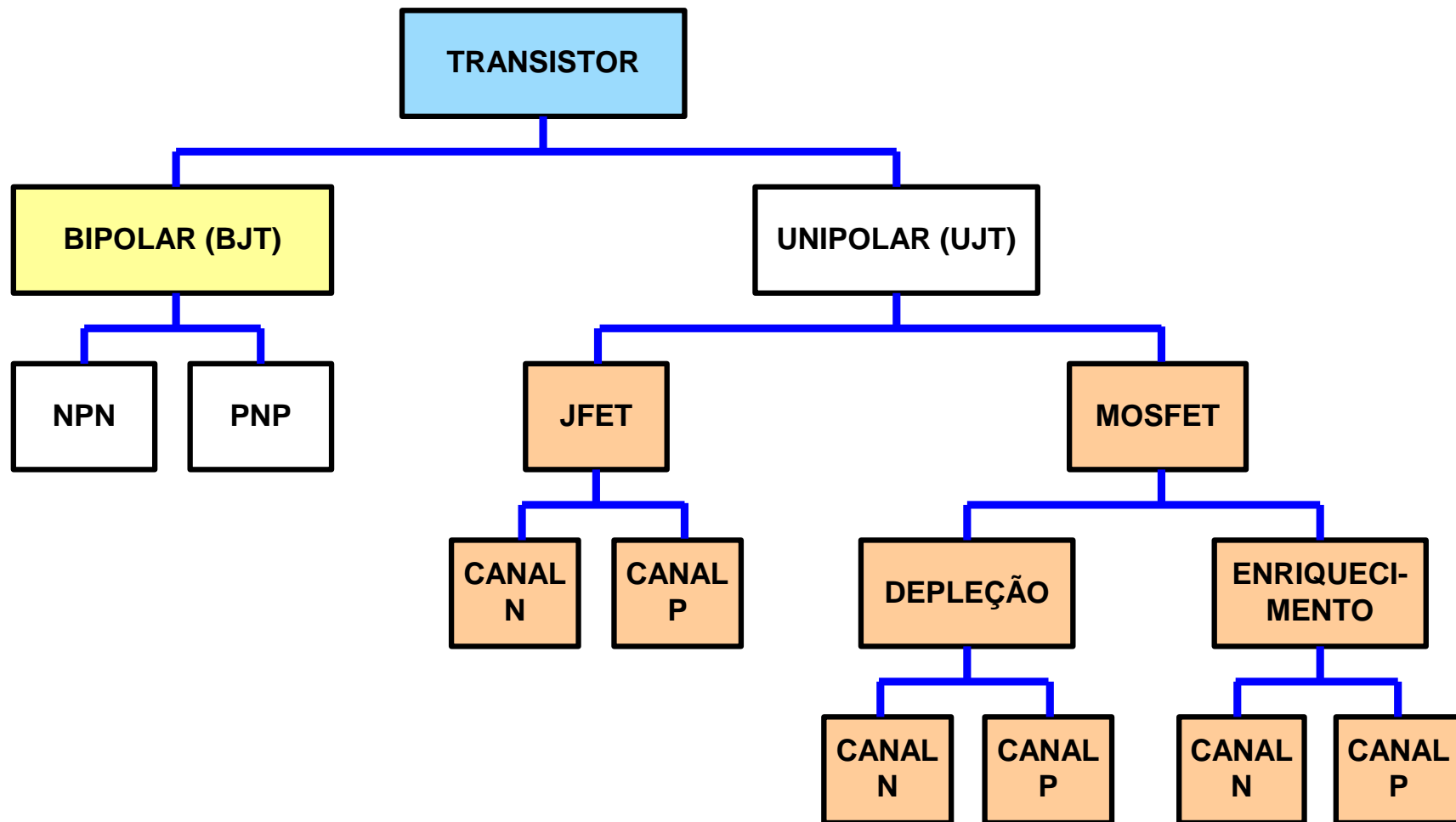
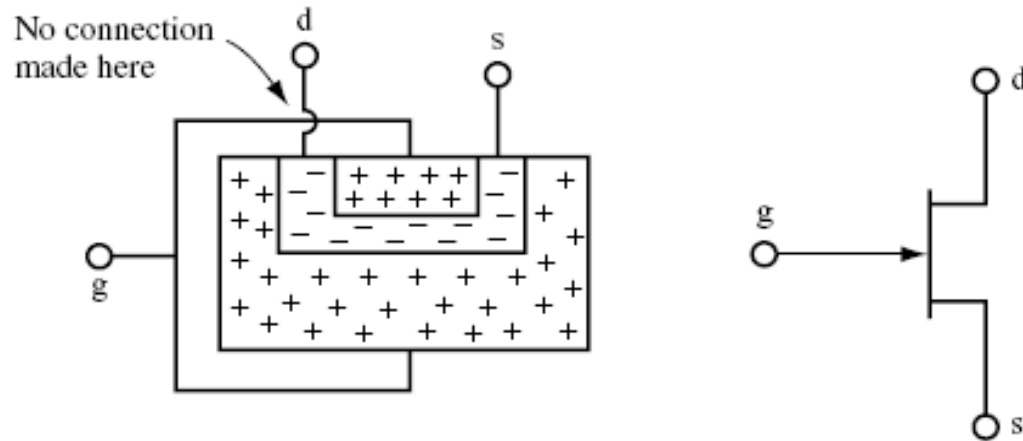


# **Transistores de efeito de campo (FET)**

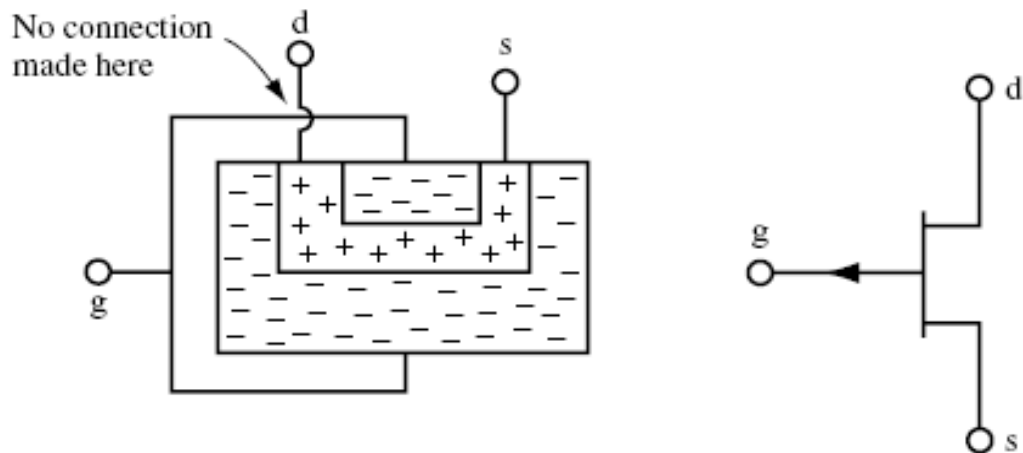
# Classificação dos transistores



# Transistor de Efeito de Campo: JFET

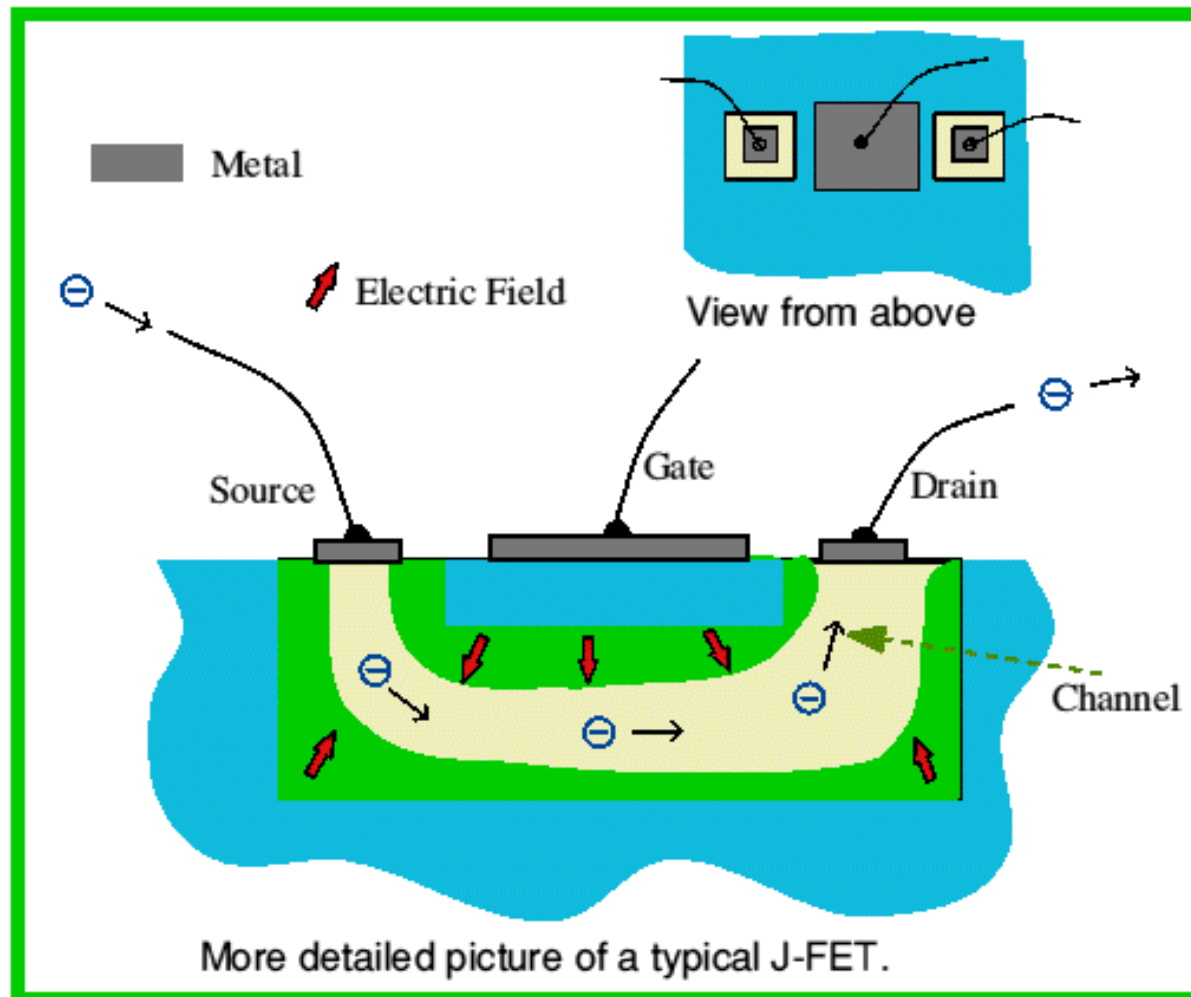


N-channel JFET

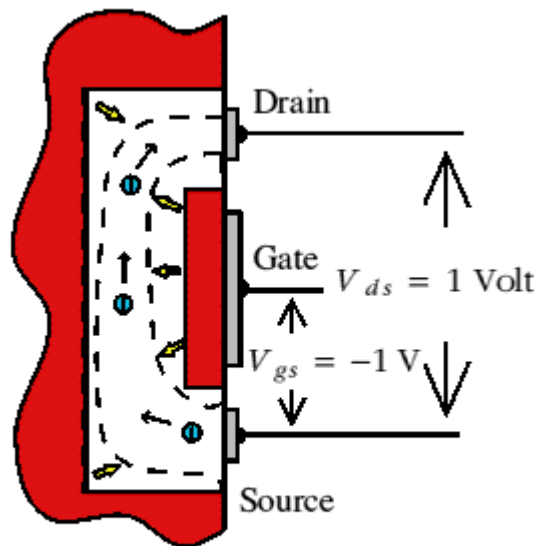


P-channel JFET

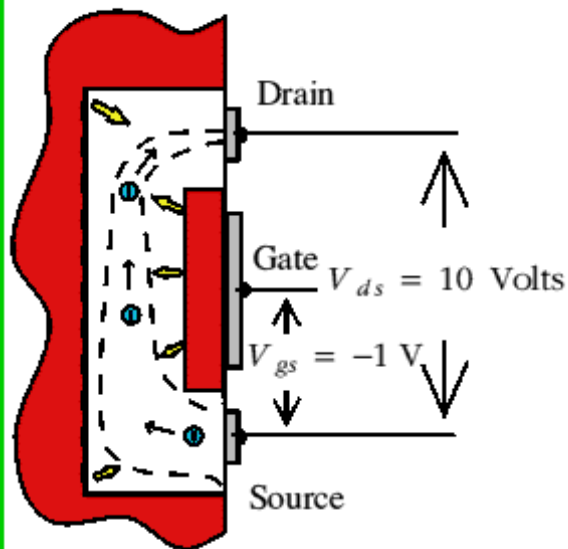
# Funcionamento do JFET



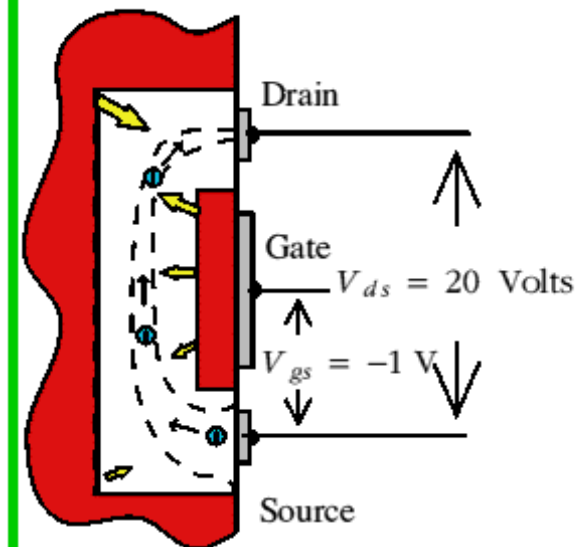
# Funcionamento do JFET



1 Volt drain-source

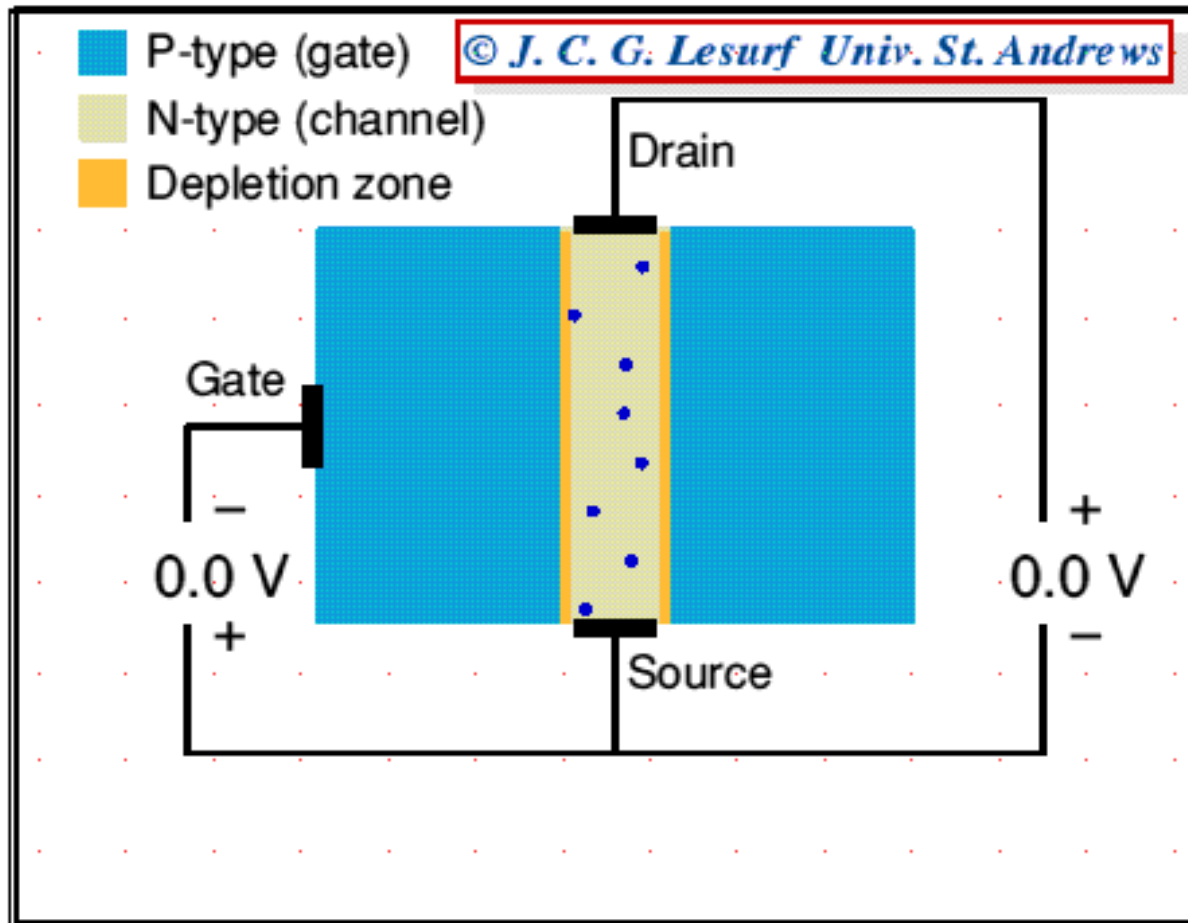


10 Volts drain-source

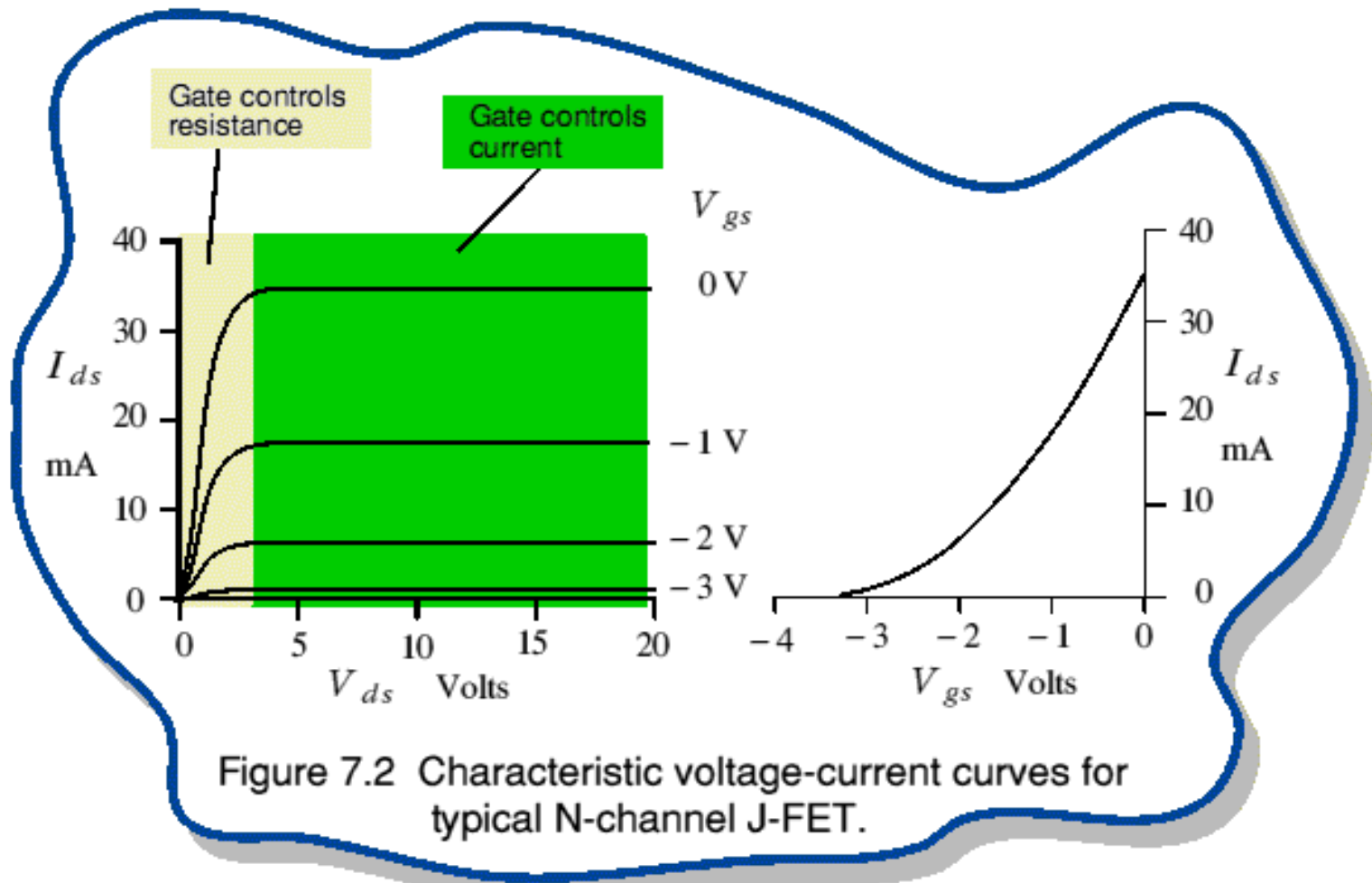


20 Volts drain-source

# Transistor de Efeito de Campo: JFET

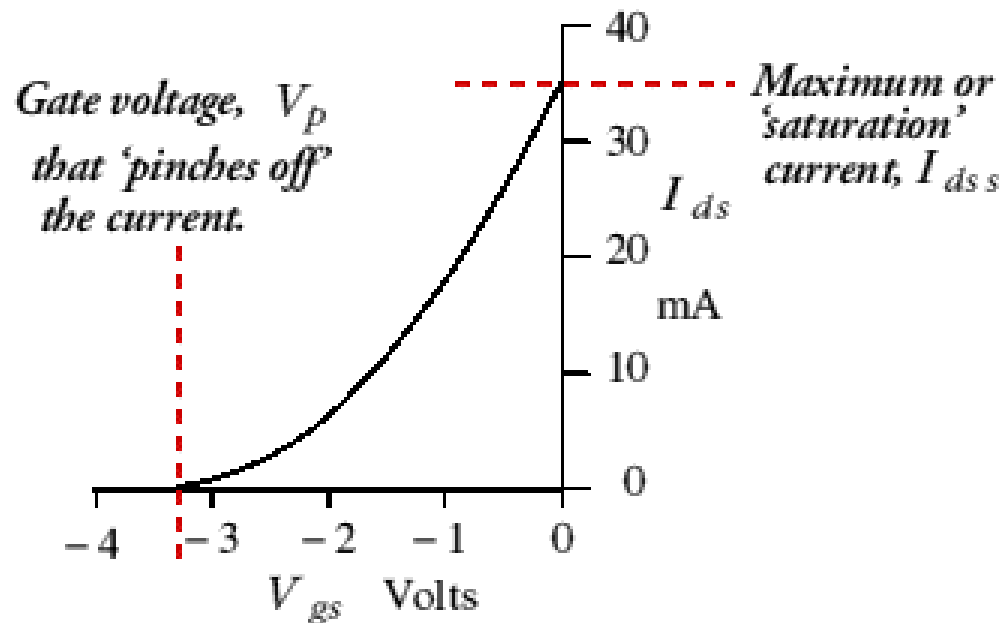


# Curvas características do JFET



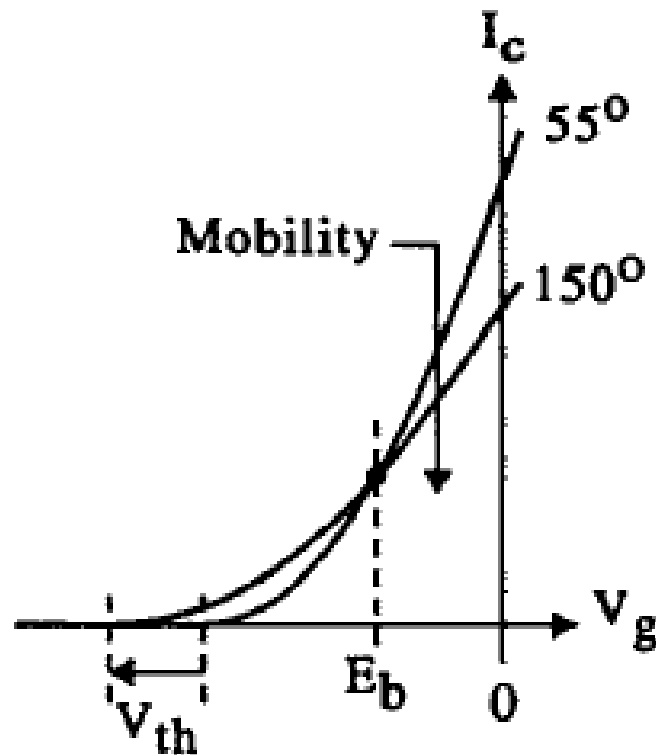
# Curvas características do JFET

Simplified characteristic curve for any drain-source voltage above a few volts.



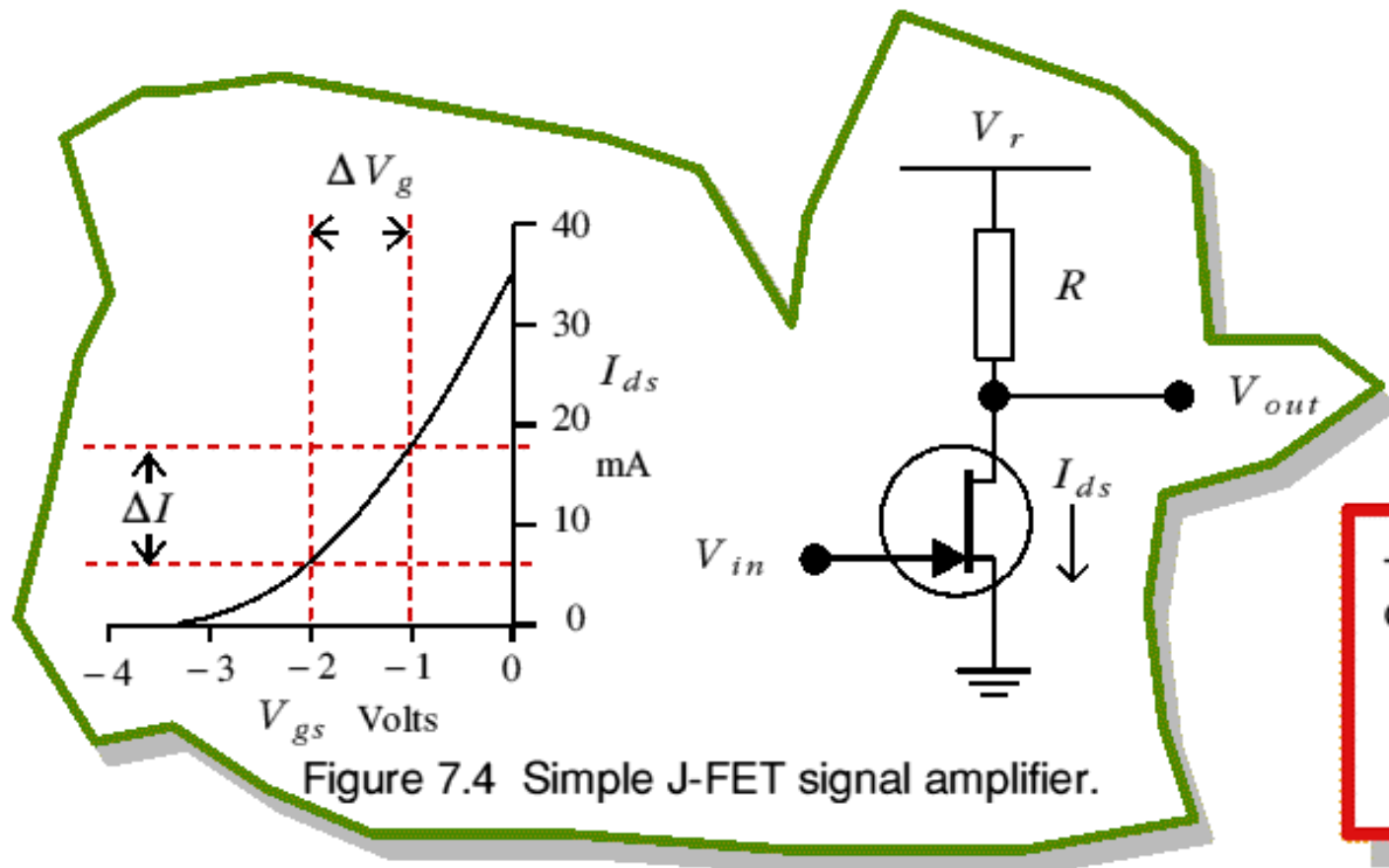


# Efeito da temperatura sobre as características do JFET



Efeito da temperatura sobre a curva característica  $I_C$  vs.  $V_G$  do JFET.

# Circuito de polarização do JFET



Transconductance  
of a FET

$$g \equiv \frac{\Delta I_{ds}}{\Delta V_{gs}}$$

# Ganho de tensão do amplificador JFET

Changing the input voltage by

$$\Delta V_{in}$$

Alters the drain-source current by

$$\Delta I = g\Delta V_{in}$$

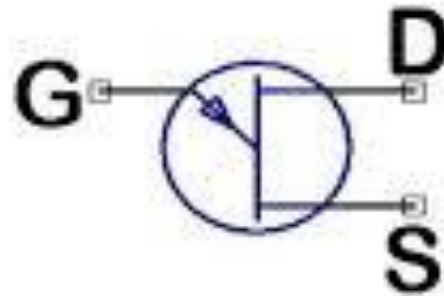
This changes the output voltage by an amount

$$\Delta V_{out} = -R \times \Delta I = -gR\Delta V_{in}$$

By taking the out/input voltage ratio we get a value

$$A_v = \frac{\Delta V_{out}}{\Delta V_{in}} = -gR$$

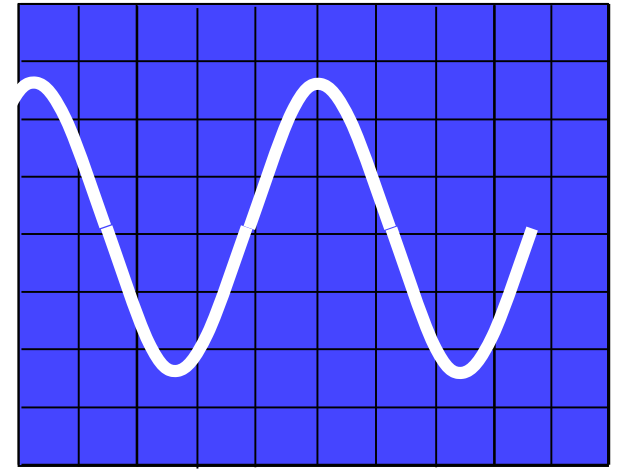
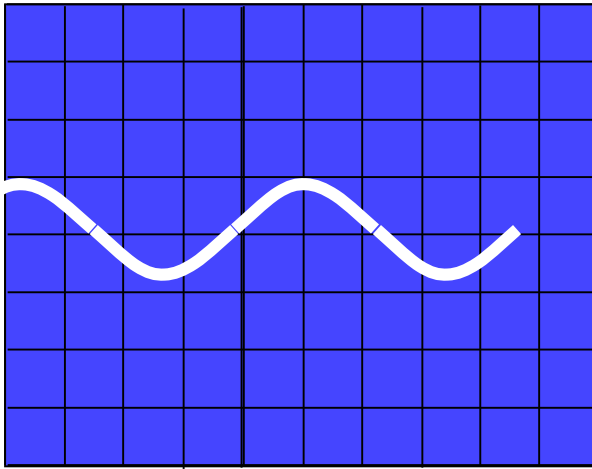
# Transistor de Efeito de Campo: JFET



S = Source

D = Drain

G = Gate



**Entrada de Corrente**

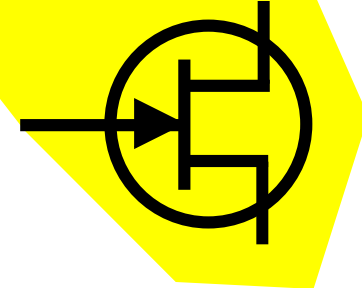
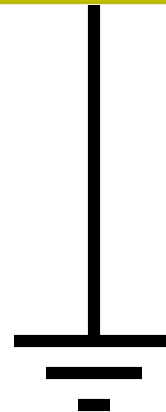
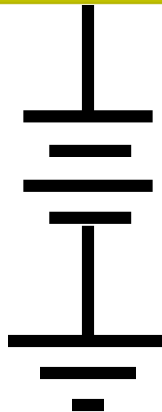


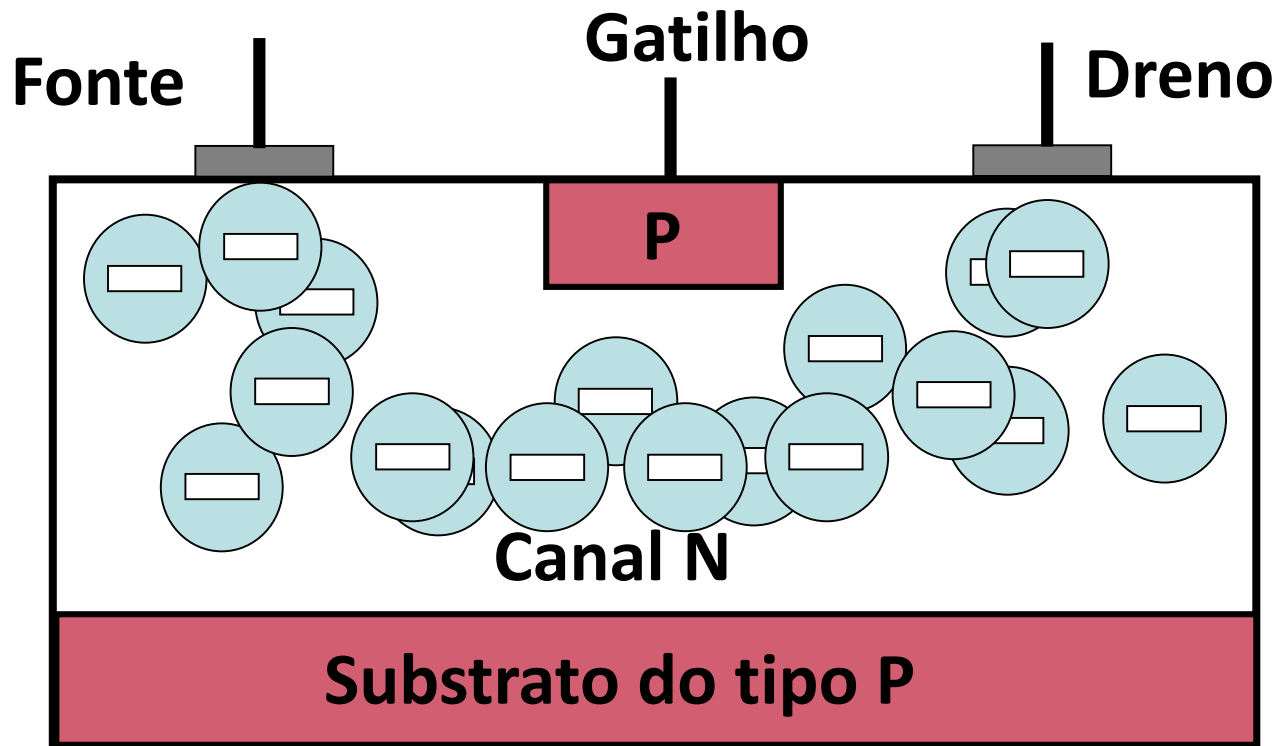
**Amplificador  
de  
Tensão**

**Saída de Corrente**



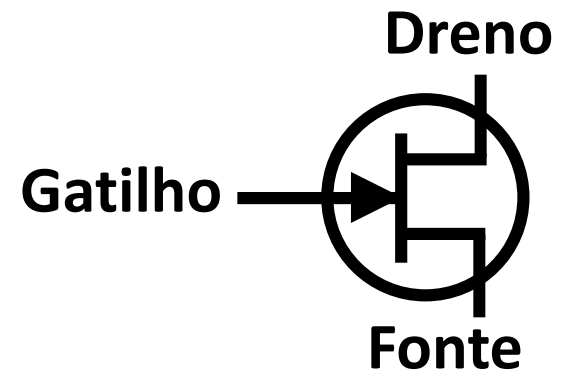
O JFET é  
um amplificador  
de tensão  
controlada.

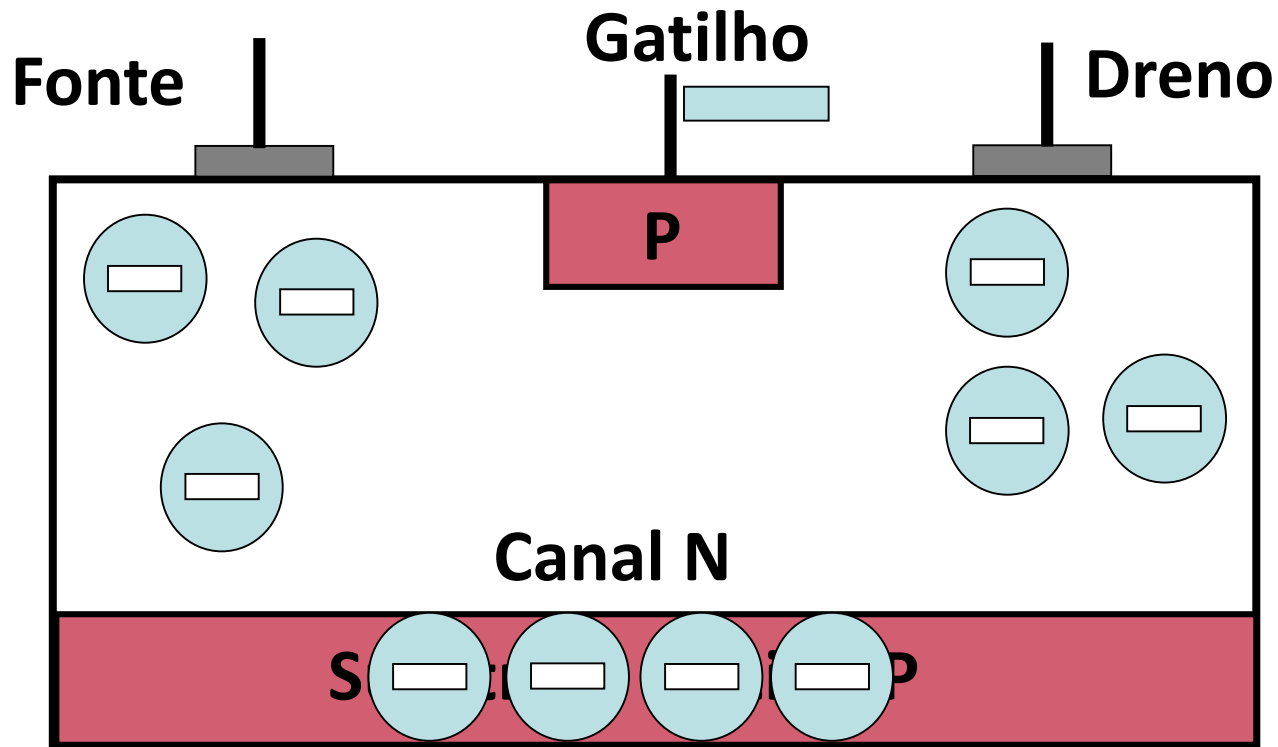




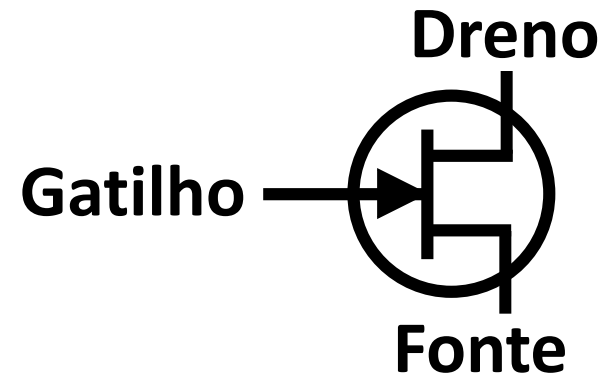
**Estrutura de um  
canal N JFET**

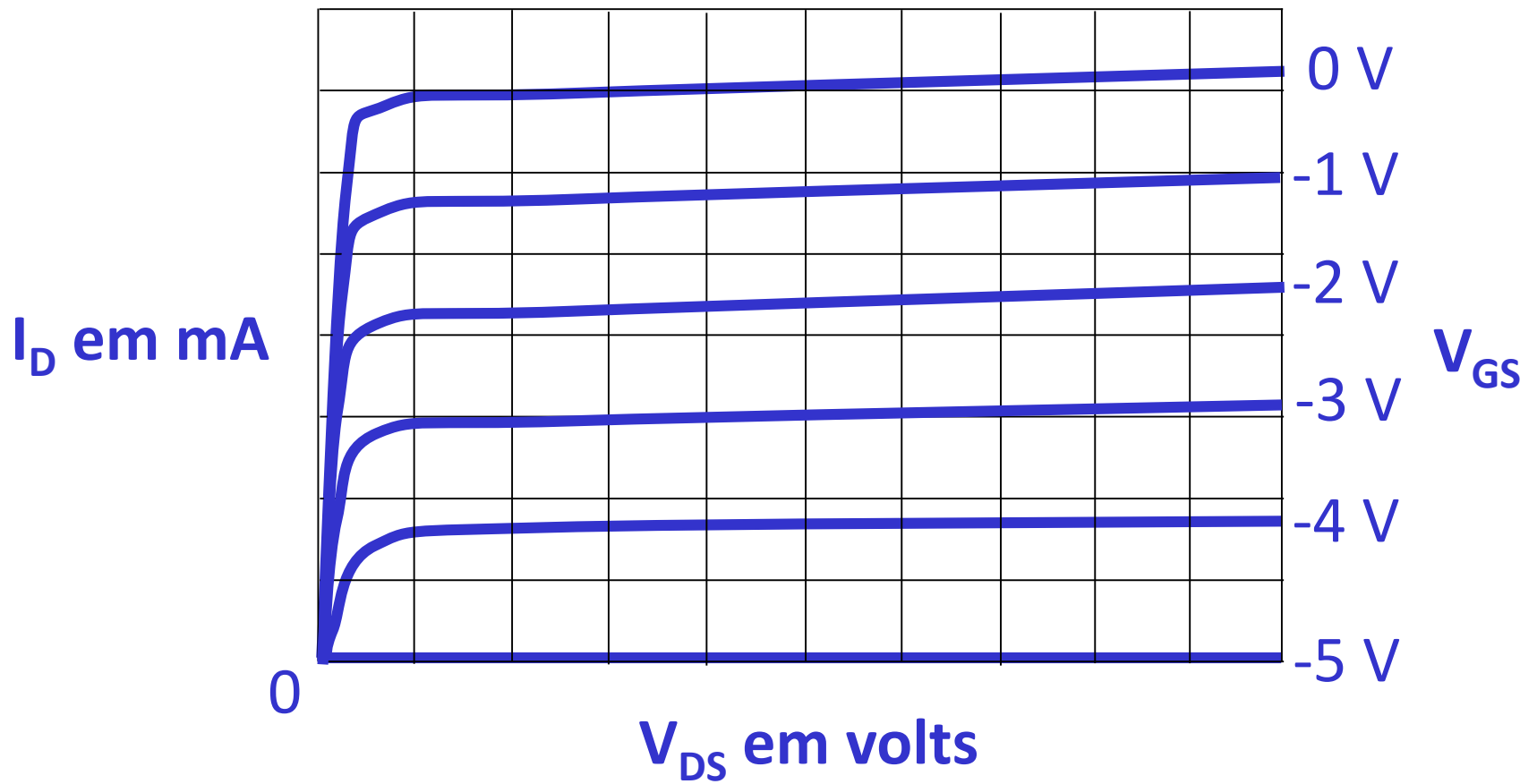
O canal possui portadores para que se possa  
conduzir da fonte para o dreno.





Uma tensão de gatilho negativa pode empurrar os portadores do canal e desligar o JFET.



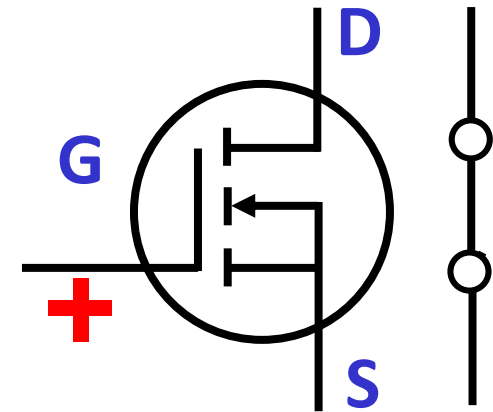
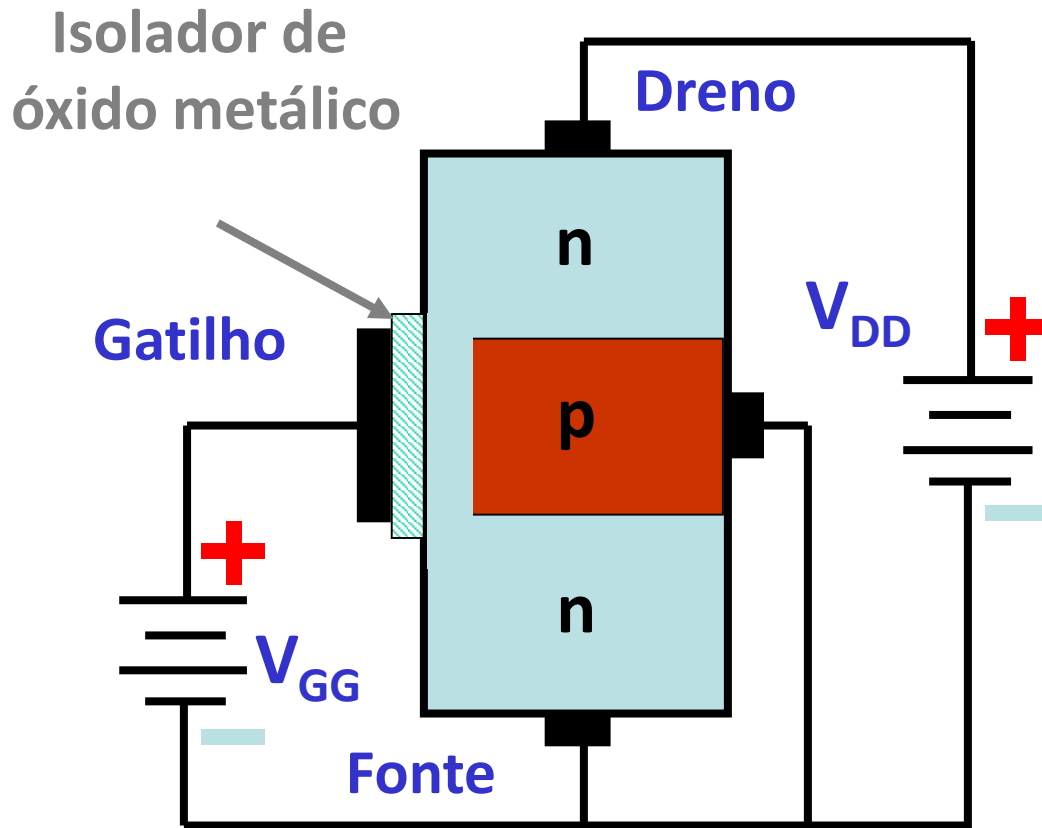


Isto é conhecido como um dispositivo de modo depleção.

Família de curvas características de um canal N de dreno JFET

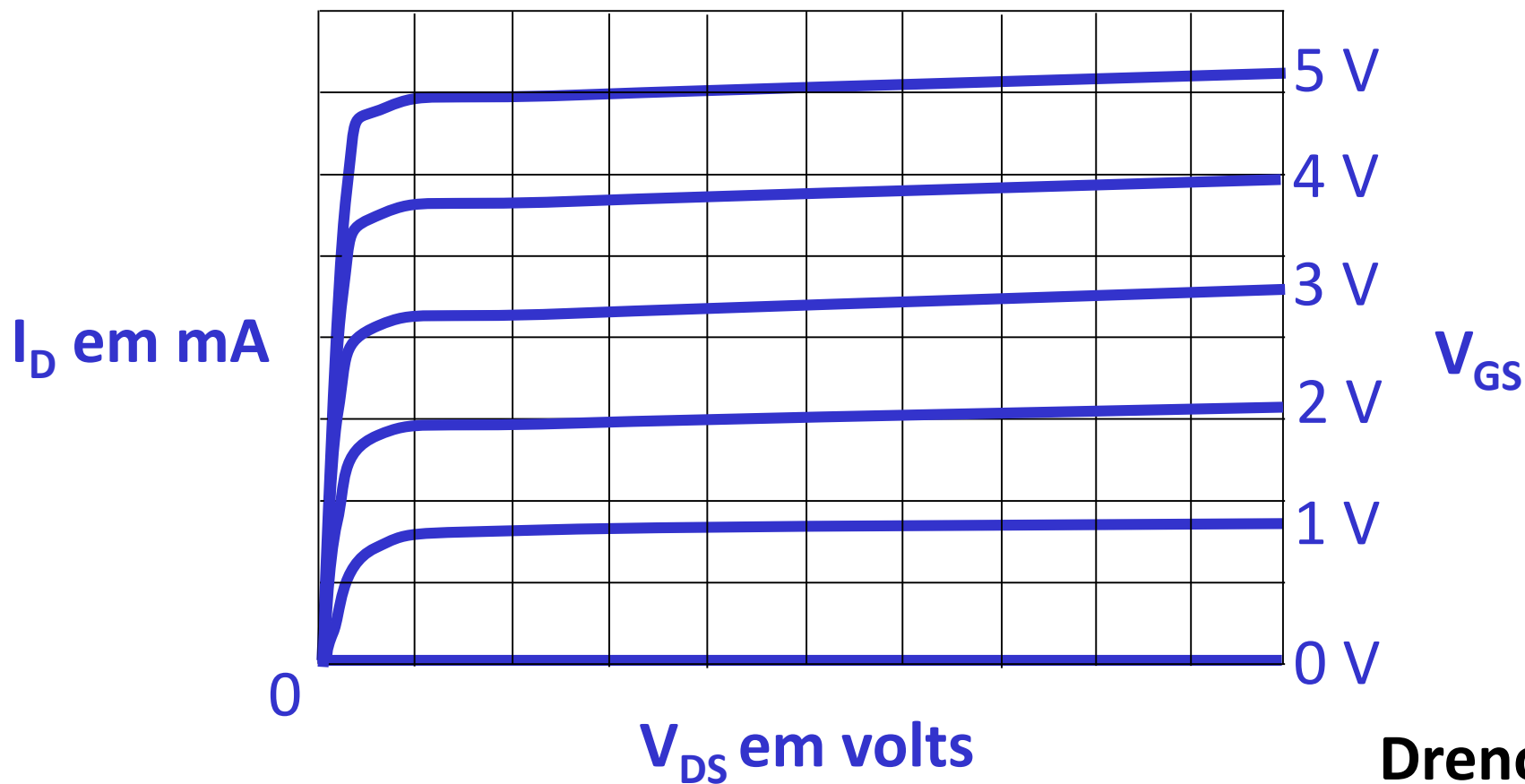


É possível fazer transistores de efeito de campo de potência também.

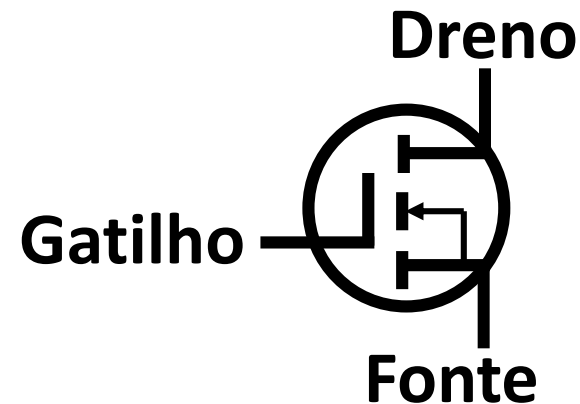


Canal N  
MOSFET

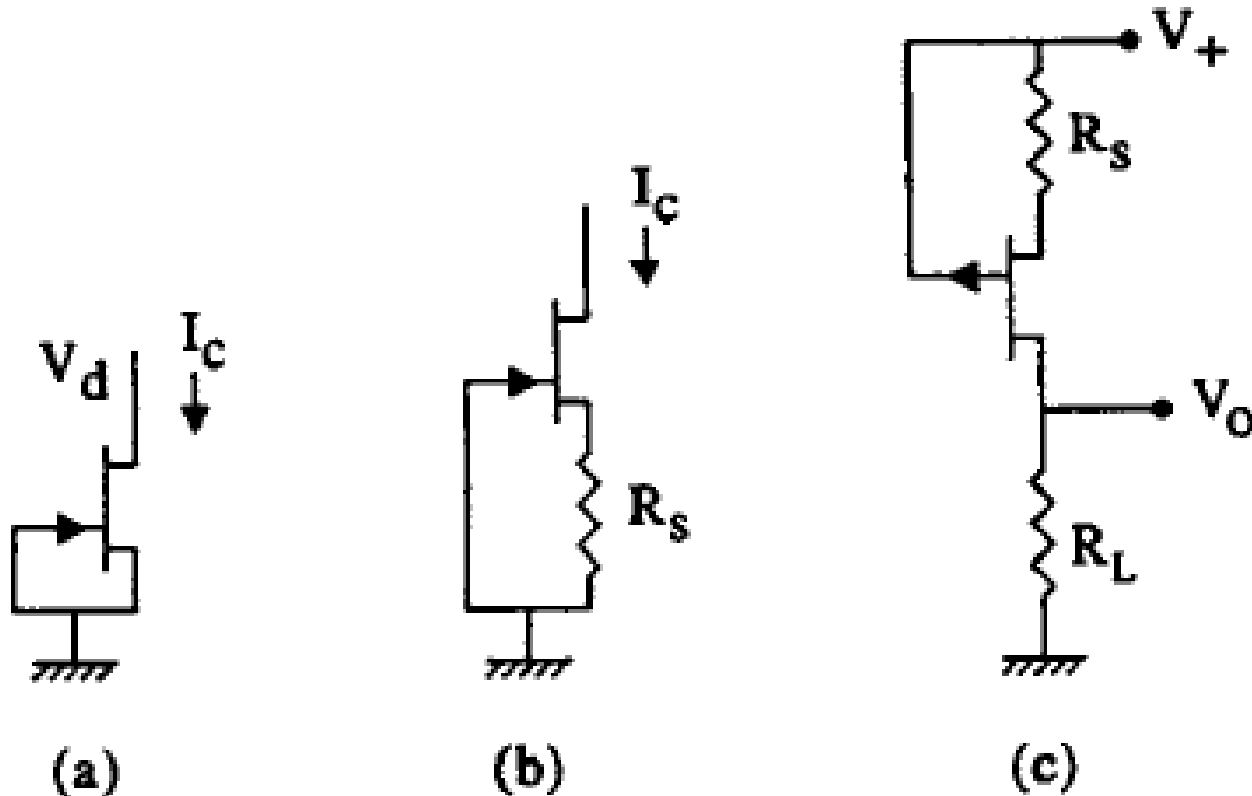
Polarização de gatilhos potencializa o canal e liga o dispositivo.



**Família de curvas características  
de um dreno MOSFET  
em modo de intensificação**



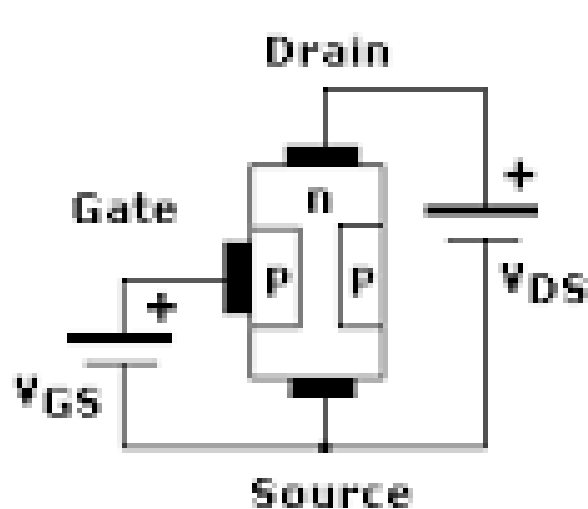
# Aplicação de JFET: fonte de corrente



JFET com o fonte de corrente constante: (a) circuito básico; (b) adição de  $R_s$  para corrigir efeito de temperatura; (c) referência de tensão de baixo ruído usando JFET canal P.

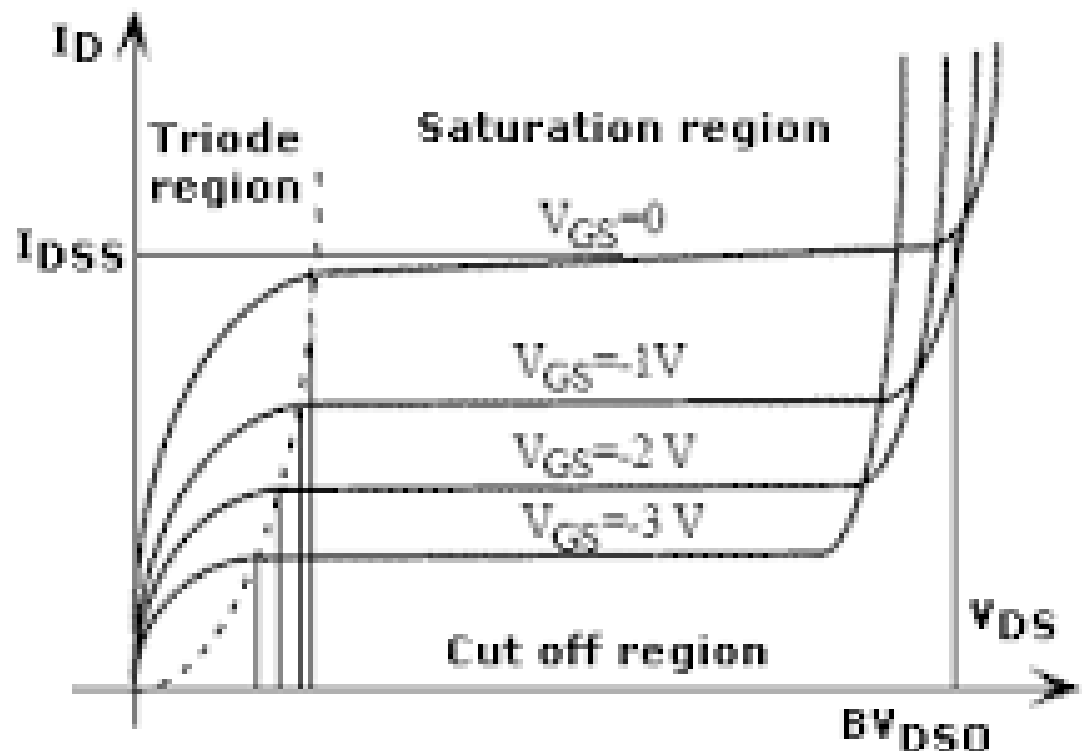
# Transistor de Efeito de Campo: JFET

## Curva característica do JFET



NJFET  
Characteristics

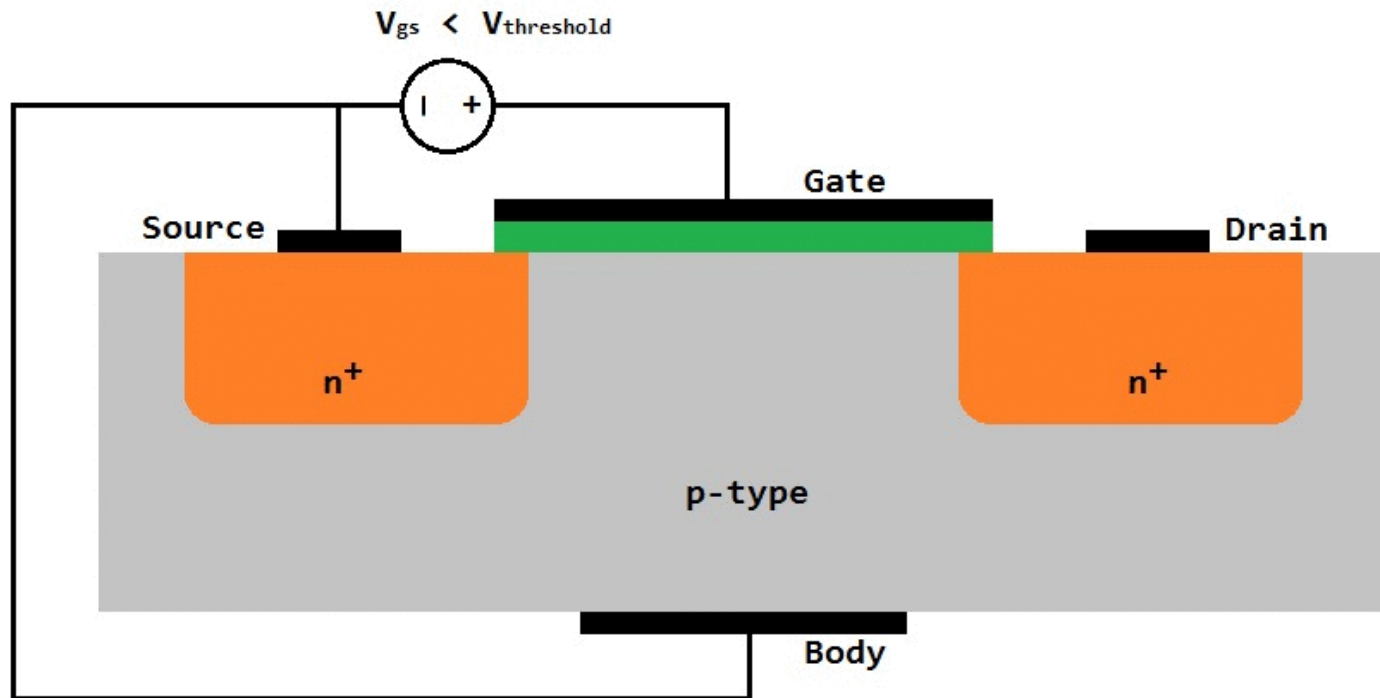
[www.electronicsdata.com](http://www.electronicsdata.com)



# **Transistor de Efeito de Campo de Óxido Metálico: MOSFET**

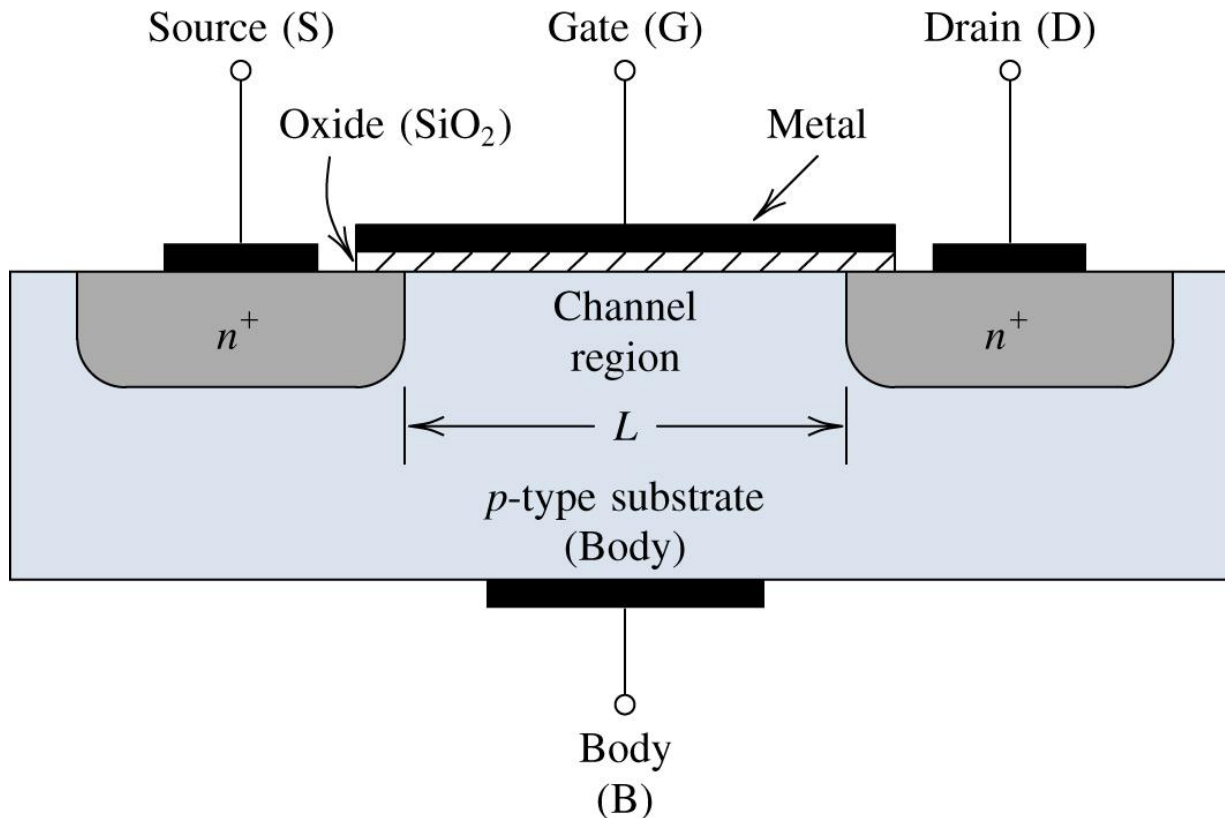
**Transistor de efeito de campo de porta isolada  
ou FET óxido metálico semiconductor**

# MOSFET

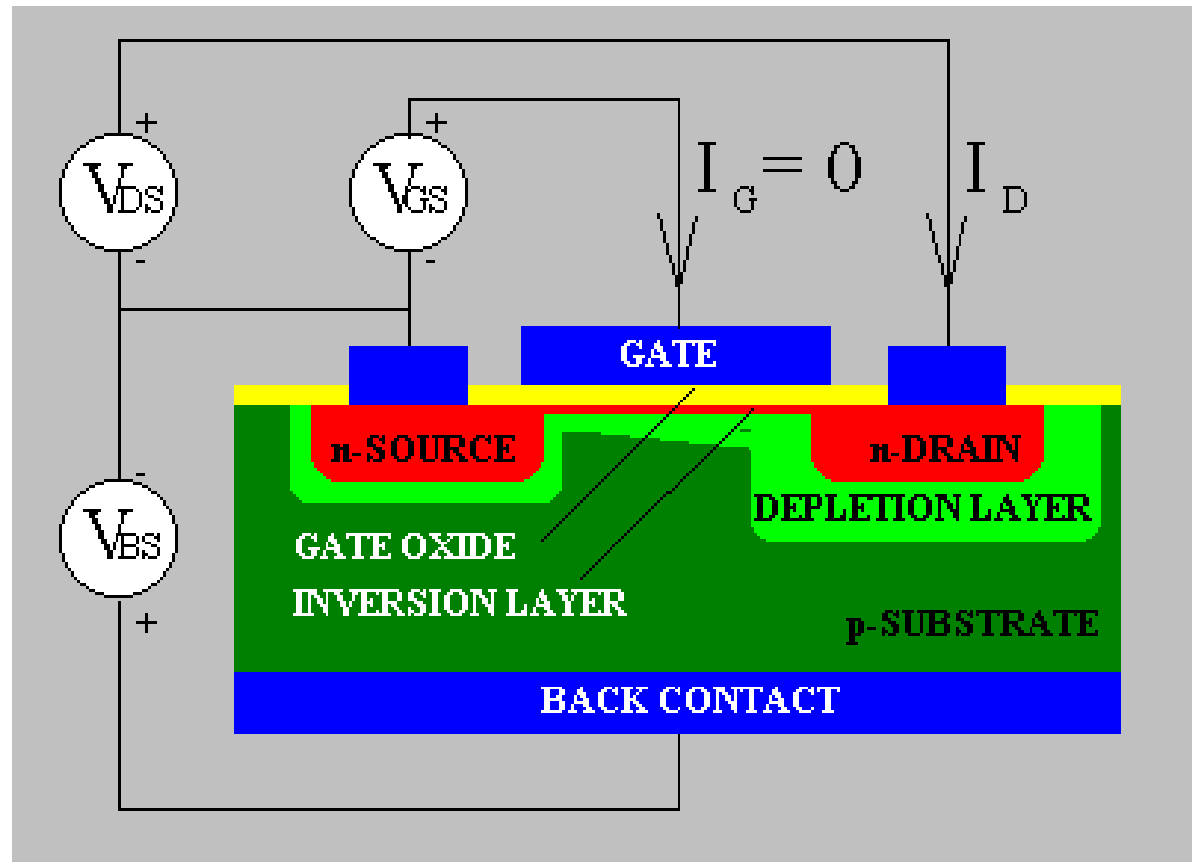


# MOSFET

Dispositivo semiconductor de quatro terminais: Gate (G), Source (S), Dreno (D) e Substrato ou Body (B), controla a corrente  $I_{DS}$  por meio da tensão  $V_{GS}$ .

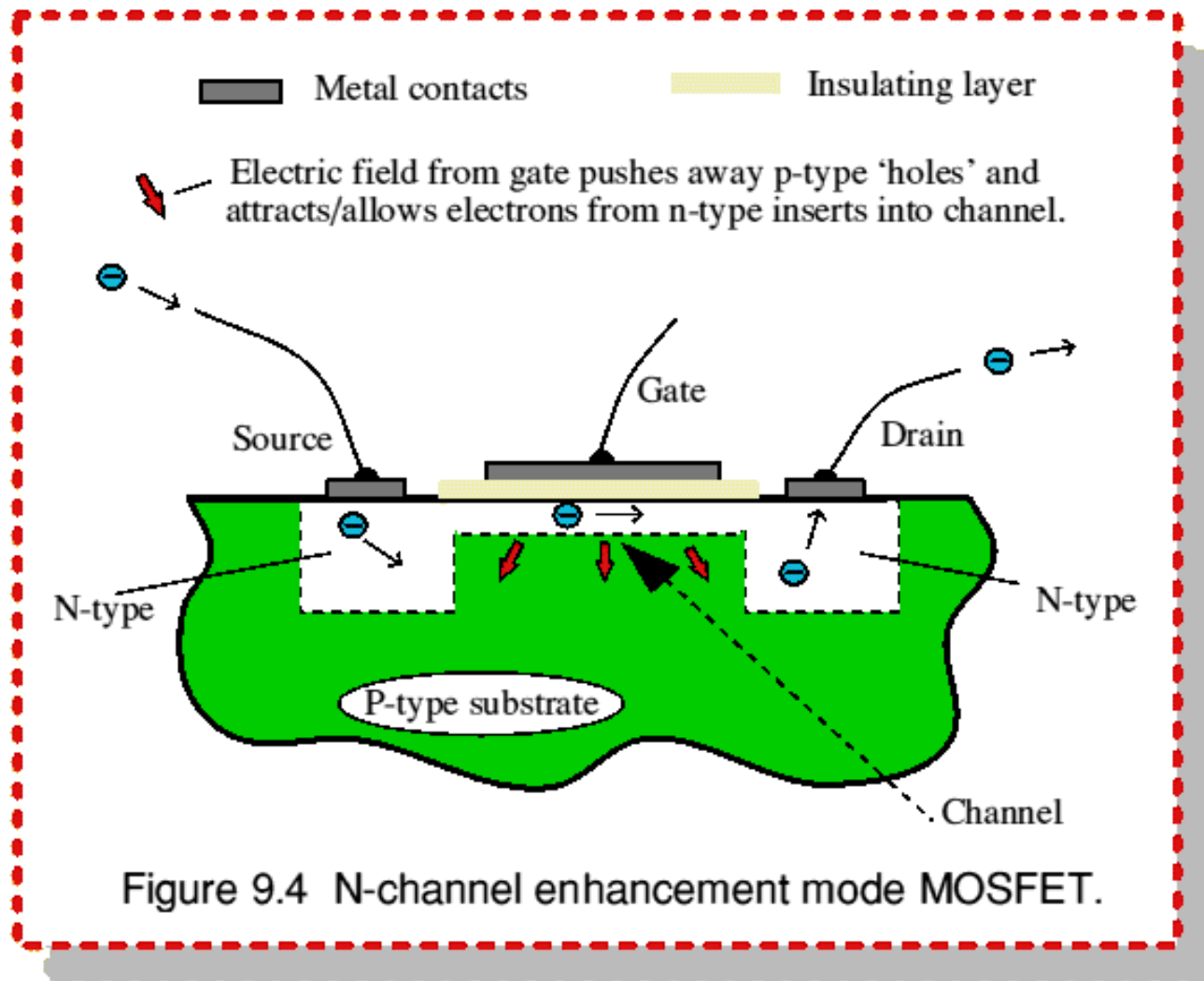


# MOSFET





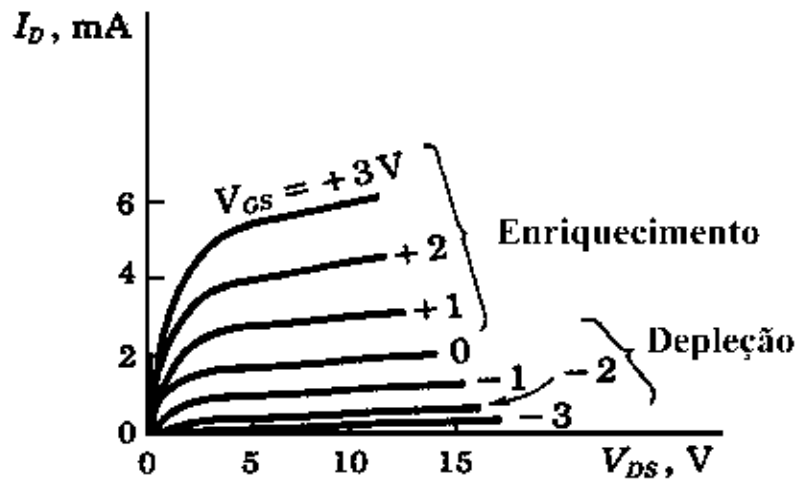
# Funcionamento do MOSFET



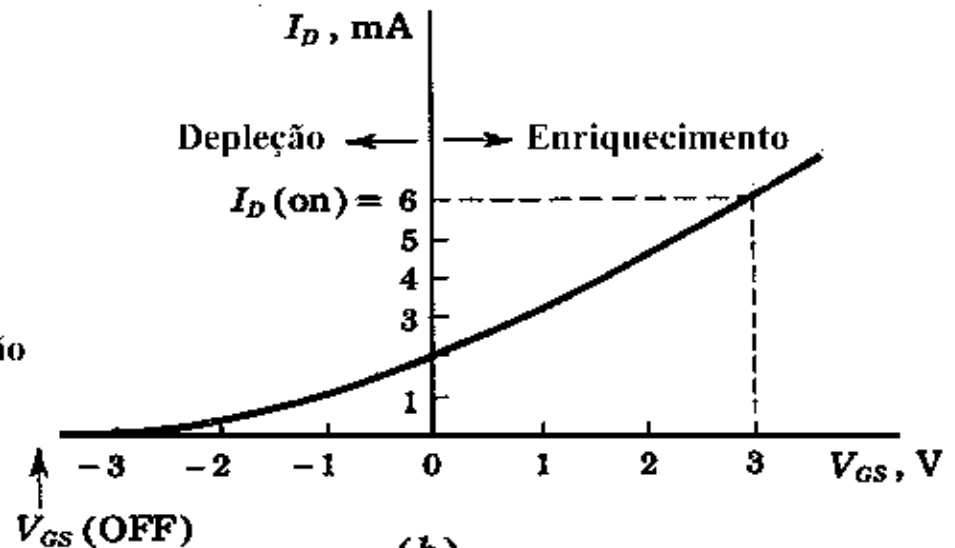
# Modos de operação do MOSFET

## Curvas características

## Curva de transferência



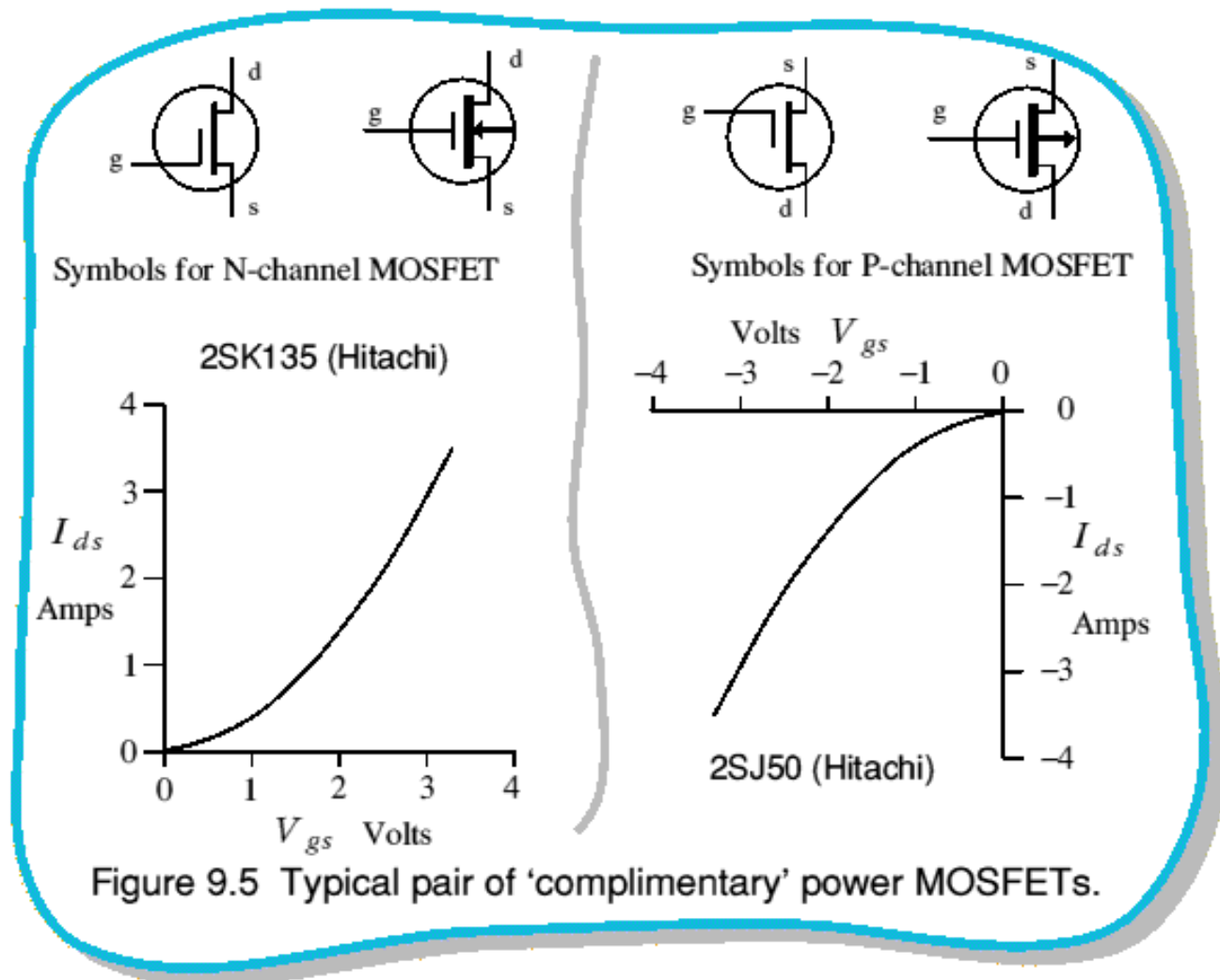
(a)



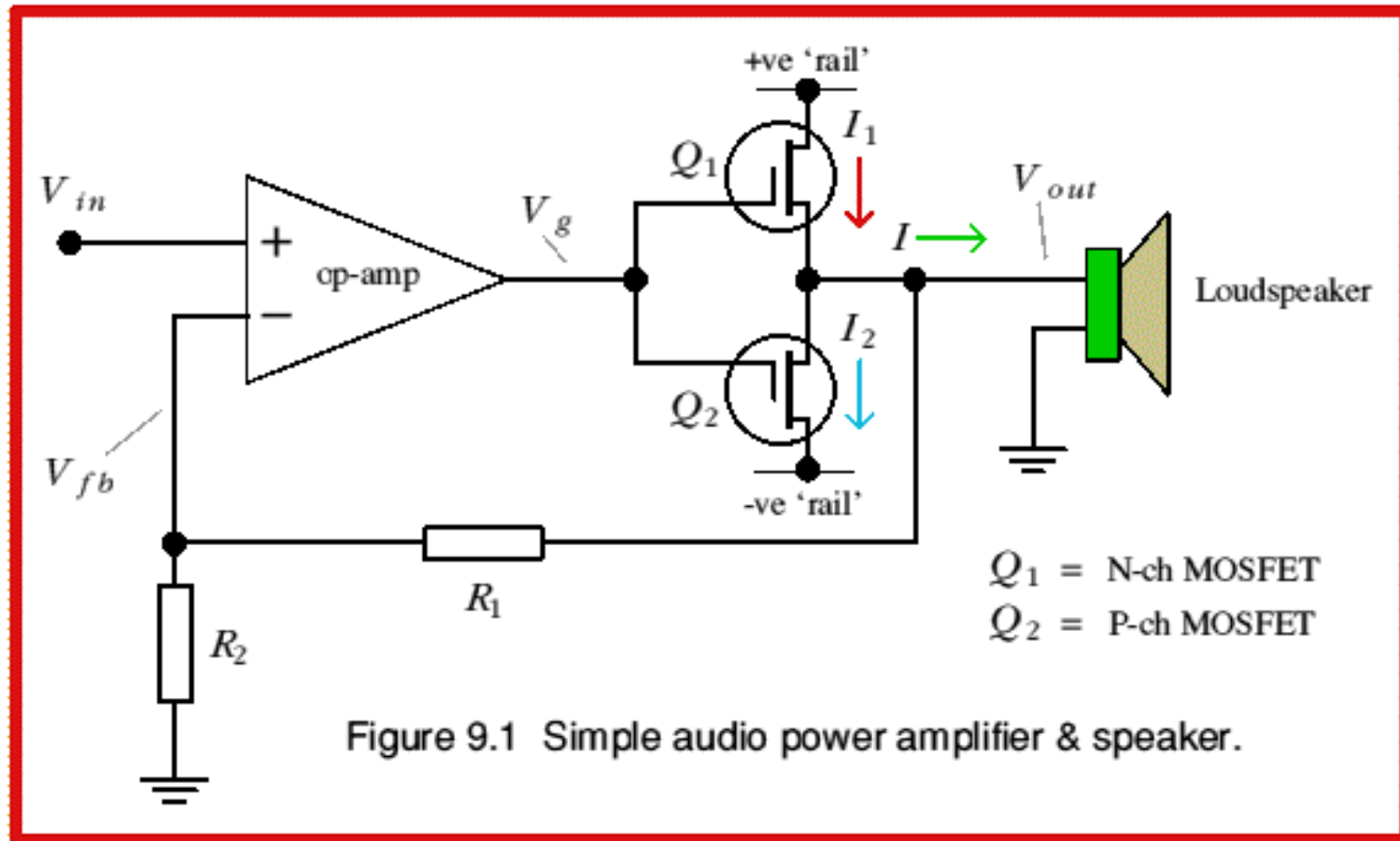
(b)

(a) Curvas I-V características e (b) curva de transferência (para  $V_{DS} = 10$  V) para um NMOSFET que tanto pode ser usado no modo de depleção quanto no modo de enriquecimento.

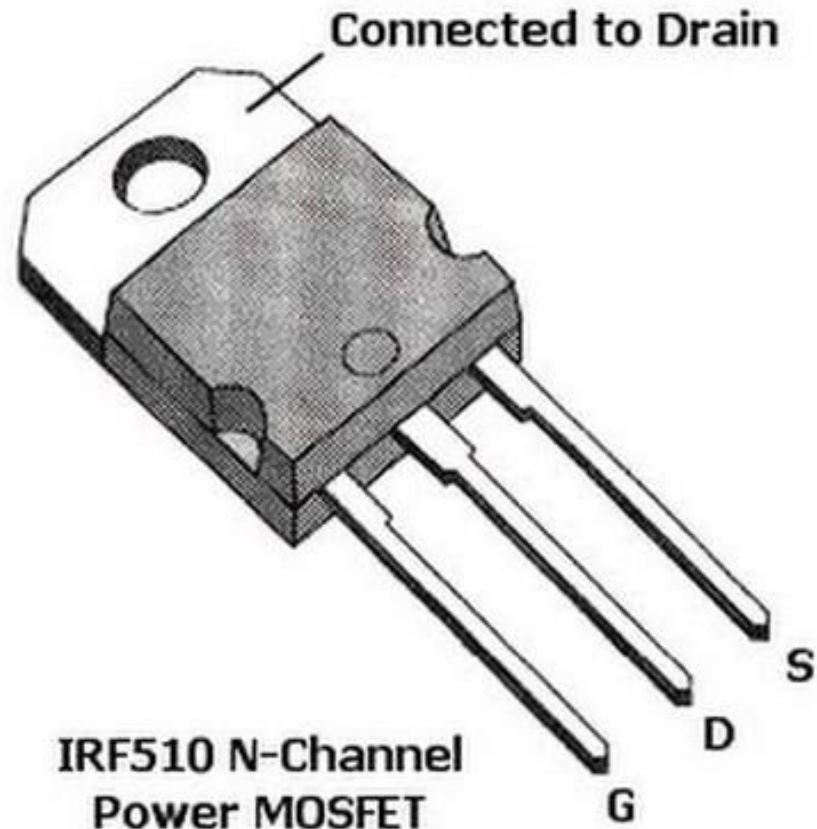
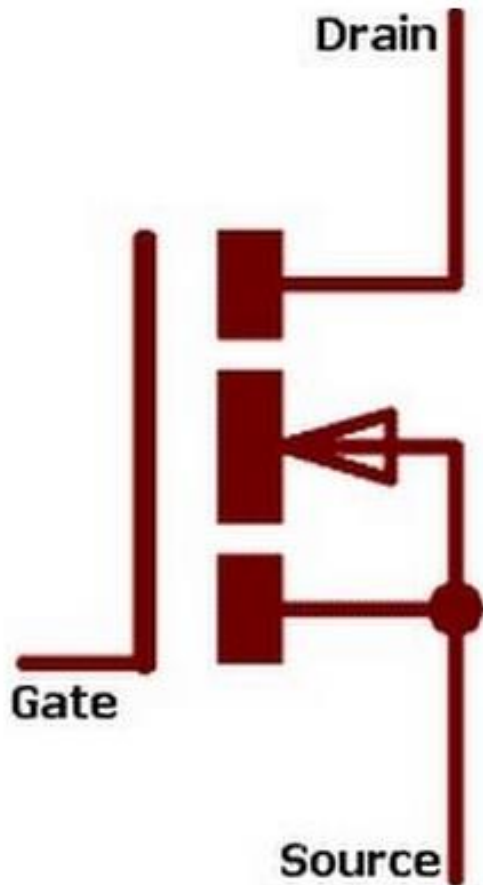
# Curvas características do CMOSFET



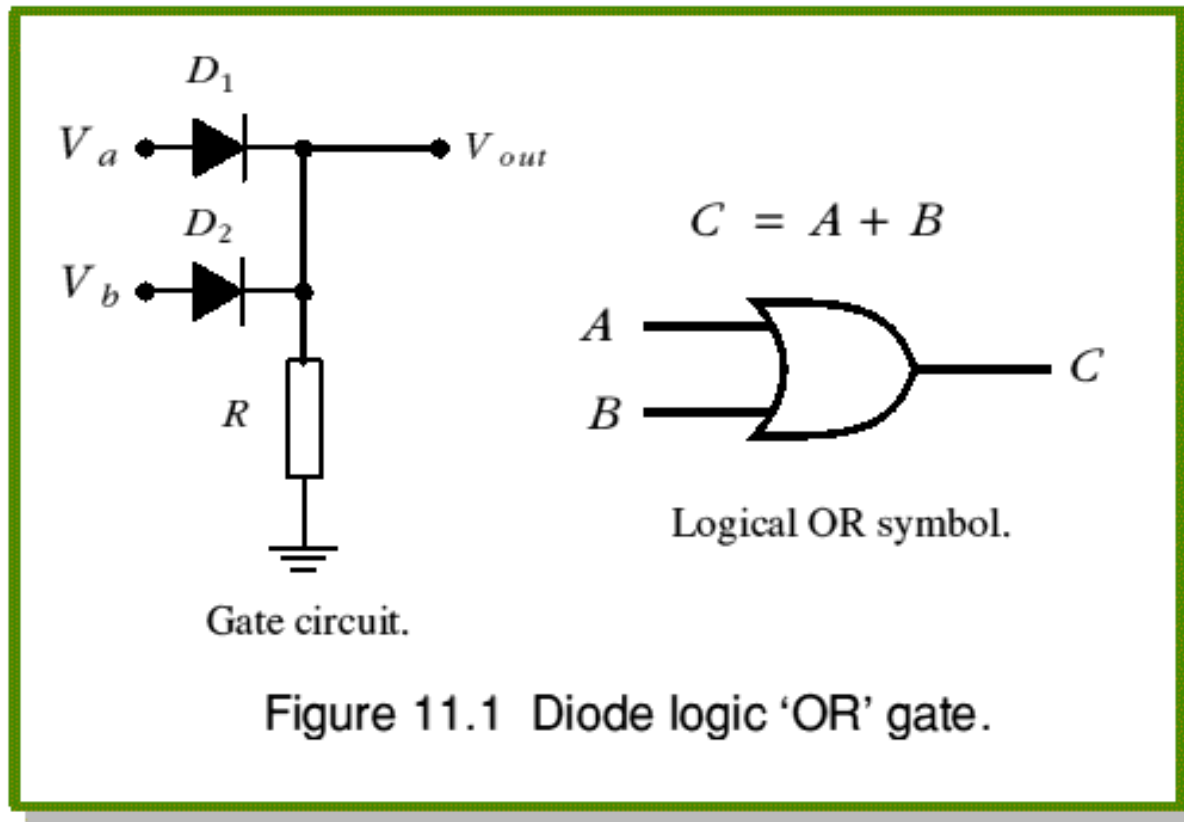
# O MOSFET como Amplificador



# MOSFET de potência

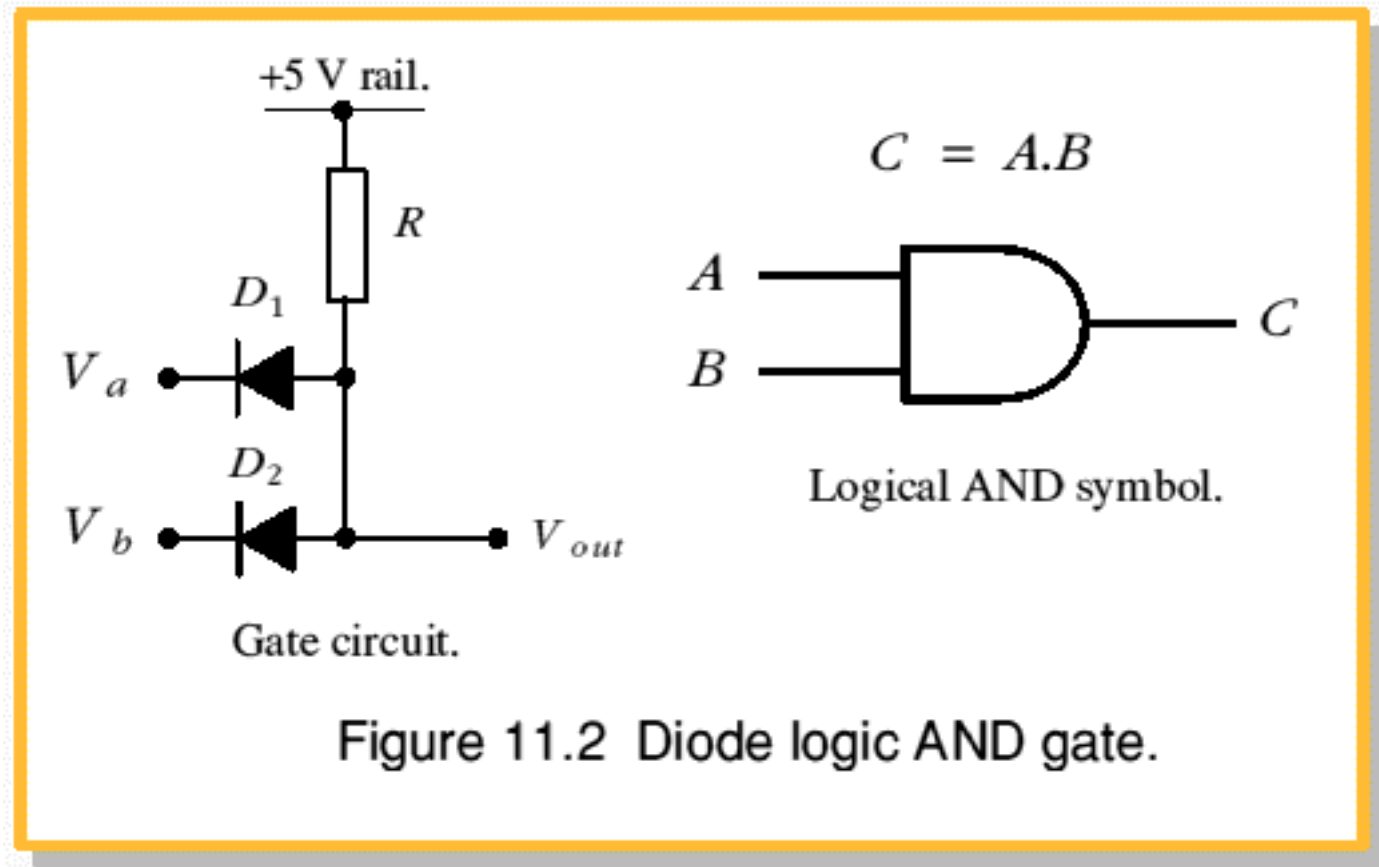


# Portas lógicas e circuitos digitais



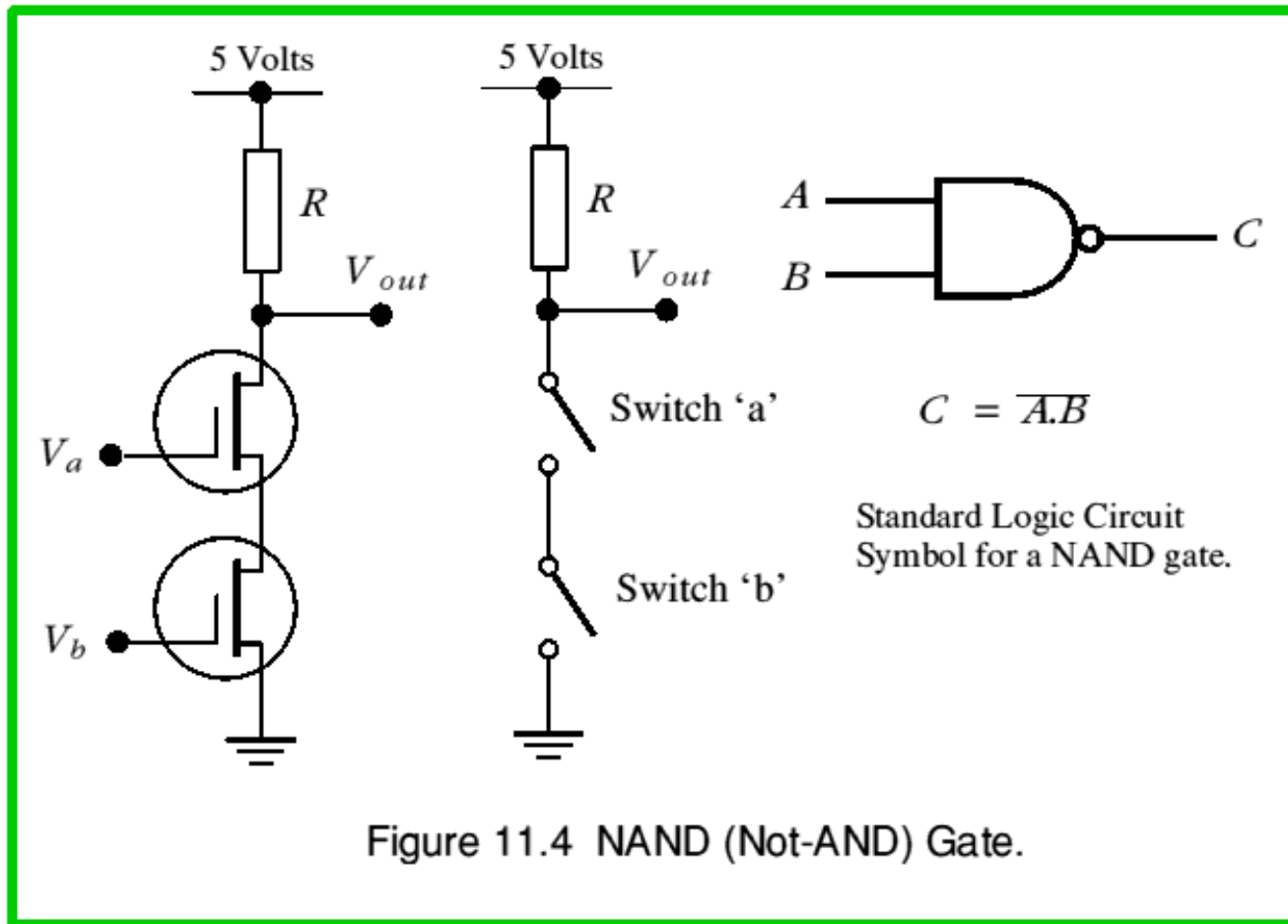
Porta lógica OU

# Portas lógicas e circuitos digitais



Porta lógica AND

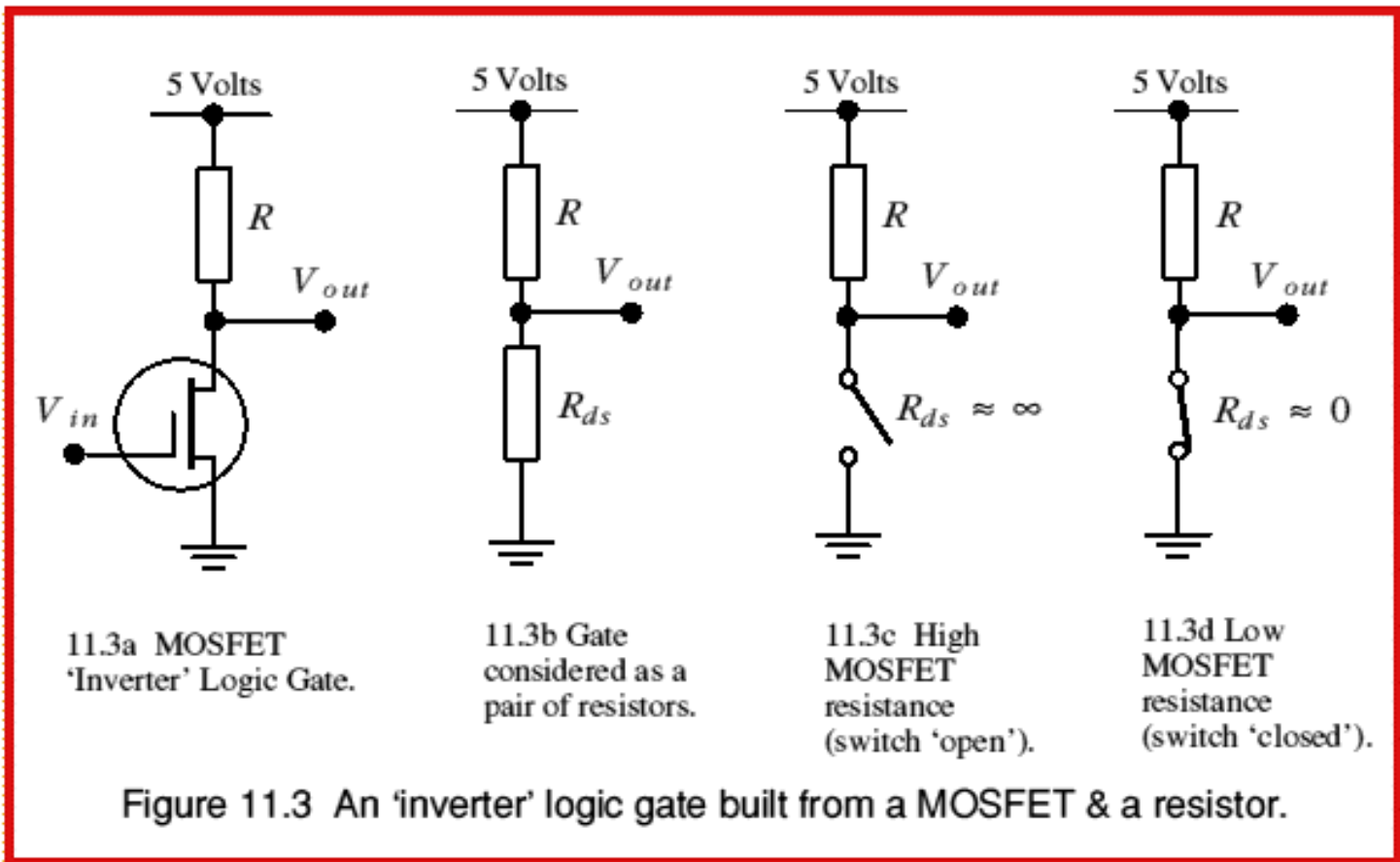
# O transistor como chave: portas lógicas e circuitos digitais



Porta lógica NAND

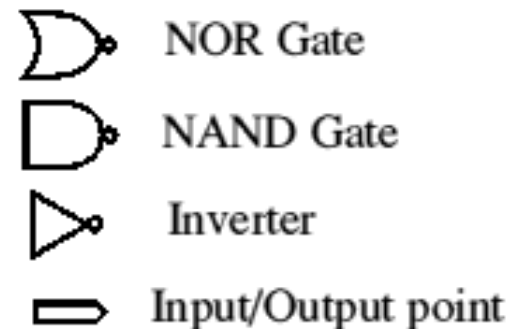
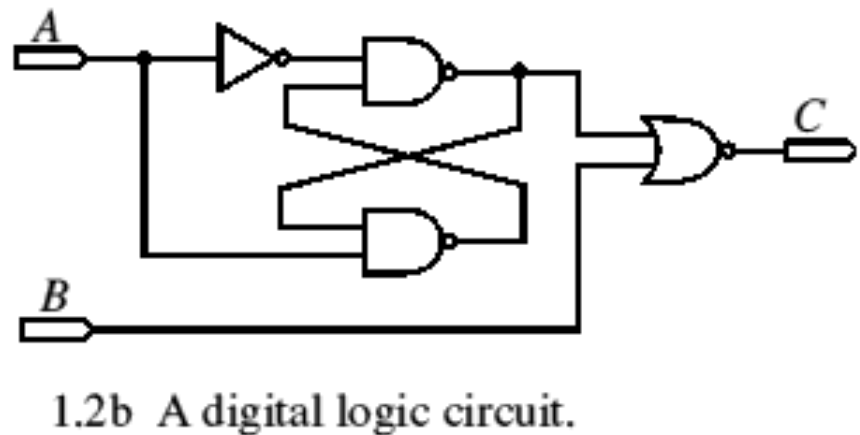
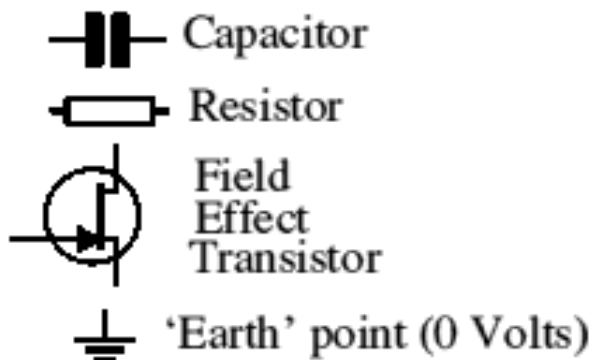
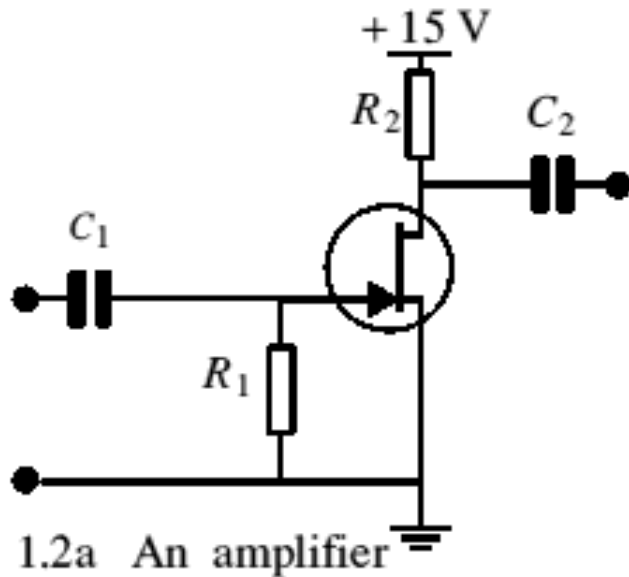


# O transistor como chave: portas lógicas e circuitos digitais

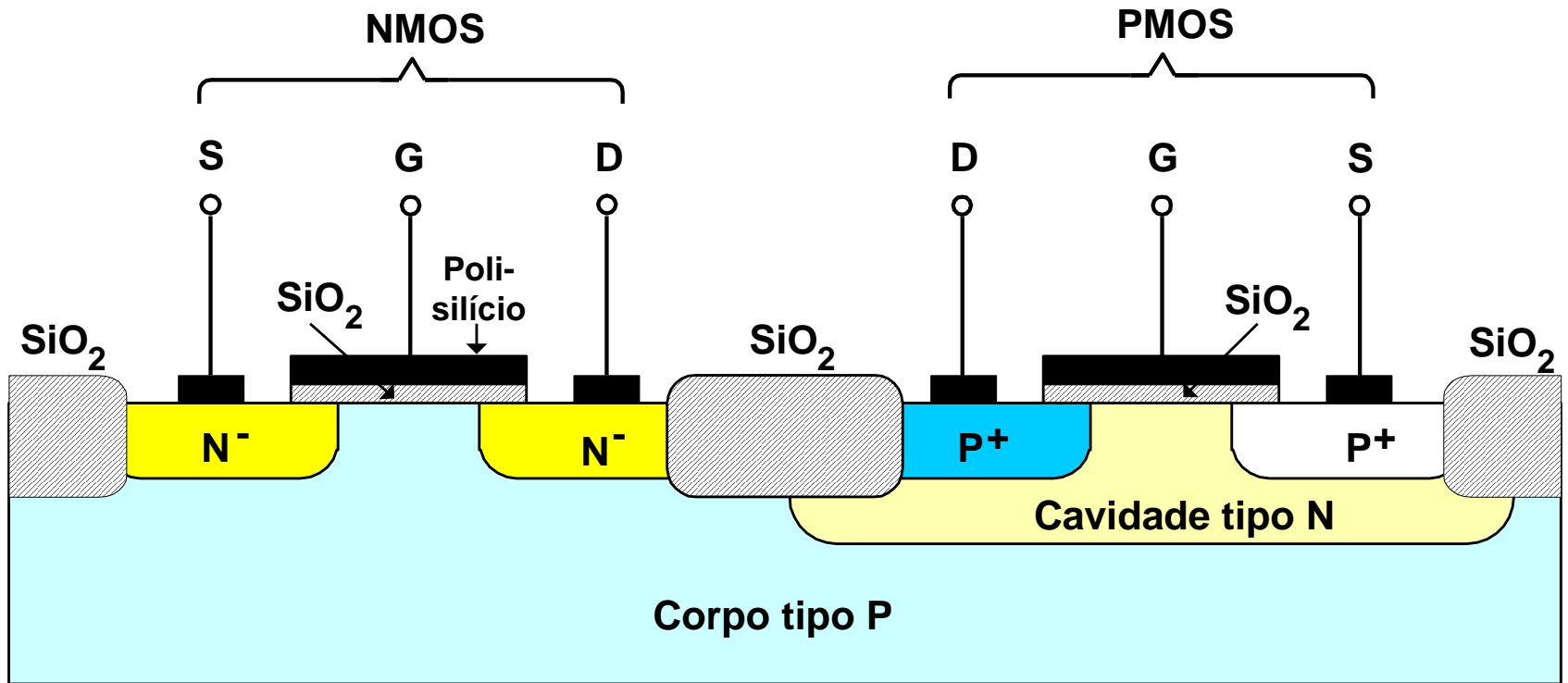


Porta lógica inversora

# Circuitos com transistor: amplificador e porta lógica

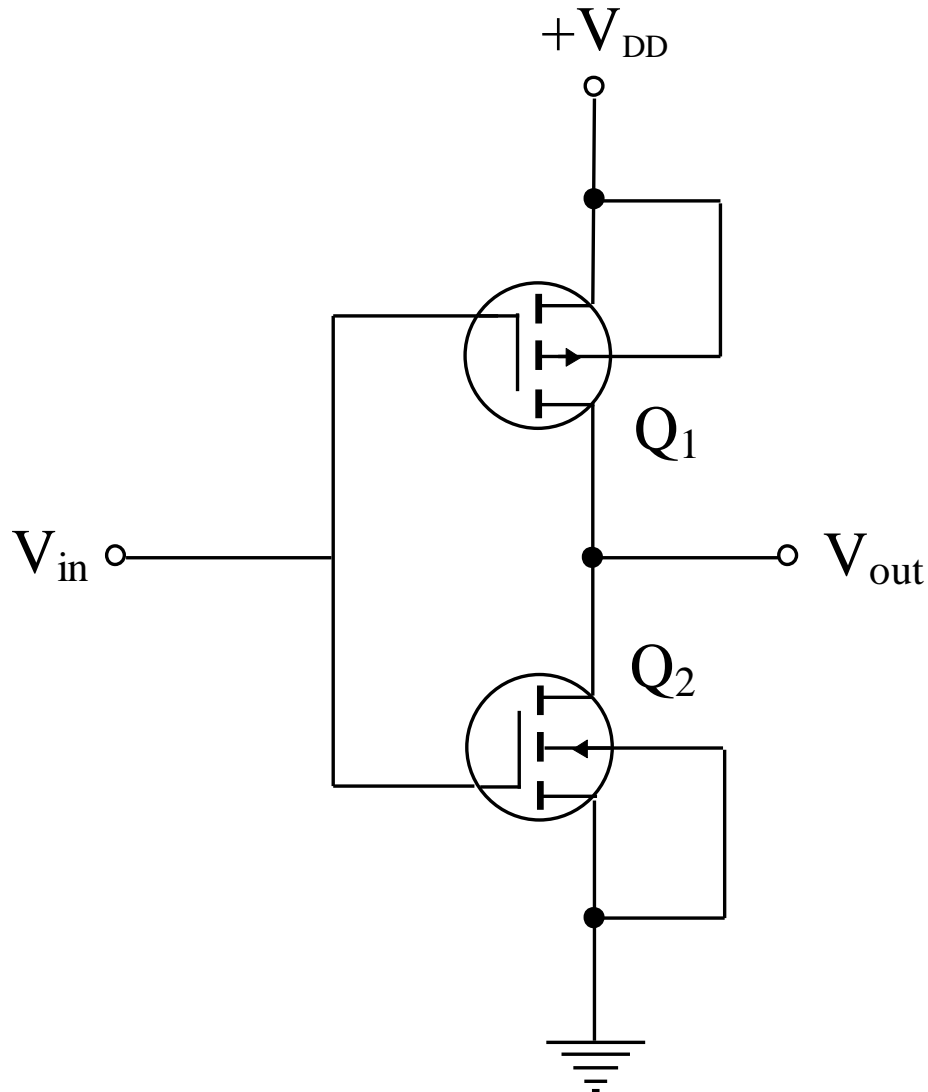


# Transistores FET complementares: CMOS



Par complementar de MOSFETs canal N e canal P = CMOS

# Transistor CMOS: porta lógica inversora



## Parâmetros operacionais:

$$V_{DD} = 3 \text{ a } 15 \text{ V}$$

$$P_d = 0,3 \text{ mW},$$

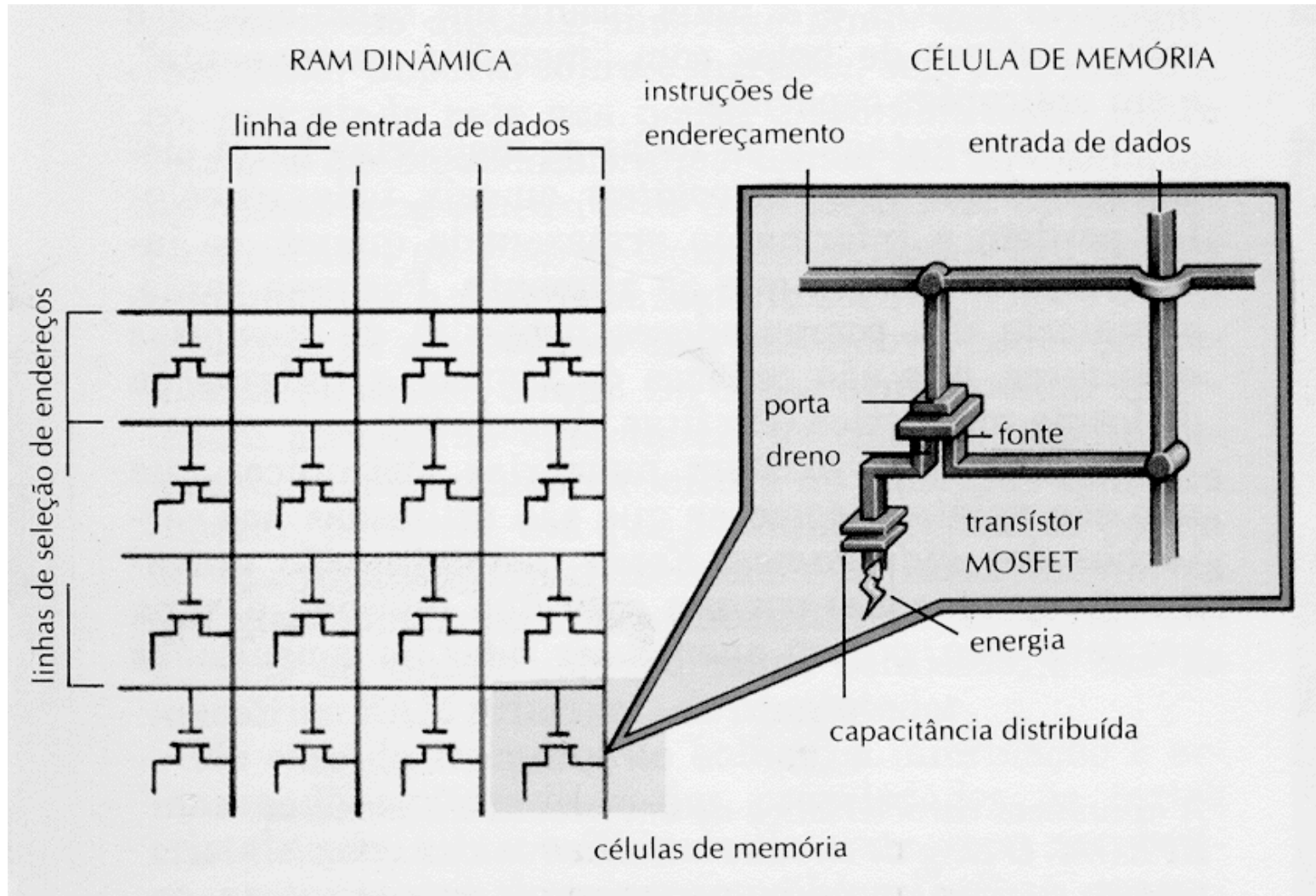
$$\tau_d = 200 \text{ ns},$$

$$V_{NM} = 0,4 V_{DD}$$

Estado lógico "1"  $V_o \cong V_{DD}$

Estado lógico "0"  $V_o = 0 \text{ V}.$

# Transistores MOSFET: memória RAM



# Comparação de circuitos chave com transistor: bipolar (BJT) e JFET

SWITCH	BJT	JFET
OFF or open		
No current	No collector current	No drain current
Full voltage across terminals	Full supply voltage between collector and emitter	Full supply voltage between drain and source
ON or closed		
Full current	Full circuit current	Full circuit current
No voltage across terminals	Collector to emitter voltage is 0 V	Drain to source voltage is 0 V

# Comparação de transistores: bipolar (BJT) vs. FET

Características	BJT	FET
Impedância de entrada	<	>
Sensibilidade à temperatura	>	<
Controle de corrente de saída.	>	<
Ganho de tensão	>	<
Estabilidade	<	>
Tamanho	>	<

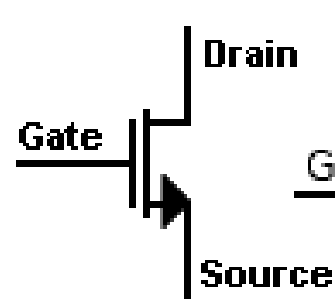
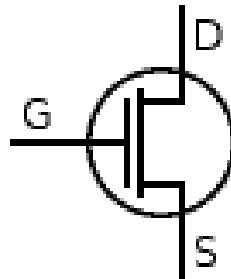
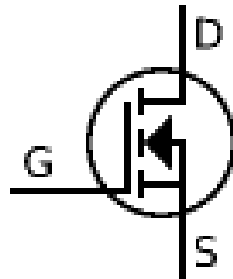
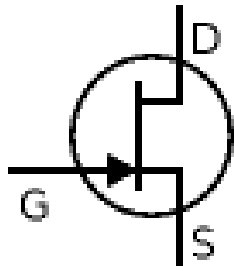
# Comparação de transistores: bipolar (BJT), JFET e MOSFET

Corrente de polarização e impedância de entrada

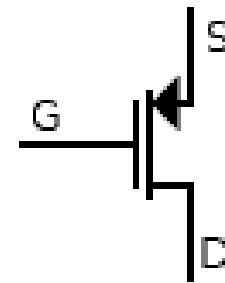
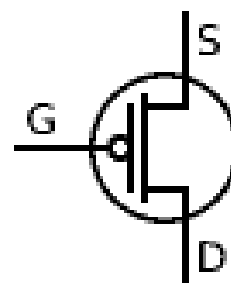
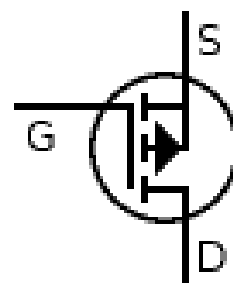
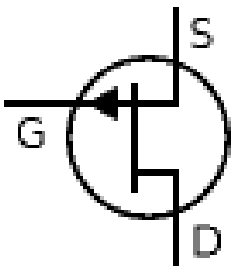
	Bipolar	JFET	MOS
$I_b$	$5\mu A$	$30pA$	$1pA$
$r_{in}$	$5k\Omega$	$1G\Omega$	$25G\Omega$



# Símbolos FET



N-channel



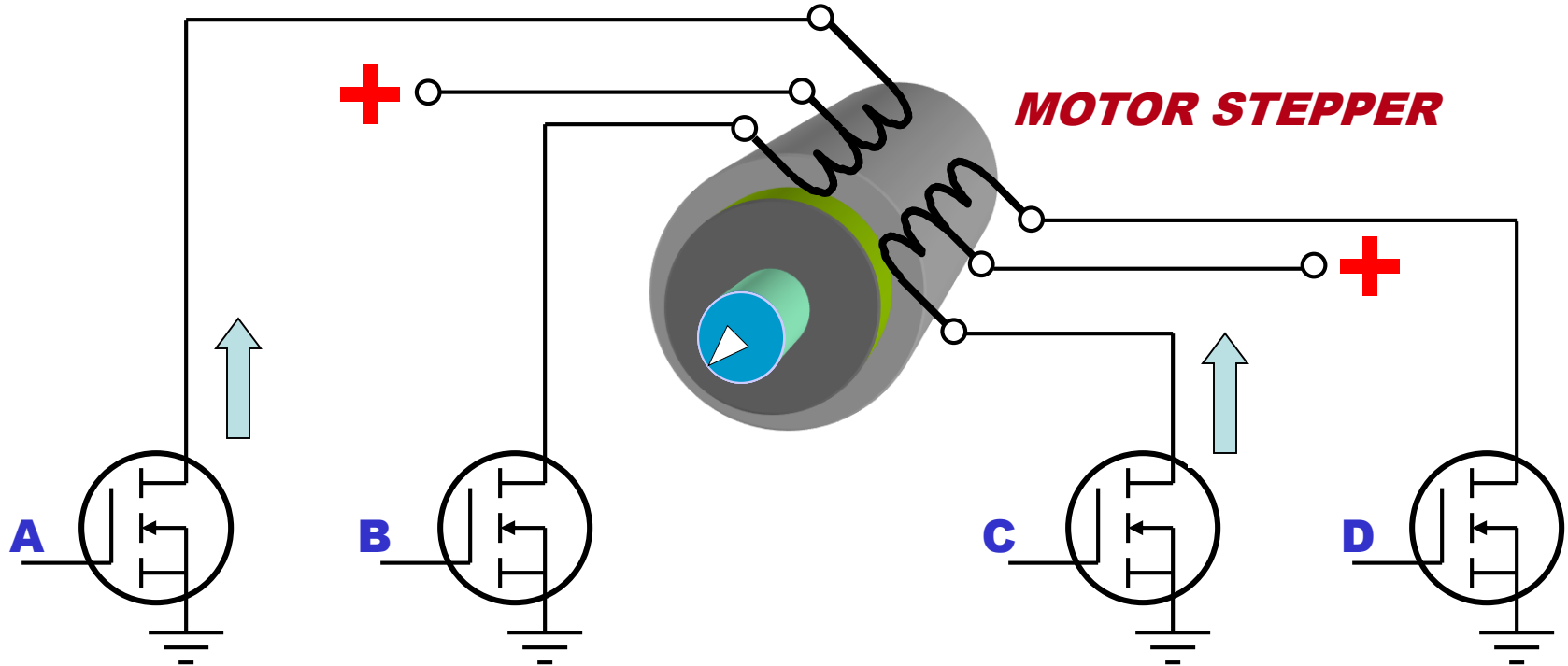
P-channel

JFET

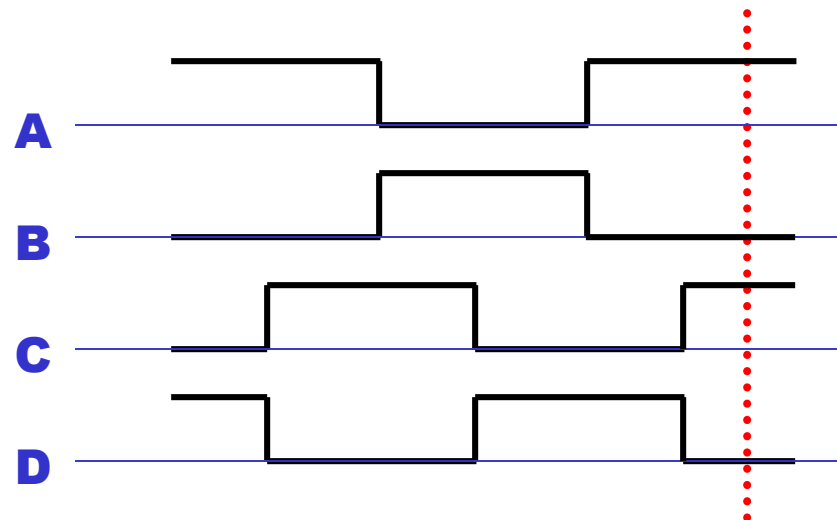
MOSFET  
enhancement  
mode

MOSFET enhanced  
without bulk (body terminal) shown

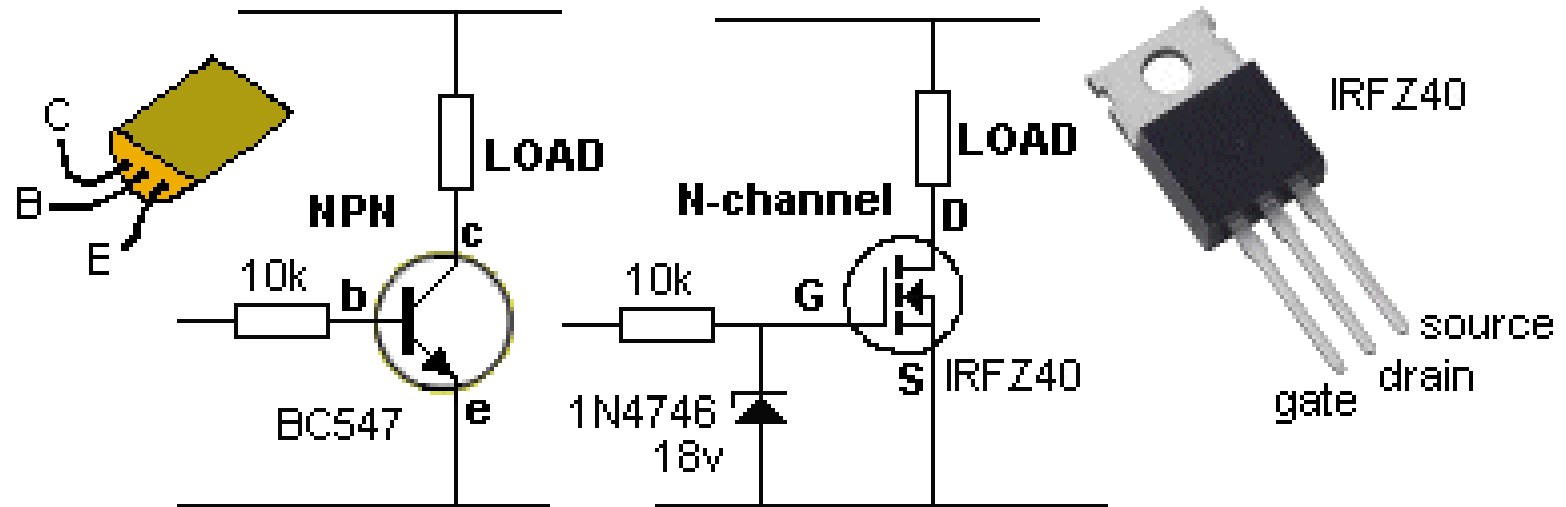
MOSFET  
depletion  
mode



Energia do modo  
de intensificação  
de MOSFETs  
usada como chaves

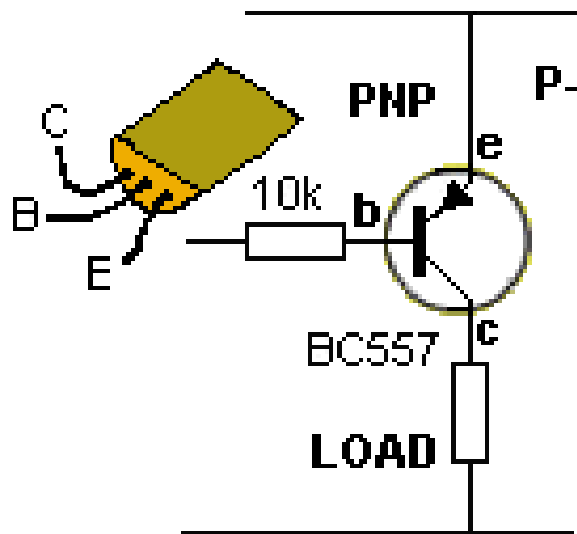


# Amplificador BJT x FET

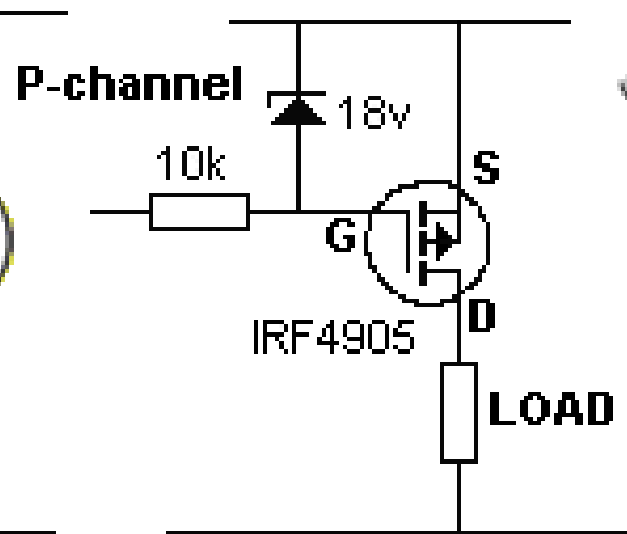


Um diodo zener deve ser colocado no terminal gate do MOSFET se a tensão no gate vindo da fonte for maior que 20V.

# Amplificador BJT x FET



BJT PNP



PMOSFET