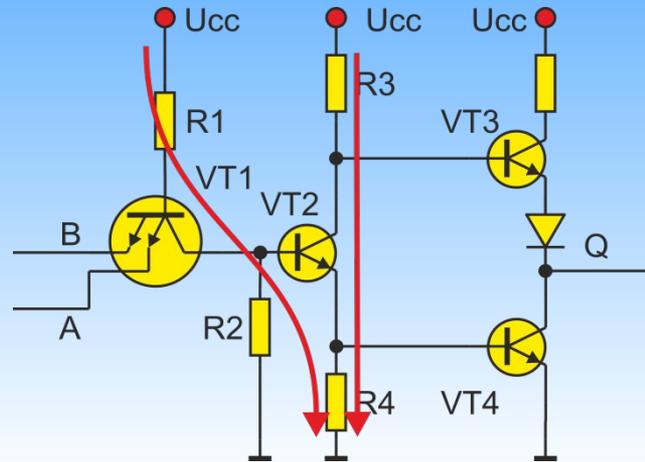




КМОП логика

CMOS



Недостаток – большое энергопотребление

Практически невозможно использовать в устройствах с автономным питанием.

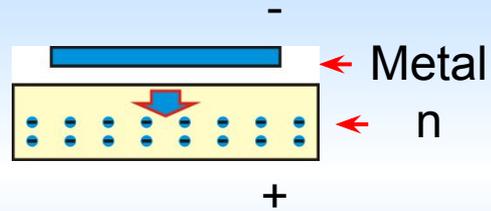
Причина – биполярный транзистор управляемый **ТОКОМ** базы.

**Необходим новый электронный компонент**

# Полевой транзистор

## MOS FET

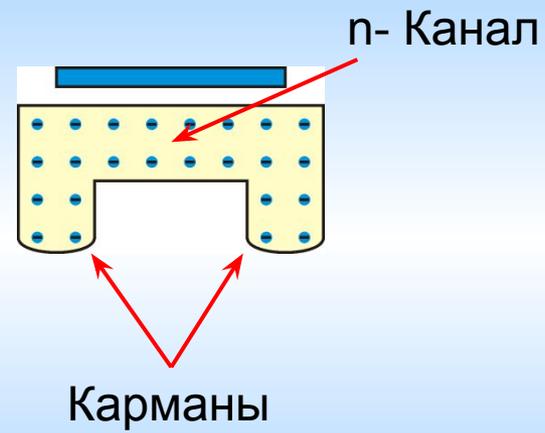
## Metal-Oxide-Semiconductor Field-Effect Transistors



# Полевой транзистор

## MOS FET

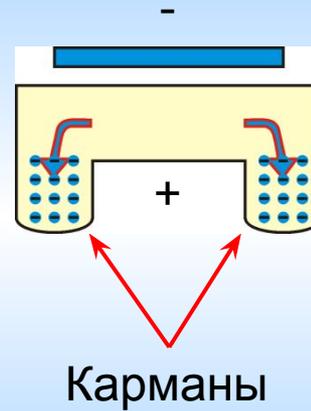
## Metal-Oxide-Semiconductor Field-Effect Transistors



# Полевой транзистор

## MOS FET

## Metal-Oxide-Semiconductor Field-Effect Transistors

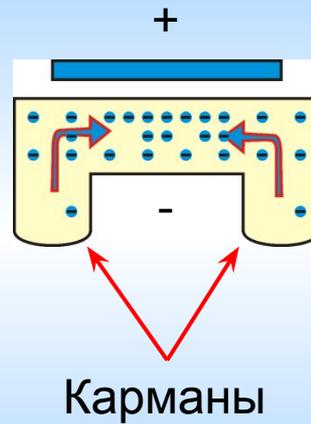


Режим обеднения канала.  
Depletion mode.

# Полевой транзистор

## MOS FET

### Metal-Oxide-Semiconductor Field-Effect Transistors

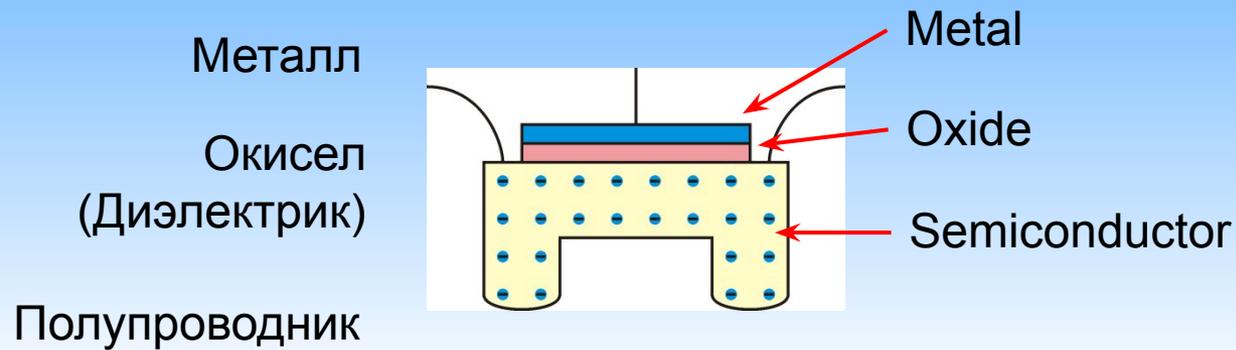


Режим обогащения канала.  
Enhancement mode.

# Полевой транзистор

Как сделать?

Вариант 1



МОП транзистор  
или  
МДП транзистор

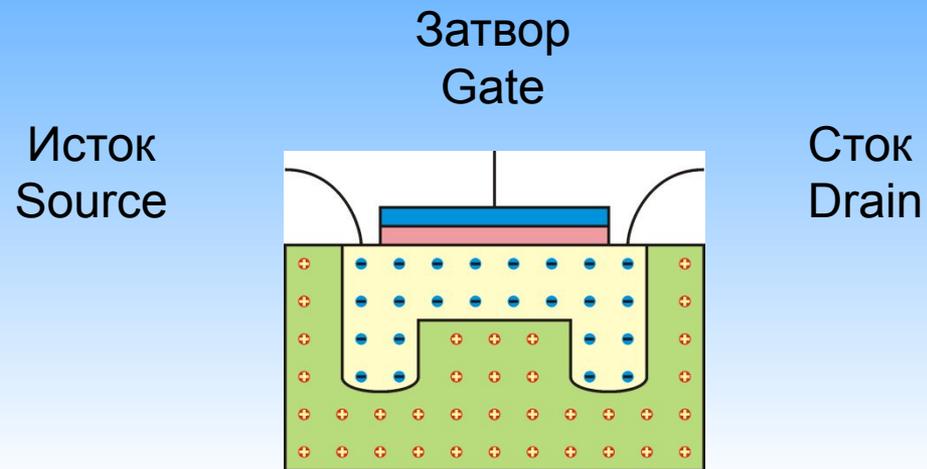
MOS Transistor

n - channel

# Полевой транзистор

Как сделать?

Вариант 1



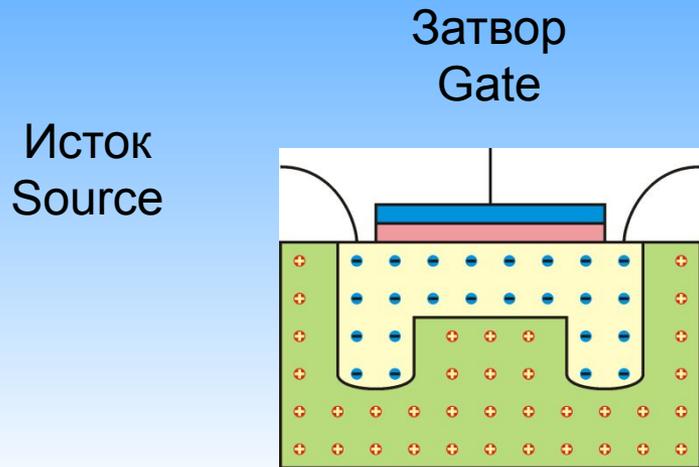
МОП транзистор  
или  
МДП транзистор

MOS Transistor

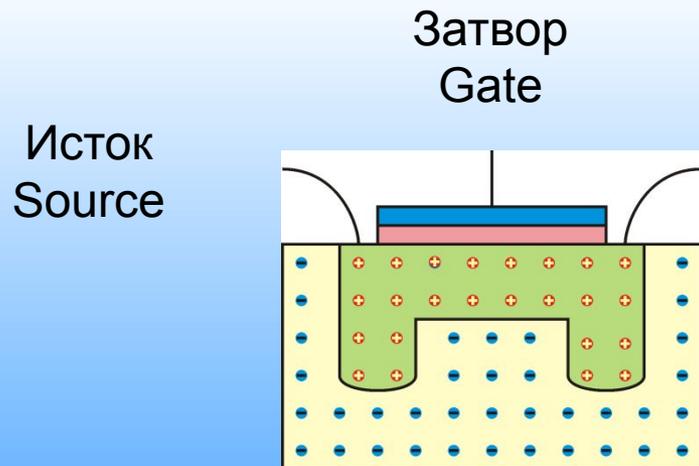
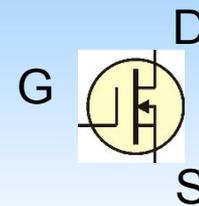
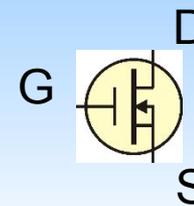
n - channel

# Полевой транзистор

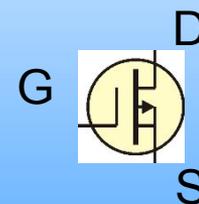
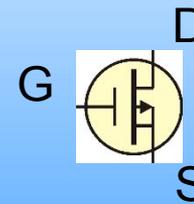
## MOSFET обозначение



n - channel

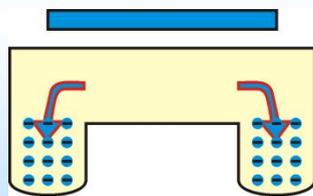
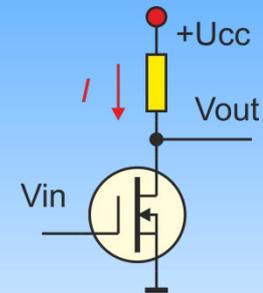
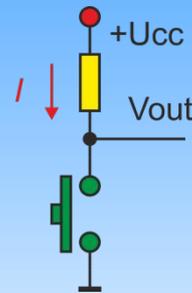
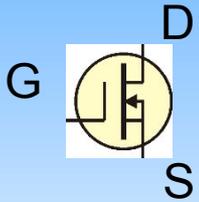


p - channel

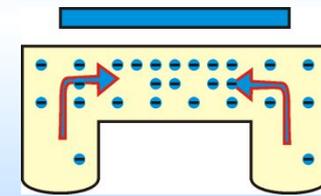
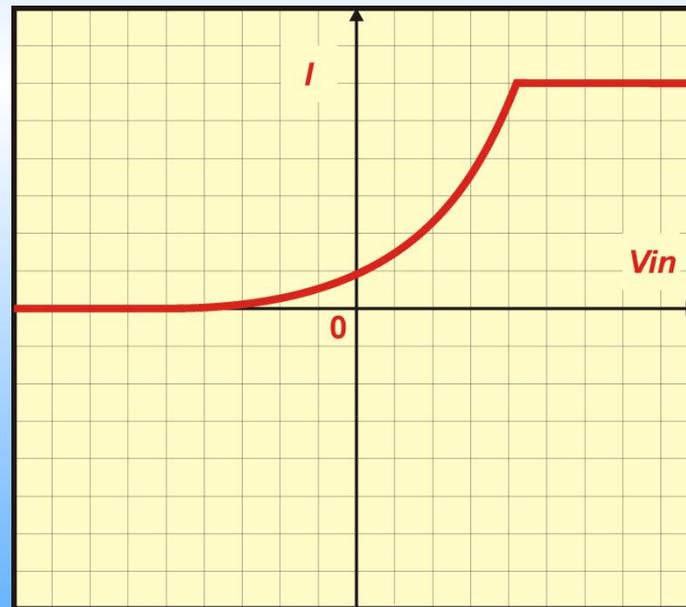


# Полевой транзистор

## MOSFET включение и характеристики



Depletion



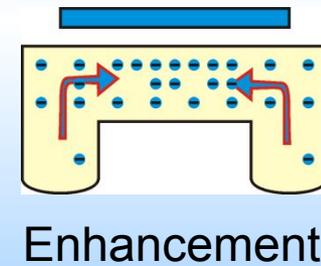
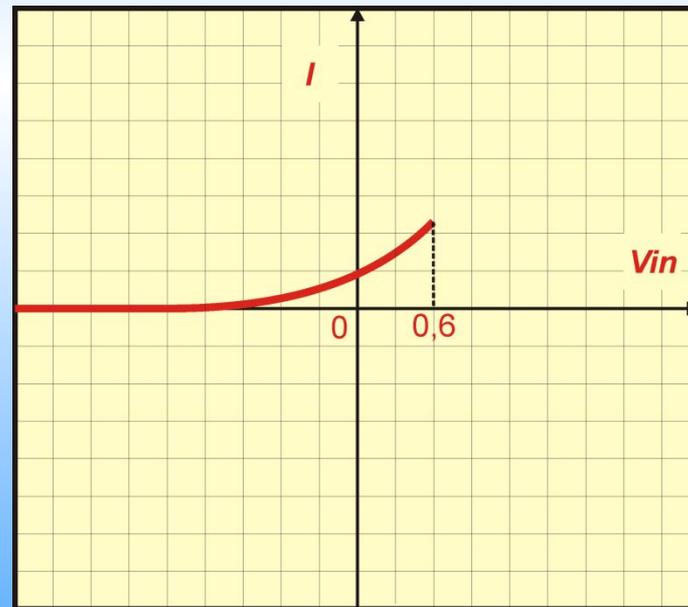
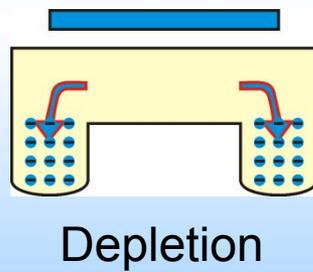
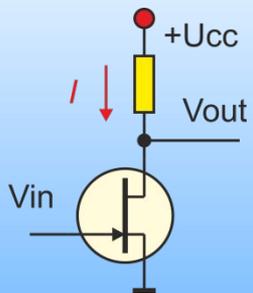
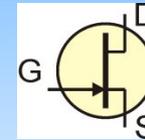
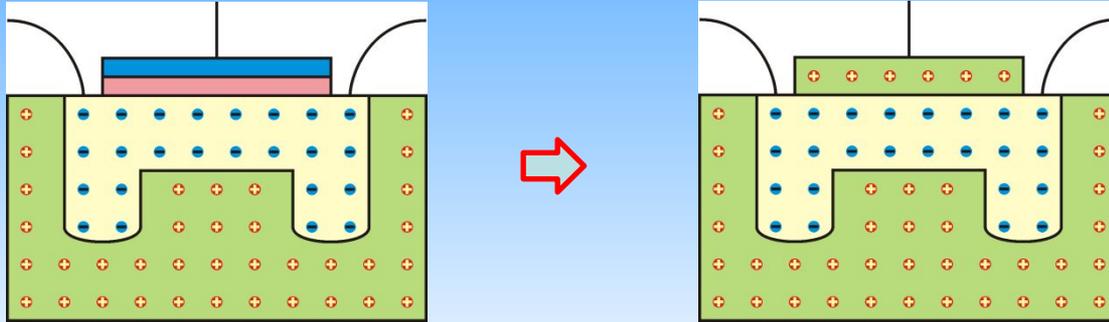
Enhancement

Неудобный ключ

**Открывается плюсом.  
Закрывается минусом.**

# Полевой транзистор с управляющим р-п переходом

## JFET (Junction Field-Effect Transistor)

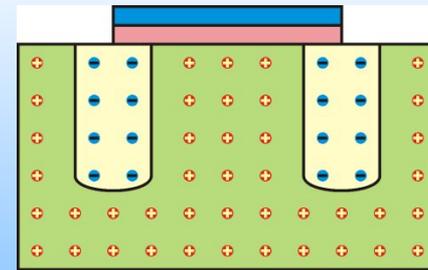
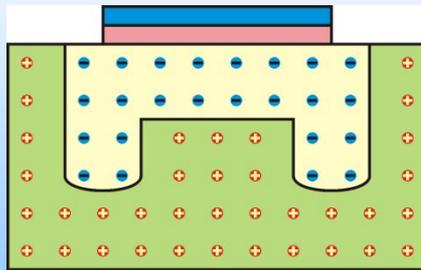
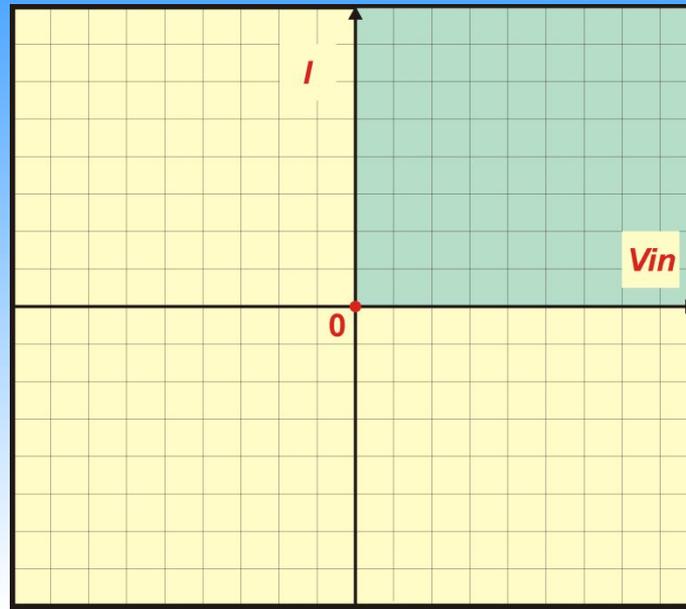


Это не ключ

**Транзистор не насыщается**

# Полевой транзистор с индуцированным каналом

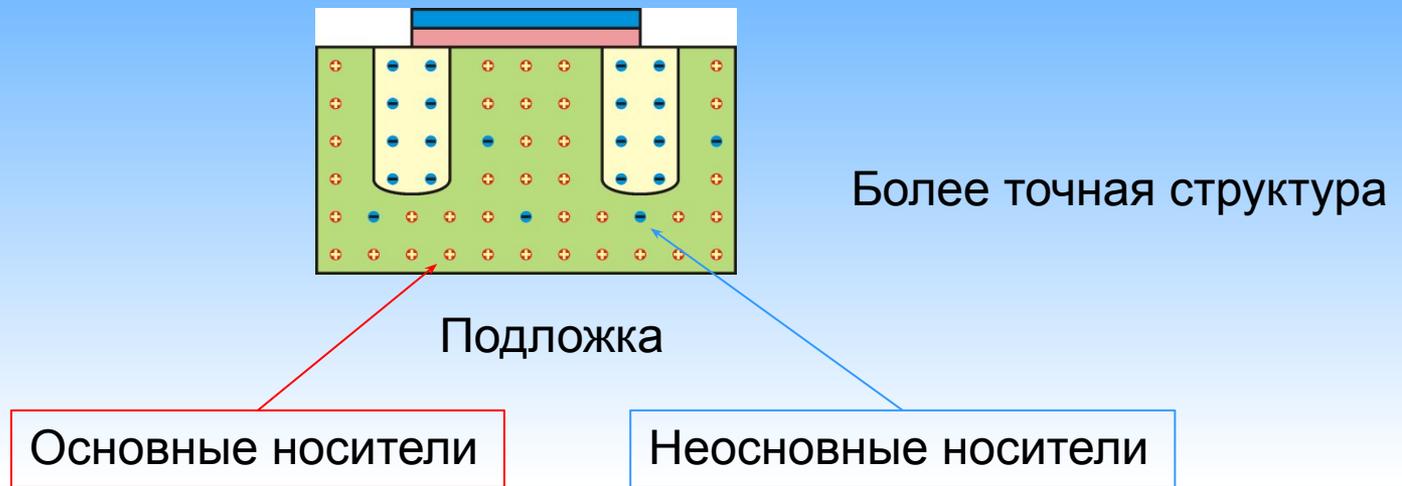
## MOSFET



Ну и как этот транзистор открыть?

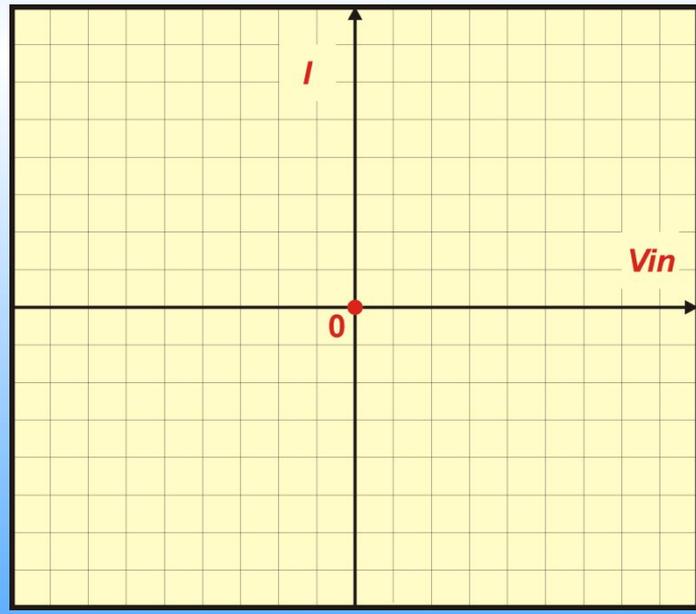
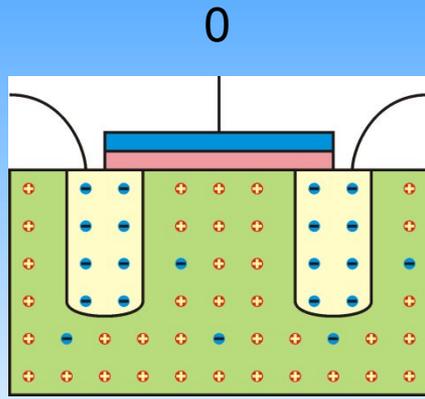
# Полевой транзистор с индуцированным каналом

## MOSFET



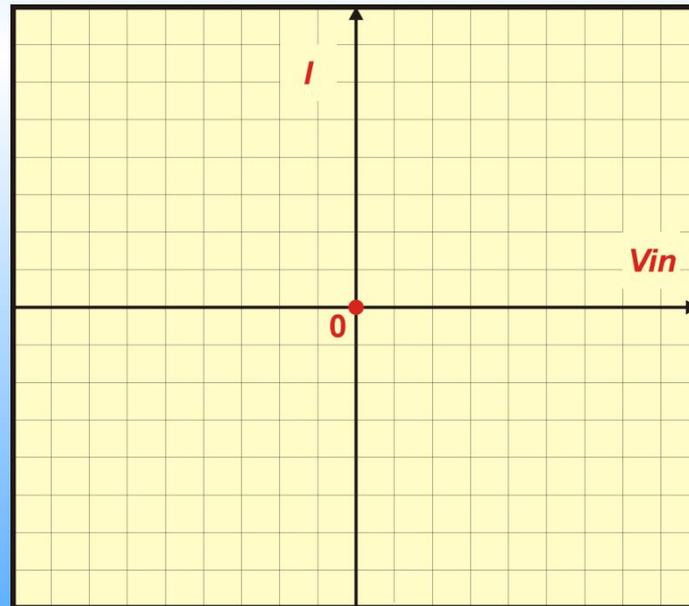
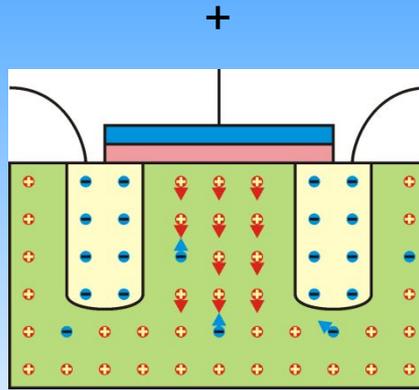
# Полевой транзистор с индуцированным каналом

## MOSFET



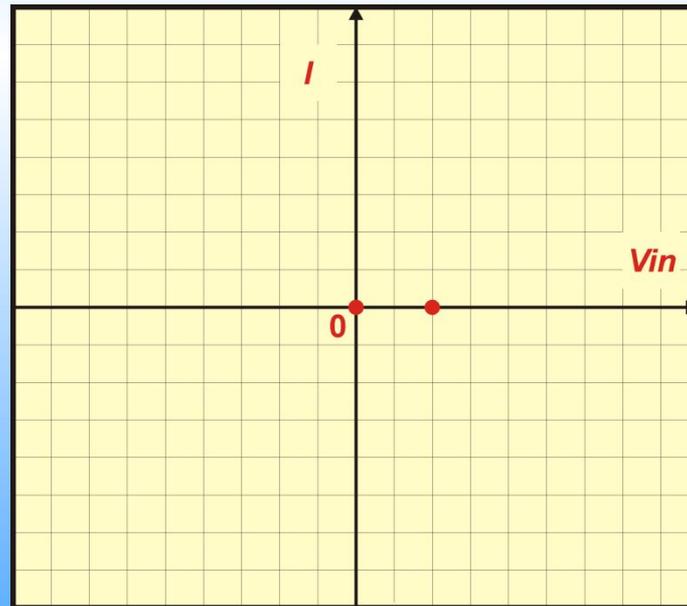
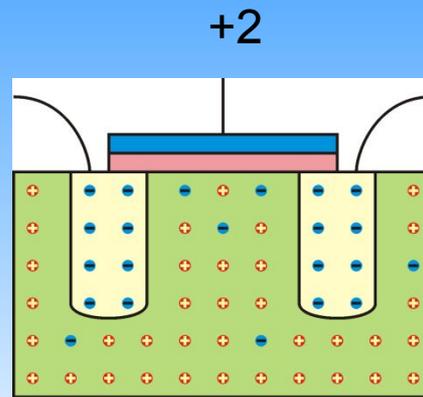
# Полевой транзистор с индуцированным каналом

## MOSFET



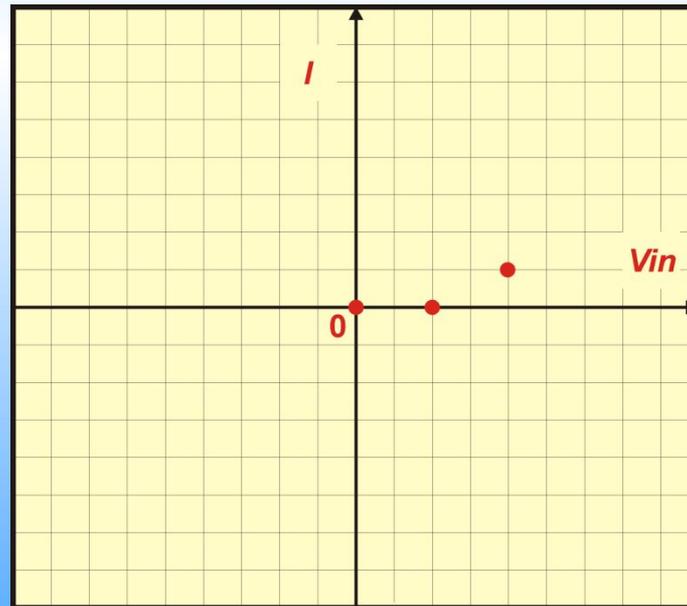
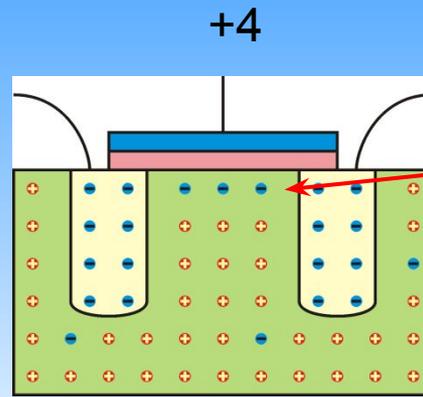
# Полевой транзистор с индуцированным каналом

## MOSFET



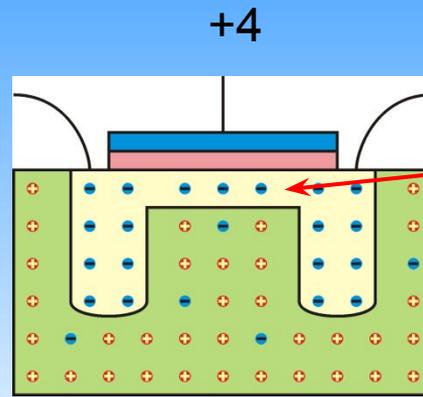
# Полевой транзистор с индуцированным каналом

## MOSFET

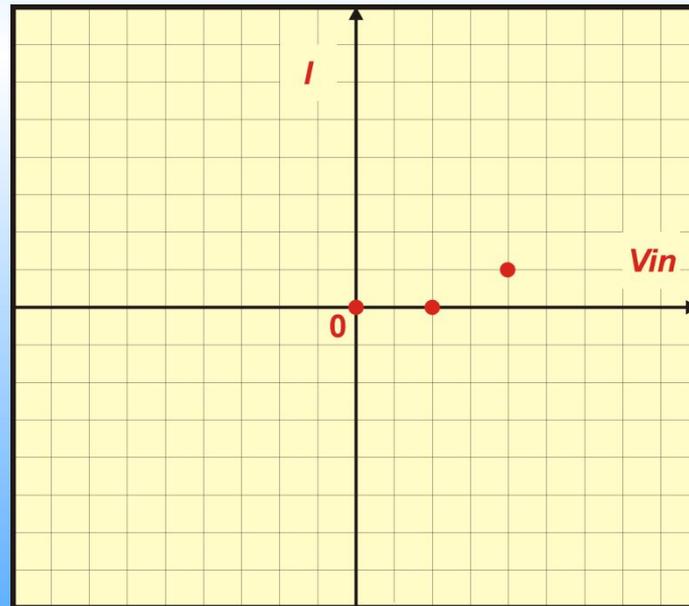


# Полевой транзистор с индуцированным каналом

## MOSFET

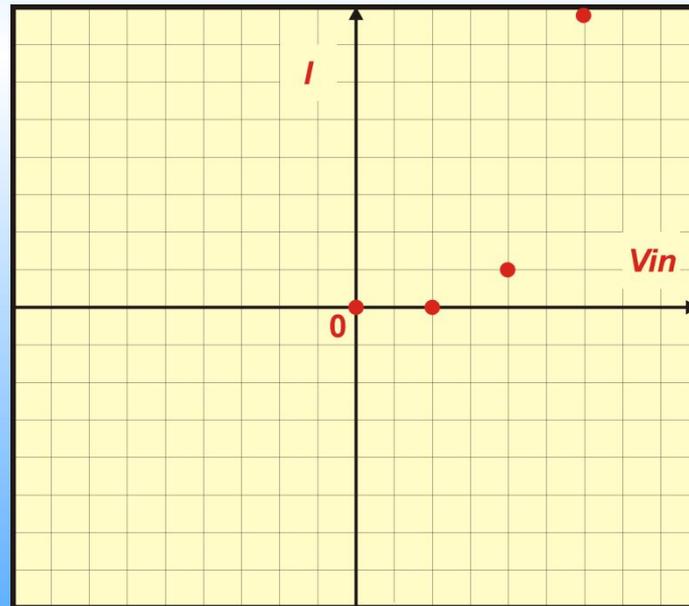
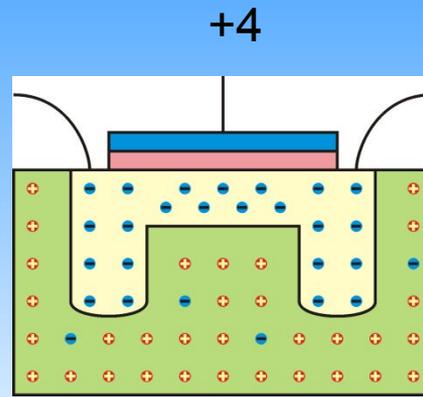


Индукцированный канал



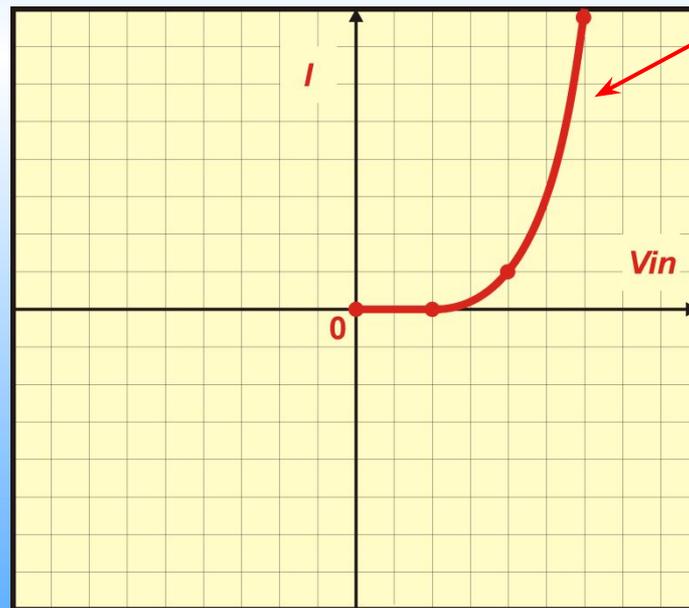
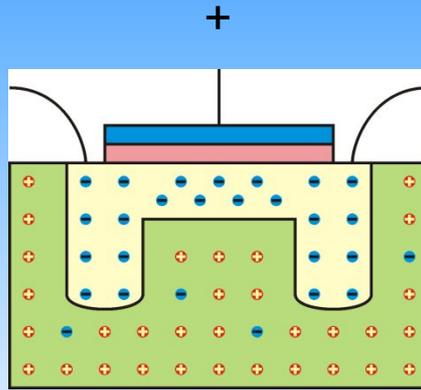
# Полевой транзистор с индуцированным каналом

## MOSFET



# Полевой транзистор с индуцированным каналом

## MOSFET

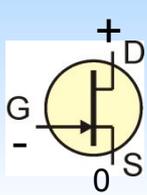
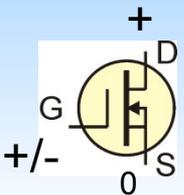
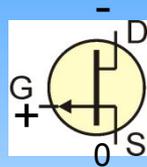
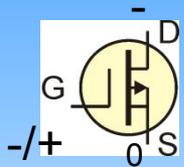


Смещенная парабола

Только режим обогащения  
Enhancement mode

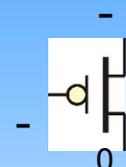
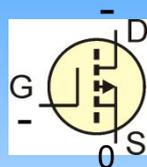
# Полевые транзисторы

## Типы

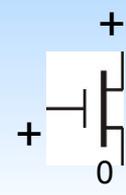
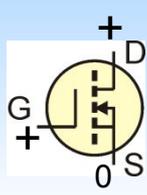


MOSFET

JFET



p-channel



n-channel

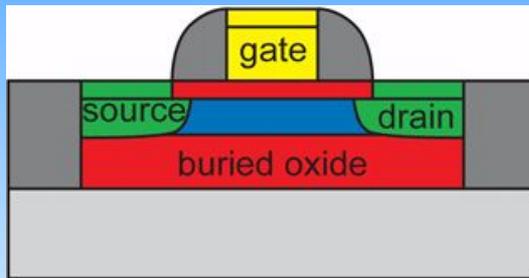
Enhancement  
MOSFET

Enhancement  
MOSFET

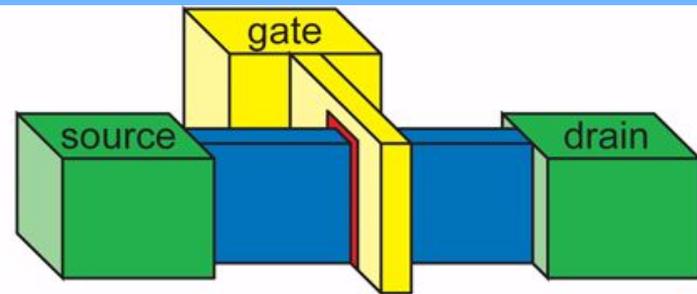
Полевой транзистор с  
индуцированным каналом

# Полевой транзистор - развитие

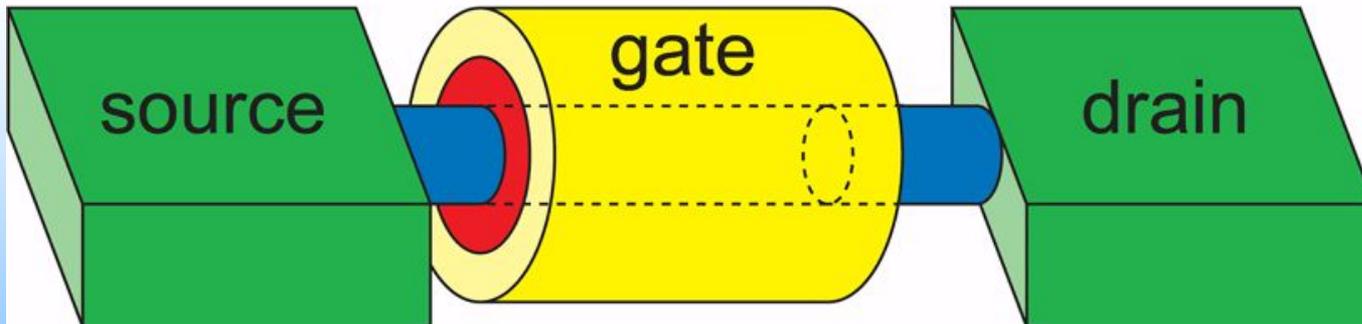
MOSFET



FinFET (3D MOSFET)

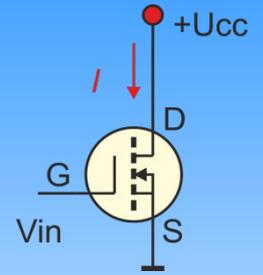
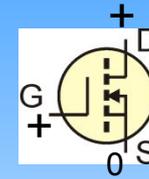
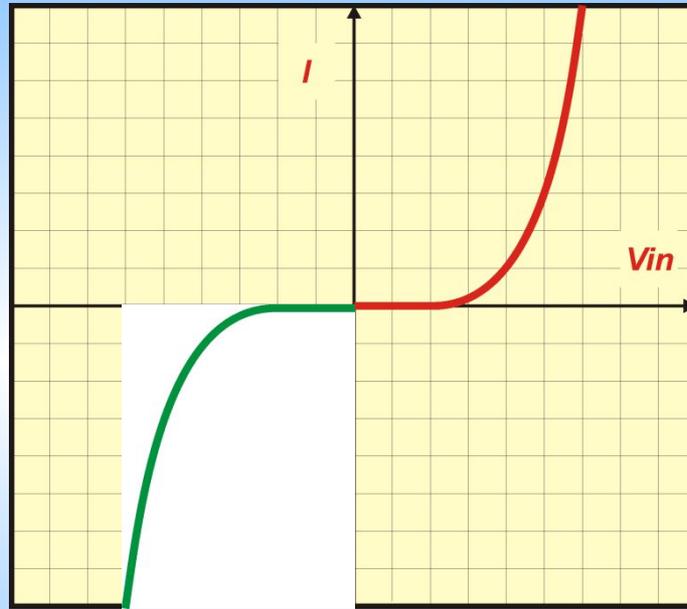
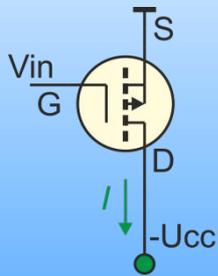
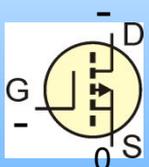


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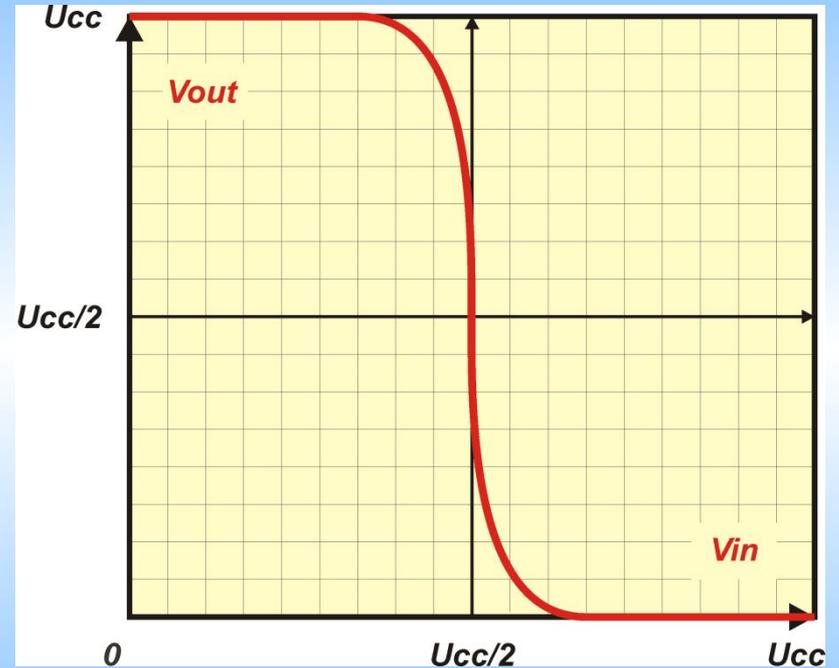
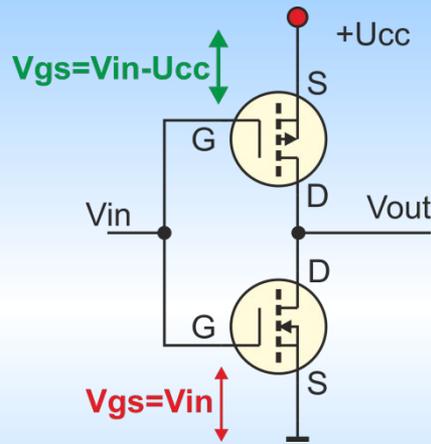


[http://ieeexplore.ieee.org/ieee\\_pilot/articles/96jproc02/96jproc02-appenzeller/article.html](http://ieeexplore.ieee.org/ieee_pilot/articles/96jproc02/96jproc02-appenzeller/article.html)

# Комплементарная пара полевых транзисторов



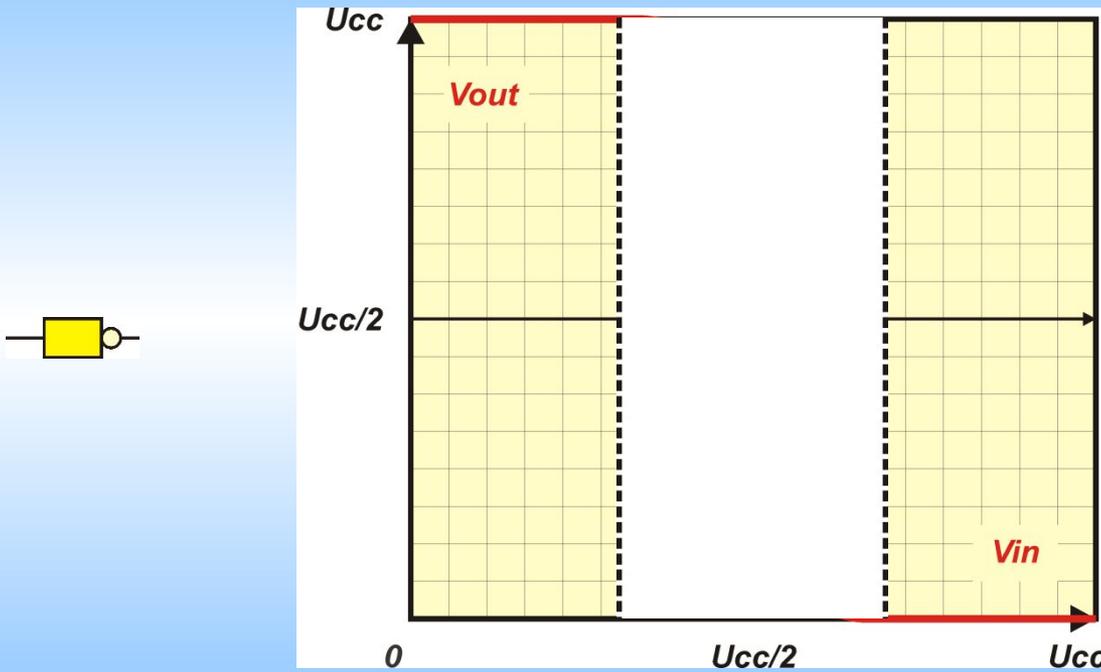
# КМОП логика. Инвертор.



Передаточная характеристика симметрична, т.к. транзисторы комплементарны!

# КМОП логика. Питание и логические уровни.

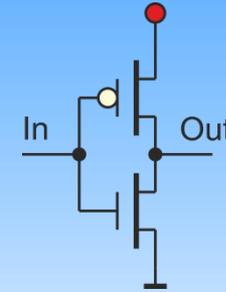
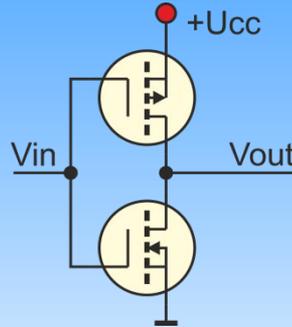
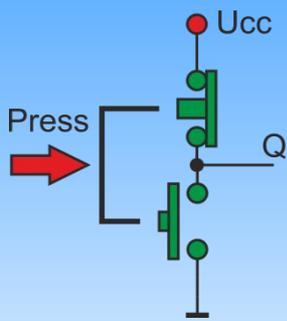
Напряжение питания  $U_{cc}$  может меняться в широких пределах. Передаточная характеристика будет просто масштабироваться.



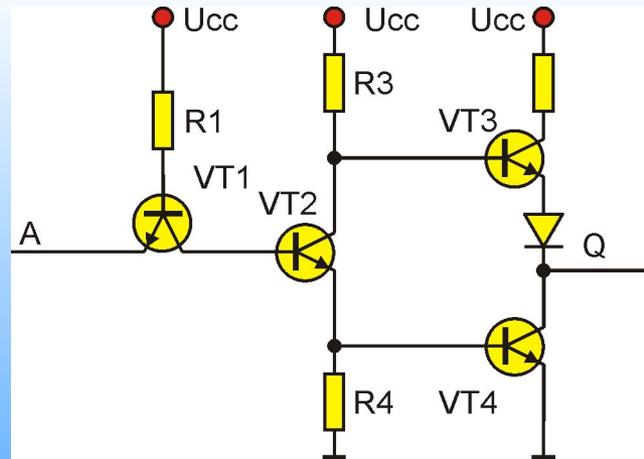
КМОП уровни	
$U_{in0}$	$(0 \div 30\%) U_{cc}$
$U_{in1}$	$(70 \div 100\%) U_{cc}$
$U_{out0}$	$\approx 0 \text{ В}$
$U_{out1}$	$\approx U_{cc}$

# КМОП логика. Основные логические элементы.

## Инвертор

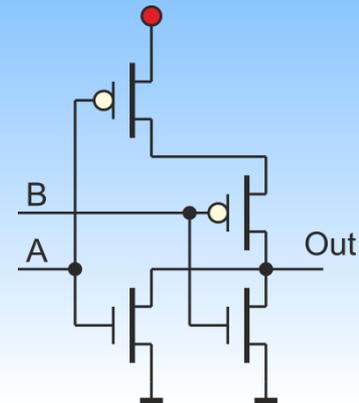
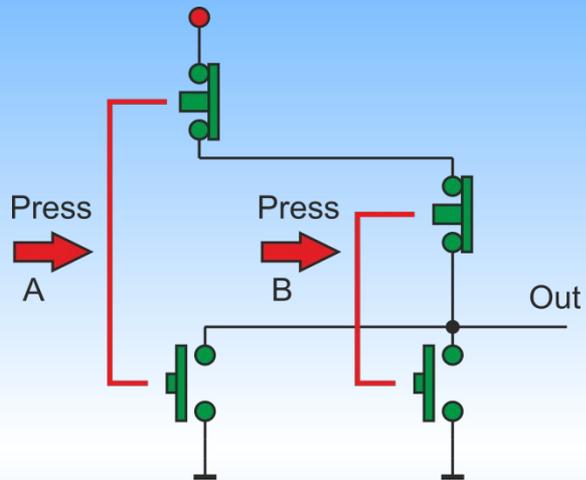


Сравните с инвертором ТТЛ



# КМОП логика. Основные логические элементы.

2 ИЛИ-НЕ  
2 NOR

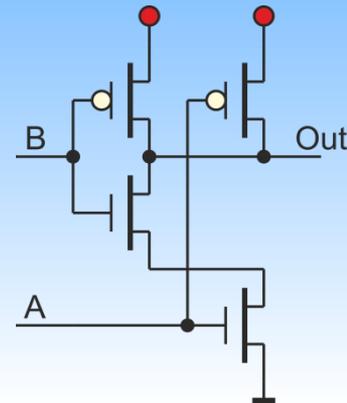
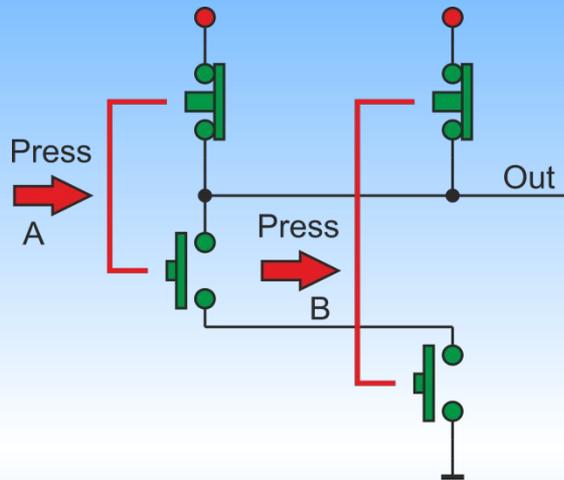


B	A	Q
0	0	1
0	1	0
1	0	0
1	1	0

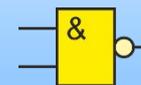


# КМОП логика. Основные логические элементы.

2 И-НЕ  
2 NAND



B	A	Q
0	0	1
0	1	1
1	0	1
1	1	0



# *КМОП логика. Потребление.*

Pd (Power Dissipation)

$$Pd = Pd_{dynamic} + P_{static}$$

$$P_{static} \approx 0$$

$$Pd_{dynamic} \sim F$$

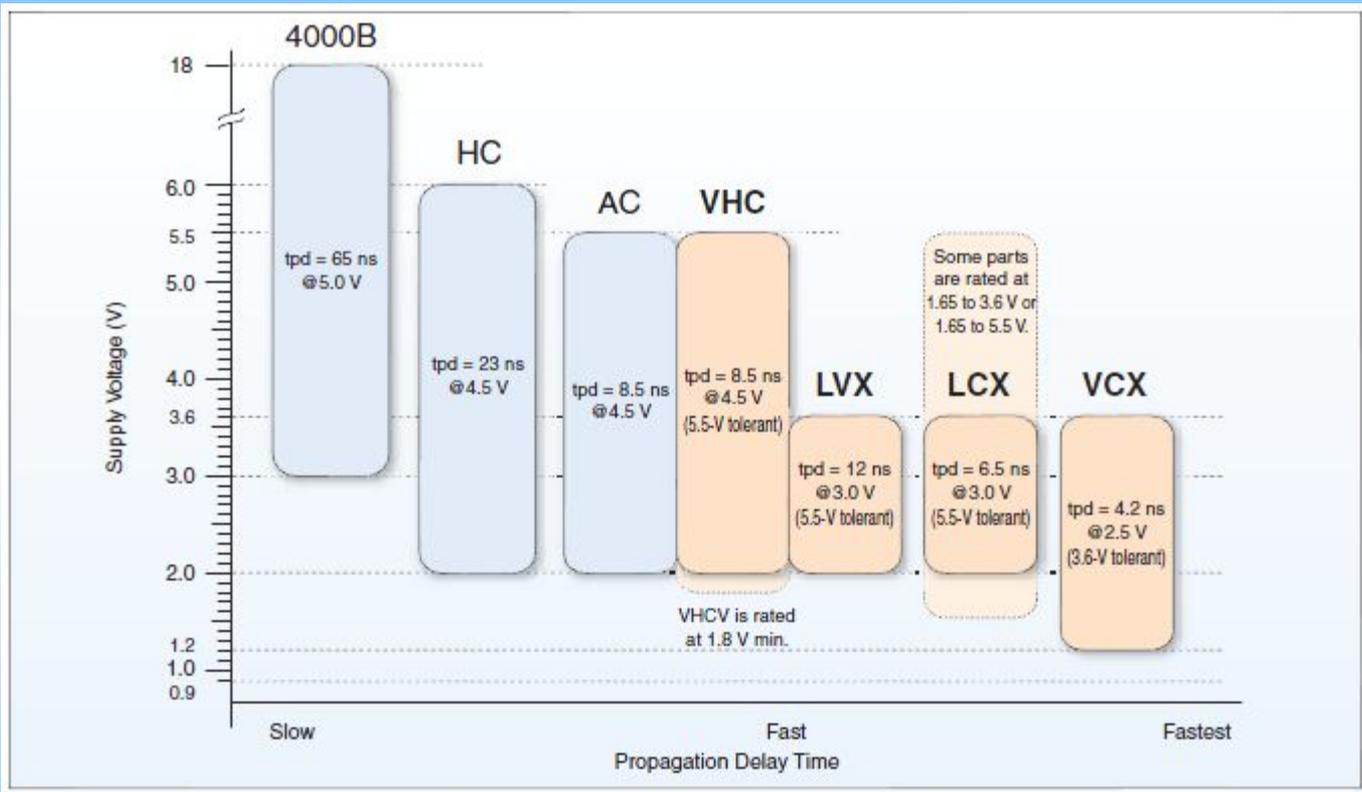
$$Pd_{dynamic} \sim U_{cc}^2$$

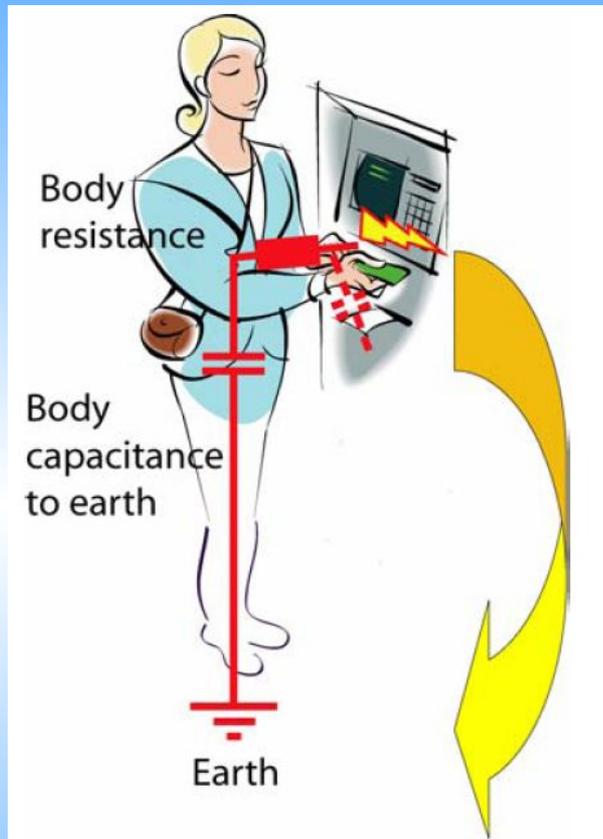
$$Pd = C_{pd} \times U_{cc}^2 \times F$$

$C_{pd}$  – power dissipation capacitance

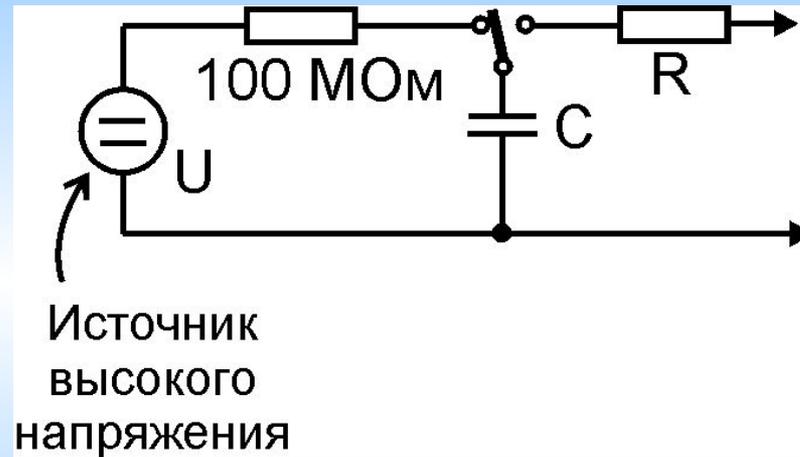
# Семейство CMOS

Тип	Питание [В]	Задержка [нс]	
			при $U_{cc} = V$
CD4000B	3÷16 (18)	45	5
74C	3÷16	60	5
74HC/HCU	2÷6	12	5
74HCT	4,5÷5,5	12	5
74AC/ACU	2÷6	4	5
74ACT	4,5÷5,5	4	5
74VHC	2÷5,5	4	5
74LVX	2÷3,6	5	3,3
74LCX	2÷3,6	4	3,3
74VCX	1,8÷3,6	4	2,3

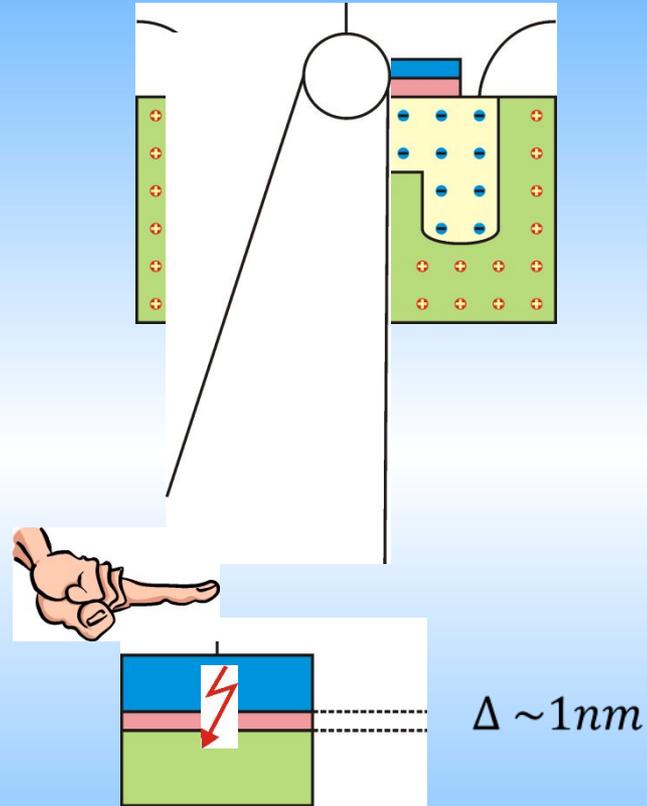
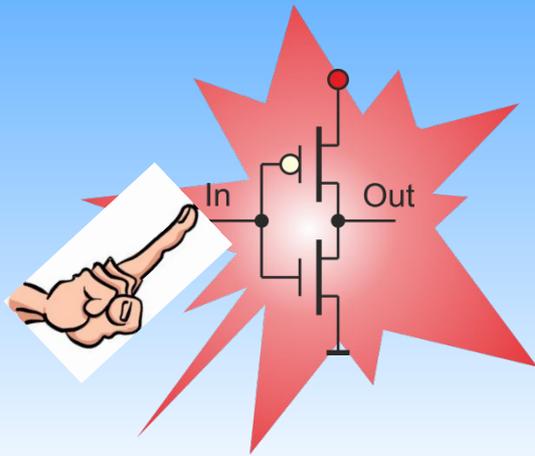




## Модель человеческого тела Human Body Model (HBM)

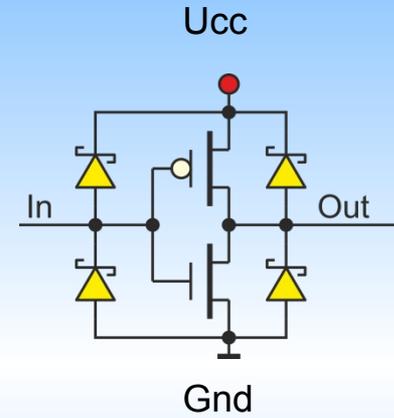
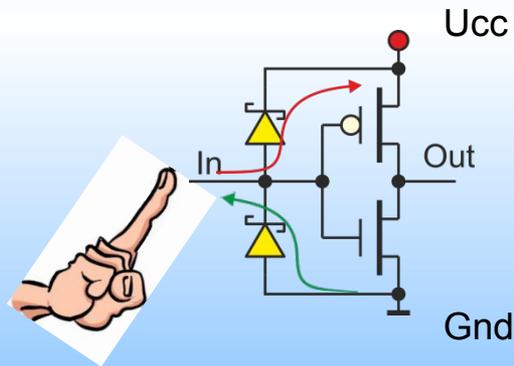
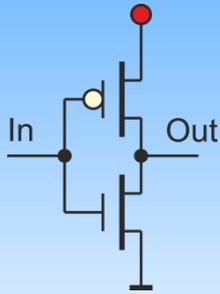


$$R = 330 \text{ Ом}$$
$$C = 150 \text{ пФ}$$
$$U = 2 \div 8 \text{ кВ}$$





# Электростатика



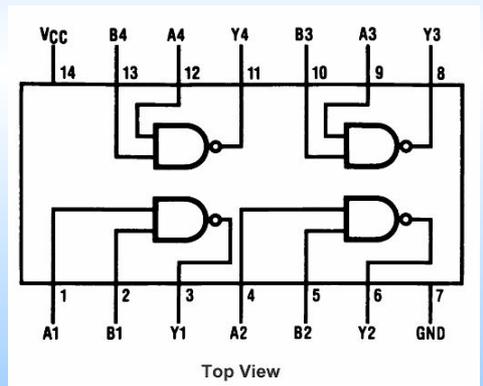
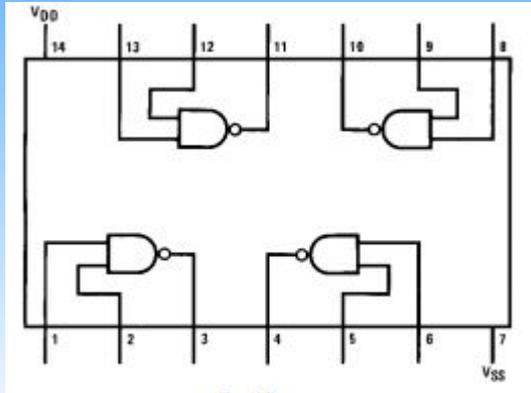
# Семейство CMOS. Цоколевка.

TTL  
74XXYYY

CMOS  
CD4YYY

CD4011

7400



74XXYYY

74XX4YYY