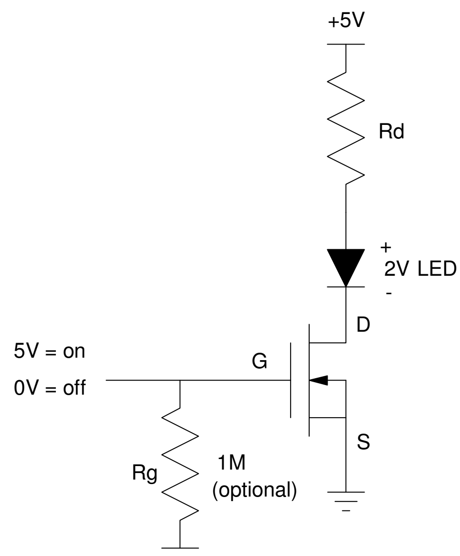
MOSFETs Used as a Switch

Problem: Use a MOSFET to turn on and off an LED. Assume the LED draws 20mA at 2V.

Solution: A MOSFET switch is very much like a BJT switch:



When VGS = 0V, the MOSFET is off, as is the LED.

When VGS = 5V, you want the LED to turn on with 20mA flowing. Rd serves to limit the current to 20mA (if needed). Rg is for safety: it discharges any static on the gate, making sure it's 0V when left floating.

First, pick out your favorite MOSFET. What we need is a MOSFET with an on-resistance less than 150 Ohms:

$$R_{on} = \frac{I_{DS}}{V_{DS}} = \frac{20mA}{5V-2V} = 150\Omega$$

Going to Digikey (www.digikey.com) and searching for MO SFET's results in 22,000 MOSFET's to choose from:

Discrete Semiconductor Products | MOSFETs, GaNFETs - Single

Series	Manufacturer	FET Type	FET Feature	Rds On (Max) @ Id, Vgs	Drain to Source Voltage (Vdss)	Current - Continuous Drain (Id) @ 25° C	Vgs(th) (Max) @ Id	Gate Charge (Qg) @ Vgs
*	Alpha & Omega Semiconductor Inc	-	Current Sensing	-	-	-	-	-
-	Clare	GaNFET N-Channel, Gallium Nitride	Depletion Mode	0.7 mOhm @ 61A, 10V	6V	5mA	400mV @ 100µA	0.01nC @ 5V
CoolMOS™	Diodes Inc	MOSFET N-Channel, Metal Oxide	Diode (Isolated)	0.95 mOhm @ 100A, 10V	8V	10mA	400mV @ 1mA	0.31nC @ 4.5V
Dual Cool™, PowerTrench®	Diodes/Zetex	MOSFET N-Channel, Schottky, Metal Oxide	Logic Level Gate	1 mOhm @ 100A, 10V	12V	20mA	400mV @ 250µA	0.6nC @ 10V
Dual Cool™, PowerTrench®, SyncFET™	Diodes/Zetex	MOSFET P-Channel, Metal Oxide	Standard	1 mOhm @ 160A, 10V	14V	21mA	450mV @ 100µA	0.6nC @ 2.5V
eGaN™	Diodes/Zetex (VA)			1 mOhm @ 80A, 10V	15V	35mA	450mV @ 250µA	0.6nC @ 4.5V
FDmesh™	EPC			1.1 mOhm @ 100A, 10V	16V	45mA	500mV @ 250µA	0.6nC @ 5V
FETKY™	Fairchild Optoelectronics Group			1.15 mOhm @ 50A, 10V	20V	50mA	570mV @ 1mA	0.62nC @ 4.5V
FRFET™	Fairchild Semiconductor			1.17 mOhm @ 20A, 10V	24V	60mA	600mV @ 1.2mA	0.622nC @ 4.5V
GigaMOS™	Honeywell Microelectronics & Precision Sensors			1.2 mOhm @ 15A, 10V	25V	70mA	600mV @ 11µA	0.65nC @ 4.5V

☐ In stock
☐ Lead free
☐ RoHS Compliant

Reset | Apply Filters

You have selected 22,889 items, spanning 916 pages.
View Page | 1

To narrow the search, select

- MOSFET, N Channel
- Through Hole
- In Stock
- 100mA < IDS < 200mA

This limits the number to something more manageable:

Image	Digi-Key Part Number	Manufacturer Part Number	Description	Series	Manufacturer	FET Type	FET Feature	Rds On (Max) @ Id, Vgs	Drain to Source Voltage (Vdss)	Current - Continuous Drain (Id) @ 25° C	Vgs (th) (Max) @ Id	Gate Charge (Qg) @ Vgs	Input Capacitance (Ciss) @ Vds	Power - Max	Mounting Type	Package / Case	Packaging	Quantity Available	Minimum Quantity	Unit Price	D
	2N7000_D26ZTR-ND	2N7000_D26Z	MOSFET N-CH 60V 200MA TO-92	-	Fairchild Semiconductor	MOSFET N-Channel, Metal Oxide	Logic Level Gate	5 Ohm @ 500mA, 10V	60V	200mA	3V @ 1mA	-	50pF @ 25V	400mW	Through Hole	TO-92-3 (Standard Body), TO-226	Tape & Reel (TR)	38,000 Note Alternate Packaging	2,000	0.06400	D
	2N7000_D26ZCT-ND	2N7000_D26Z	MOSFET N-CH 60V 200MA TO-92	-	Fairchild Semiconductor	MOSFET N-Channel, Metal Oxide	Logic Level Gate	5 Ohm @ 500mA, 10V	60V	200mA	3V @ 1mA	-	50pF @ 25V	400mW	Through Hole	TO-92-3 (Standard Body), TO-226	Cut Tape (CT)	39,732 Note Alternate Packaging	1	0.68000	D
	2N7000FS-ND	2N7000	MOSFET N-CH 60V 200MA TO-92	-	Fairchild Semiconductor	MOSFET N-Channel, Metal Oxide	Logic Level Gate	5 Ohm @ 500mA, 10V	60V	200mA	3V @ 1mA	-	50pF @ 25V	400mW	Through Hole	TO-92-3 (Standard Body), TO-226	Bulk	176,258	1	0.42000	D
	ZVN0124A-ND	ZVN0124A	MOSFET N-CHAN 240V TO92-3	-	Diodes/Zetex	MOSFET N-Channel, Metal Oxide	Logic Level Gate	16 Ohm @ 250mA, 10V	240V	160mA	3V @ 1mA	-	85pF @ 25V	700mW	Through Hole	TO-92-3 (Standard Body), TO-226	Bulk	4,000	1	0.72000	D

Selecting the third on (it's in stock, costs $0.42 each, has an on resistance of 5 Ohms) gives you the pricing information:

All prices are in US dollars.

Digi-Key Part Number	2N7000FS-ND
Quantity Available	176,258
Manufacturer	Fairchild Semiconductor
Manufacturer Part Number	2N7000
Description	MOSFET N-CH 60V 200MA TO-92
Lead Free Status / RoHS Status	Lead free / RoHS Compliant

Price Break	Unit Price	Extended Price
1	0.42000	0.42
10	0.30200	3.02
100	0.17810	17.81
250	0.12600	31.50
500	0.10080	50.40
750	0.08568	64.26
1,000	0.07728	77.28
2,000	0.06720	134.40
4,800	0.06048	290.30

Quantity	Item Number	Customer Reference	
	2N7000FS-ND		Add to Order

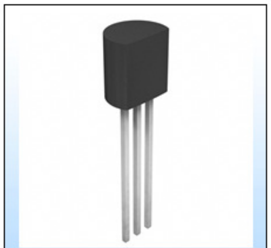
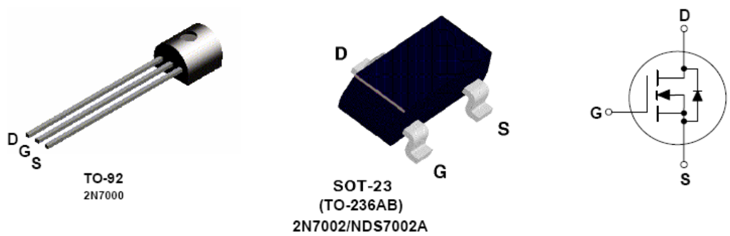


Image shown is a representation only. Exact specifications should be obtained from the product data sheet.

Click on the data sheet and you get the technical specs for this MOSFET:



Absolute Maximum Ratings T_A = 25°C unless otherwise noted

Symbol	Parameter	2N7000	2N7002	NDS7002A	Units
V_{DSS}	Drain-Source Voltage		60		V
V_{DGR}	Drain-Gate Voltage (R_{GS} ≤ 1 MΩ)		60		V
V_{GSS}	Gate-Source Voltage - Continuous		±20		V
	- Non Repetitive (tp < 50µs)		±40		
I_D	Maximum Drain Current - Continuous	200	115	280	mA
	- Pulsed	500	800	1500	
P_D	Maximum Power Dissipation	400	200	300	mW
	Derated above 25°C	3.2	1.6	2.4	mW/°C
T_J,T_{STG}	Operating and Storage Temperature Range	-55 to 150		-65 to 150	°C
T_L	Maximum Lead Temperature for Soldering Purposes, 1/16" from Case for 10 Seconds		300		°C
THERMAL CHARACTERISTICS					
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient	312.5	625	417	°C/W

We're operating at +5V and 20mA. This MOSFET can take +/- 20V and 115mA, so it will work.

To analyze this circuit, we need to know VTN and Kn, however. On page 2 of the data sheets, the following is given:

$R_{DS(ON)}$	Static Drain-Source On-Resistance	V_{GS} = 10 V, I_D = 500 mA		2N7000		1.2	5	Ω
			T_J =125°C			1.9	9	
		V_{GS} = 4.5 V, I_D = 75 mA				1.8	5.3	
		V_{GS} = 10 V, I_D = 500 mA		2N7002		1.2	7.5	
			T_J =100°C			1.7	13.5	
		V_{GS} = 5.0 V, I_D = 50 mA				1.7	7.5	
			T_J =100C			2.4	13.5	

At

- VGS = 5.0V
- ID = 50mA
- RDS = 1.7 Ohms (nominal)

This lets you solve for Kn:

$$\frac{1}{R_{DS}} = \frac{I_{DS}}{V_{DS}} = K_n\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right)$$

(1) $$\frac{1}{1.7\Omega} = K_n\left(5V - 2 - \frac{(50mA)(1.7\Omega)}{2}\right)$$

Kn = 0.1989

Assume Rds = 1.7 Ohms. Then

$$R_{net} = \frac{5V-2V}{20mA} = 150\Omega$$

$$R_{net} = R_{DS} + R_d$$

$$R_d = 148.3\Omega$$

(plus or minus 5%. We have 5% tolerance resistors in lab.)

Assume you have a 148.3 Ohm resistor. Find the approximate (Vds, Ids)

When ON, the MOSFET is approximately 1.7 Ohms

$$I_{ds} = \left(\frac{5V-2V}{148.3\Omega+1.7\Omega}\right)$$

$$I_{ds} = 20mA$$

Find the actual resistance using the MOSFET model with Kn = 0.1989 A/V2

The Mosfet gives us one equation for two unknowns:

$$I_{ds} = K_n\left(V_{gs} - V_{th} - \frac{V_{ds}}{2}\right)V_{ds}$$

$$I_{ds} = 0.1989\left(5 - 2 - \frac{V_{ds}}{2}\right)V_{ds}$$

The circuit gives the second equation

$$V_{ds} = 3 - 148.3 I_{ds}$$

This is a quadradic with two solutions:

Vds = { 0.0337V, 6.0341V }

The one close to zero is the correct one:

- Vds = 33.7mV
- Ids = 20.002mA

Taking the ratio:

Rds = Vds / Ids = 1.6854 Ohms

The actual resistance when on isn't exactly 1.7 Ohms, but it's pretty close.

Note that you can power just about anything you like with this MOSFET, providing that

- 1.7 Ohms is small relative to the resistance of what you're driving (150 Ohms in this case),
- The net current flow is less than 115mA continuous, 800mA pulsed (from the data sheets),
- The power supply you're using is less than 60V. The maximum VDS = 60V for this MOSFET.

It also takes some time for the MOSFET to turn on. The capacitance is (from the data sheets)

$$C_{GS} = 20pF$$

$$C_{DS} = 11pF$$

Likewise, when you turn the MOSFET off, the capacitor charges up to +5V as

$$V_{DS} = 5V \cdot \left(1 - \exp\left(\frac{-t}{RC}\right)\right)$$

or

$$RC = (150\Omega)(11pF) = 1.6ns$$

In three time constants, you're at 95% of 5V:

$$e^{-3} \approx 0.05$$

$$\left(\frac{t}{RC}\right) = 3$$

$$t = 3RC = 4.95ns$$

It takes about 5 nanoseconds to turn the LED on, and 5 nanoseconds to turn it off with this MOSFET. The maximum frequency is likewise 100MHz (1 / 10ns).

MOSFETs are *fast* relative to BJT transistors.

If you need to power a bigger device, use a bigger MOSFET. For example, doing the same search in Digikey but looking for a MOSFET that takes 8A results in a slightly more expensive MOSFET ($1.51 each):

All prices are in US dollars.

Digi-Key Part Number	869-1043-ND
Quantity Available	142
Manufacturer	SANYO Semiconductor (U.S.A) Corporation
Manufacturer Part Number	2SK4096LS
Description	MOSFET N-CH 500V 8A TO-220FI
Lead Free Status / RoHS Status	Lead free / RoHS Compliant

Price Break	Unit Price	Extended Price
1	1.51000	1.51
25	1.20400	30.10
100	1.05350	105.35
250	0.92452	231.13
500	0.81700	408.50
1,000	0.64500	645.00
2,500	0.60200	1,505.00

Quantity | Item Number | Customer Reference

869-1043-ND | Add to Order

Image shown is a representation only. Exact specifications should be obtained from the product data sheet.

with one table from the data sheets:

Electrical Characteristics at Ta=25°C

Parameter	Symbol	Conditions	Ratings			Unit
			min	typ	max	
Drain-to-Source Breakdown Voltage	$V_{(BR)DSS}$	I_D=10mA, V_{GS}=0V	500			V
Zero-Gate Voltage Drain Current	I_{DSS}	V_{DS}=400V, V_{GS}=0V			100	μA
Gate-to-Source Leakage Current	I_{GSS}	V_{GS}=±30V, V_{DS}=0V			±100	nA
Cutoff Voltage	$V_{GS}(off)$	V_{DS}=10V, I_D=1mA	3		5	V
Forward Transfer Admittance	|yfs|	V_{DS}=10V, I_D=4A	2.2	4.5		S
Static Drain-to-Source On-State Resistance	$R_{DS}(on)$	I_D=4A, V_{GS}=10V		0.65	0.85	Ω
Input Capacitance	Ciss	V_{DS}=30V, f=1MHz		600		pF
Output Capacitance	Coss	V_{DS}=30V, f=1MHz		130		pF
Reverse Transfer Capacitance	Crss	V_{DS}=30V, f=1MHz		28		pF
Turn-ON Delay Time	$t_d(on)$	See specified Test Circuit.		18.5		ns
Rise Time	t_r	See specified Test Circuit.		46		ns
Turn-OFF Delay Time	$t_d(off)$	See specified Test Circuit.		75		ns
Fall Time	t_f	See specified Test Circuit.		33		ns
Total Gate Charge	Qg	V_{DS}=200V, V_{GS}=10V, I_D=8A		24		nC
Gate-to-Source Charge	Qgs	V_{DS}=200V, V_{GS}=10V, I_D=8A		4.5		nC
Gate-to-Drain "Miller" Charge	Qgd	V_{DS}=200V, V_{GS}=10V, I_D=8A		14		nC
Diode Forward Voltage	V_{SD}	I_S=8A, V_{GS}=0V		0.9	1.2	V

Note that this device

- Can turn on and off devices which take up to 8A and 500V
- Has an on-resistance of about 0.65 Ohms
- V_{GS} needs 10V to be on. The off voltage (V_{TN}) is between 3V and 5V.

It's also a bit slower: it takes 18ns (turn-on delay) or 75ns (turn off delay) to turn on and off. That's still really fast relative to a BJT.