MOSFETs Used as a Switch

ECE 320 Electronics I

Jake Glower - Lecture #23

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

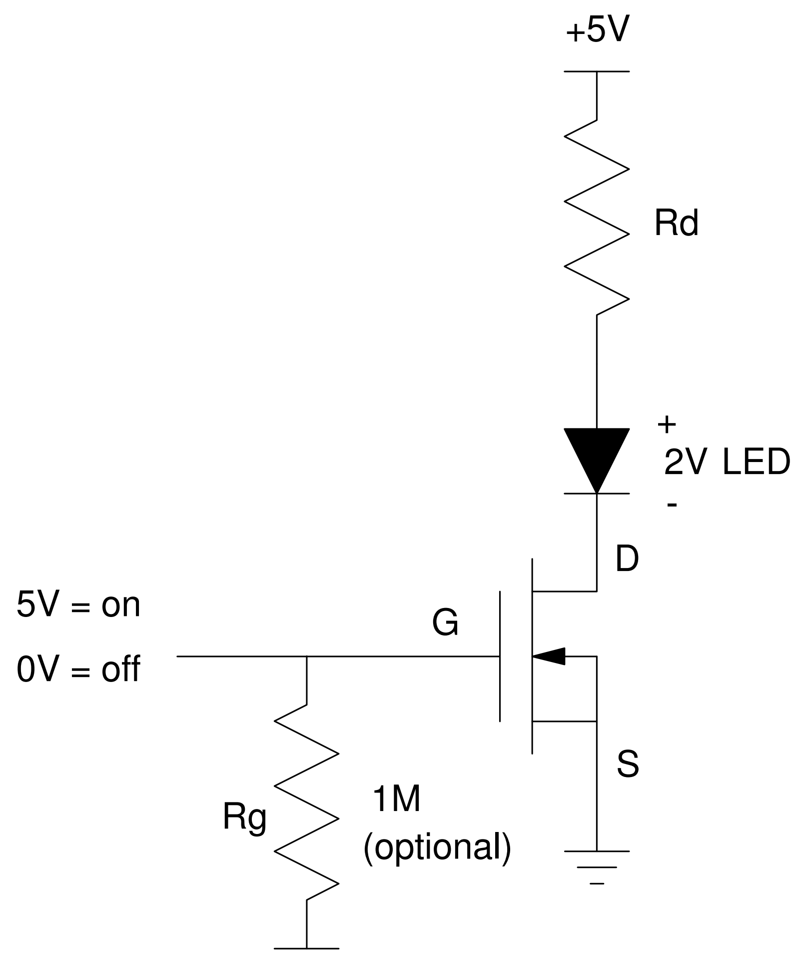
MOSFETs Used as a Switch

Problem: Use a MOSFET to turn on and off an LED.

- Vf = 2.0V @ 20mA
- $R = \left(\frac{5V - 2V}{20mA}\right) = 150\Omega$

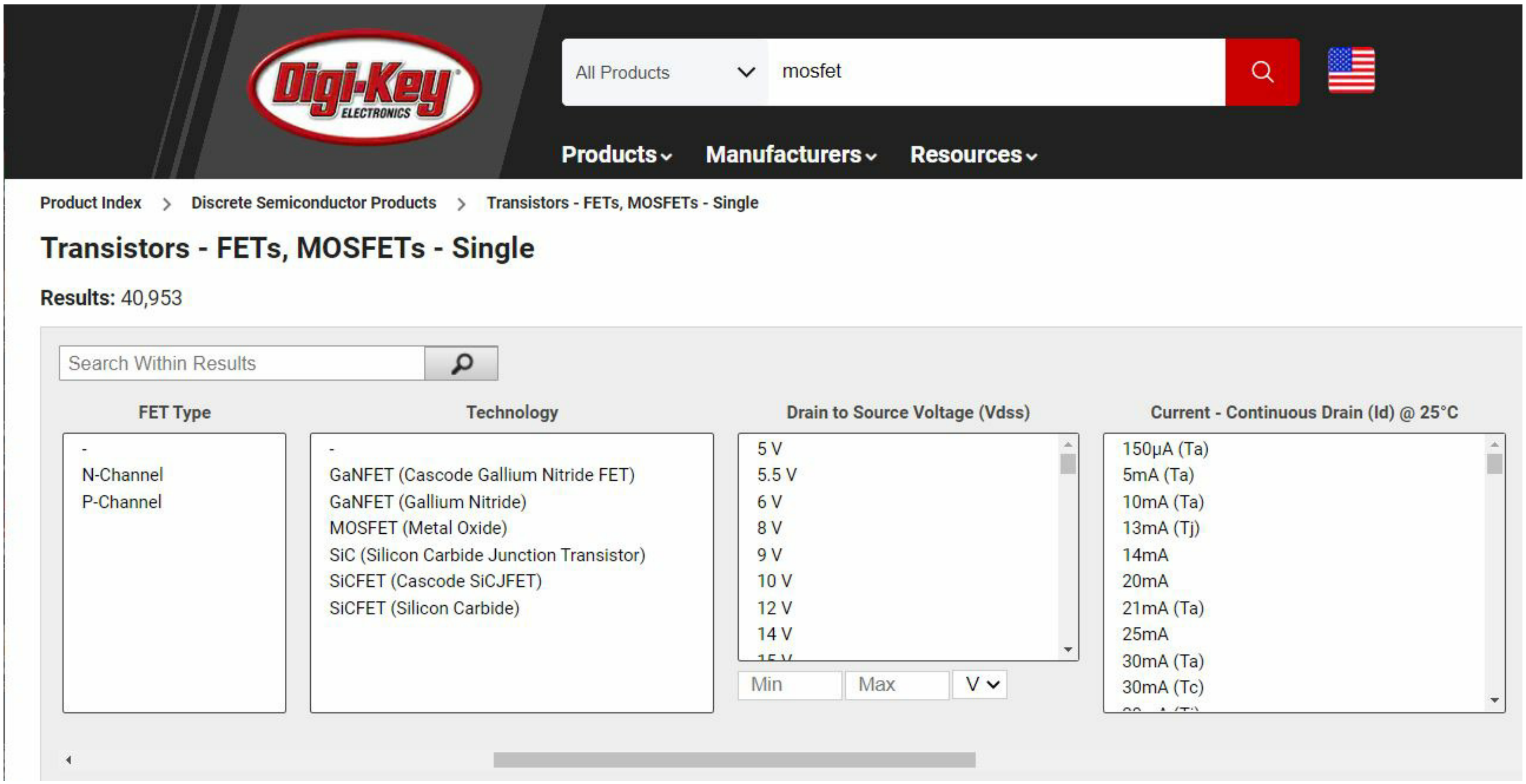
Solution: A MOSFET switch is very much like a BJT switch:

- Vgs = 0V, the MOSFET is off
- Vgs = 5V, MOSFET is on (ohmic)



Select a MOSFET (Digikey)

- Search MOSFET
- 40,953 results (2022)



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

Select one

- in stock, costs $0.42 each, has an on resistance of 5 Ohms

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

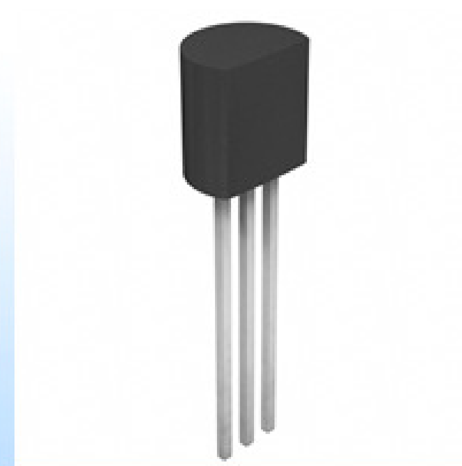
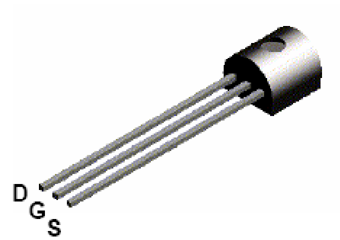


Image shown is a representation only. Exact specifications should be obtained from the product data sheet.

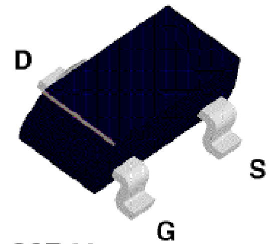
Click on the data sheet and you get the technical specs for this MOSFET:

Datasheets

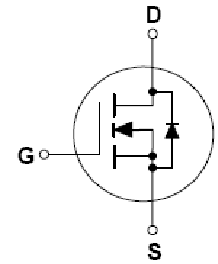
- max(Vds) = 60V
- max(Ids) = 115mA
- = 800mA (pulsed)
- Vtn = ?
- kn = ?



TO-92
2N7000



SOT-23
(TO-236AB)
2N7002/NDS7002A



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

Page 2: Data Sheets

$R_{DS(ON)}$	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	

- V_{GS} = 5.0V, I_D = 50mA, R_{DS} = 1.7 Ohms (nominal)

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

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

- **kn = 0.1989 A/V²**

Final Design: (take 1)

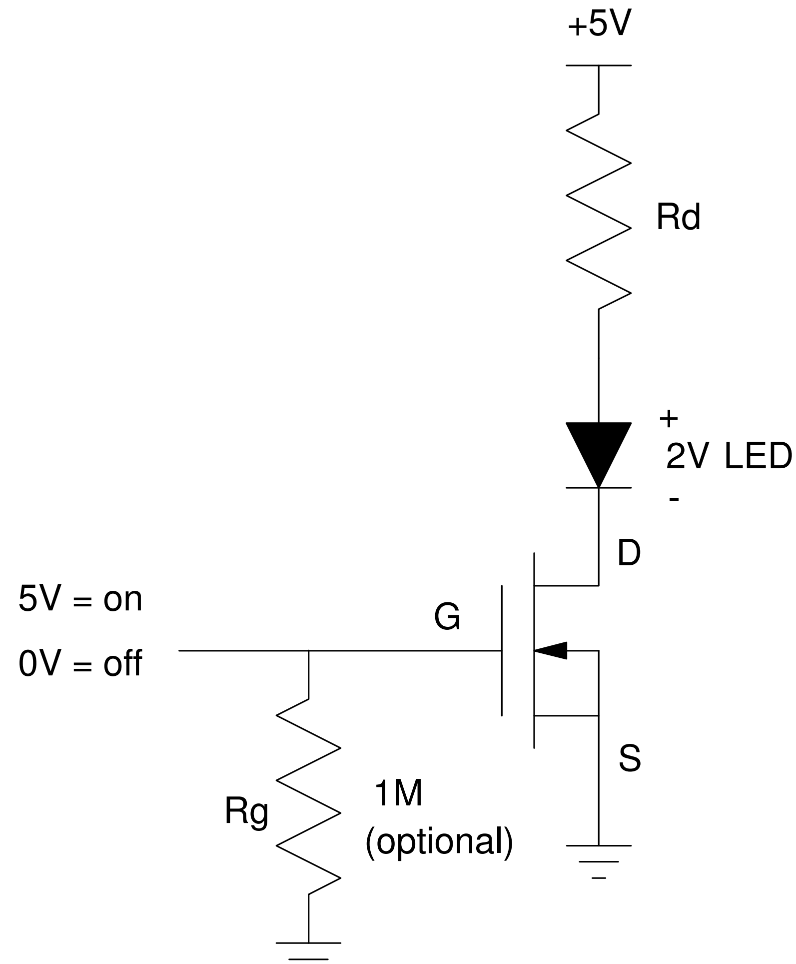
Assume Rds = 1.7 Ohms. Then

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

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

$$R_d = 148.3\Omega$$

(plus or minus 5%: resistors have 5% tolerance)



Final Design (take 2):

Determine { Vds, Id, Rds }

- Need 2 equations for 2 unknowns
- Assume Ohmic region

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

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

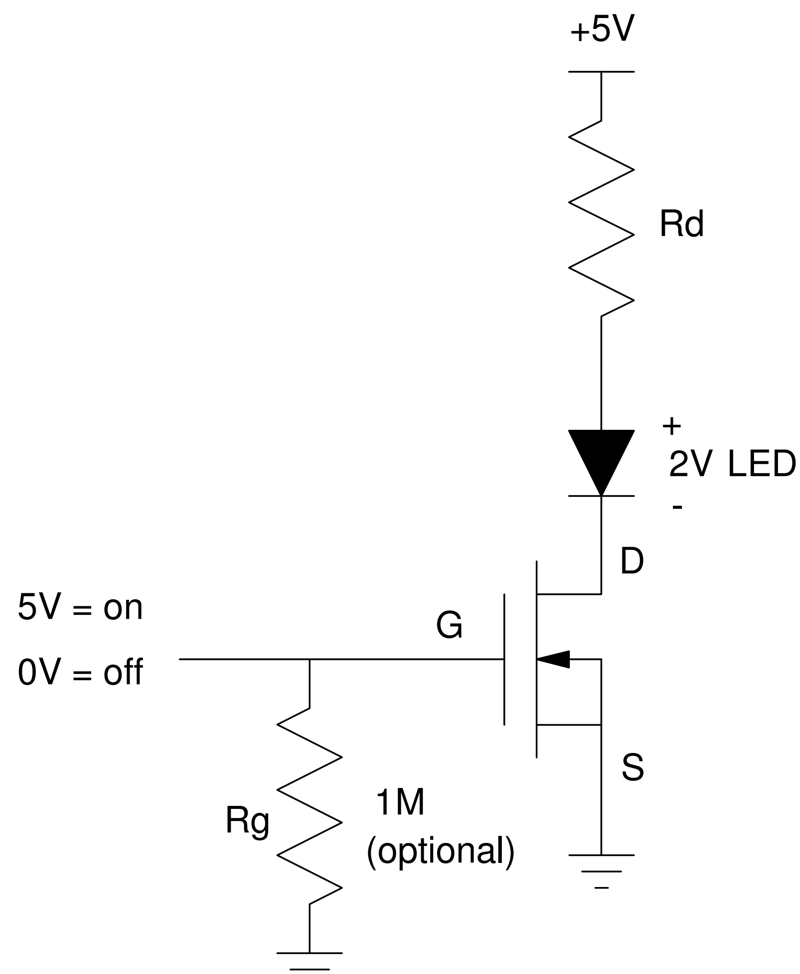
The circuit gives the second equation

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

Vds = { 0.0337V, 6.0341V }

The one close to zero is the correct one:

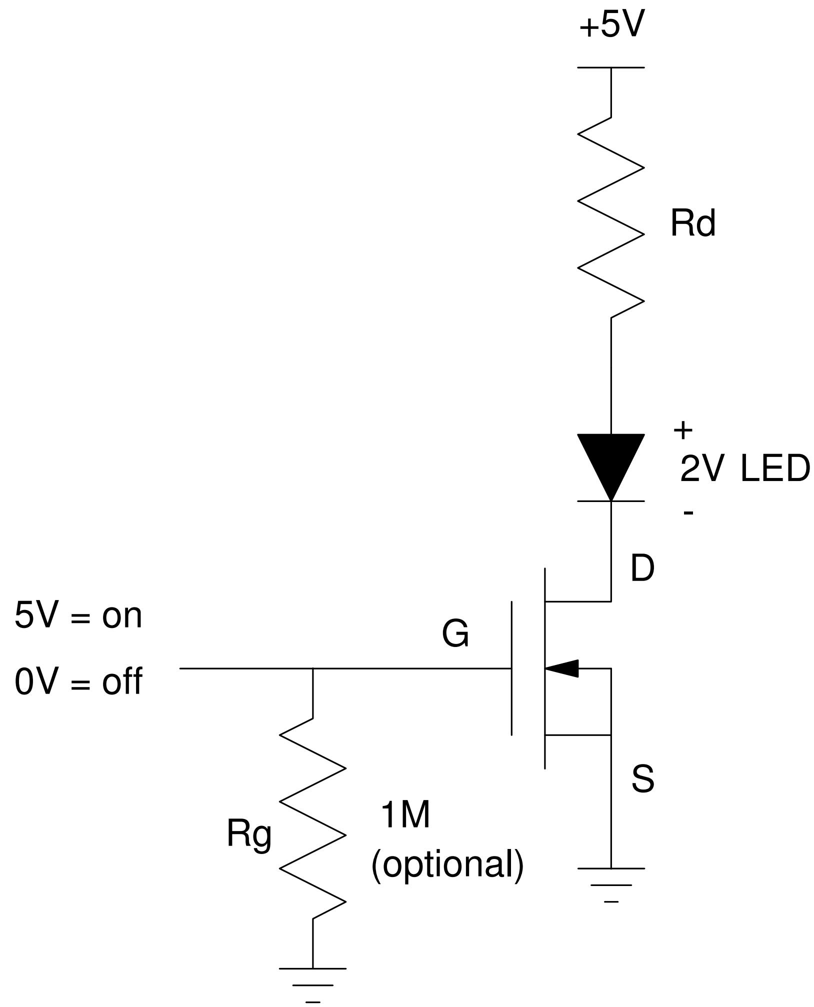
- Vds = 33.7mV
- Ids = 20.002mA
- Rds = Vds / Ids = 1.6854 Ohms



Note: Works for any load providing...

- 1.7 Ohms is small relative to the resistance of what you're driving
- The net current flow is less than 115mA continuous, 800mA pulsed (from the data sheets),

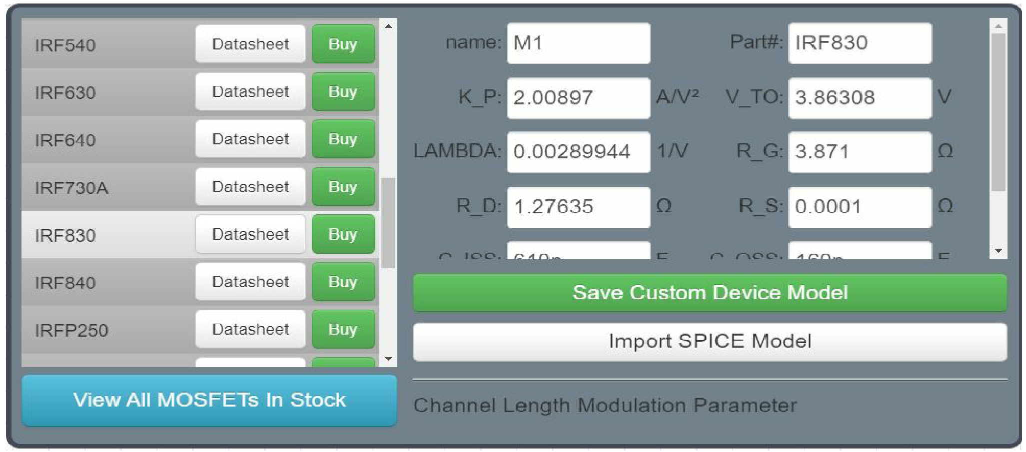
The power supply you're using is less than 60V. The maximum VDS = 60V for this MOSFET.



Checking in CircuitLab

2N7000FS isn't an option in CircuitLab

- Pick a MOSFET with kn close to 0.1989
  - IRF830: K_P = 2.00897 A/V^2
- Modify parameters to match
  - K_P = k_n = 0.1989 A/V^2
  - V_TO = V_{th} = 2V



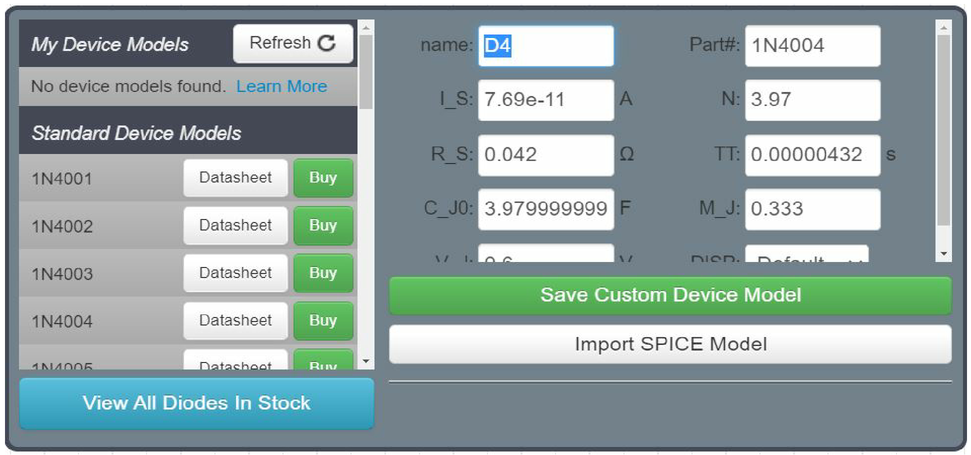
Red LED isn't available.

- Modify 1N4004: Vd = 2.0V @ 20mA

$$V_d = nV_T \cdot \ln\left(\frac{I_d}{I_{dss}} + 1\right)$$

$$2.00V = n \cdot 0.026V \cdot \ln\left(\frac{20mA}{7.69e{-}11A} + 1\right)$$

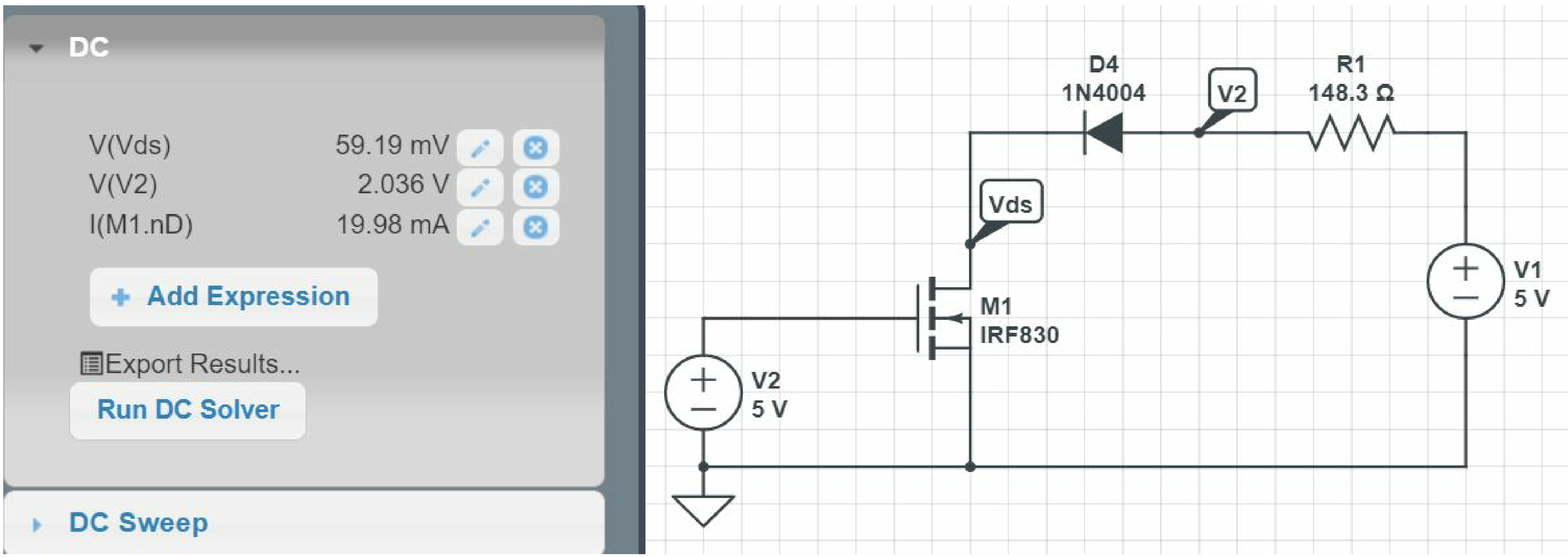
$$n = 3.97$$



Checking in CircuitLab

Calculated:

- Vds = 33.7mV
- Ids = 20.00mA



T(on), T(off)

It also takes some time for the MOSFET to turn on & off.

$$C_{GS} = 20pF$$

$$C_{DS} = 11pF$$

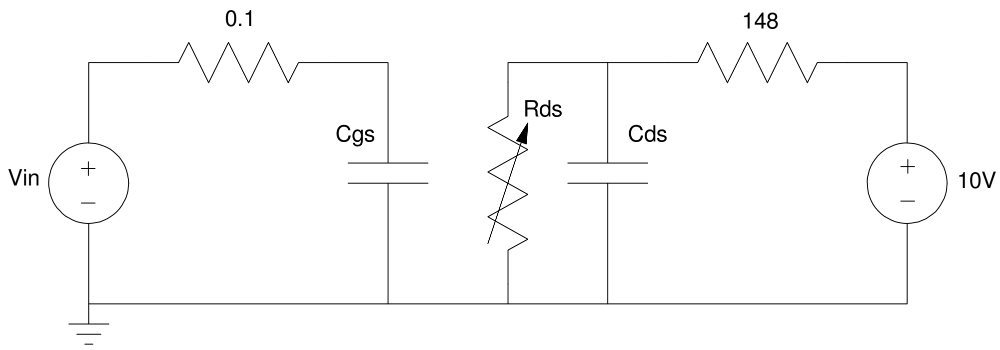
Charge through 148 Ohms

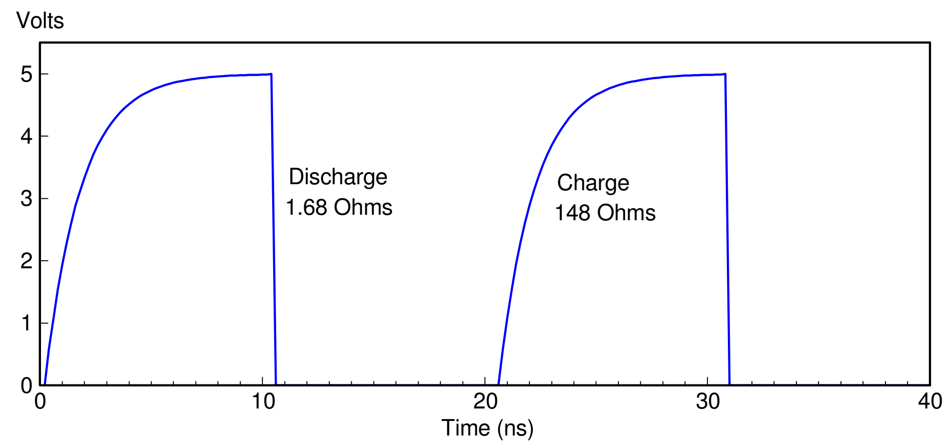
$$V_{DS} = 5V \cdot \left(1 - \exp\left(\frac{-t}{RC}\right)\right)$$

Discharge through 1.68 Ohms (Rds)

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

MOSFETs are *fast* relative to BJT transistors.



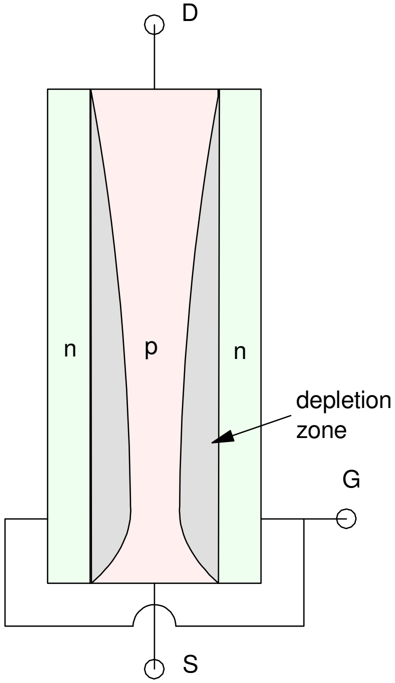


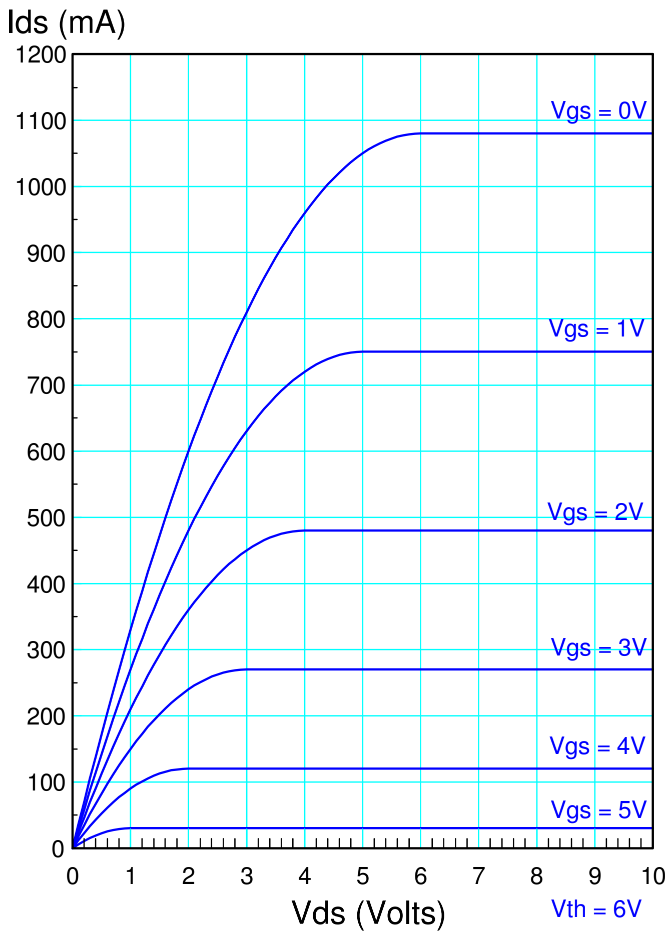
JFET: Junction Field Effect Transistor

- MOSFET: Normally Open Switch
- JFET: Normally Closed Switch

Same equations as a MOSFET

- "on" when Vgs < Vth





Bigger is Better

- MOSFETs are inexpensive, fast, tolerate high voltages and high currents
- max(Ids) = 8A and 500V
- Rds(on) = 0.65 Ohms
- V_{GS} needs 10V to be on. The off voltage (V_{TN}) is between 3V and 5V.

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.

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

Summary

MOSFET switches are actually really easy to use

- Off: Vgs < Vth
- On: Vgn > Vth

The "on" resistance is usually very small

- Can often ignore

The "on" current can be very large

- 1000A for some MOSFETs

Most switches used in industry are MOSFETs

- We avoid them in lab due to static electricity