Device Parameters Research & Simulation

Contents

1. Diode Parameters

a. <u>Define the 5 important power diode characteristics with their symbol and meanings.</u>

1. Forward Voltage Drop (V_F): Power diodes have a voltage drop across them when they are subjected voltage in forward direction. The voltage drop is around 0.7 to 1.5 volts for Silicon Diodes, 2 to 4 volts for Germanium Diodes.

2. Reverse Breakdown Voltage (V_R): The reverse breakdown voltage is the maximum reverse voltage that the diode withstand before it breaks down and start the conducting in the reverse direction.

3. Forward Current Rating (I_F): The forward current rating is the maximum current value in forward direction that the diodes can safely handle without damaging it.

4. Reverse Current Rating (I_R): The reverse current rating is the maximum reverse current value that the diodes can safely handle without damaging it.

5. Reverse Recovery Time (t_{RR}): The reverse recovery time of a power diode is the time it takes for the diode to stop conducting current in the reverse direction after it has been switched off. This is an important parameter to consider when designing circuits that use power diodes, as it can affect the overall performance of the circuit.

b. Losses in Power Diodes

1. Conduction Losses: They are the losses that relates with the current. Conduction losses increase with the current value.

2. Switching Losses: They are the losses that relates to the switching frequency and turn-on, turn-off time. If the frequency gets higher, switching losses are increased proportionally.

c. Select diodes with around 5A, 20A, and 100A current ratings. (at most 5 different types/samples for each current rating, considering different speed, different voltage rating, different material type, i.e., Si, SiC, etc.). Put them into a table to compare the change in most important parameters.

Diode Name & Package	**V & I Ratings**	**Forward Voltage Drop (V_F)**	**Type/Speed**	**T_{RR} (Reverse Recovery Time)**	**Mounting Type**	**Temp. Range (°C)**
RFN5BM6SFHTL / TO252	600V / 5A	1.55V @ 5A	Fast Recovery / =< 500 ns, 200mA (I_O)	50 ns	Surface mount	-45 to 150
1N3899R / DO-5	50V / 20A	Not Specified	Fast Recovery /	Not Specified	Standard	-65 to 150
1N3140 / DO-8	100V / 100A	1.2V @ 200A	Standard Recovery / > 500 ns	Not Specified	Stud Mount	-65 to 200
SK56C / DO-214AB	60V / 5A	0.75V @5A	Not Specified	Not Specified	Surface mount	- 55 to 150
STTH100W04C / TO-247	400V / 100A	0.98V	Ultrafast	35 ns	Not Specified	-65 to 175

d. Select diodes with around 10V, 100V, and 500V voltage ratings. (at most 5 different types/samples for each voltage rating, considering different speed, different current rating, different material type, i.e., Si, SiC, etc.). Put them into a table to compare the change in most important parameters.

Diode Name & Package	V & I Ratings	Forward Voltage Drop (V_F)	Type/Speed	T_{RR} (Reverse Recovery Time)	Mounting Type	Temp Range. (°C)
ES1H / DO-214AC	500V / 1A	1.3 to 1.7	Fast/Ultrafast	35 ns	Surface mount	-55 to 150
BYC20X-600 / TO-220F	500V / 20A	2.9	Fast/Ultrafast	35 ns	Through Hole	-40 to 150
BY448TAP / SOD-57	100V / 100A	1.6	Slow	2000 ns	Any	-55 to 175
ES2B / DO-214AA	100V / 2A	0.75V @5A	Fast/Ultrafast	20 ns	Surface mount	- 55 to 150
MBRM110LT3G / CASE 457-04	10V / 1A	0.325	Not Specified	Not Specified	Surface mount	-55 to 125

e. By referencing the selected MOSFETs in part 2.c and 2.d, comment on the trade-offs of the MOSFET parameters in detail. How does other parameters change when voltage and current ratings are increased? What may be the advantages and/or disadvantages of choosing an overdesign MOSFET? Explain in detail.

In general, if voltage ratings get higher, switching time visibly increase. Furthermore, the current ratings increase with the voltage ratings.

2. MOSFET Parameters

a. <u>Define the 5 most important power MOSFET characteristics with their symbol and meanings.</u>

1. Drain-Source Voltage (V_{DS}): This is the maximum voltage that can be applied between the drain and source of the MOSFET. It is typically denoted by the symbol "V_{DS}" and is usually specified in volts (V).

2. Drain Current (I_D): This is the maximum current that can be safely conducted through the drain terminal of the MOSFET. It is typically denoted by the symbol "I_D" and is usually specified in amperes (A).

3. Gate-Source Voltage (V_{GS}): This is the voltage applied between the gate and source of the MOSFET. It is typically denoted by the symbol "V_{GS}" and is usually specified in volts (V).

4. Drain-Source On-Resistance ($R_{DS(ON)}$): This is the resistance between the drain and source of the MOSFET when it is in the on state. It is typically denoted by the symbol "$R_{DS(ON)}$" and is usually specified in ohms (Ω).

5. Maximum Drain-Source On-State Current (I_{DM}): This is the maximum drain-source current that the MOSFET can safely handle in the on state. It is typically denoted by the symbol "I_{DM}" and is usually specified in amperes (A).

b. Explain the losses of MOSFETs. Which parameters affect the losses?

There are several types of losses that can occur in MOSFETs, including conduction losses, switching losses, and gate drive losses:

Conduction losses occur when the MOSFET is in the on state and a current is flowing through it. These losses are caused by the resistance of the MOSFET ($R_{DS(ON)}$) and are proportional to the square of the drain current (I_D). The power dissipated due to conduction losses can be calculated using the following equation:

$$Conduction\ Loss\ (Pcond) = {I_D}^2 * R_{DS(ON)}$$

Switching losses occur when the MOSFET is transitioning between the on and off states. These losses are caused by the internal capacitances of the MOSFET (C_{GS}, C_{GD}, and C_{SS}) and the rate at which the MOSFET is switching (dI/dt). The power dissipated due to switching losses can be calculated using the following equation:

$$Switching\ Loss\ (Psw) = V_{IN}.I_{OUT}.f.\left(t_{rise} + t_{fall}\right)\ or\ V_{IN}.I_{OUT}.f.\left(\frac{Q_{GS} + Q_{GD}}{I_G}\right)$$

where f is the switching frequency.

Gate drive losses occur when the MOSFET is being driven by a gate driver. These losses are caused by the resistance of the gate driver and the gate-source capacitance of the MOSFET (CGS). The power dissipated due to gate drive losses can be calculated using the following equation:

$$Gate\ Drive\ Loss\ (Pgd) = {V_{GS}}^2(2.R_G) + C_{GS} * {V_{GS}}^2 * f$$

where R_G is the resistance of the gate driver.

In summary, the main factors that affect the losses in MOSFETs are the drain current (ID), the drain-source voltage (VDS), the gate-source voltage (V_{GS}), the switching frequency (f), and the gate driver resistance (R_G).

c. Select MOSFETs with around 5A, 20A, and 100A current ratings. (at most 5 different types/samples for each current rating, different voltage rating, different material type, i.e., Si, SiC, etc.). Put them into a table to compare the change in most important parameters.

MOSFET Name & Package	**Channel Type**	**V_{DS} & I_D Ratings**	**On-Resistance (R_{DS}) (Ω)**	**Gate Source Voltage (V_{GS}) / Max Value**	**Pulsed Drain Current**	**Temp Range. (℃)**
AO3415A/ SOT-23-3	p-channel	-20V / -5A	65mΩ	± 1.8V / 8V	-30A	-55 to 150
RUQ050N02HZGTR/TSMT6 (SC-95)	n-channel	20V / 5A	30mΩ	1V	±10A	-55 to 150
AO4576 / 8-SOIC	n-channel	30V / 20A	7.6mΩ	±20V	144A	-55 to 175
CSD19502Q5BT/ 8-VSON-CLIP (5x6)	n-channel	80V / 100A	3.8 mΩ	±20V	400A	- 55 to 150
MBRM110LT3G / CASE 457-04	p-channel	-60V / -100A	5mΩ	±20V	-400A	-55 to 125

d. Select MOSFETs with around 10V, 100V, and 500V voltage ratings. (at most 5 different types/samples for each voltage rating, considering different current rating, different material type, i.e., Si, SiC, etc.). Put them into a table to compare the change in most important parameters.

MOSFET Name & Package	**Channel Type**	**V_{DS} & I_D Ratings**	**On-Resistance (R_{DS}) (Ω) / Admittance (S)**	**Gate Source Voltage (V_{GS}) / Max Value**	**Pulsed Drain Current**	**Temp Range. (℃)**
EPC2037 / Die	n-channel	100V / 1.7A	550mΩ	6V	2.4A	-40 to 150
2SK209-Y(TE85L,F)/ SC-59	n-channel	10V / 0.5mA	15mS	0V	14mA	-55 to 125
STD15N50M2AG / TO-252	n-channel	500V / 10A	0.380Ω	±30V	40A	-55 to 175

3. Simulation

Select two different diodes and MOSFETs from the devices selected for above questions. Simulate the semiconductor devices with their parameters. Show the losses of semiconductors and compare the results. (Hint: You can use below circuit to examine losses. To compare losses of diodes, keep the MOSFET same for two different diode selection and vice versa. Non-idealities can be modelled in LTspice or in Simulink with Simscape Electrical blue components.)

Results: The simulation is created in Simulink with Simscape and tested. $R_{DS(ON)}$ is directly proportional to the loss of the MOSFET. Also, V_{GS} is affecting the loss because we use MOSFET in saturation region and I_D (Drain Current) of the MOSFET in saturation will be:

$$I_D = \frac{K'_n}{2}\frac{W}{L}(V_{GS} - V_{TN})^2$$

As the V_{GS} is increased, I_D will be larger than before. Therefore, the MOSFET loss which is:

$$P_{LOSS(MOSFET)} = {I_D}^2 . R_{DS(ON)}$$ will increase.

Simulation design can be found in the same repository in Github.