MOSFETS Power Consumption and Power Dissipation Calculation

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Abstract. Metal oxide semiconductor field effect transistors are usually called MOSFET. Nowadays, MOSFET is one of the most crucial electrical components that engineers usually use when constructing laptops and desktop computers. A large number of MOSFETS are usually integrated together to form control and logic functions of computers CPU. Thus, it is essential for electrical engineers to know what type of MOSFETS is appropriate for them to use when designing the integrated circuits. Engineers can seek the answer through calculating two of the most basic and important components of MOSFET power consumption and power dissipation. This article walks through the steps of calculating the power consumption and power dissipation of MOSFETS to provide electrical engineers, students and circuit designers with a clear thought of how to do the calculation under some complex circumstances. MOSFETS power consumption calculation is different under 3 different modes which are cutoff mode, saturation mode and triode mode. Under cutoff mode, the power consumption is zero. Under saturation mode, power consumption is calculated by MOSFETS consume certain amount of power and the total amount of power can be calculated by finding integral of the IV curve. For triode mode, power consumption can be determined by the equation derived later in the article. As for power dissipation, in this article, total power dissipation is divided into two parts which are switching power dissipation and resistive power dissipation. Then, each part of power dissipation is calculated by equations listed in the article and then added together which is the total power dissipation of MOSFETS.

1. Introduction

Electrical power is one of the most significant standards helping electrical engineers to determine whether an electrical component is applicable to a certain circuit design. Therefore, knowing how to calculate the power consumption and power dissipation is important. Power consumption and power dissipation of one MOSFET have different way to calculate since there are difference between two concepts. Power consumption means the total power consumption of that device. Power dissipation stands for the part of the power that is consumed by things not related to the desired tasks. MOSFET represents Metal oxide semiconductor field effect transistors and MOSFETS are now widely used in electrical components. There are four terminals of MOSFETS which are body, gate, drain and source. Drain and source will be conductive when certain amount of voltage is applied to the gate[2]. MOSFETS consumes power when they are operating and the formula of calculating the power consumption is current flows through the MOSFET times the voltage across it. However, MOSFETS can operate under three different modes which are cutoff mode, triode mode and saturation mode[1]. The way to calculate the power consumption under...
different modes are different. The power consumption of MOSFETS under triode mode can be variable which makes it complex for electrical engineers to calculate it precisely. Therefore, this paper will introduce some thoughts of calculating the variable power consumption. In addition, power dissipation is as important as power consumption for electrical engineers to calculate when they need to determine whether the MOSFET is applicable to a particular design. MOSFETS power dissipation mainly consists of resistive loss and switching loss and this paper will also discuss how to calculate the power dissipation of MOSFETS[2].

2. Power Consumption of MOSFETS Working under Cutoff and Saturation Saturation Mode

Normally, the basic equation of power which is written as power equals current times voltage is used to calculate the amount of power electrical components consumed. 

\[ P = IE \]

\[ P = \frac{E^2}{R} \]

\[ P = I^2R \]

Figure 1. Basic equations of power

Therefore, a graph showing the function of current can be plotted according to the basic power equation and voltage and the area under the IV curve indicates the power consumption. The area under the IV curve can be determined through finding the integral of the IV function and this is the approach that can be used to find the power consumption of MOSFETS. MOSFETS can operate under three different modes. Compared with triode mode, the power consumption of MOSFETS under cutoff mode and saturation mode are easier to calculate. For cutoff mode, the voltage applied to gate is not sufficient to turn on the MOSFET which indicates that there is no connection between source and drain. Therefore, the power consumption of the MOSFET under cutoff mode is zero. There is no power consumption under cutoff mode. For saturation mode, the voltage applied to the gate is sufficient to fully turn on the MOSFET and the connection between source and drain is built. MOSFETS consume certain amount of power and the total amount of power can be calculated by finding integral of the IV curve (usually a straight line for this case) which indicates the area under the IV curve or through the equation that power equals to current times voltage.

Figure 2. When gate voltage reaches certain value, the connection between drain and source is built.

3. Power Consumption of MOSFETS Working under Triode Mode
Methods of calculating the power consumption under cutoff mode and saturation mode have been discussed before and they are straightforward. However, when it comes to triode mode, calculating power consumption becomes more complex to analyze because the voltage applied to the gate is not sufficient to fully turn on the MOSFET. The resistance between source and drain is proportional to the voltage applied to the gate and unlike saturation mode, there is a weak connection between source and drain. Thus, it is better to analyze how to calculate the power consumption from exploring a certain type of MOSFETs.

There are many types of MOSFETs which have different working principles. However, n-channel MOSFETs are relatively straightforward to discuss. Under enhancement mode, n-channel MOSFETs are working under linear region. A function which shows the relationship of voltage and current can be derived. The area under the IV function represents the power consumption which is mentioned before. Therefore, for n-channel MOSFETs working under enhancement mode, a function of the relationship of current and voltage can be written as [4]:

\[
I_D = \mu_n C_{ox} \left( \frac{W}{l} \right) \left( V_{GS} - V_{TH} \right) V_{DS} \cdot \frac{1}{2} V_{DS}^2
\]

For this IV function, \( I_D \) stands for drain current and \( \mu_n \) represents the charge-carrier effective mobility. Gate oxide capacitance per unit is represented by Cox. \( W \) stands for the gate width and \( l \) means gate length. \( V_{GS} \) is the voltage for the gate-source and \( V_{TH} \) is the threshold voltage. \( V_{DS} \) is voltage for the drain-source. After understanding the IV function above, the integral of this function can be calculated which indicates the power consumption of the MOSFET working under triode mode. The following equations show that how to calculate the integral of the IV function. These equations help to find the integral over the region from drain-source in “off stage” to drain-source in “on stage” [1].

\[
W = \int_{V_{off}}^{V_{on}} I_D dV_{DS} = k \left[ (V_{GS} - V_{TH}) \int_{V_{off}}^{V_{on}} V_{DS} dV_{DS} - \frac{1}{2} \int_{V_{off}}^{V_{on}} V_{DS}^2 dV_{DS} \right]
\]

\[
= k \left( (V_{GS} - V_{TH}) \left[ \frac{1}{2} V_{DS}^2 \right]_{V_{off}}^{V_{on}} - \frac{1}{2} \left[ \frac{1}{3} V_{DS}^3 \right]_{V_{off}}^{V_{on}} \right)
\]

\[
= \frac{1}{2} k ((V_{GS} - V_{TH}) (V_{on}^2 - V_{off}^2) - \frac{1}{3} (V_{on}^3 - V_{off}^3))
\]

All of calculation can be done with the parameters listed on the data sheets. With these functions above, the power consumption of a particular MOSFET under triode mode can be easily determined. Although calculating the power consumption of MOSFETs under different working modes can be extremely complicated, these methods discussed above are still applicable in many cases.

### 4. Dividing the Total Power Dissipation

After discussing calculating the power consumption, power dissipation is another topic that worthy discussing. Different from power consumption, power dissipation means that the part of the power that is consumed by things not related to desired tasks which makes power dissipation become another important quality to measure during the circuits design. Power dissipation is mainly divided into two forms: resistive power dissipation and switching power dissipation [4]. Resistive loss is caused by internal resistance. Switching loss is the power loss during switching MOSFETs on and off stage. Therefore, the total power loss of a particular MOSFET can be written as:

\[
PD_{total} = PD_{resistive} + PD_{switching}
\]
5. Resistive Power Dissipation Calculation

MOSFETs power dissipation mainly depends on its drain-source on resistance which means the drain-source resistance during MOSFETs turning on. Therefore, to find the power dissipation, determining the drain-source on resistance is a significant step. However, the drain-source on resistance is related to the junction temperature which is indicated by symbol TJ and junction temperature relates to thermal resistance which is represented by $\Theta_{TR}$. Since there are too many variables, starting with assuming a junction temperature TJ seems like a good option. Assuming max permitted die junction is our junction temperature which is represented by symbol TJMax can make the calculation easier and max permitted die junction temperature can be found from data sheets[4]. After assuming the junction temperature, it is essential to find the function of temperature and drain-source on resistance. Data sheets usually have plots which indicate the functions of temperature and drain-source on resistance. To simplify the calculation, NDS351AN MOSFET seems like a good choice to analyze. Here is the plot of junction temperature and drain-source on resistance function found in NDS351AN MOSFET data sheet.

According to this graph, simple calculation can be done to get the function of drain-source on resistance and junction temperature.

$$y = 0.004x + 0.9$$

This function indicates the relationship of drain-source on resistance and junction temperature for NDS351AN MOSFET. Then, the drain-source on resistance at any given junction temperature can be derived using this function. TJ is the same as TJMax which is the assumption made previously. We use RDSon to represent drain-source on resistance. Thus, the drain-source on resistance at TJMax which is indicated by symbol RDSon(max) can be easily determined[2]. The equation of RDSon(max) derived from the information above is written as:

$$R_{DSon(max)} = 0.004* T_{JMax} + 0.9$$

After getting the value of RDSon(max), the next step is to determine the resistive power dissipation at TJMax using ohm’s law and duty factor $\frac{V_{out}}{V_{in}}$[4].

$$PD_{resistive} = \left( I_r^2 * R_{DSon(max)} \right) * \left( \frac{V_{out}}{V_{in}} \right)$$
6. Switching Power Dissipation Calculation

Then, switching power dissipation needs to be dealt with. For switching power dissipation, it is hard to calculate the very precise value because calculating switching power dissipation involves many parameters which are hard to determine. Therefore, using a formula which is generally used to determine the switching power dissipation is an acceptable solution[4].

\[
PD_{\text{switching}} = \left( C_{\text{RSS}} \cdot V_{\text{in}}^2 \cdot f_{\text{sw}} \cdot I_R \right) / I_{\text{gate}}
\]  

(9)

In this equation, \( C_{\text{RSS}} \) represents reverse-transfer capacitance and \( f_{\text{sw}} \) means switching frequency. \( I_{\text{gate}} \) means gate-driver’s sink/source current at the MOSFET’s turn-on threshold. \( C_{\text{RSS}} \) and \( I_{\text{gate}} \) can be found from data sheets. Thus, switching power dissipation can be easily determined knowing all the parameters equation (9) needs. After determining the \( PD_{\text{switching}} \) and \( PD_{\text{resistive}} \) at \( T_{\text{JMax}} \), \( PD_{\text{total}} \) can be determined by the equation listed above. What’s more, since junction temperature is related to thermal resistance \( \Theta_{\text{TR}} \) and \( \Theta_{\text{TR}} \) is listed on data sheet, the degree of temperature rising above the ambient temperature can be calculated by[6]:

\[
T_{\text{JRise}} = T_{\text{JMax}} \cdot \Theta_{\text{TR}}
\]

(10)

After calculating the rise temperature, we can easily determine the ambient temperature[7].

\[
T_{\text{ambient}} = T_{\text{JMax}} - T_{\text{JRise}}
\]

(11)

Calculating ambient temperature can also help to determine what type of MOSFETs is applicable to certain situation during circuit design.

7. Conclusion

MOSFETs are one of the most popular electrical devices used in integrated circuits and nowadays are being widely used in electronic devices. Therefore, this fact makes knowing how to analyze power consumption and power dissipation necessary and significant. For power consumption, the integral of IV function can simply manifest it. When MOSFETs are working under cutoff mode and saturation mode, power consumption is simple to analyze. Under cutoff mode, the power consumption of MOSFETs are zero. Under saturation mode, the power consumption is simply the integral of IV function and it can also be calculated using basic power equation listed above. In addition, when it comes to triode mode, the equation (4) derived above can be used to calculate the power consumption and parameters in the equation (4) are in data sheets. Moreover, total power dissipation is divided into resistive power dissipation and switching power dissipation. Each part of power dissipation can be calculated and then added together to get the total power dissipation. For resistive power dissipation, determining drain-source on resistance is an essential step to do. Drain-source resistance can be easily determined by giving junction temperature a certain value[5]. After getting the value of drain-source on resistance, equation (8) can be used to calculate the resistive power dissipation. As for switching power dissipation, equation (9) is used to calculate it since switching power is hard to calculate precisely. All of the parameters required in equation (9) can be found in data sheets. Finally, adding resistance power dissipation and switching power dissipation together determines the final value of total power dissipation. Although there are more complex and robust ways to analyze more complicate cases about the MOSFETs power consumption and power dissipation, the methods we discussed are still applicable to most of power analysis cases.

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