Electric Circuits & Electronics Design Lab

EE 316-01

# Lab 11&12: MOSFETs

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## Introduction:

The purpose of this lab is to look at the behavior of a MOSFET, specifically its saturation region, mode, and bandwidth. This report will have 5 main sections. First is the theoretical analysis which is done as the pre-lab and includes Multisim simulations. There is no handwritten theoretical part for this lab. Then we have the physical circuits which are constructed on breadboards in lab. Afterwards, we compare the results from those 3 sections and conclude with an analysis of the results.

## Theoretical Analysis:

To start, we look at how a MOSFET is constructed, works, behaves depending on the state or mode it is in. The MOSFET is a three terminal unipolar semiconductor that is a voltage-controlled field effect transistor. The main gate is isolated from the current carrying channel and no current flows into the gate. They operate in two modes: depletion which requires the gate source voltage to switch off and enhancement which requires a gate source voltage to switch the device on. Figures 1 and 2 gives the characteristic curves for an n-channel MOSFET and p-channel MOSFET in depletion (a) and enhancement mode (b).

Graphical user interface, chart

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**Figure 1**. Characteristics of N-Channel MOSFET

Chart

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Chart, histogram

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**Figure 2.** Characteristics of P-Channel MOSFET

## Simulations:

For the next phase of the lab, we built the circuits shown in Figures 3 and 4 in Multisim. We used the 2N70000 MOSFET. For the circuit in Figure 3, we were taking note of the drain to source voltage and drain current when the MOSFET started to saturate. Using the plots, we created with the data obtained. we looked at the minimum drain to source voltage that put the MOSFET in saturation and whether it was n or p channel MOSFET in depletion or enhancement mode. For Figure 4, we were observing the MOSFET as an amplifier and what the bandwidth of the MOSFET was given a range of frequencies. We plotted the gain and frequency in order to determine the bandwidth.

Tables 1 – 3 is the data gathered from MultiSim and Figures 5 – 7 are plots generated from the data.

Diagram, schematic

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**Figure 3**: MOSFET circuit

Diagram, schematic

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**Figure 4.** Signal Amplification with MOSFET

**Table 1.** Output Characteristics

|  |  |  |  |
| --- | --- | --- | --- |
| V2 = 2.5 | | | |
| Vds | Vgs (mV) | Id (mA) | V1 |
| 0 | 2.475 | 0 | 0 |
| 0.008529 | 2.44 | 0.000356 | 0.4 |
| 0.019 | 2.405 | 0.00071 | 0.8 |
| 0.021 | 2.396 | 0.000799 | 1.1 |
| 0.028 | 2.379 | 0.000975 | 1.4 |
| 0.038 | 2.353 | 0.001238 | 1.7 |
| 0.051 | 2.327 | 0.001499 | 2.5 |
| 0.107 | 2.26 | 0.002176 | 3 |
| 0.215 | 2.225 | 0.002532 | 3.1 |
| 0.312 | 2.224 | 0.002534 | 3.2 |
| 0.412 | 2.224 | 0.002534 | 3.3 |
| 0.512 | 2.224 | 0.002534 | 3.4 |
| V2 = 3 | | | |
| 0 | 2.97 | 0 | 0 |
| 0.005374 | 2.926 | 0.00045 | 0.5 |
| 0.011 | 2.881 | 0.000899 | 1 |
| 0.018 | 2.837 | 0.001347 | 1.5 |
| 0.022 | 2.81 | 0.001616 | 1.8 |
| 0.028 | 2.775 | 0.001974 | 2.2 |
| 0.033 | 2.748 | 0.002243 | 2.5 |
| 0.04 | 2.713 | 0.0026 | 2.9 |
| 0.048 | 2.678 | 0.002956 | 3.3 |
| 0.057 | 2.642 | 0.003311 | 3.7 |
| 0.073 | 2.59 | 0.003842 | 4.3 |
| 0.089 | 2.546 | 0.004282 | 4.8 |
| 0.124 | 2.477 | 0.004978 | 5.6 |
| 0.19 | 2.402 | 0.005736 | 6.5 |
| 0.266 | 2.364 | 0.006121 | 7 |
| 0.294 | 2.358 | 0.006187 | 7.1 |
| 0.338 | 2.353 | 0.006238 | 7.2 |
| 0.432 | 2.352 | 0.006243 | 7.3 |
| 0.532 | 2.352 | 0.006243 | 7.4 |
| V2 = 3.5 | | | |
| 0 | 3.465 | 0 | 0 |
| 0.003699 | 3.421 | 0.000451 | 0.5 |
| 0.007609 | 3.376 | 0.000902 | 1 |
| 0.012 | 3.331 | 0.001353 | 1.5 |
| 0.016 | 3.287 | 0.001803 | 2 |
| 0.021 | 3.242 | 0.002254 | 2.5 |
| 0.026 | 3.198 | 0.002704 | 3 |
| 0.031 | 3.153 | 0.003153 | 3.5 |
| 0.037 | 3.109 | 0.003603 | 4 |
| 0.043 | 3.064 | 0.004051 | 4.5 |
| 0.05 | 3.02 | 0.0045 | 5 |
| 0.058 | 2.975 | 0.004947 | 5.5 |
| 0.066 | 2.931 | 0.005395 | 6 |
| 0.069 | 2.914 | 0.005573 | 6.2 |
| 0.075 | 2.887 | 0.005841 | 6.5 |
| 0.081 | 2.861 | 0.006108 | 6.8 |
| 0.085 | 2.843 | 0.006286 | 7 |
| 0.09 | 2.825 | 0.006464 | 7.2 |
| 0.097 | 2.799 | 0.00673 | 7.5 |
| 0.0104 | 2.773 | 0.006996 | 7.8 |
| 0.11 | 2.755 | 0.007173 | 8 |
| 0.115 | 2.738 | 0.007349 | 8.2 |
| 0.125 | 2.711 | 0.007614 | 8.5 |
| 0.135 | 2.685 | 0.007877 | 8.8 |
| 0.143 | 2.668 | 0.008052 | 9 |
| 0.151 | 2.651 | 0.008227 | 9.2 |
| 0.164 | 2.625 | 0.008487 | 9.5 |
| 0.179 | 2.599 | 0.008746 | 9.8 |
| 0.19 | 2.582 | 0.008918 | 10 |
| 0.203 | 2.566 | 0.009088 | 10.2 |
| 0.225 | 2.541 | 0.009341 | 10.5 |
| 0.252 | 2.516 | 0.009589 | 10.8 |
| 0.274 | 2.5 | 0.00975 | 11 |
| 0.337 | 2.47 | 0.01 | 11.4 |
| 0.361 | 2.463 | 0.01 | 11.5 |
| 0.5 |  | 0.01 |  |
| V2 = 4 | | | |
| 0 | 3.96 | 0 | 0 |
| 0.002887 | 3.916 | 0.000452 | 0.5 |
| 0.005889 | 3.871 | 0.000904 | 1 |
| 0.009014 | 3.826 | 0.001355 | 1.5 |
| 0.012 | 3.781 | 0.001807 | 2 |
| 0.016 | 3.737 | 0.002258 | 2.5 |
| 0.019 | 3.692 | 0.00271 | 3 |
| 0.023 | 3.647 | 0.003161 | 3.5 |
| 0.027 | 3.603 | 0.003612 | 4 |
| 0.0031 | 3.558 | 0.004063 | 4.5 |
| 0.035 | 3.514 | 0.004513 | 5 |
| 0.04 | 3.469 | 0.004964 | 5.5 |
| 0.043 | 3.442 | 0.005234 | 5.8 |
| 0.045 | 3.424 | 0.005414 | 6 |
| 0.05 | 3.38 | 0.005864 | 6.5 |
| 0.055 | 3.335 | 0.006313 | 7 |
| 0.058 | 3.317 | 0.006493 | 7.2 |
| 0.061 | 3.291 | 0.006762 | 7.5 |
| 0.067 | 3.246 | 0.007211 | 8 |
| 0.07 | 3.229 | 0.007391 | 8.2 |
| 0.074 | 3.202 | 0.00766 | 8.5 |
| 0.082 | 3.158 | 0.008108 | 9 |
| 0.085 | 3.14 | 0.008287 | 9.2 |
| 0.089 | 3.113 | 0.008555 | 9.5 |
| 0.094 | 3.087 | 0.008823 | 9.8 |
| 0.098 | 3.069 | 0.009002 | 10 |
| 0.102 | 3.051 | 0.00918 | 10.2 |
| 0.107 | 3.025 | 0.009448 | 10.5 |
| 0.113 | 2.998 | 0.009715 | 10.8 |
| 0.118 | 2.981 | 0.009893 | 11 |
| 0.122 | 2.963 | 0.01 | 11.2 |
| 0.129 | 2.937 | 0.01 | 11.5 |
| 0.25 |  | 0.01 |  |
| 0.4 |  | 0.01 |  |
| 0.55 |  | 0.01 |  |

**Table 2.** Mode Characteristics

|  |  |
| --- | --- |
| Vgs | Id (mA) |
| 1.98 | 0.003553 |
| 2.136 | 0.931 |
| 2.224 | 2.537 |
| 2.293 | 4.338 |
| 2.352 | 6.244 |
| 2.404 | 8.219 |
| 2.451 | 10 |
| 2.494 | 12 |
| 2.535 | 14 |
| 2.573 | 17 |
| 2.609 | 19 |
| 2.755 | 20 |
| 2.992 | 20 |

**Table 3.** Output and Gain

|  |  |  |
| --- | --- | --- |
| F(HZ) | VOUT | Gain(db) |
| 30 | 0.02135 | -13.4120424 |
| 45 | 0.06591 | -3.62097377 |
| 60 | 0.126 | 2.007410902 |
| 100 | 0.192 | 5.666024574 |
| 200 | 0.286 | 9.127320663 |
| 500 | 0.368 | 11.31695637 |
| 1k | 0.372 | 11.4108588 |
| 10k | 0.37 | 11.36403448 |
| 100k | 0.372 | 11.4108588 |
| 500k | 0.372 | 11.4108588 |
| 1M | 0.371 | 11.38747819 |
| 1.5M | 0.363 | 11.1981325 |
| 2M | 0.352 | 10.93085327 |
| 3M | 0.338 | 10.57833401 |
| 4M | 0.305 | 9.685996787 |
| 5M | 0.271 | 8.659385817 |
| 7M | 0.145 | 3.227360045 |
| 10M | 0.102 | 0.172003435 |
| 11M | 0.07789 | -2.17036592 |
| 12M | 0.0534 | -5.44917486 |
| 15M | 0.04295 | -7.34073664 |
| 16M | 0.02952 | -10.5976729 |

**Figure 5**. Characteristics of MOSFET

**Figure 6.** Transfer Characteristics

**Figure 7.** Gain vs Frequency

## Experimental:

For the last portion of the lab, we did the same things as prior but on a physical board to further validate the output results we obtained. For the first part, we looked at the drain source voltage versus the drain current characteristics of the MOSFET. Excel was used for any calculations and plots. Table 4 and 5 gives the values collected and Figures 8 and 9 are the characteristic plots. A few extra values were added at the end so that the points would all extend to around the same ending VDS­ value. The star marks the threshold voltage. Extra values were also added to the mode characteristics table to make the line connect from 0 to the threshold voltage.

For the amplification circuit, Table 6 contains the output voltage and gain observed for each frequency. Figure 10 is the plot of gain versus frequency. The lowest frequency that could be done in lab with results was 20 Hz and the highest frequency was 3M Hz, so the table for this portion looks a little different than the one for the previous section. The bandwidth is shown by the green line.

**Table 4.** Output Characteristics

|  |  |  |  |
| --- | --- | --- | --- |
| V2 = 2.5 | | | |
| Vds | Vgs (mV) | Id (mA) | V1 |
| 0 | 2.49 | 0 | 0 |
| 0.00386 | 2.46 | 0.000438 | 0.5 |
| 0.009057 | 2.40 | 0.000955 | 1 |
| 0.01127 | 2.39 | 0.001077 | 1.2 |
| 0.0156 | 2.37 | 0.001243 | 1.4 |
| 0.01938 | 2.35 | 0.001496 | 1.6 |
| 0.02428 | 2.33 | 0.001642 | 1.8 |
| 0.03294 | 2.31 | 0.001891 | 2.1 |
| 0.04287 |  | 0.002076 | 2.3 |
| 0.05952 |  | 0.002285 | 2.5 |
| 0.08109 |  | 0.002449 | 2.7 |
| 0.10443 |  | 0.002554 | 2.9 |
| 0.128 |  | 0.00262 | 3 |
| 0.204 |  | 0.002718 | 3.2 |
| 0.348 |  | 0.002775 | 3.4 |
| 0.5 |  | 0.002776 |  |
| V2 = 3 | | | |
| 0 | 2.96 | 0 | 0 |
| 0.00158 | 2.91 | 0.000453 | 0.5 |
| 0.00259 |  | 0.000718 | 0.8 |
| 0.004174 |  | 0.001095 | 1.2 |
| 0.005133 | 2.83 | 0.001306 | 1.4 |
| 0.006971 |  | 0.001676 | 1.8 |
| 0.008371 |  | 0.001927 | 2.1 |
| 0.010719 |  | 0.002303 | 2.5 |
| 0.013359 |  | 0.002663 | 2.9 |
| 0.015752 |  | 0.00295 | 3.2 |
| 0.018294 |  | 0.003205 | 3.5 |
| 0.021855 |  | 0.003515 | 3.8 |
| 0.025696 |  | 0.003792 | 4.2 |
| 0.029746 |  | 0.004036 | 4.4 |
| 0.0329 |  | 0.0042 | 4.6 |
| 0.03582 |  | 0.004333 | 4.8 |
| 0.04215 | 2.51 | 0.004576 | 5 |
| 0.05147 |  | 0.00485 | 5.3 |
| 0.05642 |  | 0.004965 | 5.5 |
| 0.07562 |  | 0.00529 | 5.8 |
| 0.10093 |  | 0.005539 | 6.1 |
| 0.1256 |  | 0.005685 | 6.3 |
| 0.14 |  | 0.005745 | 6.4 |
| 0.175 |  | 0.005838 | 6.6 |
| 0.272 |  | 0.005961 | 6.8 |
| 0.362 |  | 0.006005 | 6.9 |
| 0.437 |  | 0.006024 | 7 |
| 0.52435 | 2.39 | 0.006039 | 7.1 |
| V2 = 3.5 | | | |
| 0 | 3.529 | 0 | 0 |
| 0.001031 |  | 0.000453 | 0.5 |
| 0.002087 |  | 0.000896 | 1 |
| 0.003433 |  | 0.001432 | 1.5 |
| 0.004812 |  | 0.00195 | 2.1 |
| 0.00578 |  | 0.002295 | 2.5 |
| 0.007202 |  | 0.002773 | 3 |
| 0.0087 |  | 0.003243 | 3.5 |
| 0.010256 | 3.168 | 0.003698 | 4 |
| 0.01178 |  | 0.004109 | 4.5 |
| 0.013772 |  | 0.004605 | 5 |
| 0.015804 |  | 0.005061 | 5.5 |
| 0.017988 |  | 0.005503 | 6 |
| 0.02065 |  | 0.005981 | 6.5 |
| 0.023232 |  | 0.00639 | 7 |
| 0.025277 |  | 0.00679 | 7.3 |
| 0.027638 |  | 0.00698 | 7.6 |
| 0.031021 |  | 0.00736 | 8 |
| 0.03345 |  | 0.007603 | 8.3 |
| 0.036443 |  | 0.00786 | 8.6 |
| 0.039538 |  | 0.008102 | 8.9 |
| 0.04297 |  | 0.008333 | 9 |
| 0.043585 |  | 0.008376 | 9.2 |
| 0.048322 |  | 0.00865 | 9.5 |
| 0.0535 |  | 0.00901 | 9.7 |
| 0.0586 |  | 0.009112 | 10 |
| 0.06457 |  | 0.00932 | 10.2 |
| 0.07214 |  | 0.009538 | 10.5 |
| 0.08604 |  | 0.009842 | 10.8 |
| 0.09787 |  | 0.010034 | 11 |
| 0.105207 |  | 0.01013 | 11.1 |
| 0.11085 |  | 0.010196 | 11.2 |
| 0.11492 |  | 0.01023 | 11.3 |
| 0.2 |  | 0.01024 |  |
| 0.3 |  | 0.01025 |  |
| 0.5 |  | 0.01025 |  |
| V2 = 4 | | | |
| 0 |  | 0 | 0 |
| 0.000999 |  | 0.000516 | 0.5 |
| 0.001913 |  | 0.000976 | 1 |
| 0.002787 |  | 0.001402 | 1.5 |
| 0.003787 |  | 0.001873 | 2 |
| 0.004712 |  | 0.002294 | 2.5 |
| 0.005718 |  | 0.002738 | 3 |
| 0.006858 | 3.63 | 0.003219 | 3.5 |
| 0.008014 |  | 0.003687 | 4 |
| 0.009046 |  | 0.004089 | 4.5 |
| 0.010352 |  | 0.004575 | 5 |
| 0.011771 |  | 0.005074 | 5.5 |
| 0.013128 |  | 0.005527 | 6 |
| 0.014405 |  | 0.005929 | 6.5 |
| 0.015989 |  | 0.006402 | 7 |
| 0.017685 |  | 0.006872 | 7.5 |
| 0.019385 |  | 0.007316 | 8 |
| 0.02143 |  | 0.007807 | 8.5 |
| 0.023338 |  | 0.008227 | 9 |
| 0.025628 |  | 0.008688 | 9.5 |
| 0.028376 |  | 0.009186 | 10 |
| 0.031054 | 3.0166 | 0.00962 | 10.5 |
| 0.034445 |  | 0.010103 | 11 |
| 0.037393 |  | 0.010474 | 11.5 |
| 0.041842 |  | 0.010955 | 12 |
| 0.04389 |  | 0.011152 | 12.2 |
| 0.04596 |  | 0.011337 | 12.4 |
| 0.05095 |  | 0.011726 | 12.8 |
| 0.05359 |  | 0.011906 | 13 |
| 0.05634 |  | 0.012078 | 13.2 |
| 0.060022 |  | 0.012286 | 13.4 |
| 0.063839 |  | 0.012478 | 13.6 |
| 0.068025 | 2.72 | 0.012663 | 13.8 |
| 0.07234 |  | 0.012835 | 14 |
| 0.07575 |  | 0.012956 | 14.2 |
| 0.08186 |  | 0.013147 | 14.4 |
| 0.08846 |  | 0.01323 | 14.6 |
| 0.0984 |  | 0.013541 | 14.8 |
| 0.1065 |  | 0.01369 | 15 |
| 0.1102 |  | 0.01375 | 15.1 |
| 0.1172 |  | 0.01385 | 15.2 |
| 0.12617 |  | 0.013961 | 15.3 |
| 0.1324 |  | 0.014029 | 15.4 |
| 0.14464 |  | 0.014137 | 15.5 |
| 0.2 |  | 0.014138 |  |
| 0.35 |  | 0.014139 |  |
| 0.5 |  | 0.014139 |  |

**Table 5.** Mode Characteristics

|  |  |
| --- | --- |
| Vgs | Id (mA) |
| 0 | 0 |
| 1 | 0.1 |
| 1.5 | 0.12 |
| 1.95 | 0.175 |
| 2.15 | 1.61 |
| 2.2 | 2.68 |
| 2.24 | 3.65 |
| 2.28 | 4.96 |
| 2.34 | 7.38 |
| 2.37 | 9.01 |
| 2.4 | 10.969 |
| 2.45 | 12.67 |
| 2.5 | 15.75 |
| 2.54 | 17.927 |
| 2.56 | 18.865 |
| 2.596 | 20.016 |
| 2.64 | 20.172 |
| 2.71 | 20.204 |

**Figure 8.** Output Characteristics

**Figure 9.** Mode Characteristics

**Table 6.** Amplification observations

|  |  |  |
| --- | --- | --- |
| F(HZ) | VOUT (mV) | Gain(db) |
| 20 | 320 | 2.462658715 |
| 30 | 380 | 3.955331081 |
| 60 | 400 | 4.400858975 |
| 100 | 400 | 4.400858975 |
| 200 | 420 | 4.824644956 |
| 500 | 420 | 4.824644956 |
| 1000 | 420 | 4.824644956 |
| 2000 | 460 | 5.614815782 |
| 5000 | 460 | 5.614815782 |
| 10000 | 460 | 5.614815782 |
| 15000 | 460 | 5.331169692 |
| 20000 | 420 | 4.540998866 |
| 50000 | 380 | 3.67168499 |
| 75000 | 340 | 2.705591399 |
| 100000 | 280 | 1.019173685 |
| 150000 | 240 | -0.31976211 |
| 200000 | 200 | -1.90338703 |
| 500000 | 100 | -7.92398694 |
| 750000 | 80 | -9.8621872 |
| 1000000 | 60 | -13.1602279 |
| 1500000 | 60 | -13.1602279 |

**Figure 10.** Gain vs Frequency

## Results and Discussion:

As far the look of the plots, the outputs and lines were as we expected. Given the plots we collected, we had a n-channel MOSFET in enhancement mode with a threshold voltage of 2. The results gathered for the first portion for both experimental and simulation were pretty close with each other. They both saturated at the same Id with a little discrepancy due to lab equipment vs software.

The gain portion of the lab differ a lot between the experimental and simulation sections because the oscilloscope in the lab was not working correctly. After every change of frequency if you auto scaled the output it gave back around 420 mV every time. From the data I could collect it seemed to be acting in reverse, which was not correct, so I did reverse the data for the graph so that it would come out to the correct shape. The bandwidth for the experimental portion is shifted by about 50 to the left compared to the simulation. The amplitude that determines the bandwidth is also about half that of what was seen in the simulation portion.

## Conclusion

Overall, the results of lab where in line with what we expected from the information gathered from the theoretical sections. Our results for the experimental and simulation matched for the first portion of the lab with discrepancies due to real equipment and components versus software. The amplification portion of the lab differed greatly due to in lab equipment not working correctly or possibly a component/circuit problem. This lab showed us the behavior for MOSFET and allowed us to identify mode and type based on behavior. It also gave us the information to compare the MOSFET to BJTs and JFETs.

## Appendix 1:

N/A

## Appendix 2:

Signed lab results

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Pictures of Circuits

A picture containing electronics

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**Figure 1**. Characteristic Circuit (ref Figure 3)

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**Figure 2.** Amplification Circuit (ref Figure 4)