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MOSFET gate charge parameters extracted from simulation models
...and the application/use examples for math analysis

$V_{GS_import} :=$

	0
0	...

Insert --> Data --> Data Import Wizard

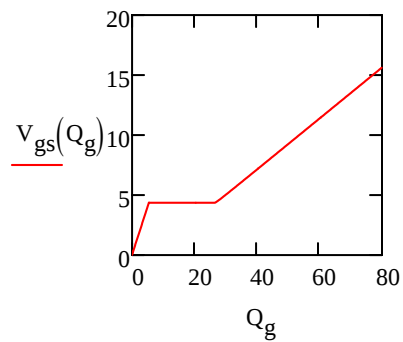
- * Select "Microsoft Excel" and find the appropriate file
- * Import the column (and rows) of interest

$Q_g := 0, 0.1 .. 79.9$

$V_{gs}(Q_g) := V_{GS_import} Q_g \cdot 10$

Create a range variable to use as argument
in function calls (and vector/array indexing)

Convert vector/array to "function" for easier plotting



Plot for checking against DS

$$Q_{g_plat0} := \left| \begin{array}{l} Q_{g_temp} \leftarrow 0 \\ \text{while } V_{gs}(Q_{g_temp}) < V_{gs}(Q_{g_temp} + 0.1) \\ \left| \begin{array}{l} Q_{g_plat} \leftarrow Q_{g_temp} \\ Q_{g_temp} \leftarrow Q_{g_temp} + 0.1 \end{array} \right. \end{array} \right.$$

Identify charge at the beginning of plateau

$$Q_{g_plat0} = 5.4 \quad \text{nC}$$

$$V_{gs_plat} := V_{gs}(Q_{g_plat0}) = 4.356 \quad \text{V}$$

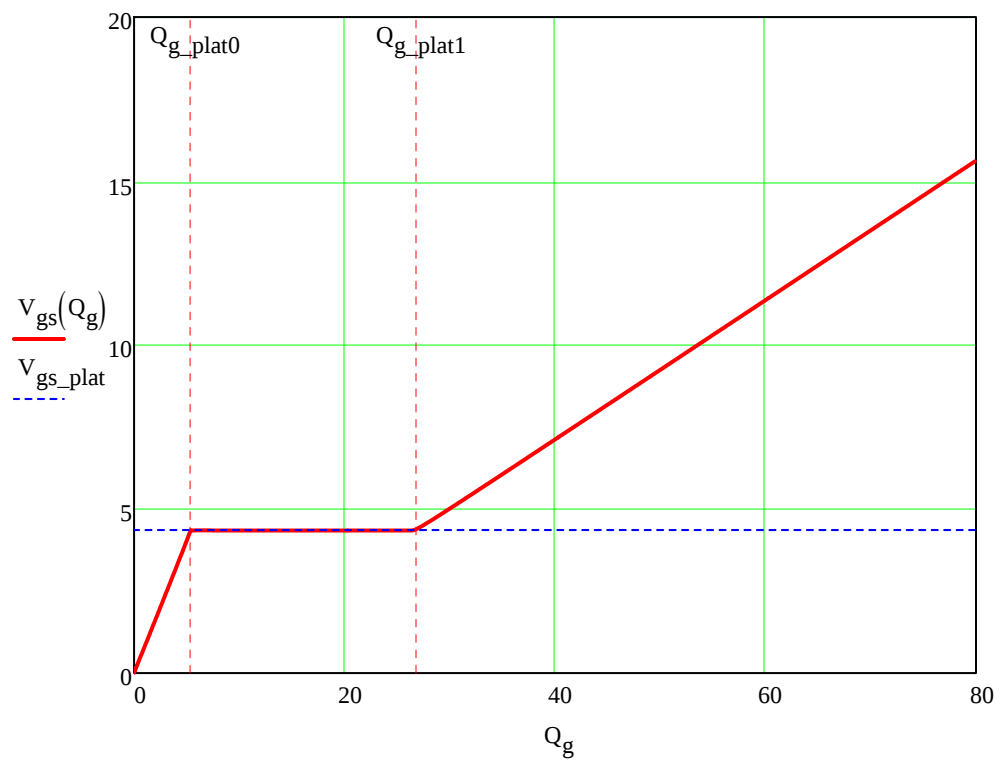
Identify plateau voltage

$$Q_{g_plat1} := \left| \begin{array}{l} Q_{g_temp} \leftarrow Q_{g_plat0} \\ \text{while } V_{gs}(Q_{g_temp}) < V_{gs_plat} + 0.01 \\ \left| \begin{array}{l} Q_{g_plat1} \leftarrow Q_{g_temp} \\ Q_{g_temp} \leftarrow Q_{g_temp} + 0.1 \end{array} \right. \end{array} \right.$$

Identify charge at the end of plateau

$$Q_{g_plat1} = 26.8 \quad \text{nC}$$

$$V_{gs_plat1} := V_{gs}(Q_{g_plat1}) = 4.381 \quad \text{V}$$



$$Q_{gs} := Q_{g_plat0} = 5.4 \text{ nC}$$

$$Q_{gd} := Q_{g_plat1} - Q_{gs} = 21.4 \text{ nC}$$

$$V_{GS} := 12 \quad V$$

$$Q_{g_VGS} := \begin{cases} Q_{g_temp} \leftarrow 0 \\ \text{while } V_{gs}(Q_{g_temp}) < V_{GS} \\ \quad Q_{g_temp} \leftarrow Q_{g_temp} + 0.1 \\ \quad Q_{g_VGS} \leftarrow Q_{g_temp} \end{cases}$$

$$Q_{g_VGS} = 63 \quad nC$$

$$R_{g_int} := 1.2 \quad \text{Ohms}$$

Internal gate resistance (internal to the MOSFET)

$$R_{g_ext} := 10 \quad \text{Ohms}$$

External gate resistance (discrete resistance between driver output and MOSFET gate-pin)

$$C_{gs_tr} := \frac{Q_{gs}}{V_{gs_plat}} = 1.24 \quad nF$$

Find the time-related gate-source capacitance based on charge at beginning of Miller Plateau

$$C_{gs_gd_tr} := \frac{Q_{g_VGS} - (Q_{gd} + Q_{gs})}{V_{GS} - (V_{gs_plat})} = 4.736 \quad nF$$

Find the time-related gate-drain and gate-source parallel capacitance value above Miller Plateau

$$V_{gs_1}(t) := V_{GS} \cdot \left[1 - e^{\frac{-t}{(R_{g_int} + R_{g_ext}) \cdot C_{gs_tr}}} \right] V$$

RC response for V_{gs} rising to the start of Miller Plateau (t is time in nano-seconds)

$$i_{plat} := \frac{V_{GS} - V_{gs_plat}}{R_{g_int} + R_{g_ext}} = 0.682 \quad A$$

Constant drive current during Miller Plateau

$$t_{plat} := \frac{Q_{gd}}{i_{plat}} = 31.357 \quad ns$$

Time spent at Miller Plateau

$$V_{gs_3}(t) := (V_{GS} - V_{gs_plat}) \cdot \left[1 - e^{\frac{-t}{(R_{g_int} + R_{g_ext}) \cdot C_{gs_gd_tr}}} \right] V$$

RC response for V_{gs} rising beyond Miller plateau (up to target V_{GS}) (t is time in ns)

Given

$$V_{gs_1}(t_guess) = V_{gs_plat}$$

$$t_guess := 15 \quad ns$$

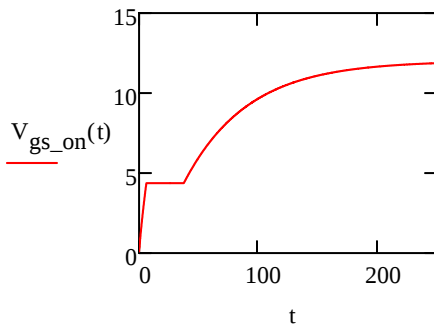
$$t_{plat1} := \text{Minerr}(t_guess) = 6.262 \quad ns$$

$$t := 0, 0.1 \dots 1000$$

Solver-block to return time (in ns), when gate-source voltage has reached the Miller Plateau

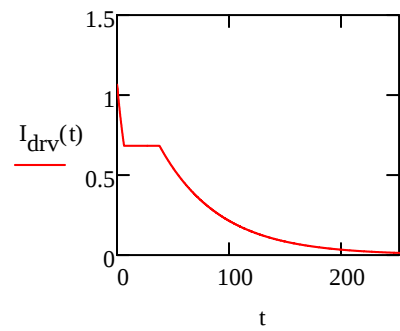
Time from $V_{gs}=0V$ to $V_{gs}=V_{plateau}$

$$V_{gs_on}(t) := \begin{cases} V_{gs_1}(t) & \text{if } 0 < t < t_{plat1} \\ V_{gs_plat} & \text{if } t_{plat1} < t < (t_{plat1} + t_{plat}) \\ \left[V_{gs_plat} + V_{gs_3} \left[t - (t_{plat1} + t_{plat}) \right] \right] & \text{if } t_{plat1} + t_{plat} < t \end{cases}$$



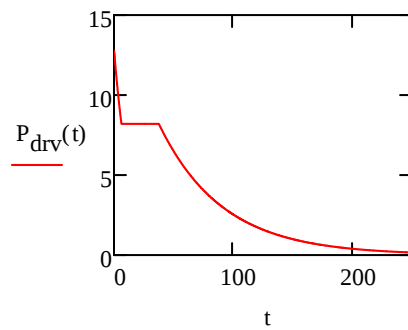
Piece-wise $V_{gs}(t)$ from RC time constant first charging C_{gs}
then constant voltage/current charging C_{gd} at Plateau
then RC time constant charging $C_{gs}+C_{gd}$ after Plateau

$$I_{\text{drv}}(t) := \frac{V_{\text{GS}} - V_{\text{gs_on}}(t)}{R_{\text{g_int}} + R_{\text{g_ext}}} \quad \text{A}$$



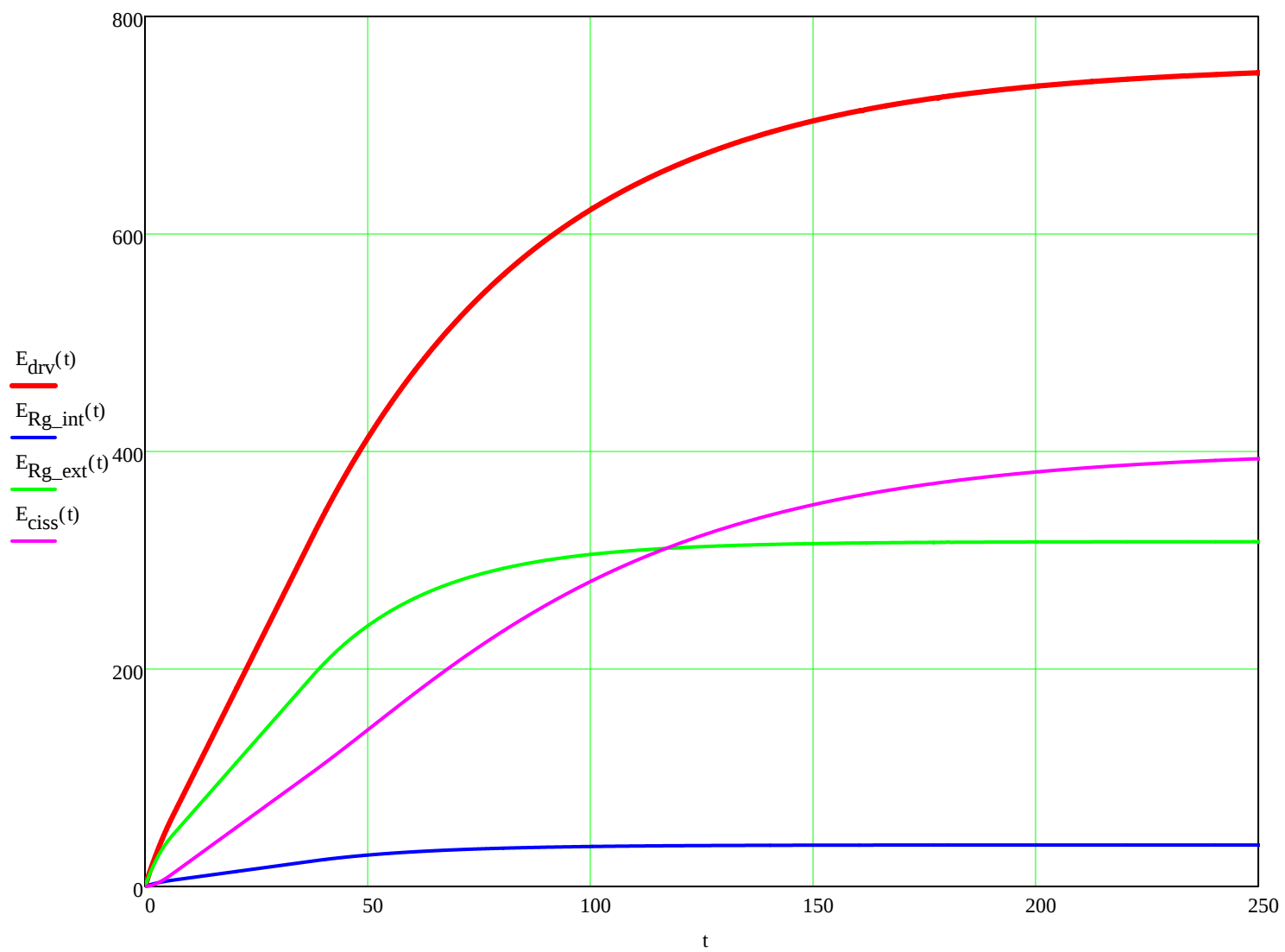
Gate-driver current derived by Ohm's law when knowing gate-driver voltage, gate-source voltage and gate resistors

$$P_{\text{drv}}(t) := V_{\text{GS}} \cdot I_{\text{drv}}(t) \quad \text{W}$$



Instantaneous power is voltage * current

$P_{Rg_int}(t) := I_{drv}(t)^2 \cdot R_{g_int}$	W	Instantaneous power dissipation in Rg_int
$P_{Rg_ext}(t) := I_{drv}(t)^2 \cdot R_{g_ext}$	W	Instantaneous power dissipation in Rg_ext
$P_{ciss}(t) := P_{drv}(t) - P_{Rg_int}(t) - P_{Rg_ext}(t)$	W	Instantaneous power in the gate charge
$E_{drv}(t) := \int_0^t P_{drv}(t) dt$	nJ	Cummulative energies integral of power
$E_{Rg_int}(t) := \int_0^t P_{Rg_int}(t) dt$	nJ	
$E_{Rg_ext}(t) := \int_0^t P_{Rg_ext}(t) dt$	nJ	
$E_{ciss}(t) := \int_0^t P_{ciss}(t) dt$	nJ	



$$\begin{array}{l} \text{t_E_drv_final} := \left| \begin{array}{l} \text{t_temp} \leftarrow 0 \\ \text{while } E_{\text{drv}}(\text{t_temp} + 1) - E_{\text{drv}}(\text{t_temp}) > 0.01 \\ \quad \left| \begin{array}{l} \text{t_temp} \leftarrow \text{t_temp} + 1 \\ \text{t_E_drv_final} \leftarrow \text{t_temp} \end{array} \right. \end{array} \right. \end{array}$$

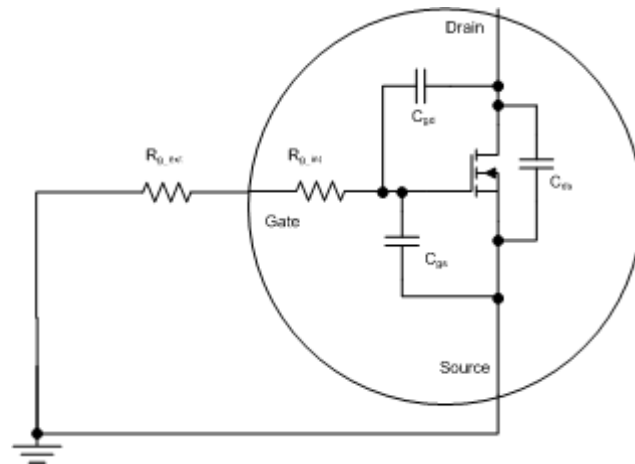
Quasi-arbitrarily chosen dE/dt criterion for slope to be very near "flat" is defined (in this particular case, the desired slope "flatness" is less than 10pJ per ns).

$$t_{E_drv_final} = 271 \quad ns$$

Time at which the criterion for dE/dt is met (energy difference over 1 ns is less than 10pJ)

$$E_{\text{drv_final}} := E_{\text{drv}}(t_{\text{E_drv_final}}) = 750.789 \quad \text{nJ}$$
$$E_{\text{Rg_int_final}} := E_{\text{Rg_int}}(t_{\text{E_drv_final}}) = 38.029 \quad \text{nJ}$$
$$E_{\text{Rg_ext_final}} := E_{\text{Rg_ext}}(t_{\text{E_drv_final}}) = 316.91 \quad \text{nJ}$$
$$E_{\text{ciss_final}} := E_{\text{ciss}}(t_{E_drv_final}) = 395.728 \quad \text{nJ}$$

Final gate drive energies at completed turn-on for all components



MOSFET turn-off equivalent circuit

$$V_{gs_off1}(t) := V_{GS} \cdot e^{\frac{-t}{(R_{g_int} + R_{g_ext}) \cdot C_{gs_gd_tr}}} \quad V$$

RC logarithmic decay from initial voltage (standard RC circuit response)

$$t_{Miller1} := \begin{cases} t_{temp} \leftarrow 0 \\ \text{while } V_{gs_off1}(t_{temp}) > V_{gs_plat} \\ \quad t_{temp} \leftarrow t_{temp} + 0.1 \\ \quad t_{Miller1} \leftarrow t_{temp} \end{cases}$$

Identify the time (in ns), when Vgs (on its first RC-trajectory from VGS) reaches the Miller Plateau voltage

$$t_{Miller1} = 53.8 \quad ns$$

Record the time (in ns)

$$t_{Miller} := \frac{\frac{Q_{gd}}{V_{gs_plat}}}{R_{g_int} + R_{g_ext}} = 55.018 \quad ns$$

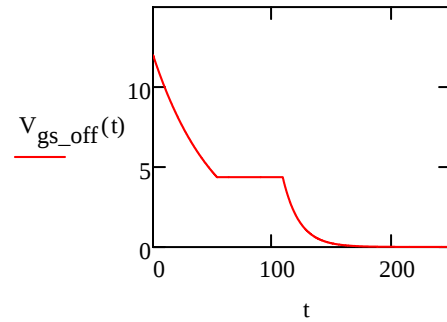
Calculate the time spent at Miller Plateau (by $I(t) = dQ(t)/dt \Rightarrow t = Q/I$)

$$V_{gs_off3}(t) := V_{gs_plat} \cdot e^{\frac{-t}{(R_{g_int} + R_{g_ext}) \cdot C_{gs_tr}}} \quad V$$

RC logarithmic decay from Miller Plateau voltage (standard RC circuit response)

$$V_{gs_off}(t) := \begin{cases} V_{gs_off1}(t) & \text{if } 0 < t < t_{Miller1} \\ V_{gs_plat} & \text{if } t_{Miller1} < t < (t_{Miller1} + t_{Miller}) \\ V_{gs_off3}[t - (t_{Miller1} + t_{Miller})] & \text{if } (t_{Miller1} + t_{Miller}) < t \end{cases}$$

Combine the three segments



Expected gate-source voltage waveform
(if measured on the MOSFET gate itself -
on the inside of the internal gate resistor).

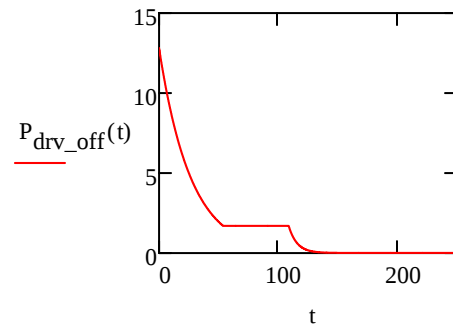
Gate-source voltage in V vs. time in ns

$$i_{drv_off}(t) := \frac{V_{gs_off}(t)}{R_{g_int} + R_{g_ext}} \quad A$$

Current flowing around the gate-driver loop

$$P_{drv_off}(t) := i_{drv_off}(t) \cdot V_{gs_off}(t) \quad W$$

Instantaneous power (reactive power from Ciss)



Power in W removed from Ciss vs. time in ns

$$P_{Rg_int_off}(t) := i_{drv_off}(t)^2 \cdot R_{g_int} \quad W$$

Power dissipation in the resistive elements

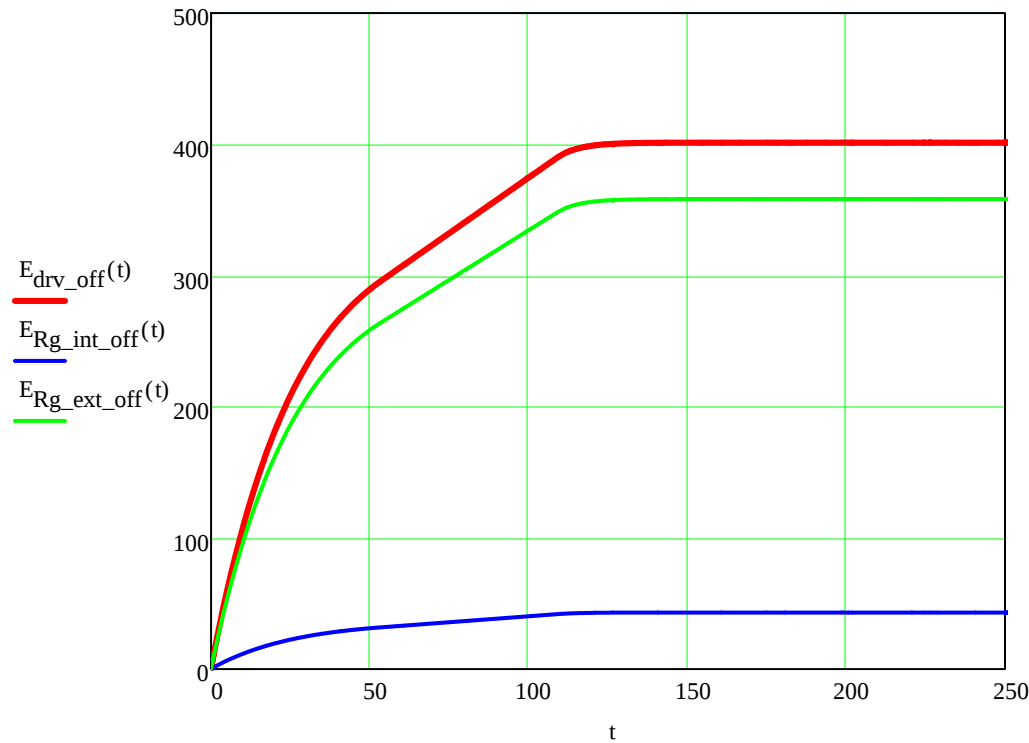
$$P_{Rg_ext_off}(t) := i_{drv_off}(t)^2 \cdot R_{g_ext} \quad W$$

$$E_{\text{Rg_int_off}}(t) := \int_0^t P_{\text{Rg_int_off}}(t) dt \quad \text{nJ}$$

$$E_{\text{Rg_ext_off}}(t) := \int_0^t P_{\text{Rg_ext_off}}(t) dt \quad \text{nJ}$$

$$E_{\text{drv_off}}(t) := \int_0^t P_{\text{drv_off}}(t) dt \quad \text{nJ}$$

Energy in the resistive and reactive elements
calculated as the integral of the power



Plot of various turn-off energies (in nJ) vs time (in ns)
RED is total turn-off energy
BLUE is energy dissipated in the internal gate resistor
GREEN is energy dissipated in the external gate resistor

$$t_{E_drv_off_final} := \left| \begin{array}{l} t_{temp} \leftarrow 0 \\ \text{while } E_{drv_off}(t_{temp} + 1) - E_{drv_off}(t_{temp}) > 0.01 \\ \quad \left| \begin{array}{l} t_{temp} \leftarrow t_{temp} + 1 \\ t_{E_drv_off_final} \leftarrow t_{temp} \end{array} \right. \end{array} \right.$$

Quasi-arbitrarily chosen dE/dt criterion for slope to be very near "flat" is defined (in this particular case, the desired slope "flatness" is less than 10pJ per ns).
The time of which that criterion is first met is recorded

$t_{E_drv_off_final} = 141 \text{ ns}$

Time at which the criterion for dE/dt is met (energy difference over 1 ns is less than 10pJ)

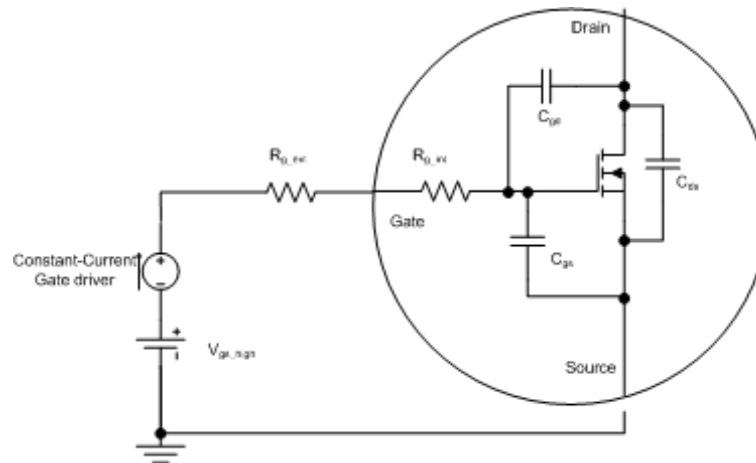
$E_{drv_off_final} := E_{drv_off}(t_{E_drv_off_final}) = 401.016 \text{ nJ}$

$E_{Rg_int_off_final} := E_{Rg_int_off}(t_{E_drv_off_final}) = 42.966 \text{ nJ}$

$E_{Rg_ext_off_final} := E_{Rg_ext_off}(t_{E_drv_off_final}) = 358.05 \text{ nJ}$

Difference in energy content (401 nJ initially on Ciss for turn-off vs. 396 nJ finally after turn-on) is due to the slope criterion for "final time", where $t=\infty$ would represent the "accurate" value for a logarithmically converging function

Current drive turn-on:



$$I_{gd_cc} := i_{plat} = 0.682 \quad A$$

$$V_{gs_drop} := I_{gd_cc} \cdot (R_{g_ext} + R_{g_int}) = 7.644 \quad V$$

$$V_{gs_high} := V_{GS} + V_{gs_drop} = 19.644 \quad V$$

$$t_{Qgs_on} := \frac{Q_{gs}}{I_{gd_cc}} = 7.912 \quad ns$$

$$t_{Miller_cc_on} := \frac{Q_{gd}}{I_{gd_cc}} = 31.357 \quad ns$$

$$t_{VGS_cc_on} := \frac{Q_{g_VGS} - (Q_{gs} + Q_{gd})}{I_{gd_cc}} = 53.043 \quad ns$$

Assuming same current-driving capability as the former
Miller-plateau current

Voltage-source voltage (in addition to target V_{gs}) required
for supplying real, physical
current-drive gate driver

Voltage source required to power gate-driver current source

Time it will take to get to beginning of Miller Plateau

Time spent at the Miller Plateau

Time it will take to get to the target gate-source voltage

$$t_{cc_Miller1} := t_{Qgs_on} \quad ns$$

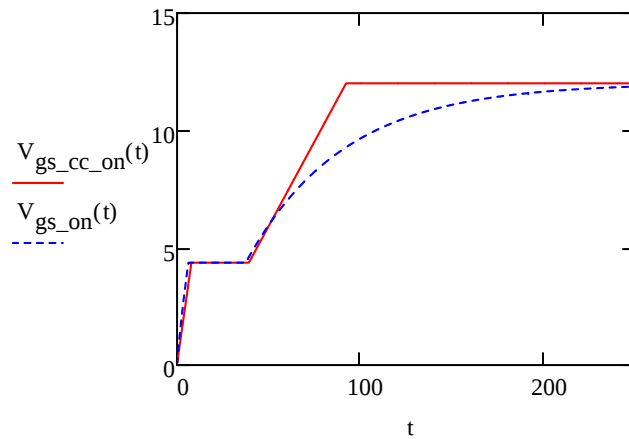
$$t_{cc_Miller2} := t_{Qgs_on} + t_{Miller_cc_on} \quad ns$$

Time points of interest; total elapsed time at ends of intervals

$$t_{cc_VGS} := t_{cc_Miller2} + t_{VGS_cc_on} \quad ns$$

$$V_{gs_cc_on}(t) := \begin{cases} \left(\frac{V_{gs_plat}}{t_{Qgs_on}} \cdot t \right) & \text{if } 0 < t < t_{cc_Miller1} \\ V_{gs_plat} & \text{if } t_{cc_Miller1} < t < t_{cc_Miller2} \\ \left[V_{gs_plat} + \frac{VGS - V_{gs_plat}}{t_{VGS_cc_on}} \cdot (t - t_{cc_Miller2}) \right] & \text{if } t_{cc_Miller2} < t < t_{cc_VGS} \\ VGS & \text{if } t_{cc_VGS} < t \end{cases}$$

Piece wise linear voltage
waveshape - assuming piece wise
linear Q-segments



Plot of Vgs waveforms if driven by
RED = current source
BLUE = voltage source

(gate-source voltage in V vs. time in ns)

$$I_{cc_gd}(t) := \begin{cases} I_{gd_cc} & \text{if } 0 < t < t_{cc_VGS} \\ 0 & \text{otherwise} \end{cases}$$

$$P_{cc_Rg_ext}(t) := I_{cc_gd}(t)^2 \cdot R_{g_ext}$$

$$P_{cc_Rg_int}(t) := I_{cc_gd}(t)^2 \cdot R_{g_int}$$

$$P_{cc_drv_on}(t) := I_{cc_gd}(t) \cdot V_{gs_high}$$

$$P_{cc_src}(t) := [V_{gs_high} - V_{gs_cc_on}(t) - I_{cc_gd}(t) \cdot (R_{g_ext} + R_{g_int})] \cdot I_{cc_gd}(t)$$

$$P_{cc_ciss}(t) := P_{cc_drv_on}(t) - P_{cc_Rg_ext}(t) - P_{cc_Rg_int}(t) - P_{cc_src}(t)$$

W

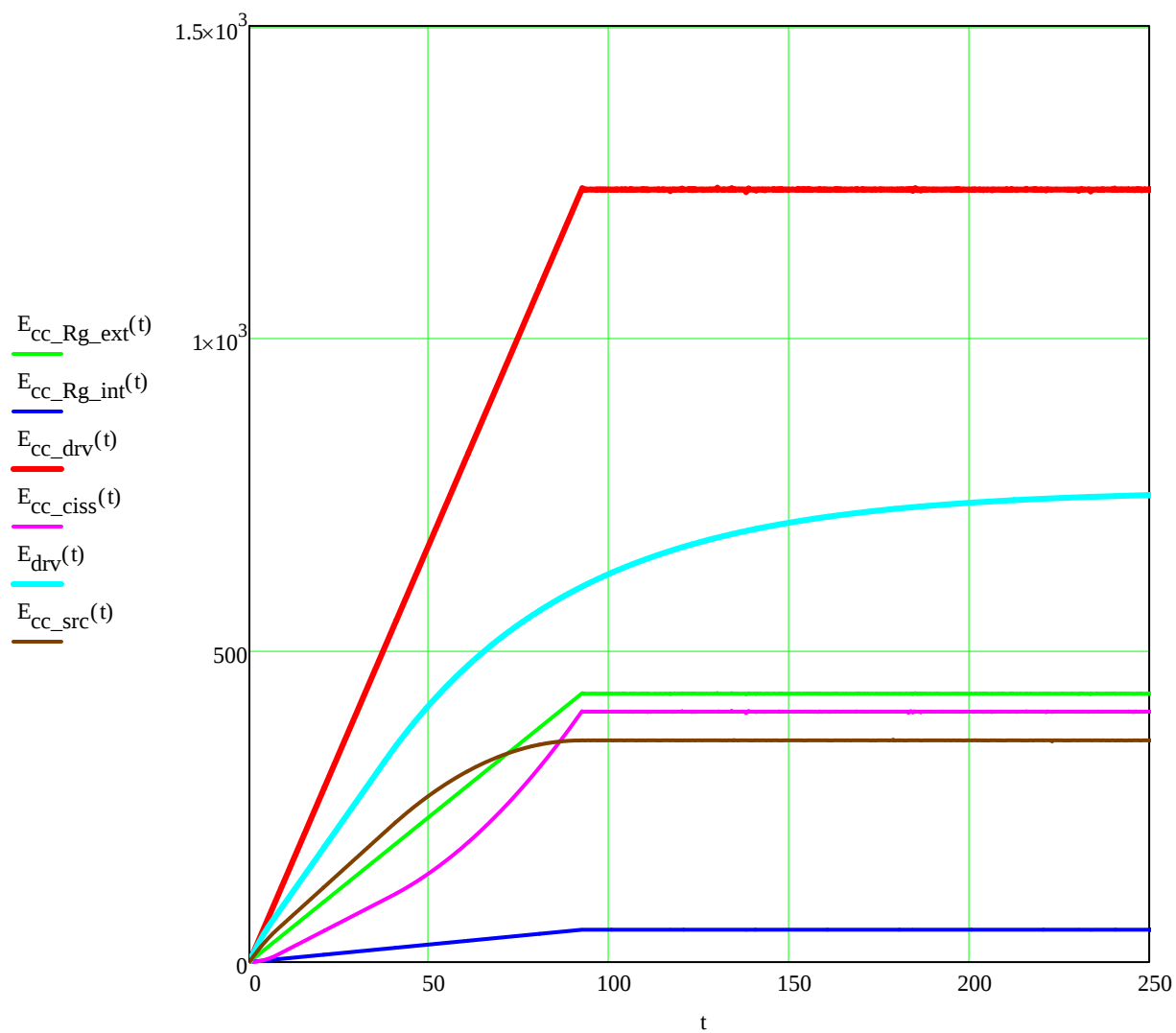
Instantaneous power in the various dissipative and reactive elements of gate driver loop during turn-on for current-drive

$$E_{cc_Rg_ext}(t) := \int_0^t P_{cc_Rg_ext}(t) dt$$

$$E_{cc_Rg_int}(t) := \int_0^t P_{cc_Rg_int}(t) dt \quad E_{cc_src}(t) := \int_0^t P_{cc_src}(t) dt$$

Turn-on energies (nJ) over time (ns) during turn-on with constant current drive

$$E_{cc_drv}(t) := \int_0^t P_{cc_drv_on}(t) dt \quad E_{cc_ciss}(t) := \int_0^t P_{cc_ciss}(t) dt$$



$$E_{cc_Rg_ext_final} := E_{cc_Rg_ext}(t_{cc_VGS} + 1) = 429.974 \quad nC$$

$$E_{cc_Rg_int_final} := E_{cc_Rg_int}(t_{cc_VGS} + 1) = 51.597 \quad nC$$

$$E_{cc_drv_final} := E_{cc_drv}(t_{cc_VGS} + 1) = 1.238 \times 10^3 \quad nC$$

$$E_{cc_ciss_final} := E_{cc_ciss}(t_{cc_VGS} + 1) = 401.047 \quad nC$$

$$E_{cc_src_final} := E_{cc_src}(t_{cc_VGS} + 1) = 354.964 \quad nC$$

Final energies for the various dissipative and non-dissipative elements for current-drive turn-on