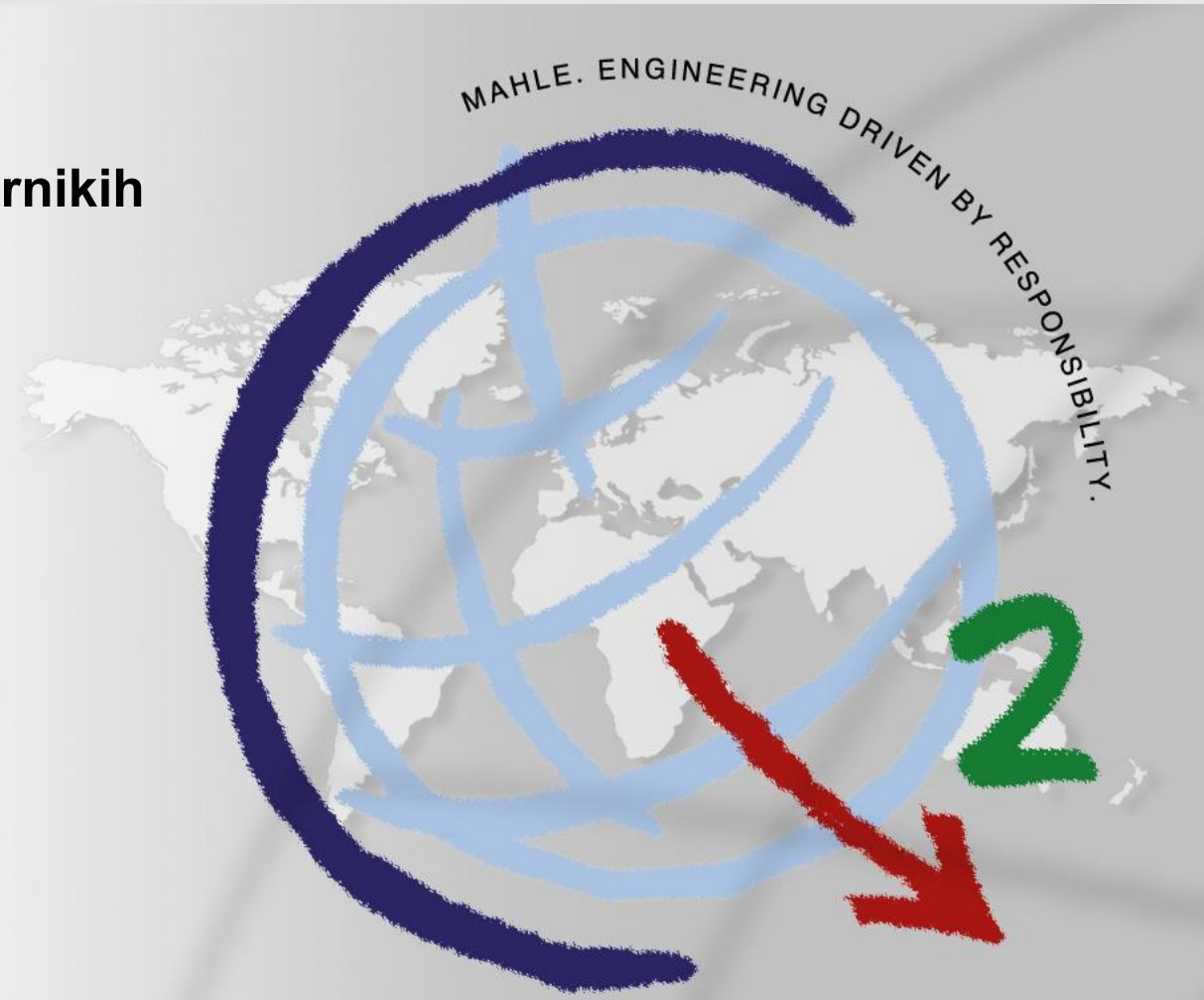
MAHLE

Driven by performance

Preklopi pri močnostnih pretvornikih

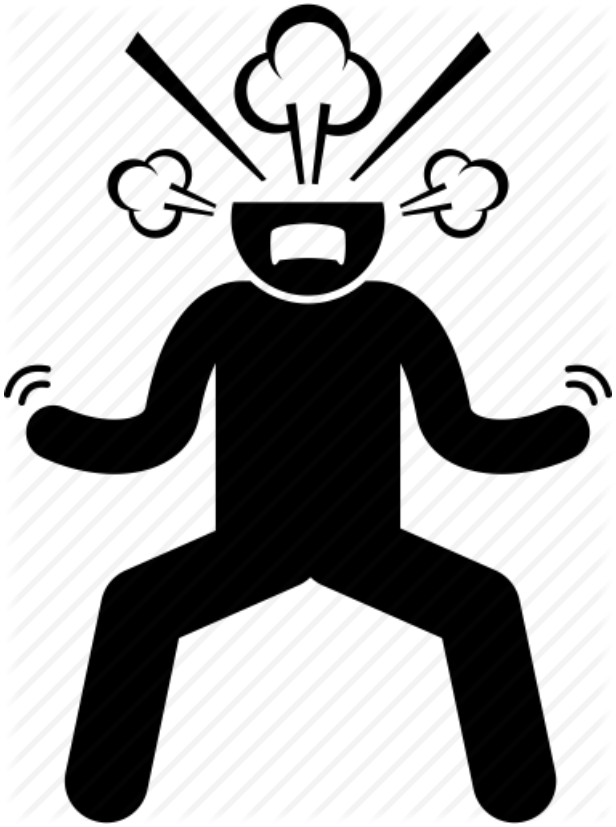


Jernej Sorta
Električni pogoni
ELP

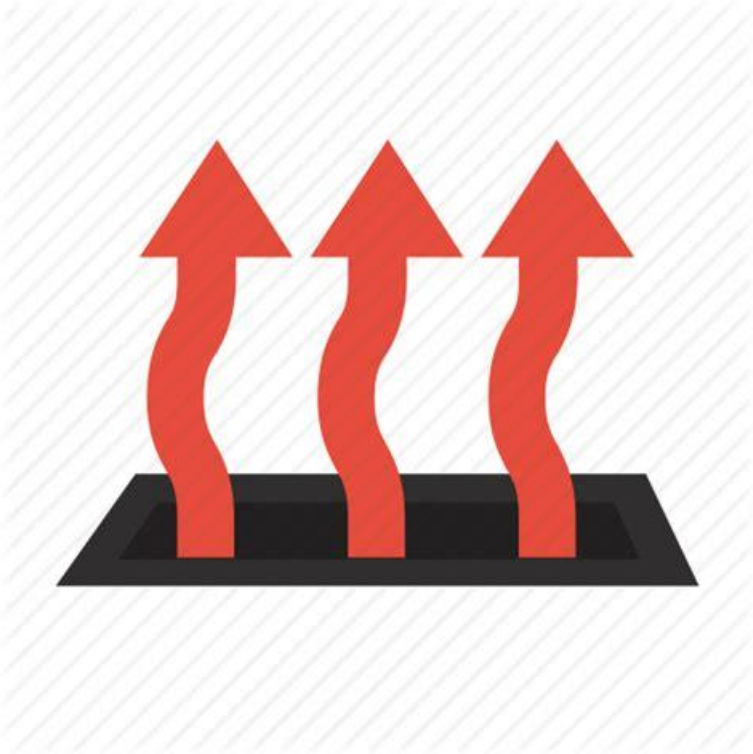
Zakaj je dobro poznati pojave ob preklopu?

MAHLE
Driven by performance

- EMC



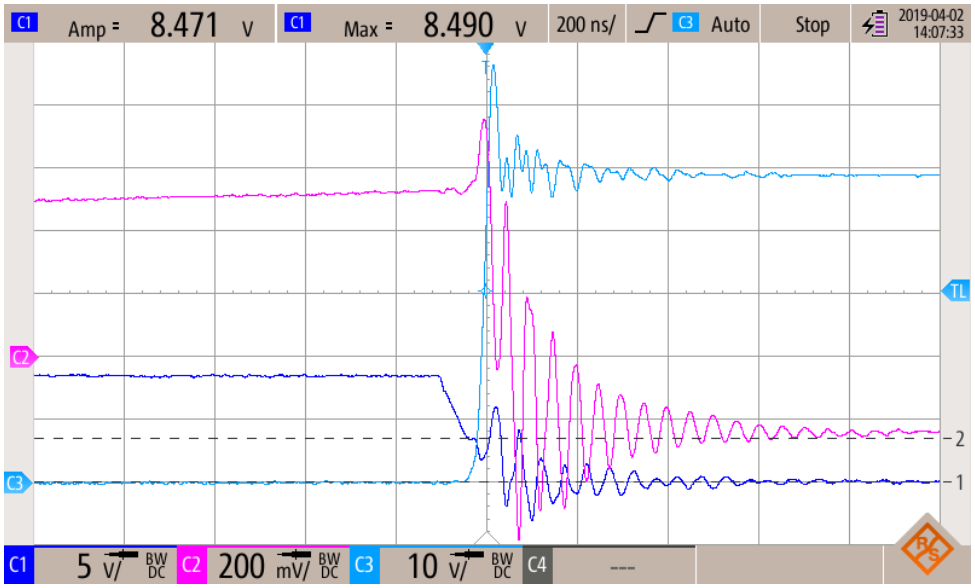
- Izkoristek



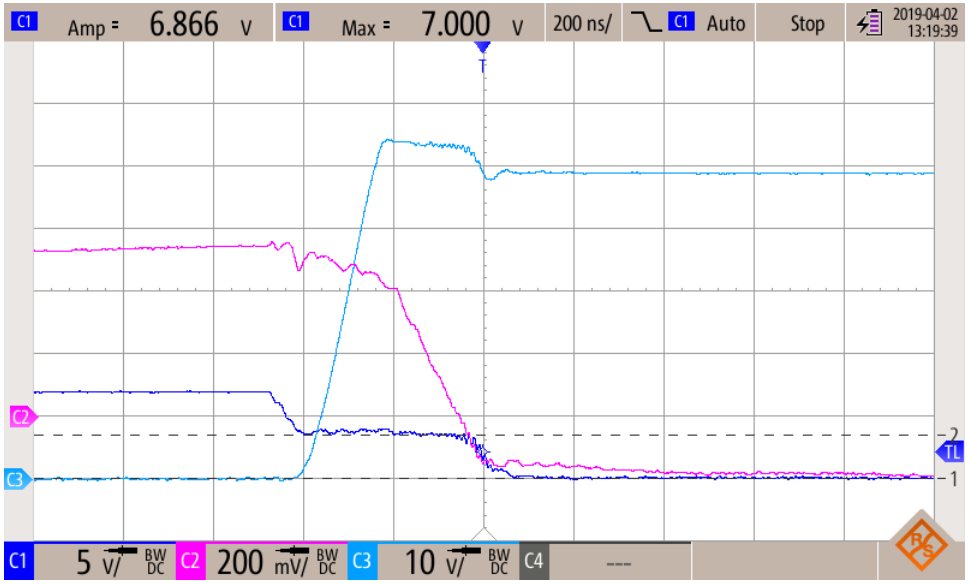
MAHLE

Driven by performance

- Prej



- Potem

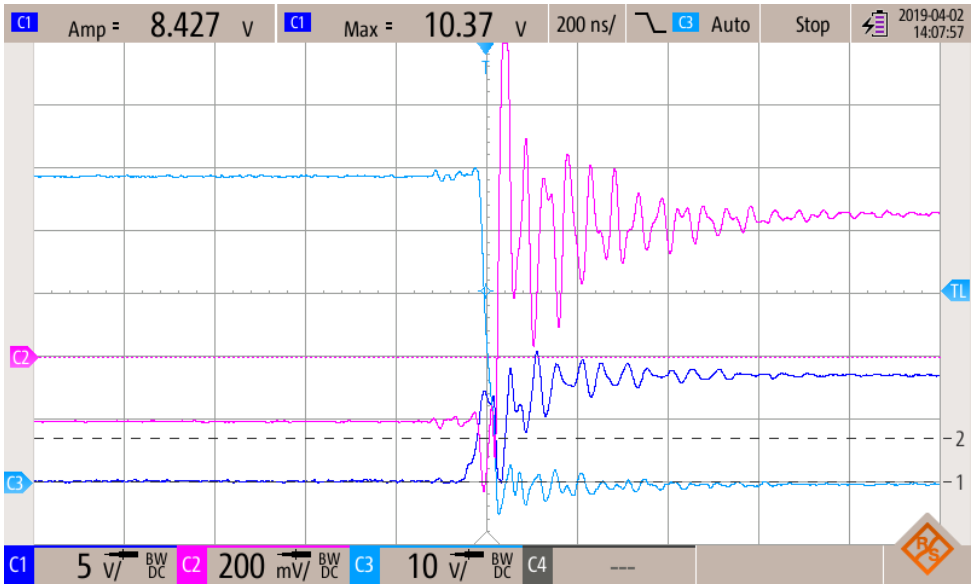


Ugs, Is, Uds

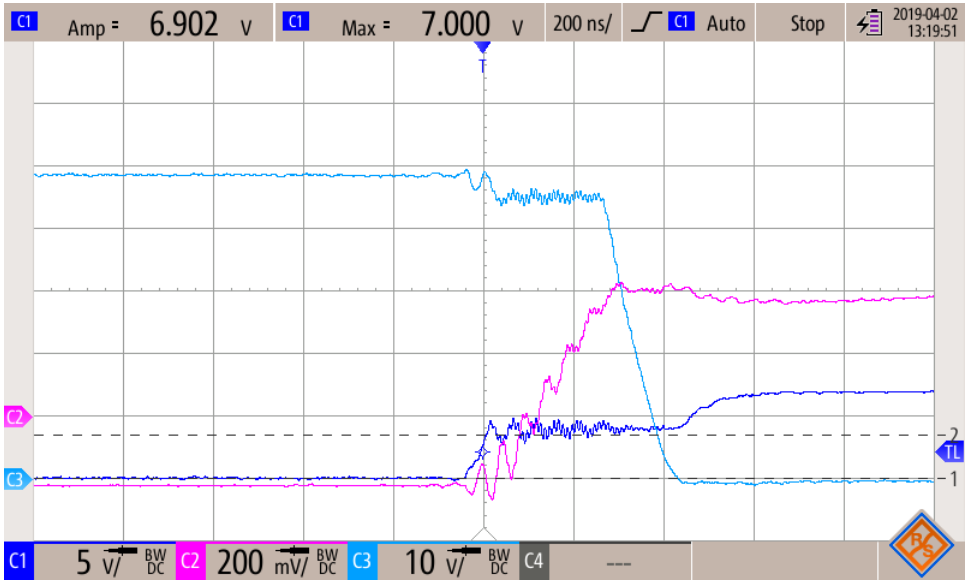
MAHLE

Driven by performance

- Prej



- Potem



Ugs, Is, Uds

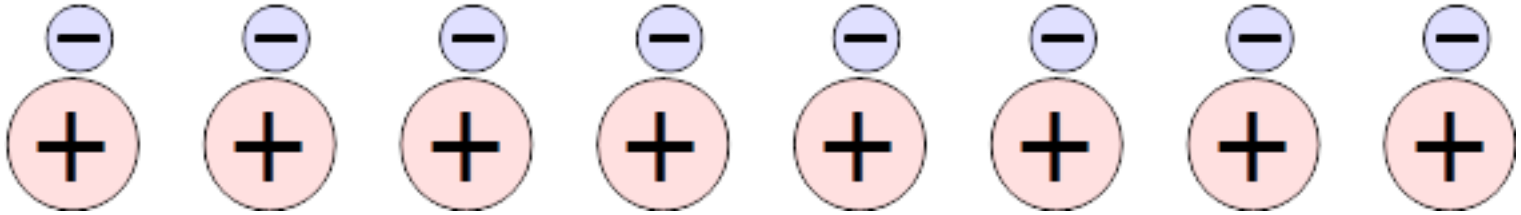
Zakaj preklopi?

MAHLE

Driven by performance

MAHLE

Driven by performance



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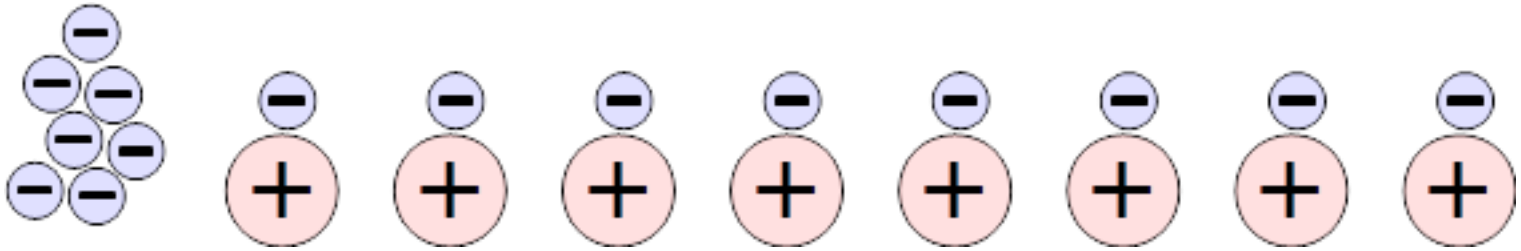
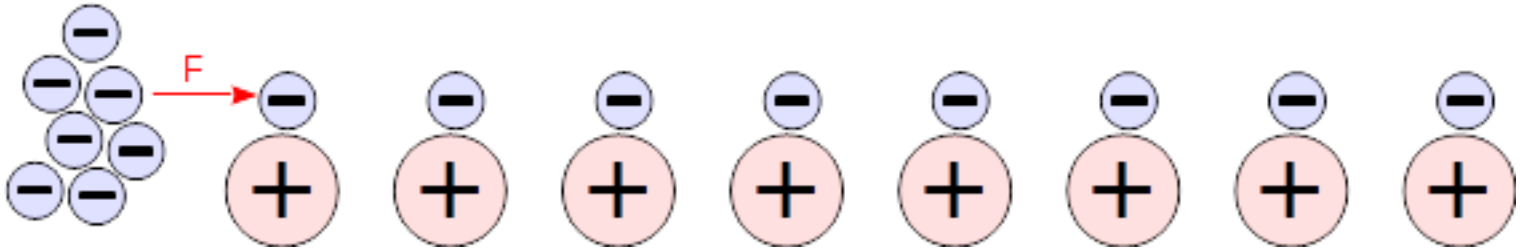
Driven by performance



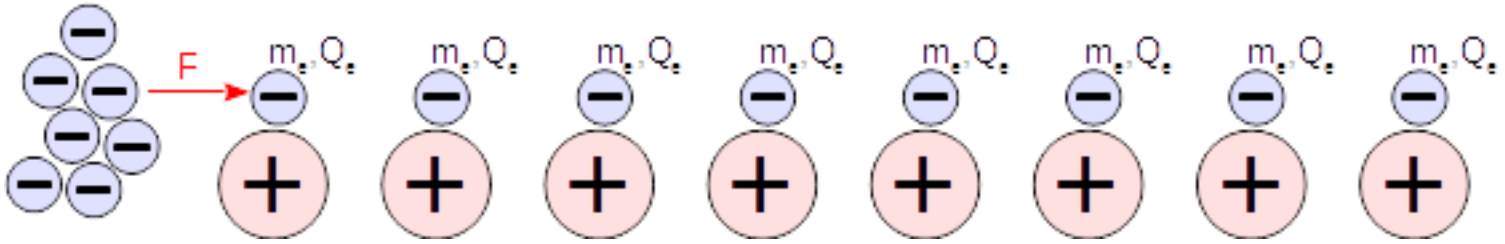
MAHLE

Driven by performance



MAHLE

Driven by performance



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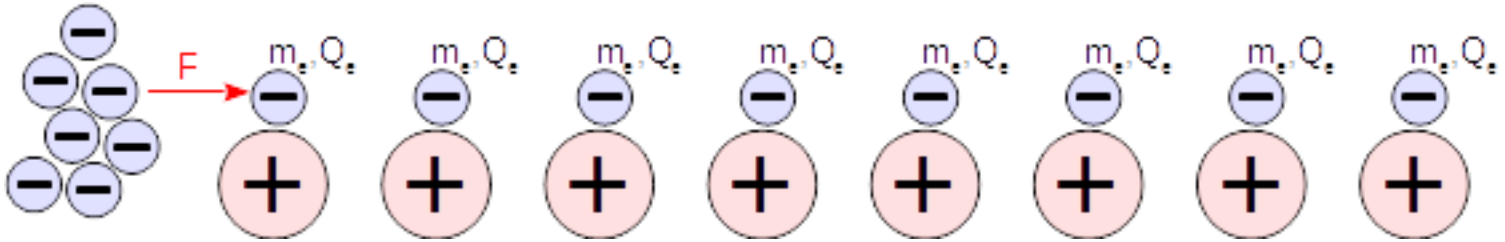
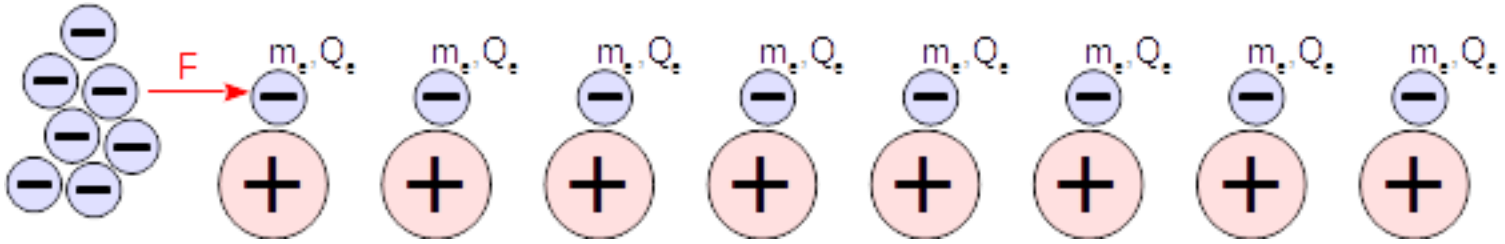
Driven by performance



MAHLE

Driven by performance

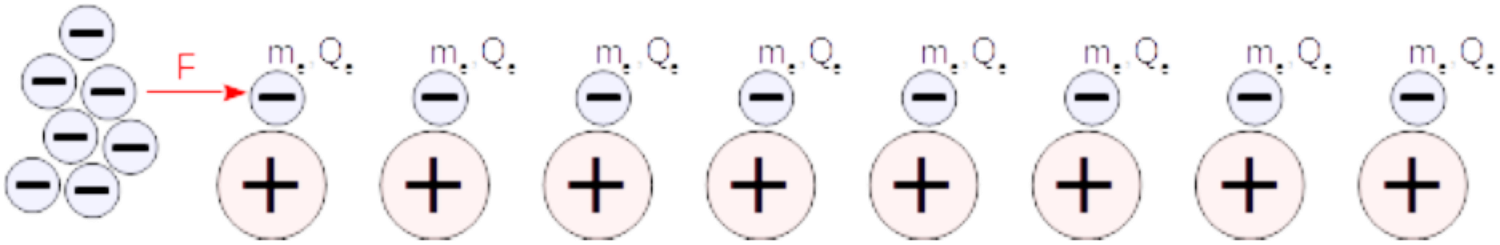


$$\frac{d}{dt}\left(m_e v_e\right) = F$$

$$v_e \cdot Q_e \propto I$$

MAHLE

Driven by performance

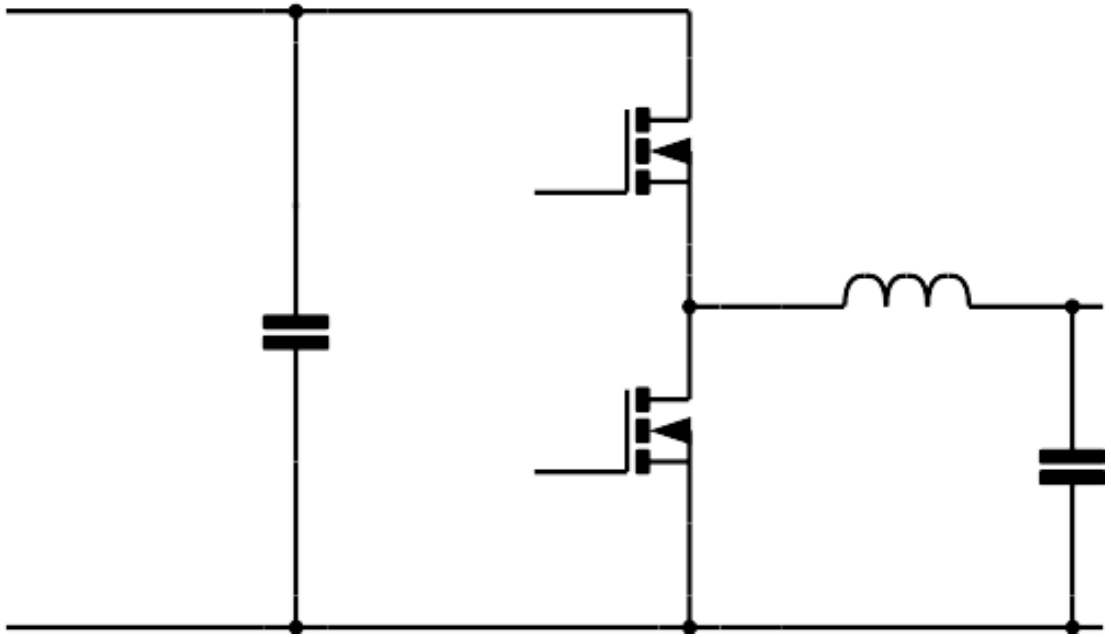


$$\frac{d}{dt}(m_e v_e) = F \qquad v_e \cdot Q_e \propto I$$

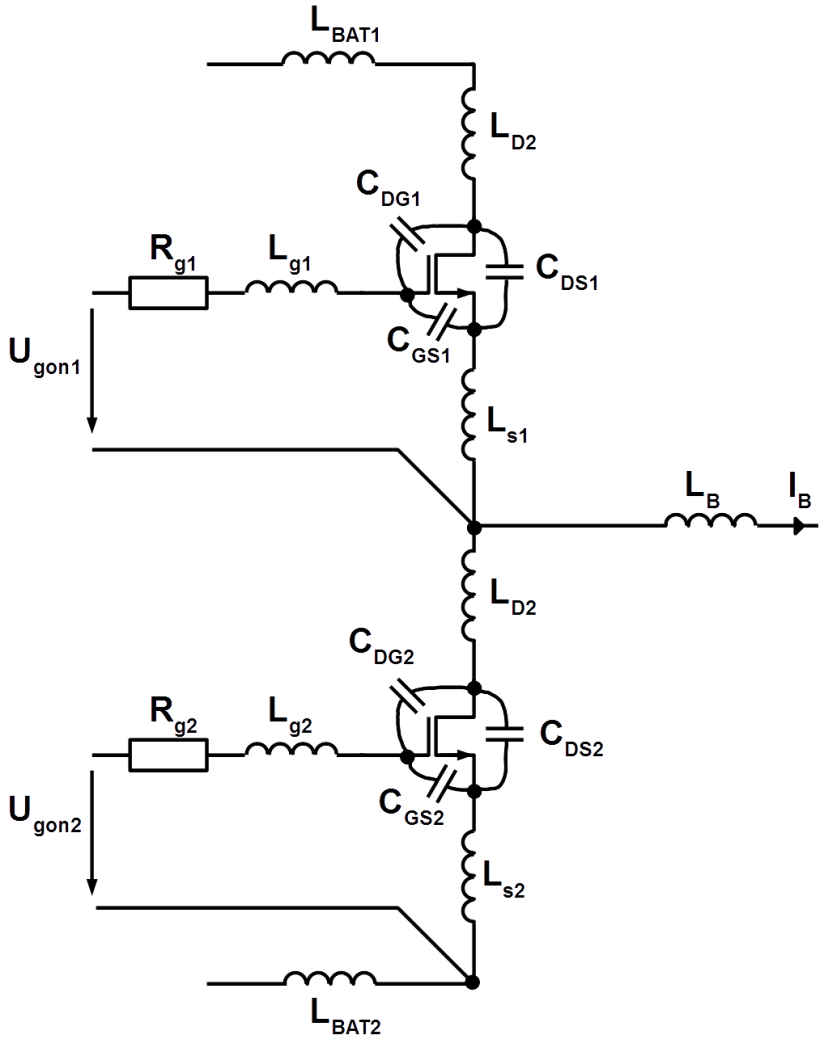
$$m\frac{dI}{dt} \propto F \longleftrightarrow L\frac{dI}{dt} = U_L$$

MAHLE

Driven by performance



Pol-mostič



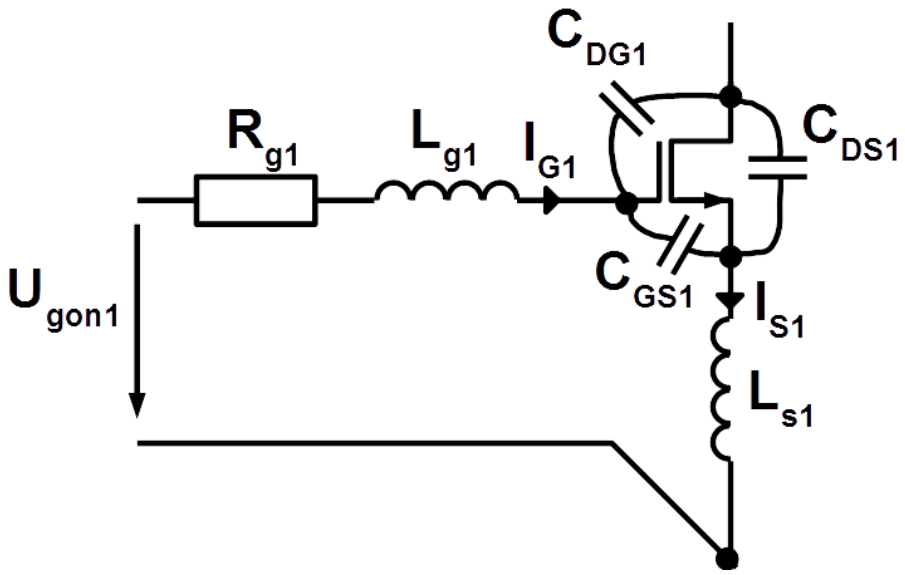
Začetni pogoji

MAHLE
Driven by performance

- Tok teče v breme
- Spodnji tranzistor je izklopljen, tok teče skozi notranjo diodo
- Gornji tranzistor je izklopljen
- Priključimo Ugon1 (stopnica)

Driven by performance

Preklop toka



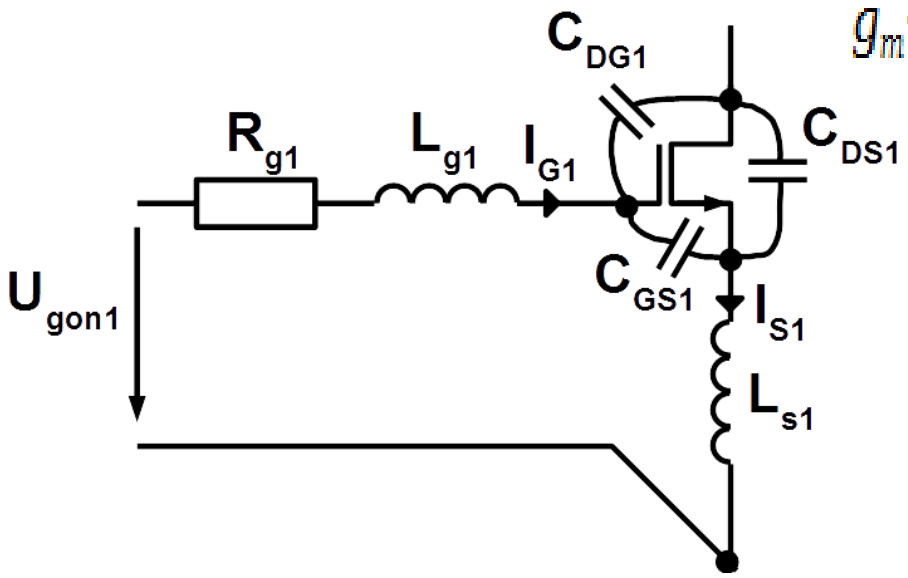
$$U_{gon} = R_g \cdot I_g + L_g \cdot I_g' + U_{GS} + L_s \cdot I_S'$$

$$I_g \approx C_{GS} \cdot U_{GS}'$$

$$I_{DS} \approx U_{GS} \cdot g_m$$

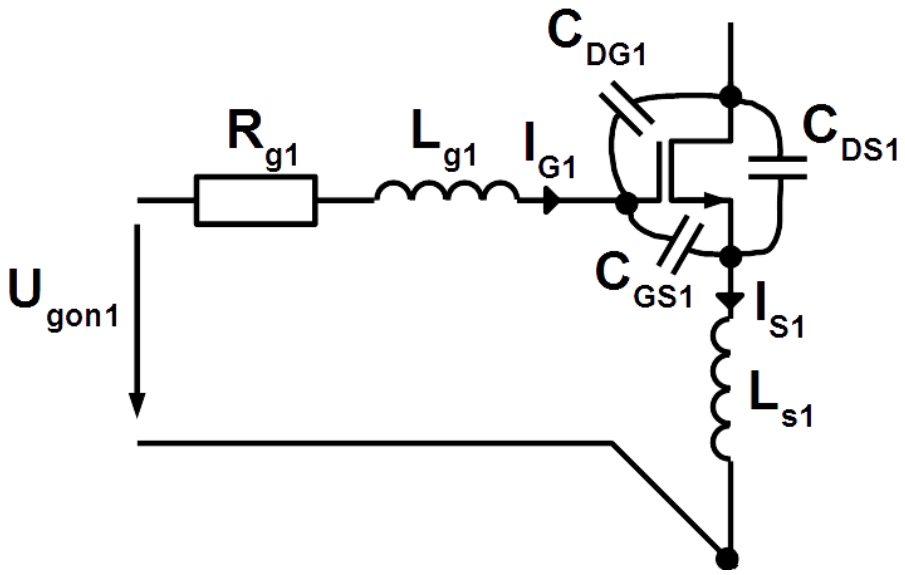
$$I_S = I_g + I_{DS}$$

Driven by performance



$$g_m \cdot U_{gon} = I''_{DS} \cdot (L_s + L_g) C_{GS} + I'_{DS} \cdot (g_m L_s + R_g C_{GS}) + I_{DS}$$

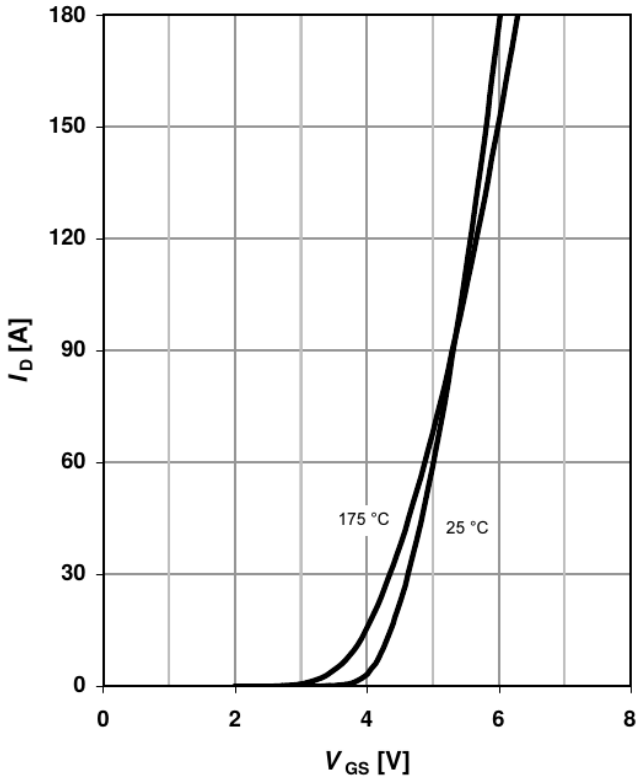
$$I_0 = I''_{DS} \cdot \left(\frac{1}{\omega_n^2}\right) + I'_{DS} \cdot \frac{2\zeta}{\omega_n} + I_{DS}$$

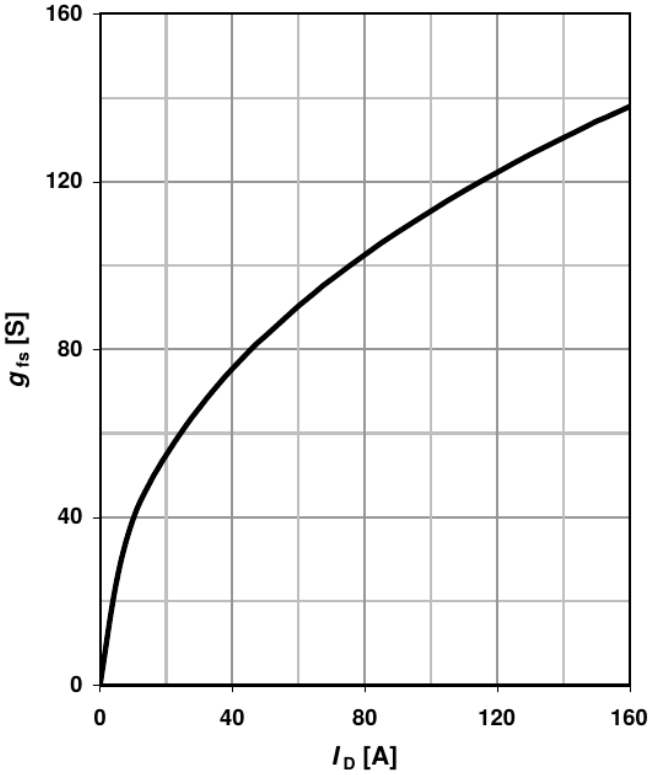


$$\zeta = \frac{g_m L_s + R_g C_{GS}}{\sqrt{(L_s + L_g) C_{GS}}} = \frac{g_m L_s}{\sqrt{(L_s + L_g) C_{GS}}} + \frac{R_g C_{GS}}{\sqrt{(L_s + L_g) C_{GS}}}$$

Driven by performance

- Ls ~ 7nH (TO-220 ->konec priključka)
- gm:





Driven by performance

- Ls ~ 7nH (TO-220 ->konec priključka)
- gm:

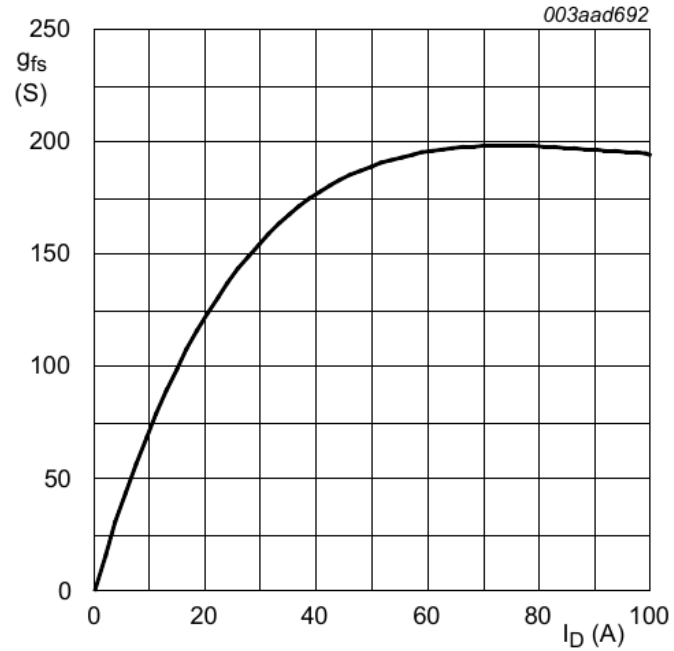
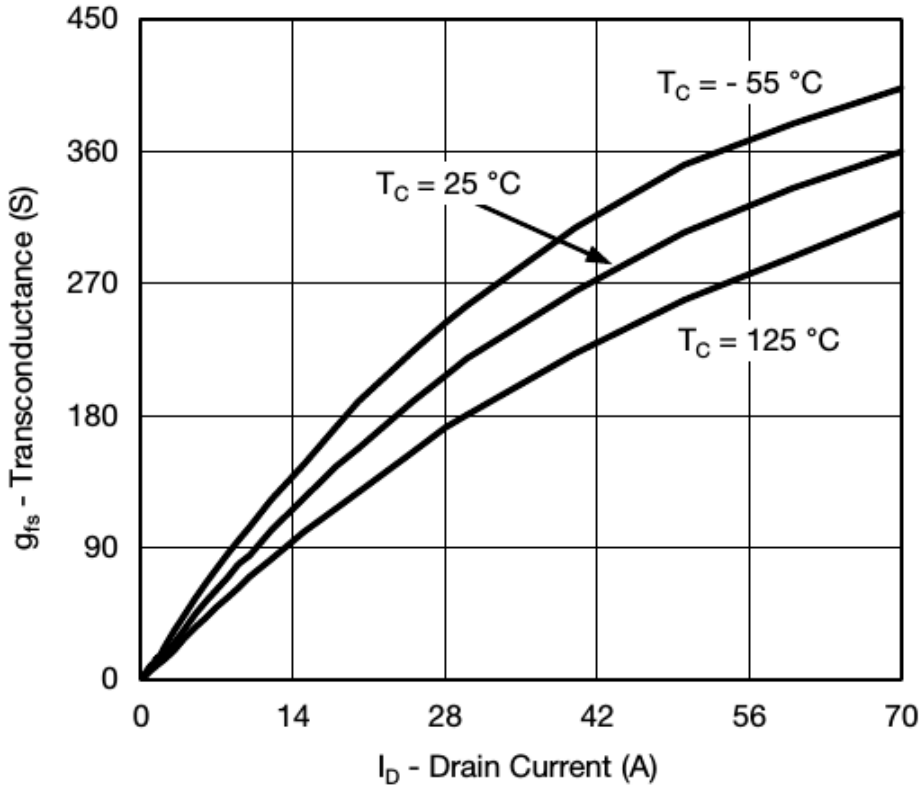


Fig. 6. Forward transconductance as a function of drain current; typical values

MAHLE
Driven by performance

- Ls ~ 7nH (TO-220 ->konec priključka)
- gm:



Transconductance

MAHLE
Driven by performance

- Ls*gm ~ 7nH*70A/V = 490 ns
- Rg*Cgs ~10Ω*10nF = 100 ns

MAHLE

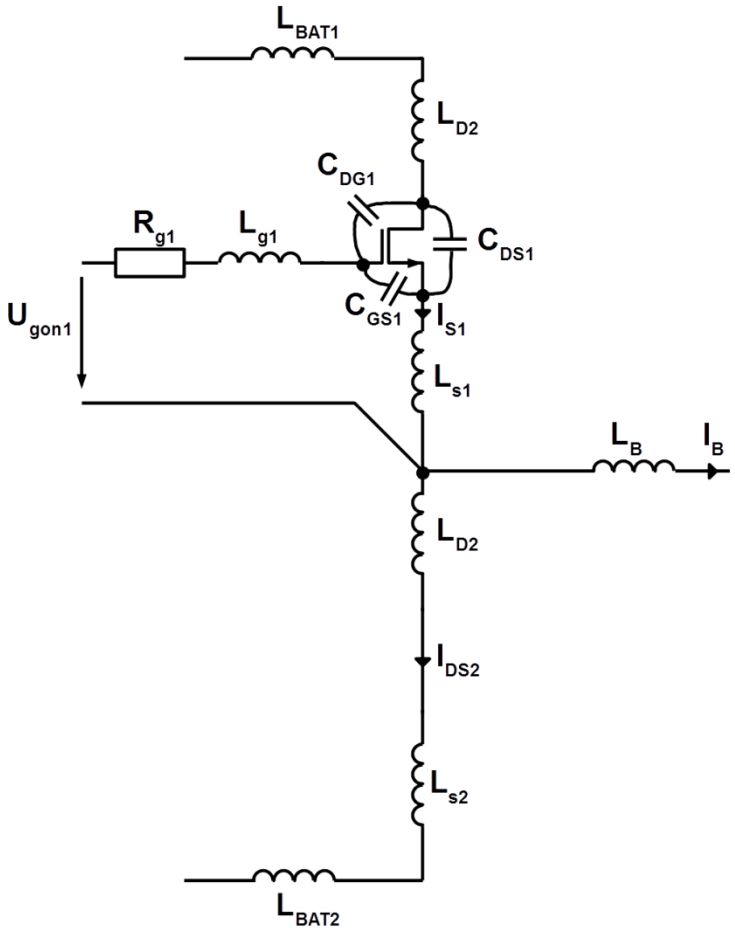
Driven by performance

- Če je gm*Ls >> Rg*Cgs, Rg*Ig +Lg*Ig‘~0:

$$\frac{d I_{DS}}{dt} \approx \frac{U_{gon} - U_{GS}}{L_s}$$

MAHLE
Driven by performance

- Nadomestno vezje, dokler spodnja dioda prevaja in se še preklaplja tok:



Predpostavke:

- Tok čez Rg2, Lg2 << tok čez Ls2
- Rds_diff ~0
- Ib ~konst

- Ids1 - Ids2 = konst
- Ids1‘ = Ids2‘

MAHLE
Driven by performance

- Med preklopom toka:
- Ids‘ ~konst., torej Uind = L*Ids‘ ~konst.
- Padec napetosti na induktivnostih:

$$\sum U_i = \left(L_{BAT1} + L_{D1} + L_{S1} + L_{D2} + L_{S2} + L_{BAT2} \right) \cdot \frac{d\, I_{DS}}{dt}$$

Preklop toka

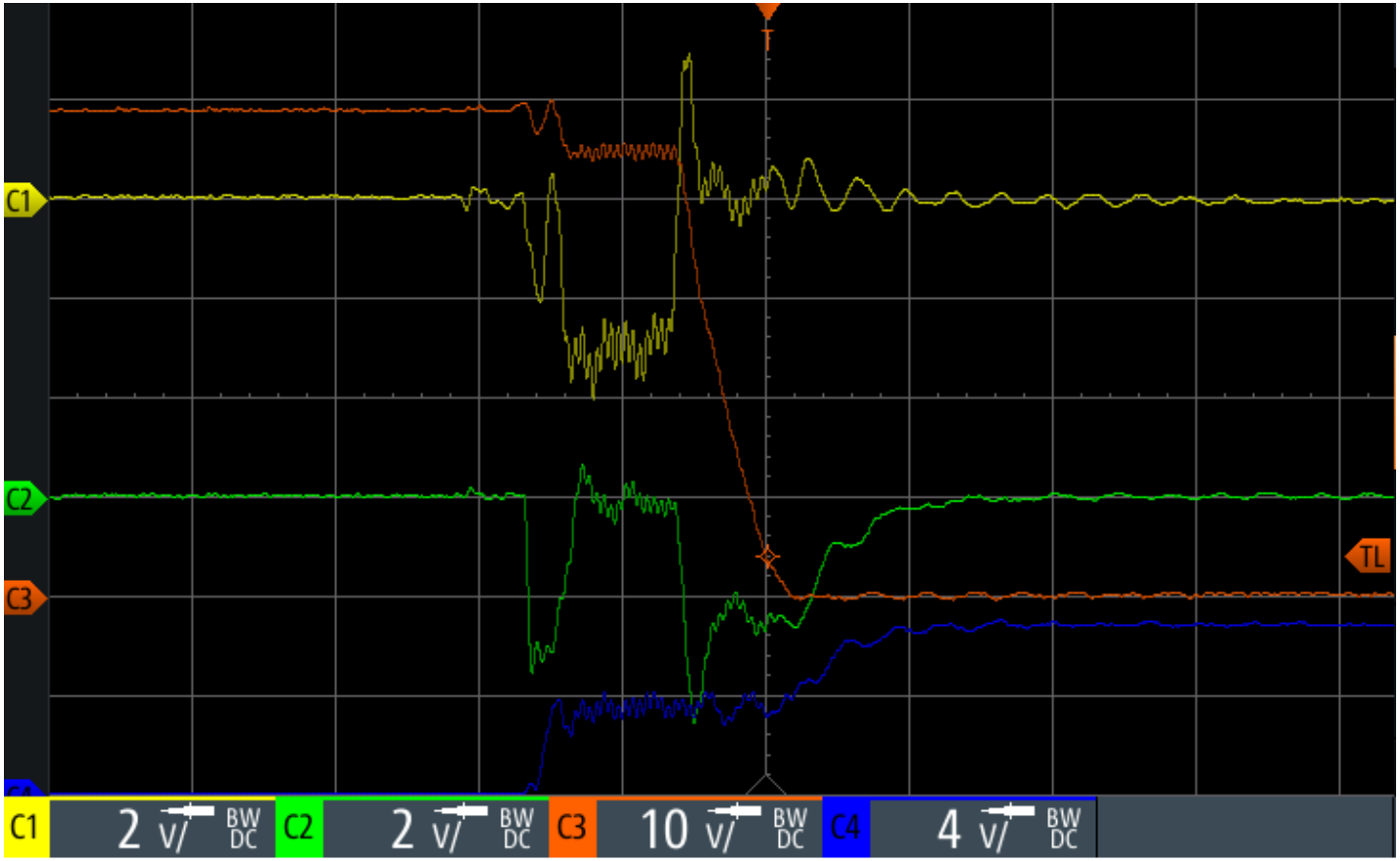
MAHLE

Driven by performance

Preklop toka

MAHLE

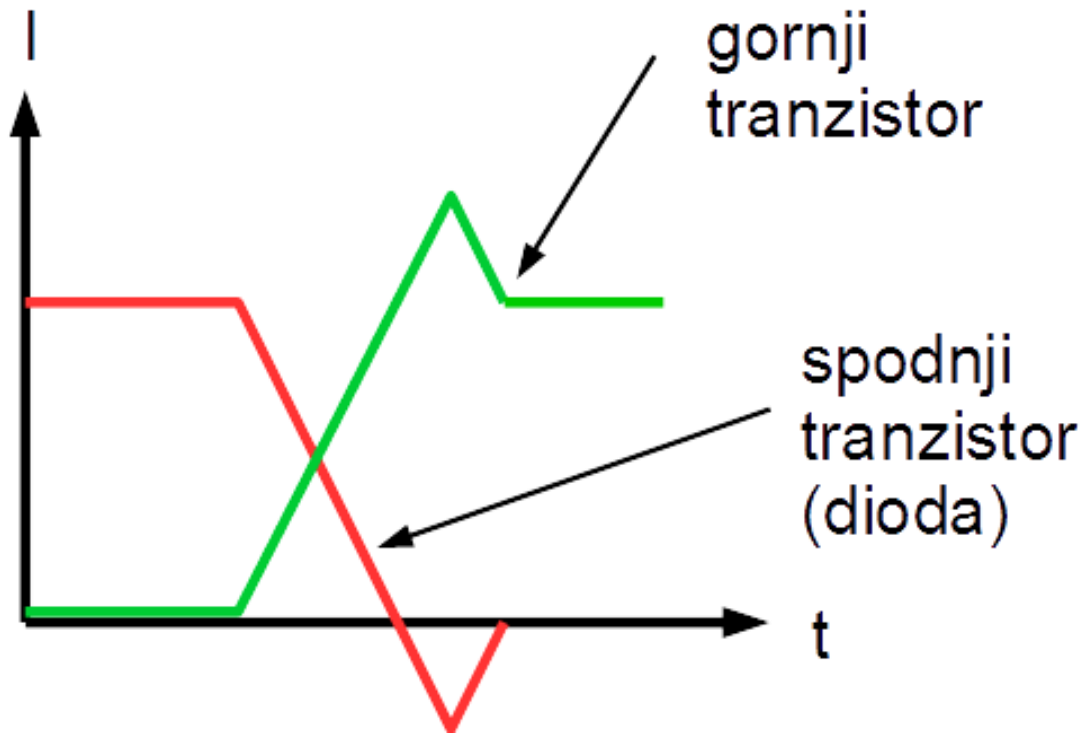
Driven by performance

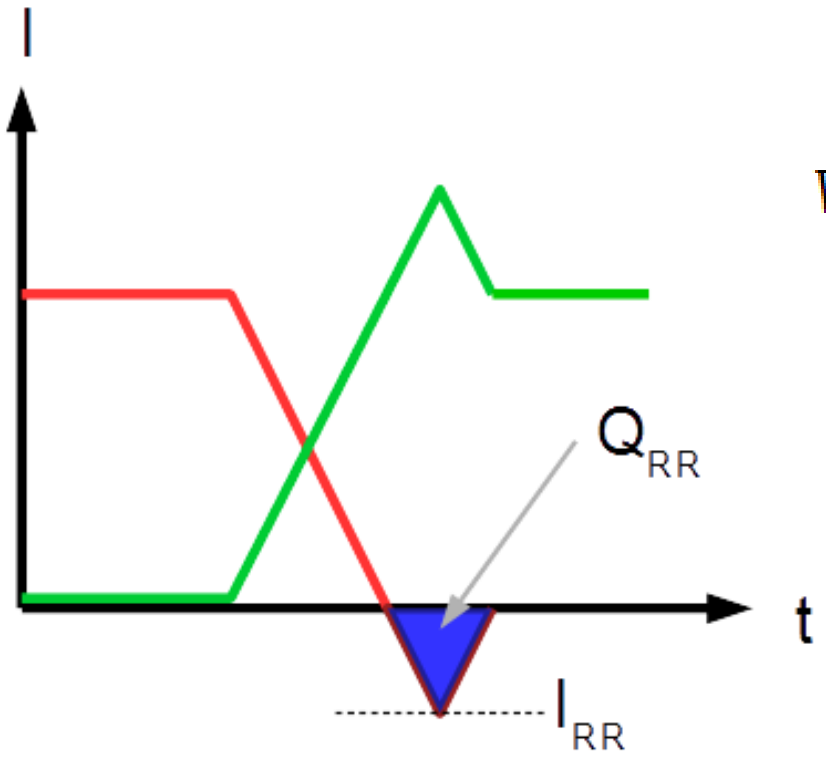


U_{Ls}, U_{Rg}, U_{GS}, U_{DS}

Rekombinacije!

MAHLE
Driven by performance





Izgube zaradi rekombinacij:

$$W_{RR} = \int I_{RR} \cdot U_{DS} dt = U_{DS} \cdot \int I_{RR} dt = Q_{RR} \cdot U_{DS}$$

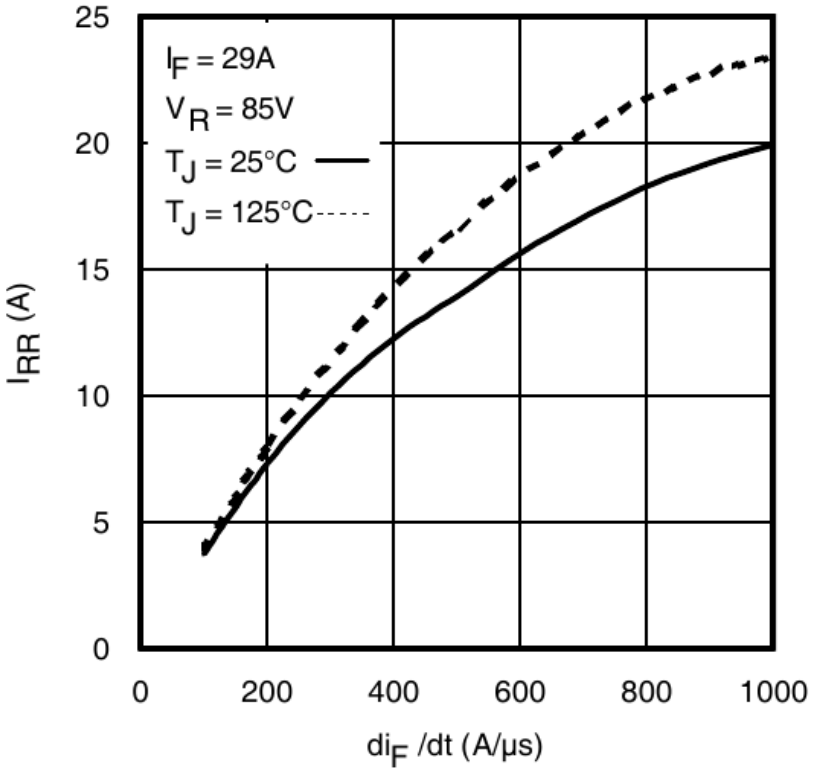


Fig. 17 - Typical Recovery Current vs. di_f/dt

MAHLE
Driven by performance

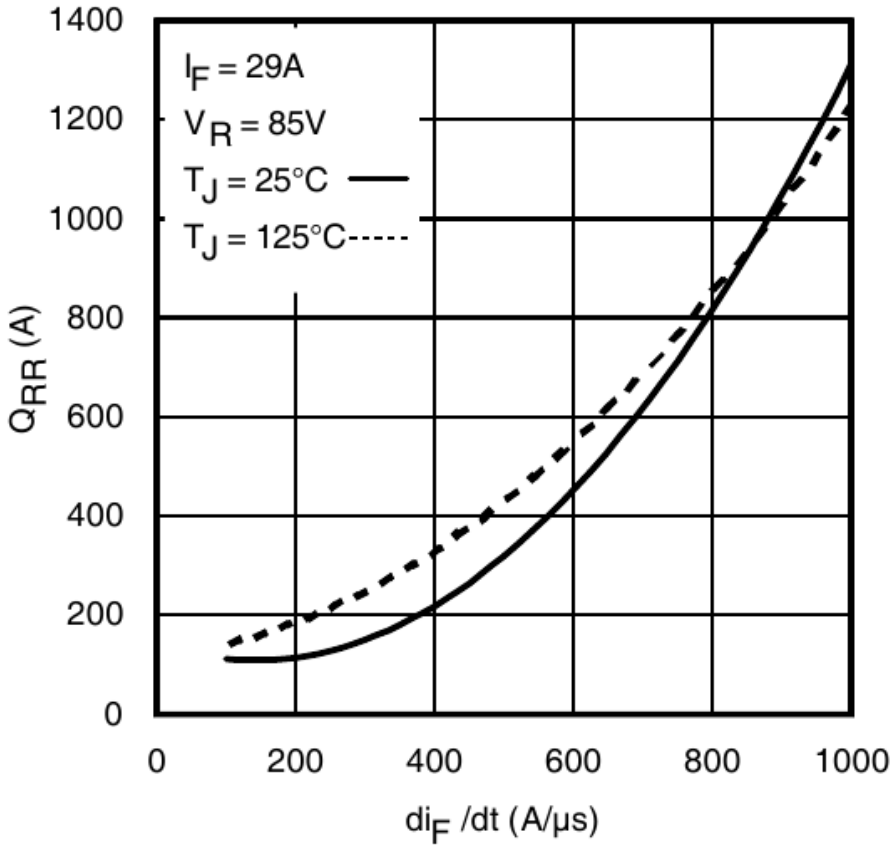
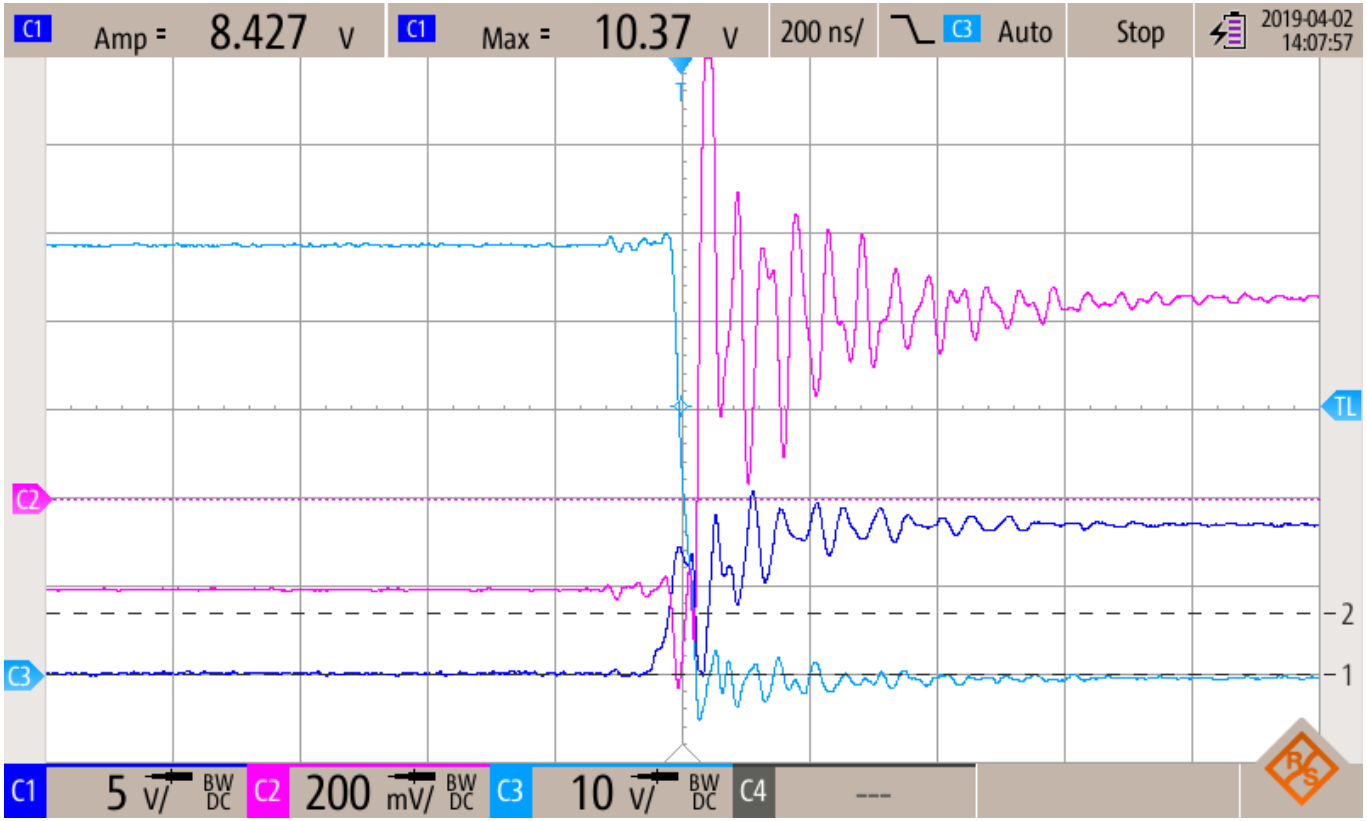


Fig. 19 - Typical Stored Charge vs. di_f/dt

Preklop toka

MAHLE

Driven by performance

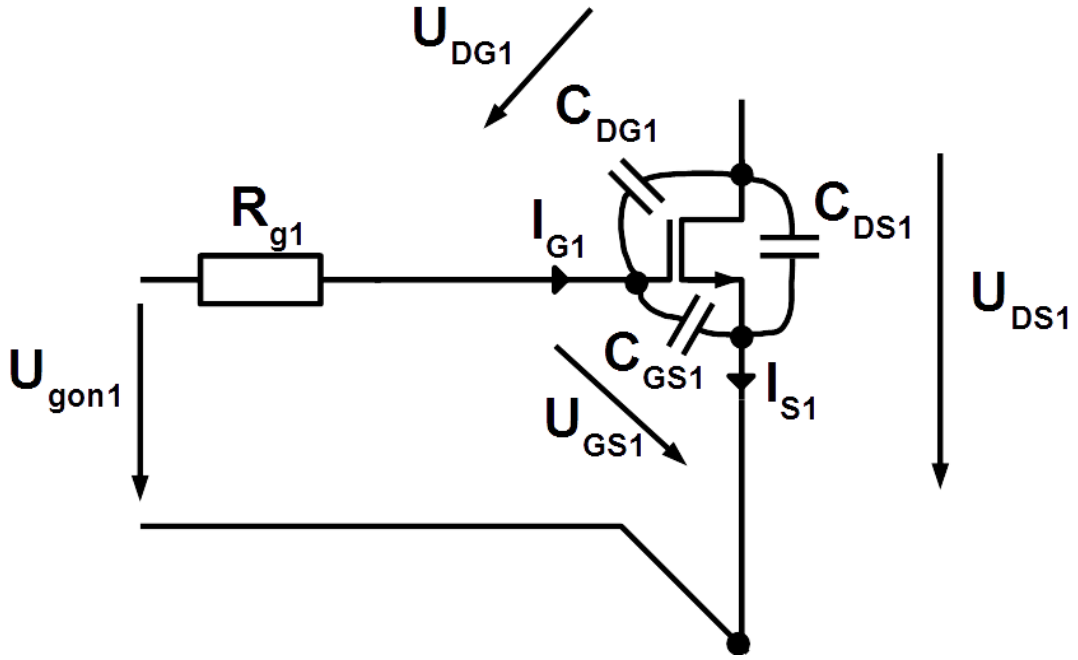


Preklop napetosti

MAHLE
Driven by performance

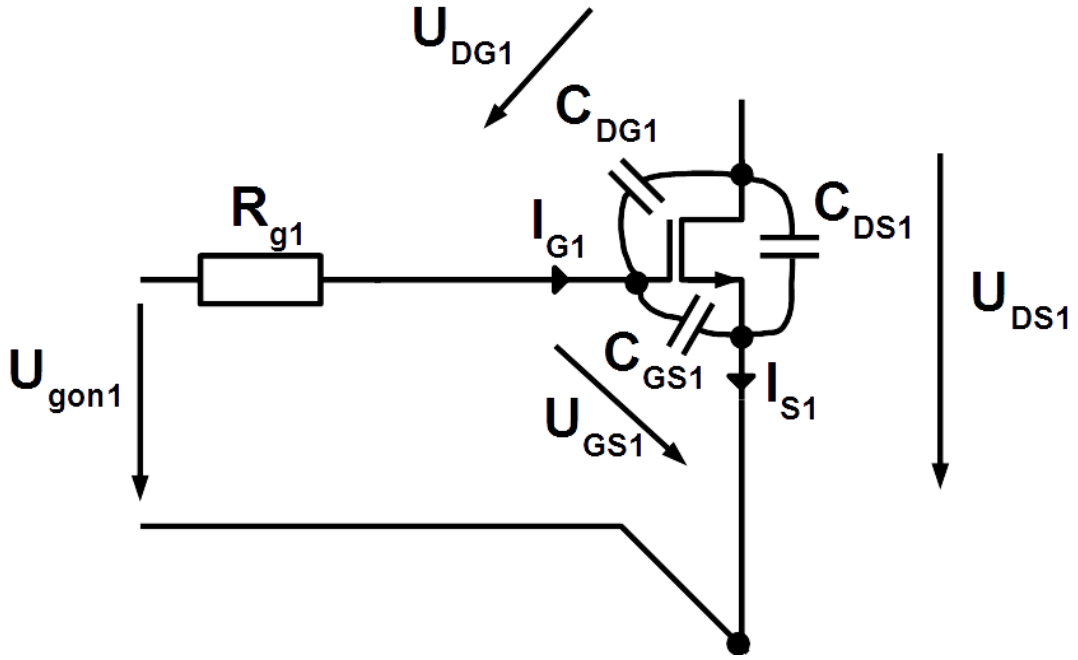
- Med preklopom napetosti (in tudi med preklopom toka) se Ugs ne pretirano spreminja (rekurzivni argument?)
- Izprazniti moramo kapacitivnosti Cdg in Cgs gornjega tranzistorja
- Strmina spreminjanja Udg je približno konstantna

MAHLE
Driven by performance



$$I_g \approx \frac{U_{gon} - U_{GS}}{R_g} = -I_{DG}$$

MAHLE
Driven by performance



$$\frac{dU_{DG}}{dt} = \frac{I_{DG}}{C_{DG}} \approx -\frac{U_{gon} - U_{GS}}{R_g C_{DG}}$$

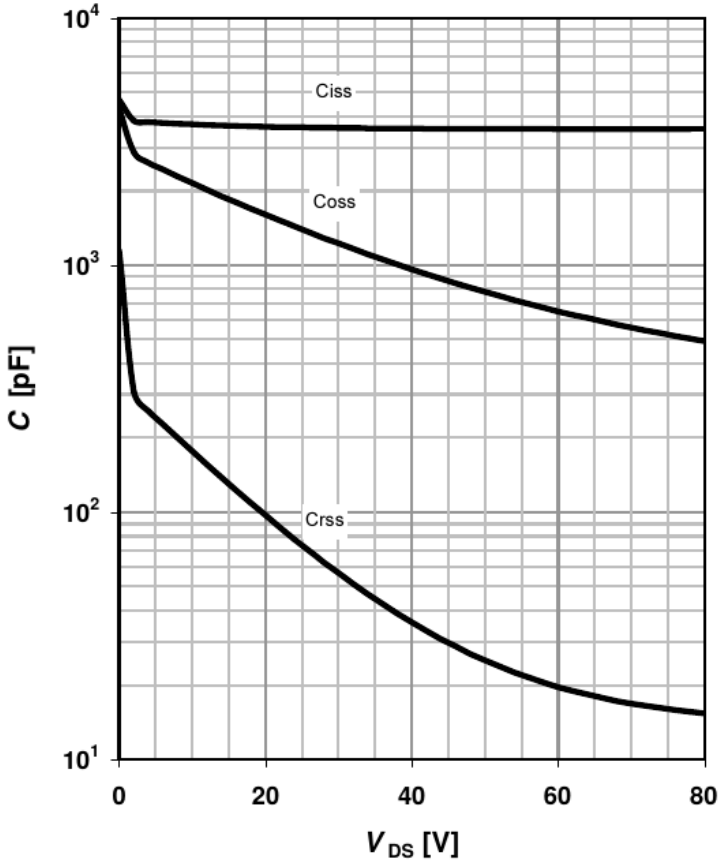
Preklop napetosti

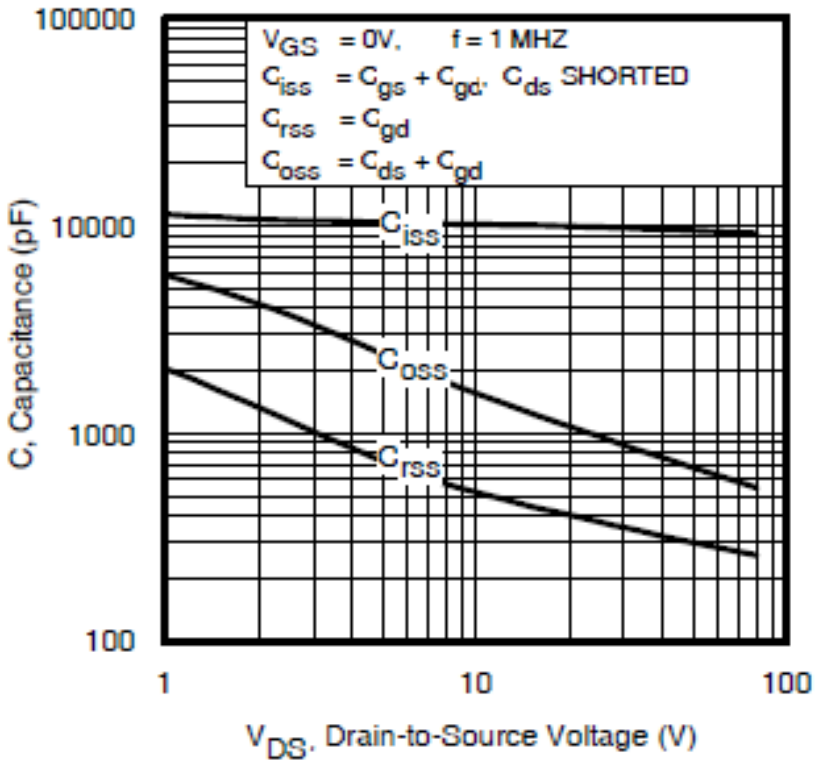
MAHLE

Driven by performance

Preklop napetosti

Driven by performance

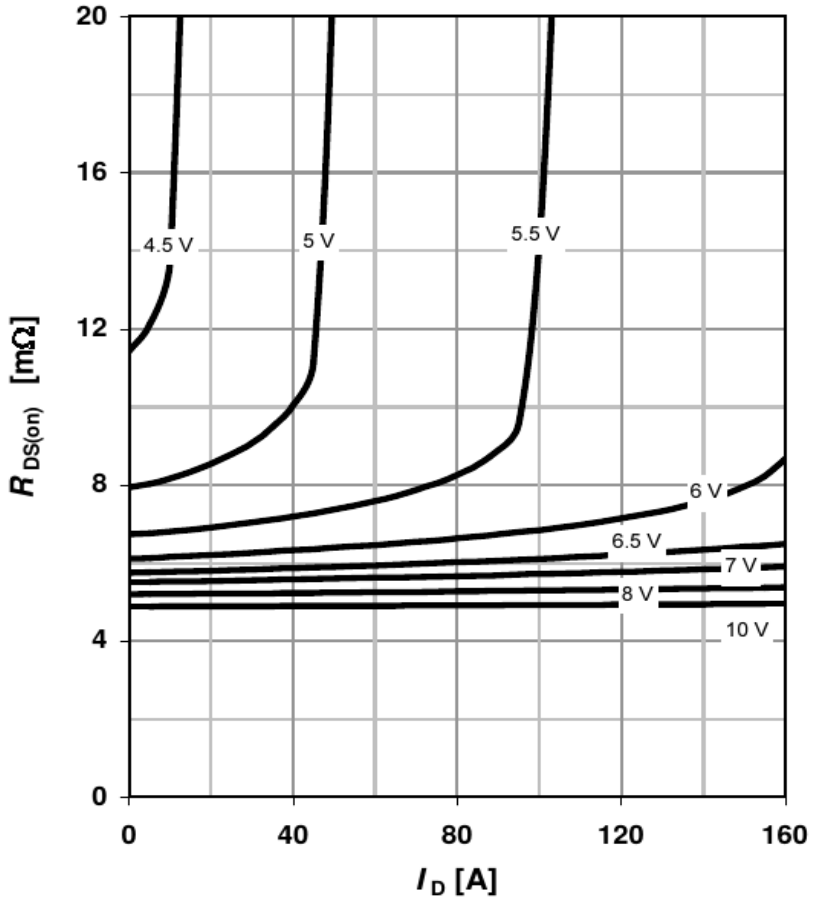




Prevajanje

MAHLE

Driven by performance



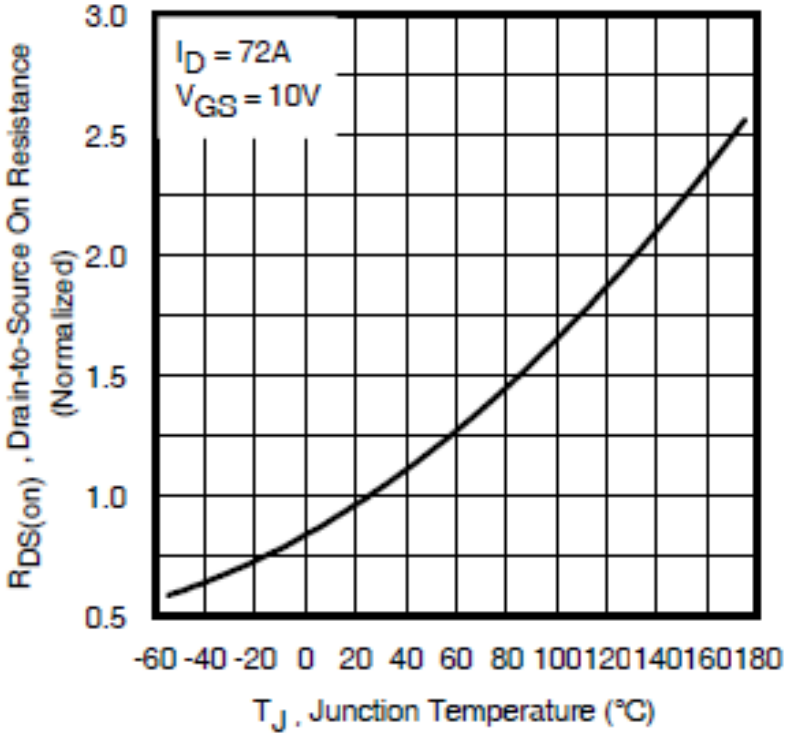


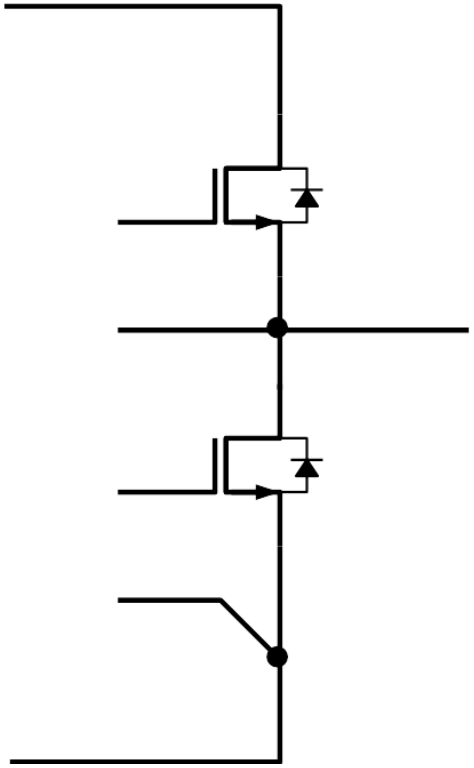
Fig 4. Normalized On-Resistance vs. Temperature

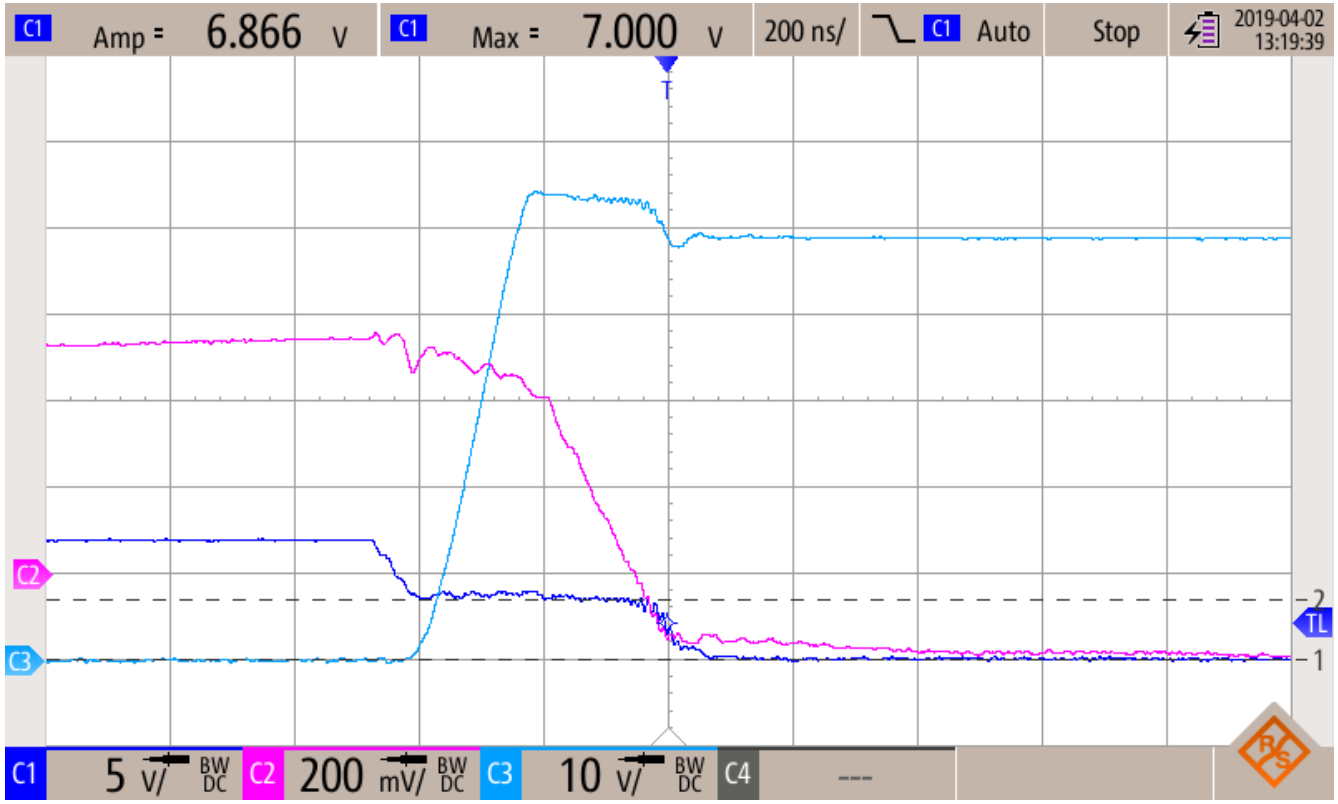
Izklop

Izklop

Driven by performance

- Najprej se preklopi napetost, nato tok





Razlike v primerjavi z vklopom

Driven by performance

U_{Ls}, U_{Rg}, U_{GS}, U_{DS}

MAHLE
Driven by performance

$$\frac{dU_{DG}}{dt} \approx \frac{U_{GS}}{R_g C_{DG}}$$

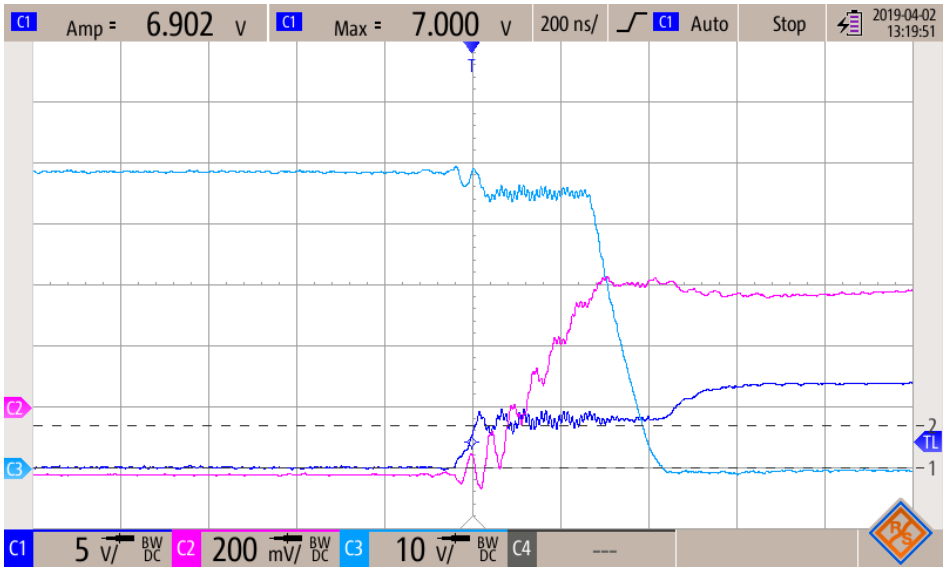
$$\frac{d\,I_{DS}}{dt} \approx \frac{-U_{GS}}{L_s} \approx konst\,.$$

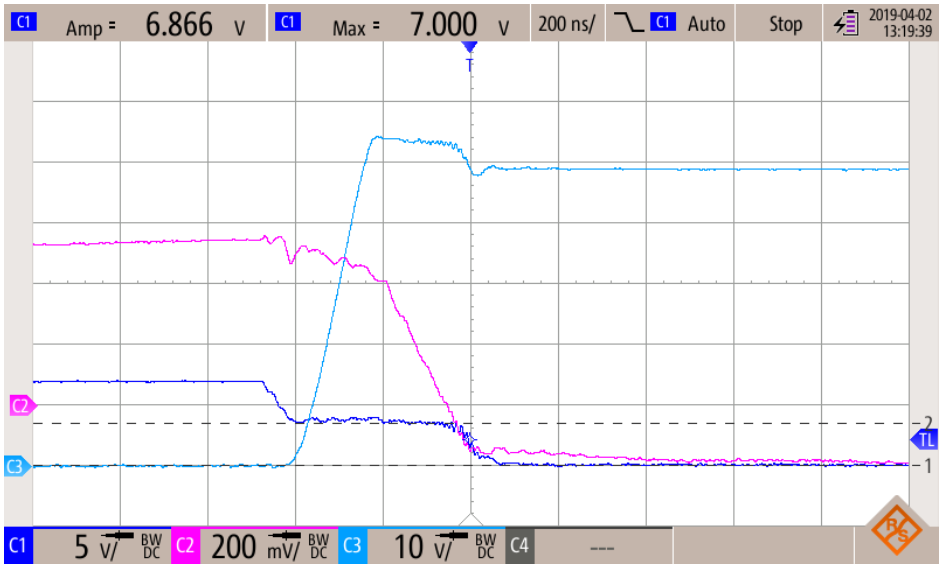
(pri pogoju gm*Ls >> Rg*Cgs)

Izklop

MAHLE

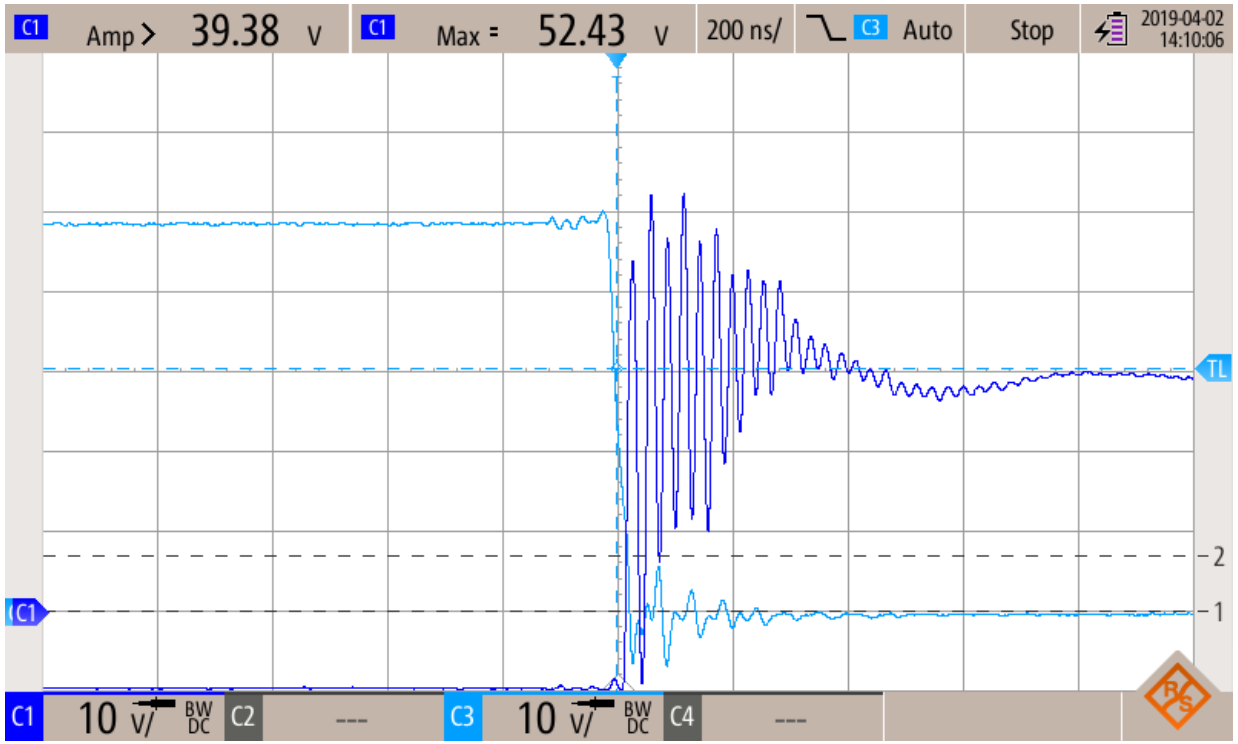
Driven by performance





Drugi primeri

Minimalna Ls



U_{DS1}, U_{DS2}

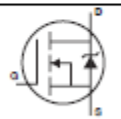
Majhna Ls + dodan Cdg

Driven by performance

U_{DS1}, U_{DS2}

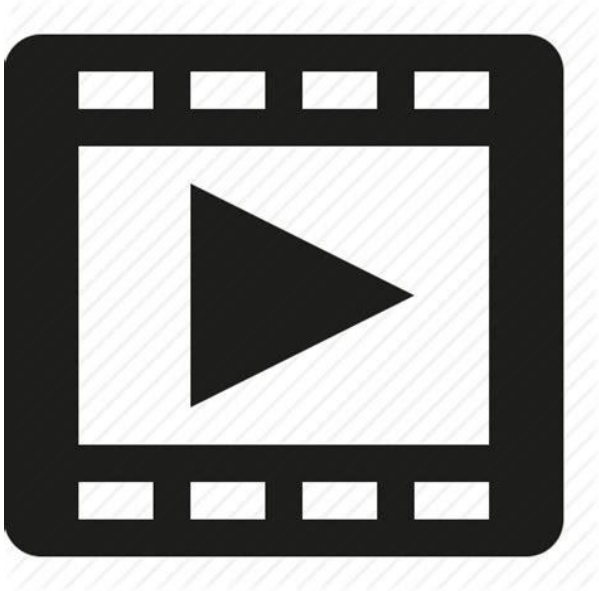
Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
gfs	Forward Transconductance	260	—	—	S	V_{DS} = 50V, I_D = 43A
Q_g	Total Gate Charge	—	190	290	nC	I_D = 43A
Q_{gs}	Gate-to-Source Charge	—	40	—		V_{DS} = 50V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	49	—		V_{GS} = 10V ④
R_G	Gate Resistance	—	1.3	—	Ω	
$t_{d(on)}$	Turn-On Delay Time	—	24	—	ns	V_{DD} = 65V
t_r	Rise Time	—	58	—		I_D = 43A
$t_{d(off)}$	Turn-Off Delay Time	—	81	—		R_G = 2.6Ω
t_f	Fall Time	—	71	—		V_{GS} = 10V ④
C_{iss}	Input Capacitance	—	9540	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	680	—		V_{DS} = 50V
C_{rss}	Reverse Transfer Capacitance	—	300	—		f = 1.0MHz
C_{oss} eff. (ER)	Effective Output Capacitance (Energy Related)⑥	—	760	—		V_{GS} = 0V, V_{DS} = 0V to 80V ⑥
C_{oss} eff. (TR)	Effective Output Capacitance (Time Related)⑤	—	1120	—		V_{GS} = 0V, V_{DS} = 0V to 80V ⑤

Diode Characteristics

Symbol	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	72	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ②⑦	—	—	290		
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S = 43A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	50	75	ns	T_J = 25°C V_R = 85V,
		—	60	90		T_J = 125°C I_F = 43A
Q_{rr}	Reverse Recovery Charge	—	100	150	nC	T_J = 25°C di/dt = 100A/µs ④
		—	140	210		T_J = 125°C
I_{RRM}	Reverse Recovery Current	—	3.5	—	A	T_J = 25°C
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by LS+LD)				

MAHLE

Driven by performance



Unotisto!