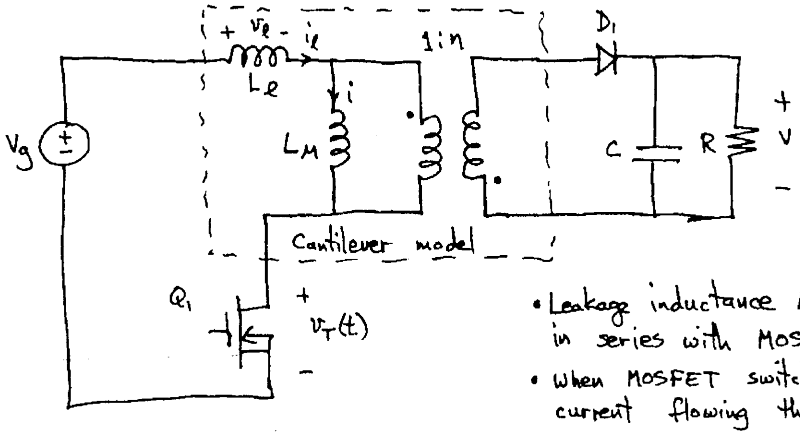
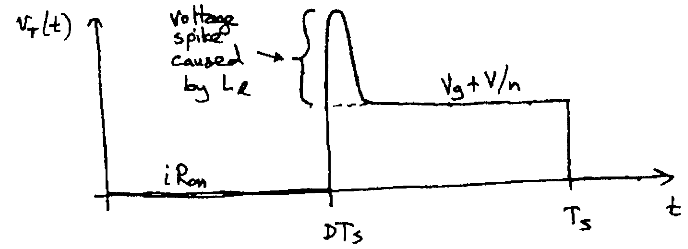
Effect of transformer leakage inductance

Voltage clamp snubber



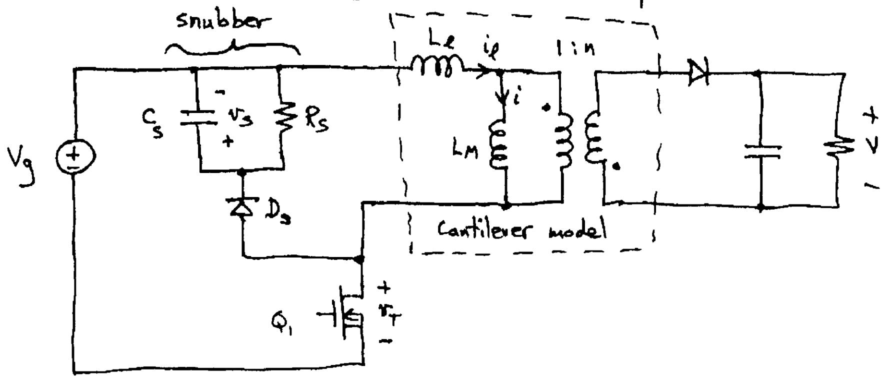
- Leakage inductance L_ℓ is effectively in series with MOSFET Q_1
- When MOSFET switches off, it interupts current flowing through L_ℓ
- L_ℓ induces voltage spike according to $v_\ell(t) = L_\ell \frac{di_\ell(t)}{dt}$

transistor voltage waveform:

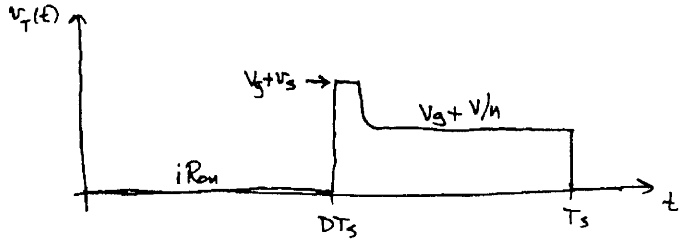


If the peak magnitude of the voltage spike exceeds the voltage rating of the MOSFET, then Q_1 will fail.

Protection of Q_1 using a voltage clamp snubber



- snubber provides a path for i_ℓ to flow after Q_1 has turned off
- energy stored in $L_\ell = \frac{1}{2} L_\ell i_\ell^2 = \frac{1}{2} L_\ell I^2$ is transferred to C_s and then is dissipated by R_s. Average power $= \frac{1}{2} L_\ell I^2 f_s$
- peak transistor voltage is clamped to $V_g + v_s > V_g + \frac{V}{n}$



An approach to select R_s and C_s:

- use large C_s, so that $v_s(t)$ has negligible ripple:

$$C_s \gg \frac{T_s}{R_s} \quad \Rightarrow v_s(t) \approx V_s$$

- Voltage V_s rises until power dissipated by R_s is equal to average power transferred from L_ℓ:

$$\frac{V_s^2}{R_s} = \frac{1}{2} L_\ell I^2 f_s$$

$\Rightarrow$ choose R_s such that V_s is acceptably low

- Note that L_ℓ depends on winding geometry, and is not known until transformer is wound.

$\Rightarrow$ measure L_ℓ in short circuit test, or guess its value

Example – a first-pass selection of R_s and C_s

Given $V_g = 150\,\text{V}$, $V = 15\,\text{V}$, $n = 0.2$
$f_s = 100\,\text{kHz}$, $L_M = 1\,\text{mH}$ $I = 1.5\,\text{A}$
MOSFET peak voltage rating $= 400\,\text{V}$
It is desired to limit peak v_T to $325\,\text{V}$

Estimate L_ℓ: in a good, carefully wound transformer, it may be possible to achieve $L_\ell = 3\%$ of $L_M = 30\,\mu\text{H}$

Energy stored in L_ℓ during $0 < t < DT_s$:

$$W_\ell = \frac{1}{2} L_\ell I^2 = \left(\frac{1}{2}\right)(30\,\mu\text{H})(1.5\,\text{A})^2 = 33.75\,\mu\text{J}$$

Average power transferred from L_ℓ to snubber:

$$P_\ell = W_\ell f_s = (33.75\,\mu\text{J})(100\,\text{kHz}) = 3.375\,\text{W}$$

To limit peak v_T to $325\,\text{V}$, we need

$$V_s = (\text{peak } v_T) - V_g = 325 - 150 = 175\,\text{V}$$

So choose

$$R_s = \frac{V_s^2}{P_\ell} = \frac{(175)^2}{(3.375\,\text{W})} = 9074\,\Omega$$

we might use a $10\,\text{k}\Omega$, $5\,\text{W}$ resistor. Then

$$C_s \gg \frac{T_s}{R_s} = \frac{(10\,\mu\text{s})}{(10\,\text{k}\Omega)} = 1\,\text{nF}$$

A good choice might be $C_s = 47\,\text{nF}$, $250\,\text{V}$.

The above calculations are based on the estimate $L_\ell = 3\%$ of L_M, and should be considered first-pass estimates.