Power converters AC/DC and DC/AC - MM5

Thyristors

Content MM5

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2. Thyristor working principle
3. Protection circuits
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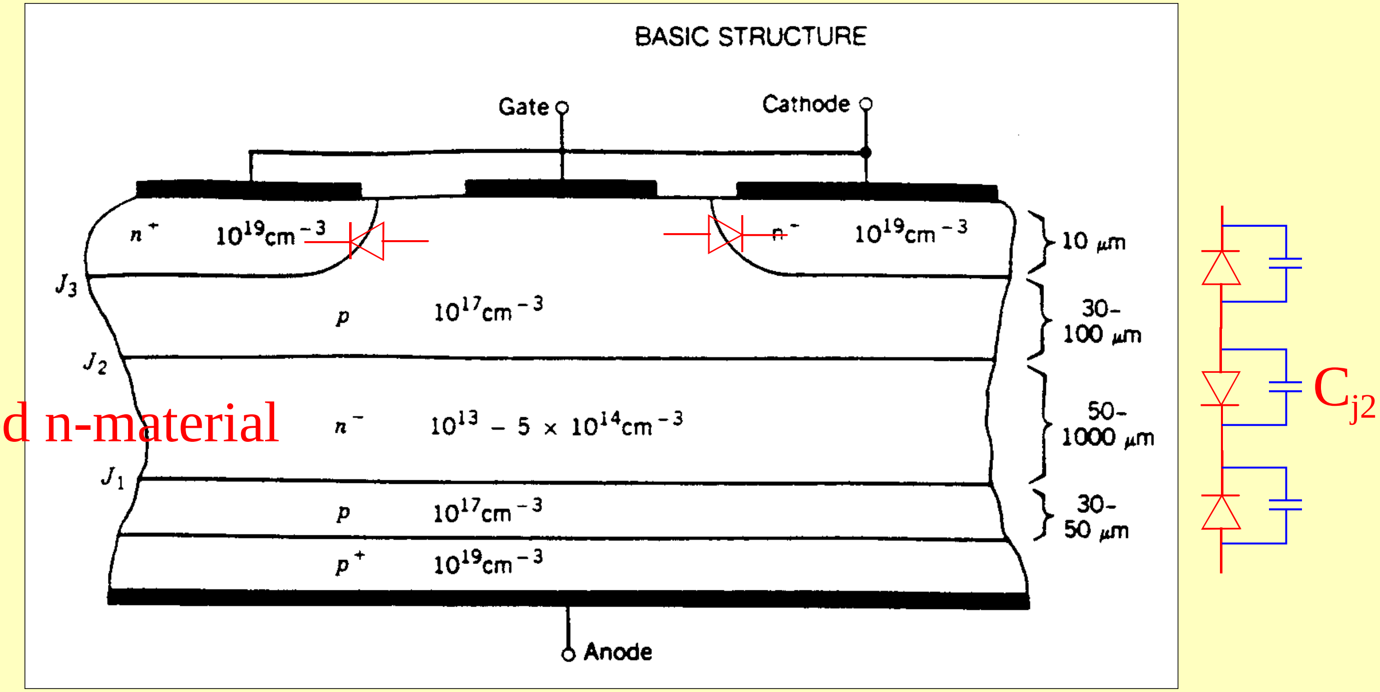
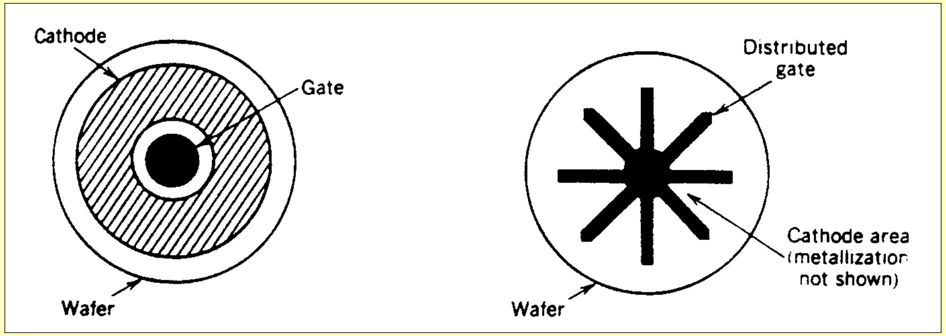
2. Thyristor working principle

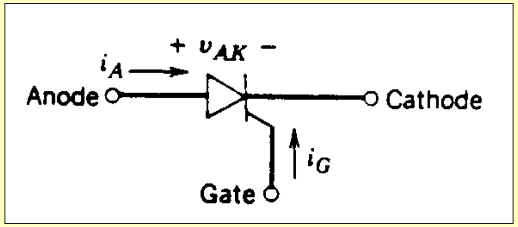
Physical layout

Lightly doped n-material



C_{j2}

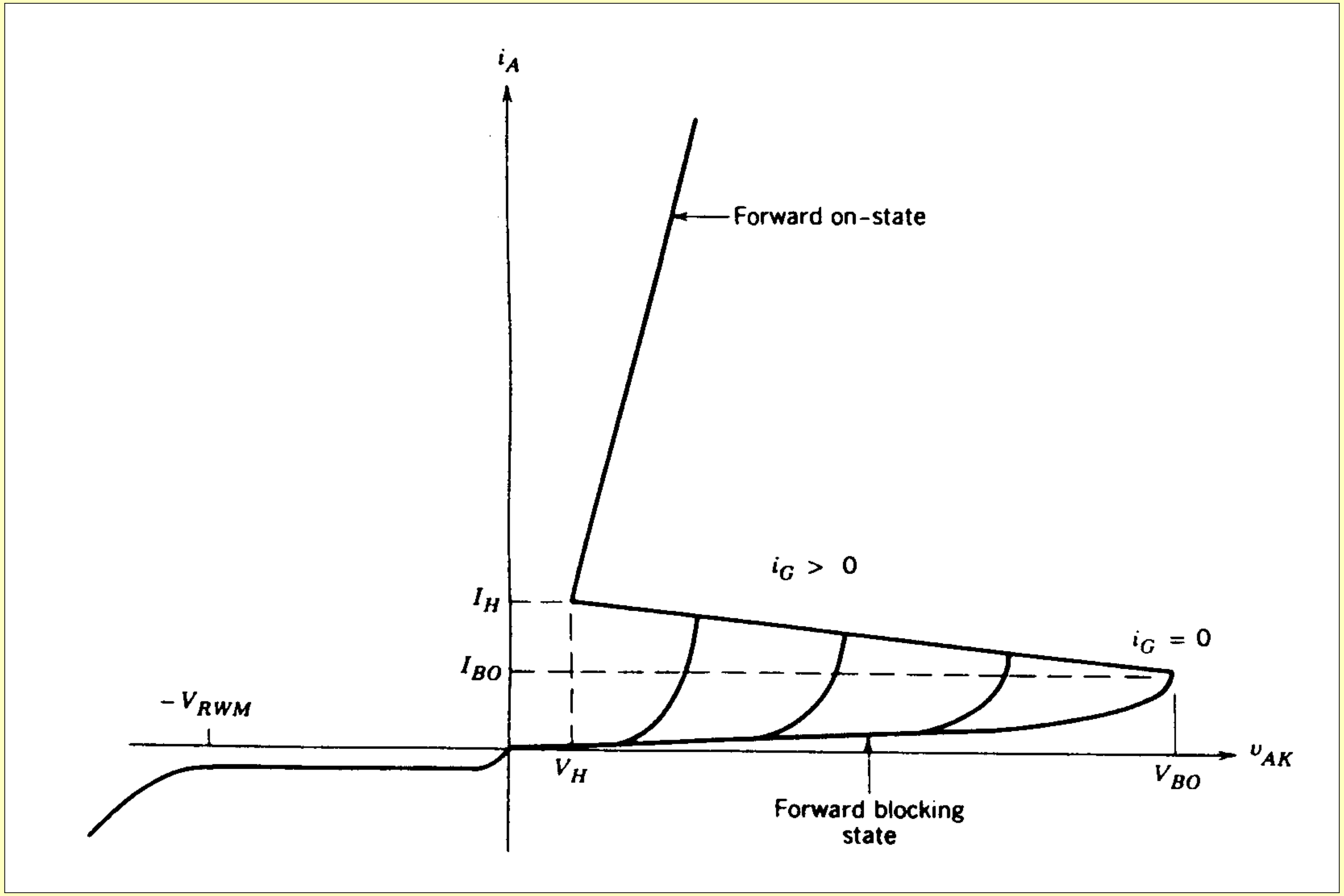




Symbol

2. Thyristor working principle

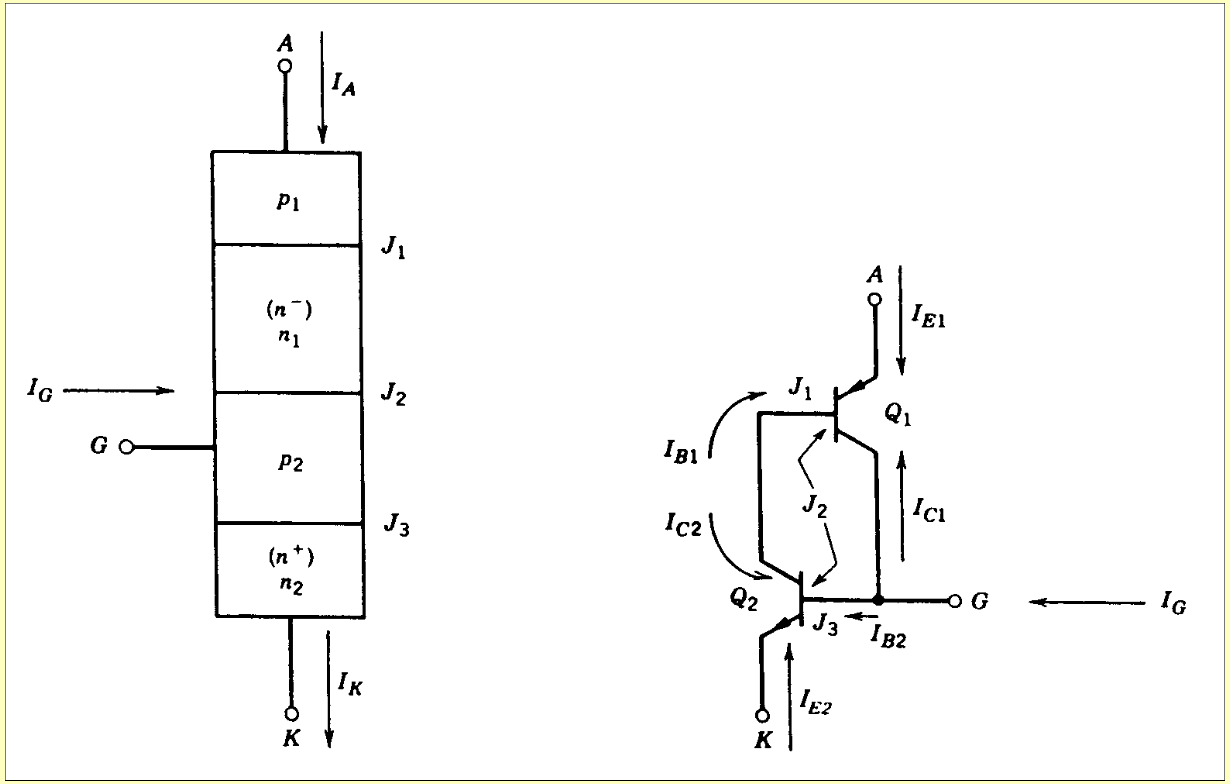
Static characteristic



$$-V_{RWM} \approx V_{B0}$$

2. Thyristor working principle

Model



Q1: $I_{C1} = -\alpha_1 I_{E1} + I_{CO1}$

Collector currents

Q2: $I_{C2} = -\alpha_2 I_{E2} + I_{CO2}$

$I_{CO} = I_{CS}[1 - \alpha_f \alpha_r]$

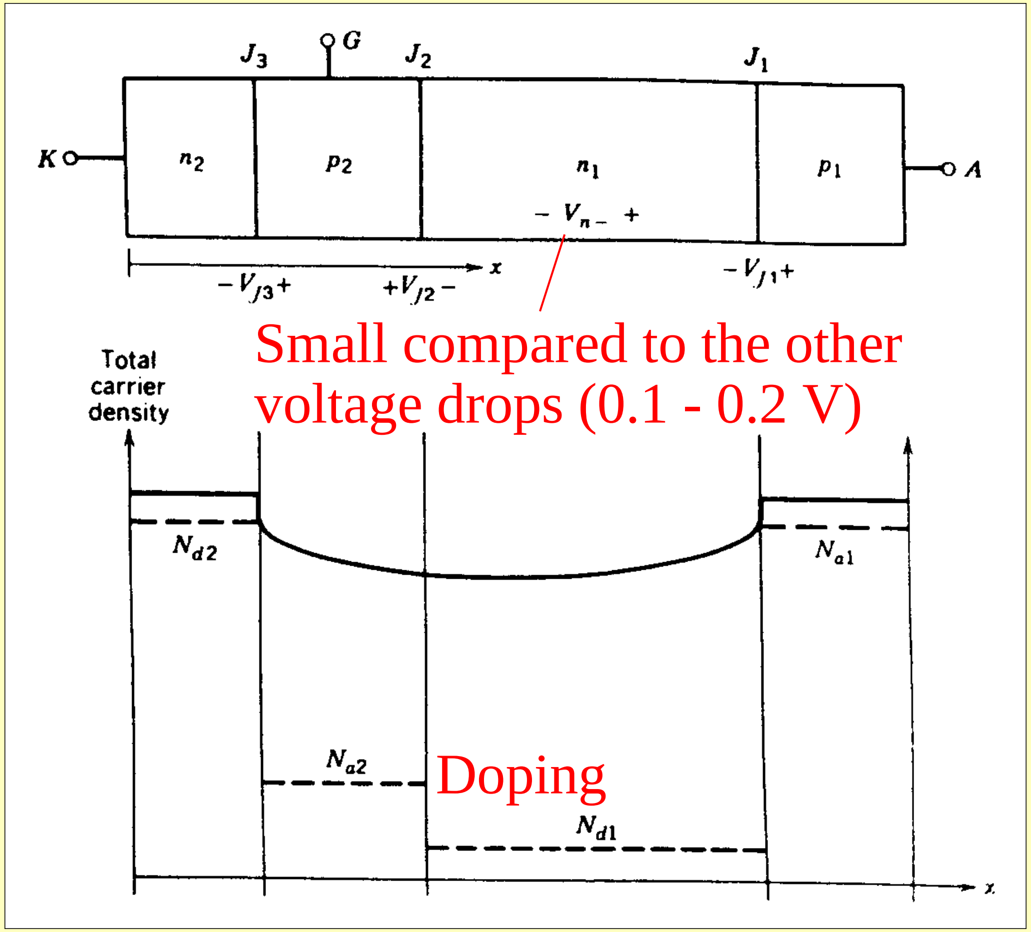
Leakage current

$$I_A = \frac{\alpha_2 I_G + I_{CO1} + I_{CO2}}{1 - (\alpha_1 + \alpha_2)}$$

$\alpha_1 + \alpha_2 << 1$ when off

2. Thyristor working principle

On-state



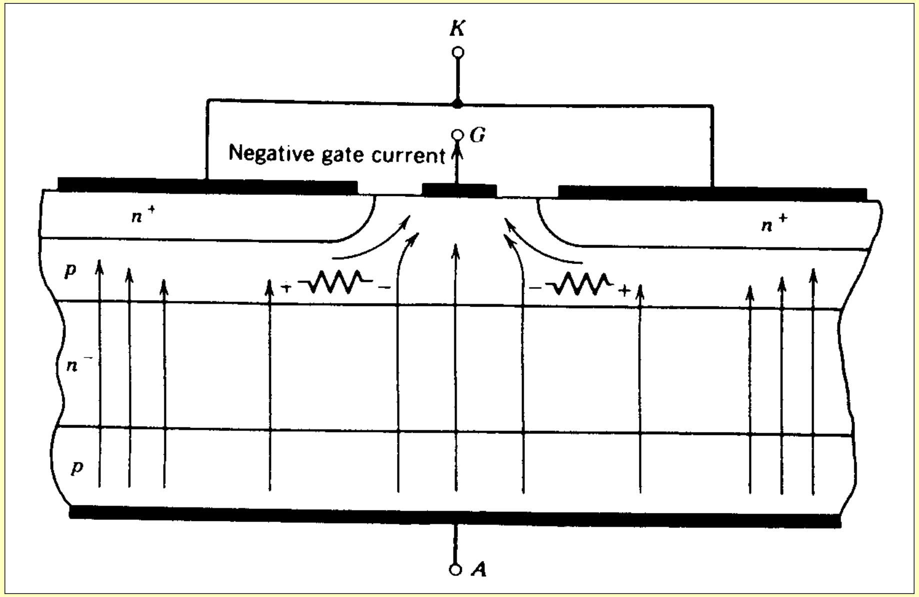
Small compared to the other voltage drops (0.1 - 0.2 V)

Doping

Voltage drop

$$V_{AK(on)} = V_{J1} - V_{J2} + V_{J3} + V_{n-}$$

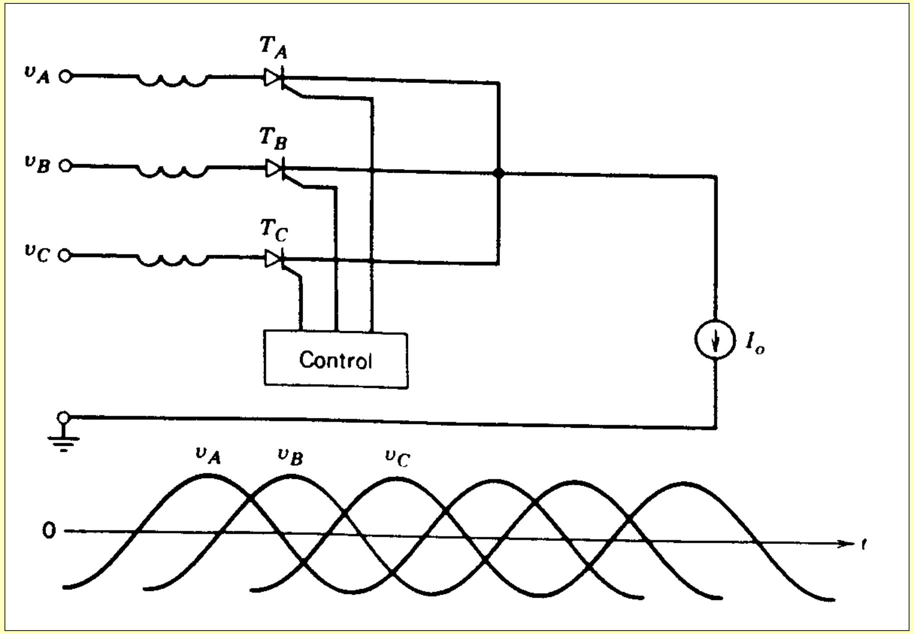
Attempted turn-off



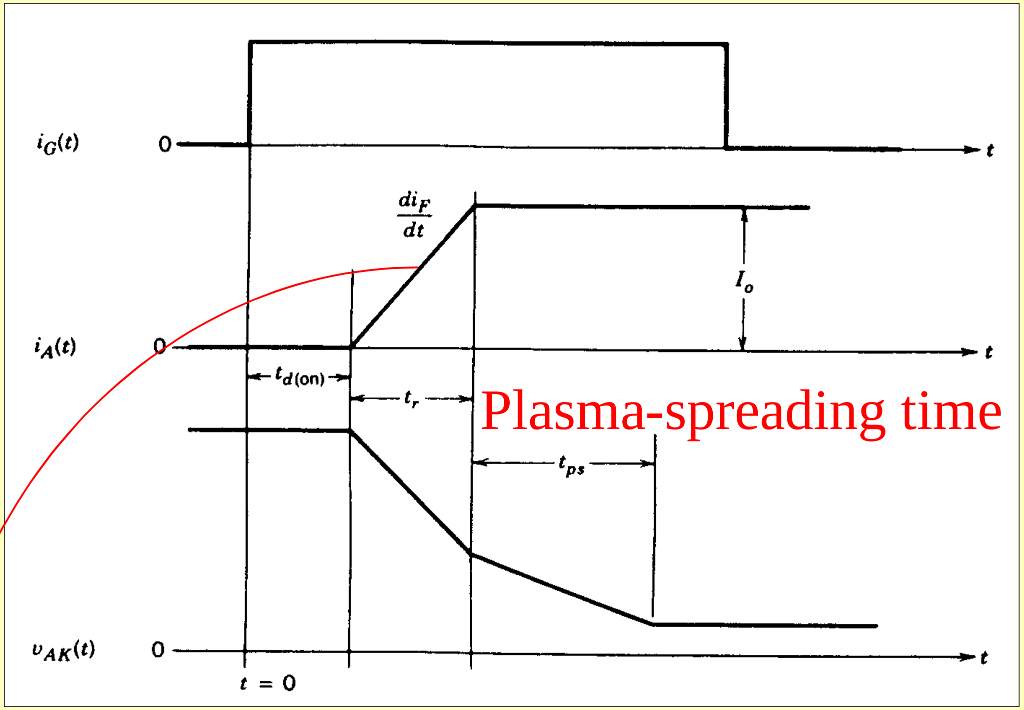
Negative gate current vil make it difficult for the current to flow in the middle of the Thyristor. But the Thyristor will **not** turn-off.

2. Thyristor working principle

Turn-on



Voltage and current

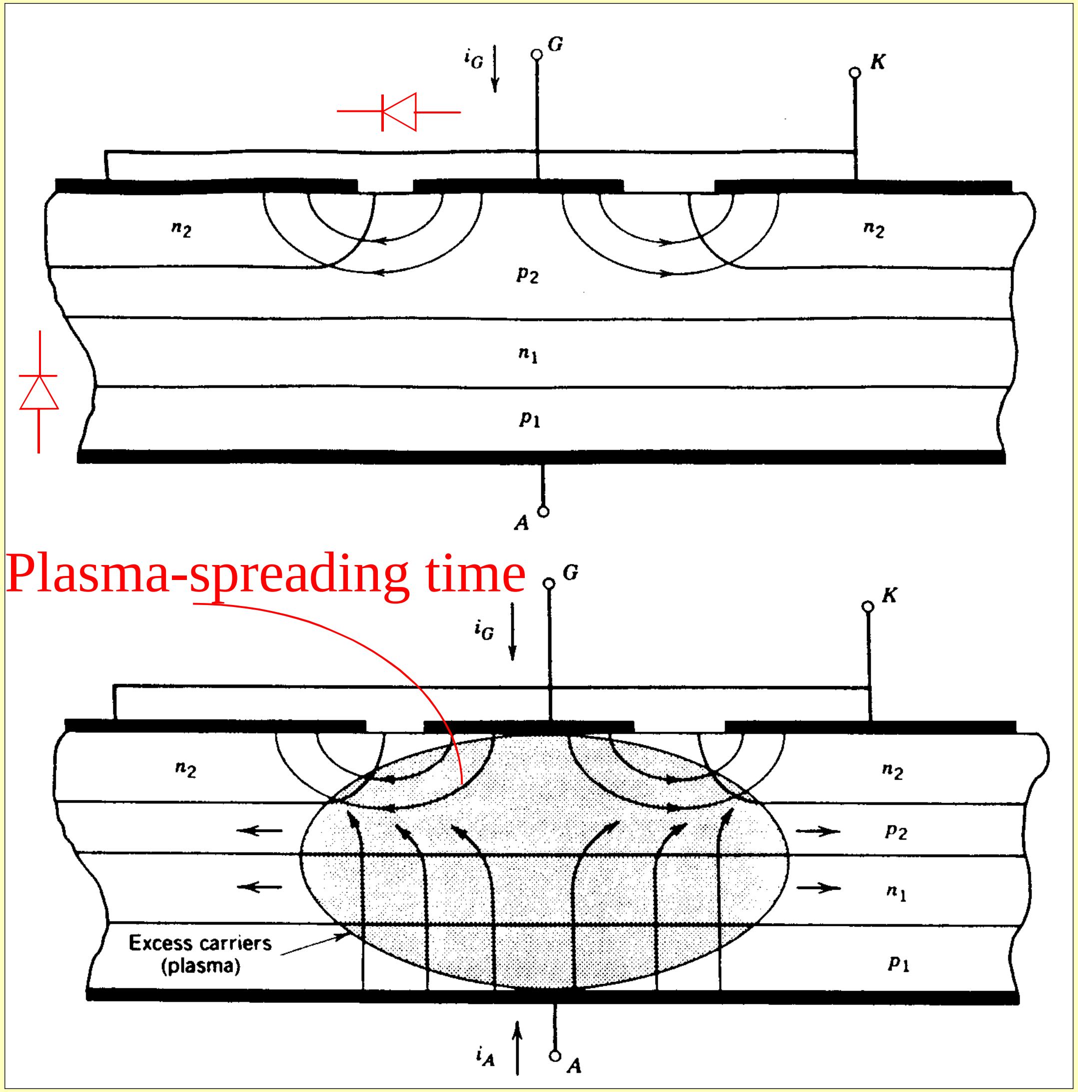


Plasma-spreading time

Determined by the inductance in the circuit. Maximum value is often given in data-sheet.

Controlled turn-on

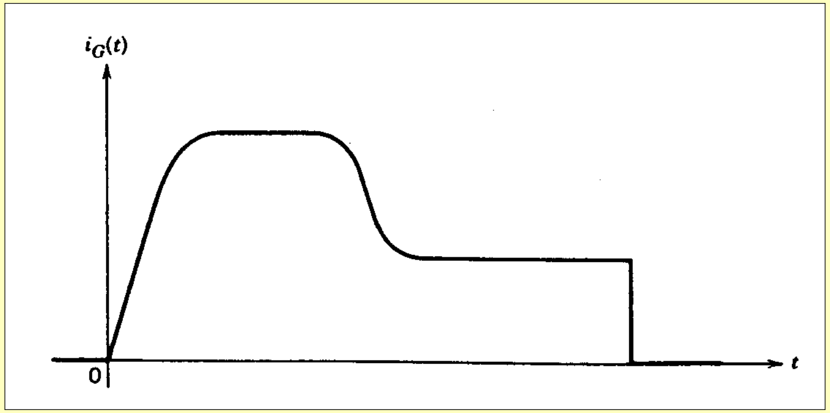
2. Thyristor working principle



Plasma-spreading time

- Current amplification
- Large physical spreading

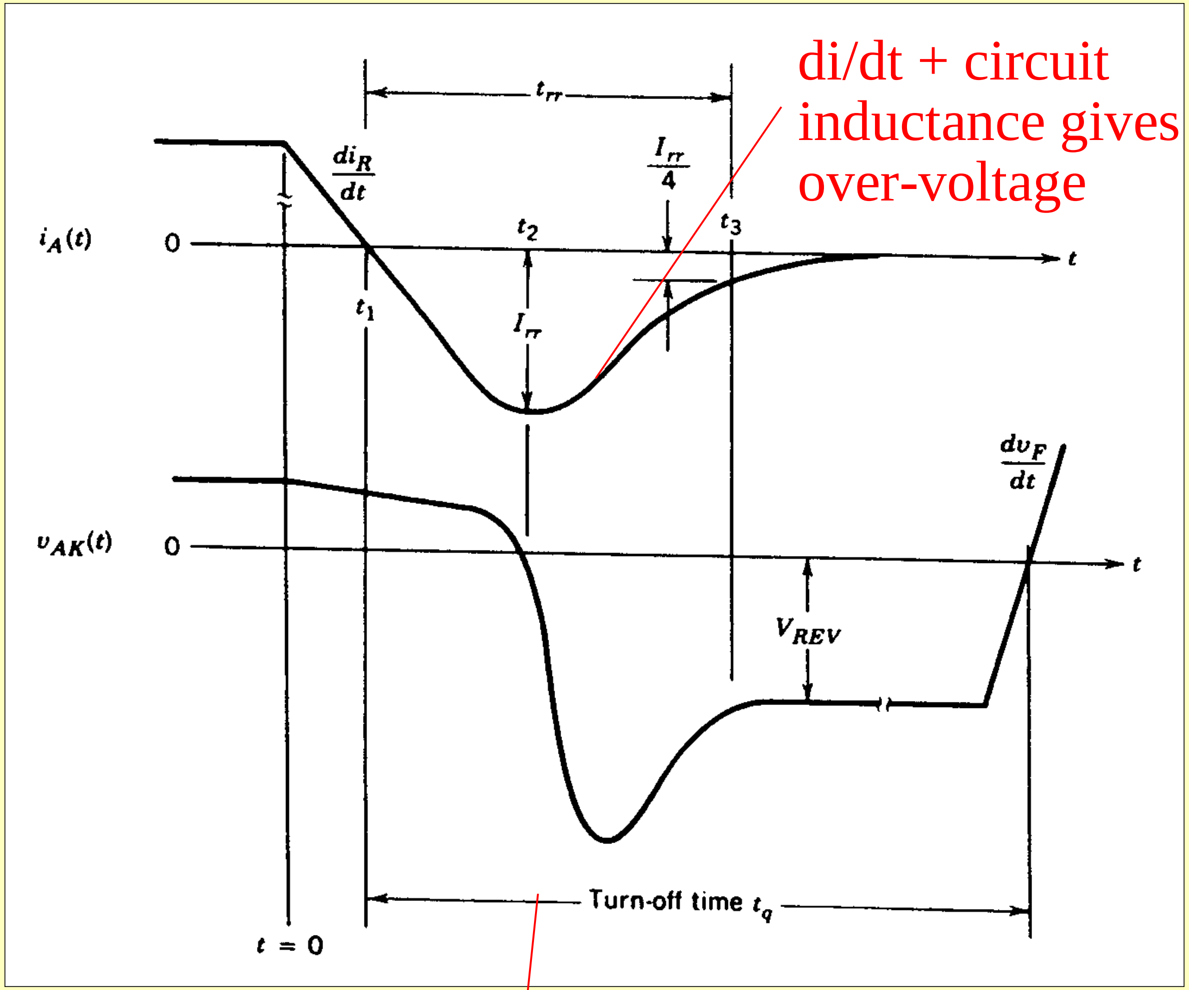
Gate current



Gate current with an initial large value in order to maximize the initial turn-on area.

2. Thyristor working principle

Turn-off



di/dt + circuit inductance gives over-voltage

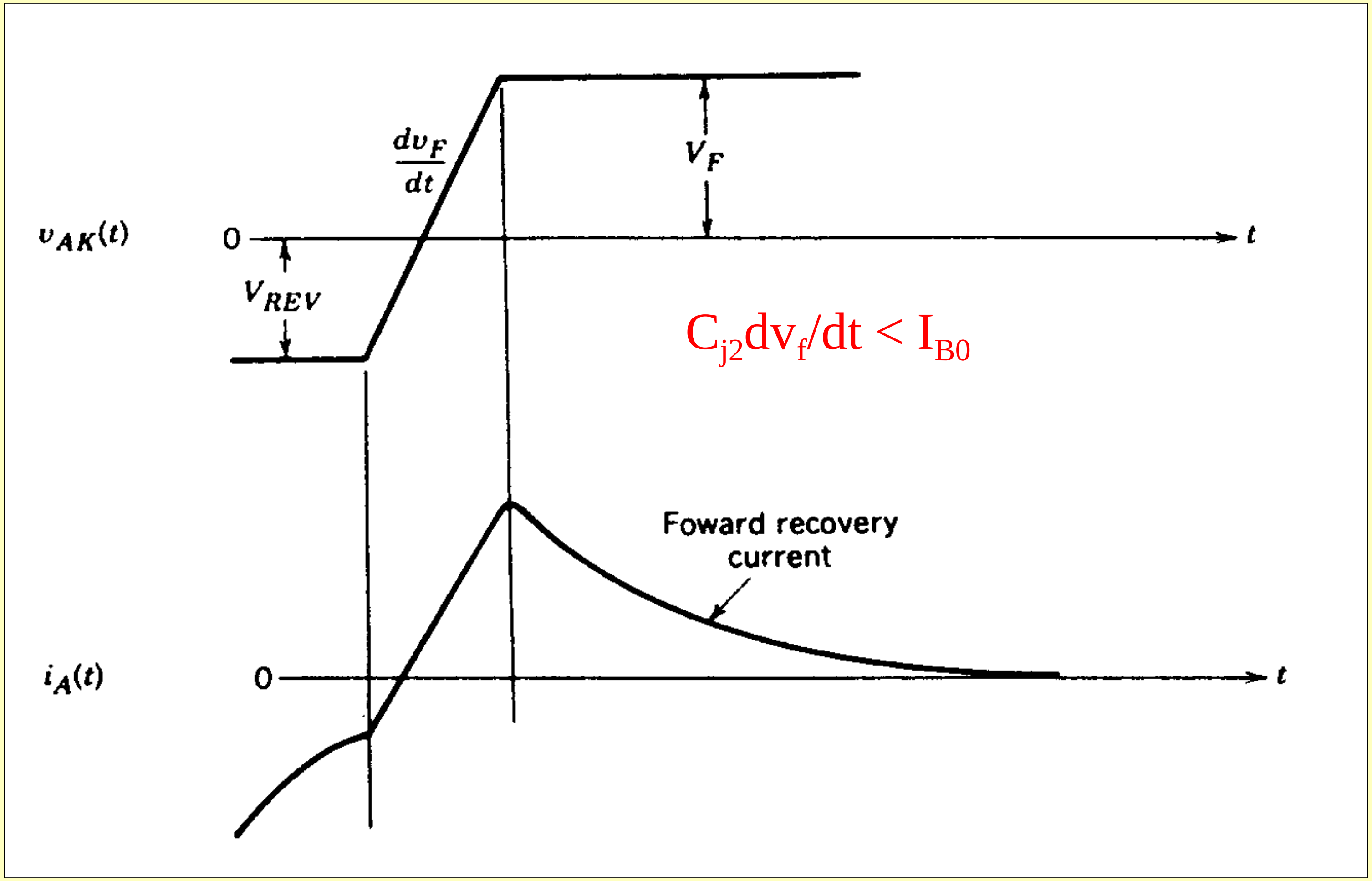
Notes

- di/dt determined by the circuit.
- Thyristor is first turned-off when the carries in n^- layer is disappear.
- With decreasing current at turn-off is an over-voltage generated.
- $Q_{rr} = \frac{1}{2} t_{rr} I_{rr}$ is often listed in the data-sheet.
- Same characteristic for the diode.

No forward blocking voltage before the time is elapsed.

2. Thyristor working principle

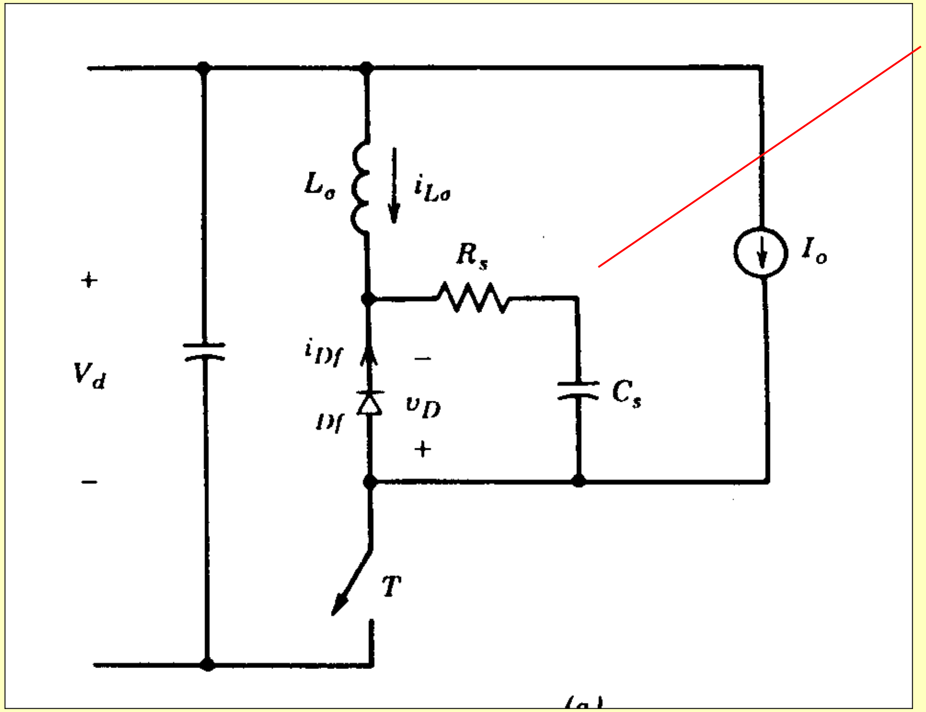
Accidental turn-on due to dv/dt



$C_{j2}dv_f/dt < I_{B0}$

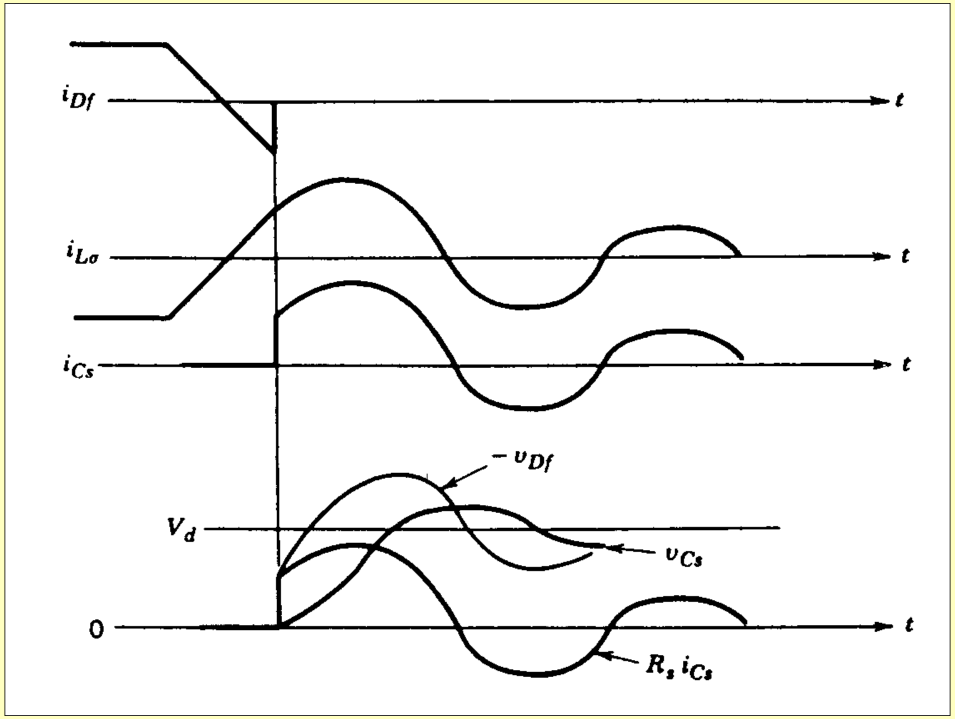
3. Protection circuits

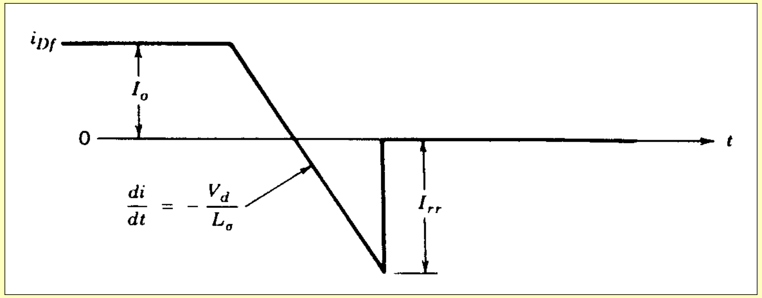
Snubber circuits



Over-voltage snubber / diode snubber

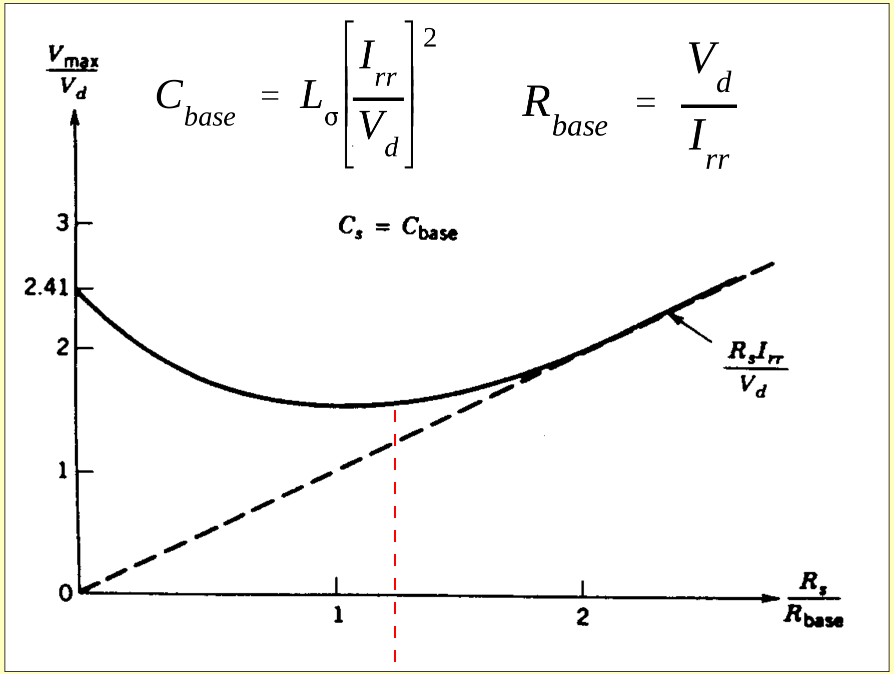
Snubber waveforms





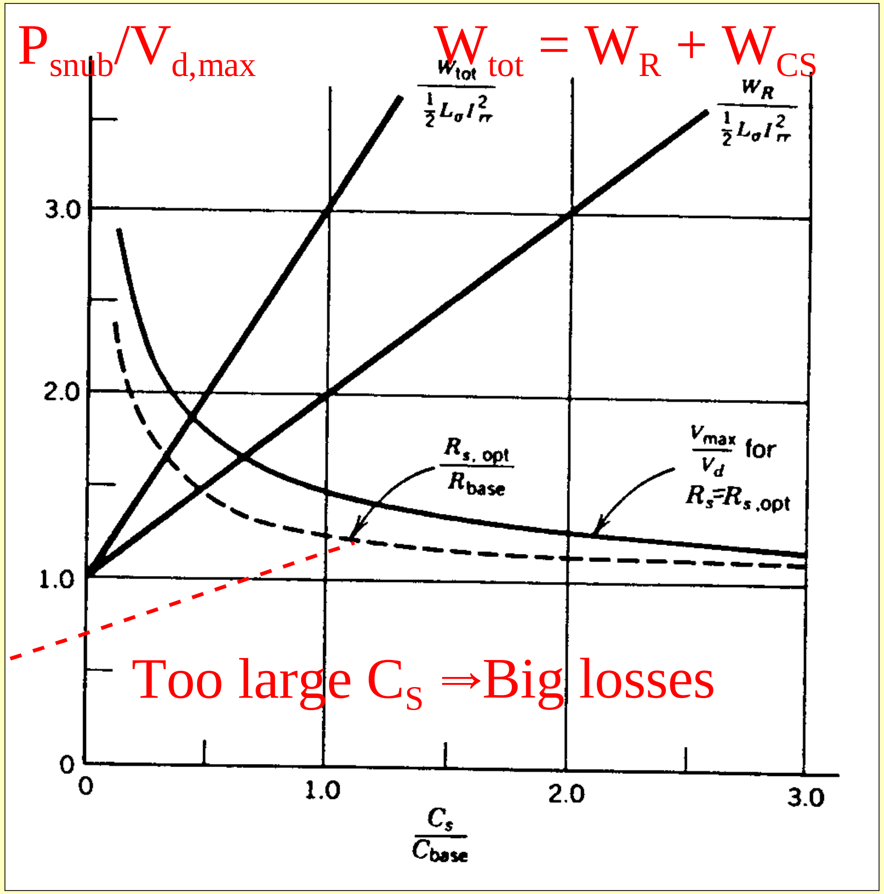
3. Protection circuits

“Optimal” Snubbers



$$C_{base} = L_\sigma \left[\frac{I_{rr}}{V_d}\right]^2 \qquad R_{base} = \frac{V_d}{I_{rr}}$$

Characteristic



$P_{snub}/V_{d,max}$

$W_{tot} = W_R + W_{CS}$

Too large C_S ⇒Big losses

$R_s = R_{opt} = 1.3R_{base}$

Optimum for V_{max}

Determination of $R_{s,opt}$ when C_s is found

3. Protection circuits

Thyristors are sensitive

Causes :

- Too large currents and voltages
- Large mechanical construction

Limits :

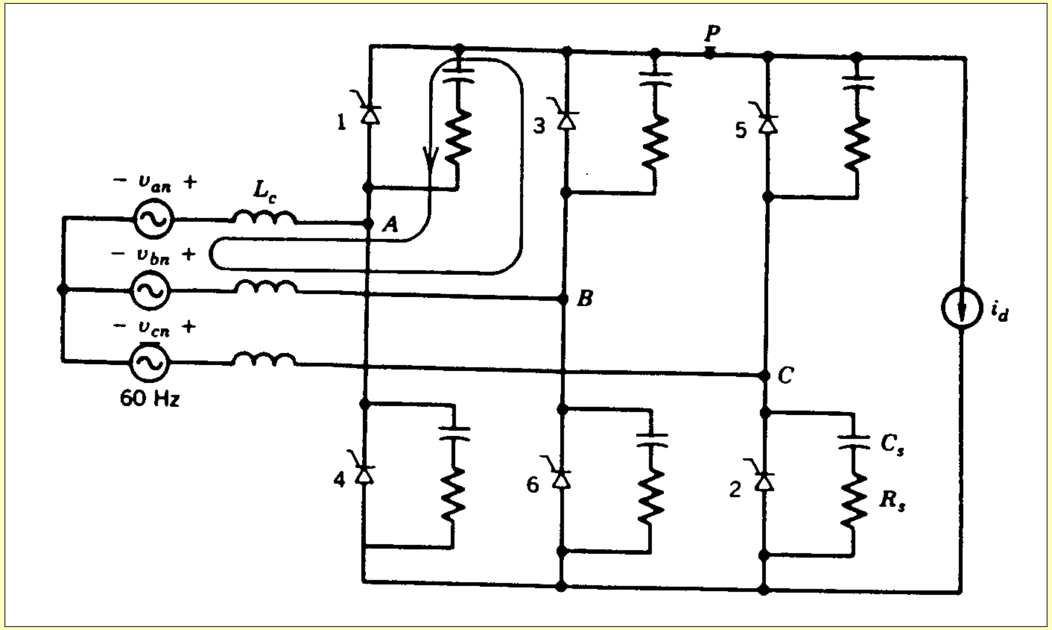
- di/dt_{on} (skin-effects)
- dv/dt (Internal capacitances can trig the Thyristor)
- Over voltages

⇒ Therefore Snubbers !

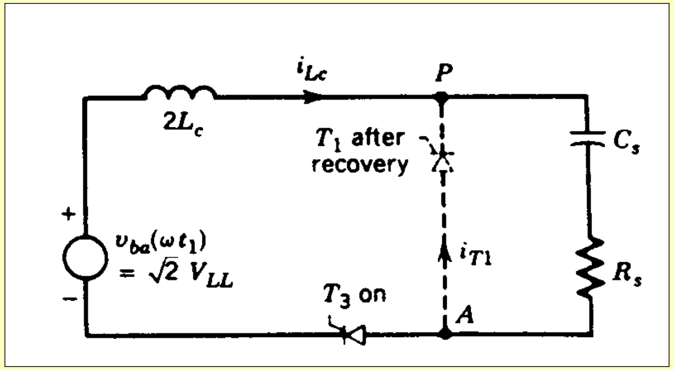
Now we will look on line-commutated Thyristor protection.

3. Protection circuits

Circuit



Equivalent circuit



- L_c is line inductance ⇒ Limits di/dt

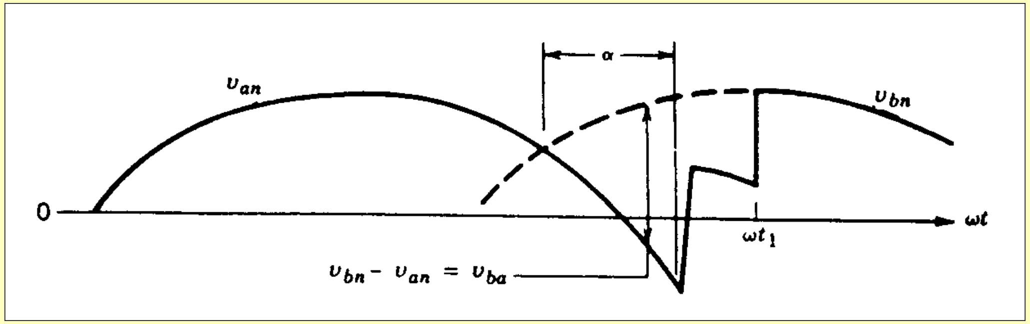
- R,C controls dv/dt and over voltage together with L_c

Worst case ($\alpha = 90°$)

$$\boxed{\frac{di}{dt} = \frac{\sqrt{2}\,V_{LL}}{2L_c}}$$

If di/dt is too large an extra inductance must be added.

Waveforms



3. Protection circuits

Reverse recovery current

$$I_{rr} = \left(\frac{di}{dt}\right) \cdot t_{rr}$$

Energy in $2L_c$ is moved over in C

Reasonable guess

$$C = L_c \left(\frac{I_{rr}}{V_{LL}}\right)^2$$

Optimal choice of R

$$R = 1.3\sqrt{2}\,\frac{V_{LL}}{I_{rr}}$$

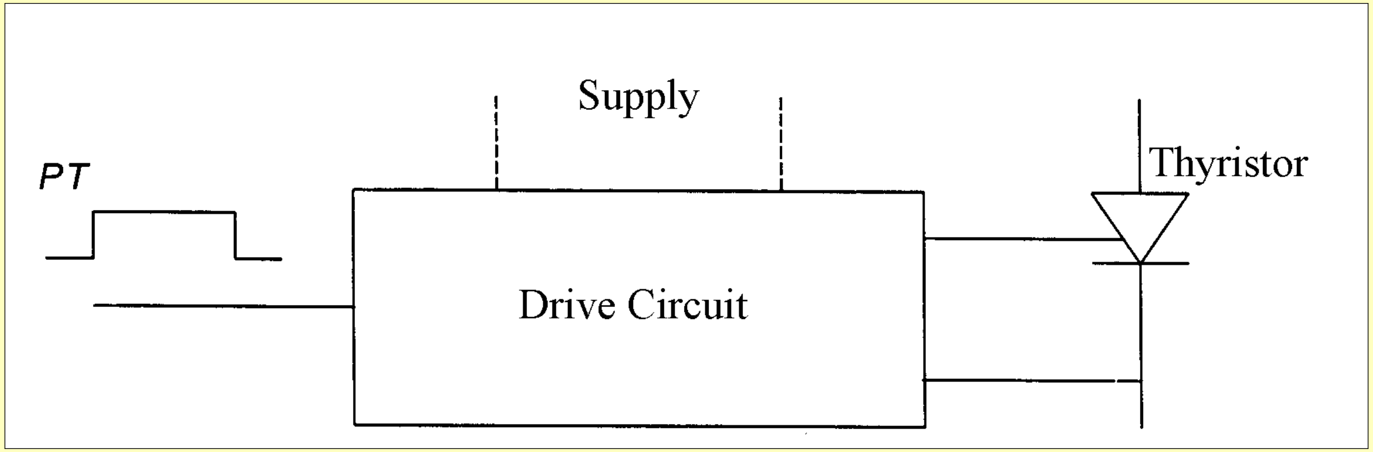
If R is large ⇒ Large over-voltage

If R is small ⇒ Large power losses

Choice of C and R is a compromise between power-loss and over-voltage. The given values is a good starting point for a optimization. dv/dt has also to be checked.

Drive circuit

4. Drive circuits

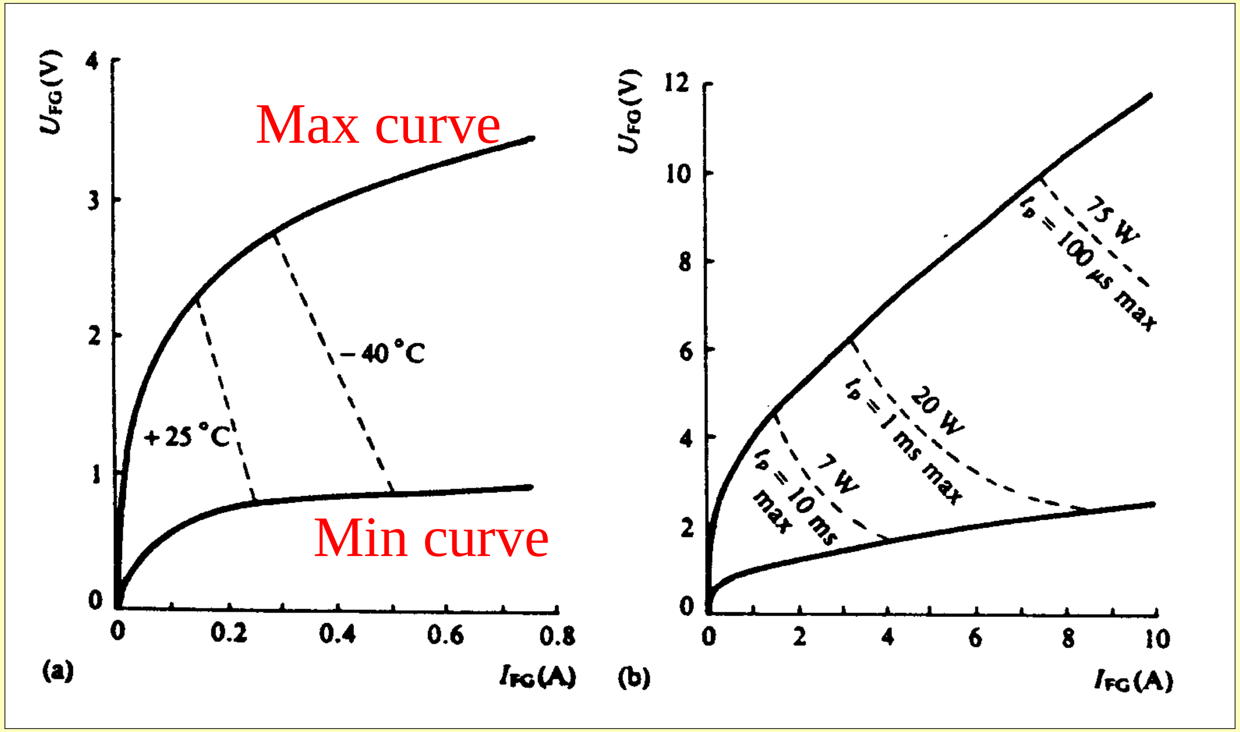


Demands

- Safety turn-on
- Normally galvanic isolation
- React with minium delay
- Noise immunity (small capacitance)
- Simple and cheap
- Small losses
- Limit the amount of supplies

Thyristor input characteristic

4. Drive circuits



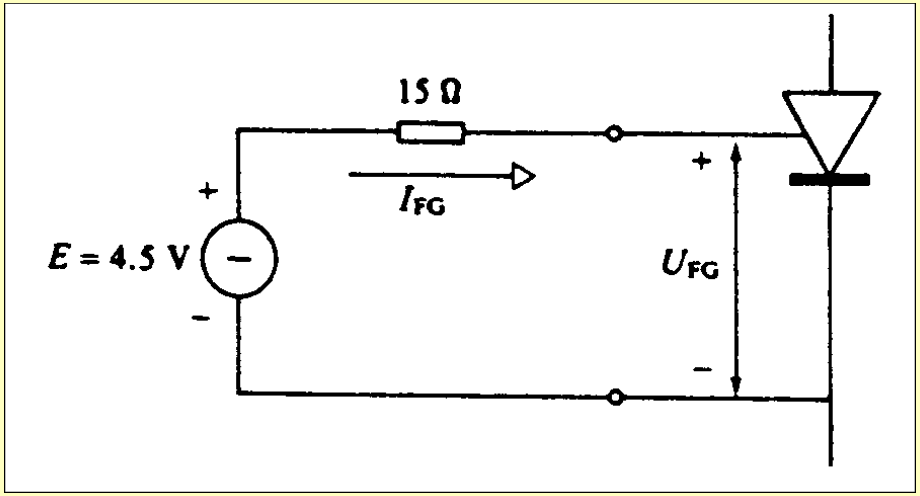
Problems

- Minimum trigger current
- Temperature dependence
- Variations in different components

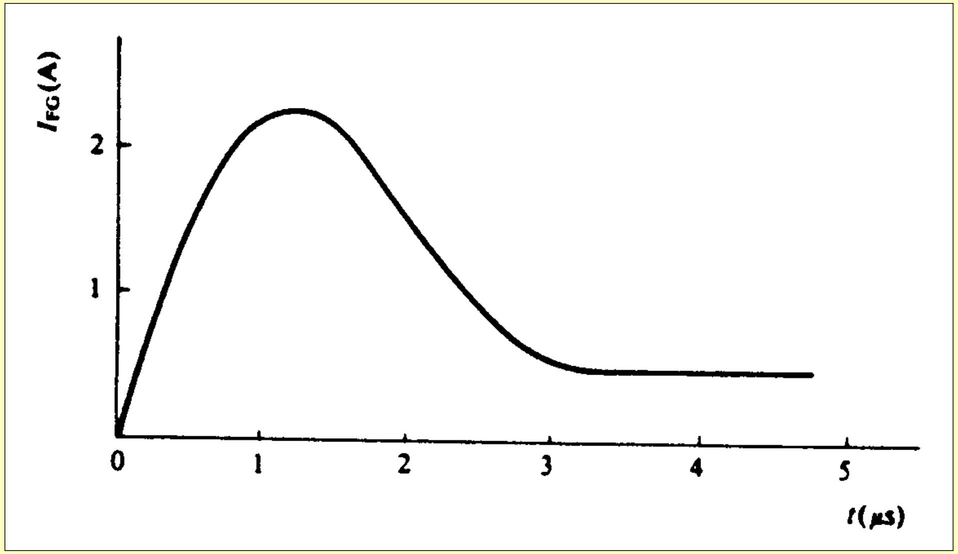
A kind of diode input characteristic

4. Drive circuits

Idealized drive circuit



Idealized current pulse



- Large initial current pulse ⇒Safety turn-on
- Small initial current pulse ⇒local turn-on ⇒ destruction

4. Drive circuits

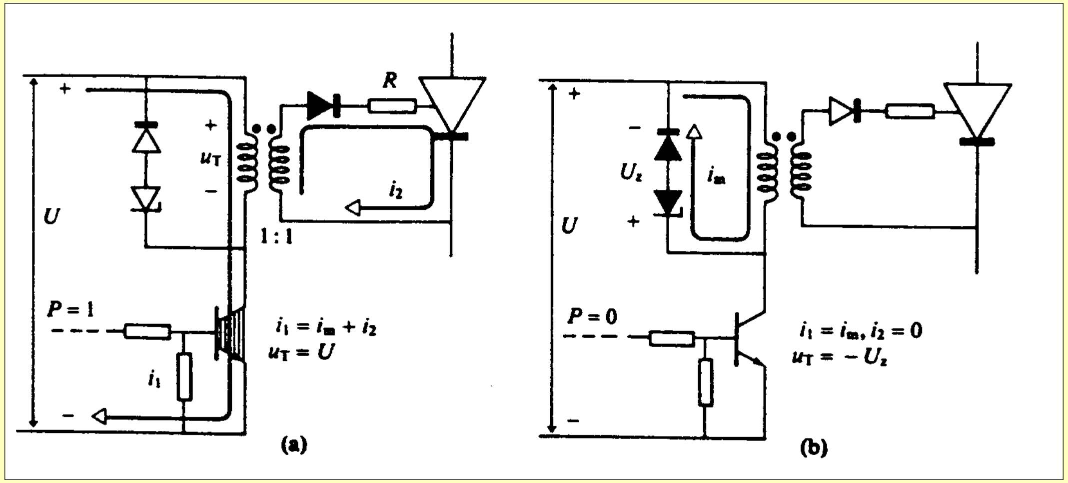
Galvanic isolation

1. Pulse-transformer ⇒ Turn-on energy is also supplied
2. Optocoupler ⇒ Energy for turn-on is not supplied. Extra supplies is required. Fast
3. Light ⇒ Energy for turn-on is not supplied. Extra supplies is required. Fast and very noise immune.

Today is light-conductor and Thyristor integrated.

4. Drive circuits

Simple drive-circuit with transformer



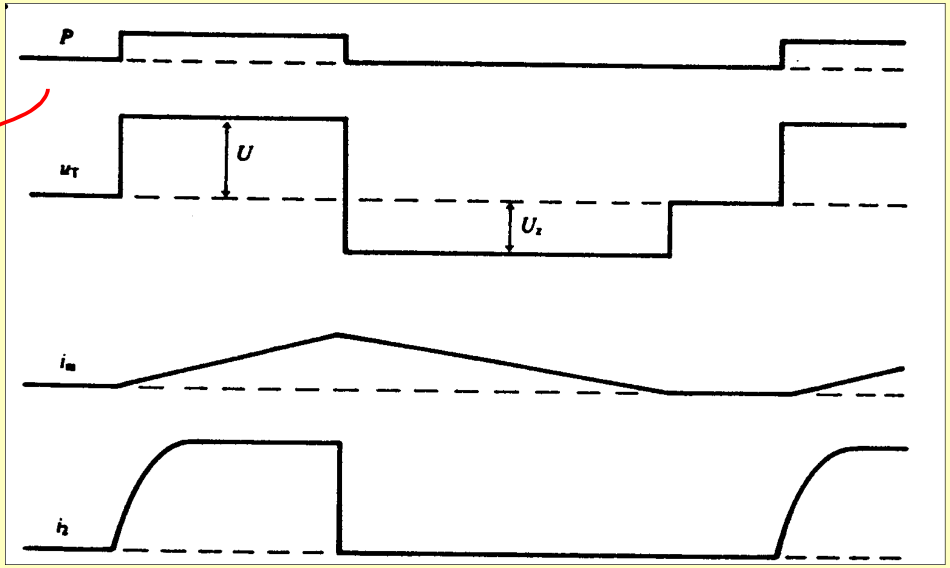
1 pulse

- Large main field inductance.
- Large amount of fringing.

Many pulses

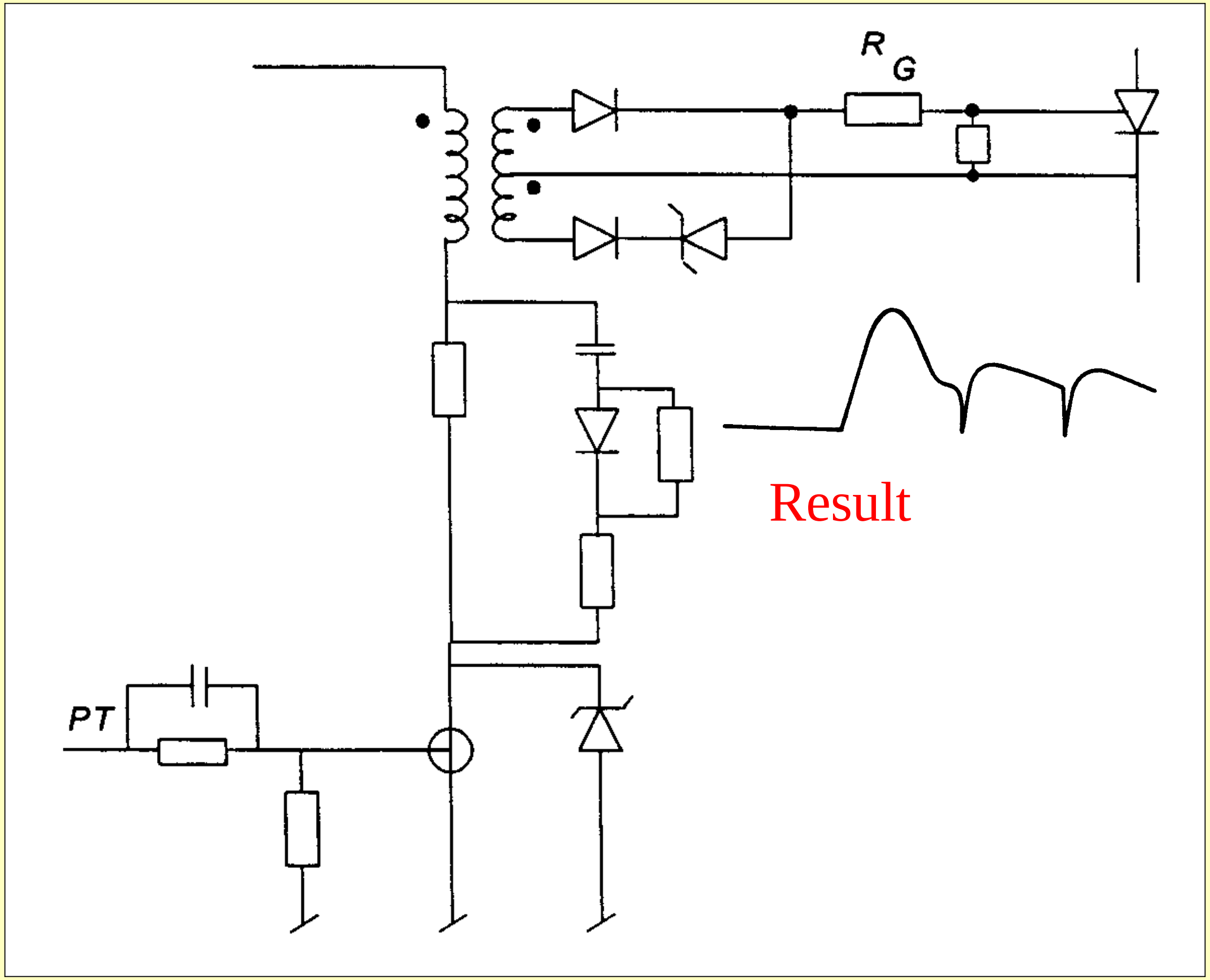
- low main field inductance.
- Low amount of fringing.

Waveforms



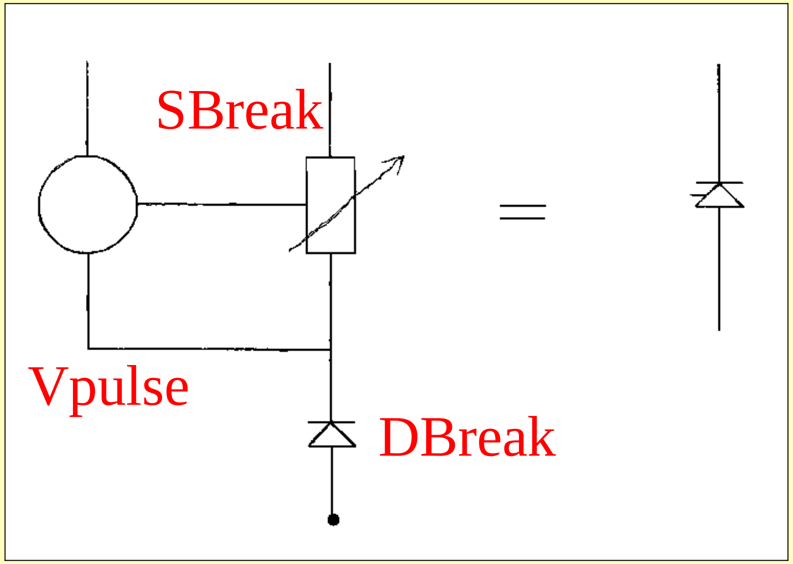
4. Drive circuits

Improved drive circuit



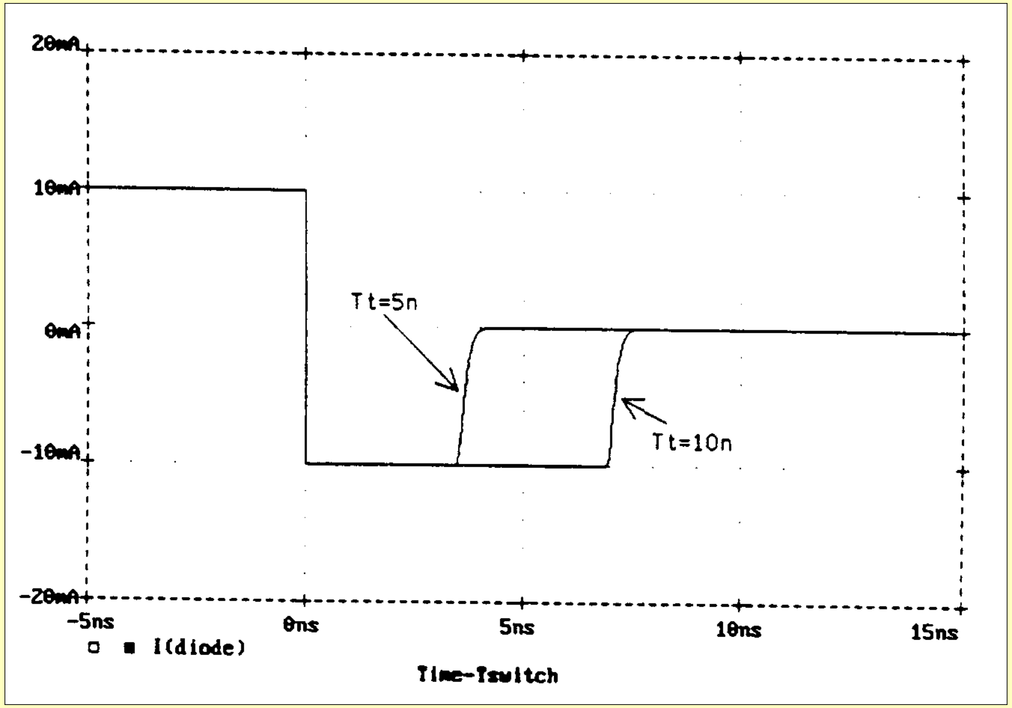
5. Modeling reverse recovery

Simple Thyristor model



The Diode has a reverse recovery model

Simulation result :



Important

Transit time TT : Time for the carriers to leave the diffusion layer
Capacitance C_{jo} : Capacitance in the diode under blocking state.

5. Modeling reverse recovery

Charges before turn-off

$$Q_F = \tau\, I_F$$

τ the charges life-time

Charges after turn-off

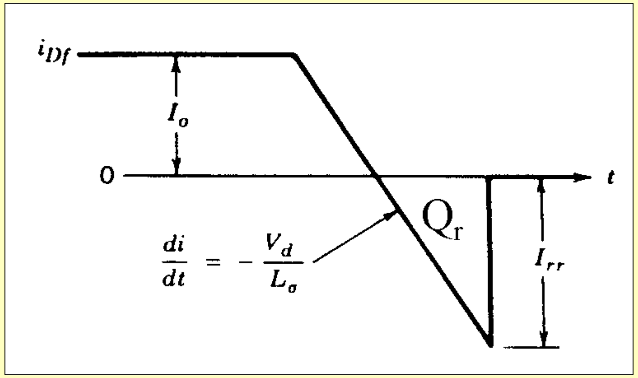
$$Q_R = \frac{1}{2} t_{rr}^2 \left.\frac{di}{dt}\right|_{off}$$

No recombination

$$t_{rr} = \sqrt{\frac{2\tau I_F}{\frac{di}{dt}}}$$

Or

$$I_{RR} = \sqrt{2\tau I_F \frac{di}{dt}}$$



τ can be estimated from data-sheets and be used as TT in the diode model.
Limits

- No “SOFT” turn-off. But OK because snubbers often is designed in worse case.
- Capacitor is not OK for a high-voltage diode.

7. Exercises

Look at Course home-page