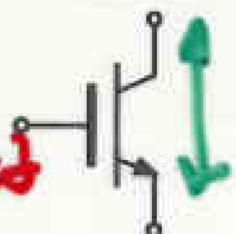
Figs 4.38 4.39 Pg 287

The IGBT

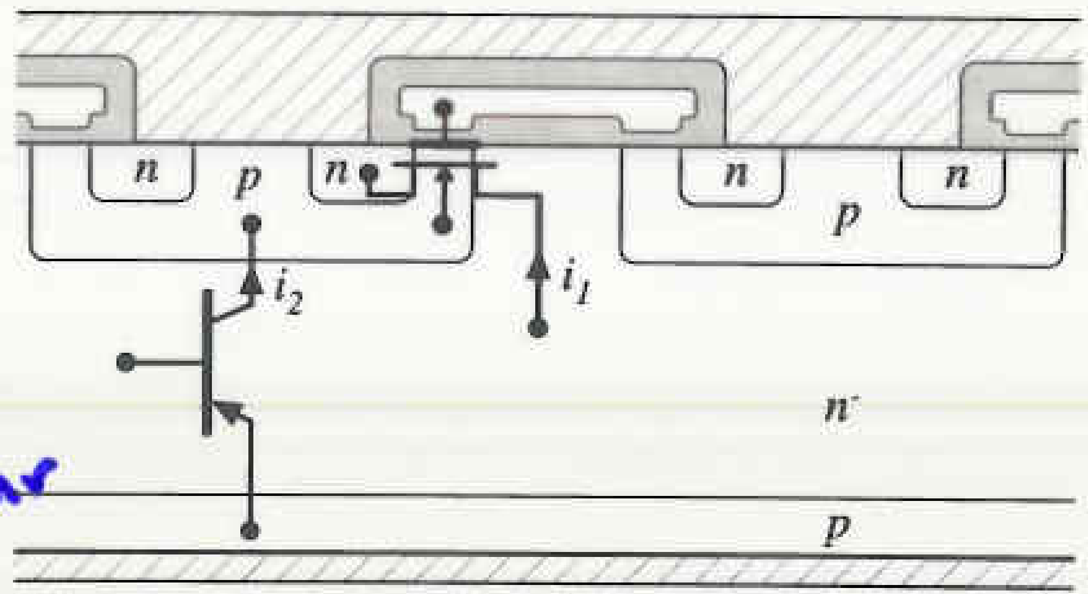
1700V – 2600V } Now in place is 6000V IGBT for "Power system SVC"

Symbol

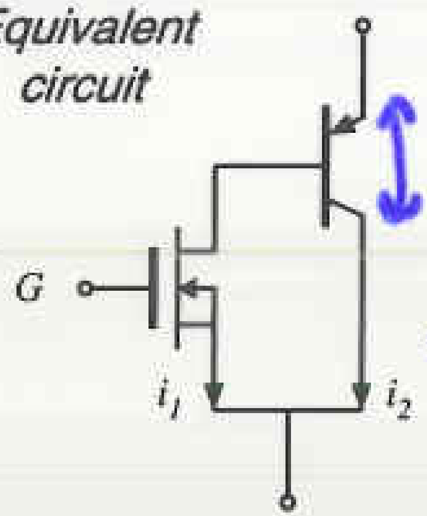


. NO S.S. i_{ON} needed to keep sw ON

Location of equivalent devices



Equivalent circuit



low V_{ON} of bipolar

Conclusions: IGBT

Wide use

- Becoming the device of choice in 500-1700V applications, at power levels of 1-1000kW
  } in Motors ⇒ low cost sw
- Positive temperature coefficient at high current —easy to parallel and construct modules
- Forward voltage drop: diode in series with on-resistance. 2-4V typical — V_{ON}
- Easy to drive —similar to MOSFET
- Slower than MOSFET, but faster than Darlington, GTO, SCR
- Typical switching frequencies: 3-30kHz
- IGBT technology is rapidly advancing —next generation: 2500V — ? 10KV 12KV o power system

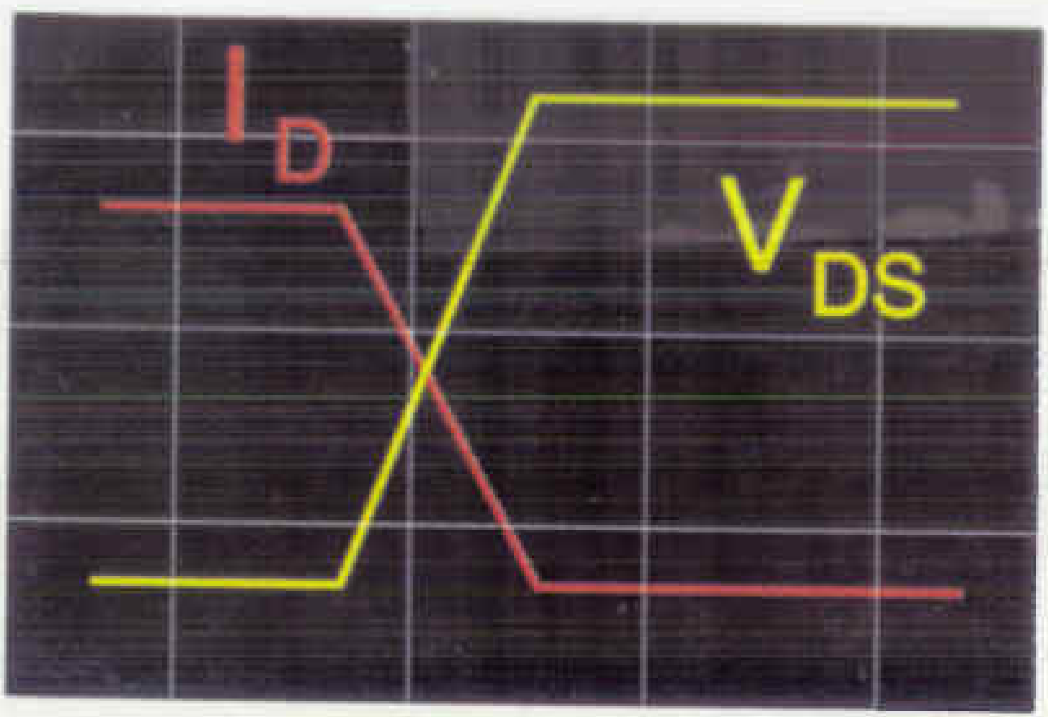
! 6000 !

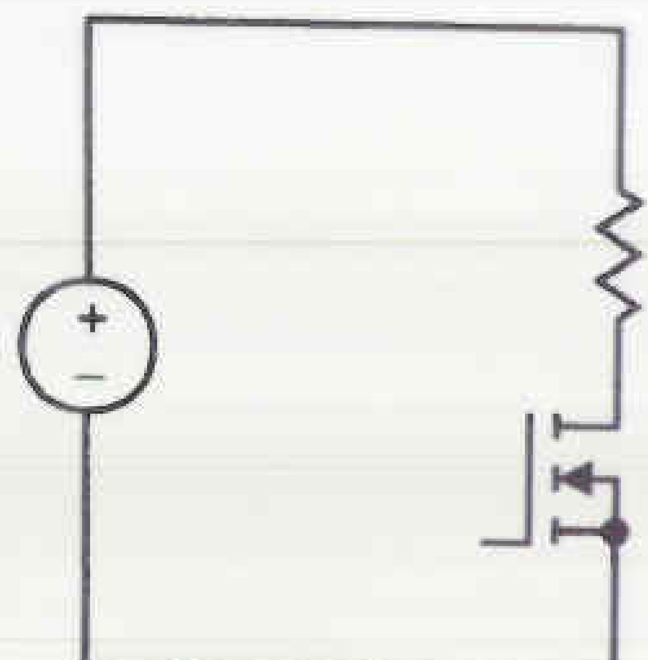
ON to off Transition R load

$$\left[\frac{1}{6} V_{off} I_{ON}\right] = P_{loss}$$

$$P_{loss} * \Delta t = W_{loss}$$

Fig 3a: Ideal Voltage and Current Waveforms with Resistive Loading } other





Ringing

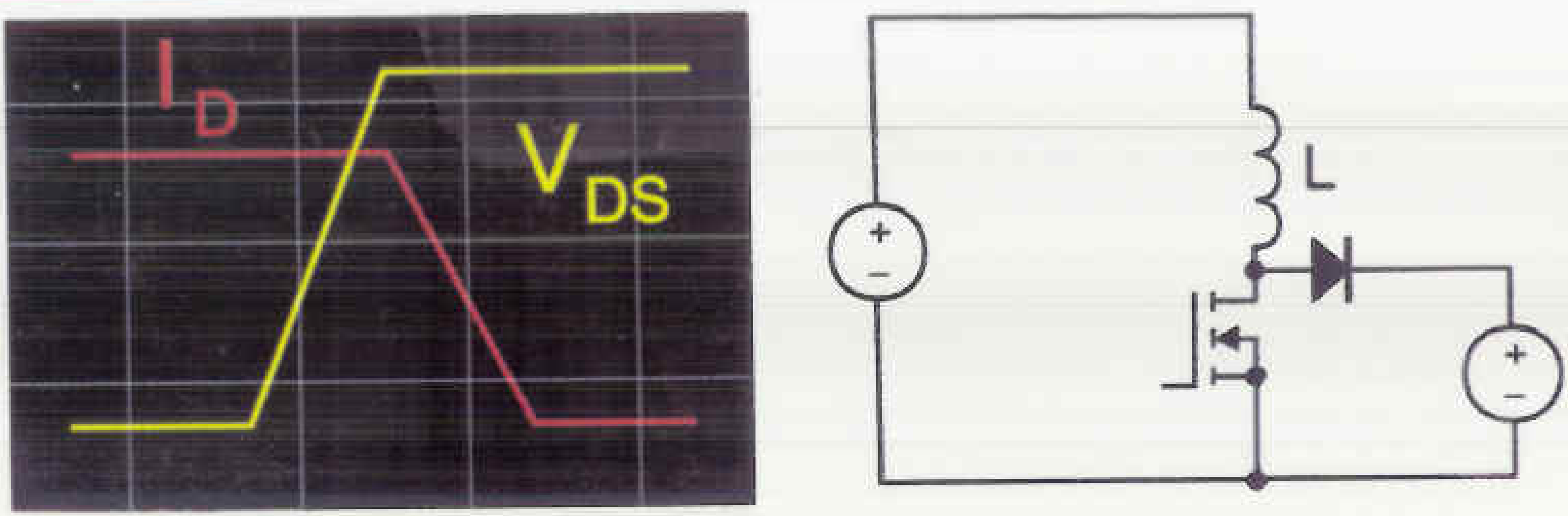
ON to off transition "L" load

$$P_{loss} = \frac{1}{2} V_{off} I_{ON}$$

$$W_{loss} = P_{loss} * \Delta t$$

Blithley assumes I_L hangs till $V_{DS} \rightarrow$ Max

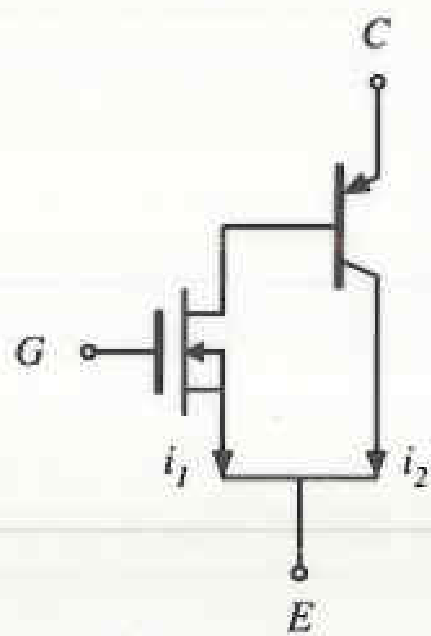
Fig 3b: Ideal Voltage and Current Waveforms with Inductive Loading



Worst Featur Pbm 4.7

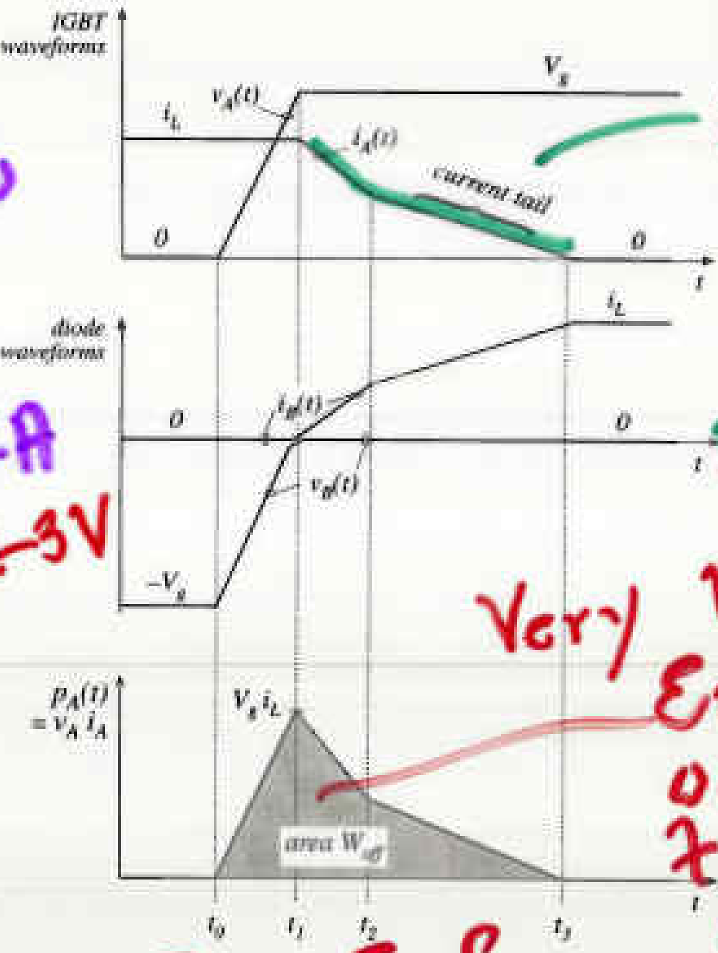
Current tailing in IGBTs

The new kid has a tail – a long one



Wow I_{ON} of 1–2 KA

V_{ON} : 2–3V



sw loss $I_{ON} V_{off} \Delta t$

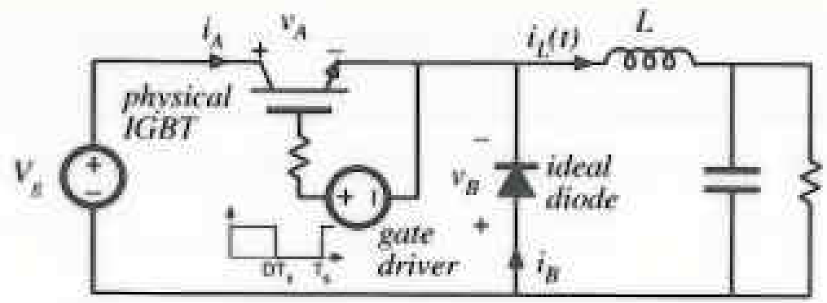
too long

high loss

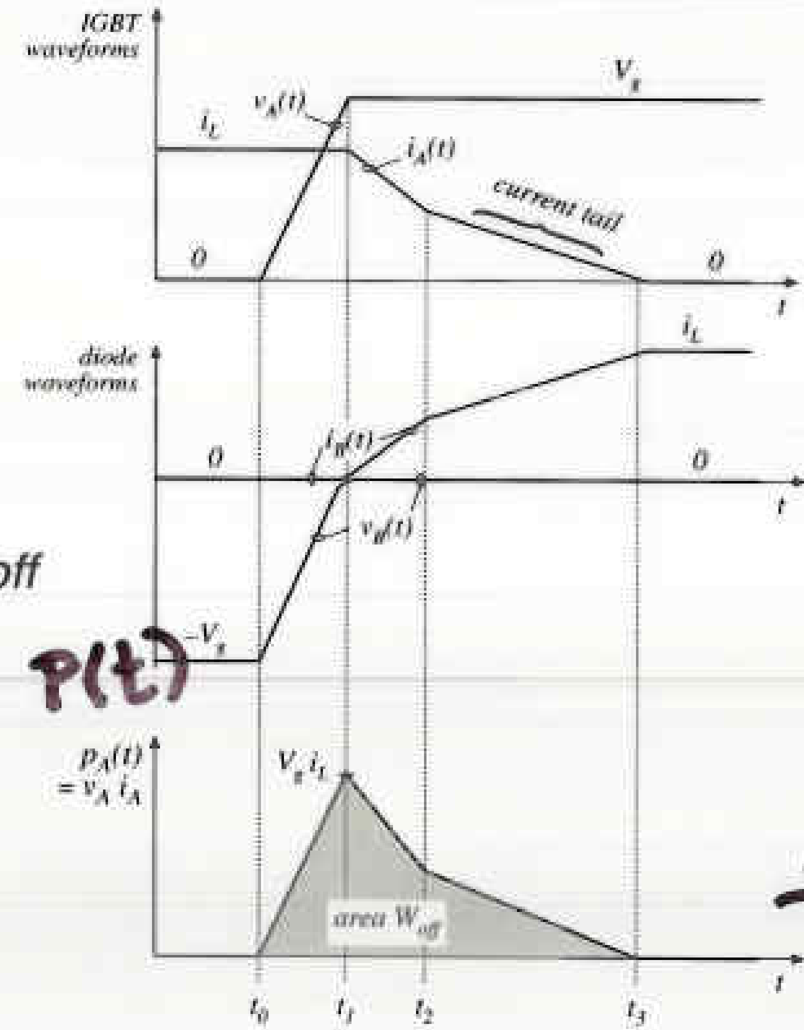
Very High Energy per on-off transition due to long t_{off}

$P = E_{on/off} f_{sw}$

Switching loss due to current-tailing in IGBT



Example: buck converter with IGBT



transistor turn-off transition

P(t)

t

f_{sw}

each sw cycle

$$P_{sw} = \frac{1}{T_s} \int_{\substack{\text{switching}\\ \text{transitions}}} p_A(t)\, dt = (W_{on} + W_{off})\, f_s$$

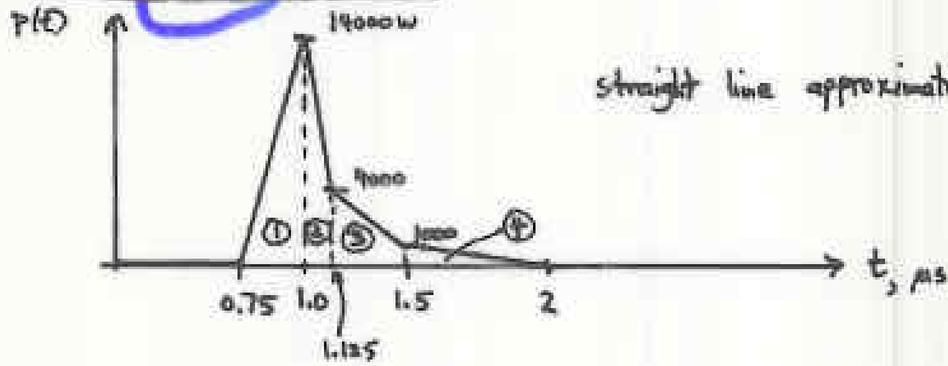
Modern scope → $\mathcal{E}_{total}$ for transition

Problem 4.7

Multiply $v_{CE}(t)\, i_c(t) = p(t)$

Estimate energy under $p(t)$ waveform by graphical integration

IGBT turn-on transition



straight line approximation

Sum areas ① - ④:

① $\frac{1}{2}(14000)(0.25\cdot10^{-6}) =$ 1.75 mJ

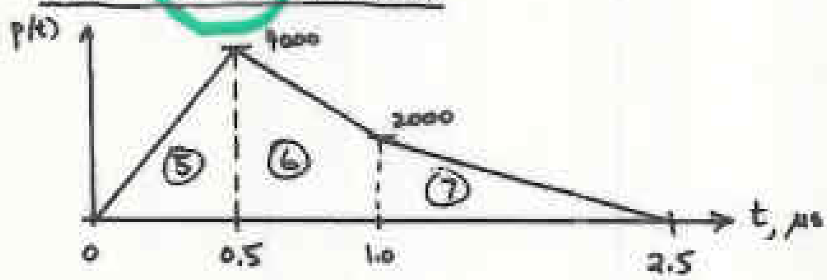
② $\frac{1}{2}(14000+4000)(0.125\cdot10^{-6}) =$ 1.125 mJ

③ $\frac{1}{2}(4000+1000)(0.375\cdot10^{-6}) =$ 0.9375 mJ

④ $\frac{1}{2}(1000)(0.5\cdot10^{-6}) =$ 0.25 mJ

total 4.1 mJ $= E_{on}$

IGBT turn-off transition



⑤ $\frac{1}{2}(4000)(0.5\mu s) =$ 1.0 mJ

⑥ $\frac{1}{2}(4000+2000)(0.5\mu) =$ 1.5 mJ

⑦ $\frac{1}{2}(2000)(1.5\mu) =$ 1.5 mJ

total 4.0 mJ $= E_{off}$

each cycle at f_{sw}

Total $E_{on} + E_{off}$

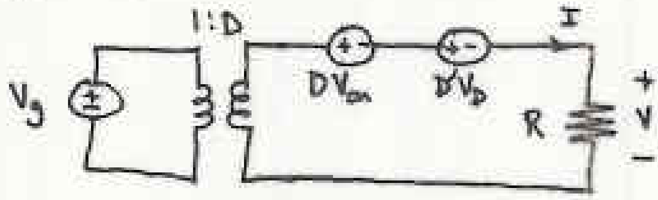
$E_{sw} = 8.1$ mJ

(any estimate near this value is OK)

Diode: DC losses Buck are f(D)

b) IGBT

Buck converter model: conduction loss



$V_g = 400\,V$
$V = 200\,V$
$I = 10\,A$
$R = 20\,\Omega$
$V_{on} = 2.5\,V$
$V_D = 1.5\,V$

$$V = DV_g - DV_{on} - D'V_D$$

$$\Rightarrow V + V_D = D\left(V_g - V_{on} + V_D\right)$$

so $$D = \frac{V+V_D}{V_g - V_{on} + V_D} = 0.505$$

Element	power loss
IGBT	$IDV_{on} = 12.6\,W$
diode	$ID'V_D = 7.4\,W$
total	$20\,W = P_{cond}$

DC loss both switches

c) Converter efficiency $= \dfrac{P_{OUT}}{P_{in}}$ with $P_{OUT} = (200V)(10A) = 2kW$

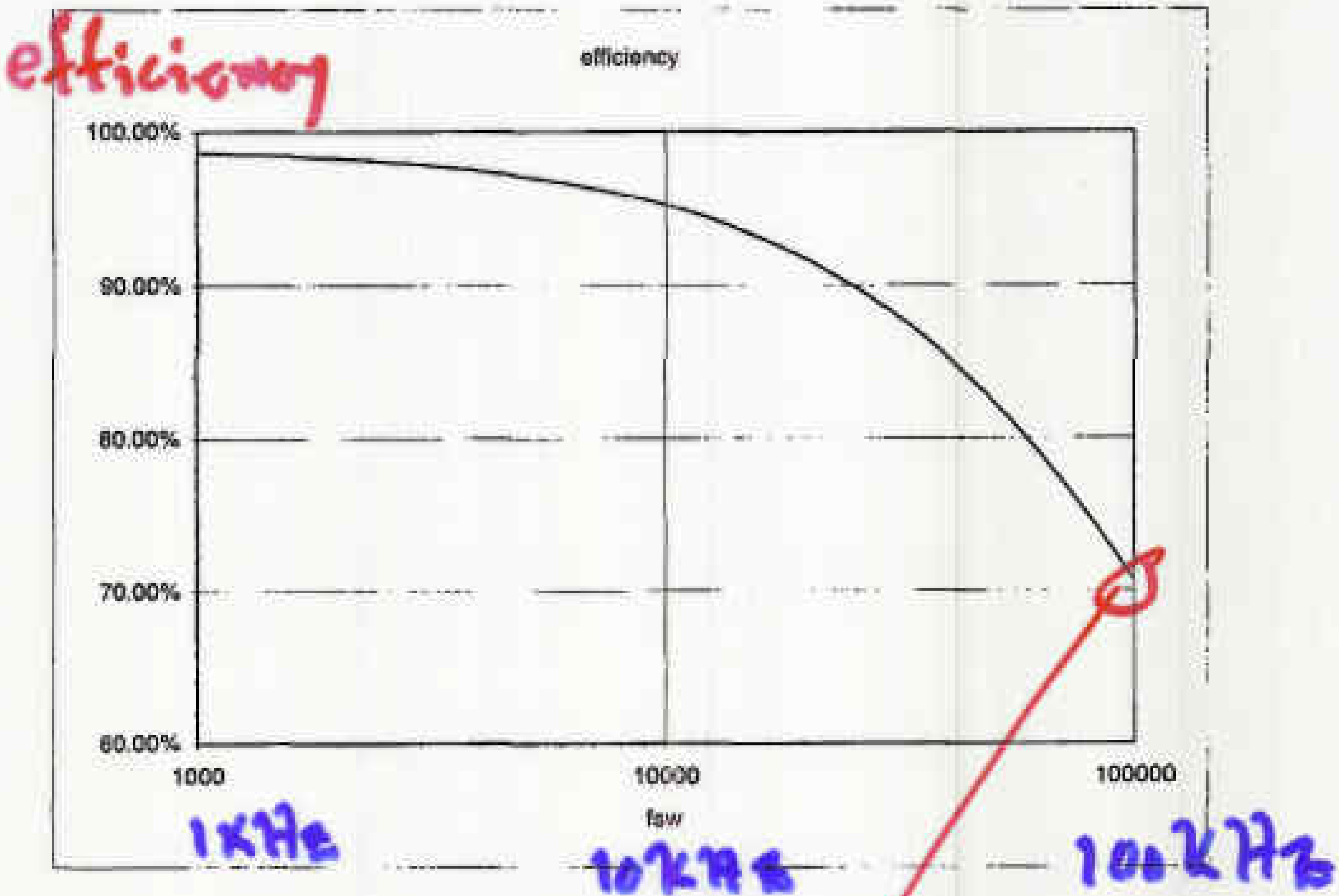
$$P_{in} = P_{OUT} + P_{loss} = P_{OUT} + P_{cond} + E_{sw} f_{sw}$$

so $$\eta = \frac{P_{OUT}}{P_{OUT} + P_{cond} + E_{sw} f_{sw}} = \frac{2000}{2000 + 20 + (8.1 \cdot 10^{-3}) f_{sw}}$$

Plot on next page

From Eq. (4.23): $f_{crit} = \dfrac{20W}{8.1mJ} = 2.5\,kHz$

Problem 4.7, part (c)
Efficiency vs. switching frequency



30% heat loss

Pbm 4.7

Current tailing in IGBTs

Causes E_{sw} (off – on)