Technische Hochschule Nürnberg

LLC Circuit for High-Voltage Generation

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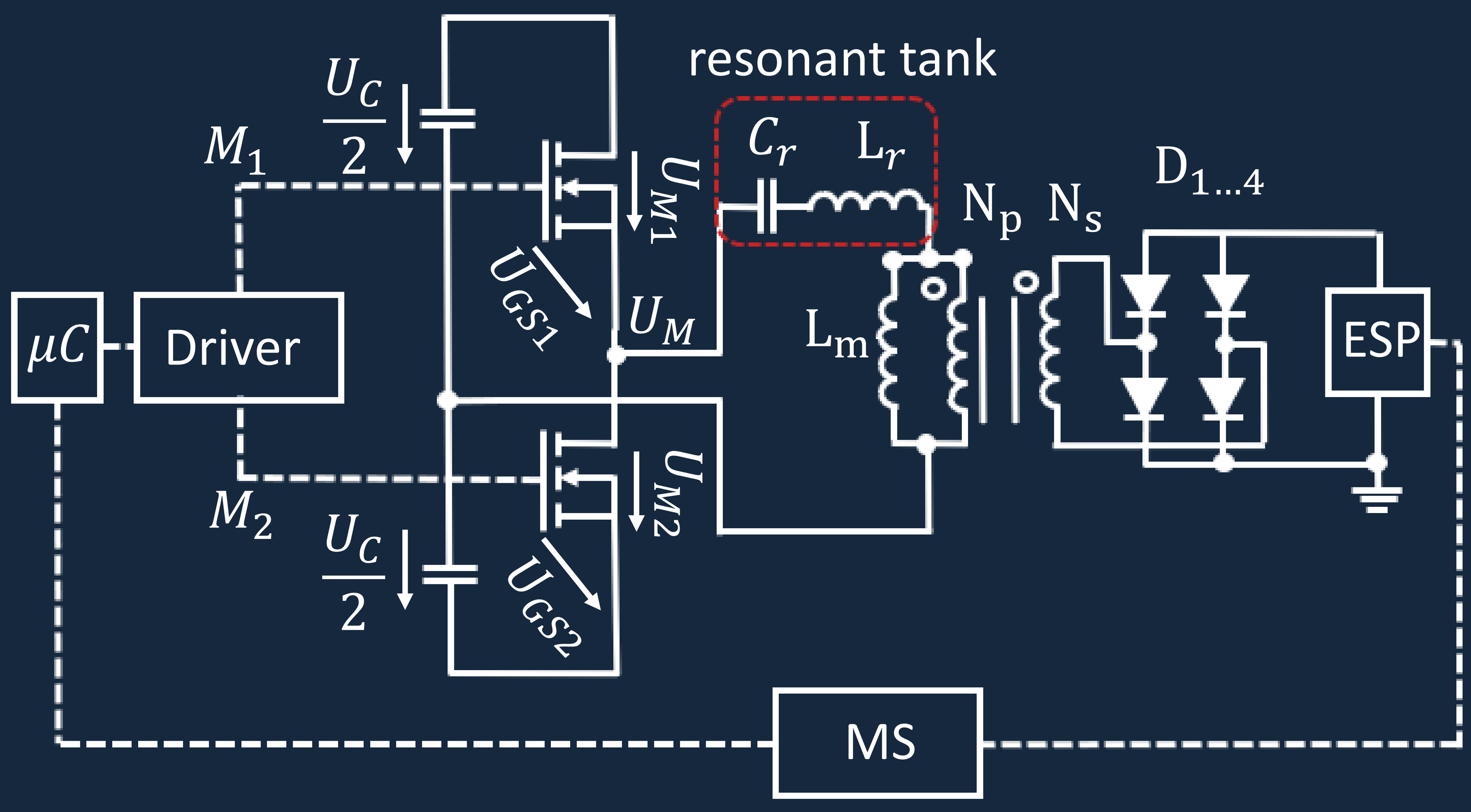

Fig. 1. Own illustration of the LLC circuit topology, based on [1]

- ESP (= electrostatic precipitator) requires negative high voltage ($-35\ kV < U_{out} < -25\ kV$)
- ESP filters combustion gases from an oven
- Half-bridge drives the LLC-Circuit
- Rectangular voltage excites the LLC tank
- First harmonic of the rectuangular voltage controls the input voltage of the primary winding
- High-frequency harmonics are filtered out by the lowpass-characteristic of the LC-Circuit above the resonant frequency
- Software implementation on a low-cost 8-bit microcontroller (PIC18-F57Q84)

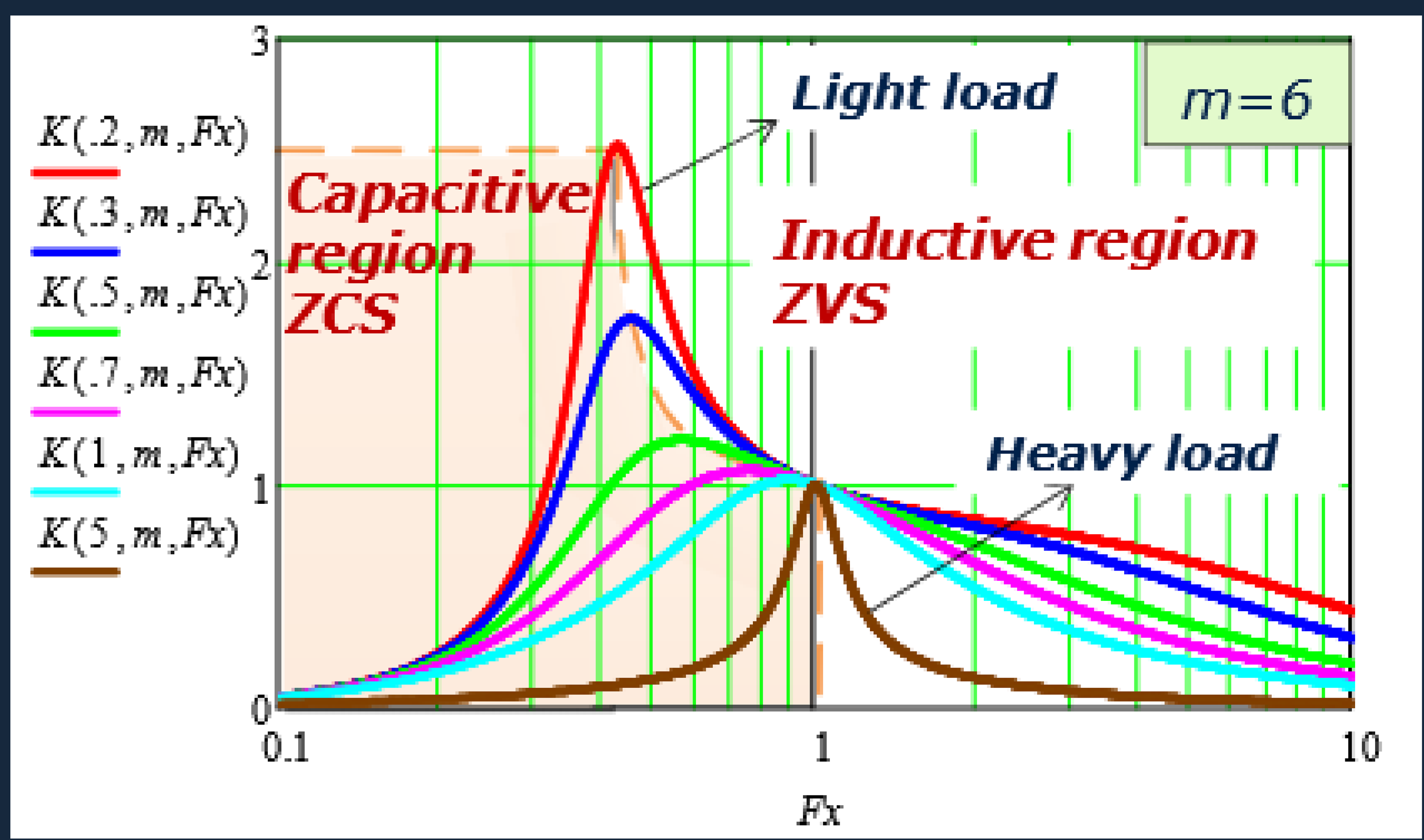

Fig. 2. [1] infineon, "magnitude response LLC-Circuit ", www.infineon.com, 16.01.2025

Control and regulation strategy

1. Resonant Tank

- Resonant frequency $f_r = \frac{1}{2\pi\cdot\sqrt{L_r\cdot C_r}} \approx 100\ k\mathrm{Hz}$
- $F_{x,normalised} = \frac{f_{first\ harmonic}}{f_r}$
- $m = \frac{L_R+L_m}{L_m}$ $Q = \frac{\sqrt{L_R/C_R}}{R_{LOAD}}$
- $K(Q, m, F_{x,normalised}) = \frac{|U_{out}|}{|U_{in}|}$
- Capacitive region ≙ current leads voltage ⟶ switch-off losses ↑
- Inductive region ≙ voltage leads current ⟶ switch-off losses ↓

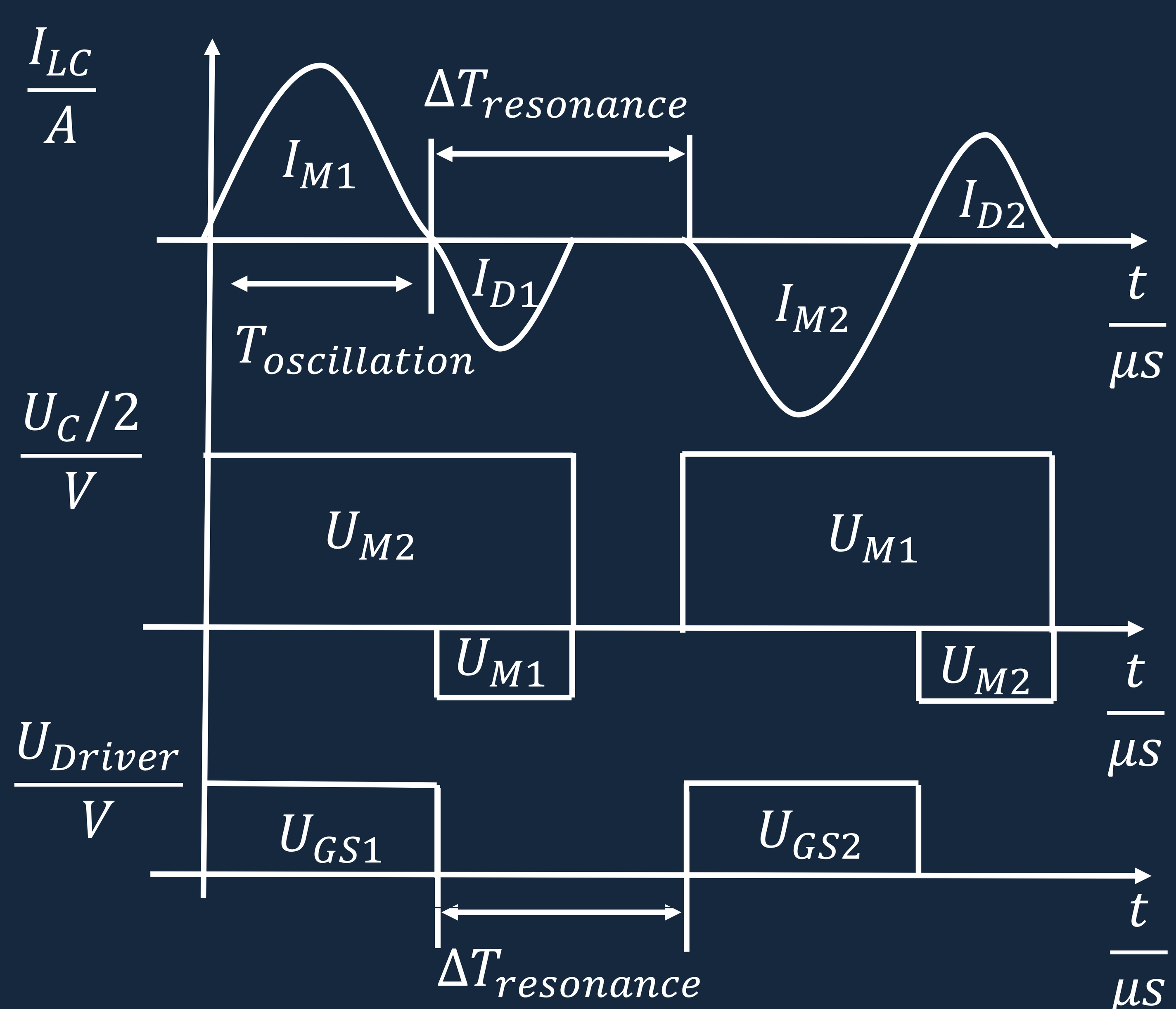

Fig. 3. Switching and output waveforms of the LLC converter (own illustration)

2. MOSFET switching strategy

- Transistor M_1 conducts the positive half-wave of the current
- After approximately $T_{oscillation} \approx \frac{1}{2}\cdot\frac{1}{f_r}$, the current reaches zero – inductance of the resonant tank causes overvoltage ($U_C < U_M$), the body diode M_{D1} conducts the negativ half-wave
- While M_{D1} conducting the current, M_1 can be turned off without of switching losses
- Transistor M_2 is controlled identically to M_1
- The input voltage of the primary winding controlled by the time interval between the conduction phases of M_1 and M_2
- As $\Delta T_{resonance}$ decreases, the LC-Circuit approaches resonance more closly

3. Measurement System (=MS)

- I_{ESP} is the rectified resonant tank current, transformed by the transformer
- If operating point is near the resonance – the current frequency is about $f_r = 100\ k\mathrm{Hz}$
- High switching frequency prevents direct current sampling
  -> a differential amplifier with low-pass filtering yields the average ESP current
- To detect electric arcs in the ESP, the operating voltage is measured via an amplifier
- The measured analog signals will be digitalized and transfered by an optocoupler to the μC

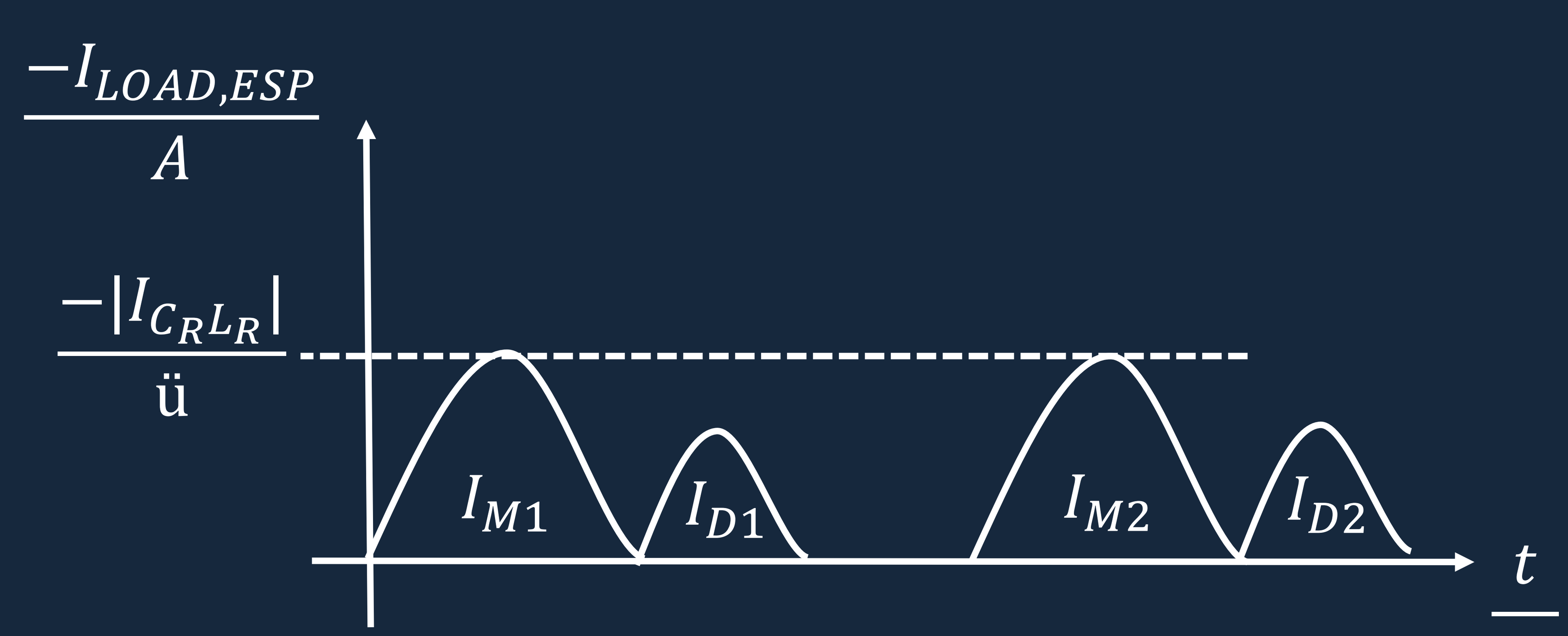

Fig. 4. output waveforms of the rectifier (own illustration)

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