DC Link Capacitor and Wireless Power Transfer
A Perfect Couple?!

APEC 2020 in New Orleans
Capacitor Workshop PSMA

Frank Puhane
Leader Technical Engineering
eiCap / eiRis Capacitors & Resistors Division

Introduction of the Presenter

Frank Puhane

Leader Technical Engineering

eiCap / eiRis – Capacitors & Resistors Divison

Background:

- More than 10 years of work experience in electronics industry
- Background in Electronics, Power Supply Development and formerly worked as Field Application Engineer
- In charge for technical engineering, product services and application support of capacitor division at Würth Elektronik

+49 7942945 4033

frank.puhane@we-online.com

www.we-online.com

PSMA

Agenda

- **Why and What is a DC Link Capacitor?**
- **Differences to other Technologies**
- **Example of Capacitance Calculation**
- **11kW Wireless Power Transfer System**
- **Further Possibilities**

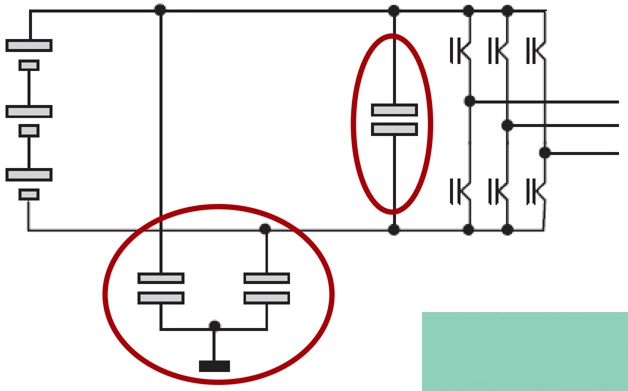
Why and What is a DC Link Capacitor?

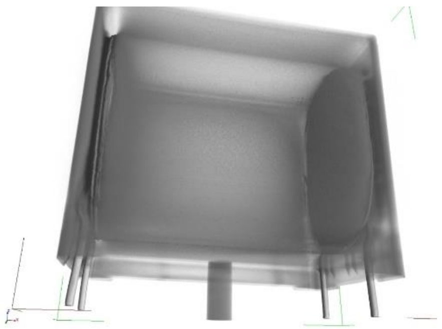
- **Essential stage in power conversion**

- **Applications like:**
  - Three-phase inverters
  - Photovoltaic and wind power inverters
  - Industrial motor drives
  - Automotive onboard chargers and inverters
  - Medical equipment power supplies

- **They stabilize the DC Link voltage**

- **Withstand high RMS currents**
  - Design DC Link capacitor on RMS current value

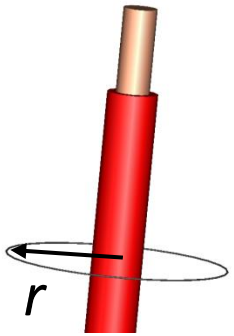




Picture: Freepik.com

Why and What is a DC Link Capacitor?

- **DC Link capacitors are used to absorb voltage peaks**
- **These peaks are generated due to the inductance of the input wire**



$$H = \frac{I}{2 \cdot \pi \cdot r}$$

- **The inductance of a wire can be calculated with the following formula**

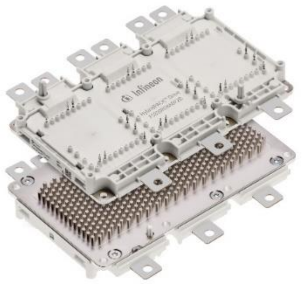
$$L = \left[\frac{\mu_0 \; * \; \mu_{Copper}}{8 \; * \; \pi}\right] * \; I$$

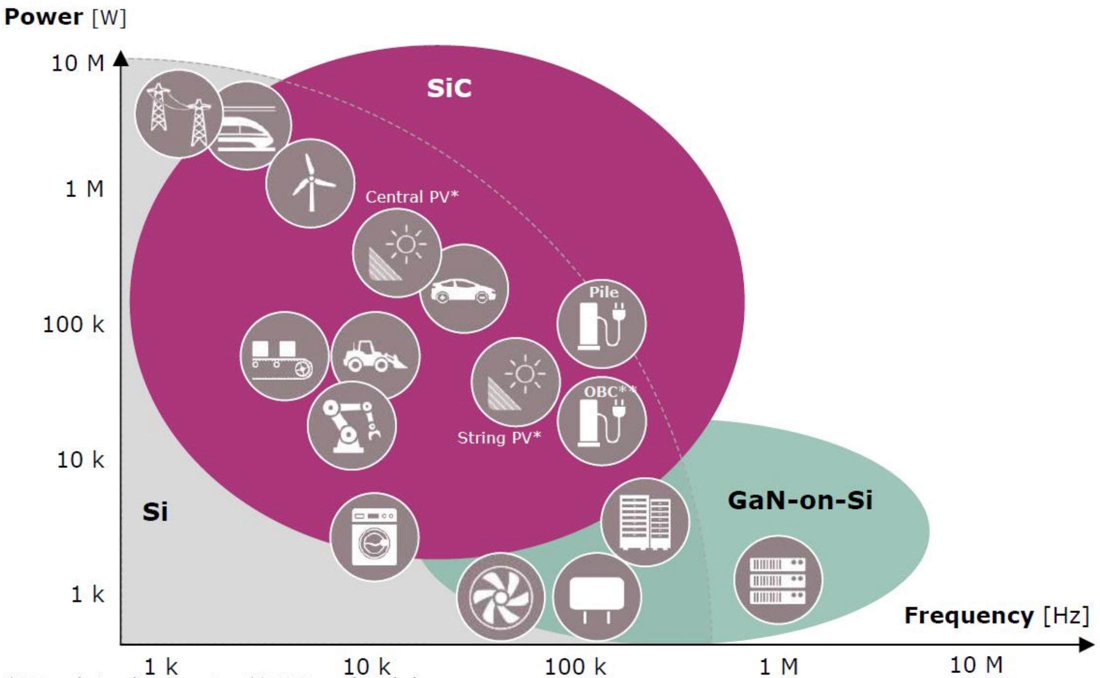
- **So for a 1m wire the inductance will be 50nH.**
- **Depending on the calculated inductance of the wire, there will be limitation of the recommended length of the wire in the system**
- **DC-Link capacitor < 1 nH per mm of lead spacing**

DC Link Capacitor and SiC Modules

- **SiC technology has some key points:**
  - Very high switching voltages
  - High switching frequency possible
  - Low losses in the semiconductor
  - 15kV/µsec are typical values for silicon carbide

- **There are different vendor for silicon carbide**
  - Cree, Infineon, Rohm and so on



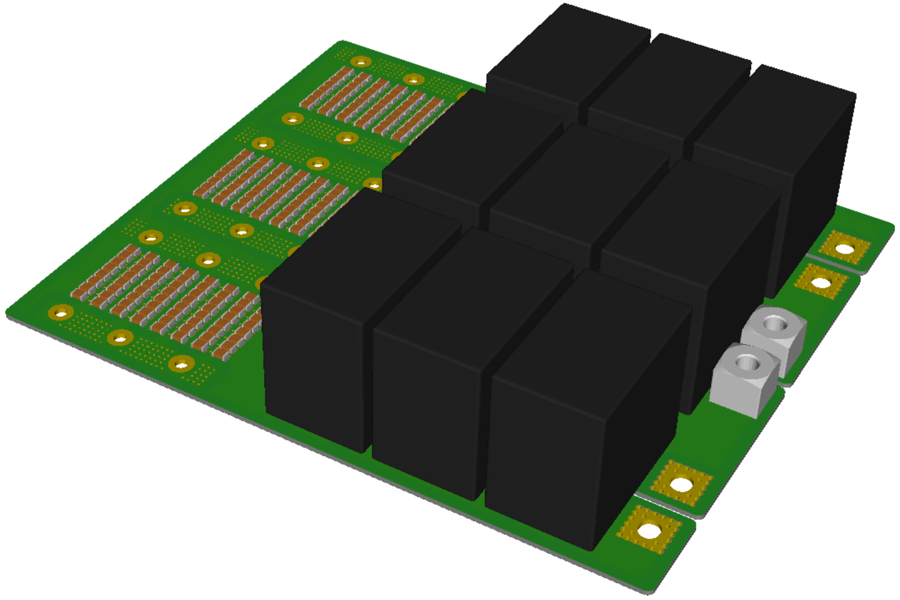


Picture: Infineon

DC Link Capacitor and SiC Modules

- **SiC technology has some key points:**
  - Very high switching voltages
  - High switching frequency possible
  - Low losses in the semiconductor
  - 15kV/µsec are typical values for silicon carbide

- **There are different vendors for silicon carbide**
  - Cree, Infineon, Rohm and so on



Film vs. Aluminum DC Link Technology

Film DC Link Capacitor

- **High RMS current capabilities**
  - Up to 1 A_{RMS} per µF
- **Over voltage withstanding**
  - Up to 2 times the rated voltage
- **Handle voltage reversal**
- **No acid inside**
- **Long lifetime / no storage problem**
- **Good temperature cooling system possible**
- **Self-healing properties**

Aluminum Electrolytic DC Link Capacitor

- **High capacitance values**
  - Going up to 4700 µF
- **RMS current capabilities**
  - Depends on the part 1 mA…20 mA or higher
- **Rated voltages up to 650 V**
  - R&D is ongoing
  - Cascade assembly to reach the desired voltage level

Picture: Freepik.com

Film vs. Aluminum DC Link Technology

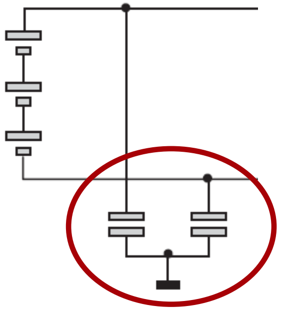
Property	Film Capacitor	Aluminum Electrolytic Capacitor
Capacitance	low	high
Voltage	up to 1,300 V_{DC}	actually 650V_{DC}
Lifetime	approx. 100,000 hours	10,000 - 20,000 hours (probably longer with higher C - derating >20%)
ESR	low	high
Ripple Current Capabilities	High	Low (possibly increased with additional cooling)
Energy density	<0.2 J/cm^3	about 0.82 J/cm^3

- **The replacement microfarad for microfarad will not work**
- **Replacement won’t be possible for each application**

How to Calculate the Capacitance?

Bypass application

- Film Capacitor
- Working voltage: 240 V_{DC}
- Ripple voltage max: 5 V_{RMS}
- RMS current: 50 A_{RMS} @ 15 kHz
- Needed capacitance value:



- Aluminum Electrolytic capacitor
- RMS current capability 10 mA per µF
- Have to handle the 50 A_{rms}
- Needed capacitance value:

- $C = \frac{I_{rms}}{V_{ripple} \cdot 2 \cdot \pi \cdot f} = \frac{50A}{5V \cdot 2 \cdot \pi \cdot 15kHz} = 106\mu F$

- $C = \frac{I_{rms}}{Max\ I\ per\ \mu F} = \frac{50A}{0.01A} * 1\mu F = 5000\mu F$

How to Calculate the Capacitance?

Energy Storage

- **Supply frequency is lower than converter frequency**

- $$C = \frac{P_{load}}{V_{ripple} \cdot \left[V_{max} - \frac{V_{ripple}}{2}\right] \cdot F_{rectifier}}$$

- **I_{RMS} approximation depends on the power of load, V_{max} and V_{ripple}**

- $$I_{rms} = \frac{V_{ripple}}{2 \cdot \sqrt{2}} \cdot C \cdot 2 \cdot \pi \cdot F_{rectifier}$$

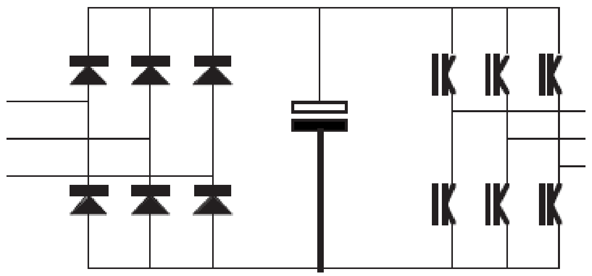
- $$I_{rms} = \frac{P_{load} \cdot \pi}{\left[V_{max} - \frac{V_{ripple}}{2}\right] \cdot \sqrt{2}}$$

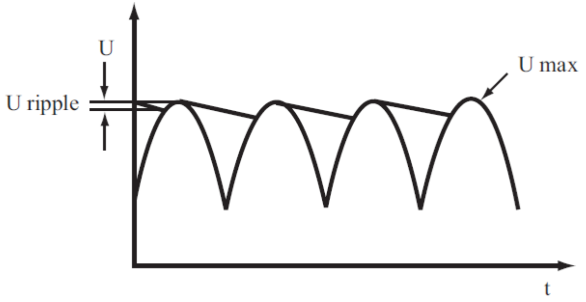
Example:

- **P_{load} = 10 kW**
- **V_{max} = 800 V**
- **V_{ripple} = 100 V**

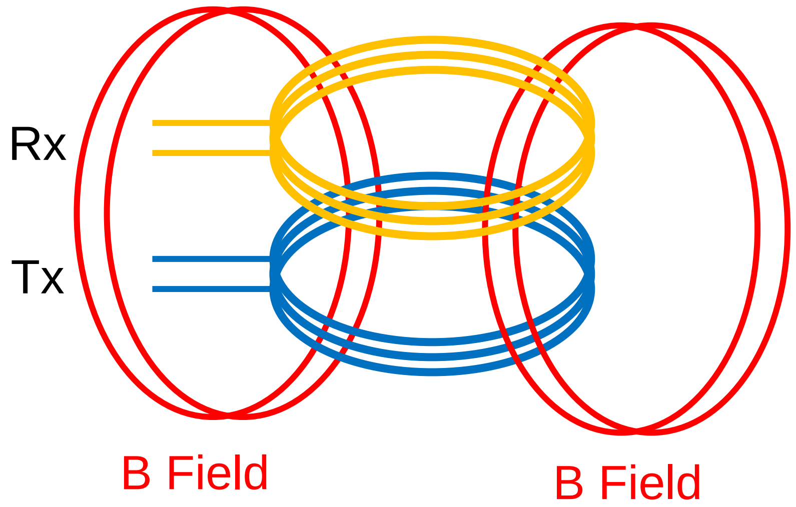
- **Film Technology**
  - **C = 444 µF**
  - **I_{rms} = 29.6 A**

- **Aluminum Technology**
  - **With 20 mA_{rms} per µF**
  - **C = 1480 µF**

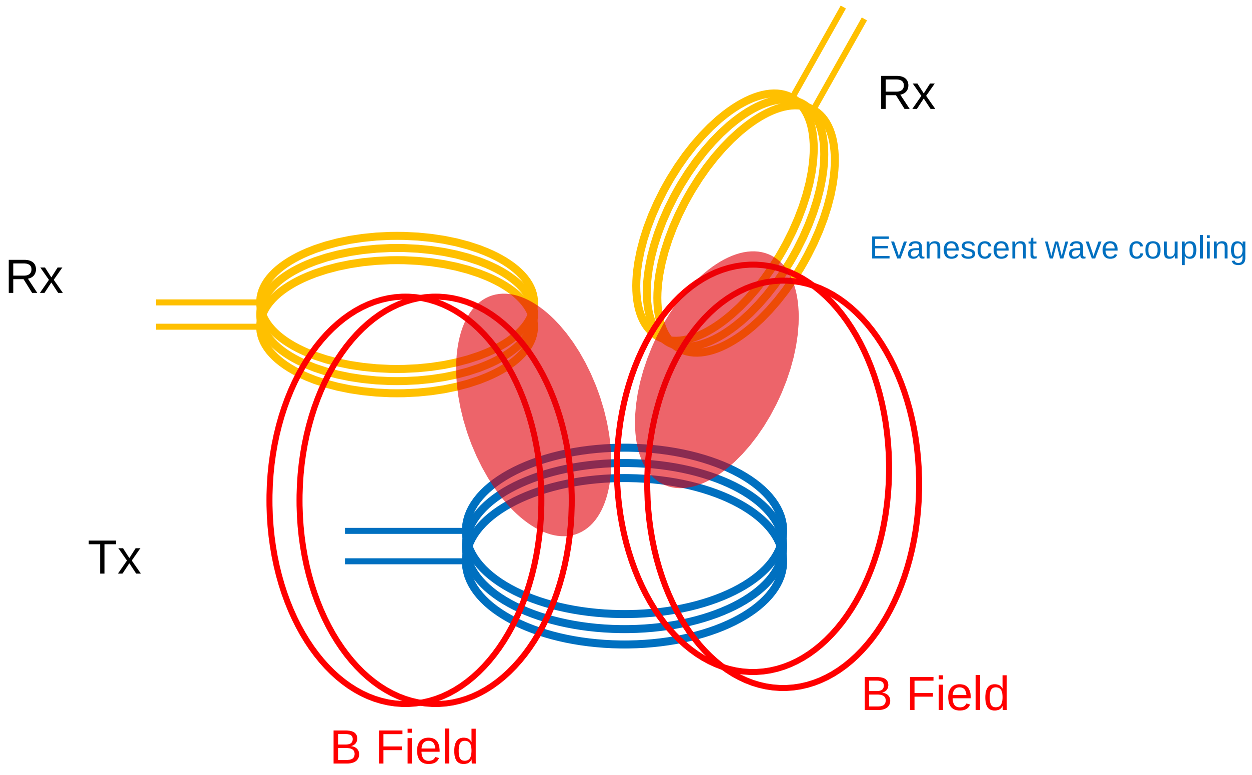




Wireless Power Transfer System



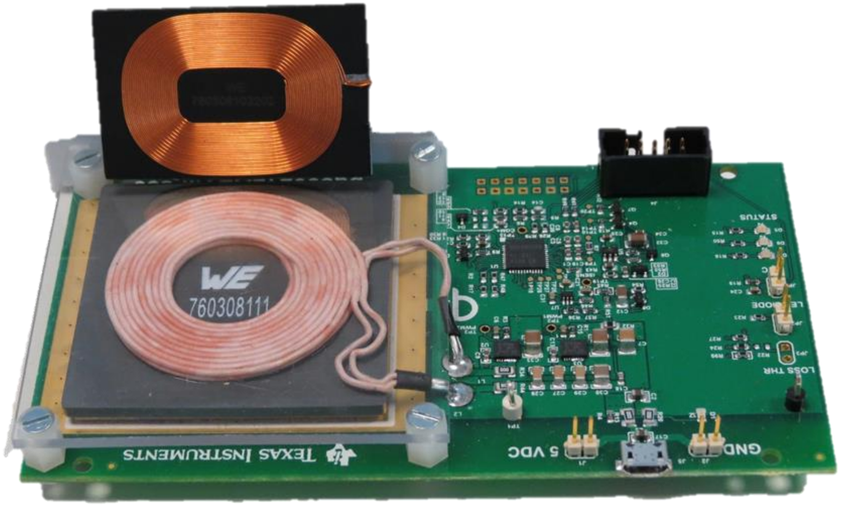
Inductive Power Transfer

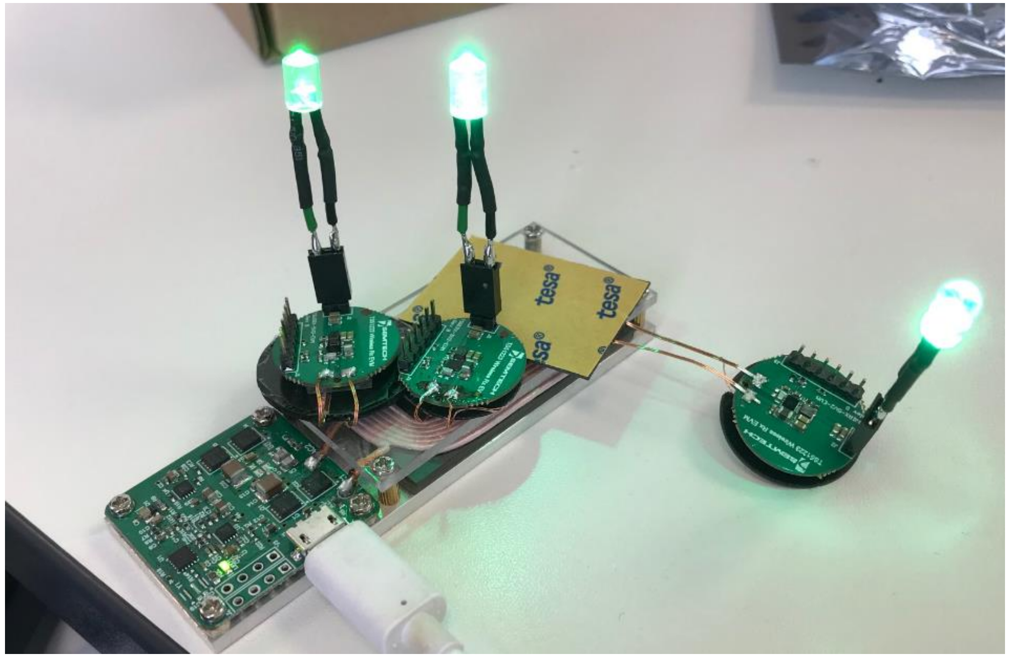


Resonant Power Transfer

Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som

Wireless Power Transfer System





Inductive Power Transfer

Resonant Power Transfer

Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som

11kW Wireless Power Transfer System

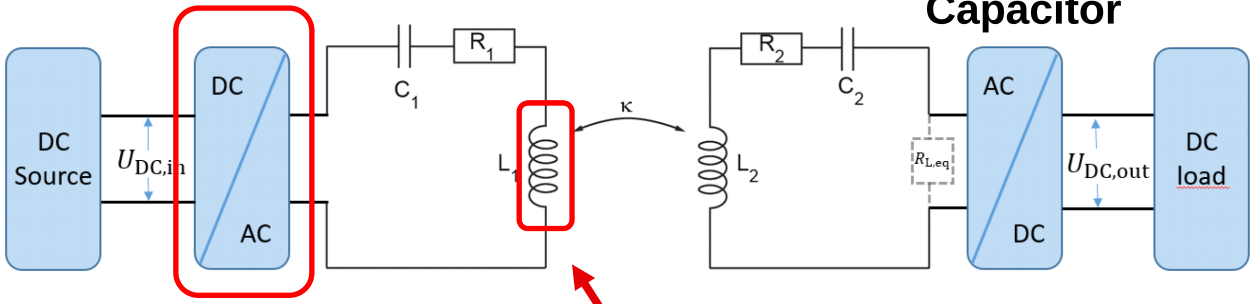
- **Specification of the system:**

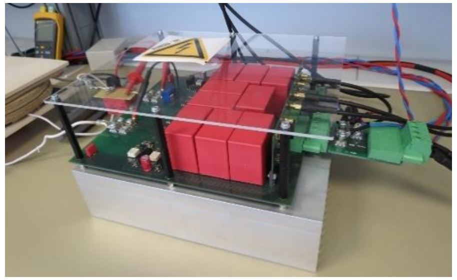
- $P_{out} = 11\ kW$
- $V_{DC} \approx 370\ V$
- $I_{RMS} \approx 30\ A$
- **V_{ripple} = 0.2 V**

- **DC to DC efficiency** $\approx 98\ \%$

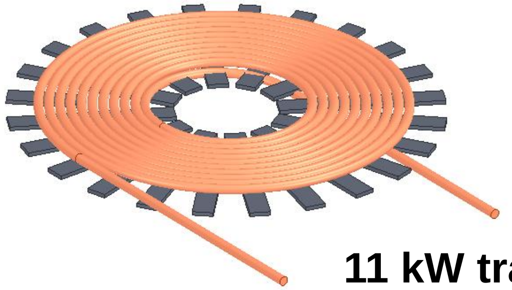
DC Link Capacitor

DC Link Capacitor





Inverter



11 kW transmitter coil

Source: Würth Elektronik eiSos Wireless Power Transfer Division, Christoph Utschick

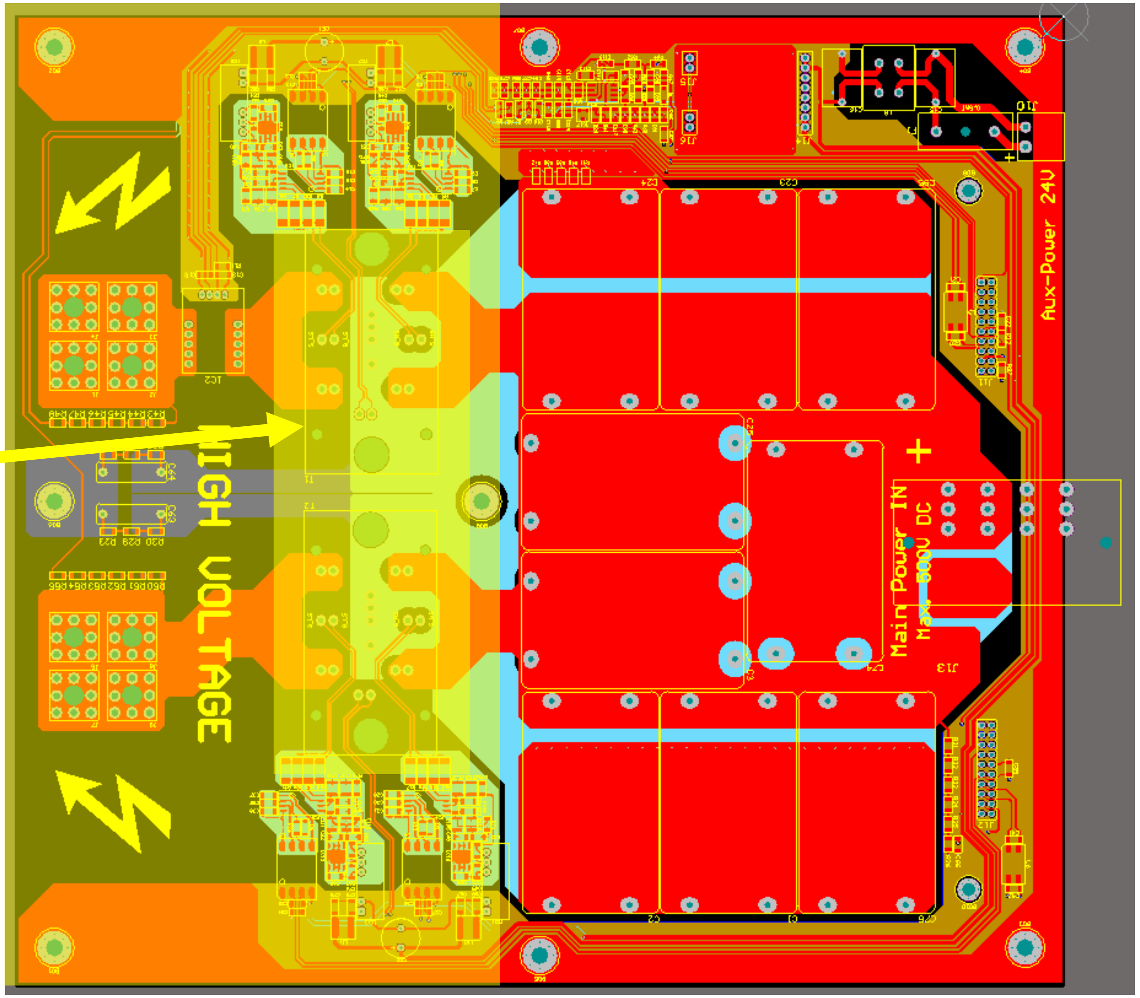
11kW Wireless Power Transfer System

Key points of the design:

- **Symmetrical construction**
- **High-Side / Low-Side Gate Control**

- **Two SiC Modules**
  - FF23MR12W1M1B11BOMA1
  - Dual CoolSiC^{TM} MOSFET
  - V_{DSS} = 1200 V
  - I_{D_nom} = 50 A
  - I_{D_pulse} = 100 A
  - f_{switch} = 100 kHz…200 kHz

Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som



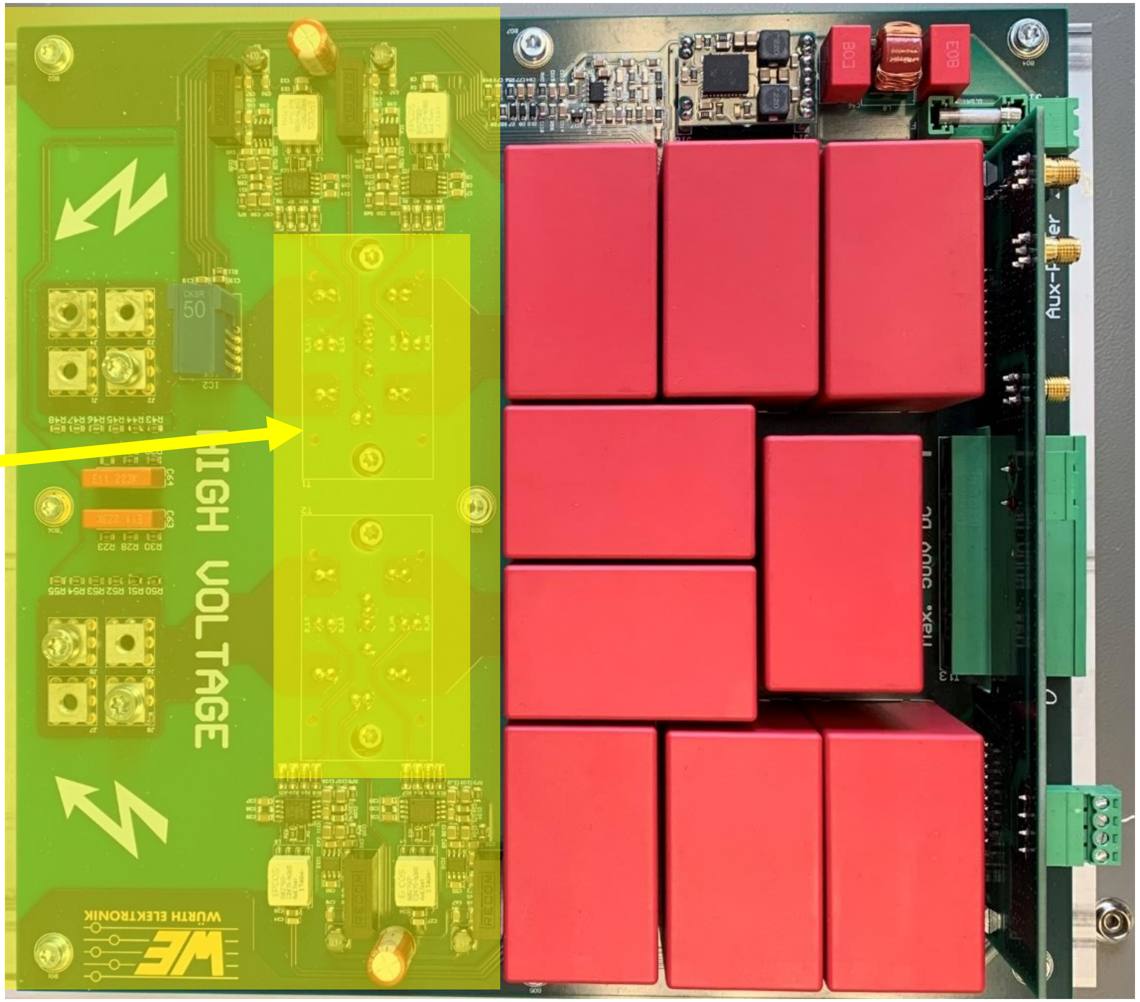
11kW Wireless Power Transfer System

Key points of the design:

- **Symmetrical construction**
- **High-Side / Low-Side Gate Control**

- **Two SiC Modules**
  - FF23MR12W1M1B11BOMA1
  - Dual CoolSiC™ MOSFET
  - V_{DSS} = 1200 V
  - I_{D_nom} = 50 A
  - I_{D_pulse} = 100 A
  - f_{switch} = 100 kHz…200 kHz

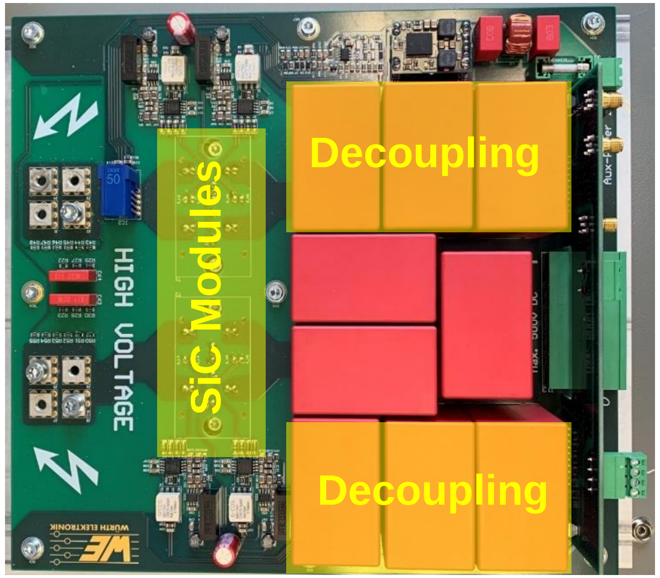
Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som



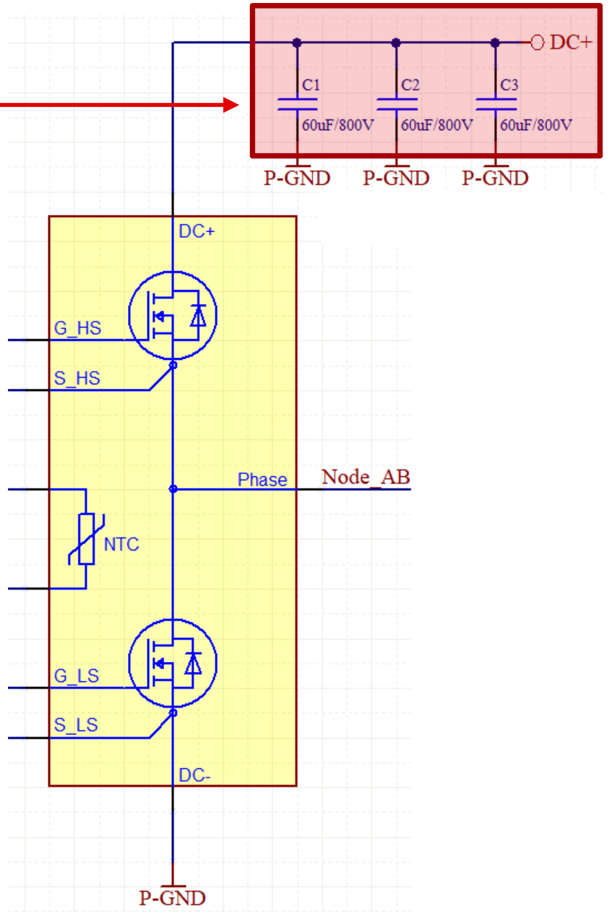
11kW Wireless Power Transfer System

Calculation of the capacitance values:

- **Decoupling for the SiC Modules**
- $C = \frac{I_{rms}}{V_{ripple} \cdot 2 \cdot \pi \cdot f} = \frac{30A}{0.2V \cdot 2 \cdot \pi \cdot 150kHz} = 160\mu F$



Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som



Specification:

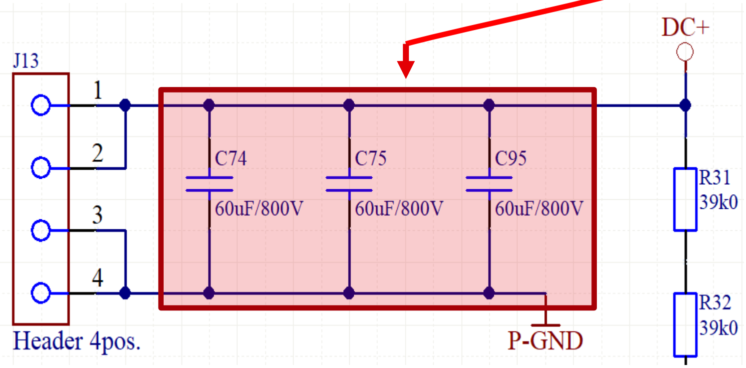
- $P_{out} = 11\ kW$
- $V_{DC} \approx 370\ V$
- $I_{RMS} \approx 30\ A$
- $V_{ripple} = 0.2\ V$

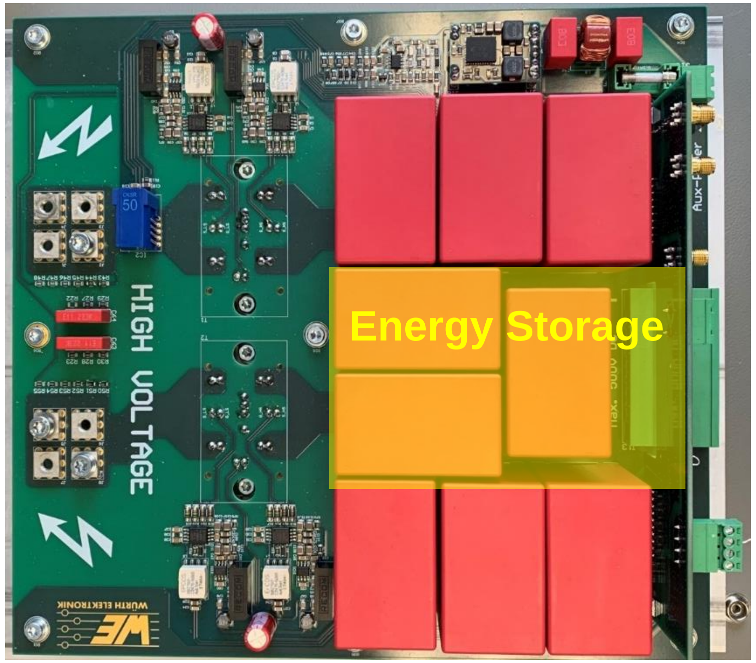
11kW Wireless Power Transfer System

PSMA

Calculation of the capacitance values:

- Energy Storage for V_{DC}
- $C = \frac{P_{load}}{V_{ripple} \cdot \left[V_{max} - \frac{V_{ripple}}{2}\right]} = 150\mu F$
- $I_{rms} = \frac{P_{load} \cdot \pi}{\left[V_{max} - \frac{V_{ripple}}{2}\right] \cdot \sqrt{2}} = 61A$





Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som

Specification:

- $P_{out} = 11\ kW$
- $V_{DC} \approx 370\ V$
- $I_{RMS} \approx 30\ A$
- $V_{ripple} = 0.2\ V$

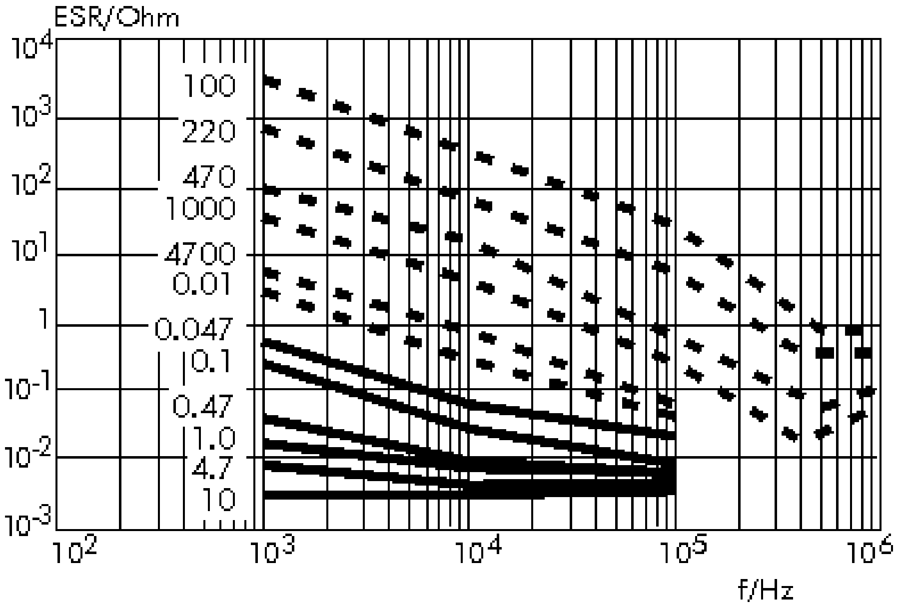
11kW Wireless Power Transfer System

- **DC Link capacitor in film technology**
  - Capacitance = 60 uF
  - Rated voltage = 800 V
  - Low ESR = 2.9 mR
  - RMS current = 21.5 A

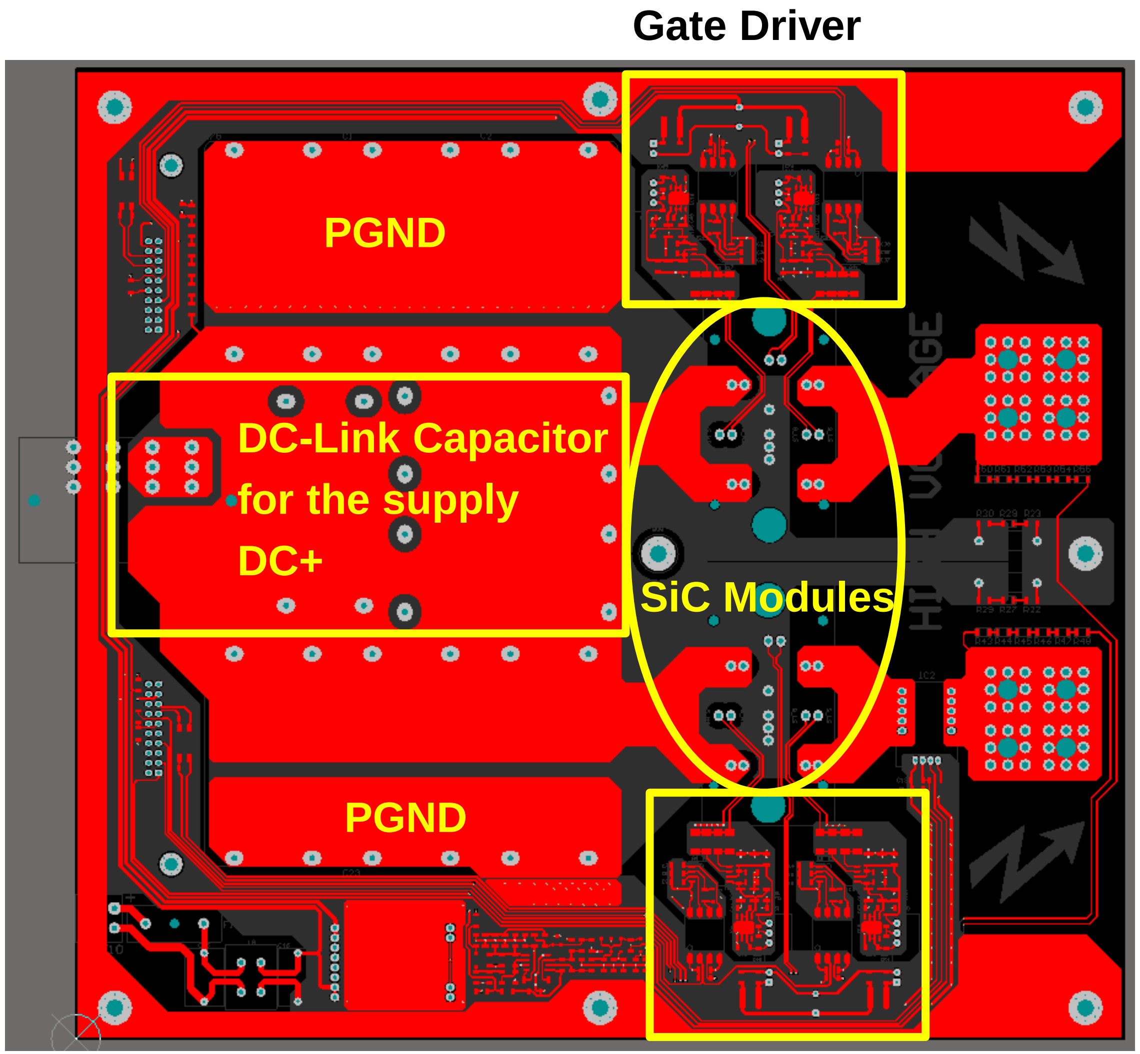
  - Impulse voltage capability = 15V/µs
  - Easy to achieve in the needed voltage rating > 500 V

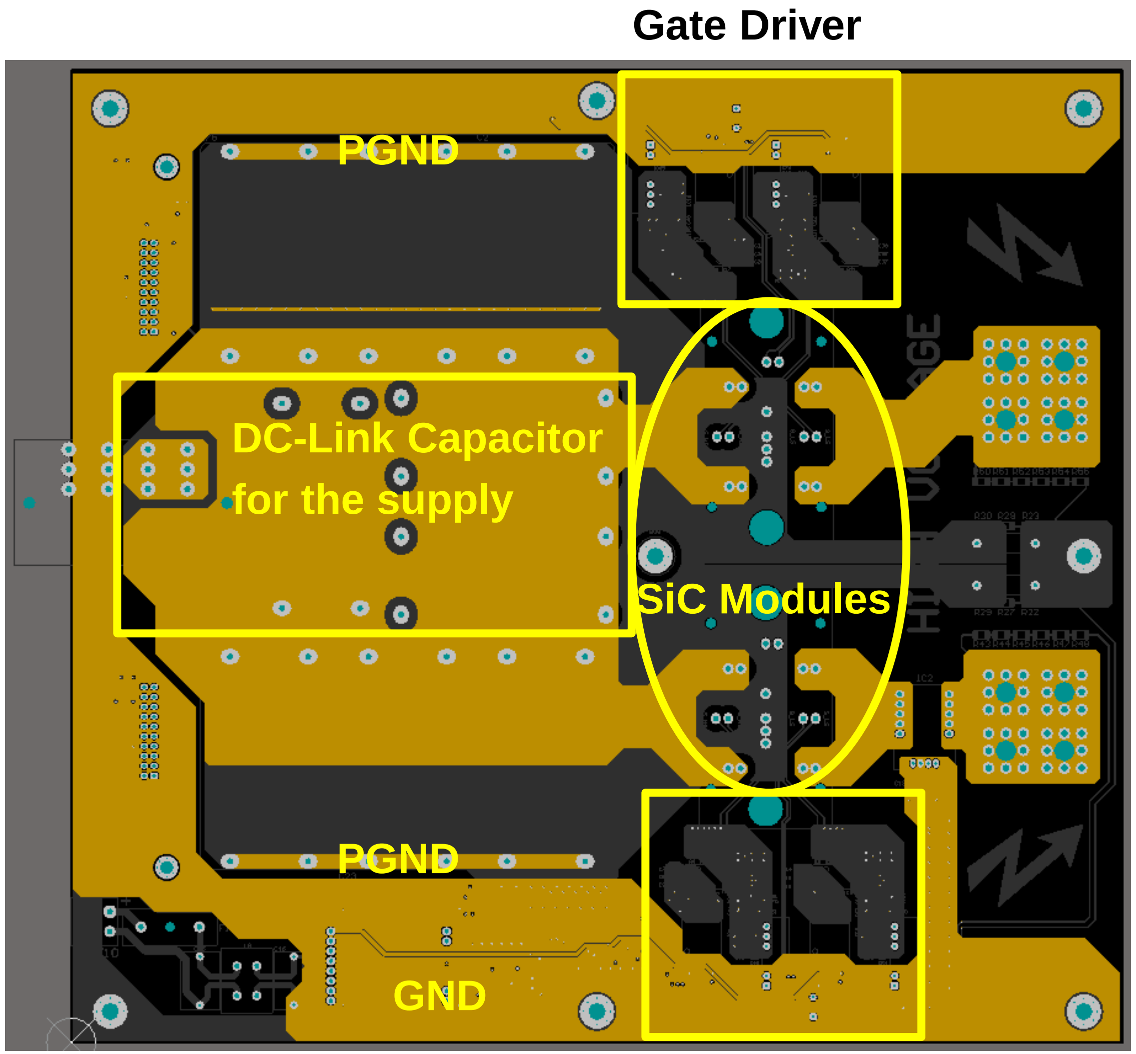
- **Decoupling capacitance => 160 µF / 30 A_{rms}**
  - 3 * 60 µF = 180 µF
  - 3 * 21.5 A = 64.5 A

- **Energy storage capacitance => 150µF / 61 A_{rms}**
  - 3 * 60 µF = 180 µF
  - 3 * 21.5 A = 64.5 A



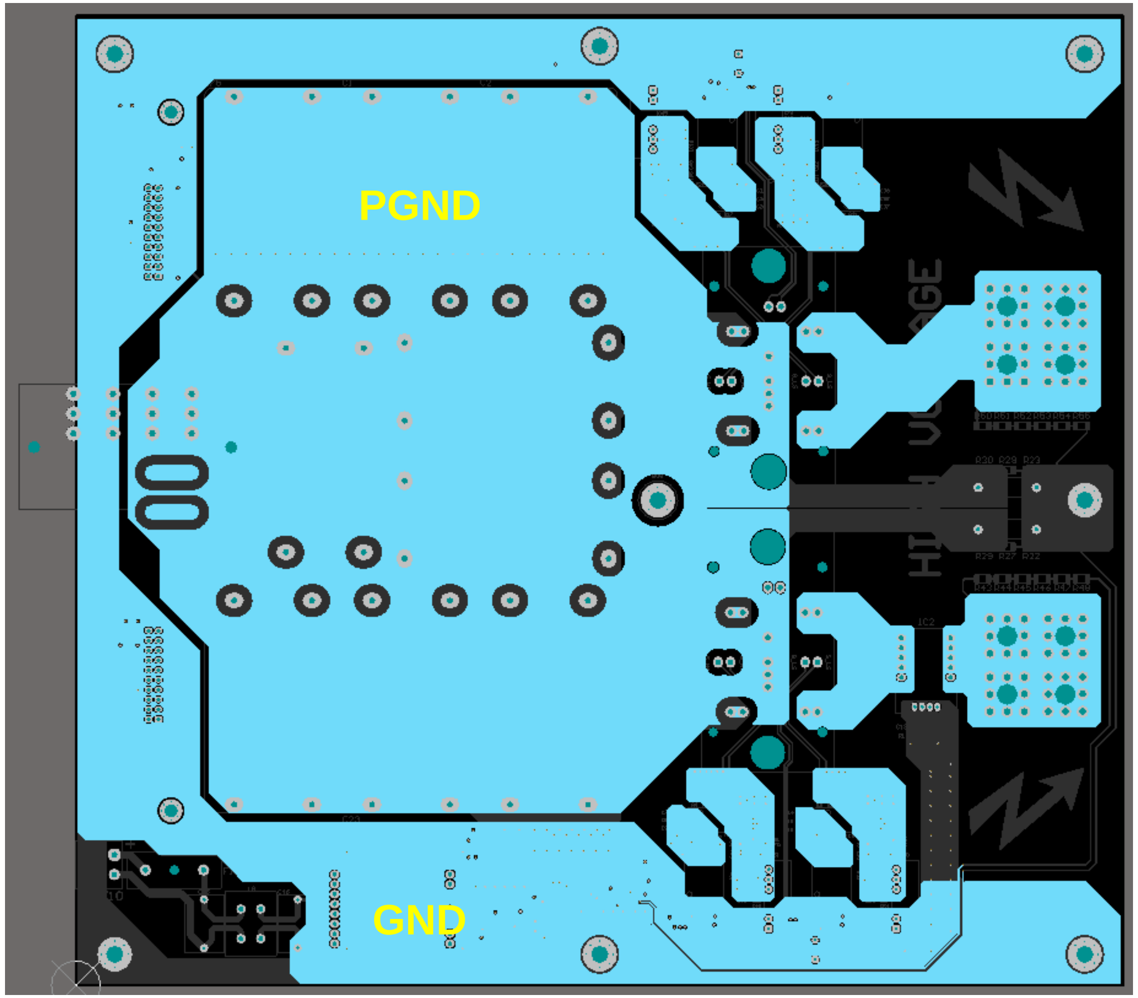
11kW Wireless Power Transfer System

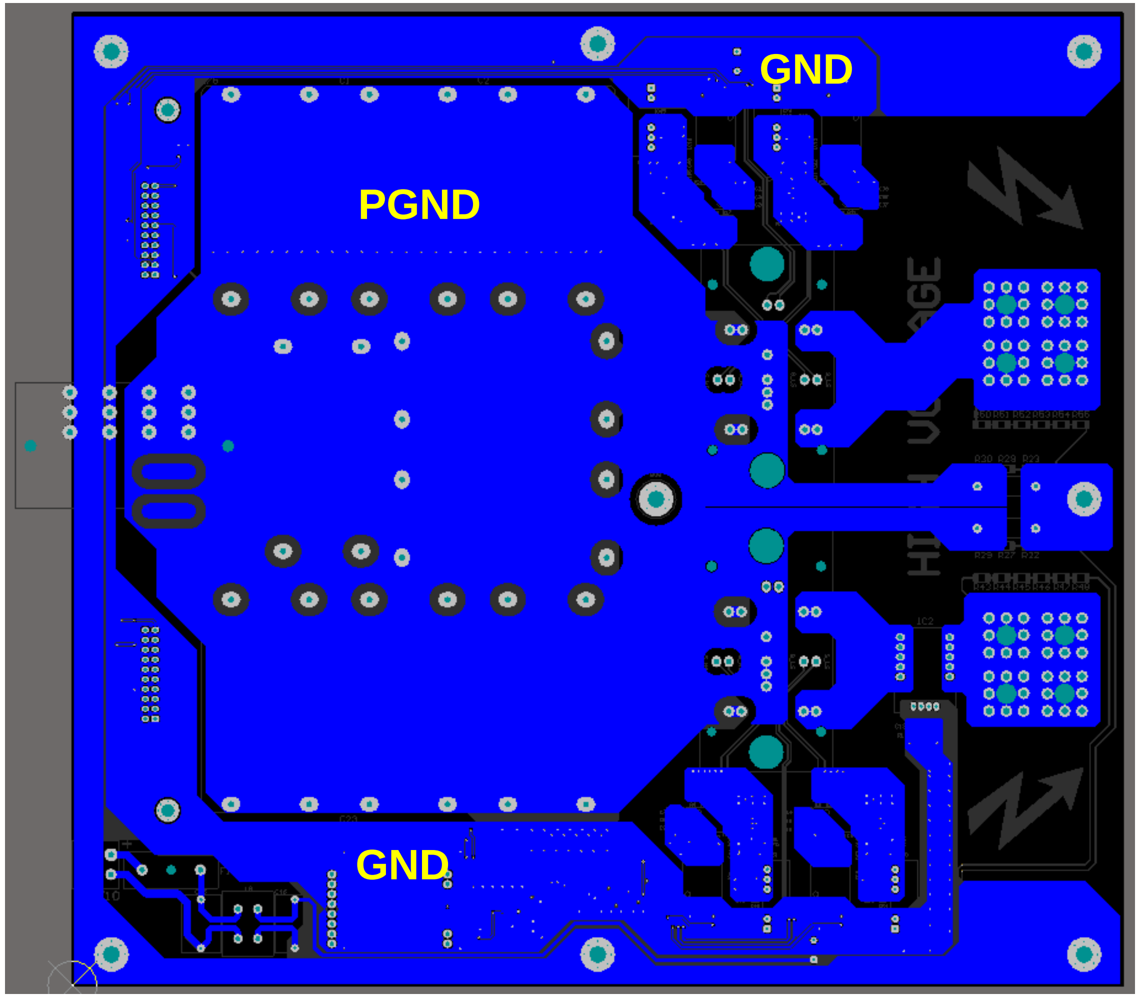




Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som

11kW Wireless Power Transfer System



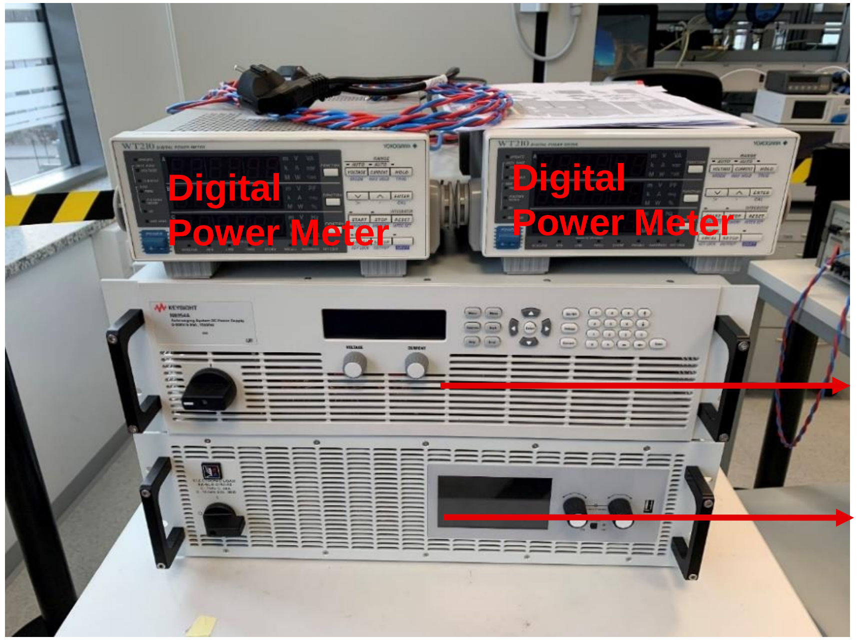


Source: Würth Elektronik eiSos Wireless Power Transfer Division, Cem Som

Test Setup of the 11kW WPT System

Specification:

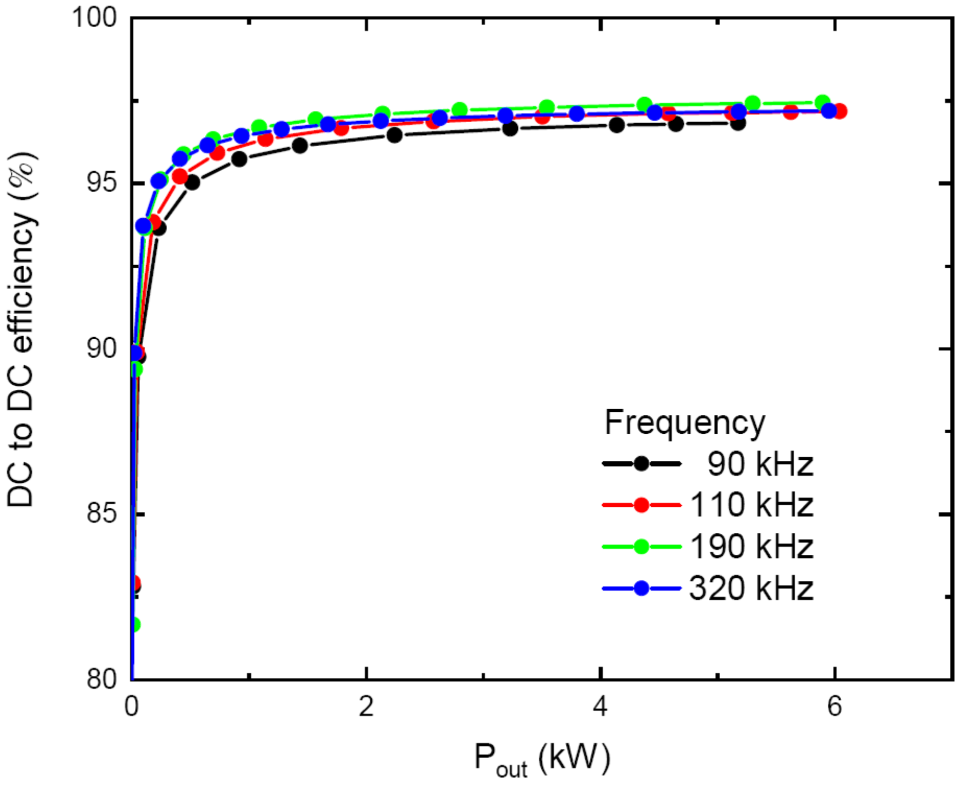
- $P_{out} = 11\ kW$
- $V_{DC} \approx 370\ V$
- $I_{RMS} \approx 30\ A$
- $V_{ripple} = 0.2\ V$



DC Power Supply
15 kW / 500 V / 90 A

Electronic Load
11 kW / 750 V max.

Characteristic Full System Efficiency Curve
DC to DC efficiency ≈ 98 %

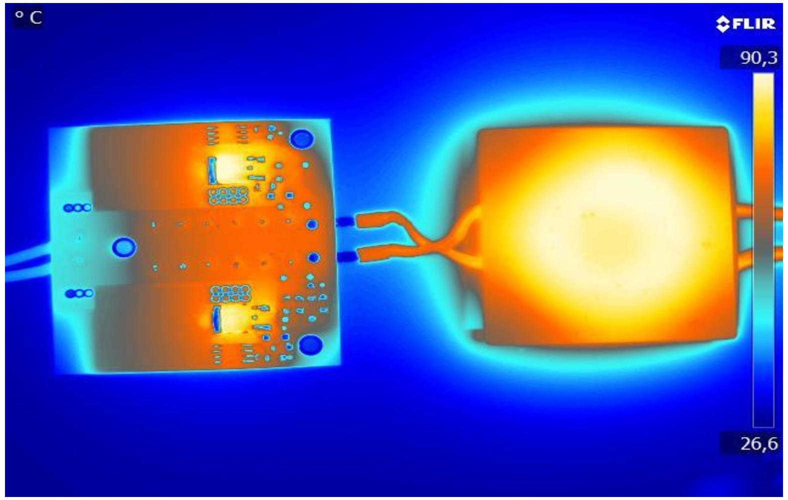


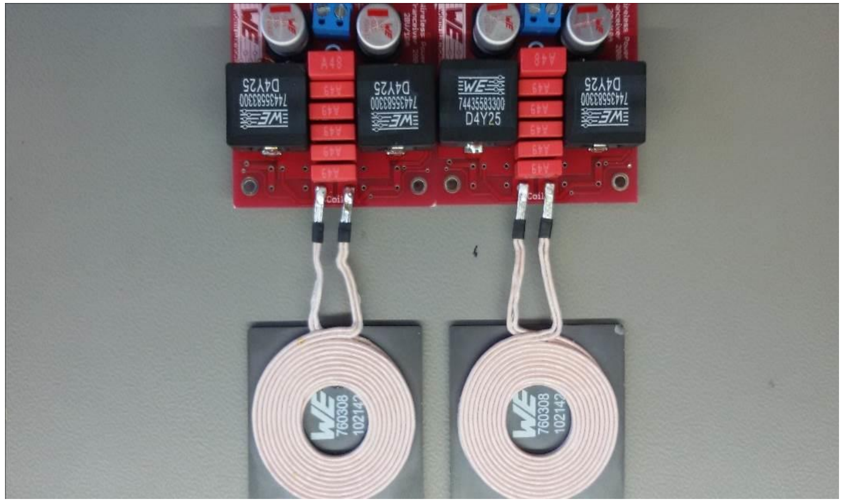
Source: Würth Elektronik eiSos Wireless Power Transfer Division, Christoph Utschick

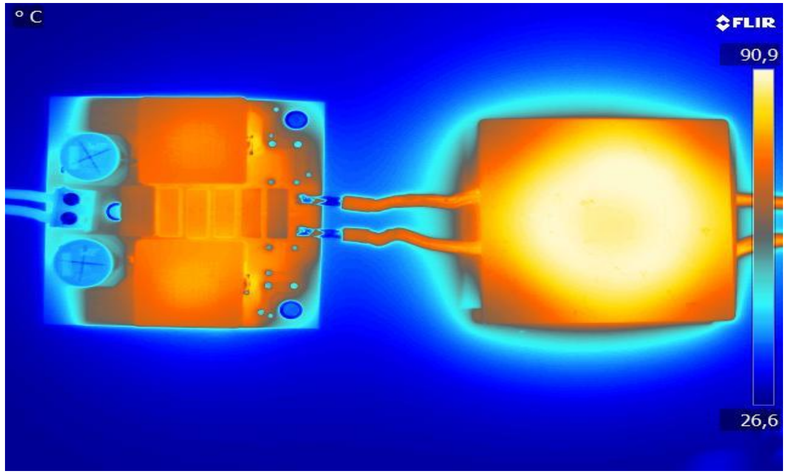
Wireless Power Transfer 100W

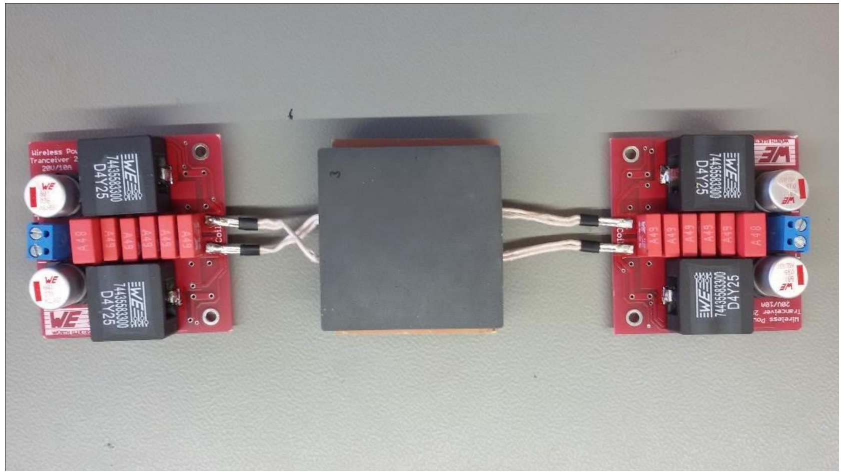
- **Resonant converter**
  - Scalable
- **Using film X2 capacitor for the resonant circuit**
- **Using aluminum electrolytic capacitor for buffering**
- **Simple discrete solution**
  - No micro controller
  - No software

Source: Würth Elektronik eiSos Andreas Nadler









Questions?

Thanks for your attention!