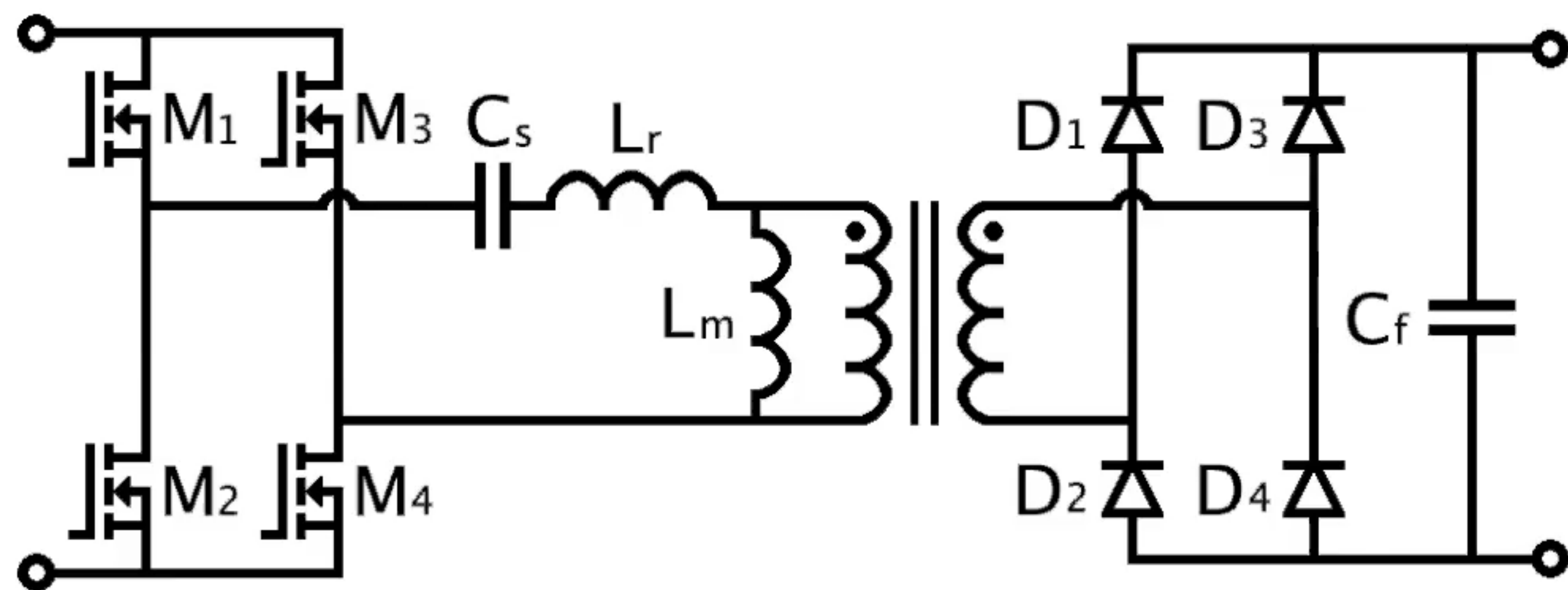
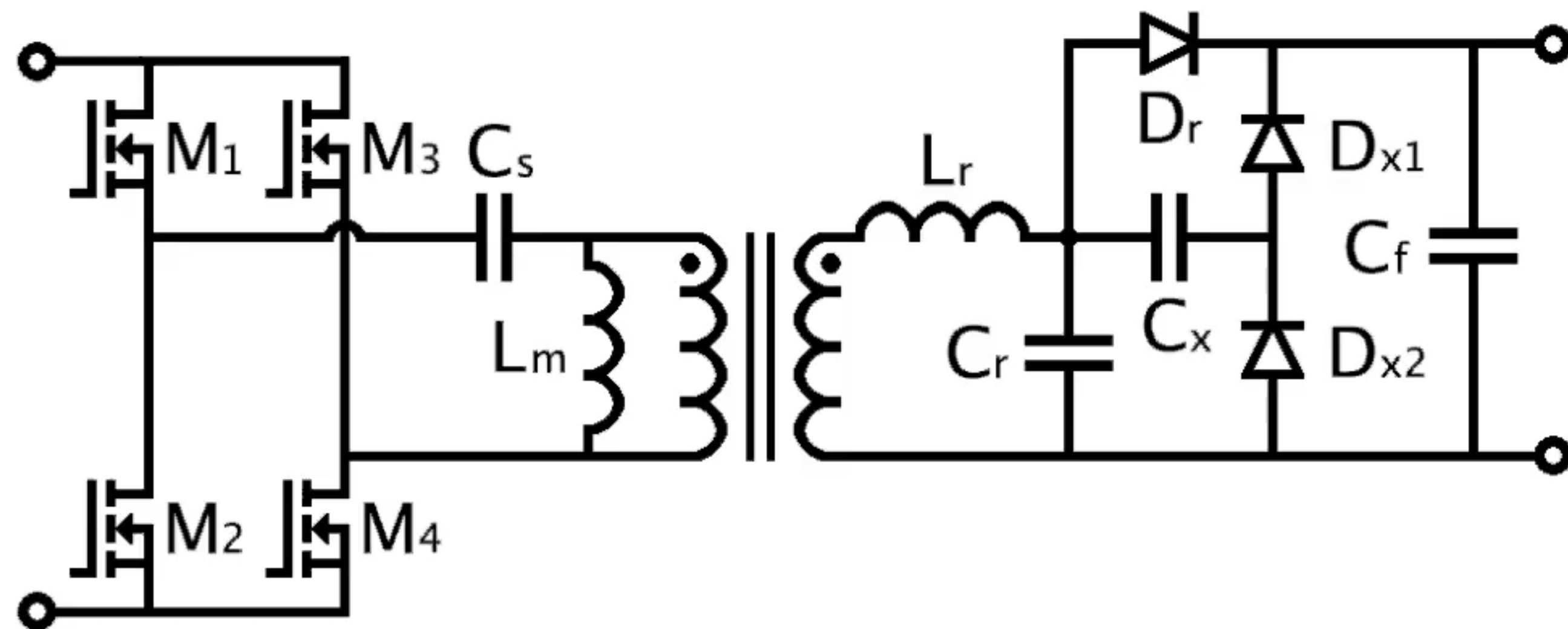


The Pe17 Circuit



VS.

The LLC Circuit

Comparison of the Pe17 circuit and the LLC resonant circuit for DC/DC conversion in on-board EV charger

Created by: Tal Abramovici

Agenda

-> 1. DC-DC Converter Stage

- Specifications
- Circuit Implementation
- Magnetic Components

2. Component Stresses Comparison

- $V_{in} = 725 \text{ V}$, $V_o = 250 \text{ V}$
- $V_{in} = 675 \text{ V}$, $V_o = 420 \text{ V}$

3. Summery

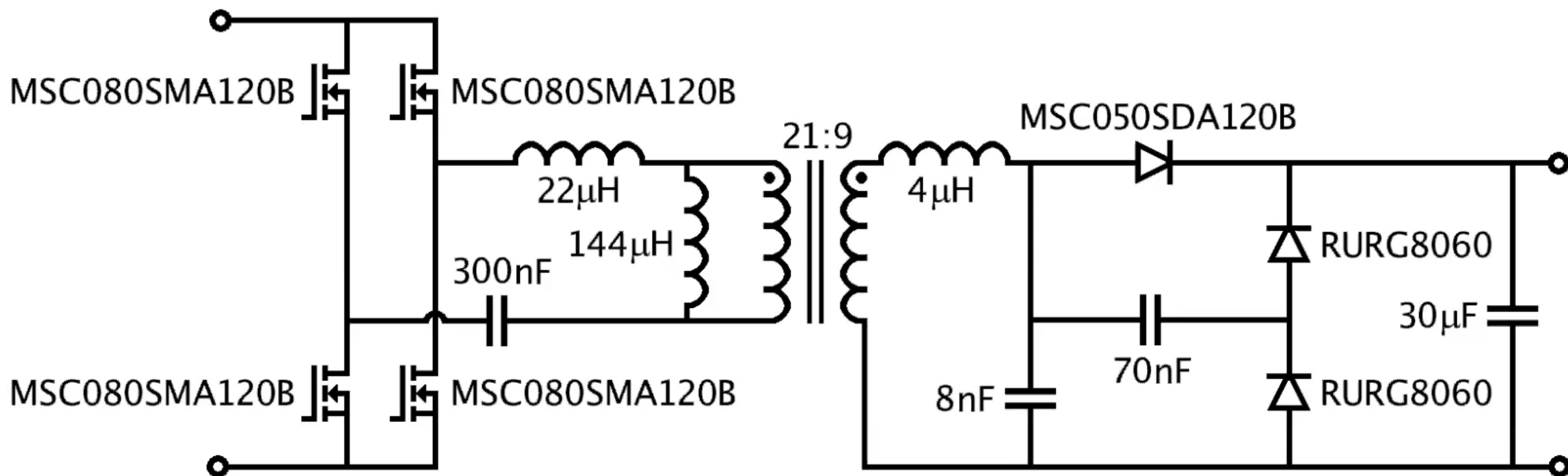
- Loss Breakdown and Efficiency results
-

Specifications



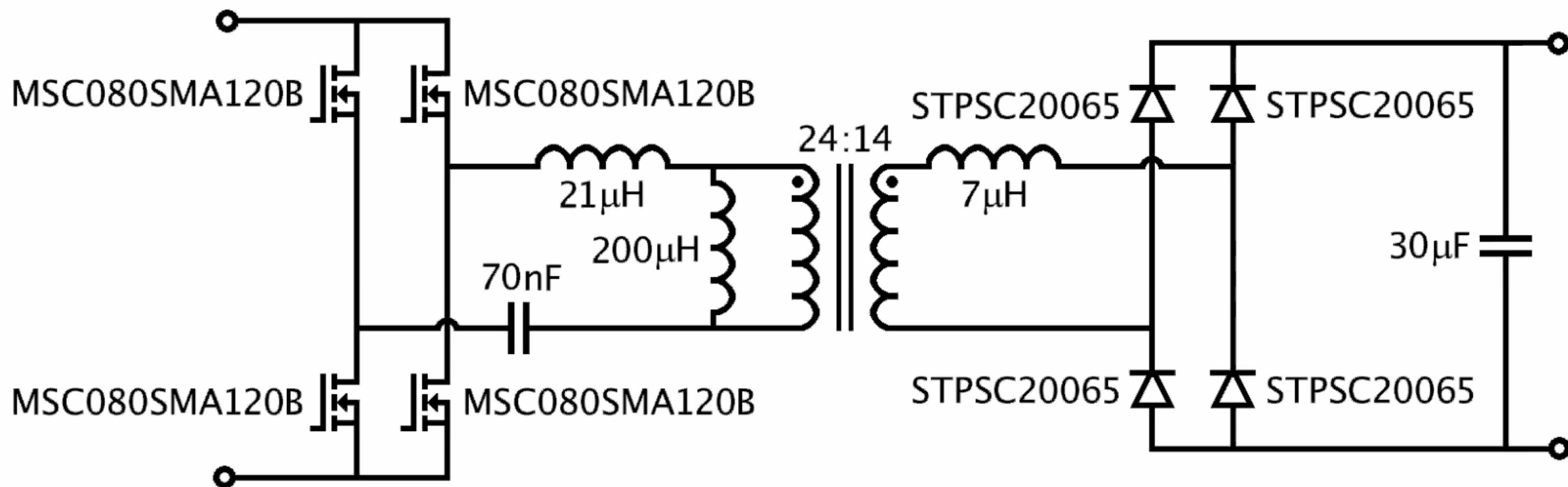
The DC-DC stage of the on-board charger provides the EV battery with a constant current of 15.7 A as its voltage rises from 250 V to 420 V. Thus, the peak output power is 6.6 kW. The input voltage provided from a PFC stage is 700 ± 25 V.

Circuit Implementation



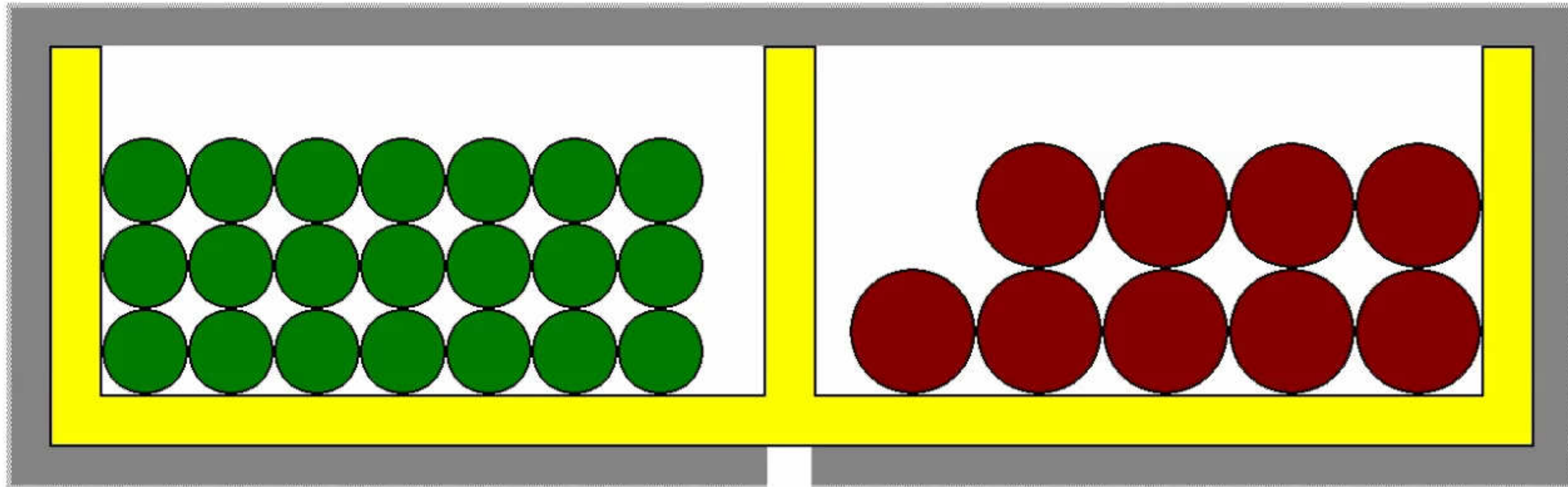
The schematic above represents the implementation of the DC-DC converter with the Pe17 circuit. Four 1200 V SiCFETs are connected in a full bridge configuration. A 1200 V SiC Schottky diode and two additional 600 V ultra fast diodes are used for rectification. The resonant inductors are integrated with the transformer. All of the capacitors are assumed to be loseless.

Circuit Implementation



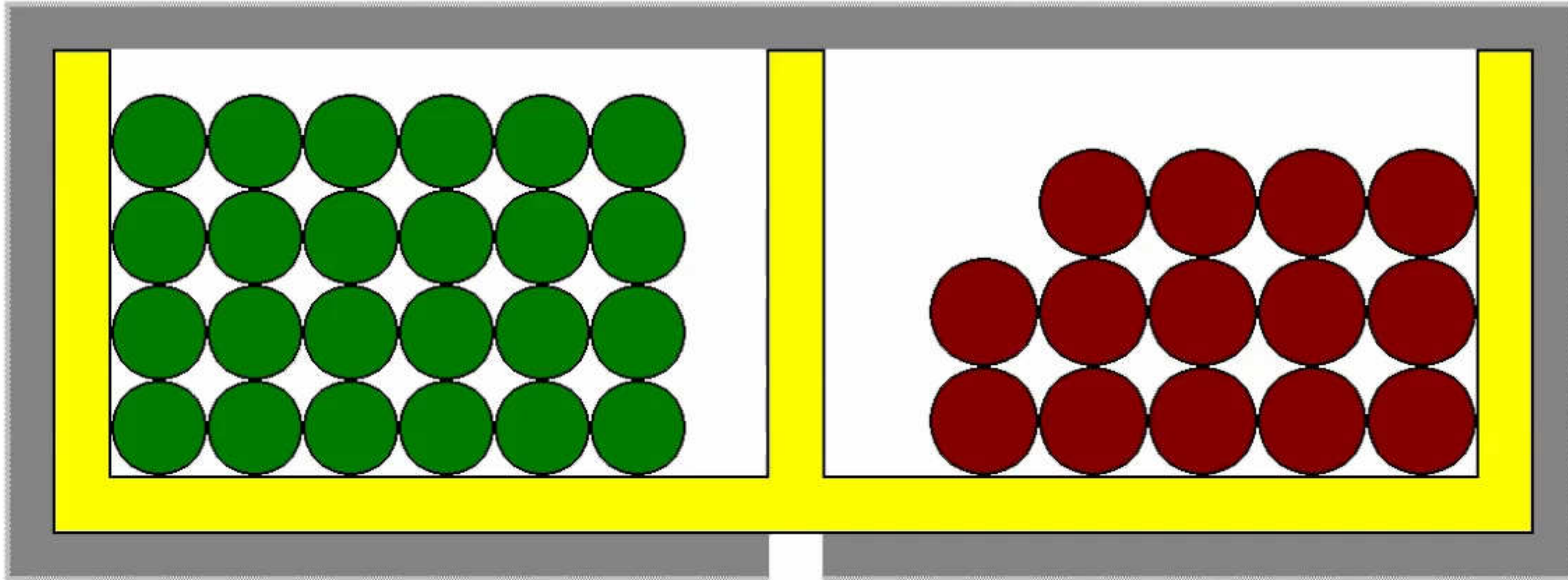
The schematic above represents the implementation of the DC-DC converter with the LLC circuit. The same 1200 V SiCFETs are used in the full bridge inverter. Four 650 V SiC Schottky diodes are connected in a full bridge rectifying configuration. The resonant inductors are integrated with the transformer. The switching frequency ranges from 100 kHz to 200 kHz.

Magnetic Components



The figure above illustrates the structure of the transformer in the Pe17 circuit. The magnetic core is assumed to be made from the DMR95 ferrite material or equivalent. The geometry of the core is that of ETD54, having a center leg area of $280 \mu\text{m}^2$. The air-gap in the center leg is 1.3 mm. The primary and the secondary windings are wound side by side and isolated from each other by a split-section bobbin. The primary winding consists of 21 turns of litz wire having a diameter of 2.3 mm. The secondary winding consists of 9 turns of litz wire having a diameter of 3.5 mm. Thus, the resistance of the primary winding is 18 mOhm, and the resistance of the secondary winding is 4 mOhm. The expected leakage inductance is about 44 μH , and can be fine-tuned by adjusting the gap between the windings.

Magnetic Components



The figure above illustrates the structure of the transformer in the LLC resonant circuit. The geometry of the magnetic core is that of PQ50, having a center leg area of $328 \mu\text{m}^2$. The ferrite material is the same as that of the transformer in the Pe17 circuit. The air-gap in the center leg is 1.4 mm. The primary and the secondary windings are wound side by side and isolated from each other by a split-section bobbin. The primary winding consists of 24 turns of litz wire having a diameter of 2.3 mm. The secondary winding consists of 14 turns of litz wire having a diameter of 2.4 mm. Thus, the resistance of the primary winding is 25 mOhm, and the resistance of the secondary winding is 11 mOhm. The expected leakage inductance is about 44 μH , and can be fine-tuned by adjusting the gap between the windings.

Agenda

1. DC-DC Converter Stage

- Specifications
- Circuit Implementation
- Magnetic Components

-> 2. Component Stresses Comparison

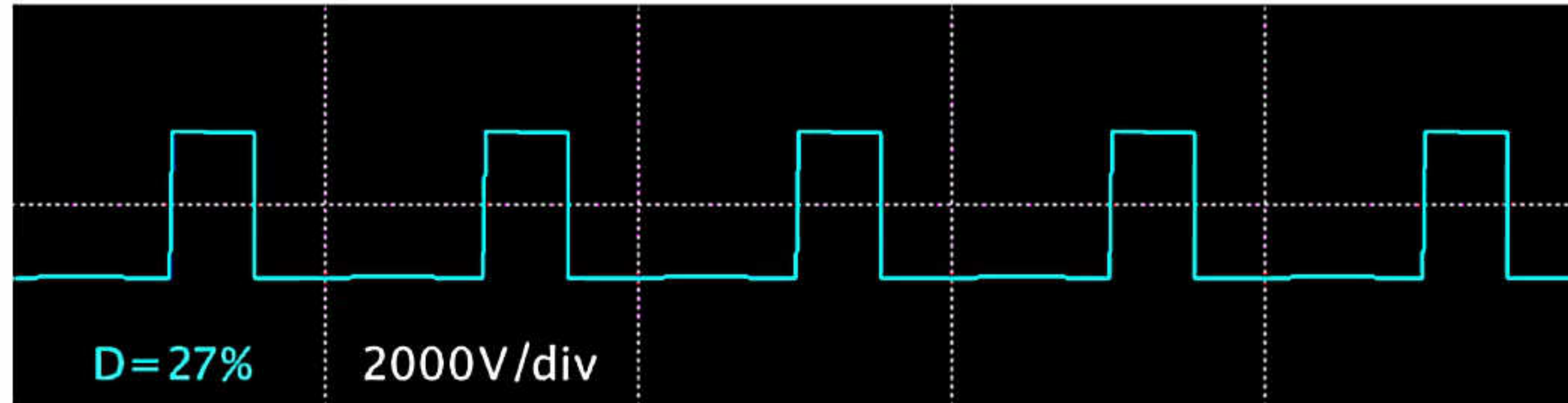
- $V_{in} = 725\text{ V}$, $V_o = 250\text{ V}$
- $V_{in} = 675\text{ V}$, $V_o = 420\text{ V}$

3. Summery

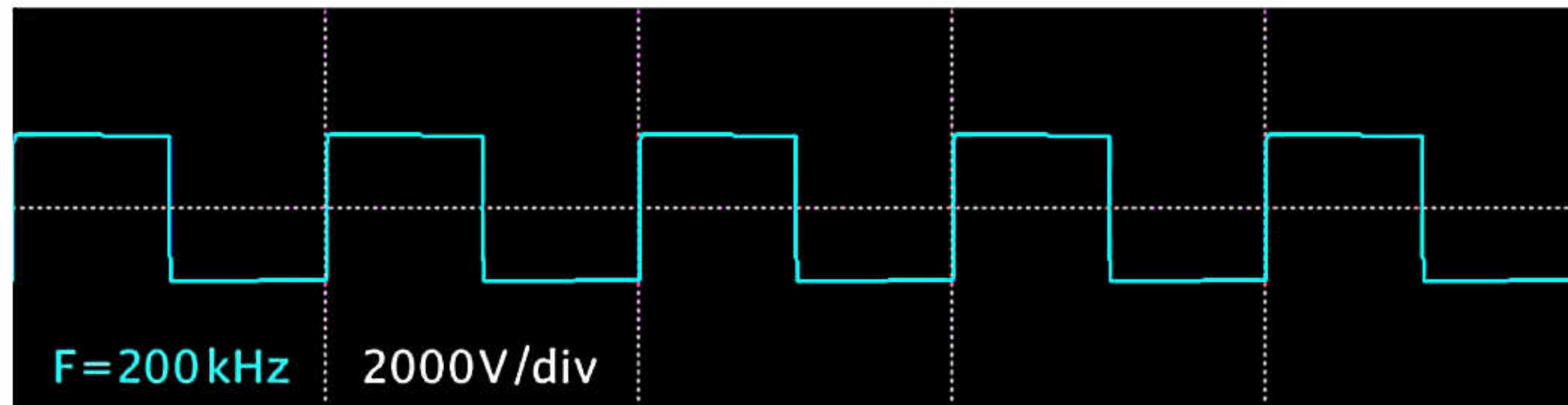
- Loss Breakdown and Efficiency results
-

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

Pe17 Circuit



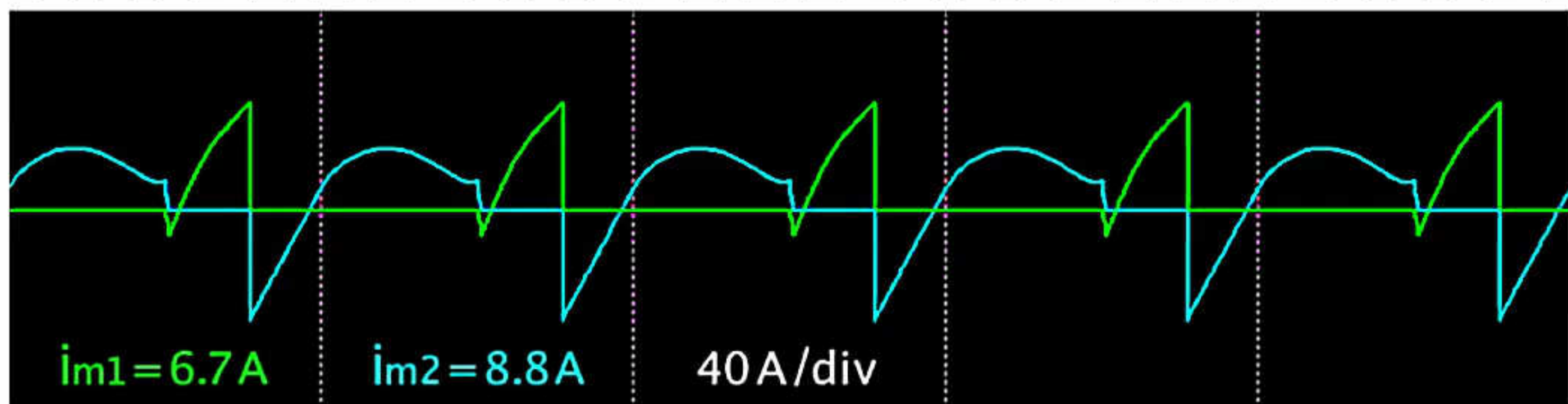
LLC Circuit



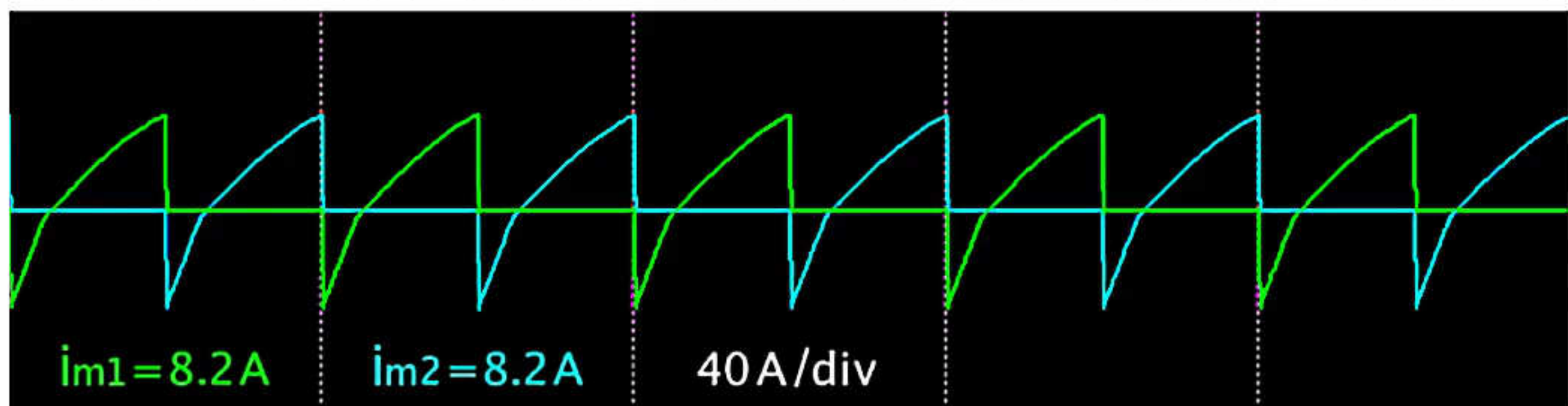
In the Pe17 circuit, the full bridge inverter generates a pulse wave voltage with a duty cycle of 27 %.
In the LLC resonant circuit, the full bridge inverter generates a 200 kHz square wave voltage.

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

Pe17 Circuit



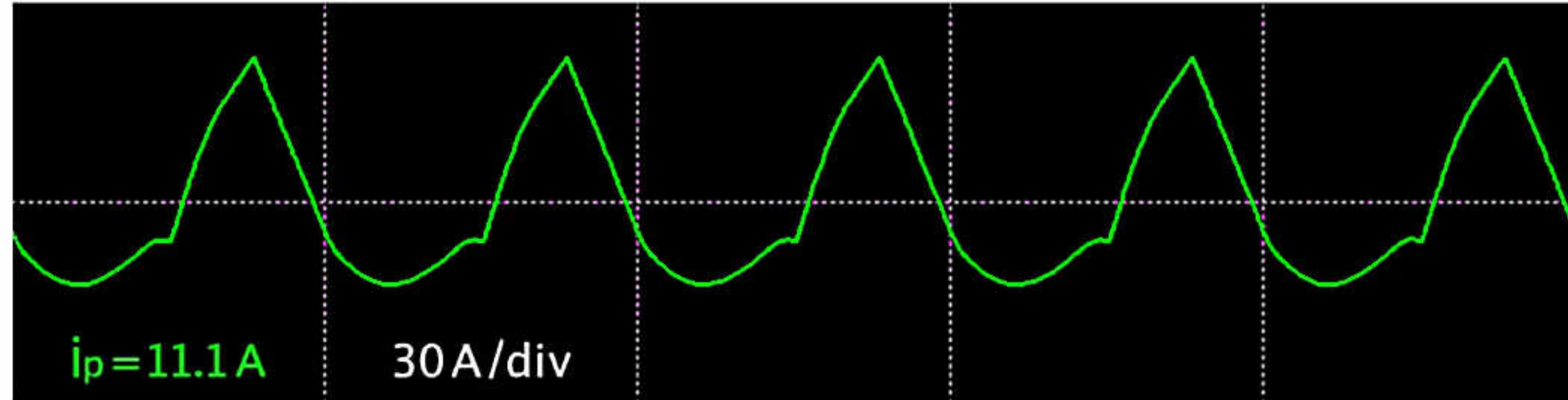
LLC Circuit



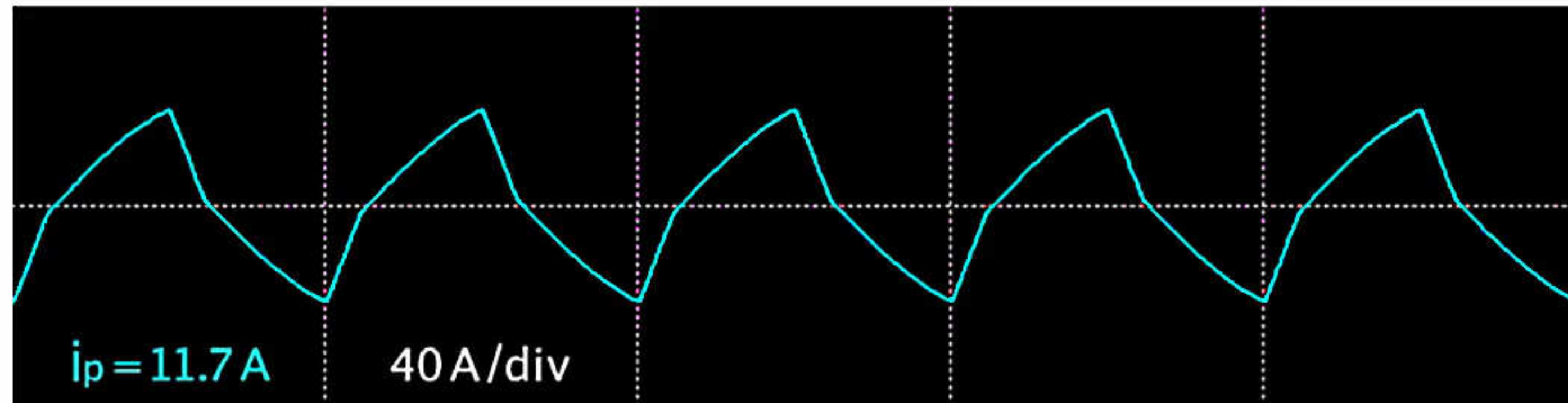
In the Pe17 circuit, the current through one pair of full bridge SiCFETs is 6.7 Arms and each one in the pair dissipates 4.5 W. The current through the other pair of the full bridge SiCFETs is 8.8 Arms and each one in the other pair dissipates 7.7 W. In the LLC resonant circuit, the current through every full bridge SiCFET is 8.2 Arms, and each SiCFET dissipates 6.7 W.

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

Pe17 Circuit



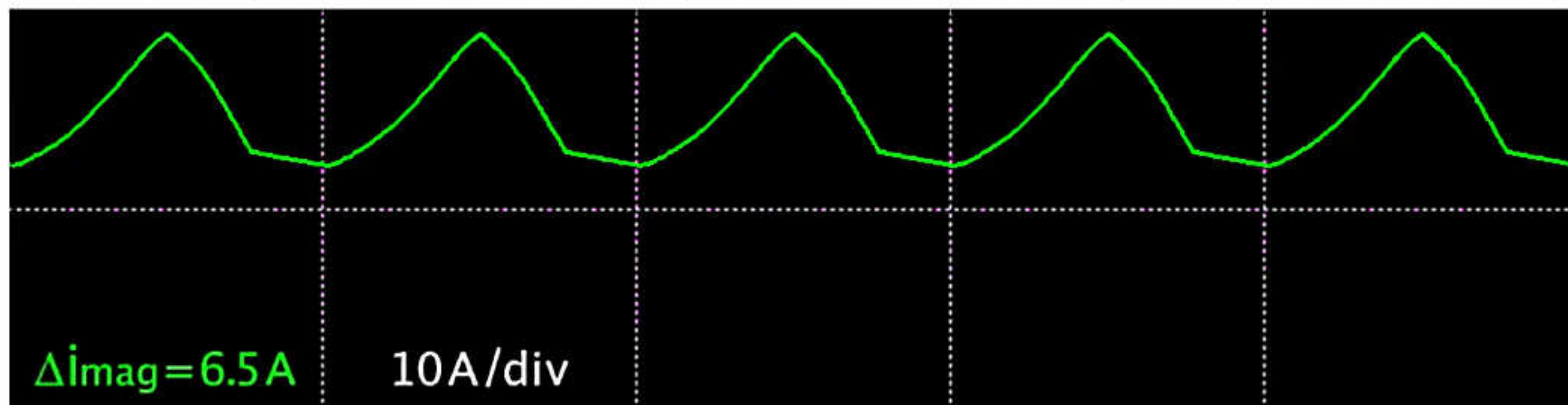
LLC Circuit



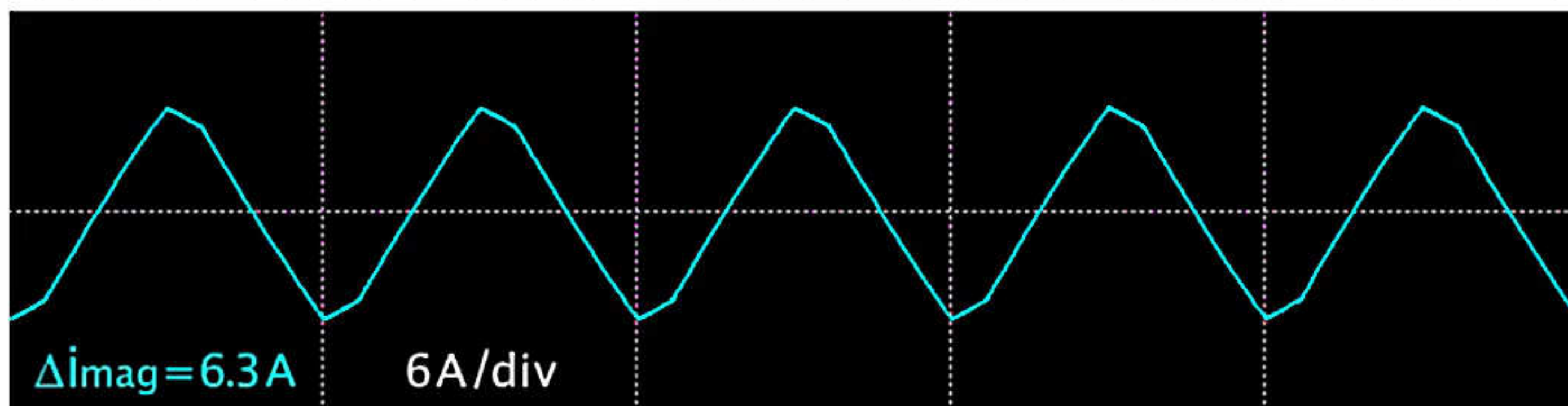
In the Pe17 circuit, the current through the primary winding is 11.1 Arms and it dissipates 2.2 W.
In the LLC circuit, the current through the primary winding is 11.7 Arms and it dissipates 3.4 W.

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

Pe17 Circuit



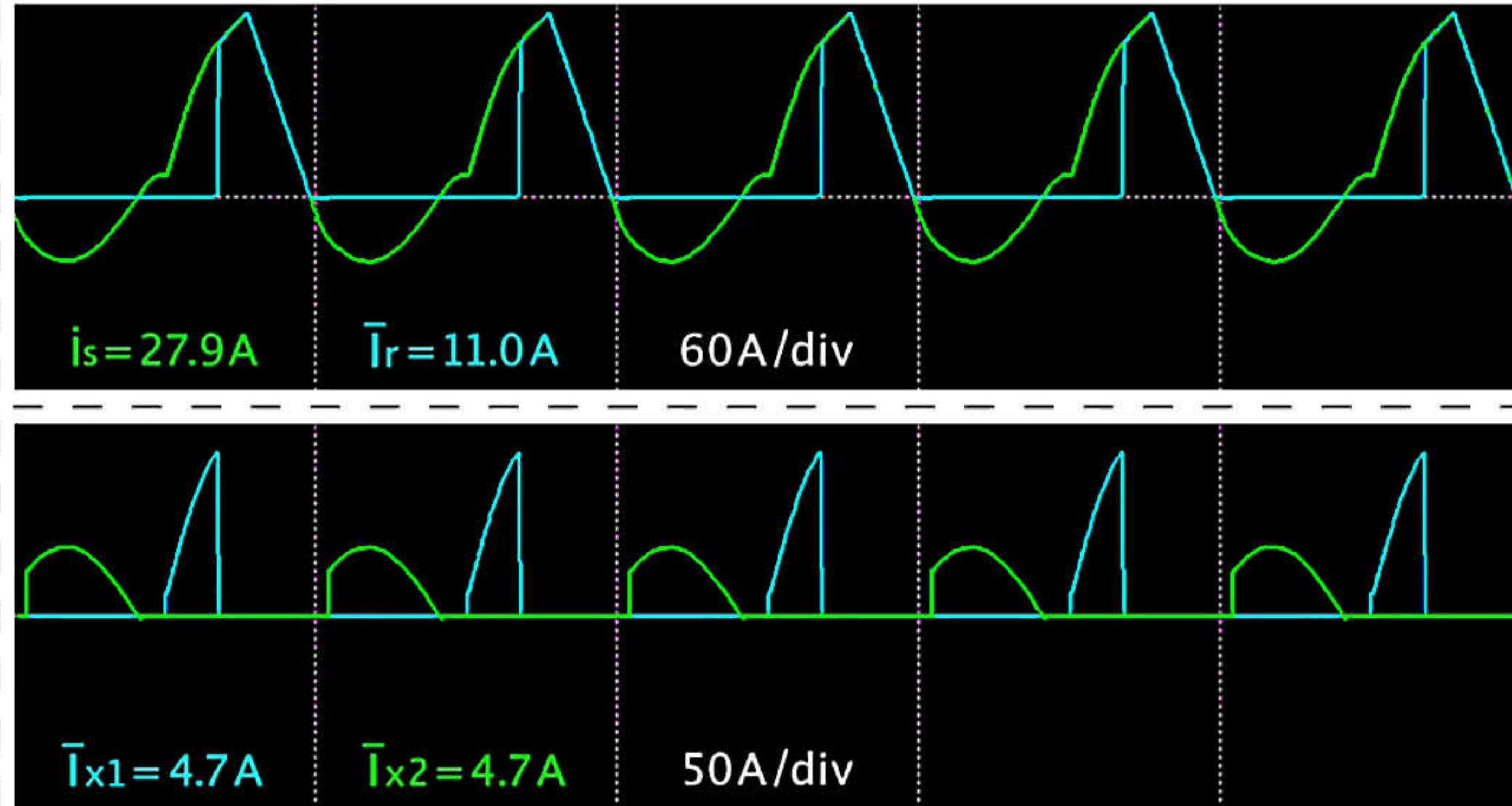
LLC Circuit



In the Pe17 circuit, the peak to peak current through the magnetizing inductance is 6.5 A. Thus, the magnetic flux density swing through 21 turns of the primary winding is 160 mT, and the core loss of the transformer is estimated at 3.3 W. In the LLC resonant circuit, the peak to peak current through the magnetizing inductance is 6.3 A. Thus, the magnetic flux density swing through 24 turns of the primary winding is 160 mT, and the core loss of the LLC transformer is estimated at 3.5 W.

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

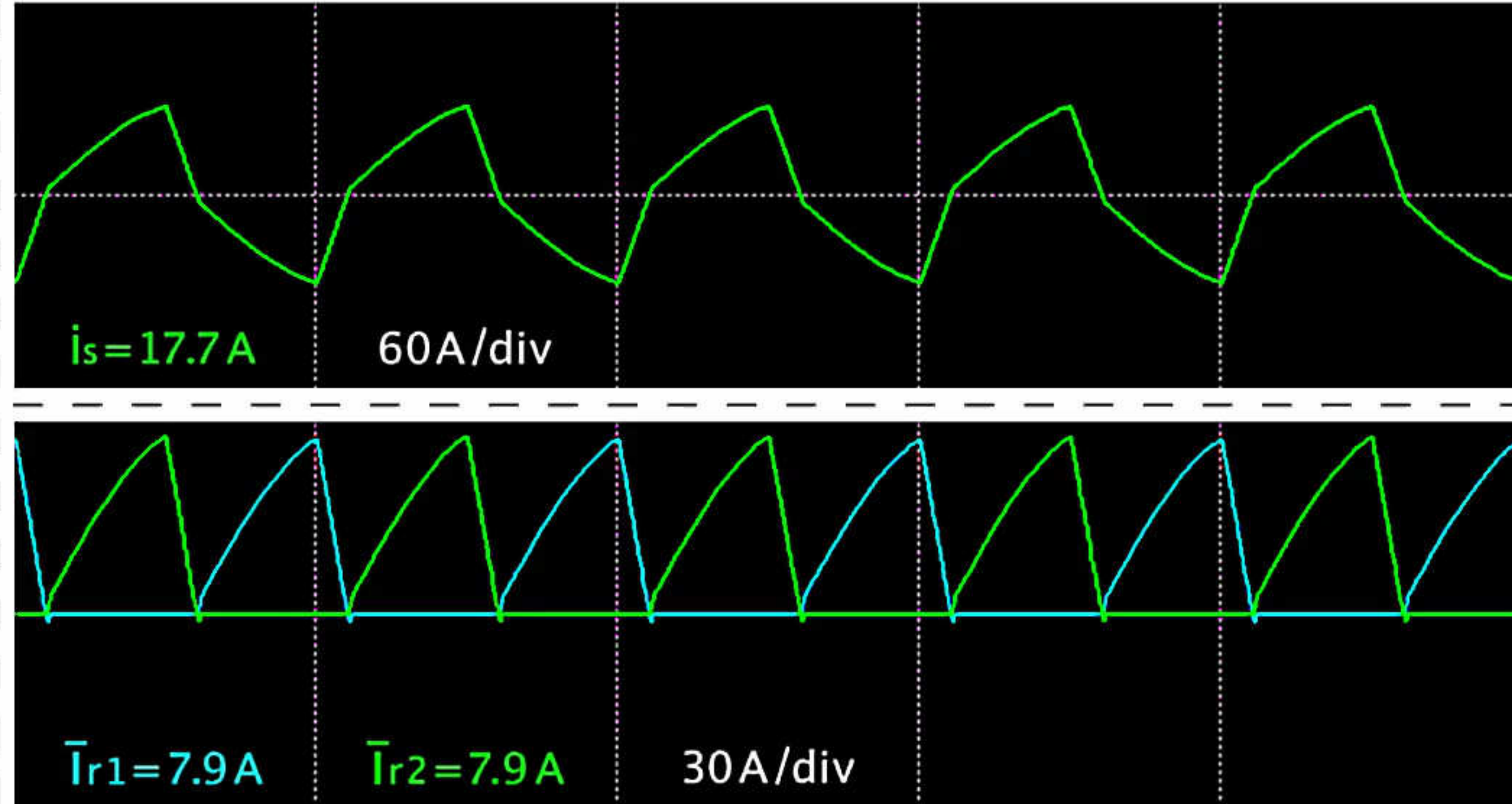
Pe17 Circuit



In the Pe17 circuit, the current through the secondary winding is 27.9 Arms and it dissipates 3.1 W. The average current through the SiC diode is 11.0 A and it dissipates 16.4 W. The average current through the ultra fast diodes is 4.7 A, for which the top one dissipates 4.2 W and the bottom one dissipates 3.7 W.

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

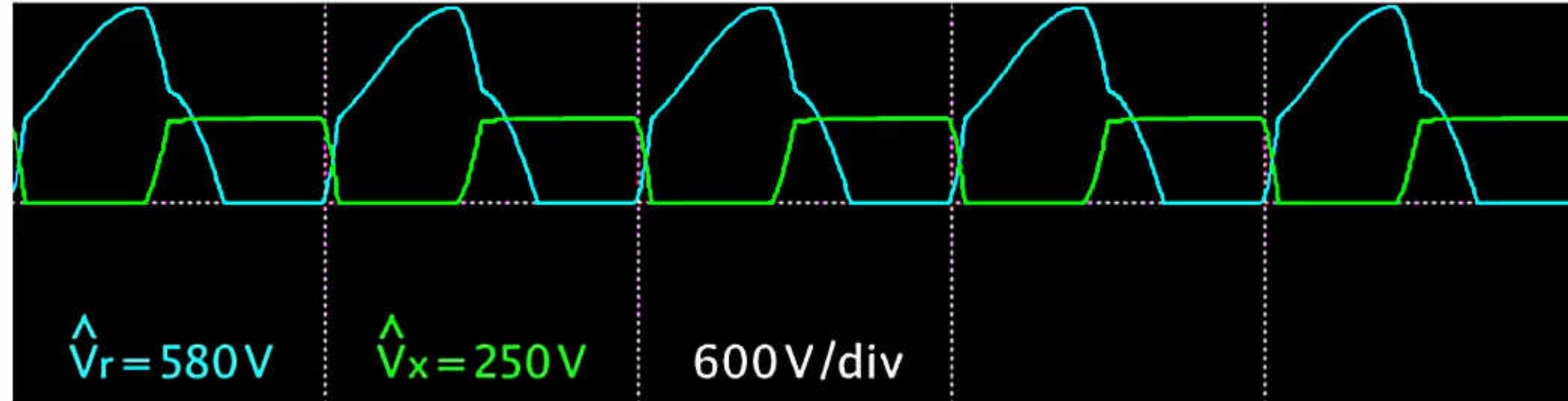
LLC Circuit



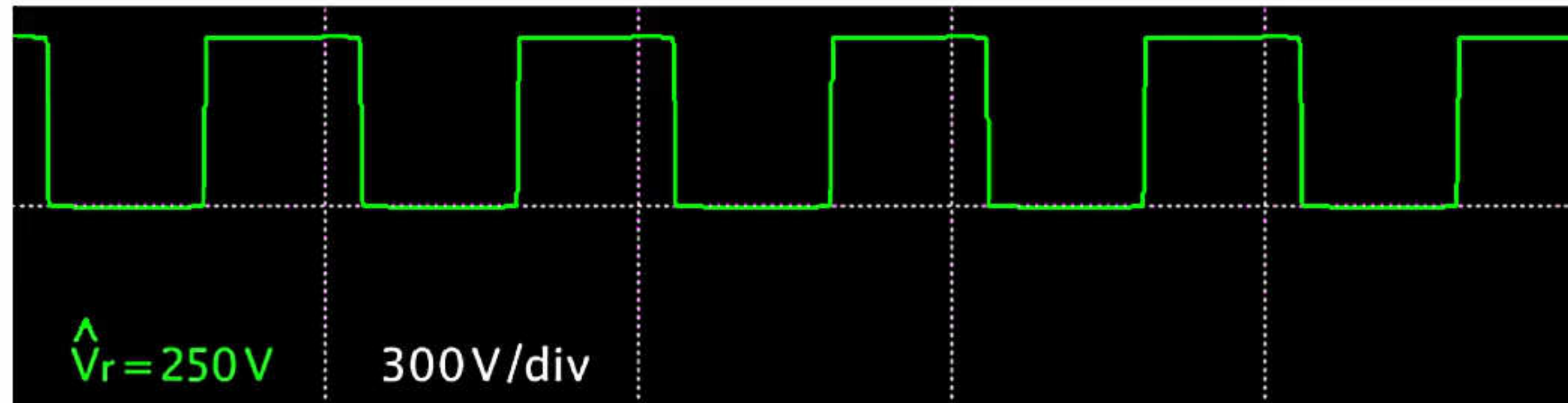
In the LLC resonant circuit, the current through the secondary winding is 17.7 Arms and it dissipates 3.4 W. The average current through each full bridge rectifying diode is 7.9 A. Thus, each diode dissipates 10.0 W.

$$V_{in} = 725 \text{ V} , V_o = 250 \text{ V}$$

Pe17 Circuit



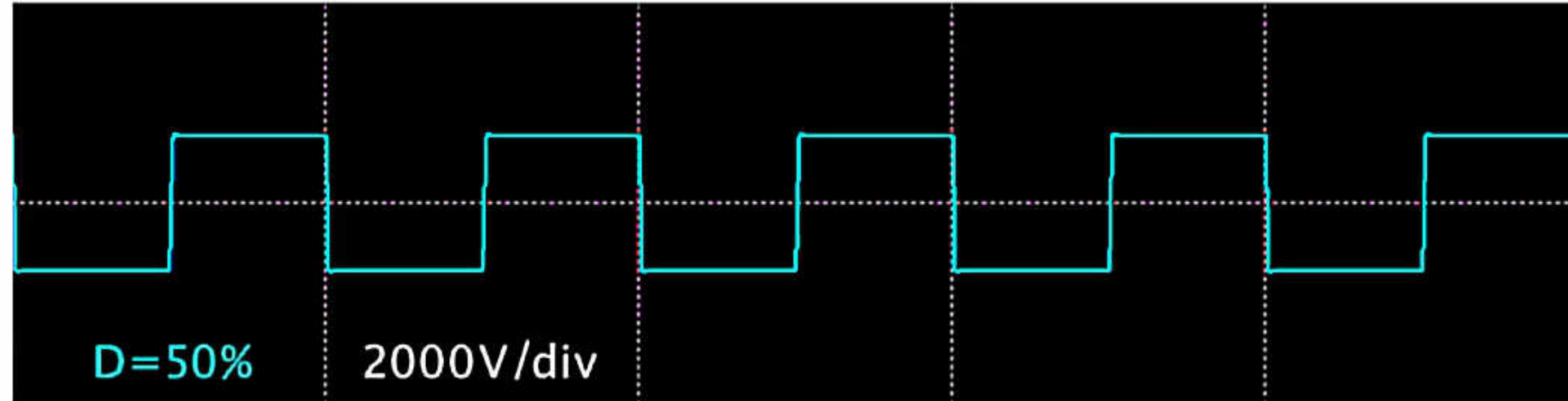
LLC Circuit



In the Pe17 circuit, the peak reverse voltage across the SiC diode is 580 V. The peak reverse voltage across the ultra fast diodes is 250 V. In the LLC circuit, each rectifying diode withstands a peak reverse voltage of 250 V.

$$V_{in} = 675 \text{ V} , V_o = 420 \text{ V}$$

Pe17 Circuit



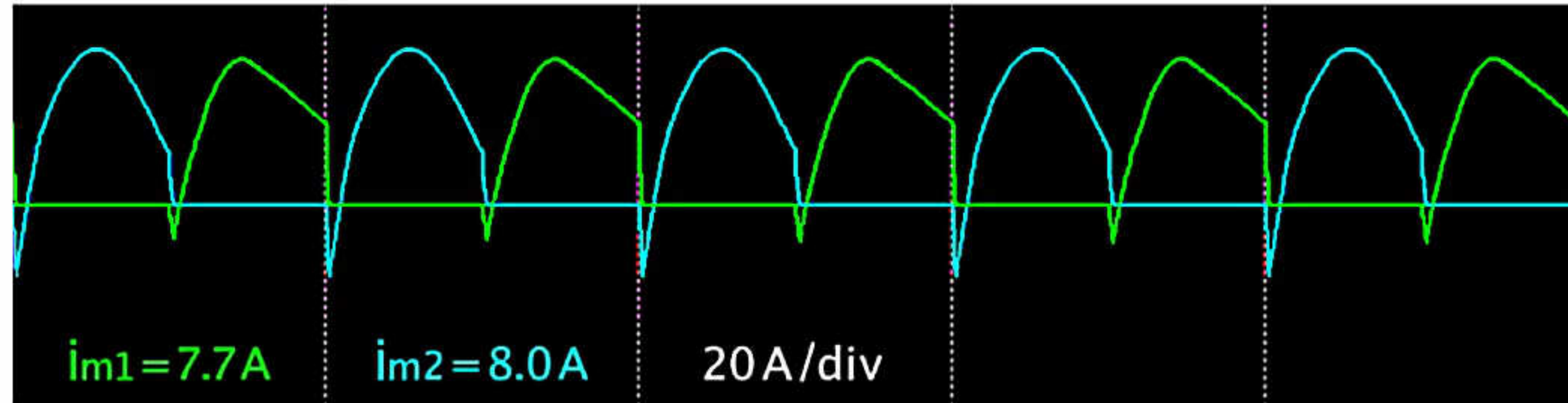
LLC Circuit



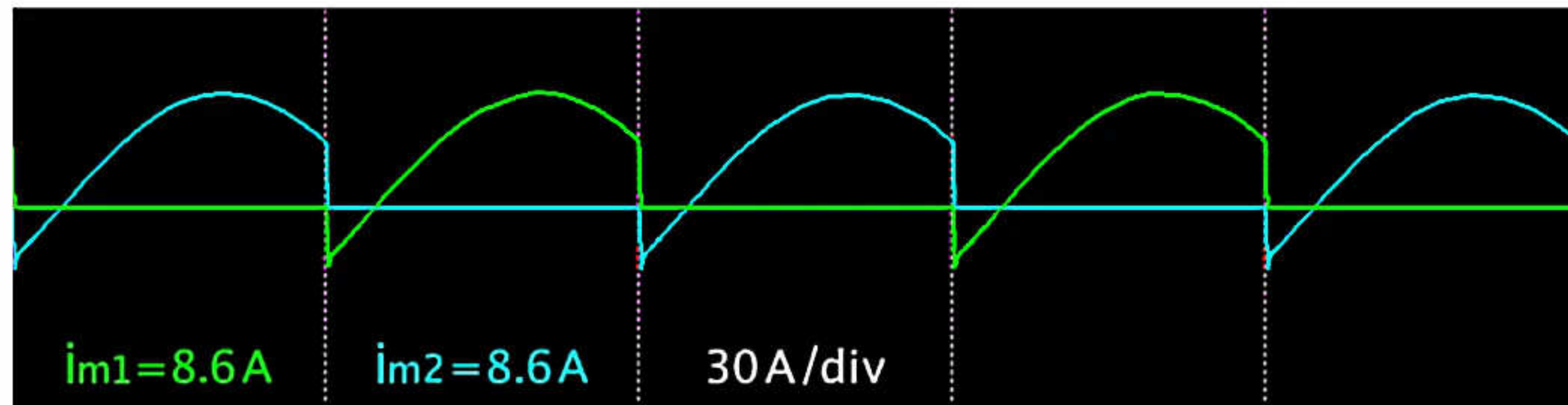
In the Pe17 circuit, the full bridge inverter generates a pulse wave voltage with a duty cycle of 50%.
In the LLC resonant circuit, the full bridge inverter generates a 100 kHz square wave voltage.

$$V_{in} = 675 \text{ V}, V_o = 420 \text{ V}$$

Pe17 Circuit



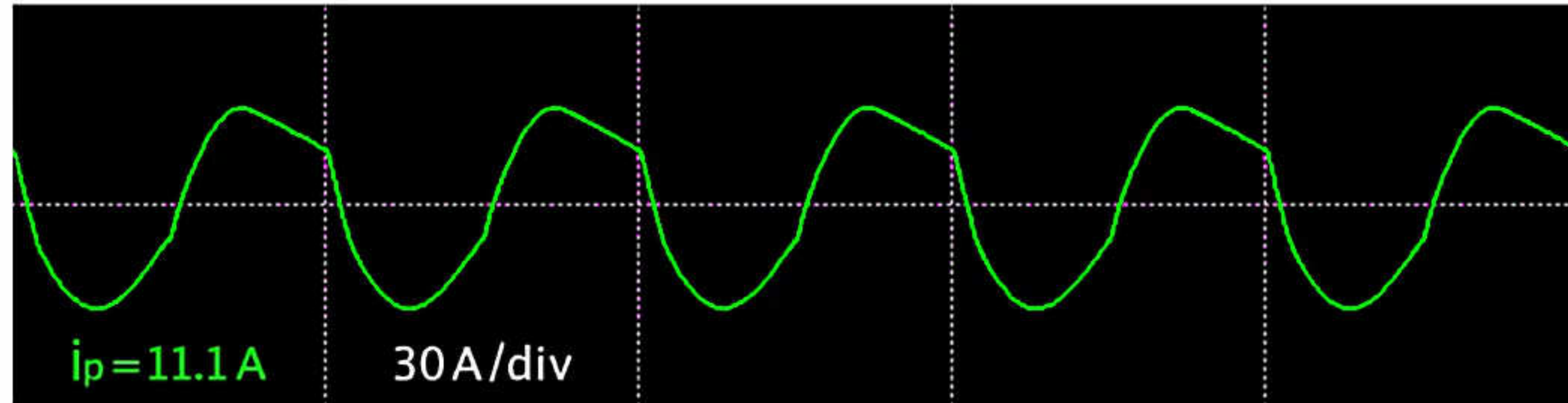
LLC Circuit



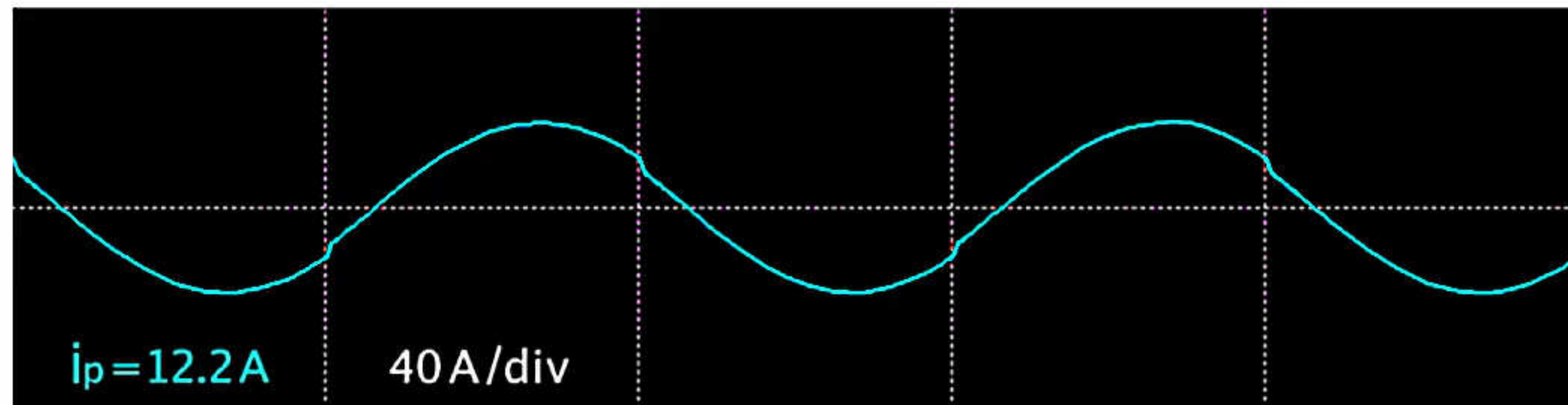
In the Pe17 circuit, the current through one pair of full bridge SiCFETs is 7.7 Arms and each one in the pair dissipates 5.9 W. The current through the other pair of the full bridge SiCFETs is 8.0 Arms and each one in the other pair dissipates 6.4 W. In the LLC resonant circuit, the current through every full bridge SiCFET is 8.6 Arms, and each SiCFET dissipates 7.4 W.

$$V_{in} = 675 \text{ V} , V_o = 420 \text{ V}$$

Pe17 Circuit



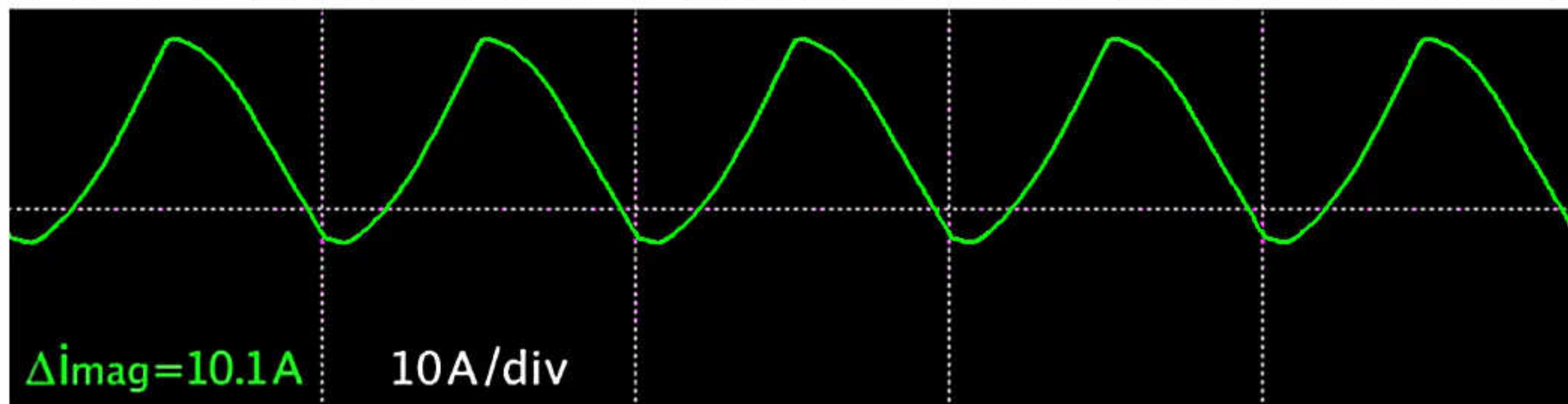
LLC Circuit



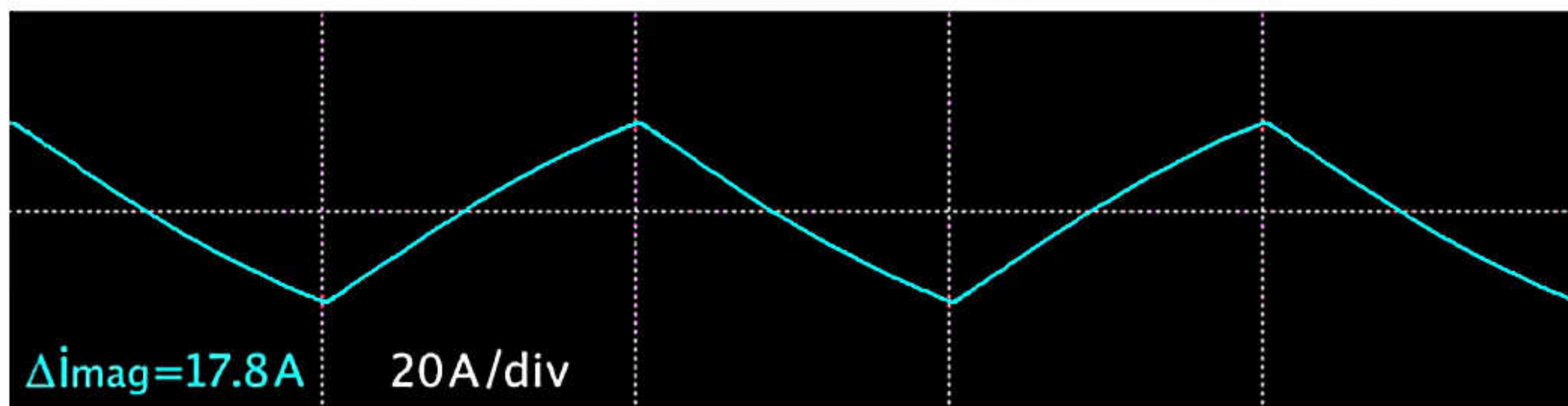
In the Pe17 circuit, the current through the primary winding is 11.1 Arms, and it dissipates 2.2 W.
In the LLC circuit, the current through the primary winding is 12.2 Arms, and it dissipates 3.7 W.

$$V_{in} = 675 \text{ V}, V_o = 420 \text{ V}$$

Pe17 Circuit



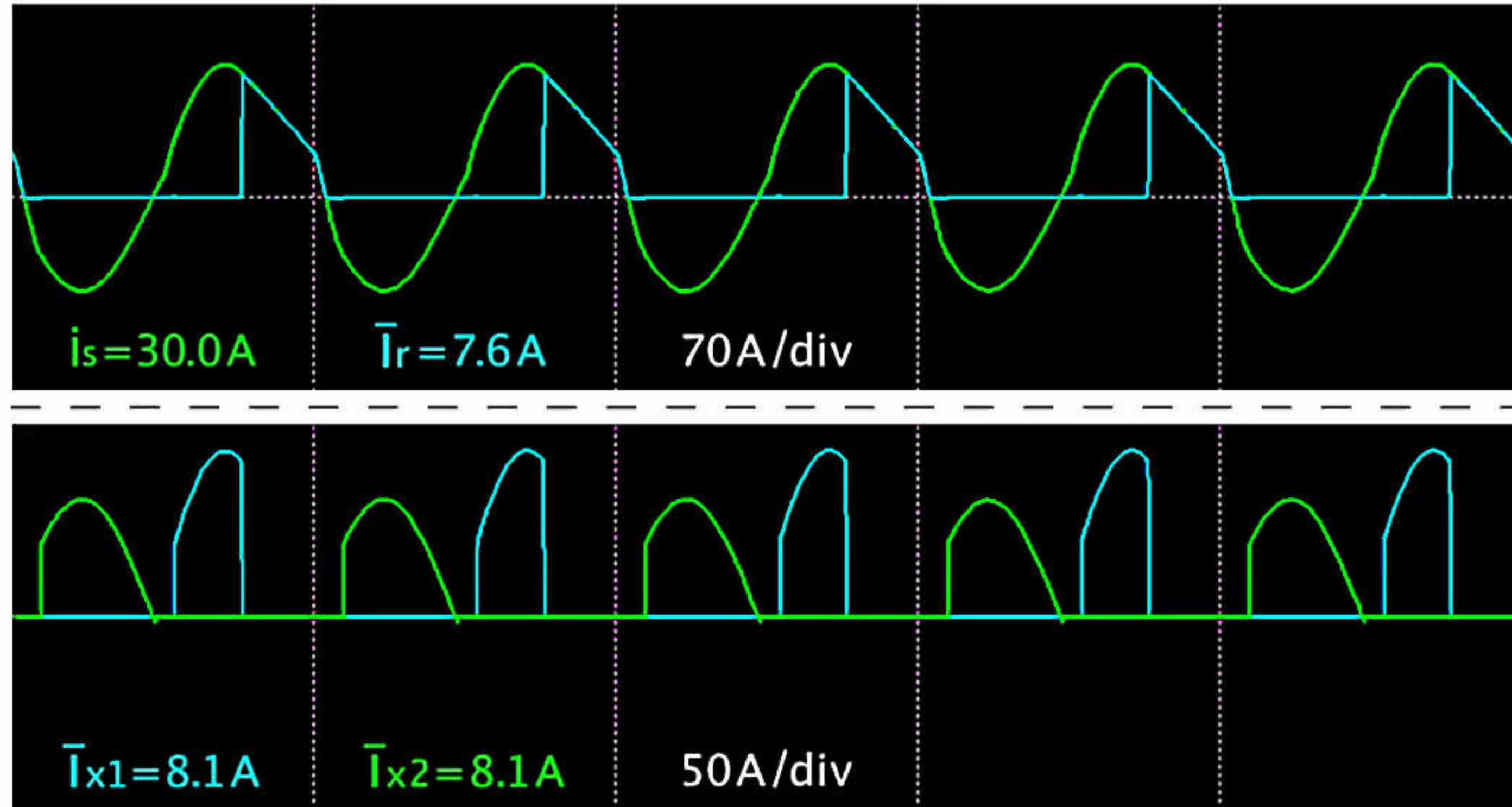
LLC Circuit



In the Pe17 circuit, the peak to peak current through the magnetizing inductance is 10.1 A, the magnetix flux density swing is 124 mT, and the core loss is estimated at 12.6 W. In the LLC resonant circuit, the peak to peak current through the magnetizing inductance is 17.8 A, the magnetix flux density swing is 226 mT, and the core loss is estimated at 21.8 W.

$$V_{in} = 675 \text{ V} , V_o = 420 \text{ V}$$

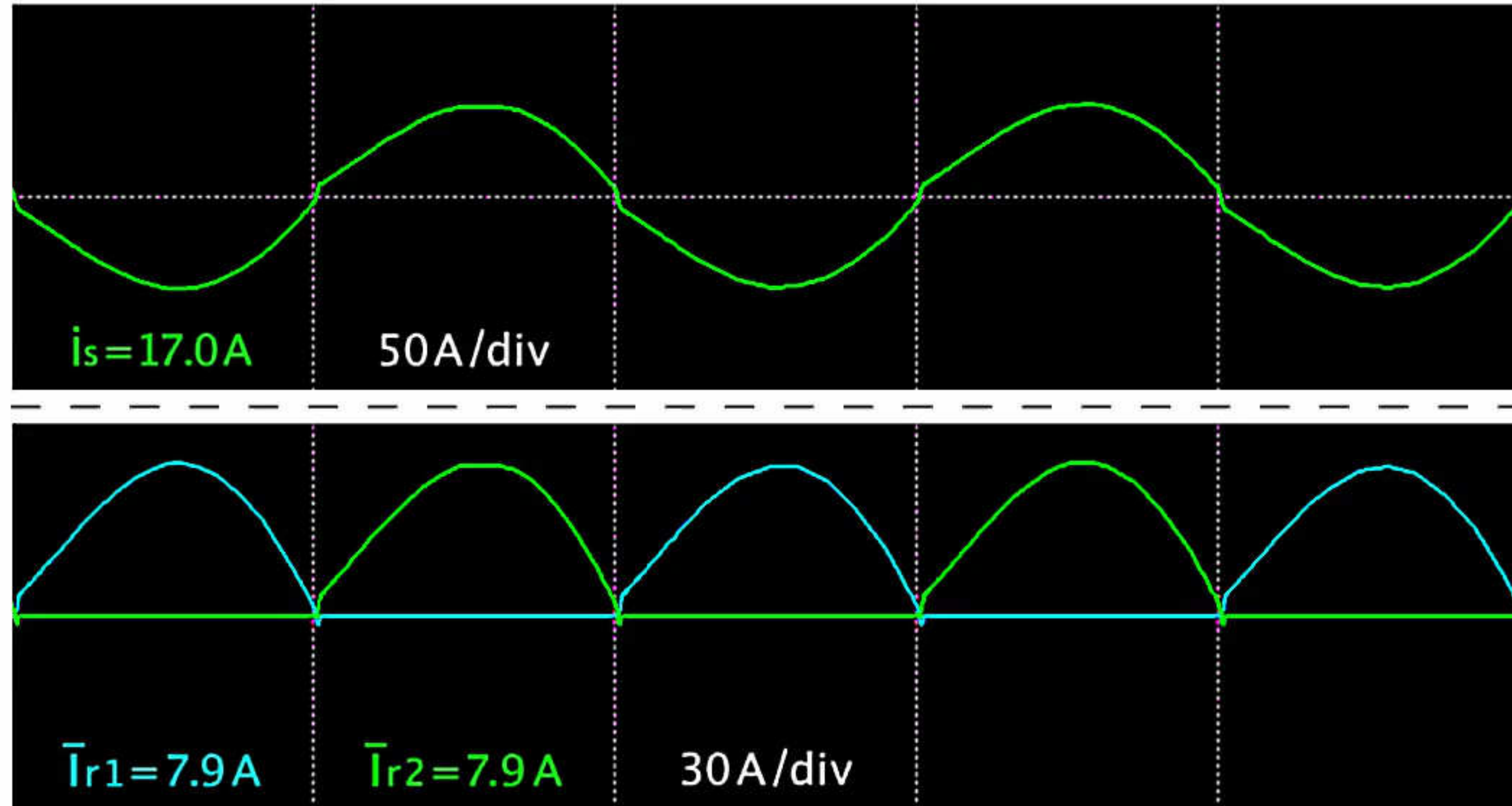
Pe17 Circuit



In the Pe17 circuit, the current through the secondary winding is 30.0 Arms and it dissipates 3.6 W. The average current through the SiC diode is 7.6 A and it dissipates 10.3 W. The average current through the ultra fast diodes is 8.1 A, for which the top one dissipates 7.5 W and the bottom one dissipates 6.9 W.

$$V_{in} = 675 \text{ V} , V_o = 420 \text{ V}$$

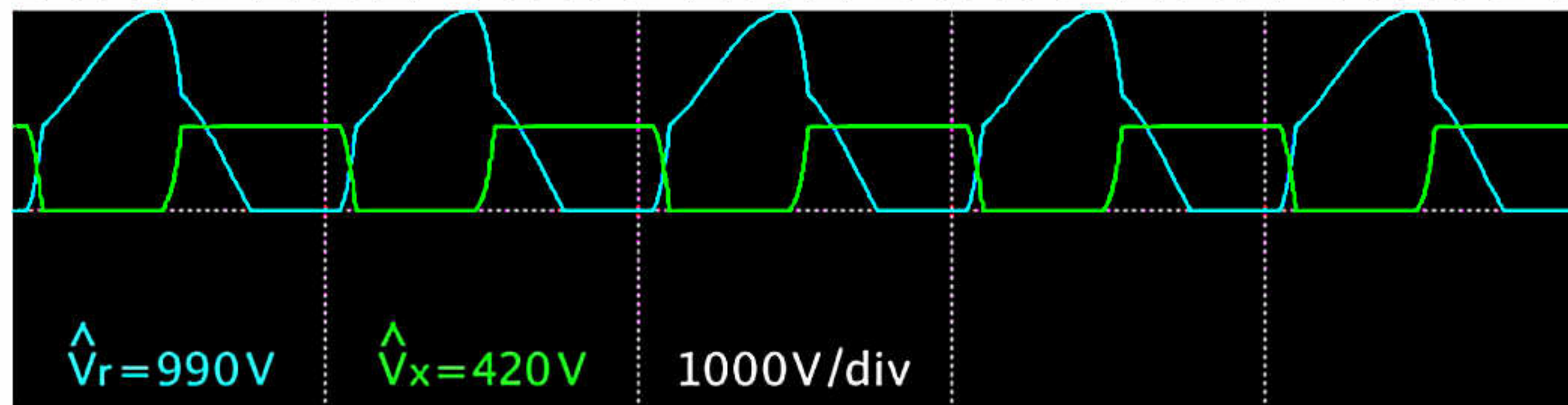
LLC Circuit



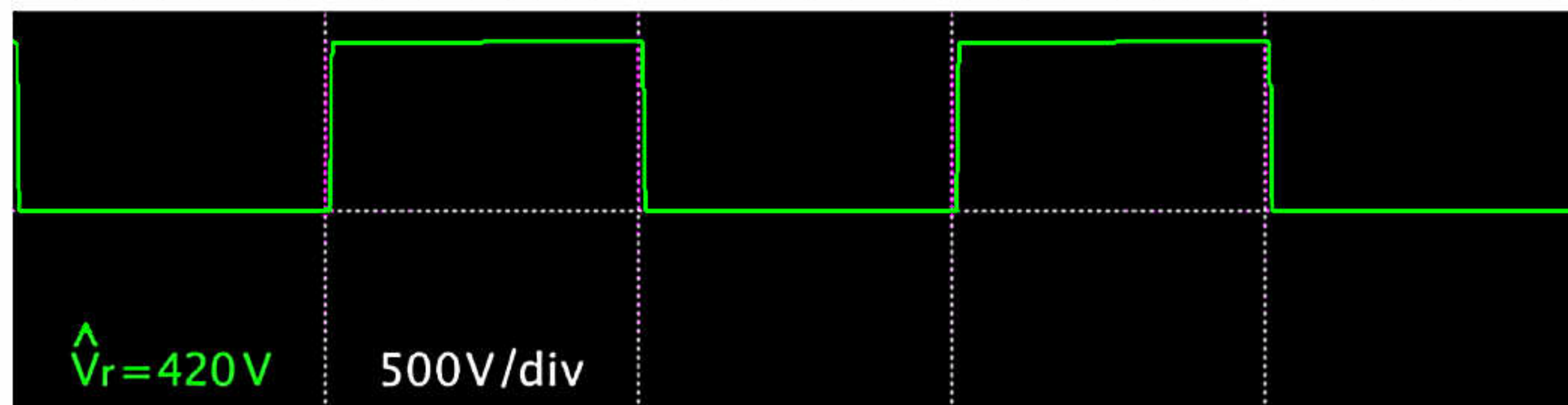
In the LLC resonant circuit, the current through the secondary winding is 17.0 Arms and it dissipates 3.2 W. The average current through each full bridge rectifying diode is 7.9 A. Thus, each diode dissipates 10.0 W.

$$V_{in} = 675 \text{ V} , V_o = 420 \text{ V}$$

Pe17 Circuit



LLC Circuit



In the Pe17 circuit, the reverse voltage across the SiC diode peaks at 990 V. The ultra fast diodes withstand a peak reverse voltage of 420 V. The rise and fall transitions are slow enough such that the reverse recovery losses in the ultra fast diodes are negligible. In the LLC circuit, each rectifying diode withstands a peak reverse voltage of 420 V.

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-> 3. Summery

- Loss Breakdown and Efficiency results
-

Loss Breakdown and Efficiency Results				
Power Loss (W)	Vo = 250 V		Vo = 420 V	
	Pe17 Circuit	LLC Circuit	Pe17 Circuit	LLC Circuit
Full Bridge Inverter	24.4	26.8	24.6	29.6
Primary Winding	2.2	3.4	2.2	3.7
Secondary Winding	3.1	3.4	3.6	3.2
Magnetic Core	3.3	3.5	12.6	21.8
Rectifiers	24.3	40.0	24.7	40.0
Efficiency	98.5 %	98.0 %	99.0 %	98.5 %

THANK YOU