Eddy Current Losses in Active Clamp Forward Converter

To check the Eddy Current Losses influence on the Active Clamp Forward Converter efficiency the two transformer on the same breadboard were replaced. One transformer had the secondary winding made by some thin wires to get eddy current losses as minimum. The secondary winding of the second transformer was made by one wire with the same DC resistance as the first one. The same core and coil former with both primary and bias windings was used, the secondary winding was replaced only.

Converter Parameters:

Vin = 299VDC
Vout = 5VDC
Iout = 15A
F_{SW} = 119kHz
D = 0.37
ΔI_{SEC} = 4.5A_{P-P}

Transformer specification:

Core: ETD-29
Ferrite: N87 by Epcos
Air gap: appr. 0.2mm to meet the primary inductance 3.2mH
Primary: 86T Ø0.19mm
Bias: 2T Ø0.1mm

Secondary – Var. 1:
4T 16 stranded wires Ø0.41mm
R_{DC} = 1.82 mΩ
R_{AC}/R_{DC} = 1.3 for one layer
R_{AC} = 2.37 mΩ

Secondary – Var. 2:
4T Ø1.7 mm.
R_{DC} = 1.83 mΩ
R_{AC}/R_{DC} = 4.5 for one layer
R_{AC} = 8.24 mΩ

RMS of secondary current is the same for both variants:

$$I_{DC} = I_{OUT} * D = 16A * 0.37 = 5.92A$$

$$I_{AC} = I_{OUT} * \sqrt{(D*(1-D)} = 16A * \sqrt{0.37*(1-0.37)} = 7.72A$$

So we must get the secondary winding losses:

Var. 1:

$$P_{\Sigma 1} = R_{DC} * I_{DC}^2 + R_{AC} * I_{AC}^2 = 1.82m\Omega * 5.92A^2 + 2.37m\Omega * 7.72A^2 = 205mW$$

Var. 2:

$$P_{\Sigma 2} = R_{DC} * I_{DC}^2 + R_{AC} * I_{AC}^2 = 1.83m\Omega * 5.92A^2 + 8.24m\Omega * 7.72A^2 = 555mW$$

This difference $P_{\Sigma 1}$ - $P_{\Sigma 2}$ = 350mW should be see in the input current as:

$$\Delta I_{IN} = \frac{P_{\Sigma 1} - P_{\Sigma 2}}{V_{IN}} = \frac{350mW}{299V} = 1.17mA$$

Test set-up and conditions:

Input voltage, Input Current, Output Voltage and Output Current were measured by ESCORT model 95T Multimeters.

The input voltage was provided by B5-50 299VDC, 299mA power supply.

The output was loaded by KIKUSUI model PLZ303W electronic load.

Primary current and drain voltage were monitored by Tektronix model TDS210 oscilloscope.

The full load (15A) was applied for appr. 20min to get stabile temperature on all components. Test was performed at 25°C with no airflow.

Test results:

Variant 1:

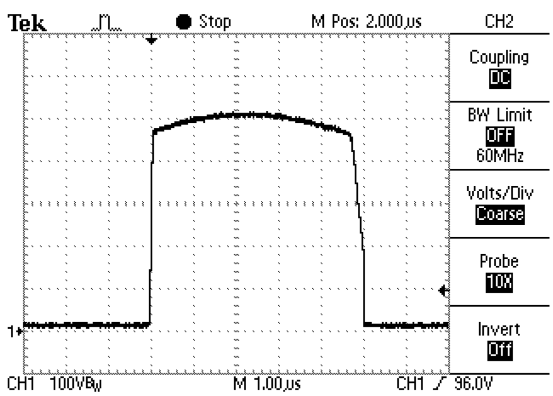
V_{IN} = 299.37V
I_{IN} = 280.50mA
V_{OUT} = 5.023V
I_{OUT} = 15.005A
Eff. = 89.75%

Variant 2:

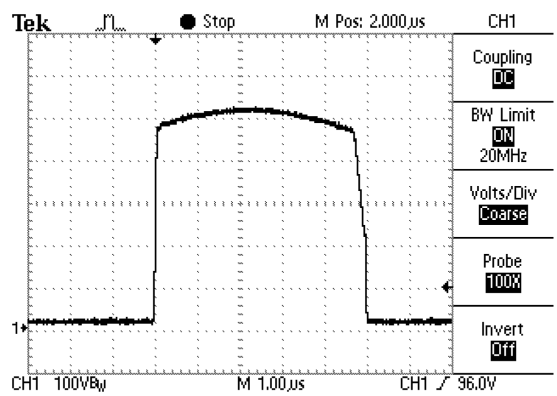
V_{IN} = 299.51V
I_{IN} = 280.37mA
V_{OUT} = 5.023V
I_{OUT} = 15.005A
Eff. = 89.75%

The drain voltage waveforms:

Variant 1:

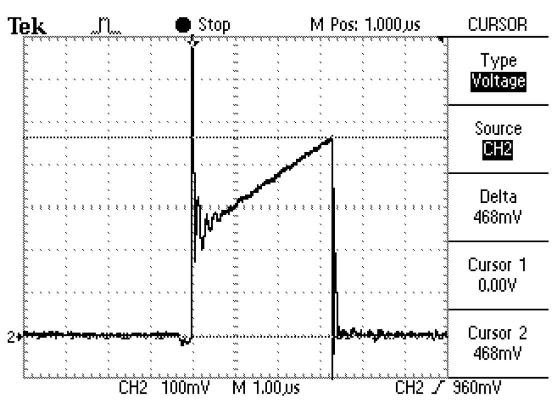


Variant 2:

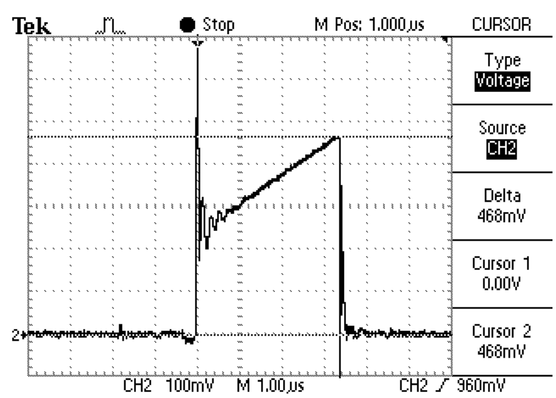


The Primary Current waveforms:

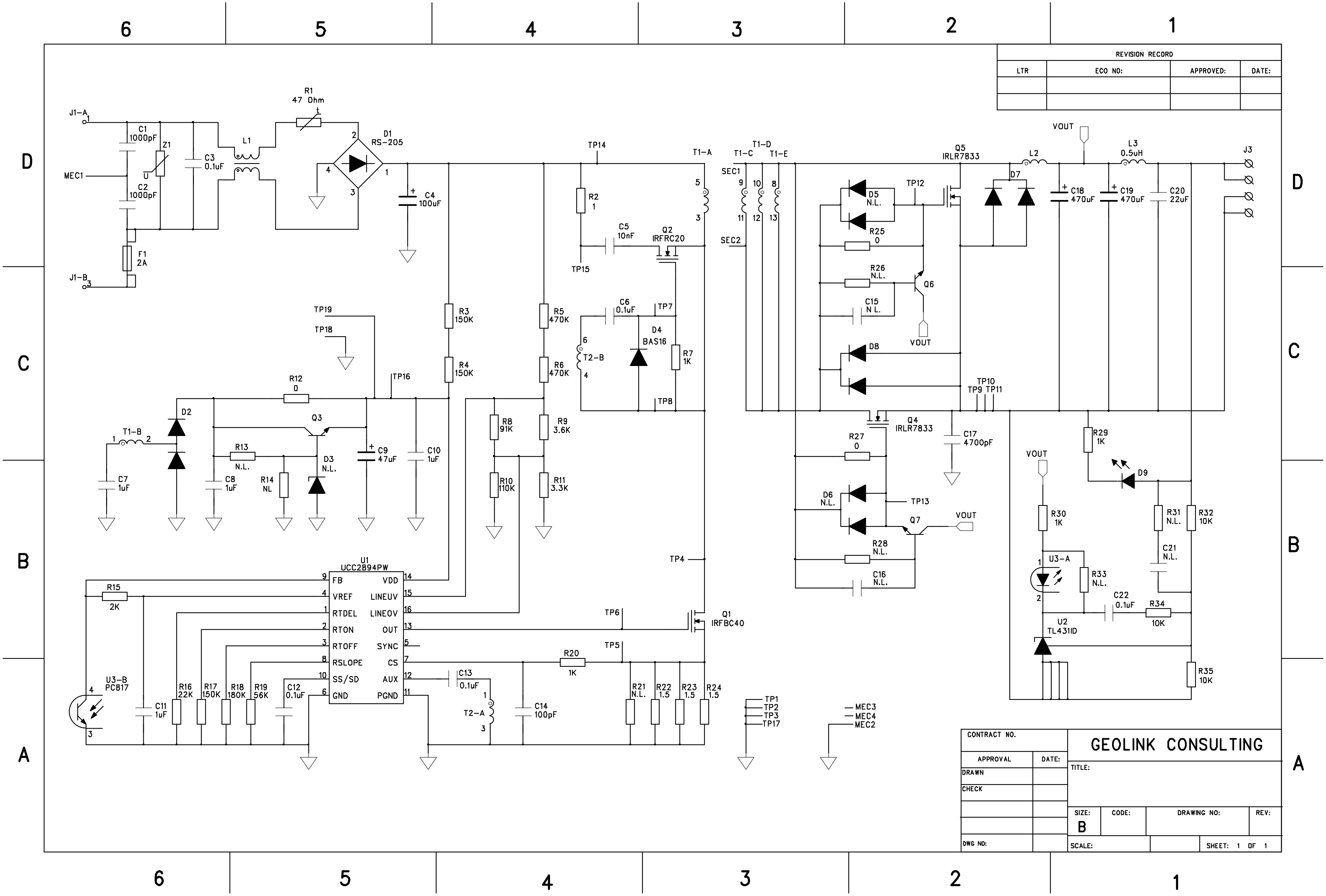
Variant 1:



Variant 2:



The Schematic diagram and Bill of Materials are shown below:



6
5
4
3
2
1
D
C
B
A
REVISION RECORD
LTR
ECO NO:
APPROVED:
DATE:
J1-A
MEC1
J1-B
C1 1000pF
C2 1000pF
Z1
U
C3 0.1uF
F1 2A
R1 47 Ohm
L1
D1 RS-205
C4 100uF
TP14
T1-A
R2 1
C5 10nF
Q2 IRFRC20
TP15
C6 0.1uF
TP7
D4 BAS16
R7 1K
T2-B
TP8
R3 150K
R4 150K
R5 470K
R6 470K
R8 91K
R9 3.6K
R10 110K
R11 3.3K
TP19
TP18
TP16
R12 0
D2
T1-B
Q3
R13 N.L.
D3 N.L.
R14 NL
C7 1uF
C8 1uF
C9 47uF
C10 1uF
U1 UCC2894PW
FB
VREF
RTDEL
RTON
RTOFF
RSLOPE
SS/SD
GND
VDD
LINEUV
LINEOV
OUT
SYNC
CS
AUX
PGND
R15 2K
U3-B PC817
C11 1uF
R16 22K
R17 150K
R18 180K
R19 56K
C12 0.1uF
C13 0.1uF
T2-A
C14 100pF
R20 1K
TP4
TP6
TP5
Q1 IRFBC40
R21 N.L.
R22 1.5
R23 1.5
R24 1.5
TP1
TP2
TP3
TP17
MEC3
MEC4
MEC2
T1-D
T1-C
T1-E
SEC1
SEC2
Q5 IRLR7833
TP12
D5 N.L.
R25 0
R26 N.L.
Q6
C15 N.L.
VOUT
D8
TP10
TP9 TP11
Q4 IRLR7833
C17 4700pF
R27 0
D6 N.L.
TP13
Q7
R28 N.L.
C16 N.L.
L2
D7
L3 0.5uH
C18 470uF
C19 470uF
C20 22uF
J3
R29 1K
D9
R30 1K
U3-A
R33 N.L.
R31 N.L.
R32 10K
C21 N.L.
C22 0.1uF
R34 10K
U2 TL431ID
R35 10K
CONTRACT NO.
APPROVAL
DATE:
DRAWN
CHECK
DWG NO:
GEOLINK CONSULTING
TITLE:
SIZE:
B
CODE:
DRAWING NO:
REV:
SCALE:
SHEET: 1 OF 1

Qty	Ref. Des.	Part Number	Manufacturer	Description
2	C1, C2	B81122-C1102	Epcos	EMI Supression Capacitor, Y2
1	C14	GRM2165C2A101JA01D	Murata	100pF, 100V, NP0, 0603 Ceramic
3	C15, C16, C21	No Load		
1	C17	DE1B3KX472M	Murata	Class Y1 Cap., 4700pF
2	C18, 19	EXR471M25B	Hitano	470uF, 25V, Low ESR, 10*16 Al. Cap.
1	C20	ECJ-4YB0J226M	Panasonic-ECG	22uF, 6V, X5R, 1210 Ceramic
1	C3	B81131-D1104	Epcos	X2 MKT Cap. 0.1uF
1	C4	KMH401E101MP30S	Nippon Chemi-Con	100uF, 400V, 25*25 Al. Cap.
1	C5	ECJ-1VB1H103K	Panasonic-ECG	0.01uF, 500V, X7R, 1206 Ceramic
4	C6, C12, C13, C22	ECJ-1VB1E104K	Panasonic-ECG	0.1uF, 25V, X7R, 0603 Ceramic
4	C7, C8, C10, C11	ECJ-1VB1C105K	Panasonic-ECG	1uF, 16V, X5R, 0603 Ceramic
1	C9	EHR470M50B	Hitano	47uF, 50V, 6.3x11, -40..+105°C Al.
1	D1	RS-205	DC components	2A, 600V SIP Bridge Rectifier
1	D2	BAV99	Philips	Series, General Purpose
5	D3, D5, D6 - D8	No Load		
1	D4	BAS16	Philips	General, 75V, 200mA, SOT-23
1	D9	FYL-30004ET	Foryard	LED Red 3mm through-hole
1	F1	FH-101		5*20 TroughHole Fuse Holder
1	J1	DG305-02V2	Degson	10mm Terminal Block, 2 term.
1	J3	DG25C-04	Degson	300mil Terminal Block, 4 term.
1	L1			AC Common mode choke
1	L2			8.7uH, Core T90-26 Ring, 11T 7*0.8 Inductor
1	L3	SC5020-R50M	EMC	0.5", 24A SMT Power Inductor
1	Q1	IRFBC40	IR	600V, 1.2 Ohm, N-Channel MOSFET, TO-220
1	Q2	IRFRC20	IR	N-ch MOSFET, 600V ,2A, 4.4Ohm, DPAK
3	Q3, Q6, Q7	No Load		
2	Q4, Q5	IRLR7833	IR	N-ch MOSFET, 600V ,2A, 4.4Ohm, DPAK
1	R1	SCK-472	Voltts	NTC termistor 47Ohm 2A
1	R10	CR0603JW114	Bourns	110kOhm, 0603, 5% resistor
1	R11	CR0603FW3301	Bourns	3.3kOhm, 0603, 1% resistor
3	R12, R25, R27	CR0603000	Bourns	0 Ohm, 0603 resistor
6	R13, R14, R31, R33, R21, R26, R28	No Load		1 KOhm, 0603, 5% resistor
1	R15	CR0603FW2001	Bourns	2kOhm, 0603, 1% resistor
1	R16	CR0603FW2202	Bourns	22kOhm, 0603, 1% resistor
1	R17	CR0603FW1503	Bourns	150kOhm, 0603, 1% resistor
1	R18	CR0603FW1803	Bourns	180kOhm, 0603, 1% resistor
1	R19	CR0603FW5602	Bourns	56kOhm, 0603, 1% resistor
1	R2	CR1206JW1R0	Bourns	1 Ohm, 1206, 5% resistor
3	R22 - R24	CR1206JW1R5	Bourns	1.5 Ohm, 1206, 5% resistor
4	R7, R20, R29, R30	CR0603JW102	Bourns	1K, 0603, 5% resistor
3	R32, R34, R35	CR0603FW1002	Bourns	10K, 0603, 1% resistor
2	R3, R4	CR1206JW153	Bourns	150kOhm, 1206, 5% resistor
2	R5, R6	CR1206FW4702	Bourns	Resistor 5% Any Value 1206
1	R8	CR0603JW913	Bourns	91K, 0603, 5% resistor
1	R9	CR0603FW3601	Bourns	3.6K, 0603, 1% resistor
1	T1			75W, 5VOUT Off-Line Power Transformer, ETD-29
1	T2	PE-68386	Pulse Ing.	1:1 Gate Drive Transformer
1	U1	UCC2894PW	TI	Active Clamp, Current Mode PWM Controller
1	U2	TL431ID	TI	Progr. Reference 2.5V,SO-8, Ind.
1	U3	PC817	Sharp	5,3 kV Through Hole Optocoupler
1	Z1	FNR-10K471		Varistor 470V, 45J