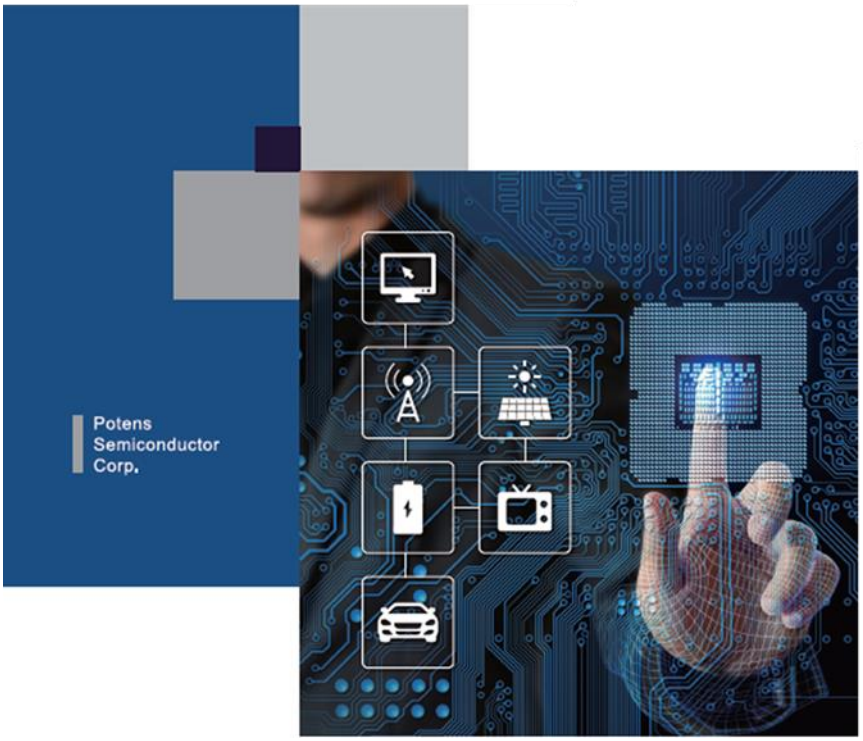
Application Information

GaN-based LLC Circuit Evaluation Board



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1. Introduction

This document provides the features, operations, board setup procedure, and GaN-based LLC design parameters and basic information to designing with the 300W LLC DC/DC resonant converter design (DK1-21) using the 650V 190mΩ Gallium Nitride (GaN) HEMT(PEP15G65H) from Potens Semiconductor Corp [1].

1.1 Circuit Diagram

The evaluation board implements current mode LLC power stage to enhance transient response and secondary side synchronous rectification to maximize efficiency and focuses mainly on GaN HEMTs applied in the power devices of LLC half bridge converter. Fig. 1 shows the power stage circuit, control and feedback circuit for the 300W LLC resonant converter. On the primary side, there are a half bridge GaN daughter board and a main board. GaN daughter board implements two 650V, 190mΩ 8x8mm DFN GaN HEMTs on both high side and low side; the gate drive ICs (LM5114), LLC control IC (NCP1398) and isolated DC/DC converter are included on the main boards to drive the GaN HEMTs [2].

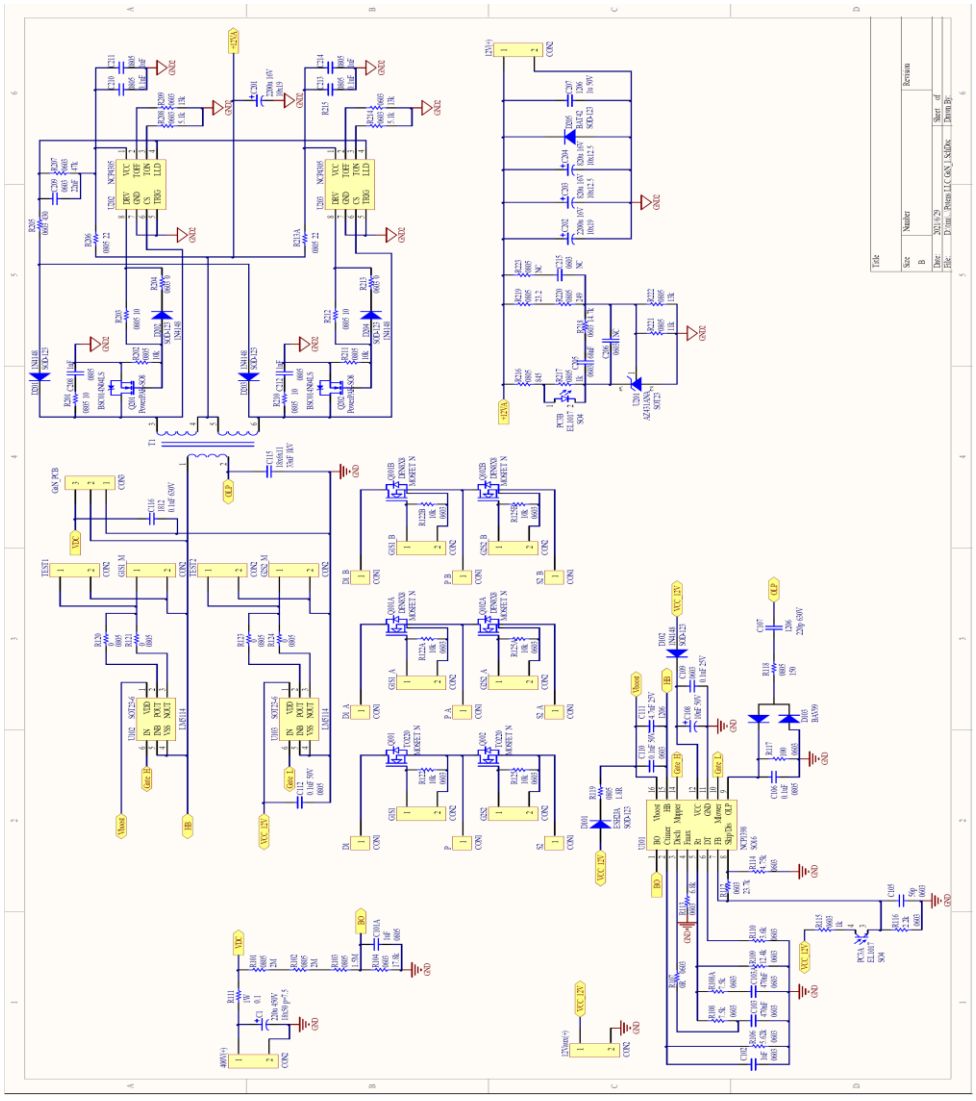


Fig. 1 The circuit diagram of DK1-21 GaN-based LLC evaluation board

1.2 Specifications

Table 1 is the main parameters of the DK1-21evaluation board.

1.3 Evaluation Board

Figure 2 shows the top side photo of the DK1-21evaluation board which include a main board and GaN daughter board. Figure 3 shows the bottom side photo of the DK1-21evaluation board.

Table 1. DK1-21evaluation board specifications

Parameter	Value
Input voltage	400Vdc
Output voltage	12Vdc
Output current	25A
Total output power	300W
Load regulation	11.4V~12.6V

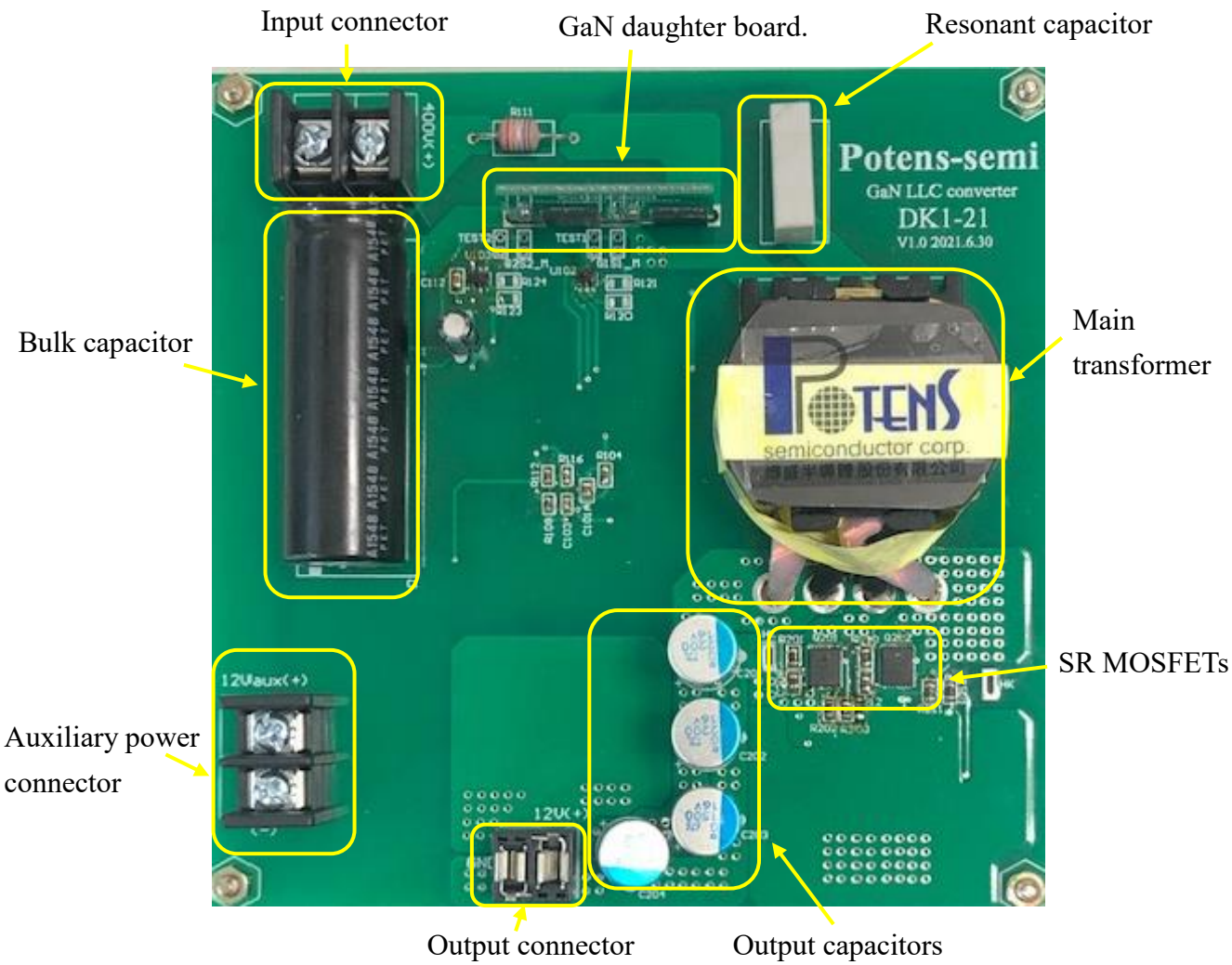


Fig. 2 the top side of the DK1-21 GaN-based LLC evaluation board

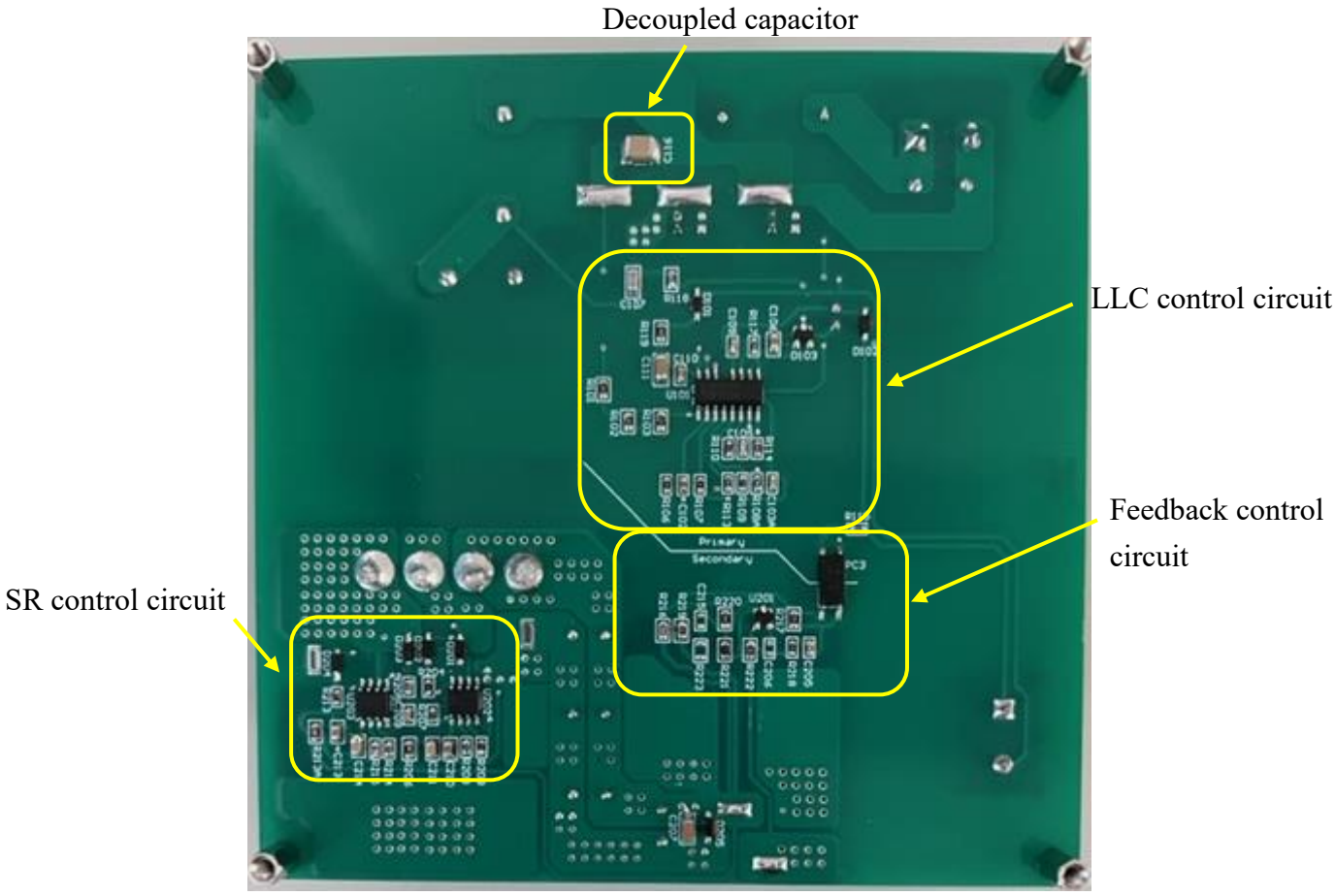


Fig. 3 the bottom side of the DK1-21 GaN-based LLC evaluation board

1.4 Test Setup

The evaluation board test setup is as follows:

Step 1. Auxiliary power connector connects to DC source(1) (Voltage setting: 12Vdc)

Step 2. Input connector connects to DC source(2) (Voltage setting:400Vdc)

Step 3. Output connector connects to DC load

Step 4. Pay attention on the inrush current and increase DC input voltage slowly from 0 to 400V.

Step 5. Power on auxiliary supply (12Vdc)

Step 6. Adjust output loading (0A~25A)

2. Design Considerations

2.1 Layout Guideline

Due to high dv/dt for GaN applying, PCB layout should be avoided or minimize the parasitic effect to reduce spike noise which could interfere PWM control signal. Please follows the some attention:

1. Connect a decoupled capacitor (Cs) to the drain terminal of Q1 and to the source of

Q2 closely shown as Fig. 4.

2. Make a very short current loop against transient switching.
3. Avoid parasitic inductance on PCB area near GaN device.

2.2 LLC Resonant Tank Design

The LLC convert is a typical soft switching converter which is widely used in DC/DC conversions. The GaNs are the high frequency power switches of half bridge and configured to output the square wave voltage. The MOSFETs with low Rdson and Qg are the power switches of the secondary side synchronous rectifier for achieving high efficiency. The fundamental harmonic approximation (FHA) method is used to simplify the voltage gain of the LLC converter [3]-[4]. By FHA method, the AC equivalent circuit of the LLC converter can be obtained as shown in Fig. 5. The resonant tank includes three main components which are resonant inductors L_r, magnetic inductor L_m and resonant capacitor C_r. The resonant frequency is given as

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \tag{1}$$

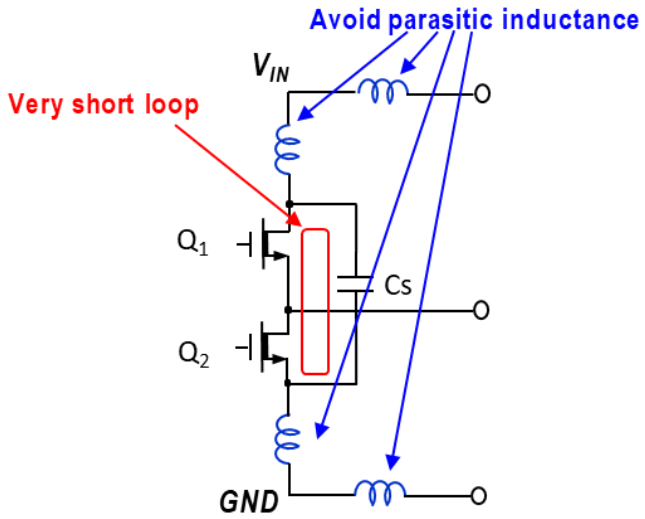


Fig. 4 Parasitic effect of LLC half bridge circuit

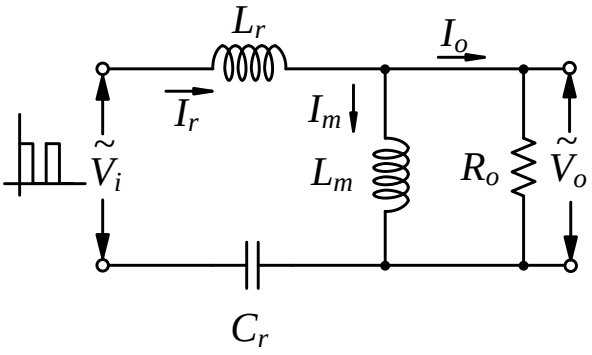


Fig. 5 Equivalent circuit of LLC converter

The voltage gain G of the LLC resonant tank can be expressed as

$$G = \frac{1}{\sqrt{\left(1+1/k(1-(f_s/f_r)^2)\right)^2 + Q^2(f_s/f_r - f_r/f_s)^2}} \quad (2)$$

where k is the ratio of inductance for magnetizing inductance to leakage inductance denoting as $k = L_m/L_r$; and f_s is the converter switching frequency, Q is the quality factor denoting as $Q = (\pi^2/8a^2R_L)\sqrt{(L_r/C_r)}$, and R_L is the equivalent load resistance. Table 2 is main parameters of LLC resonant tank design. According to (2), the voltage gain of the resonant tank under different load conditions is shown as Fig. 6.

Table 2. Main parameters of LLC converter

Parameter	Value
Resonant inductors L_r	32 μ H
Magnetic inductor L_m	383 μ H
Resonant capacitor C_r	33nF
Resonant frequency f_r	155kHz
Transformer turn ratio	34:2

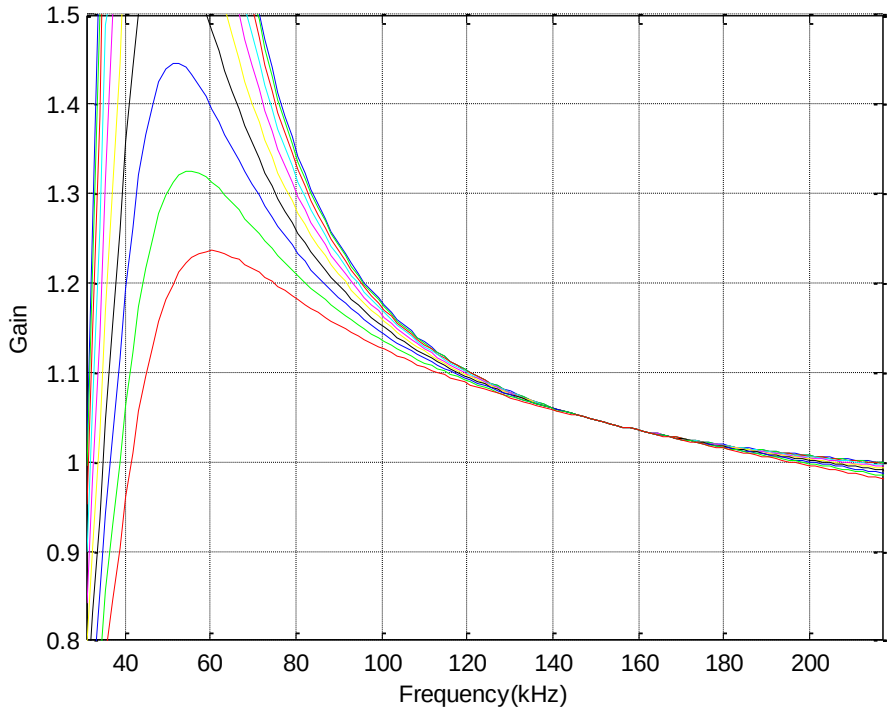


Fig. 6 The gain of the resonant tank under different load conditions

3. Test Results

The test equipment and experimental results of the DK1-21 GaN-based LLC evaluation board are shown as:

3.1 Test Equipment

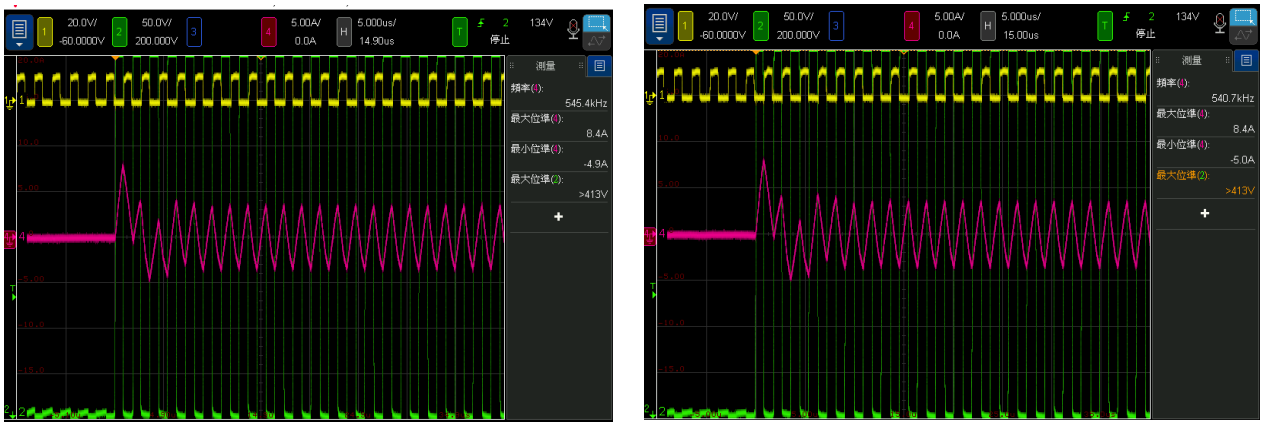
The table 3 shows the test equipment.

Table 3. List of the test equipment

Test equipment	Model
DC Power Supply	LEA HOLD GC1K-05D
DC Power Supply	ITECH IT6874A
Electronic load	ITECH IT8700
Power meter	YOKOGAWA WT310
Oscilloscope	Angilent DSO-X 6004A

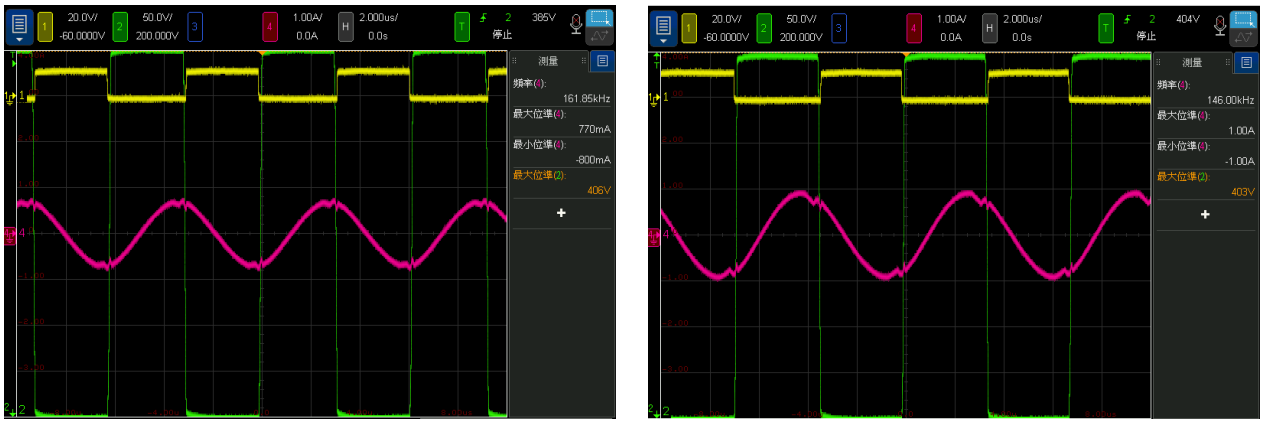
3.2 Test waveforms

Fig. 7(a)(b) shows the startup waveforms at no load and full load. During the startup, the switching frequency starts from max 540KHz and then down to the resonant frequency. (CH1: Vgs of low side GaN, CH2: Resonant current, CH4: Vds of low side GaN. Fig. 8 (a)-(f) shows the steady state waveforms at 10%, 20%, 25%, 50%, 75%, 100% load and the switching frequency is from 160kHz to 125kHz.

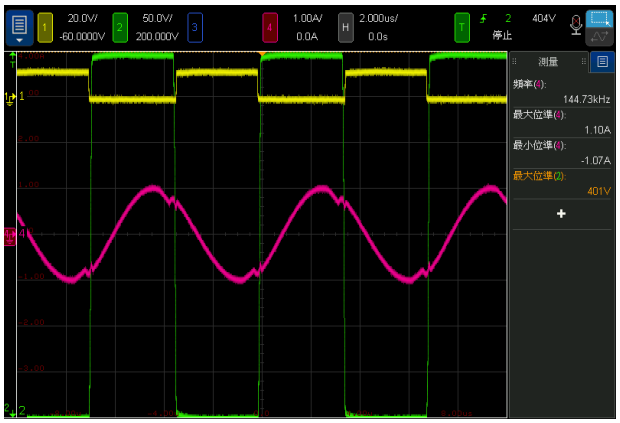


(a) (b)

Fig. 7 The startup waveforms (a) no load (b) full load



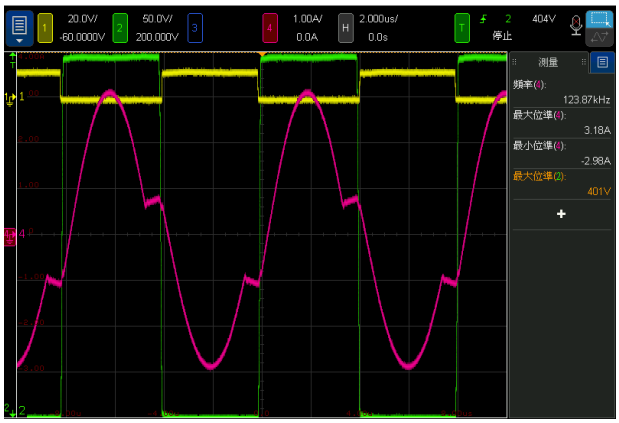
(a) (b)



(c)

(d)

(e)



(f)

Fig. 8 The steady state waveforms (a) 10% load (b) 20% load (c) 25% load (d) 50% load (e) 75% load (f) 100% load

3.3 Efficiency

The efficiency data are shown in Fig. 9.

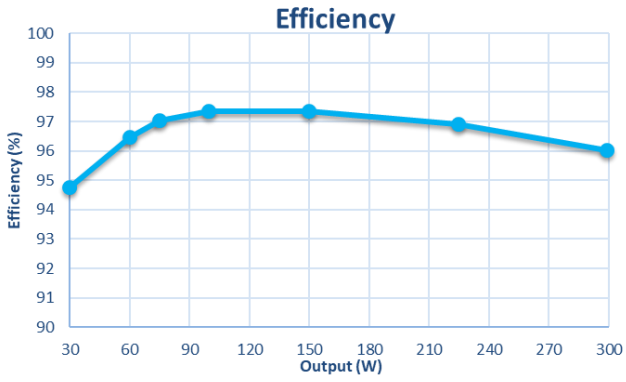


Fig. 9 the efficiency of LLC converter

4. Reference

[1] Potens Semiconductor, “650V 240mΩ GaN,” PEB15GC65HDS datasheet.

[2] Onsemi, “High Performance Resonant Mode Controller with Integrated High-Voltage Drivers,” NCP1398 datasheet.

[3] M. Mu and Fred C. Lee, “Design and Optimization of a 380-12 V High-Frequency- High-Current

LLC Converter With GaN Devices and Planar Matrix Transformers, ” IEEE J. Emerg. Sel. Topics Power Electron., vol. 4, no. 3, pp. 854-862, Sep., 2016.

[4] C. G. Chen, S. H. Lee, W. N. Huang, C. M. Yu and M. C. Meng, “Efficiency Improving Strategies on GaN-based LLC Converter with Non-uniform Air Gap Transformer, ” *in Proc. 2022 int. Power Electron. Conf.* (*IPEC-Himaji 2022 - ECCE Asia*), May 2022, pp. 471–476.

5. Appendix

The bill of materials for the DK1-21evaluation board is shown in Table 4.

Table 4. Bill of materials

Location	Layer	Description	Qty	UI	Maker List	Vendor Material
C1	Top	220u 450V	1	PC	RUBYCON	220u 450V
C101A	Top	CP 1u 50V K X7R 0805 LF	1	PC	YAGEO	CC0805KKX7R9BB105
C102	Bottom	CP 1u 16V K X5R 0603 LF	1	PC	YAGEO	CC0603KRX5R7BB105
C103	Top	CP 0.47u 25V K X7R 0603 LF	1	PC	Walsin	0603B474K250CT
C105	Bottom	CP 56p 50V J NP0 0603 LF	1	PC	YAGEO	CC0603JRNPO9BN560
C107	Bottom	CP 220p 630V J NP0 1206 LF	1	PC	YAGEO	CC1206JKNPOZBN221
C108	Top	EC 10u 50V M 105 5KH 5x11 TP=2.5 LF	1	PC	NICHICON	UHE1H100MDD1TD
C111	Bottom	CP 4.7u 25V K X7R 1206 LF	1	PC	YAGEO	CC1206KKX7R8BB475
C113, C114	Top	CP 820p 50V J NP0 0603 LF	2	PC	YAGEO	CC0603JRNPO9BN821
C115	Top	FC 33n 1KV J MPP P=15 LF	1	PC	EUROPTRONIC	MPLB333J3AL15LLD20
C106,C112,C210,C213	Top	CP 0.1u 50V K X7R 0805	4	PC	MURATA	GRM21BR71H104KA01L
C201,C202	Top	2200u 16V TP=5 LF	2	PC	NICHICON	APSG106ELL222MJ20S
C203,C204	Top	1500u 16V TP=5 LF	2	PC	NICHICON	APSG106ELL152MJ20S
C205	Bottom	CP 68n 50V K X7R 0603 LF	1	PC	YAGEO	CC0603KRX7R9BB683
C207	Bottom	CP 1u 50V K X7R 1206 LF	1	PC	YAGEO	CC1206KKX7R9BB105
C208, C212, C909	Top	CP 1n 50V J NP0 0805 LF	3	PC	WALSIN	0805N102J500CT
C209	Bottom	CP 22n 25V K X7R 0603 LF	1	PC	YAGEO	CC0603KRX7R8BB223
C211, C214	Bottom	CP 1u 50V K X7R 0805 LF	2	PC	YAGEO	CC0805KKX7R9BB105
C116	Top	CP 0.1u 630V K X7R 1812 LF	1	PC	MURATA	GRM43DR72J104KW01L
C109,C110	Bottom	CP 0.1u 25V K X7R 0603 LF	2	PC	YAGEO	CC0603KRX7R8BB104
400V(+)	Top	CONN HEADER	1	PC	ANYTEK	YK-421
12Vaux(+)	Top	CONN HEADER	1	PC	ANYTEK	YK-421
12V(+)	Top	CONN HEADER PBT 94V0 1R 2P P5.35	1	PC	JST	2R-JPSXK-2(LF)(SN)
D101	Bottom	DIODE-SMD 600V 1A	1	PC	TSC	ESH1JM
D102,201,D202,D203,D204	Bottom	DIODE-SMD 100V 150mA Trr=4ns SOD123 T/R	5	PC	DIODES	1N4148W
D103	Bottom	DIODE-SMD 85V 215mA Trr=4ns SOT23 T-R	1	PC	NXP	BAV99
D205	Bottom	SCHOTTKY-SMD 30V 200mA SOD123 T-R	1	PC	DIODES	BAT42W-7-F
PC3	Bottom	PHOTO-SMD CTR=80-160 LSOP4 T/R P=10.1	1	PC	LITE ON	LTV-1007-TP1-G
Q101,Q102	Top	PGA26E19BV	2	PC	PANASONIC	PGA26E19BV
Q201,Q202	Top	NMOS SMD 40V 100A 150C SuperSO8 FL T/R	2	PC	INFINEON	BSC014N04LS
R123,R127, R202, R211	Top	R-CHIP 10K 1/8W F 0805 Thick Film	4	PC	RALEC	RTT051002FTP
R122, R126	Top	R-CHIP 5.1 1/10W F 0603 Thick Film	2	PC	RALEC	RTT035R10FTP
R101, R102	Bottom	R-CHIP-HV 2M 1-8W F 0805	2	PC	TA-I	RH10FTN2004
R103	Bottom	R-CHIP 1.5M 1/8W F 0805 Thick Film	1	PC	RALEC	RTT051504FTP
R104	Top	R-CHIP 17.8K 1/10W F 0603 Thick Film	1	PC	TA-I	RM06FTN1782
R106	Bottom	R-CHIP 5.62K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT035621FTP
R107,R204,R213	Bottom	R-CHIP 0 1/10W F 0603 Thick Film	2	PC	RALEC	RTT030000FTP
R108	Top	R-CHIP 7.5K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT037501FTP
R109	Bottom	R-CHIP 23.7K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT032372FTP
R110	Bottom	R-CHIP 3.6K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT033601FTP
R111	Top	R-FR 0.1 1W J HOR	1	PC	FUTABA	RFB01JR100A520NH
R112	Top	R-CHIP 30K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT033002FTP
R113	Bottom	R-CHIP 6.8K 1/10W D 0603 Thick Film	1	PC	RALEC	RTT036801DTP
R114	Bottom	R-CHIP 4.75K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT034751FTP
R115	Bottom	R-CHIP 1K 1/10W D 0603 Thick Film	1	PC	RALEC	RTT031001DTP
R116	Top	R-CHIP 2.2K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT032201FTP
R117	Bottom	R-CHIP 100 1/10W F 0603 Thick Film	1	PC	RALEC	RTT031000FTP
R118	Bottom	R-CHIP 150 1/10W F 0603 Thick Film	1	PC	RALEC	RTT031500FTP
R120,R124	Top	R-CHIP 1.8K 1/10W F 0603 Thin Film	2	PC	WALSIN	WF06R1801BTL
R121, R125	Top	R-CHIP 20 1/10W F 0603 Thick Film	2	PC	RALEC	RTT0320R0FTP
R119	Bottom	R-CHIP 1.8 1/8W F 0805 Thick Film	1	PC	RALEC	RTT051R80FTP
R201, R203, R210, R212	Top	R-CHIP 10 1/8W F 0805 Thick Film	4	PC	RALEC	RTT0510R0FTP
R205	Bottom	R-CHIP 430 1/10W F 0603 Thick Film	1	PC	RALEC	RTT034300FTP
R206, R213A	Bottom	R-CHIP 22 1/8W F 0805 Thick Film	2	PC	RALEC	158F022013L0LF
R207	Bottom	R-CHIP 47K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT034702FTP
R208, R214	Bottom	R-CHIP 5.1K 1/10W F 0603 Thick Film	2	PC	RALEC	RTT035101FTP
R209, R215	Bottom	R-CHIP 13K 1/10W F 0603 Thick Film	2	PC	RALEC	RTT031302FTP
R216	Bottom	R-CHIP 845 1/8W F 0805 Thick Film	1	PC	RALEC	RTT058450FTP
R217	Bottom	R-CHIP 1K 1-8W F 0805 Thick Film	1	PC	RALEC	RTT051001FTP
R218	Bottom	R-CHIP 14.7K 1/10W F 0603 Thick Film	1	PC	RALEC	RTT031472FTP
R219	Bottom	R-CHIP 23.2K 1/8W F 0805 Thick Film	1	PC	RALEC	RTT052322FTP
R220	Bottom	R-CHIP 249 1/8W F 0805 Thick Film	1	PC	RALEC	RTT052490FTP
R221	Bottom	R-CHIP 11K 1/8W F 0805 Thick Film	1	PC	RALEC	RTT051102FTP
R222	Bottom	R-CHIP 13K 1/8W F 0805 Thick Film	1	PC	RALEC	RTT051302FTP
R227, R228	Bottom	R-CHIP 100 1/4W F 1206 Thick Film	2	PC	TA-I	RM12FTN1000
T1	Top	CC4022 JPP95 Lr=32uH, Lm=415uH, N1: 34Turns 0.1mm×50, N2: 2Turns 0.1mm×400	1	PC	NA	NA
U101	Bottom	LLC Controller	1	PC	ON	NCP1398BDR2G
U102, U103	Top	MOS Driver	2	PC	TI	LM5114AMFX/NOPB
U201	Bottom	IC-SMD REGULATOR SOT23 T-R	1	PC	DIODES-BCD	AS431ANTR-E1
U202,U203	Bottom	SR Driver	2	PC	ON	NCP4305DDR2G
		Total	103	PC		