

# LTC3765/LTC3766

## 360W Isolated Forward Converter with Synchronous Rectification

### DESCRIPTION

Demonstration circuit 2199A-A is a 360W isolated forward converter with synchronous rectification featuring the [LTC3765/LTC3766](#). It produces a regulated 12V, 30A output from an input voltage range of 36V to 60V.

This circuit was designed to demonstrate the high levels of performance, efficiency, and small solution size attainable using these parts in an active-clamp-reset forward converter power supply, suitable for telecom, industrial, and other applications. It has a 4.7in<sup>2</sup> solution footprint area. Synchronous rectification helps to attain an effi-

ciency exceeding 96%. Secondary-side control eliminates complex opto-coupler feedback, providing fast transient response with minimum output capacitance. For other output requirements, see the LTC3766 data sheet or contact the LTC sales.

**Design files for this circuit board are available at <http://www.linear.com/demo/DC2199A-A>**

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### PERFORMANCE SUMMARY Specifications are at T<sub>A</sub> = 25°C

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V <sub>IN</sub>	Input Supply Range		36		60	V
V <sub>OUT</sub>	Output Voltage		11.76	12.0	12.24	V
I <sub>OUT</sub>	Output Current Range, Continuous	200LFM	0		30	A
f <sub>SW</sub>	Switching (Clock) Frequency			200		kHz
V <sub>OUT(P-P)</sub>	Output Ripple	V <sub>IN</sub> = 24V, I <sub>OUT</sub> = 30A (20MHz BW)		60		mV <sub>P-P</sub>
I <sub>REG</sub>	Output Regulation	Line and Load (36V <sub>IN</sub> to 60V <sub>IN</sub> , 0A <sub>OUT</sub> to 30A <sub>OUT</sub> )		±0.02		%
P <sub>OUT</sub> /P <sub>IN</sub>	Efficiency (See Figure 3)	V <sub>IN</sub> = 48V, I <sub>OUT</sub> = 30A		96		%
	Isolation	Basic		1500		VDC
	Approximate Solution Size	Component Area × Top Component Height		4.7in <sup>2</sup> × 0.6		Inches

## OPERATING PRINCIPLES

The LTC3765 active clamp forward controller and gate driver is used on the primary and provides start-up, gate drive, and protection functions. Once start-up is accomplished, the LTC3766 high efficiency, secondary-side synchronous forward controller takes over, and provides the LTC3765 with timing information and bias power through a small pulse transformer.

When input voltage is applied, the LTC3765 commences soft-start of the output voltage. When the output reaches the RUN threshold, the LTC3766 comes alive and takes control by sending encoded PWM gate pulses to the LTC3765 through T2. These pulses also provide primary bias power efficiently over a wide input voltage range.

The transition from primary to secondary control occurs at some fraction of the nominal output voltage. From then on, operation and design is reduced to that of a simple

buck converter. Secondary control eliminates delays, tames large-signal overshoot, and reduces output capacitance needed to meet transient response requirements.

An optional LC filter stage on the input lowers RMS input current. The filter must have output impedance that is less than the converter input impedance to assure stability. This may require a damping impedance, which is provided by R1. (See Linear Technology Application Note 19 for a discussion of input filter stability.) R1 is coupled through a tiny 2mm × 2mm inductor L1, and provides damping with arbitrarily low source impedance. For bench testing, an electrolytic capacitor has been added at the input terminals to provide suitable ripple current capability. The values selected have a filter resonant frequency that is below the converter switching frequency, thus avoiding high circulating currents in the filter.

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## QUICK START PROCEDURE

Demonstration circuit 2199A-A is easy to set up to evaluate the performance of the LTC3765/LTC3766. Refer to Figure 1 for proper measurement equipment setup and follow the procedure below:

NOTE: When measuring the output voltage ripple, care must be taken to avoid a long ground lead on the oscilloscope probe. Measure the output voltage ripple by touching the probe tip and ground ring directly across the last output capacitor as shown in Figure 1.

1. Set an input power supply that is capable of 36V to 60V to 36V. Then turn off the supply.
2. Direct an airflow of 200LFM across the unit for sustained operation at full load.
3. With power off, connect the supply to the input terminals  $+V_{IN}$  and  $-V_{IN}$ .
  - a. Input voltages lower than 36V can keep the converter from turning on due to the undervoltage lockout feature of the LTC3765/LTC3766.

- b. If efficiency measurements are desired, an ammeter capable of measuring 15ADC or a resistor shunt can be put in series with the input supply in order to measure the DC2199A-A's input current.
- c. A voltmeter with a capability of measuring at least 60V can be placed across the input terminals in order to get an accurate input voltage measurement.

4. Turn on the power at the input.

NOTE: Make sure that the input voltage never exceeds 60V.

5. Check for the proper output voltage of 12V. Turn off the power at the input.
6. Once the proper output voltages are established, connect a variable load capable of sinking 30A at 12V to the output terminals  $+V_{OUT}$  and  $-V_{OUT}$ . Set the current for 0A.
  - a. If efficiency measurements are desired, an ammeter or a resistor shunt that is capable of handling 30ADC can be put in series with the output load in order to measure the DC2199A-A's output current.

## QUICK START PROCEDURE

- b. A voltmeter with a capability of measuring at least 12V can be placed across the output terminals in order to get an accurate output voltage measurement.
7. Turn on the power at the input.
8. Once the proper output voltage is again established, adjust the load within the operating range and observe the output voltage regulation, ripple voltage, efficiency and other desired parameters.

NOTE. If there is no output, temporarily disconnect the load to make sure that the load is not set too high.

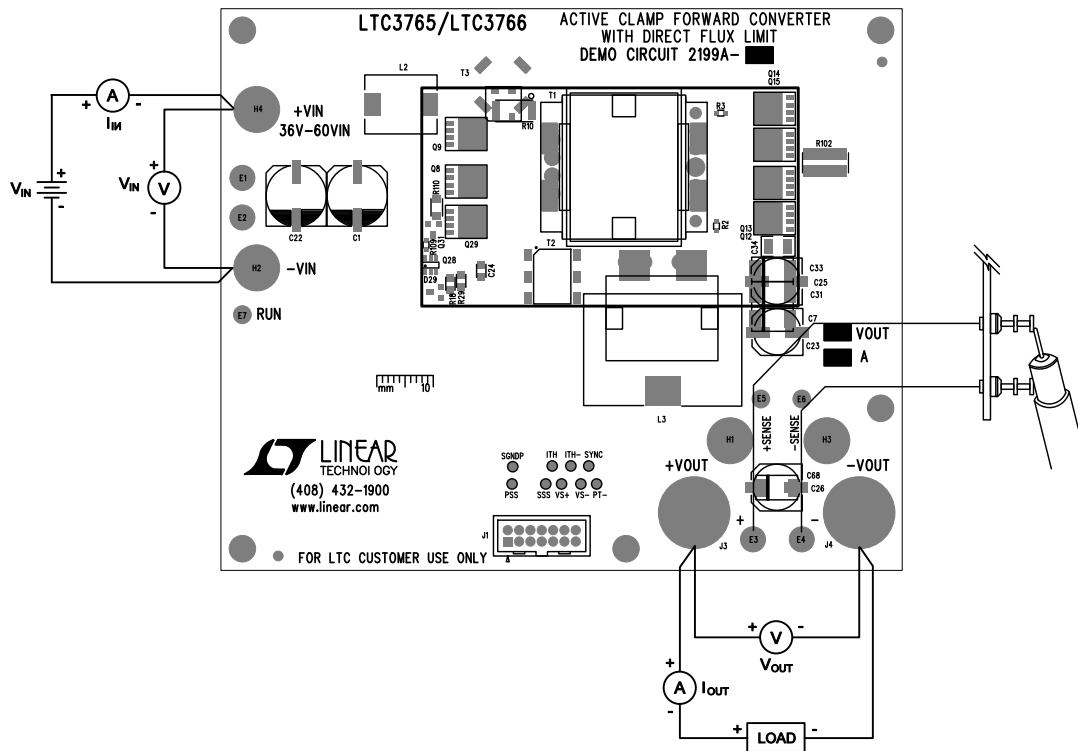


Figure 1. Proper Measurement Equipment Setup

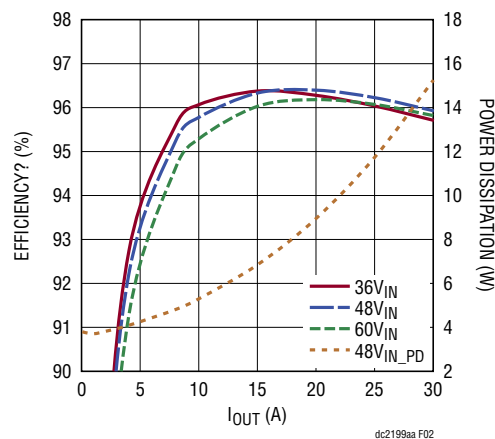


Figure 2. Efficiency and Power Dissipation

## QUICK START PROCEDURE

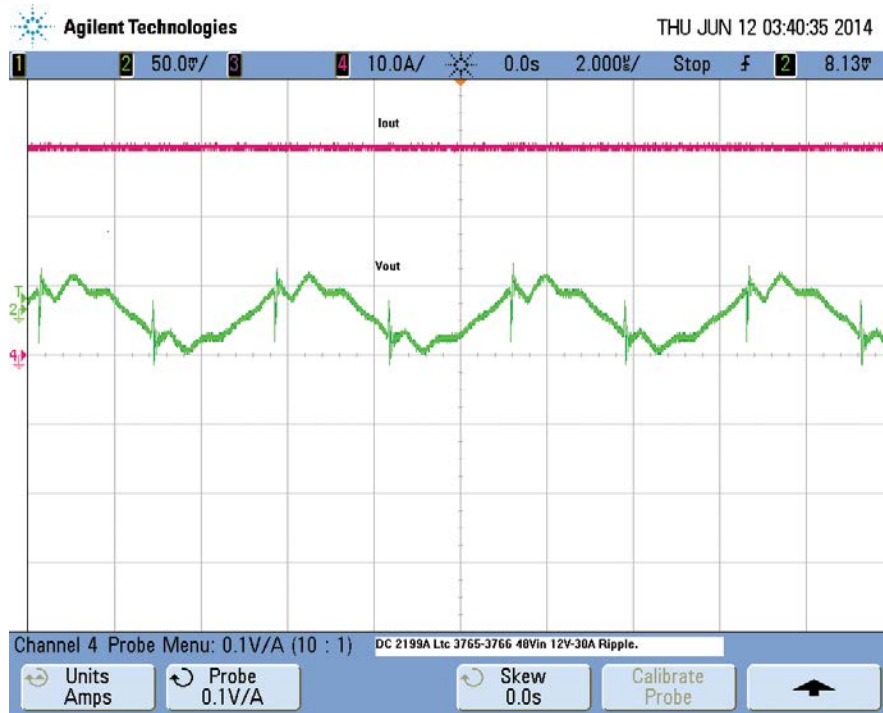


Figure 3. Output Ripple at 48V<sub>IN</sub> and 30A<sub>OUT</sub> (50mV, 10A, 2μs/DIV, 20MHz)

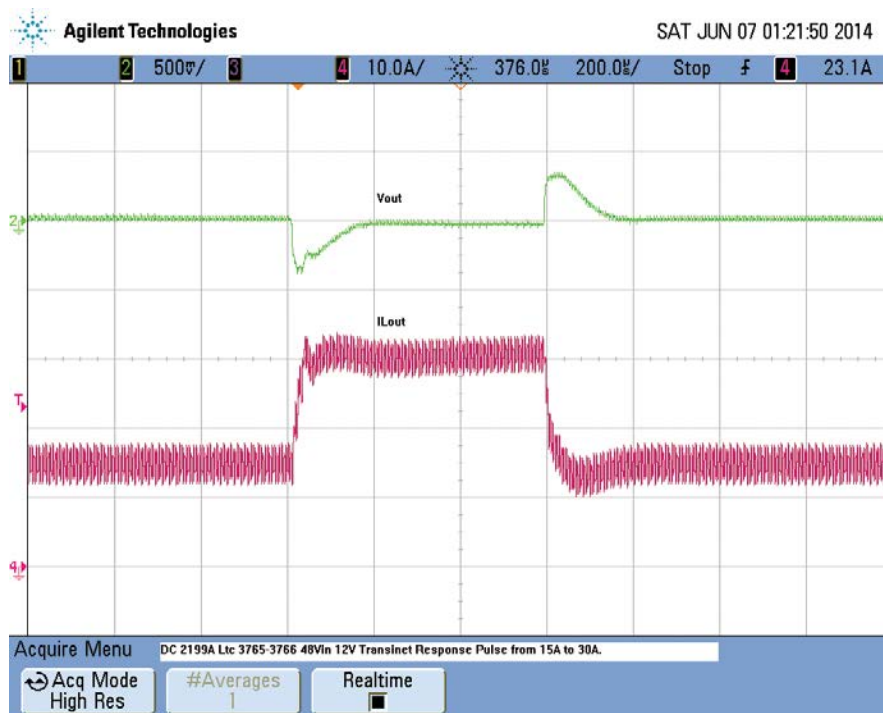


Figure 4. Transient Response Waveform at 48V<sub>IN</sub> and 15A to 30A to 15A<sub>OUT</sub> (10A, 500mV, 200μs/DIV)

**QUICK START PROCEDURE**

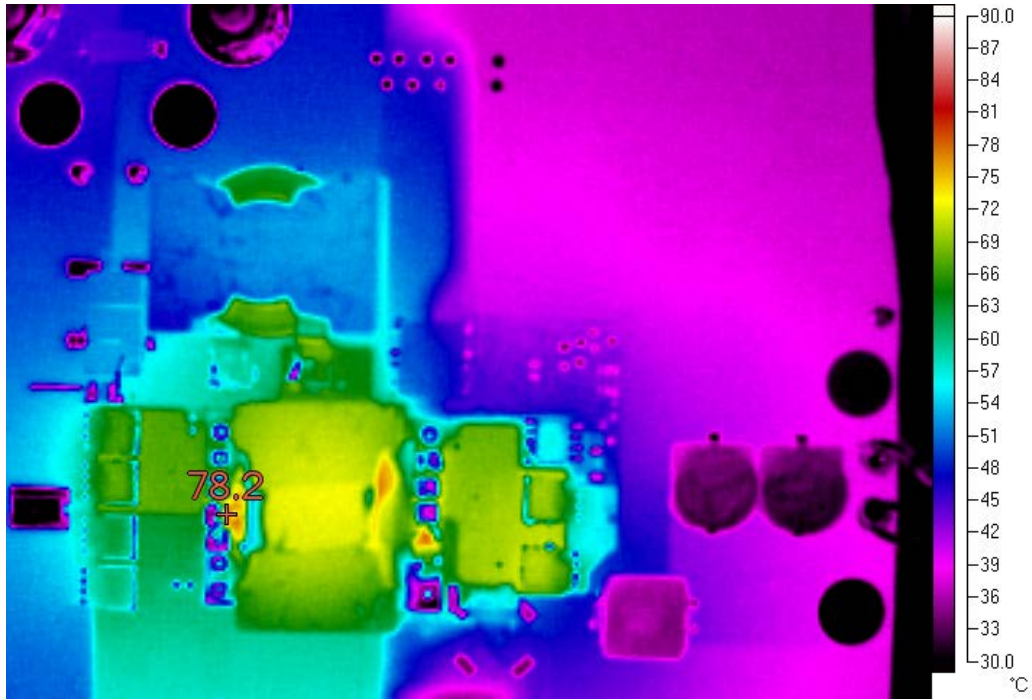


Figure 5. Thermal Map, Front Side at 48V<sub>IN</sub> and 30A<sub>OUT</sub> (T<sub>A</sub> = 25°C, 200LFM)

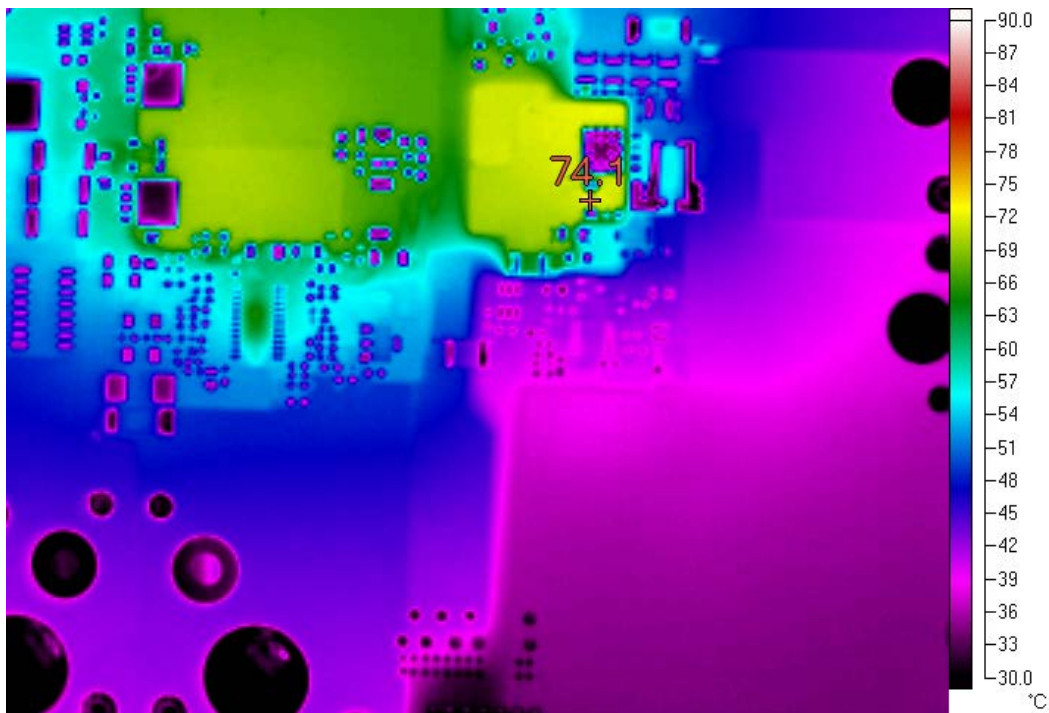


Figure 6. Thermal Map, Back Side at 48V<sub>IN</sub> and 30A<sub>OUT</sub> (T<sub>A</sub> = 25°C, 200LFM)

# DEMO MANUAL DC2199A-A

## PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
<b>Required Circuit Components</b>				
1	2	C1, C22	Cap., Alum., Elect., 33 $\mu$ F, 80V, CAP-10X12.5	PANASONIC, EEHZA1K330P
2	5	C2, C3, C4, C5, C6	CAP., X7R, 4.7 $\mu$ F, 100V, 10%, 1210	MURATA, GRM32ER72A475KE14
3	4	C7, C31, C33, C68	CAP., POSCAP, 150 $\mu$ F, 16V, 20%, 7343	PANASONIC, 16TQC150MYF
4	1	C10	CAP., X7R, 2.2nF, 630V, 5%, 1206	MURATA, GRM31A7U2J222JW31
5	1	C11	CAP., X7R, 0.015 $\mu$ F, 25V, 10%, 0603	AVX, 06033C153KAT2A
6	2	C24, C71	CAP., X7R, 1.0 $\mu$ F, 16V, 10%, 0805	MURATA, GRM21BR71C105KA01
7	1	C30	CAP., X7R, 2200pF, 250V, 10%, 1812	MURATA, GA343QR7GD222KW01L
8	1	C34	CAP., X5R, 22 $\mu$ F, 16V, 20%, 1206/1210	MURATA, GRM32ER71C226MEA8L
9	1	C51	CAP., COG, 470pF, 630V, 5%, 1206	MURATA, GRM31A5C2J471JW01
10	1	C66	CAP., X7R, 0.047 $\mu$ F, 200V, X7R, 10% 1206	MURATA, GRM31CR72D473KW03
11	1	C69	CAP., X7R, 1.5nF, 630V, 5%, 1206	MURATA, GRM31A7U2J152JW31
12	2	C70, C76	CAP., X7R, 3.3nF, 25V, 10%, 0603	AVX, 06033C332KAT2A
13	2	C72, C102	CAP., X7R, 0.1 $\mu$ F, 25V, 10%, 0805	AVX, 08053C104KAT2A
14	4	C55, C73, C80, C119	CAP., X7R, 1nF, 25V, 10%, 0603	MURATA, GRM188R71E102KA01
15	1	C75	CAP., NPO, 100pF, 25V, 5%, 0603	AVX, 06033A101JAT2A
16	1	C77	CAP., X7R, 4.7 $\mu$ F, 25V, 10%, 1206	AVX, 12063C475KAT2A
17	1	C78	CAP., NPO, 0.033 $\mu$ F, 25V, 5%, 0805	TDK, C2012C0G1E333J
18	1	C79	CAP., X7R, 4.7nF, 25V, 10%, 0603	MURATA, GRM188R71E472KA01
19	1	C101	CAP., NPO, 220pF, 25V, 5%, 0603	AVX, 06033A221JAT2A
20	1	C106	CAP., COG, 150pF, 250V, 5%, 0603	TDK, C1608C0G2E151J080AA
21	1	C112	CAP., X7R, 0.22 $\mu$ F, 250V, 10%, 1206/1210	TDK C3225X7R2E224K
22	1	C113	CAP., X7R, 0.033 $\mu$ F, 25V, 10%, 0603	AVX, 06033C333KAT2A
23	1	C118	CAP., NPO, 1500pF, 5%, 0603	AVX, 06033A152JAT2A
24	2	D1, D34	DIODE ULTRA FAST 1A, 200V, SMP	VISHAY, ES1PD-M3 / 84A
25	3	D27, D29, D30	DIODE SCHOTTKY 60V, 0.5A, SOT23	DIODES INC, ZHCS506TA
26	1	D40	DIODE, 1N4148WS, SOD323	VISHAY, 1N4148WS-E3-08
27	1	L1	INDUCTOR, 1.0 $\mu$ H, 20%	COILCRAFT, XPL2010-102ML
28	1	L2	INDUCTOR, 2.0 $\mu$ H, 20%	VISHAY, IHLP4040DZER2R0M11
29	1	L3	INDUCTOR, 3.3 $\mu$ H, 10%	COILCRAFT, SER2915L-332KL
30	2	Q8, Q9	MOSFET N-CH 150V, POWERPAK-SO-8	INFINEON, BSC190N15NS3 G
31	4	Q12, Q13, Q14, Q15	MOSFET N-CH 80V, POWERPAK-SO-8	INFINEON, BSC028N06NS3
32	1	Q27	TRANS., NPN 40V, 1A, SOT-89	DIODE INC., FCX491ATA
33	1	Q28	MOSFET, N-CH, SUPER, SOT-6	FAIRCHILD, FDC2512-NL
34	1	Q29	MOSFET, P-CH, IRF6217, POWERPAK-SO-8	IR, IRF6217TRPBF
35	1	R1	RES., CHIP, 0.33, 1/4W, 5%, 2512	PANASONIC, ERJ-1TRQJR33U
36	1	R4	RES., CHIP, 8.2k, 1W, 5%, 2512	PANASONIC, ERJ-1TYJ822U
37	1	R18	RES., CHIP, 102k, 1/8W, 1%, 0805	VISHAY, CRCW0805102KFKEA
38	1	R22	RES., CHIP, 3.74k, 1/16W, 1%, 0603	VISHAY, CRCW06033K74FKEA
39	2	R23, R24	RES., CHIP, 8.2, 1/4W, 5%, 1206	VISHAY, CRCW12068R20JKEA
40	1	R29	RES., CHIP, 100k, 1/8W, 5%, 0805	VISHAY, CRCW0805100KJNEA
41	1	R41	RES., CHIP, 11.5k, 1/16W, 1%, 0603	VISHAY, CRCW060311K5FKEA

dc2199aafa

## PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
42	1	R42	RES., CHIP, 1k, 1/16W, 1%, 0603	VISHAY, CRCW06031K00FKEA
43	1	R46	RES., CHIP, 604, 1/16W, 1%, 0603	VISHAY, CRCW0603604RFKEA
44	2	R51, R52	RES., CHIP, 3.0, 1/4W, 5%, 1206	PANASONIC, ERJ-8GEYJ3R0V
45	1	R53	RES., CHIP, 6.8, 1/2W, 1%, 1206	PANASONIC, ERJ-8RQF6R8V
46	1	R68	RES., CHIP, 2.15k, 1/16W, 1%, 0603	VISHAY, CRCW06032K15FKEA
47	1	R69	RES., CHIP, 46.4k, 1/16W, 1%, 0603	VISHAY, CRCW060346K4FKEA
48	1	R75	RES., CHIP, 215, 1/8W, 1%, 0805	VISHAY, CRCW0805215RFKEA
49	1	R76	RES., CHIP, 4.22, 1/8W, 1%, 0805	VISHAY, CRCW08054R22FKEA
50	1	R84	RES., CHIP, 1.21k, 1/8W, 1%, 0805	VISHAY, CRCW08051K21FKEA
51	4	R101, R148, R149, R151	RES., CHIP, 100, 1/16W, 1%, 0603	VISHAY, CRCW0603100RFKEA
52	1	R109	RES., CHIP, 10k, 1/16W, 1%, 0603	VISHAY, CRCW060310K0FKEA
53	1	R110	RES., CHIP, 1.20, 1/2W, 1%, 1206	SUSUMU, RL1632S-1R20-F
54	1	R114	RES., CHIP, 28.7k, 1/16W, 1%, 0603	VISHAY, CRCW060328K7FKEA
55	1	R117	RES., CHIP, 12.7k, 1/16W, 1%, 0603	VISHAY, CRCW060312K7FKEA
56	1	R118	RES., CHIP, 681k, 1/16W, 1%, 0603	VISHAY, CRCW0603681KFKEA
57	1	R121	RES., CHIP, 133k, 1/16W, 1%, 0603	VISHAY, CRCW0603133KFKEA
58	1	R123	RES., CHIP, 118k, 1/16W, 1%, 0603	VISHAY, CRCW0603118KFKEA
59	1	R125	RES., CHIP, 17.4k, 1/16W, 1%, 0603	VISHAY, CRCW060317K4FKEA
60	1	R136	RES., CHIP, 0.005, 1W, 1%, 1225	SUSUMU, KRL6432D-M-R005-F-T5
61	1	R139	RES., CHIP, 26.7k, 1/16W, 1%, 0603	VISHAY, CRCW060326K7FKEA
62	1	R140	RES., CHIP, 274, 1/8W, 1%, 0805	PANASONIC, ERJ-6ENF2740V
63	1	R150	RES., CHIP, 14.3k, 1/16W, 1%, 0603	VISHAY, CRCW060314K3FKEA
64	1	T1	TRANSFORMER	CHAMPS TECH., LTC-PQ26-0402
65	1	T2	TRANSFORMER, 1.25:1	Pulse, PA3493NL
66	1	T3	TRANSFORMER, 1:100, CT02-100	ICE COMPONENTS, CT02-100 = 1:100
67	1	U1	I.C. LTC3765EMSE, MSOP-16PIN	LINEAR TECH., LTC3765EMSE#PBF
68	1	U2	I.C. LTC3766EGN, SSOP-GN28	LINEAR TECH., LTC3766EGN#PBF

### Additional Demo Board Circuit Components

1	0	C12, C13, C14, C16, C20	CAP., OPT, 0603	OPT
2	0	C8, C9, C18, C19, C103, C111	CAP., OPT, 0603	OPT
3	0	C15, C21, C114	CAP., OPT, 0805	OPT
4	0	C17, C116	CAP., OPT, 1206	OPT
5	0	C23, C25, C26	CAP., OPT, CAP-SVPF-E12	OPT
6	2	C74, C105	CAP, 0Ω, JUMPER 0603	VISHAY, CRCW06030000Z0EA
7	0	D2	DIODE TBD SOD323	OPT
8	0	D4, D35	DIODE OPT, SOD323	OPT
9	0	D28, D37, D38	DIODE OPT, SOT23	OPT
10	0	L4	INDUCTOR, OPT, DO1606T	OPT
11	0	Q1, Q2	MOSFET, OPT, SOT23-6	OPT
12	0	Q4	MOSFET, OPT, D-PAK	OPT
13	0	Q11, Q23, Q24	MOSFET, OPT, POWERPAK-SO-8	OPT
14	0	R5	RES., OPT, 2512/2010	OPT

# DEMO MANUAL DC2199A-A

## PARTS LIST

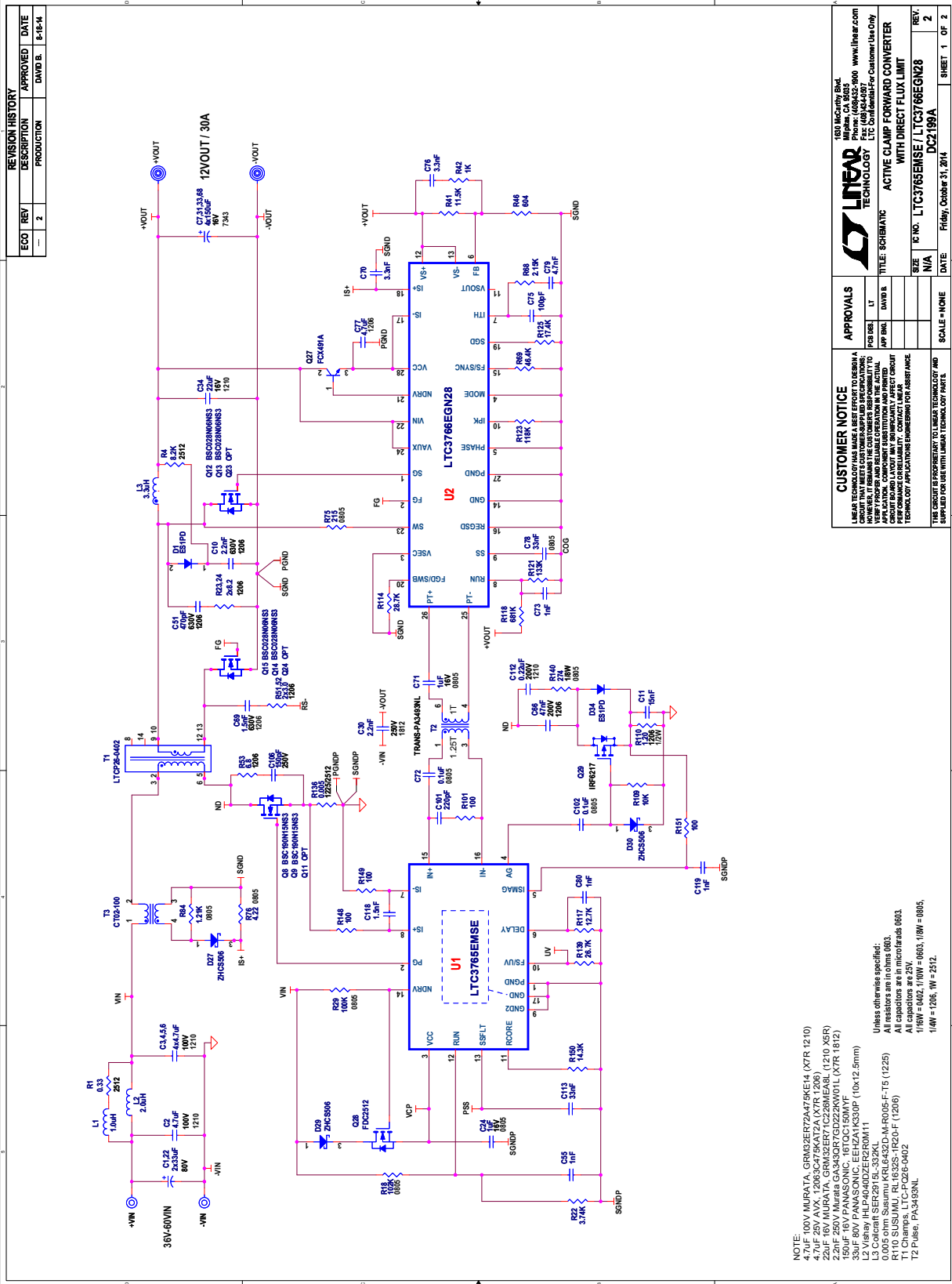
ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
15	13	R6, R7, R8, R9, R49, R103, R111, R112, R113, R122, R124, R137, R146	RES., CHIP, 0Ω, 0603	VISHAY, CRCW06030000Z0EA
16	0	R10, R13, R14, R15	RES., OPT, 2512	OPT
17	0	R17, R108, R116, R127	RES., OPT, 1206	OPT
18	0	R25, R26, R27, R28, R30, R31, R32, R33, R34, R35, R43, R106, R107, R119, R120, R126, R138, R147	RES., OPT, 0603	OPT
19	1	R77	RES., CHIP, 0, 1/8W, 0805	VISHAY, CRCW08050000Z0EA
20	1	R102	RES., CHIP, 0Ω, 1225	TEPRO, RN5326
21	1	R115	RES., CHIP, 0, 1/4W, 1206	VISHAY, CRCW12060000Z0EA
22	0	R152	RES., OPT, 0805	OPT
23	0	U3	I.C. OPT, SO16	OPT

### Hardware: For Demo Board Only

1	4	E1, E2, E3, E4	TESTPOINT, TURRET, .094"	MILL-MAX, 2501-2-00-80-00-00-07-0
2	3	E5, E6, E7	TESTPOINT, TURRET, .061"	MILL-MAX, 2308-2-00-80-00-00-07-0
3	0	J1	HEADER, OPT, 2x7PIN, 0.079CC	OPT, MOLEX, 87331-1420
4	2	J3, J4	STUD, TEST PIN	PEM, KFH-032-10
5	4	J3, J4(2 EACH)	NUT, BRASS, #10-32	ANY #10-32
6	2	J3, J4	WASHER, STAR #10 BRASS NICKEL	ANY, #10EXT BZ TN
7	2	J3, J4	Ring, Lug Ring # 10	KEYSTONE, 8205
8	0	TP1-TP6	PAD-SMD	PAD-SMD
9	4	(STAND-OFF)	STAND-OFF, NYLON 0.25"	KEYSTONE, 8831 (SNAP ON)
10	1		FAB, PRINTED CIRCUIT BOARD	DEMO CIRCUIT 2199A



SCHEMATIC DIAGRAM



REVISION HISTORY			APPROVED	DATE
ECO	REV	DESCRIPTION	DAVID B.	8-18-14
-	2	PRODUCTION		

**CUSTOMER NOTICE**  
 LINEAR TECHNOLOGY HAS MADE A BEST EFFORT TO DESIGN A CIRCUIT THAT MEETS CUSTOMER-SPECIFIED REQUIREMENTS. HOWEVER, CUSTOMER-SPECIFIED REQUIREMENTS MAY VARY FROM THE ACTUAL PERFORMANCE OF THE CIRCUIT. CUSTOMER PERFORMANCE REQUIREMENTS SHOULD BE SPECIFIED IN THE APPLICATION NOTE. CONTACT LINEAR TECHNOLOGY APPLICATION ENGINEERING FOR ASSISTANCE.

**APPROVALS**  
 FOR DESIG: LT  
 APPR: DAVID B.

**SCALE** - NONE

**SIZE** N/A  
**DATE** Friday, October 31, 2014  
**REV.** 2  
**DC2199A**

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**LINEAR TECHNOLOGY**  
 ACTIVE CLAMP FORWARD CONVERTER WITH DIRECT FLUX LIMIT

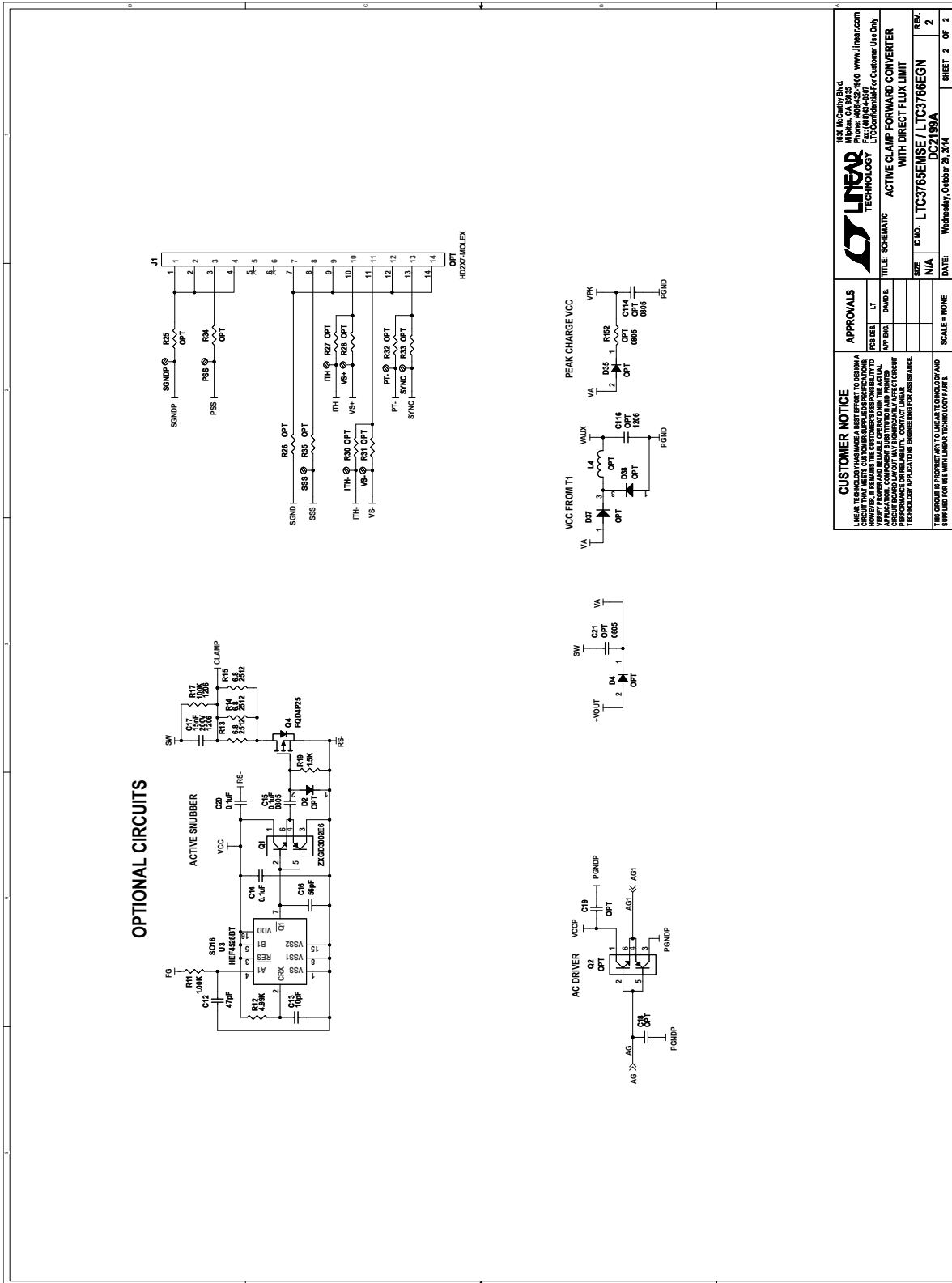
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NOTE:  
 T1: 100V MURATA, GRM32ER70A75E14 (XTR 1210)  
 L1: 4.7µF 25V AVX, 120632A75K12A (XTR 1206)  
 C1: 22µF 16V MURATA, GRM32ER71G22M6EABL (1210 X5R)  
 C2: 2.2µF 250V MURATA, GRM32ER71G22M6EABL (1210 X5R)  
 C3: 150µF 16V PANASONIC, 16TCC150MYF  
 C4: 22µF 16V PANASONIC, 16TCC150MYF  
 L2: Vishay, HLP0404DZFR2R0W11  
 L3: Coilcraft, SER2015L-332KL  
 D1: 0.005 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
 D2: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
 D3: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
 D4: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
 D5: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
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 D98: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
 D99: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)  
 D100: 100 ohm, Sanyo, KRLG432D-MR005-F-15 (1225)

Simplified Schematic (without Unneeded Components)



**SCHEMATIC DIAGRAM**



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**APPROVALS**

DESIGNER	LT
APP. ENGR.	DAVID TL
SCALE	N/A

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**TITLE: SCHEMATIC ACTIVE CLAMP FORWARD CONVERTER WITH DIRECT FLUX LIMIT**

REV. 2  
 DC2199A  
 DATE: Wednesday, October 29, 2014  
 SHEET 2 OF 3

Full Schematic, page 2

# DEMO MANUAL DC2199A-A

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