DESCRIPTION

Demonstration circuit 888A-C is a high power isolated synchronous forward converter featuring the LTC3725 and LTC3706. When powered from a 36-72V input, a single DC888A-C provides an isolated 12V at 20A in a quarter-brick footprint. If higher output current is required, multiple DC888A boards may be stacked together using on-board connectors for a complete PolyPhase current sharing solution. The converter operates at 250kHz and achieves efficiency up to 94.2% with synchronous output rectifiers. Secondary-side control eliminates complex optocoupler feedback, providing fast transient response with a minimum amount of output capacitance. Additional DC888A versions include DC888A-A (3.3V at 50A) and DC888A-B (5V at 40A). The simple architecture can be easily modified to meet different input and output voltage requirements.

Design files for this circuit board are available. Call the LTC factory.

Table 1. Performance Summary (T_A = 25°C)

PARAMETER	CONDITION	VALUE
Minimum Input Voltage		36V
Maximum Input Voltage		72V
Output Voltage V_{OUT}	V_{IN} = 36V to 72V, I_{OUT} = 0A to 20A	12V
Maximum Output Current	200LFM	20A
Typical Output Ripple V_{OUT}	V_{IN} = 48V, I_{OUT} = 20A, 250kHz	< 150mV$_{P-P}$
Output Regulation	Over All Input Voltages and Output Currents	±1% (Reference)
Load Transient Response	Peak Deviation with 10A to 20A Load Step (10A/us)	±750mV
	Settling Time	•50us
Nominal Switching Frequency		250kHz
Efficiency	V_{IN} = 36V, I_{OUT} = 12A	94.2% Typical
Isolation	BASIC	1500VDC
Size	Component Area x Top x Bottom Component Height	2.3” x 1.45” x 0.4” x 0.075”

OPERATING PRINCIPLES – SINGLE PHASE

The LTC3706 secondary side controller is used on the secondary and the LTC3725 smart driver with self-starting capability is used on the primary. When an input voltage is applied, the LTC3725 (U1 in Figure 15), which is powered through R29 and Q28, begins a controlled soft-start of the output voltage by switching MOSFETs Q9 and Q11. As the output voltage begins to rise, the LTC3706 secondary controller is quickly powered up via D24, Q29, C67, and Q27. The LTC3706 then assumes control of the output voltage by sending encoded PWM gate pulses to the LTC3725 primary driver via signal transformer, T2. The LTC3725 then operates as a simple driver receiving both input signals and bias power through T2. The transition from primary to secondary control occurs seamlessly at a fraction of the output voltage. From that point on, operation and design simplifies to that of a simple buck converter. The LTC3706 regulates by observing the output voltage directly resulting in superior output voltage regulation and transient response.

OPERATING PRINCIPLES – POLYPHASE

The LTC3725 and LTC3706 allow the user to develop modular power supply "building blocks" that can be added as power/current requirements increase. Connecting two DC888A power supplies in a PolyPhase configuration has several advantages. By distributing power across multiple high power/current supplies, heat is also distributed, reducing individual component temperatures. Each parallel module develops equal output currents so that electrical and thermal stresses are shared, increasing reliability. Multi-phase operation and Shared input and output filtering result in fewer/smaller input/output capacitors and inductors for a given voltage/current ripple or transient response.

In PolyPhase systems, one power supply is configured as a "master" and one as a "slave". The master communicates switching frequency via the PT+ pin to FS/SYNC pin of the slave (Figures 19 and 20). The relative clock phase of each stage is determined by the slave. The master's voltage error amplifier's output (ITH pin) controls the output current of all the phases via the ITH pin voltage which is distributed to each slave's unity-gain differential amplifier.

Several of the signals that are shared between the master and the slave are of a bidirectional nature. A fault on either phase can be communicated to the opposite phase via the primary side SS/FLT pin interconnection or the secondary side RUN/SS interconnection. Sharing Vcc on the secondary side ensures the master, which initially develops this bias voltage, and slave power up simultaneously. Each phase then contributes to the shared Vcc bus. Finally, the input voltage (Vin) and output voltage (Vout) busses are interconnected to allow for load sharing.

OPTIONAL POLYPHASE SETUP

Only minor modifications and minimal interconnections are needed to implement PolyPhase with the DC888. See component changes list (Figure 18) and schematics (Figures 21 and 22) for the required electrical changes to master and slave units. After the modifications are done, the boards are then stacked one on top of another (Figure 23). J1 and P1 headers interconnect small signals and E1, E2, E3, and E4 stand offs provide interconnection for the power signals.

The DC888 was designed primarily to demonstrate the chipset's single phase operation and therefore be further optimized for PolyPhase applications. A small resistor can be placed between the R76/D27 junction and C70/U2-16 junction to reduce already small PWM jitter associated with separate master and slave ground planes. Another optimization can result from combining each individual phase's input/output filter components into one shared input/output filter.

QUICK START PROCEDURE

Demonstration Circuit 888A-C is easy to set up to evaluate the performance of the LTC3725 and LTC3706. Refer to Figure 1 for proper equipment setup. Follow the procedure below:

NOTE: When measuring the input or output voltage ripple, care must be taken to avoid a long ground lead on the scope probe. Measure the output (or input) voltage ripple by touching the probe tip and probe ground directly across the +Vout and –Vout (or +Vin and –Vin) terminals. See 0 for proper scope probe technique.

1. The optional input LC filter stage (C2/L5) lowers ac input rms current. A power supply's complete input filter must have output impedance that is less than the converter input impedance to assure stability. This may require a damping impedance. (See Linear Technology Application Note AN19 for a discussion of input filter stability.) A source with a 50mOhm or higher ESR at the filter resonant frequency is one way of providing damping for the filter elements provided on the DC888A. For bench testing, adding an 82uF electrolytic capacitor such as a Sanyo 100MV82AX to the input terminals will provide suitable damping and 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.
2. Set an input power supply to a voltage of 36V. Make sure that it is capable of 36V to 72V at a current supplying capability of at least 8A per number of phases being tested. Then, turn off the supply.
3. With power off, connect the supply to the input terminals +Vin and –Vin.
   a. Input voltages lower than 36V can keep the converter from turning on due to the undervoltage lockout feature of the LTC3725.
   b. If efficiency measurements are desired, an ammeter capable of measuring at least 8Adc per phase can be put in series with the input supply in order to measure the DC888A-C's input current.
   c. A voltmeter with a capability of measuring • 72V can be placed across the input to get an accurate input voltage measurement.
4. Turn on the power at the input.

   NOTE: Make sure that the input voltage • 72V.
5. Check for the proper output voltage of 12V.
6. Turn off the power at the input.
7. Once the proper output voltages are established, connect a variable load capable of sinking 20A per phase at 12V to the output terminals +Vout and –Vout. Set current to 0A.
   a. If efficiency measurements are desired, an ammeter or a resistor current shunt that is capable of handling at least 20Adc per phase can be put in series with the output load in order to measure the DC888A-C's output current.
   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.
8. Turn on the power at the input.

   NOTE: If there is no output, disconnect the load to verify that the load is not set too high.
9. Once the proper output voltage is established, adjust the load within the operating range and observe the output voltage regulation, ripple voltage, efficiency and other desired parameters.

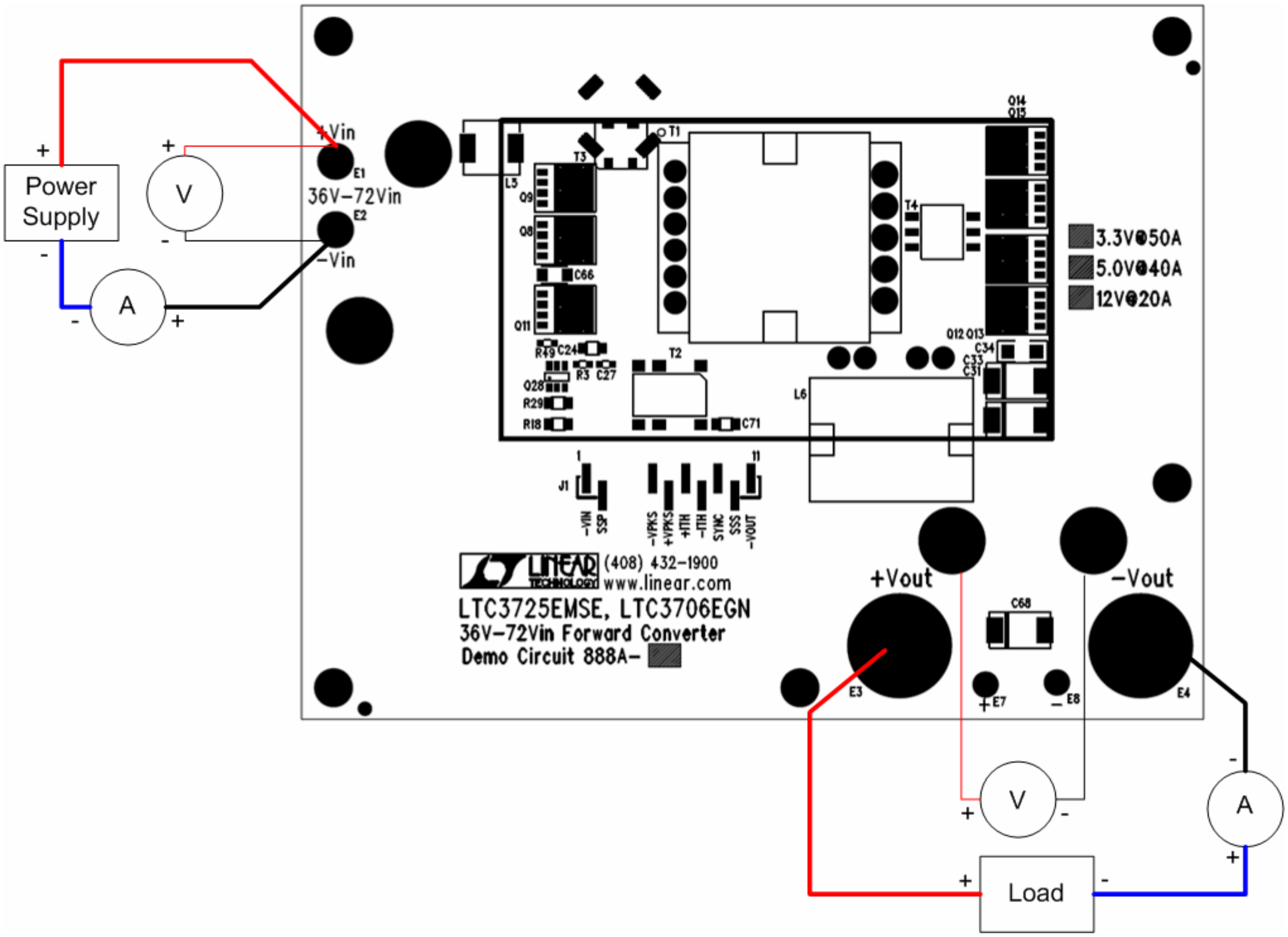


Figure 1. Proper Measurement Equipment Setup

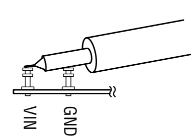


Figure 2. Measuring Input or Output Ripple

MEASURED DATA

Figures 3 through 14 are measured data for a typical DC888A-C. Figures 15 through 23 consist of schematics, bill of materials, and a picture.

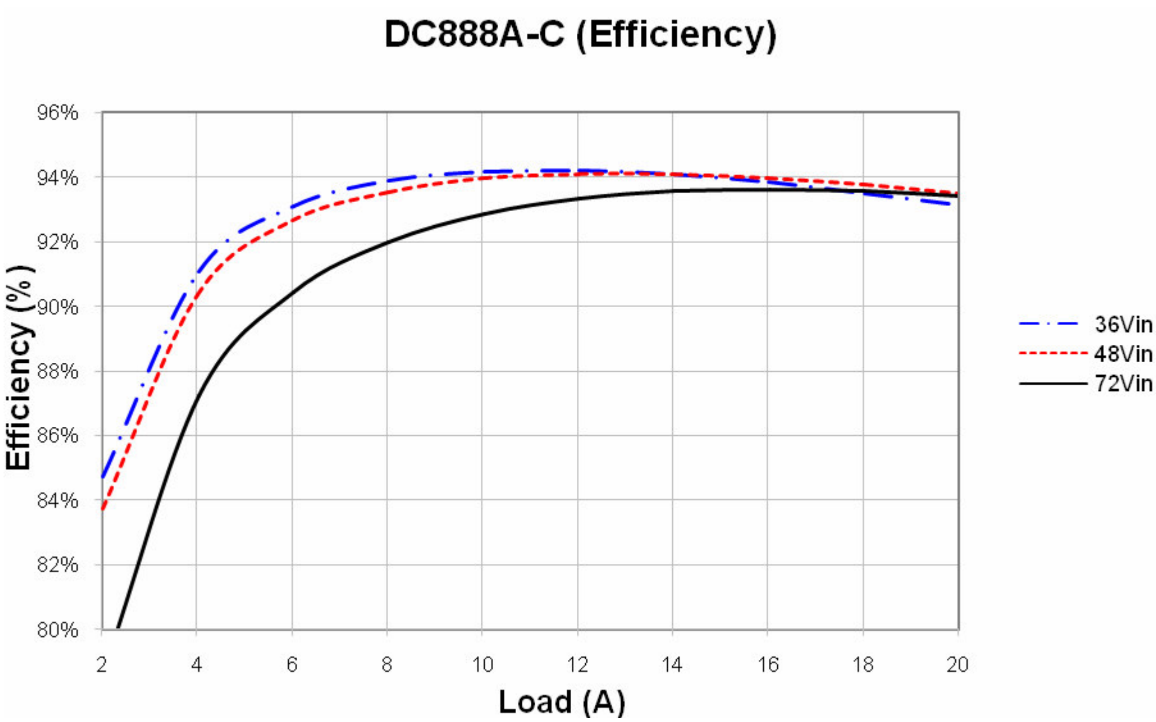


Figure 3. Efficiency

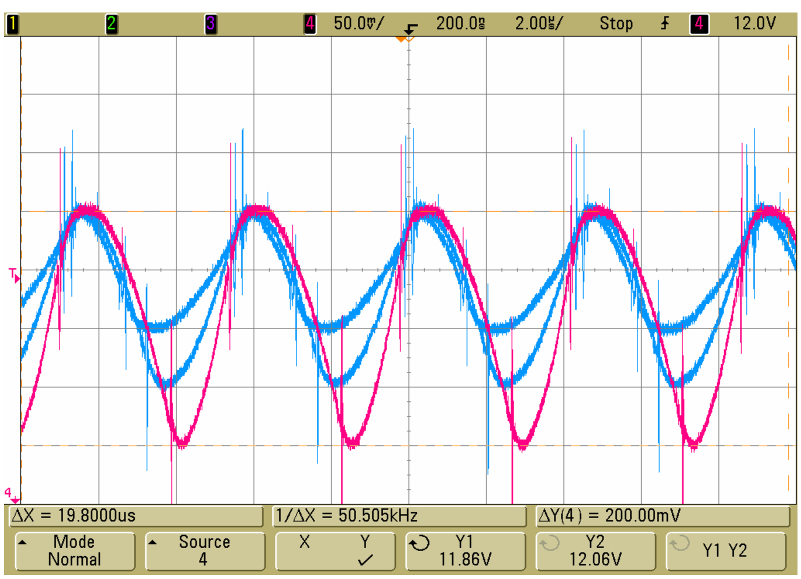


Figure 4. Output Voltage Ripple (36Vin/48Vin/72Vin, 20A, Single Phase)

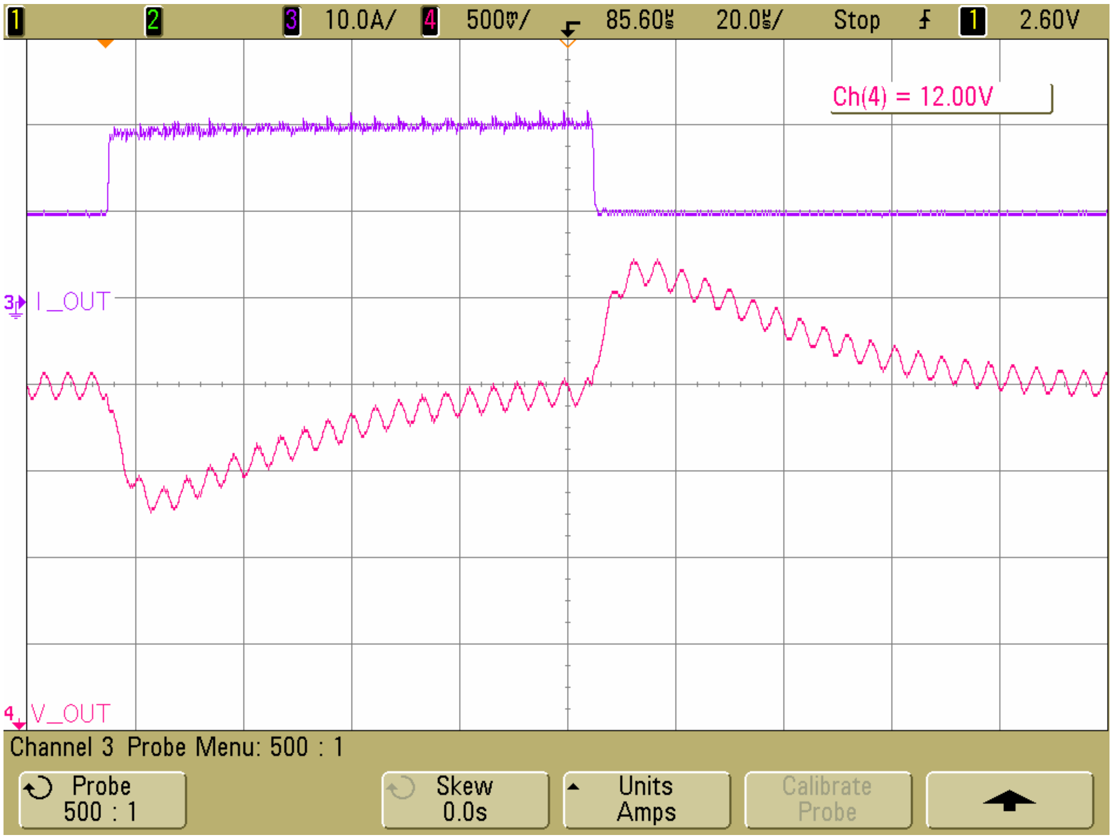


Figure 5. Load Transient Response (48Vin, 10A to 20A to 10A at 10A/us, Single Phase)

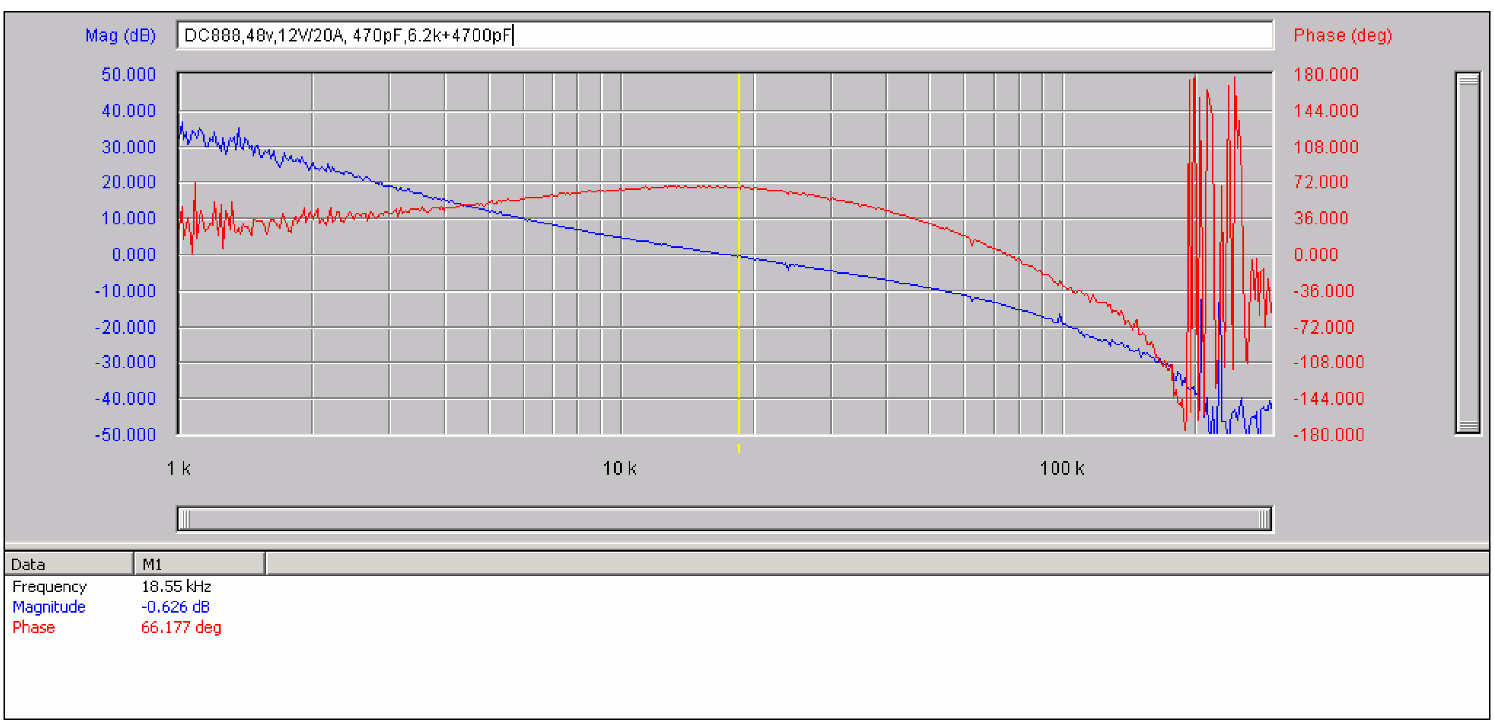


Figure 6. Loop Response (48Vin, 20A, Single Phase)

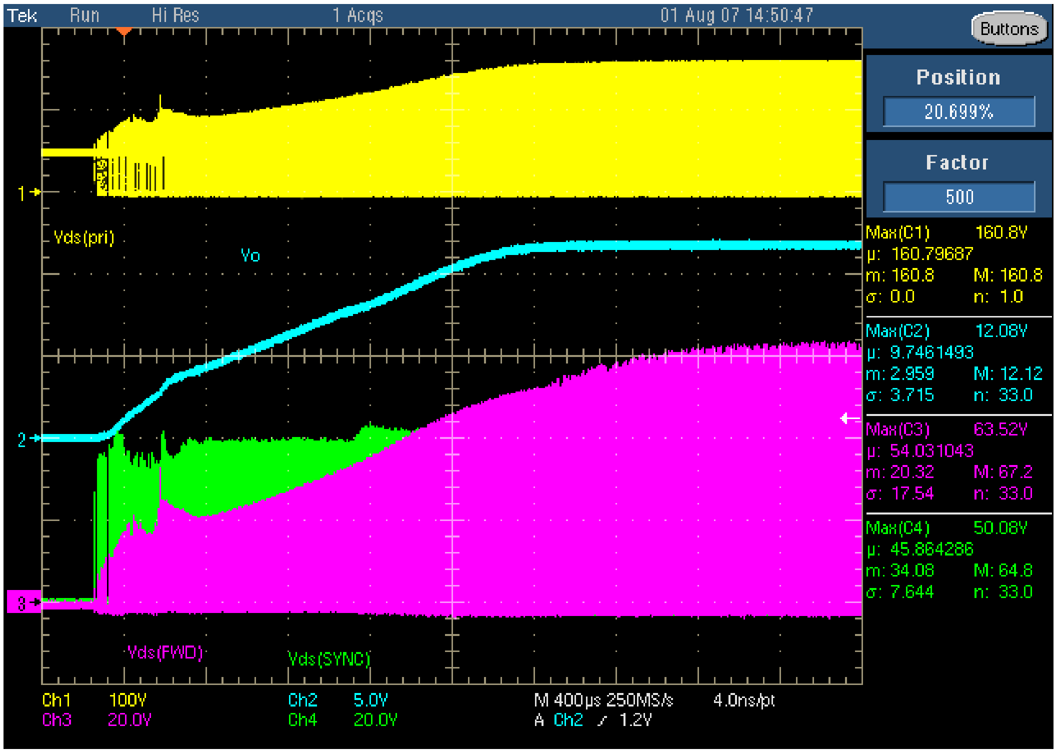


Figure 7. Turn-on (48Vin, 20A, Single Phase)

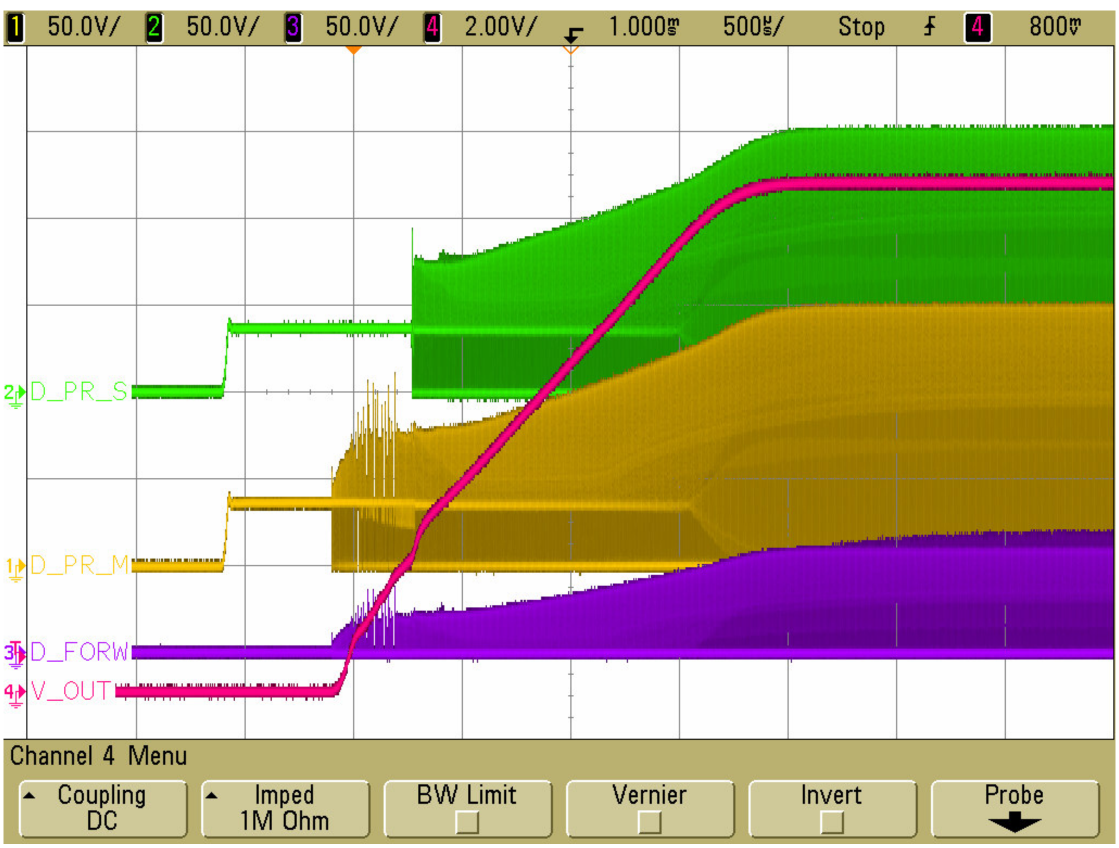


Figure 8. Turn-on (36Vin, 40A, PolyPhase)

Figure 9. Transient Sharing of Inductor Current (48Vin, 20A to 40A, PolyPhase)

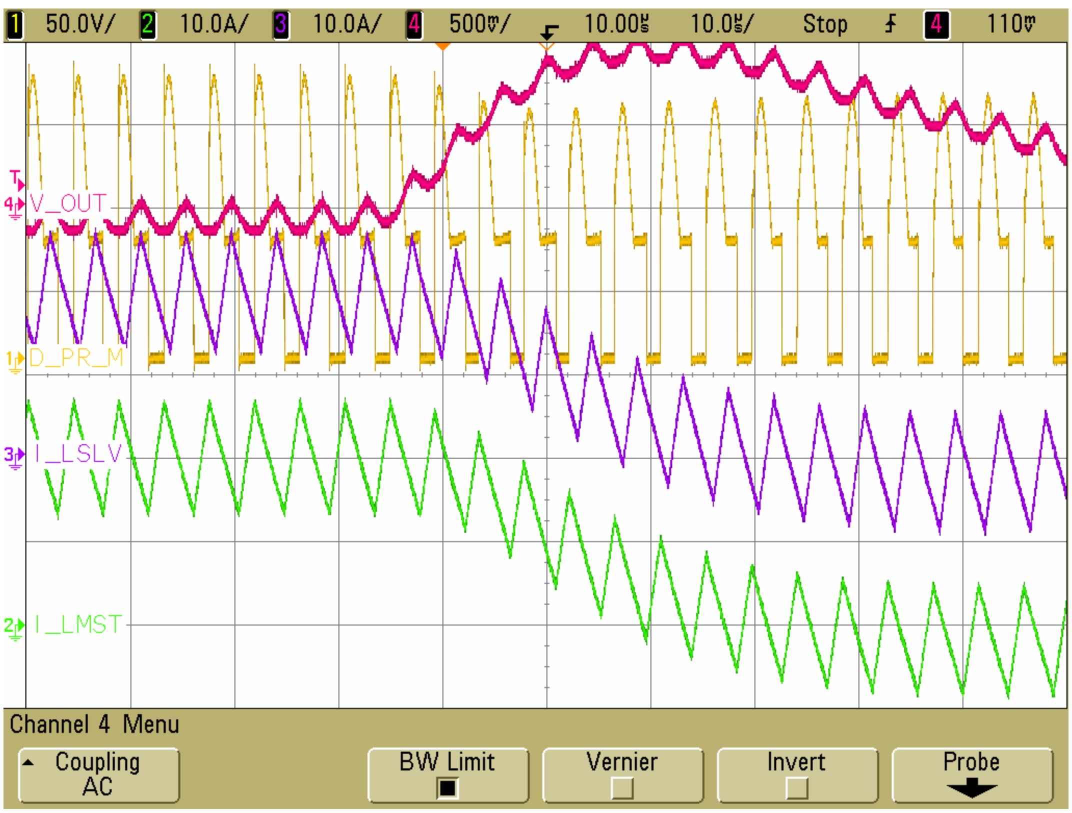


Figure 10. Transient Sharing of Inductor Current (48Vin, 40A to 20A, PolyPhase)

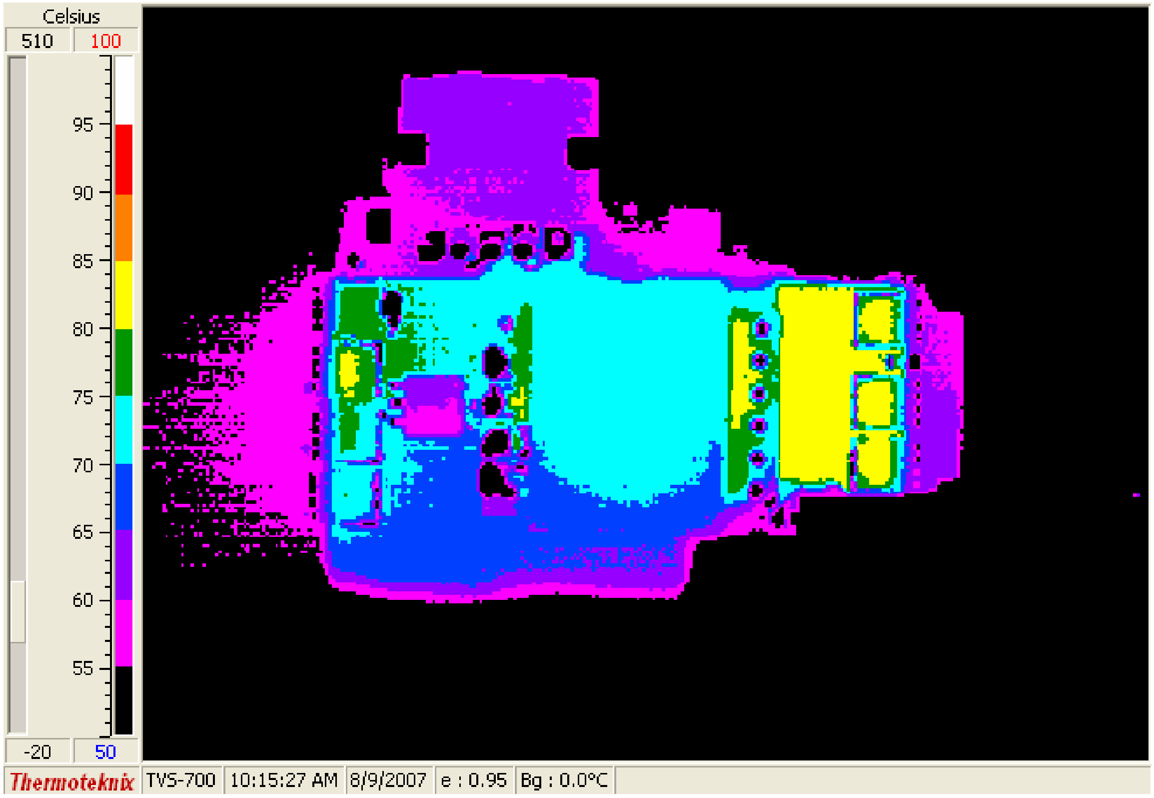


Figure 11. Temp Data (48Vin, 20A, 200LFM airflow – top)

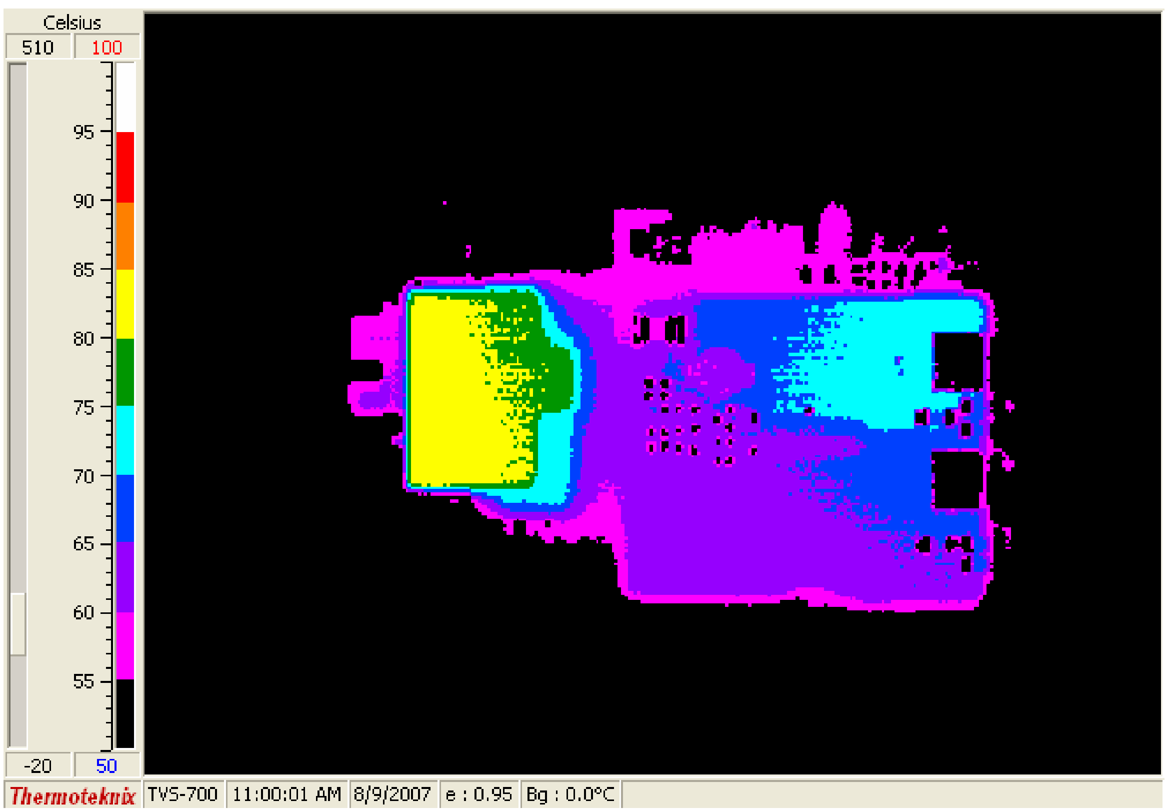


Figure 12. Temp Data (48Vin, 20A, 200LFM airflow – bottom)

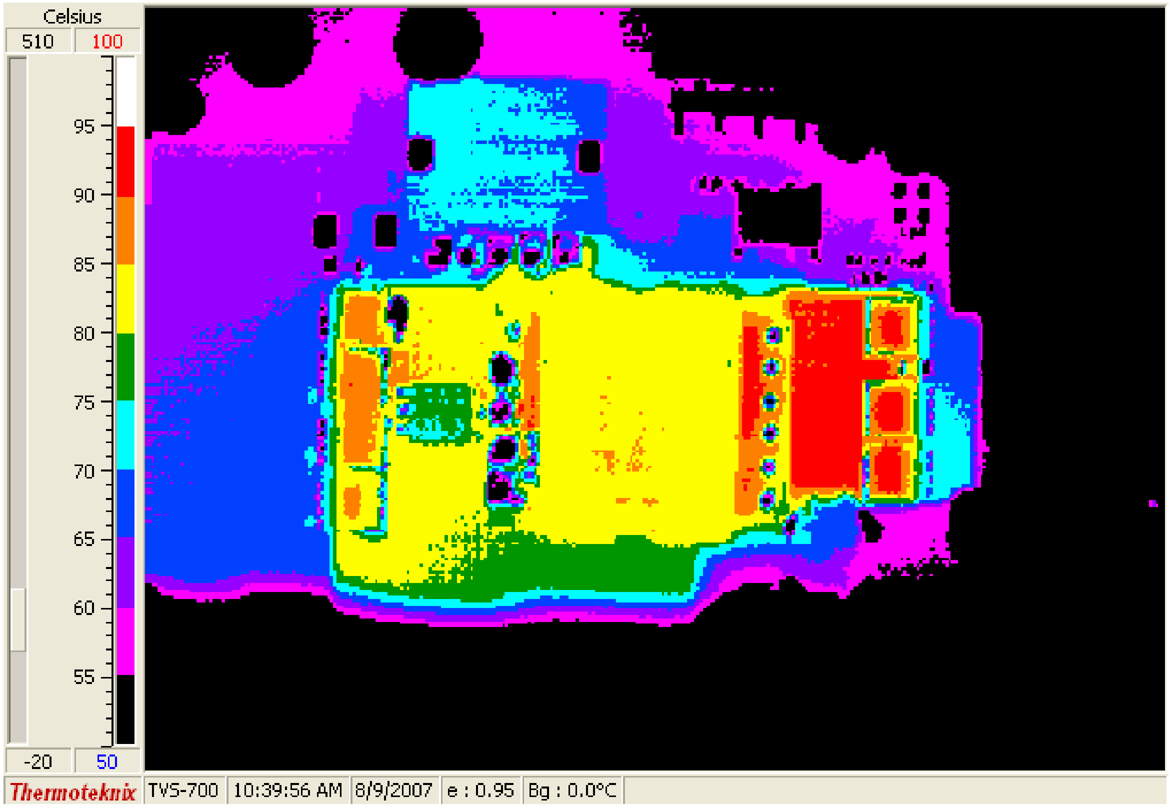


Figure 13. Temp Data (48Vin, 18A, 0LFM airflow – top)

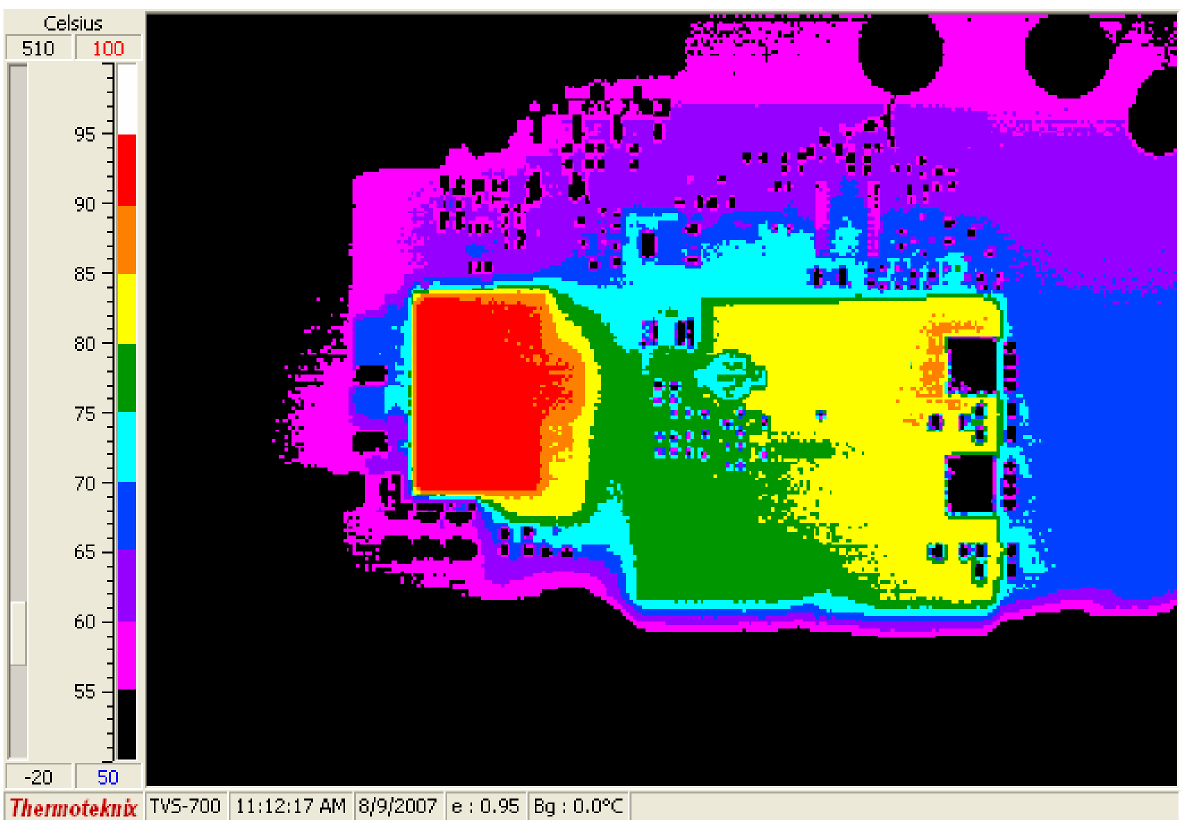


Figure 14. Temp Data (48Vin, 18A, 0LFM airflow – bottom)

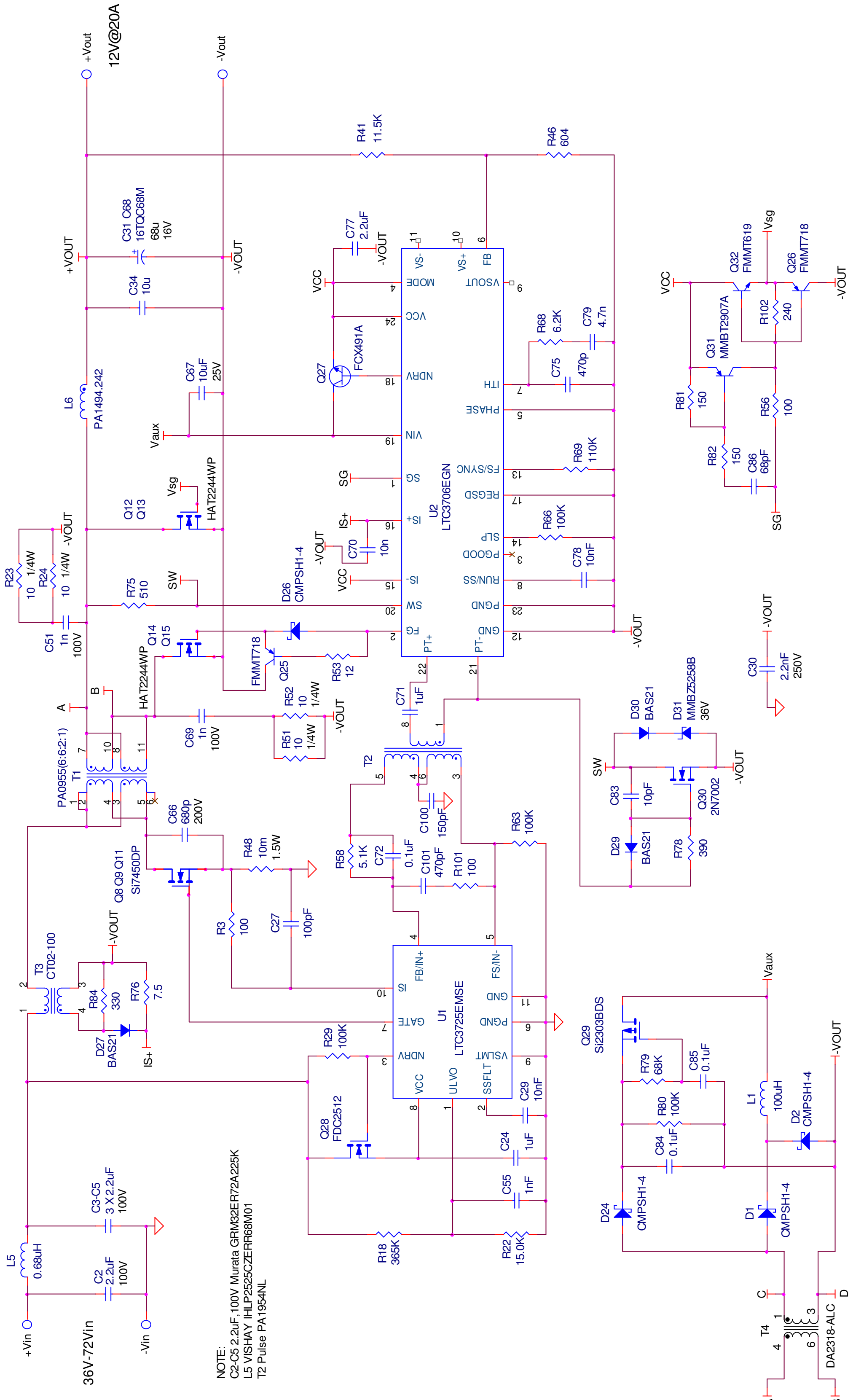
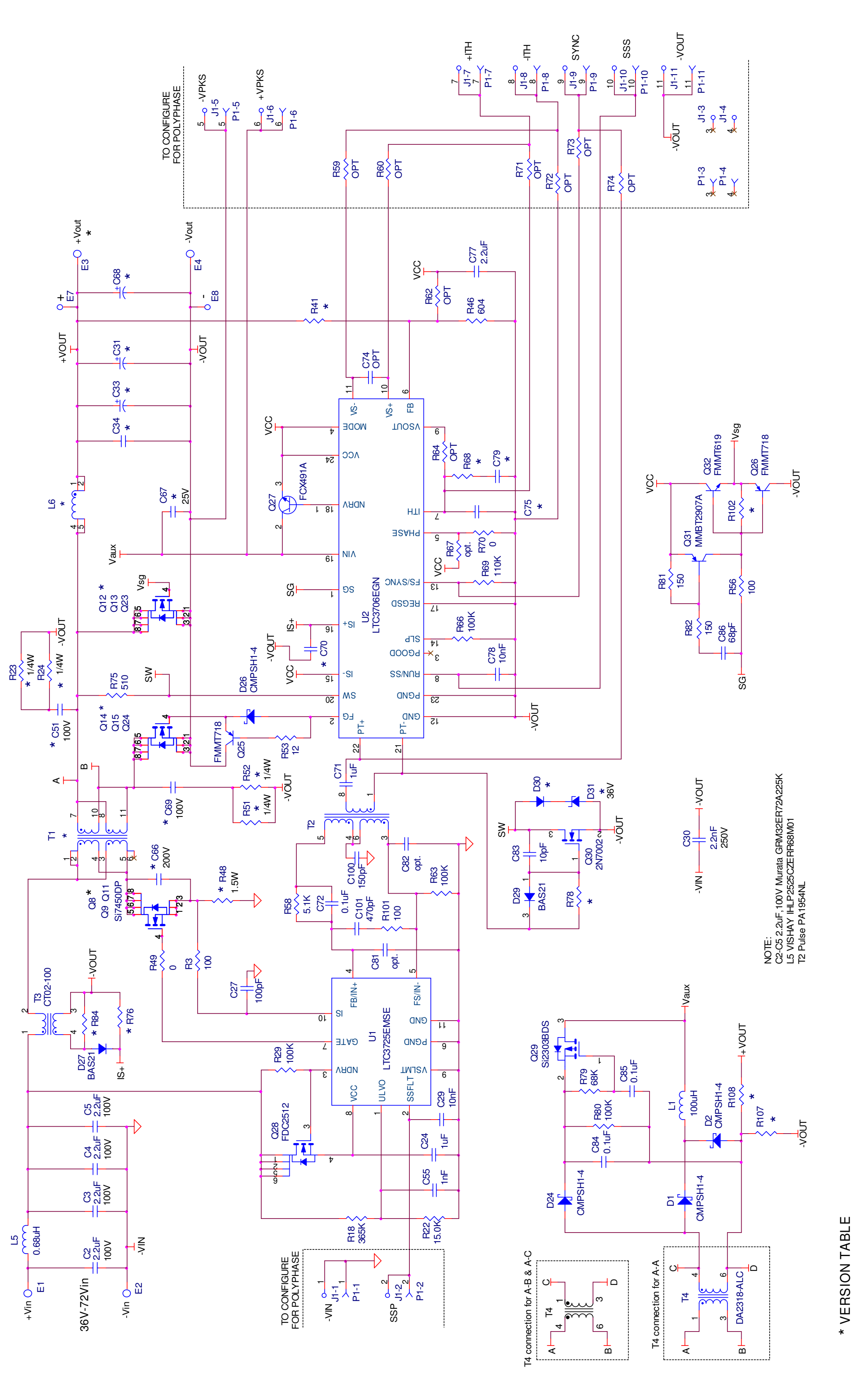


Figure 15. Single Phase Schematic



* VERSION TABLE

VERSION	Vout/Iout	C31,C68	C33	C34	C66	C51,C69	C67	C70	C75	C79	D30	D31	L6	Q8	Q12-Q15	Q23,Q24	R23,R24,R51,R52	R41	R48	R68	R76	R78	R84	R102	R107	R108	T1
DC888A-A	3.3V@50A	220uF, 4V		22uF	1.5nF	4.7nF	10uF	3.3nF	47pF	4.7nF	opt.	opt.	PA1382.650	opt.	Si7336ADP		5.1	2.74K	0.015	9.1K	9.53	620	2.2K	opt.	opt.	0	PA0950(6:6:1:1)
DC888A-B	5.0V@40A	220uF, 6.3V		22uF	1.5nF	2.2nF	10uF	3.3nF	100pF	3.3nF	opt.	opt.	PA1382.650	Si7450DP	Si7336ADP		6.8	4.42K	0.015	9.1K	8.06	750	1.0K	opt.	opt.	0	PA0954(4:4:1:1)
DC888A-C	12V@20A	68uF, 16V	opt	10uF	680pF	1.0nF	4.7uF	10nF	470pF	4.7nF	BAS21	MMBZ5258B	PA1494.242	Si7450DP	HAT2244WP	opt.	10	11.5K	0.010	6.2K	7.50	390	330	240	0	opt.	PA0955(6:6:2:1)

Figure 16. Full Single Phase Schematic

Qty	Reference	Part Description	Manufacturer / Part #
REQUIRED CIRCUIT COMPONENTS[1]			
3	C3,C4,C5	CAP., X7R, 2.2uF, 100V, 20%, 1210	Murata, GRM32ER72A225K
2	C24,C71	CAP., X7R, 1.0uF, 16V 10%, 0805	TAIYO YUDEN, EMK212BJ105KG
1	C27,	CAP., C0G, 100pF, 50V, 10%, 0603	AVX, 06035A101KAT2A
2	C29,C78	CAP., X7R, 10nF, 50V, 10%, 0603	AVX, 06035C103KAT2A
1	C30	CAP., X7R, 2.2nF, 250V, 10%, 1812	Murata, GA343QR7GD222KW01L
2	C31,C68	POSCAP, 68uF, 16V, 20%, D3L case	Sanyo, 16TQC68M
1	C34	CAP., X7R, 10uF, 16V, 10%, 1206	TDK, C3216X7R1C106K
2	C51,C69	CAP., C0G, 1.0nF, 100V, 5%, 1206	Murata, GRM3195C2A102JA01D
1	C66	CAP., C0G, 680pF, 200V, 10%, 1206	AVX, 12062A681KAT2A
1	C67	CAP., X7R, 4.7uF, 25V, 10%, 1210	Taiyo Yuden, TMK325BJ475KN
1	C70	CAP., X7R, 10nF, 50V, 10%, 0603	AVX, 06035C103KAT2A
1	C75	CAP., C0G, 470pF, 25V, 10%, 0603	AVX, 06033A471KAT2A
1	C79	CAP., X7R, 4.7nF, 50V, 10%, 0603	AVX, 06035C472KAT2A
1	C55	CAP., C0G, 1nF, 25V, 10%, 0603	AVX, 06033A102KAT2A
1	C77	CAP., X7R, 2.2uF, 16V, 20%, 1206	AVX, 1206YD225MAT2A
1	C72	CAP., X7R, 0.1uF, 25V, 10%, 0805	AVX, 08053C104KAT2A
1	C83	CAP., C0G, 10pF, 50V, 10%, 0603	AVX, 06035A100KAT2A
2	C84,C85	CAP., X7R, 0.1uF, 50V, 10%, 0603	TDK, C1608X7R1H104K
1	C86	CAP., C0G, 68pF, 25V, 10%, 0603	AVX, 06033A680KAT2A
1	C100	CAP., C0G, 150pF, 25V, 10%, 0603	AVX, 06033A151KAT2A
1	C101	CAP., C0G, 470pF, 25V, 10%, 0603	AVX, 06033A471KAT2A
4	D1,D2,D24,D26	Diode Schottky, CMPSH1-4, 40V, SOT23	CENTRAL SEMI., CMPSH1-4-LTC
2	D27,D29	Diode, BAS21 SOT23	Diodes Inc., BAS21
1	D30	Diode, BAS21 SOT23	Diodes Inc., BAS21
1	D31	Diode, 36V SOT23	Diodes Inc., MMBZ5258B-7-F
1	L1	INDUCTOR, 100uH, DO1606T	Coilcraft, DO1606T-104MLC
1	L6	INDUCTOR, PLANAR, 2.4uH	PULSE, PA1494.242
3	Q11,Q9, Q8	FET, N-CH., Si7450DP, Powerpak SO-8	VISHAY, Si7450DP
4	Q12,Q13,Q14,Q15	FET, N-CH., HAT2244WP, PW-PAK SO-8	RENESAS, HAT2244WP
2	Q25,Q26	TRANSISTOR, NPN, FMMT718, SOT23	ZETEX, FMMT718
1	Q27	TRANSISTOR, NPN, FCX491A, SOT89	ZETEX, FCX491A
1	Q28	FET, N-CH, FDC2512, SUPERSOT-6	Fairchild, FDC2512_NL
1	Q29	FET, P-CH, 30-V(D-S) SOT-23	VISHAY, Si2303BDS-T1-E3
1	Q30	N-MOSFET, 2N7002 SOT23	Diodes Inc., 2N7002-7-F
1	Q31	TRANSISTOR, PNP, SOT-23	DIODES., MMBT2907A-7-F
1	Q32	TRANSISTOR, NPN, SOT-23	ZETEX, FMMT619
3	R3,R56,R101	RES., CHIP, 100, 1/16W, 5%, 0603	VISHAY, CRCW0603100RJNEA
1	R18	RES., CHIP, 365K, 1/8W, 1%, 0805	VISHAY, CRCW0805365KFKEA
1	R22	RES., CHIP, 15.0K, 1/16W, 1%, 0603	VISHAY, CRCW060315K0FKEA
4	R23,R24,R51,R52	RES., CHIP, 10, 1/4W, 5%, 1206	VISHAY, CRCW120610R0JNEA
1	R41	RES., CHIP, 11.5K, 1/16W, 1%, 0603	VISHAY, CRCW060311K5FKEA
1	R48	RES., CHIP, 0.010, 1.5W, 2%, 2512	IRC, LRC-LRF2512-01-R010-G
1	R68	RES., CHIP, 6.2K, 1/16W, 5%, 0603	VISHAY, CRCW06036K20JNEA
1	R76	RES., CHIP, 7.50, 1/16W, 1%, 0805	VISHAY, CRCW08057R50FNEA
1	R78	RES., CHIP, 390, 1/16W, 5%, 0603	VISHAY, CRCW0603390RJNEA

Figure 17. Bill of Materials (Single Phase)

1	R84	RES., CHIP, 330, 1/16W, 5%, 0805	VISHAY, CRCW0805330RJNEA
1	R29	RES., CHIP, 100K, 1/8W, 5%, 0805	VISHAY, CRCW0805100KJNEA
1	R46	RES., CHIP, 604, 1/16W, 1%, 0603	VISHAY, CRCW0603604RFKEA
1	R53	RES., CHIP, 12, 1/16W, 5%, 0603	VISHAY, CRCW060312R0JNEA
1	R58	RES., CHIP, 5.1K, 1/16W, 5%, 0603	VISHAY, CRCW06035K10JNEA
3	R63,R66,R80	RES., CHIP, 100K, 1/16W, 5%, 0603	VISHAY, CRCW0603100KJNEA
1	R69	RES., CHIP, 110K, 1/16W, 5%, 0603	VISHAY, CRCW0603110KJNEA
1	R75	RES., CHIP, 510, 1/16W, 5%, 0603	VISHAY, CRCW0603510RJNEA
1	R79	RES., CHIP, 68K, 1/8W, 5%, 0603	VISHAY, CRCW060368K0JNEA
2	R81,R82	RES., CHIP, 150, 1/16W, 5%, 0603	VISHAY, CRCW0603150RJNEA
1	R102	RES., CHIP, 240, 1/16W, 5%, 0603	VISHAY, CRCW0603240RJNEA
1	T1	TRANSFORMER, PLANAR, 6:6:2:1	PULSE, PA0955
1	T2	TRANSFORMER, PA1954NL	PULSE, PA1954NL
1	T3	TRANSFORMER, CT02-100	ICE Components., CT02-100
1	T4	TRANSFORMER, 1.5 : 1	Coilcraft, DA2318-ALC
1	U1	I.C. LTC3725EMSE, MS10E	LINEAR TECH., LTC3725EMSE#PBF
1	U2	I.C. LTC3706EGN, SSOP-24GN	LINEAR TECH., LTC3706EGN#PBF
ADDITIONAL DEMO BOARD CIRCUIT COMPONENTS[2]			
1	C2	CAP., X7R, 2.2uF, 100V, 20%, 1210	Murata, GRM32ER72A225K
0	C33(opt)	POSCAP, D3L case	
0	C74(opt)	CAP., 0603	
0	C81,C82(opt.)	CAP., 0603	
1	L5	INDUCTOR, 0.68uH,	VISHAY, IHLP-2525CZERR68M01 e3
0	Q23,Q24(opt)	FET, N-CH., PW-PAK SO-8	
2	R49,R70	RES., CHIP, 0, 1/16W, 0603	VISHAY, CRCW06030000Z0EA
0	R59,R60.R62,R64,R67 R71-R74(opt)	RES., 0603	
1	R107	RES., CHIP, 0, 1/16W, 0603	VISHAY, CRCW06030000Z0EA
0	R108(opt)	RES., 0603	
2	E1,E2	TESTPOINT, TURRET, .094"	MILL-MAX, 2501-2-00-80-00-00-07-0
2	E8,E7	TESTPOINT, TURRET, .061"	MILL-MAX, 2308-2-00-80-00-00-07-0
2	E3,E4	STUD	PEM, KFH-032-6
4	E3,E4(2 EACH)	NUT, BRASS, #10-32	ANY
2	E3,E4	WASHER, STAR #10 BRASS NICKEL	ANY
2	E3,E4	Ring, Lug Ring # 10	KEYSTONE 8205
1	J1	HEADER, SMD, single row, 2mm	Comm Com, 2SMD1-140/335/180-11G2
1	P1	SOCKET, SMD, single row, 2mm	COMM COM, 1309-11G2
	Notes:		
	1. Required Circuit Components are those parts that are required to implement the circuit function		
	2. Additional Demo Board Circuit Components are those parts that provide added functionality for the demo board but are or may not be required in the actual circuit.		

Figure 17. Bill of Materials (Single Phase) (cont'd)

	Ref Des	Single Phase	PolyPhase
MASTER	C29	10nF	4.7nF
	C78	10nF	4.7nF
	R71	OPT	0Ω
	R72	OPT	0Ω
	R74	OPT	0Ω
SLAVE	C29	10nF	4.7nF
	C78	10nF	4.7nF
	C79	4.7nF	open
	R41	11.5kΩ	open
	R46	604Ω	open
	R59	OPT	0Ω
	R60	OPT	0Ω
	R62	OPT	0Ω
	R63	100kΩ	open
	R64	OPT	0Ω
	R67	OPT	0Ω
	R68	6.2kΩ	open
	R69	110kΩ	open
	R70	0Ω	open
	R73	OPT	0Ω

Figure 18. Single Phase to PolyPhase Electrical Component Changes

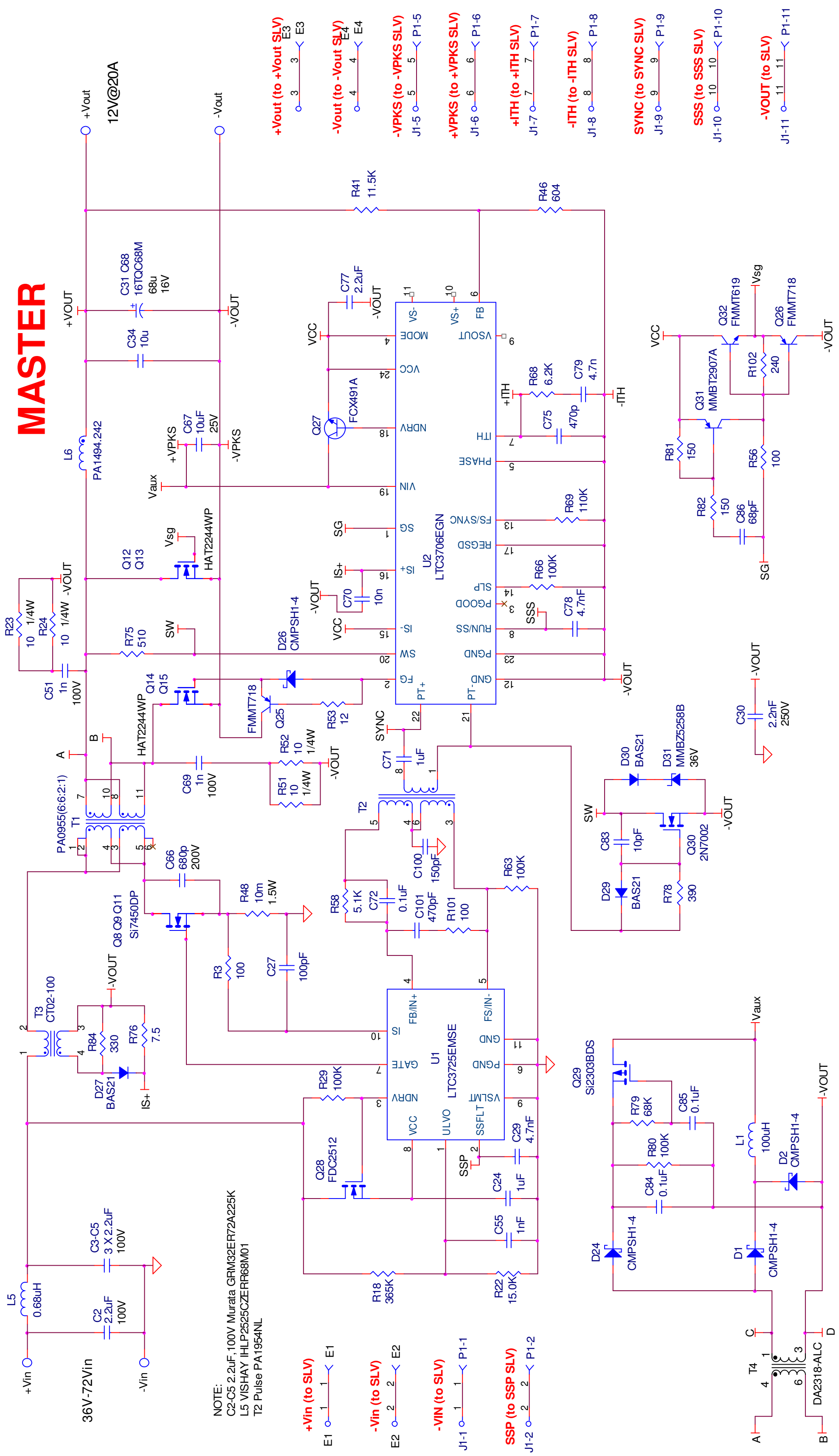


Figure 19. PolyPhase Master Schematic

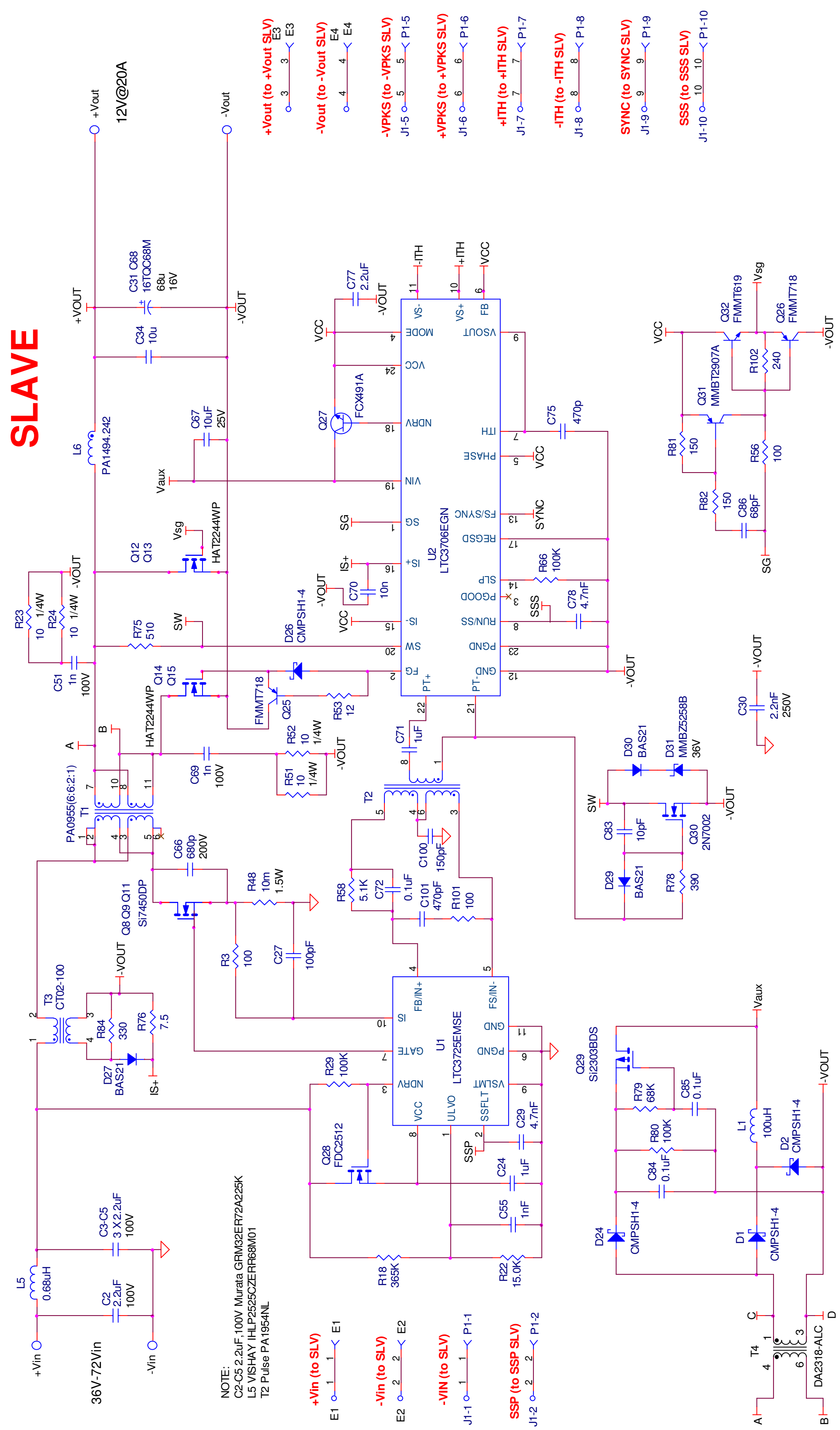


Figure 20. PolyPhase Slave Schematic

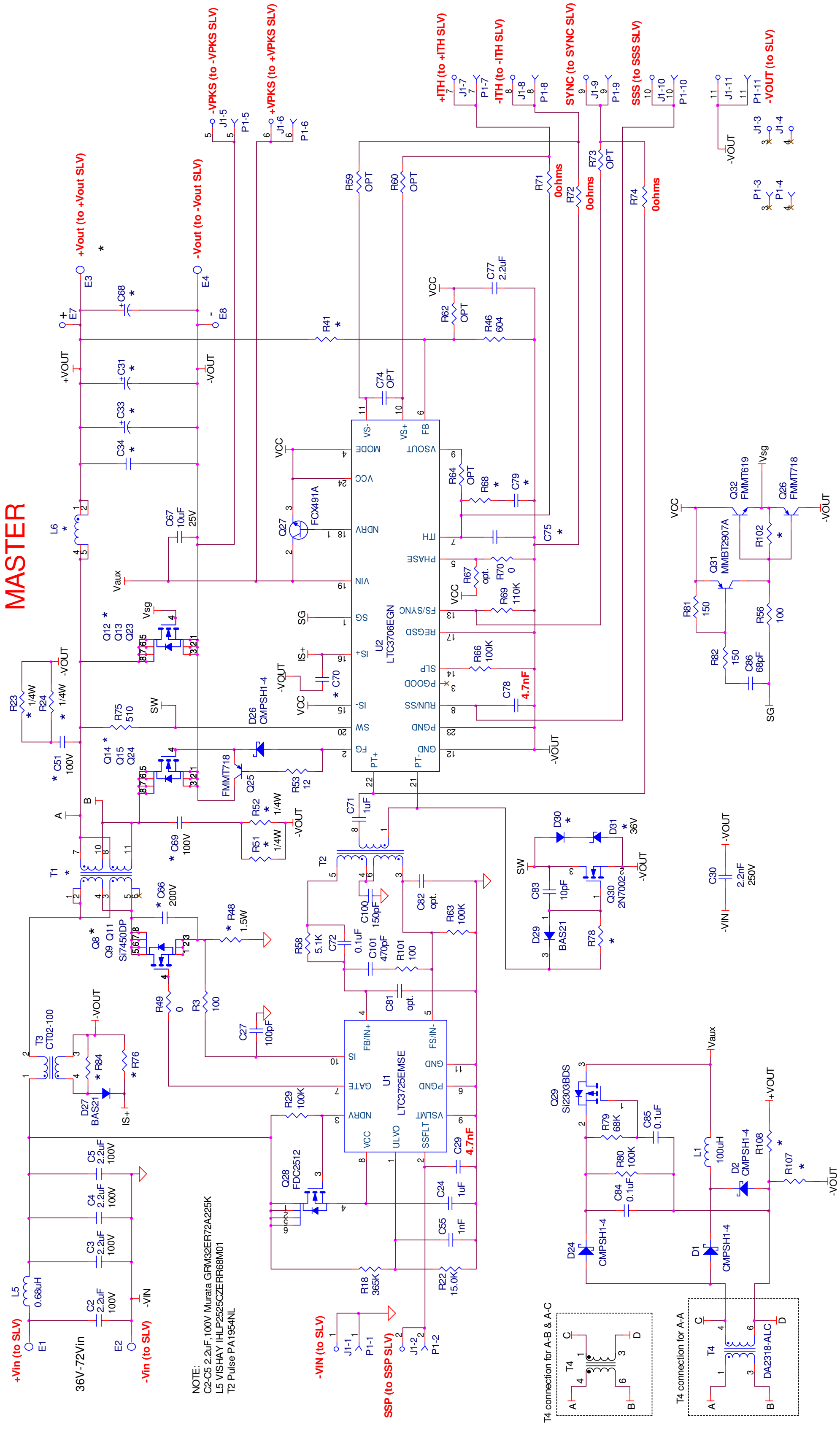
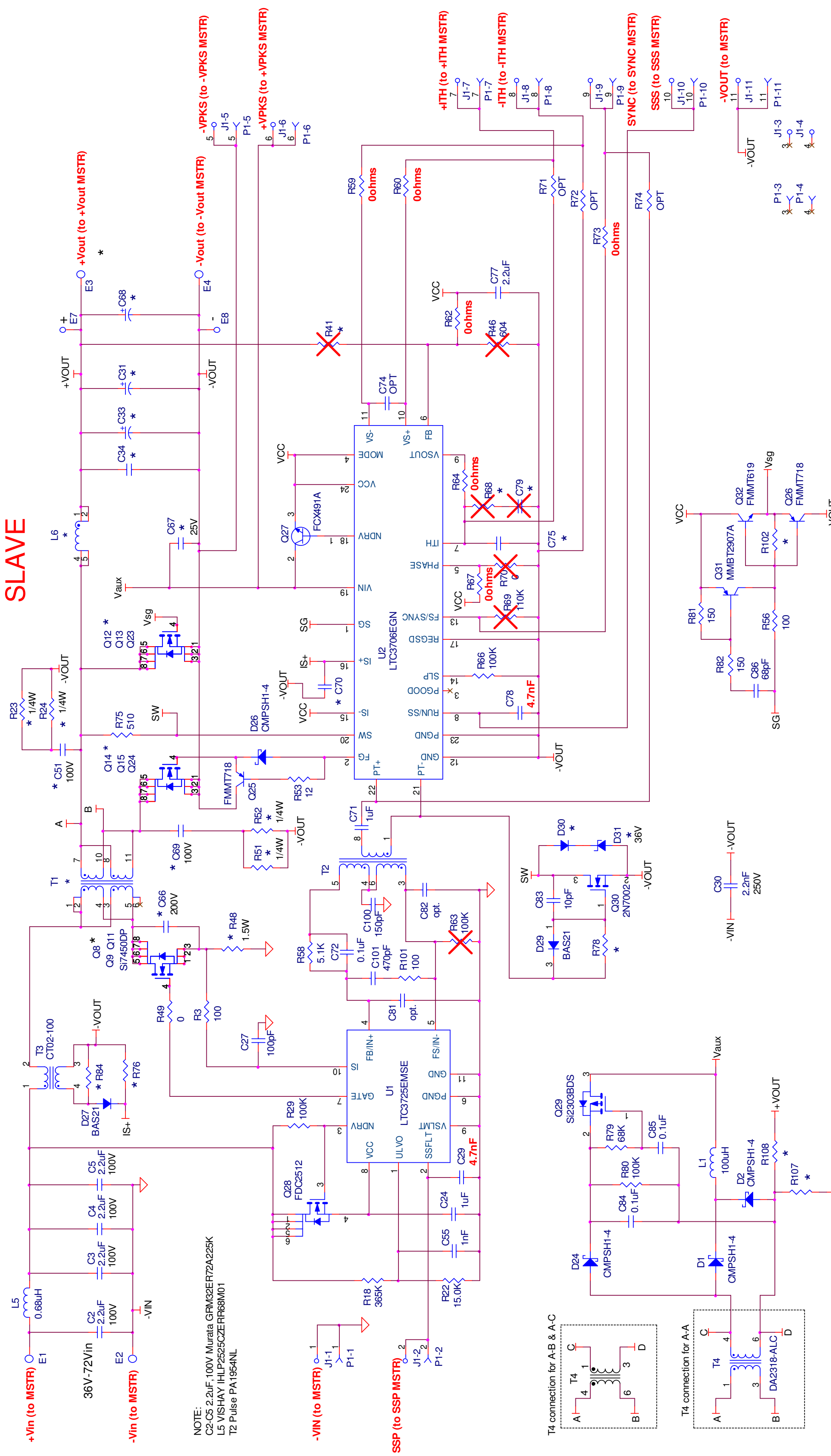


Figure 21. Full PolyPhase Master Schematic

* VERSION TABLE

VERSION	Vout/Iout	C31,C68	C33	C34	C66	C51,C69	C70	C75	C79	D30	D31	L6	Q8	Q12-Q15	Q23,Q24	R23,R24,R51,R52	R41	R48	R68	R76	R78	R84	R102	R107	R108	T1
DC888A-A	3.3V@50A	220uF, 4V		22uF	1.5nF	4.7nF	15nF	47pF	4.7nF	opt.	opt.	PA1382.650	opt.	Si7336ADP		5.1	2.74K	0.015	9.1K	9.53	620	2.2K	opt.	opt.	0	PA0950(6:6:1:1)
DC888A-B	5.0V@40A	220uF, 6.3V		22uF	1.5nF	2.2nF	15nF	100pF	3.3nF	opt.	opt.	PA1382.650	Si7450DP	Si7336ADP		6.8	4.42K	0.015	9.1K	8.06	750	1.0K	opt.	opt.	0	PA0954(4:4:1:1)
DC888A-C	12V@20A	68uF, 16V	opt	10uF	680pF	1.0nF	10nF	470pF	4.7nF	BAS21	MMBZ5258B	PA1494.242	Si7450DP	HAT2244WP	opt.	10	11.5K	0.010	6.2K	7.50	390	330	240	0	opt.	PA0955(6:6:2:1)



* VERSION TABLE

VERSION	Vout/Iout	C31,C68	C33	C34	C66	C51,C69	C70	C75	D30	D31	L6	Q8	Q12-Q15	Q23,Q24	R23,R24,R51,R52	R48	R76	R78	R84	R102	R107	R108	T1
DC888A-A	3.3V@50A	220uF, 4V		22uF	1.5nF	4.7nF	15nF	47pF	opt.	opt.	PA1382.650	opt.	Si7336ADP		5.1	0.015	9.53	620	2.2K	opt.	opt.	0	PA0950(6:6:1:1)
DC888A-B	5.0V@40A	220uF, 6.3V		22uF	1.5nF	2.2nF	15nF	100pF	opt.	opt.	PA1382.650	Si7450DP	Si7336ADP		6.8	0.015	8.06	750	1.0K	opt.	opt.	0	PA0954(4:4:1:1)
DC888A-C	12V@20A	68uF, 16V	opt	10uF	680pF	1.0nF	10nF	470pF	BAS21	MMBZ5258B	PA1494.242	Si7450DP	HAT2244WP	opt.	10	0.010	7.50	390	330	240	0	opt.	PA0955(6:6:2:1)

Figure 22. Full PolyPhase Slave Schematic

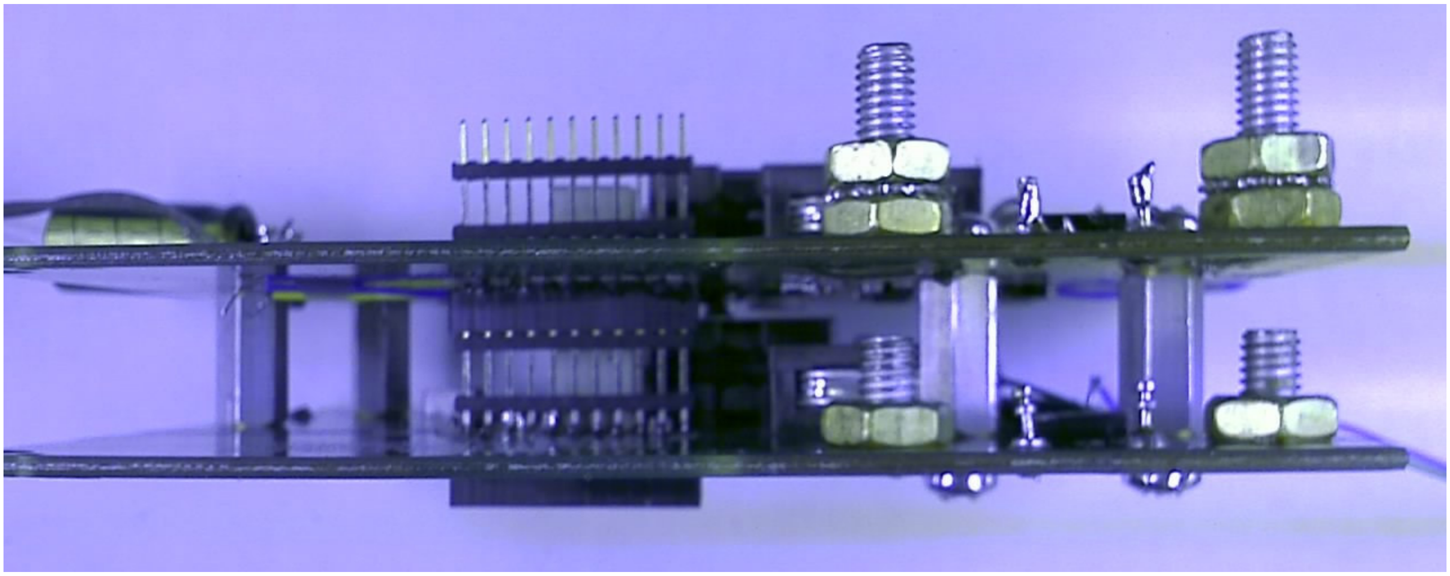


Figure 23. Picture of two DC888A's configured for PolyPhase