LTM4681
PolyPhase Single Output Step-Down µModule Regulator with Digital PSM: 3 × LTM4681 at 360A

DESCRIPTION

Demonstration circuit 3082A-B features the LTM®4681: the wide input and output voltage range, high efficiency and power density, high current PolyPhase® single output DC/DC step-down µModule® regulator with digital power system management. DC3082A-B is configured as 12-phase single output using 3 × LTM4681. The factory default input voltage is 12V typical, output voltage is 1V at 360A typical or 375A peak with recommended 400LFM forced airflow. The demo board output voltages can be adjusted from 0.6V to 1V. Programming the output voltages to any value that is greater than 1V, requires derating output current based on thermal derating curves provided in the data sheet of the LTM4681. Heat sink or other appropriate electronic cooling systems can also be used in conjunction with forced airflow to further optimize the output power when the output is on and loaded with maximum output current. The factory default switching frequency is preset at 350kHz typical. DC3082A-B comes with PMBus interface and digital power system management functions. An onboard 12-pin connector is available for users to connect the dongle DC1613A to the demo board, provides an easy way to communicate and program the part using LTpowerPlay® software development tool. LTpowerPlay software and I²C/PMBus/SMBus dongle DC1613A allows users to monitor real time telemetry of input and output voltages, input and output current, switching frequency, internal IC die temperatures, power stage component temperatures and fault logs. Programmable parameters include device address, output voltages, control loop compensation, switching frequency, phase interleaving, DCM or CCM mode of operation, digital soft-start, sequencing, and time based shutdown, fault responses to input and output overvoltage, output overcurrent, IC die and power component overtemperatures.

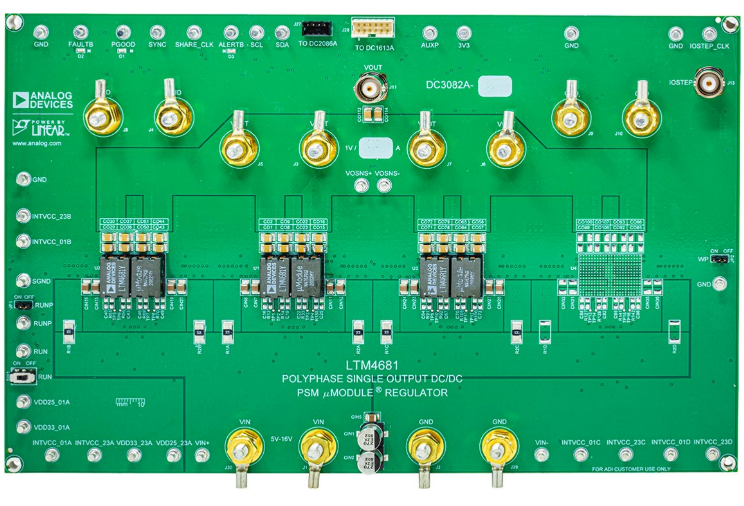
The LTM4681 is available in a thermally enhanced, low profile 330-lead (15mm × 22mm × 8.17mm) BGA package. It is recommended to read the data sheet and demo manual of LTM4681 prior to use or making any hardware changes to DC3082A-B.

LTpowerPlay software can be downloaded here.

USB to PMBus Controller Dongle DC1613A for use with LTpowerPlay is available here.

Design files for this circuit board are available.

BOARD PHOTO



PERFORMANCE SUMMARY Specifications are at T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
12-Phase Single Output					
Input Voltage V_{IN} Range		4.5	12	16	V
Demo Board Default Output Voltage V_{OUT}	f_{SW} = 350kHz, V_{IN} = 12V, I_{OUT} = 360A		1		V
Switching Frequency f_{SW}	Factory Default Switching Frequency		350		kHz
Maximum Continuous Output Current I_{OUT}	V_{IN} =12V, V_{OUT} = 0.6V to 1V, f_{SW} = 350kHz, V_{BIAS} = 5.5V (RUNP: ON), Forced Airflow = 400LFM		360	375	A
Efficiency	f_{SW} = 350kHz, V_{IN} =12V, V_{OUT} = 1V, I_{OUT} = 360A, V_{BIAS} = 5.5V (RUNP: ON), No Forced Airflow, No Heat Sink		89.6*		%

*Fast pulse current used for efficiency test.

QUICK START PROCEDURE

Demonstration circuit 3082A-B is easy to set up to evaluate the performance of the LTM4681. Please refer to Figure 1 for proper measurement equipment setup and follow the test procedure below.

1. With power off, connect the input power supply between V_{IN} (J1) and GND (J2). Set the input voltage supply to 0V.
2. Connect the load between V_{OUT} (J3, J5, J7) and GND (J4, J8, J9). Preset the load to 0A.
3. Connect the DMM between the input test points: V_{IN}^+ (E1) and V_{IN}^- (E2) to monitor the input voltage. Connect a DMM between VOSNS$^+$(E3) and VOSNS$^-$ (E4) to monitor the DC output voltage. VOSNS$^+$ and VOSNS$^-$ test points are Kelvin sensed directly across CO113 to provide accurate measurement of output voltage. Do not apply load current or connect the scope probe ground leads to any of the above test points to avoid damage to the regulator.
4. Prior to powering up the DC3082A-B, check the default position of the jumpers and switches (refer to Table 1).

Table 1. Demo Board Default Switches and Jumpers Position

SWITCH/JUMPER NAME	SW1	JP1	JP2
Description	RUN	RUNP	WP
Position	OFF	ON	OFF

5. Turn on the power supply at the input. Slowly increasing the input voltage from 0V to 12V typical.

   Measure and make sure the input supply voltage is 12V and flip SW1 (RUN) to the "ON" position. The output voltage should be 1.0V ± 0.5% typical.

QUICK START PROCEDURE

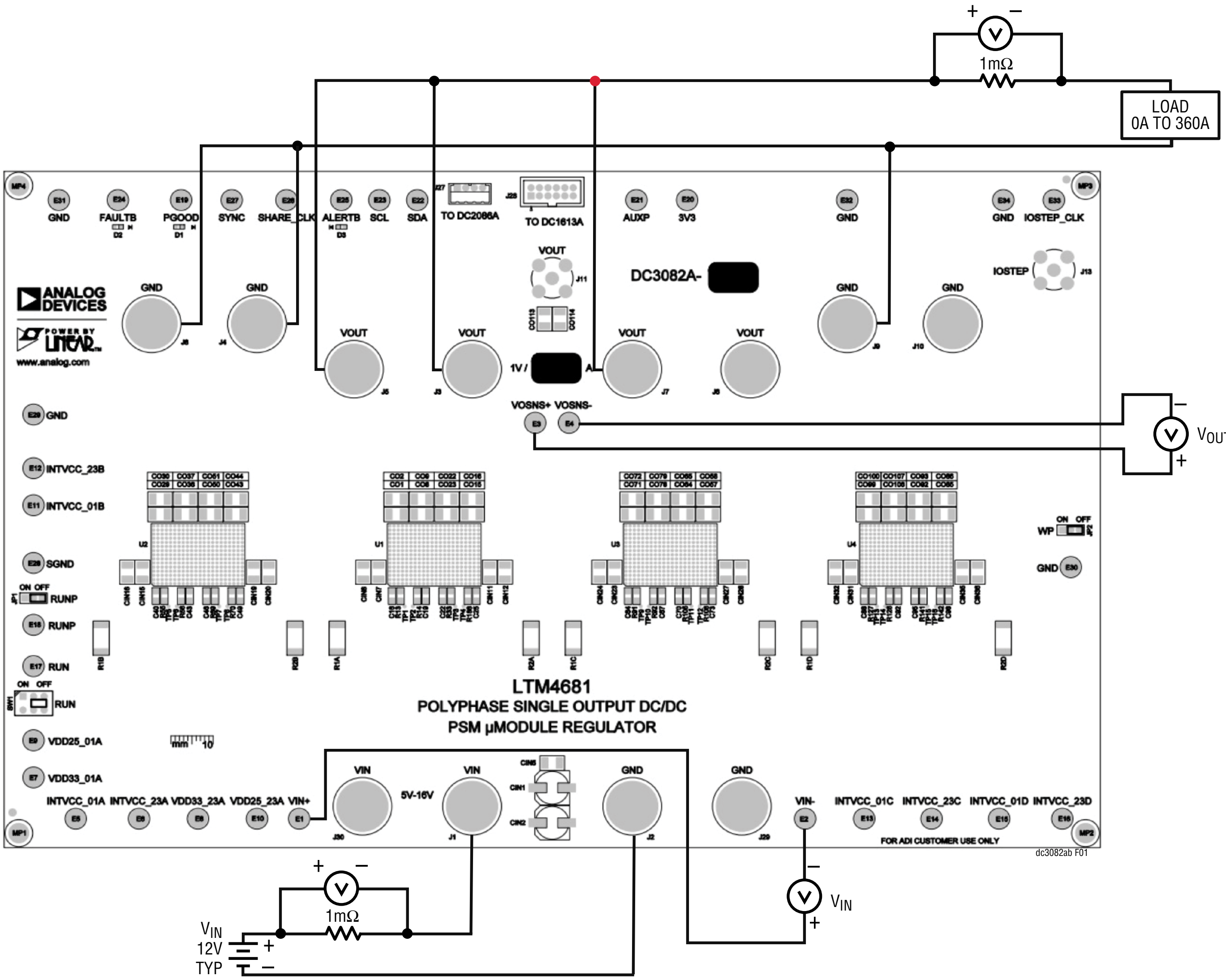


Figure 1. Proper Measurement Equipment Setup for DC3082A-B

QUICK START PROCEDURE

6. Use a fan (for example: AC Axial Fan, Model: AA128 1LS-AT, ADDA CORP. AC 110V–120V 50Hz/60Hz) to provide direct forced airflow to the demo board. Turn on the fan and place the fan about 5 inches from the demo board under test. This fan can temporarily be used for quick evaluation of the demo board at 300A load current but proper forced airflow system that can provide at least 400LFM or higher to the board under test, is strongly recommended for prolong operation of the demo board at maximum load current of 360A or 375A peak.

7. Once the input and output voltage are properly established and the fan is turned on, adjust the load current within the operating range of 0A to 360A max. Observe the output voltage regulation, output voltage ripples, switching node waveform, load transient response and other parameters. Refer to Figure 2 for proper output voltage ripples measurement.

   NOTE: To measure the input/output voltage ripples properly, do not use the long ground lead on the oscilloscope probe. See Figure 2 for the proper scope probe technique. Short, stiff leads need to be soldered to the (+) and (–) terminals of an input or output capacitor. The probe's ground ring needs to touch the (–) lead and the probe tip needs to touch the (+) lead.

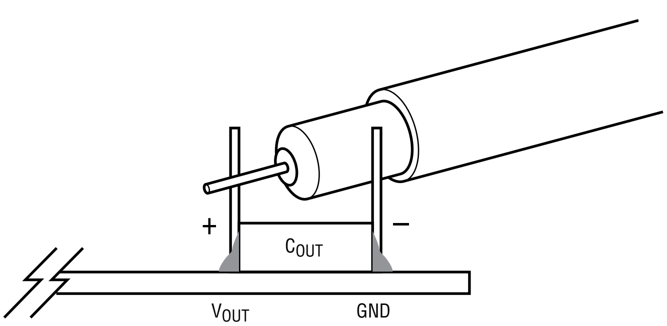


Figure 2. Scope Probe Placement for Measuring Output Ripple Voltage

   The output voltage ripples can also be monitored using onboard V_{OUT} BNC terminal. Connect a short BNC cable from V_{OUT} (J11) to the input channel of the oscilloscope (scope probe ratio 1:1, AC-coupling) to observe output voltage ripples.

8. (Option) Operation with V_{BIAS}

   V_{BIAS} pin is the 5.5V output of an internal buck regulator that can be enabled or disabled with RUNP. V_{BIAS} regulator input is V_{IN_VBIAS} pin and powered from V_{IN}. The advantage of using V_{BIAS} is bypassing the internal INTVCC_LDO powered from V_{IN}, turning on the internal switch connected the 5.5V V_{BIAS} to INTVCC_01 and INTVCC_23 of the part, therefore reducing the power loss, improving the overall efficiency and lower the temperature rise of the part while operating at high V_{IN} and high switching frequency. V_{BIAS} must exceed 4.8V and V_{IN} must be greater than 7V to activate the internal switch connecting V_{BIAS} to INTVCC _01 and INTVCC_23 of the part. In typical applications, it is recommended to enable V_{BIAS}.

9. Operation at low V_{IN}: $4.5V \le V_{IN} \le 5.75V$

   Set RUNP (JP1) to the "OFF" position. Remove R1, R47, R83 to disconnect V_{IN_VBIAS} from V_{IN}. Short V_{BIAS} to GND by stuffing R8, R54, R90 with zero-ohm resistors. Tie SV_{IN} to $INTV_{CC}$ by stuffing R157, R158, R159, R160, R161, R162 with zero-ohm resistors. Make sure V_{IN} is within $4.5V \le V_{IN} \le 5.75V$. Additional input electrolytic capacitors should be installed between V_{IN} (J1) and GND (J2) to prevent V_{IN} from drooping or overshoot to a voltage level that can exceed the specified minimum V_{IN} (4.5V) and maximum V_{IN} (5.75V) during large output load transient. Since SV_{IN} is tied to V_{IN} and $INTV_{CC}$ is tied to SV_{IN}, monitor SV_{IN} and $INTV_{CC}$ to make sure $INTV_{CC}$ abs max voltage (6V) should never be exceeded to avoid permanent damage to the regulator.

QUICK START PROCEDURE

10. (Option) Onboard Load Step Circuit

DC3082A-B provides onboard load transient circuit to measure ΔV_{OUT} peak-to-peak deviation during rising or falling dynamic load transient. The simple load step circuit consisting of three paralleled 30V N-channel power MOSFETs in series with three paralleled 3mΩ, 1W, 1% current sense resistors. The MOSFETs are configured as voltage control current source (VCCS) devices, therefore the output current step and its magnitude is created and controlled by adjusting the amplitude of the applied input voltage step at the gate of the MOSFETs. Use a function generator to provide a voltage pulse between IOSTEP_CLK (E33) and GND (E34). The input voltage pulse should be set at pulse width less than 300µs and maximum duty cycle less than 2% to avoid excessive thermal stress on the MOSFET devices. The output current step is measured directly across the current sense resistors and monitored by connecting BNC cable from IOSTEP (J13) to the input of the oscilloscope (scope probe ratio 1:1, DC-coupling). The equivalent voltage to current scale is 1mV/1A. The load step current slew rate di/dt can be varied by adjusting the rise time and fall time of the input voltage pulse applied at the gate of the MOSFETs. Output ripple voltage and output voltage during load transient of DC3082A-B should be measured at V_{OUT} BNC (J11) using short BNC cable. DC output voltage of DC3082A-B should be measured between VOSNS$^+$ (E3) and VOSNS$^-$(E4) test points.

11. Connecting a PC to DC3082A-B

Refer to Figure 3 for proper demo board set up with PC. Users can use a PC to reconfigure the power management features of the LTM4681 such as: nominal V_{OUT}, margin set points, OV/UV limits, output current and temperature fault limits, sequencing parameters, the fault logs, fault responses, GPIOs and other functionality. The DC1613A dongle can be hot plugged when V_{IN} is present.

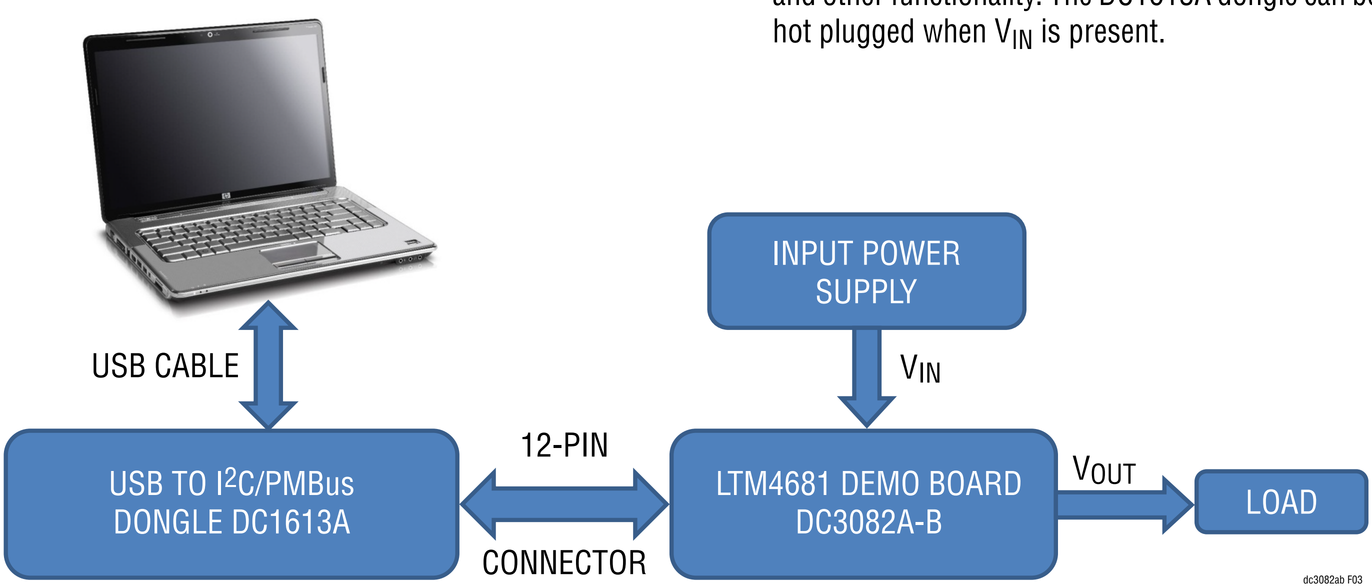


Figure 3. DC3082A-B Demo Board Setup with PC

LTpowerPlay QUICK START GUIDE

LTpowerPlay is a powerful Windows-based development environment that supports ADI power system management ICs. The software supports a variety of different tasks. You can use LTpowerPlay to evaluate ADI PSM µModule by connecting to a demo board system. LTpowerPlay can also be used in an off-line mode (with no hardware present) to build a multichip configuration file that can be saved and reloaded anytime. LTpowerPlay provides unprecedented diagnostic tool and debug features. It becomes a valuable diagnostic tool during board bring-up to program or tweak the power management scheme in a system, or to diagnose power issues when bringing up rails. LTpowerPlay utilizes the DC1613A USB-to-PMBus controller to communicate with one of many potential targets, including all the parts in ADI PSM product category demo system. The software also provides an automatic update feature to keep the software current with the latest set of device drivers and documentation.

USB to PMBus Controller Dongle DC1613A for use with LTpowerPlay is available at DC1613A.

To access technical support documents for ADI Digital Management Products, visit Help or view on-line help on the LTpowerPlay GUI main menu. The following procedure describes how to use LTpowerPlay to monitor and change the settings of LTM4681.

1. Download and install the LTpowerPlay GUI.

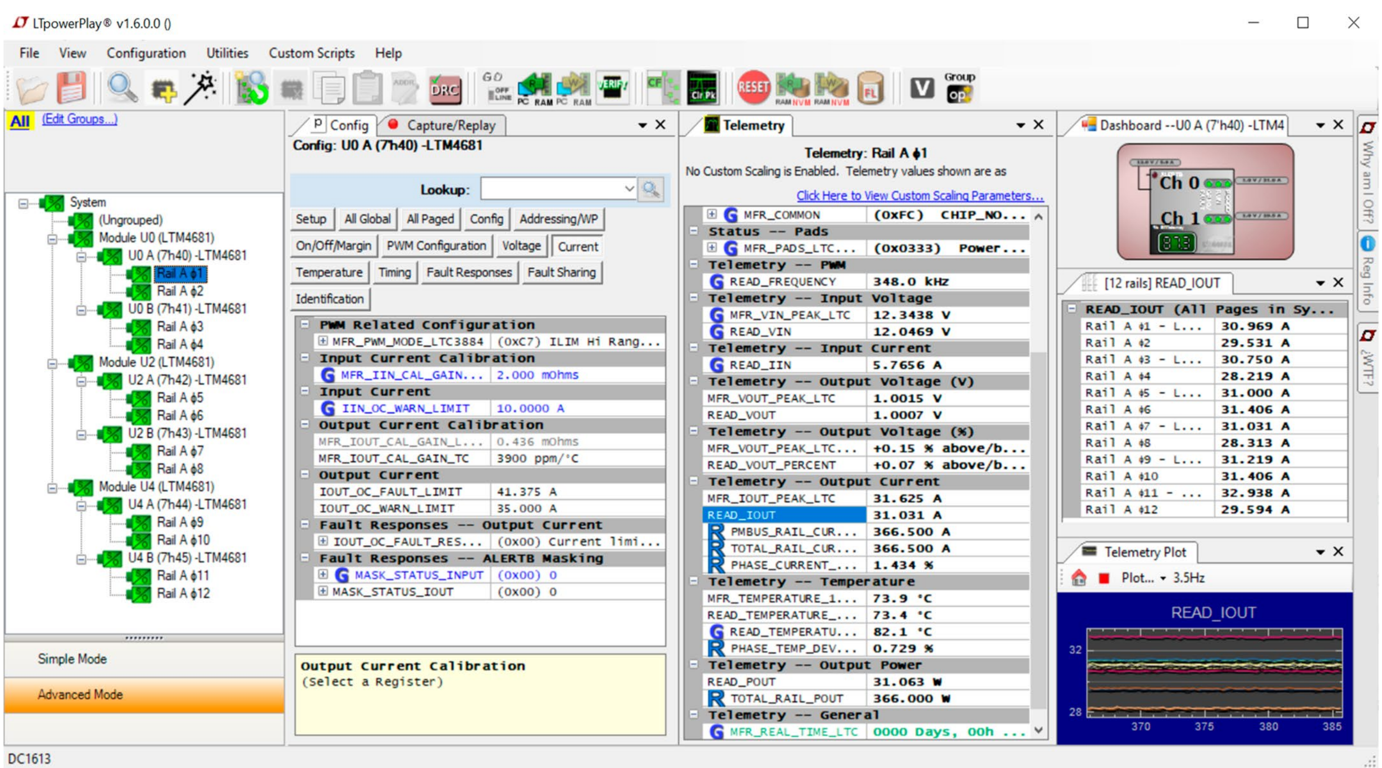


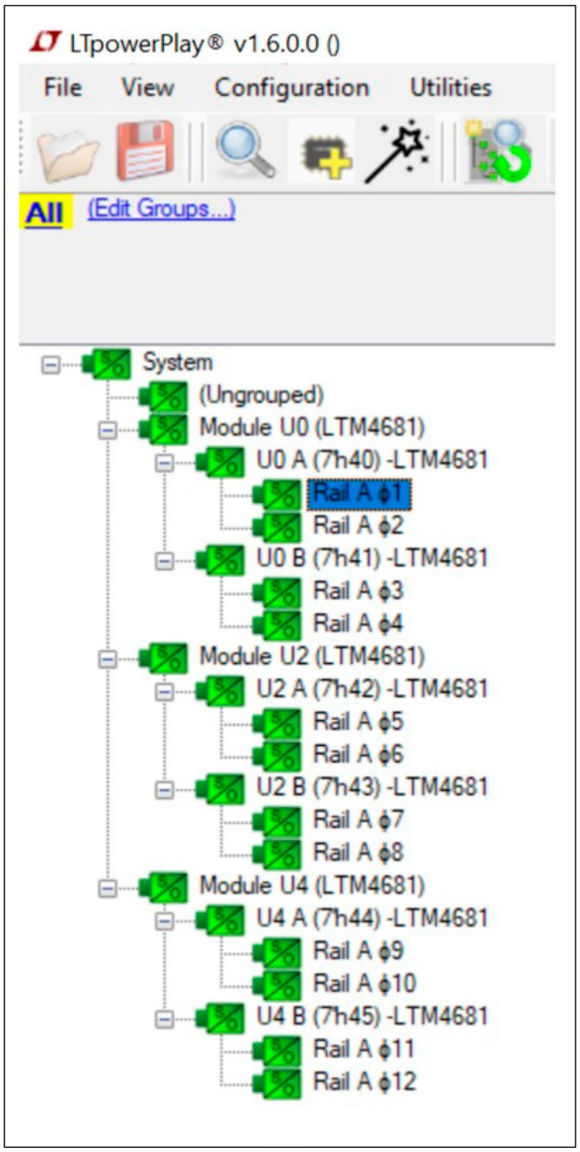
Figure 4. LTpowerPlay Main Interface

LTpowerPlay QUICK START GUIDE

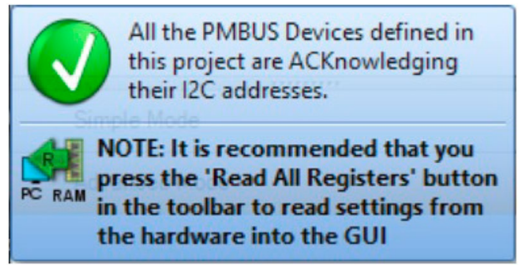
2. Launch the LTpowerPlay GUI.

   a. The GUI should automatically identify the DC3082A-B.

   The system tree on the left-hand side should look like this for DC3082A-B:



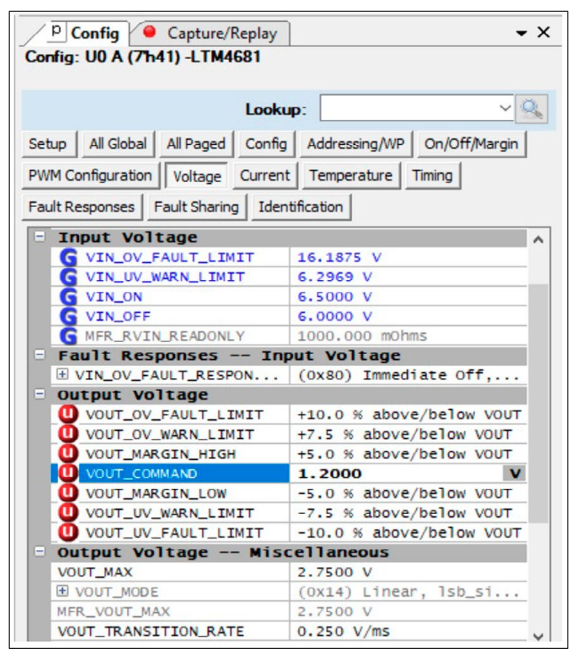
b. A green message box shows for a few seconds in the lower left-hand corner, confirming that LTM4681 is communicating:



c. In the Toolbar, click the "R" (RAM to PC) icon to read the RAM from the LTM4681. The configuration is read from the LTM4681 and loaded into the GUI:

d. Example of program the output voltage to a different value.

   In the Config Tab, click on the "Voltage" Tab in the main menu bar, type in 1.2V in the VOUT_COMMAND box as showed below:

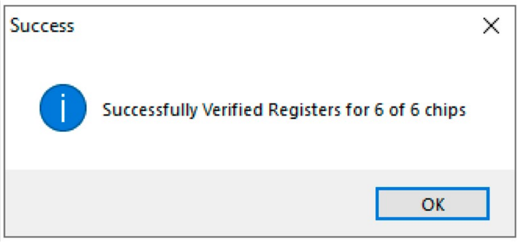


   Then click the "W" (PC to RAM) icon to write these register values to the LTM4681.

LTpowerPlay QUICK START GUIDE

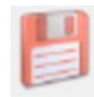
The output voltage will change to 1.2V.

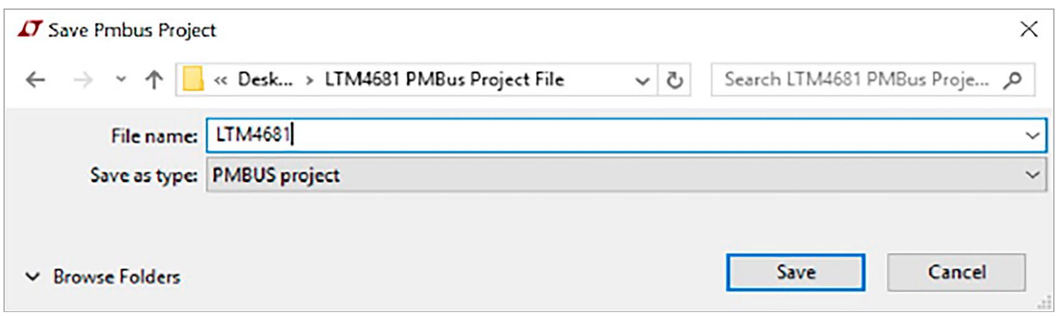
If the write command is successfully executed, the following message should be seen:



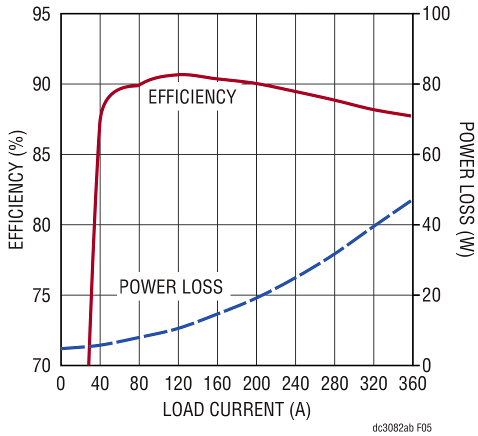
e. All user configuration or changes can be saved into the NVM. In the toolbar, click “RAM to NVM” icon:

f. Save the demo board configuration to a (*. proj) file. Click the Save icon and save the file with a preferred file name.



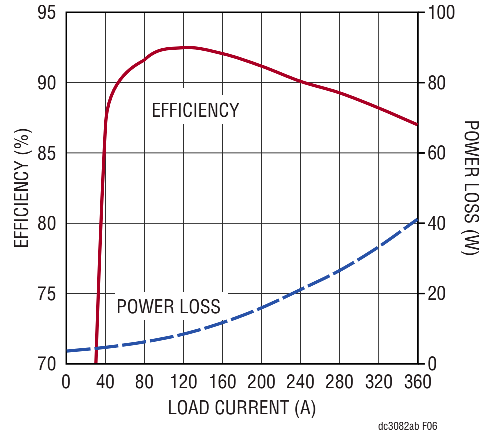


TEST RESULTS



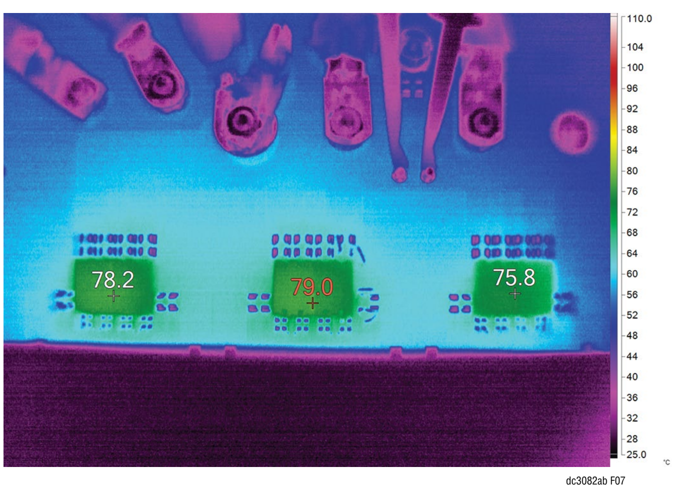
CIRCUIT CONFIGURATION: 12-PHASE SINGLE OUTPUT
f_{SW} = 350kHz, V_{IN} = 12V, V_{OUT} = 1V
I_{LOAD} = 0A TO 360A
V_{BIAS} = 5.5V (RUNP: ON)
V_{IN}, V_{OUT} WAS MEASURED ACROSS C_{IN11}, C_{O15}
FAST PULSE LOAD CURRENT USED TO MEASURE EFFICIENCY
T_A = 25°C, NO FORCED AIRFLOW, NO HEAT SINK

Figure 5. Efficiency: 1V_{OUT}



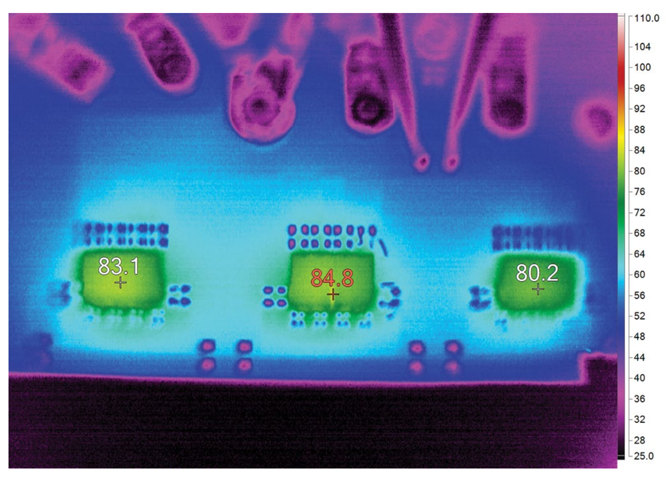
CIRCUIT CONFIGURATION: 12-PHASE SINGLE OUTPUT
f_{SW} = 250kHz, V_{IN} = 12V, V_{OUT} = 0.6V
I_{LOAD} = 0A TO 360A
V_{BIAS} = 5.5V (RUNP: ON)
V_{IN}, V_{OUT} WAS MEASURED ACROSS C_{IN11}, C_{O15}
FAST PULSE LOAD CURRENT USED TO MEASURE EFFICIENCY
T_A = 25°C, NO FORCED AIRFLOW, NO HEAT SINK

Figure 6. Efficiency: 0.6V_{OUT}



CIRCUIT CONFIGURATION: 12-PHASE SINGLE OUTPUT
f_{SW} = 350kHz, V_{IN} = 12V, V_{OUT} = 1V
I_{LOAD} = 240A
V_{BIAS} = 5.5V (RUNP: ON)
T_A = 25°C, NO FORCED AIRFLOW, NO HEAT SINK

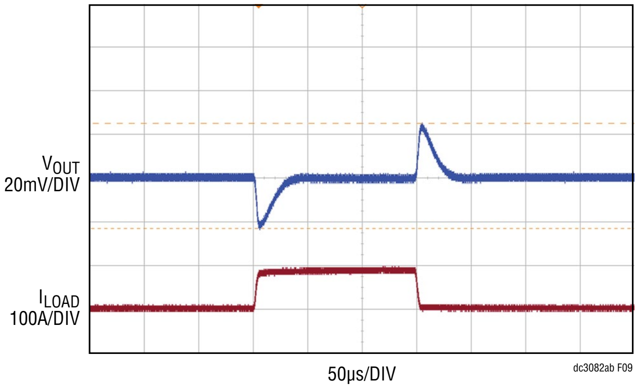
Figure 7. Thermal Performance, No Airflow



CIRCUIT CONFIGURATION: 12-PHASE SINGLE OUTPUT
f_{SW} = 350kHz, V_{IN} = 12V, V_{OUT} = 1V
I_{LOAD} = 360A
V_{BIAS} = 5.5V (RUNP: ON)
T_A = 25°C, FORCED AIRFLOW = 400LFM, NO HEAT SINK

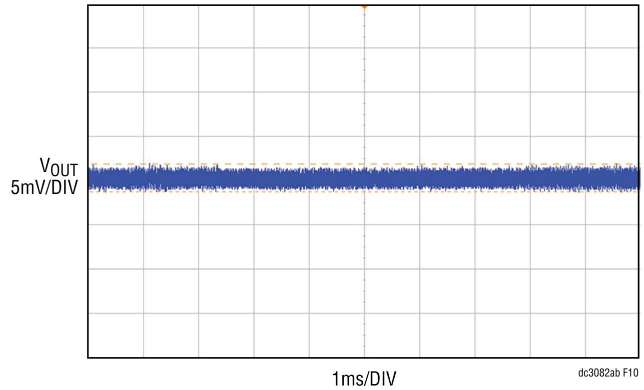
Figure 8. Thermal Performance, 400LFM Forced Airflow

TEST RESULTS



CIRCUIT CONFIGURATION: 12-PHASE SINGLE OUTPUT
f_{SW} = 350kHz, V_{IN} = 12V, V_{OUT} = 1V
$I_{LOAD-STEP}$ = 0A TO 90A AT di/dt = 30A/µs
$V_{OUT(P-P)}$ = 48.1mV
OUTPUT VOLTAGE MEASURED AT V_{OUT} BNC (J11)
AC-COUPLING, 20MHz BWL

Figure 9. Load Transient Response



CIRCUIT CONFIGURATION: 12-PHASE SINGLE OUTPUT
f_{SW} = 350kHz, V_{IN} = 12V, V_{OUT} = 1V
I_{LOAD} = 360A
$V_{OUT(P-P)}$ = 3.1mV
OUTPUT VOLTAGE MEASURED AT V_{OUT} BNC (J11)
AC-COUPLING, 20MHz BWL

Figure 10. Output Ripple Voltage

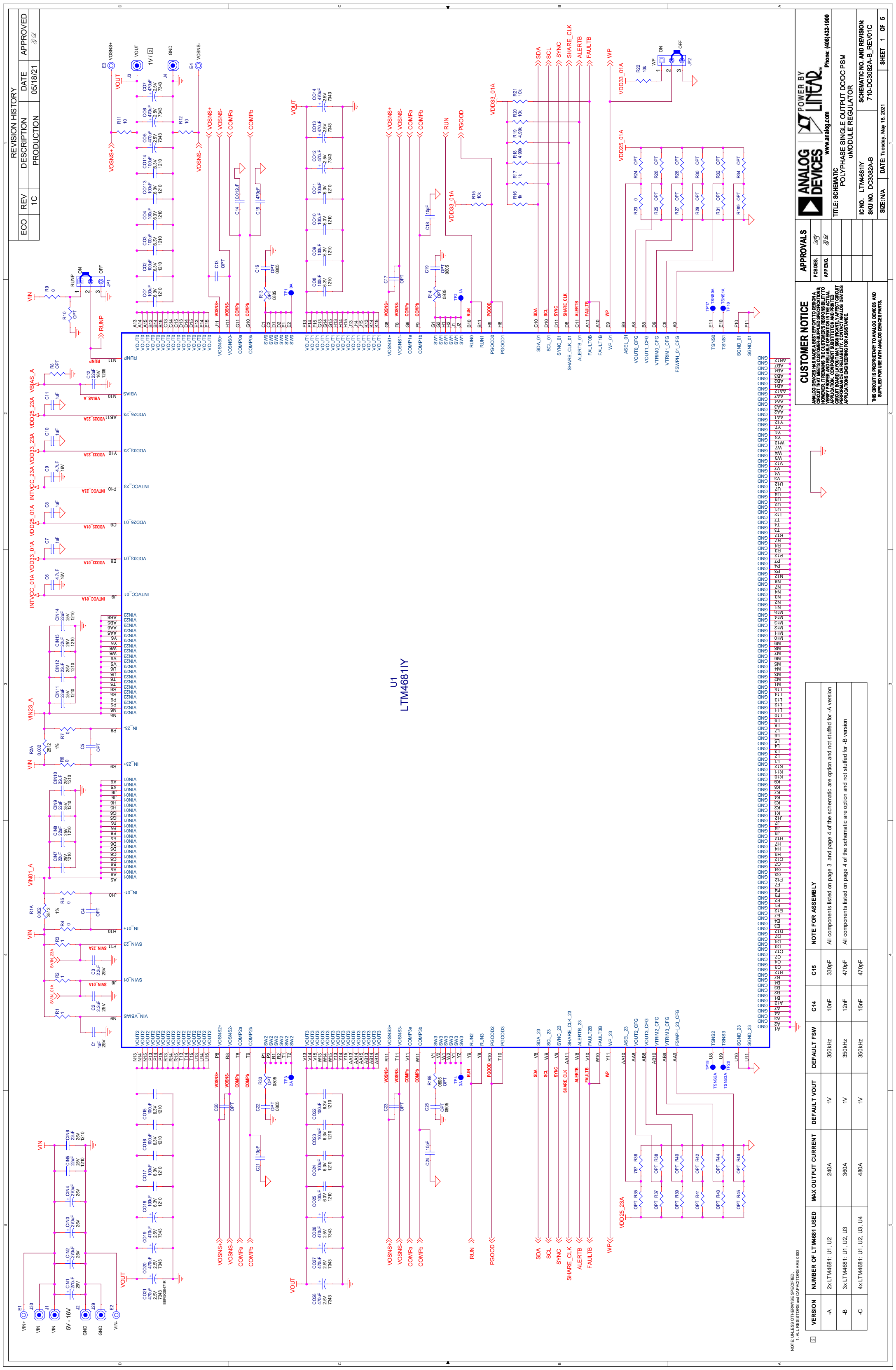
PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
Required Circuit Components				
1	15	C1, C7, C8, C10, C11, C26, C32, C33, C35, C36, C50, C56, C57, C59, C60	CAP., 1µF, X7R, 25V, 10%, 0603, AEC-Q200	MURATA, GCM188R71E105KA64D
2	6	C2, C3, C27, C28, C51, C52	CAP., 2.2µF, X5R, 25V, 10%, 0603	MURATA, GRM188R61E225KA12D
4	6	C6, C9, C31, C34, C55, C58	CAP., 4.7µF, X5R, 16V, 10%, 0603	MURATA, GRM188R61C475KAAJD
5	3	C12, C37, C61	CAP., 22µF, X5R, 16V, 10%, 1206	AVX, 1206YD226KAT2A
6	1	C14	CAP., 0.012µF, X7R, 16V, 5%, 0603	AVX, 0603YC123JAT2A
7	1	C15	CAP., 470pF, C0G, 50V, 5%, 0603	AVX, 06035A471JAT2A
8	11	C18, C21, C24, C39, C42, C45, C48, C63, C66, C69, C72	CAP., 10pF, C0G, 50V, 5%, 0603	AVX, 06035A100JAT2A
9	1	C99	CAP., 0.01µF, X7R, 50V, 10%, 0603	AVX, 06035C103KAT2A
10	2	C100, C101	CAP., 100µF, X5R, 6.3V, 10%, 1206	MURATA, GRM31CR60J107KE39L
11	2	C102, C103	CAP., 0.1µF, X7R, 16V, 10%, 0603, FLEXITERM	AVX, 0603YC104KAZ2A
12	4	CIN1–CIN4	CAP., 270µF, ALUM POLY HYB, 25V, 20%, 8mm × 10.2mm SMD, RADIAL, AEC-Q200, EEHZK	PANASONIC, EEH-ZK1E271P
13	26	CIN5–CIN30	CAP., 22µF, X5R, 25V, 10%, 1210	KEMET, C1210C226K3PACTU
14	50	CO1–CO4, CO8–CO11, CO15–CO18, CO22–CO25, CO29–CO32, CO36–CO39, CO43–CO46, CO50–CO53, CO57–CO60, CO64–CO67, CO71–CO74, CO78–CO81, CO113, CO114	CAP., 100µF, X5R, 6.3V, 20%, 1210	AVX, 12106D107MAT2A
15	36	CO5–CO7, CO12–CO14, CO19–CO21, CO26–CO28, CO33–CO35, CO40–CO42, CO47–CO49, CO54–CO56, CO61–CO63, CO68–CO70, CO75–CO77, CO82–CO84	CAP., 470µF, TANT, POSCAP, 2.5V, 20%, 7343, TPF SERIES	PANASONIC, ETPF470M5H
16	1	D1	LED, GREEN, WATER CLEAR, 0603	WURTH ELEKTRONIK, 150060GS75000
17	2	D2, D3	LED, RED, WATER CLEAR, 0603	WURTH ELEKTRONIK, 150060RS75000
18	2	D4, D5	DIODE, SCHOTTKY, 20V, 0.5A, SOD-882, LEADLESS	NEXPERIA, PMEG2005AEL, 315
19	1	Q3	XSTR., MOSFET, N-CH, 60V, 220mA, SOT23-3, AEC-Q101	DIODES INC., 2N7002A-13
20	2	Q7, Q9	XSTR., MOSFET, P-CH, 20V, 5.9A, SOT-23-3 (TO-236-3)	VISHAY, Si2365EDS-T1-GE3
21	3	Q13, Q14, Q17	XSTR., MOSFET, N-CH, 30V, 150A, D2PAK	INFINEON, IRL7833STRLPBF
22	9	R1–R3, R47–R49, R83–R85	RES., 1Ω, 1%, 1/10W, 0603, AEC-Q200	NIC, NRC06F1R00TRF
23	6	R1A, R1B, R1C, R2A, R2B, R2C	RES., 0.002Ω, 1%, 1W, 2512, SENSE	VISHAY, WSL25122L000FEA
24	14	R4–R7, R9, R23, R50–R53, R86–R89	RES., 0Ω, 1/10W, 0603, AEC-Q200	VISHAY, CRCW06030000Z0EA
25	3	R11, R12, R156	RES., 10Ω, 1%, 1/10W, 0603	VISHAY, CRCW060310R0FKEA
26	6	R15, R20–R22, R155, R180	RES., 10k, 1%, 1/10W, 0603, AEC-Q200	VISHAY, CRCW060310K0FKEA
27	2	R16, R17	RES., 1k, 1%, 1/10W, 0603	VISHAY, CRCW06031K00FKEA
28	4	R18, R19, R186, R187	RES., 4.99k, 1%, 1/10W, 0603, AEC-Q200	PANASONIC, ERJ3EKF4991V
29	1	R36	RES., 787Ω, 1%, 1/10W, 0603	NIC, NRC06F7870TRF
30	1	R58	RES., 1.65k, 1%, 1/10W, 0603	NIC, NRC06F1651TRF
31	1	R72	RES., 2.43k, 1%, 1/10W, 0603	YAGEO, 9C06031A2431FKHFT
32	1	R94	RES., 3.24k, 1%, 1/10W, 0603	YAGEO, RC0603FR-073K24L
33	1	R108	RES., 4.22k, 1%, 1/10W, 0603	NIC, NRC06F4221TRF

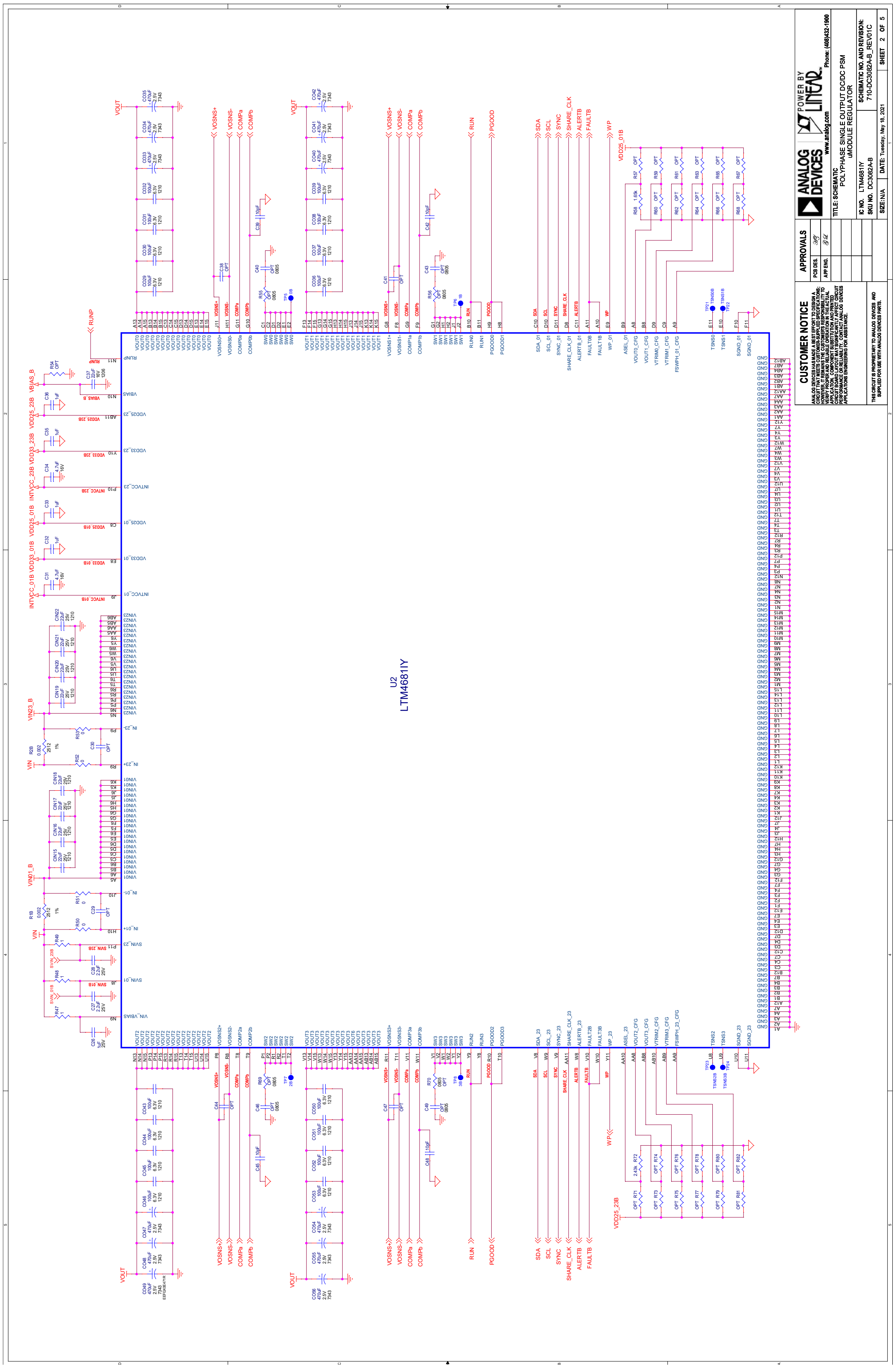
PARTS LIST

ITEM	QTY	REFERENCE	PART DESCRIPTION	MANUFACTURER/PART NUMBER
34	1	R177	RES., 200Ω, 1%, 1/10W, 0603	VISHAY, CRCW0603200RFKEA
35	2	R178, R179	RES., 127Ω, 1%, 1/10W, 0603, AEC-Q200	NIC, NRC06F1270TRF
36	3	R181–R183	RES., 0.003Ω, 1%, 1W, 2512, ±350ppm, METAL, SENSE	PANASONIC, ERJM1WSF3M0U
37	2	R184, R185	RES., 0Ω, 1W, 2512, SENSE, COPPER	VISHAY, WSL251200000ZEA9
38	3	U1–U3	IC, QUAD OUTPUT µModule REG., BGA	ANALOG DEVICES, LTM4681IY#PBF
39	1	U5	IC, MEMORY, EEPROM, 2Kb (256x8), TSSOP-8, 400kHz	MICROCHIP, 24LC025-I/ST
Additional Demo Board Circuit Components				
1	0	C4, C5, C13, C17, C20, C23, C29, C30, C38, C41, C44, C47, C53, C54, C62, C65, C68, C71	CAP., OPTION, 0603	
2	0	C16, C19, C22, C25, C40, C43, C46, C49, C64, C67, C70, C73	CAP., OPTION, 0805	
3	0	Q1	XSTR., OPTION, MOSFET, P-CH, SOT-23	
4	0	R8, R10, R24–R32, R34, R35, R37–R46, R54, R57, R59–R68, R71, R73–R82, R90, R93, R95–R104, R107, R109–R118, R157–R174, R189	RES., OPTION, 0603	
5	0	R13, R14, R33, R55, R56, R69, R70, R91, R92, R105, R106, R188	RES., OPTION, 0805	
6	0	R175, R176	RES., OPTION, 2512	
Hardware: For Demo Board Only				
1	34	E1–E34	TEST POINT, TURRET, 0.094" MTG. HOLE, PCB 0.062" THK	MILL-MAX, 2501-2-00-80-00-00-07-0
2	12	J1–J10, J29, J30	EVAL BOARD STUD HARDWARE SET, #10-32	ANALOG DEVICES, 720-0010
3	2	J11, J13	CONN., RF, BNC, RCPT, JACK, 5-PIN, ST, THT, 50Ω	AMPHENOL RF, 112404
4	1	J27	CONN., HDR, SHROUDED, MALE, 1×4, 2mm, VERT, ST, THT	HIROSE ELECTRIC, DF3A-4P-2DSA
5	1	J28	CONN., HDR, SHROUDED, MALE, 2×6, 2mm, VERT, ST, THT	AMPHENOL, 98414-G06-12ULF
6	2	JP1, JP2	CONN., HDR, MALE, 1×3, 2mm, VERT, ST, THT	WURTH ELEKTRONIK, 62000311121
7	1	LB1	LABEL SPEC, DEMO BOARD SERIAL NUMBER	BRADY, THT-96-717-10
8	4	MP1–MP4	STANDOFF, NYLON, SNAP-ON, 0.5"	WURTH ELEKTRONIK, 702935000
9	1	PCB1	PCB, DC3082A	ADI APPROVED SUPPLIER, 600-DC3082A
10	1	SW1	SWITCH, SLIDE, DPDT, 0.3A, 6VDC, PTH	C&K, JS202011CQN
11	2	XJP1, XJP4	CONN., SHUNT, FEMALE, 2 POS, 2mm	WURTH ELEKTRONIK, 60800213421

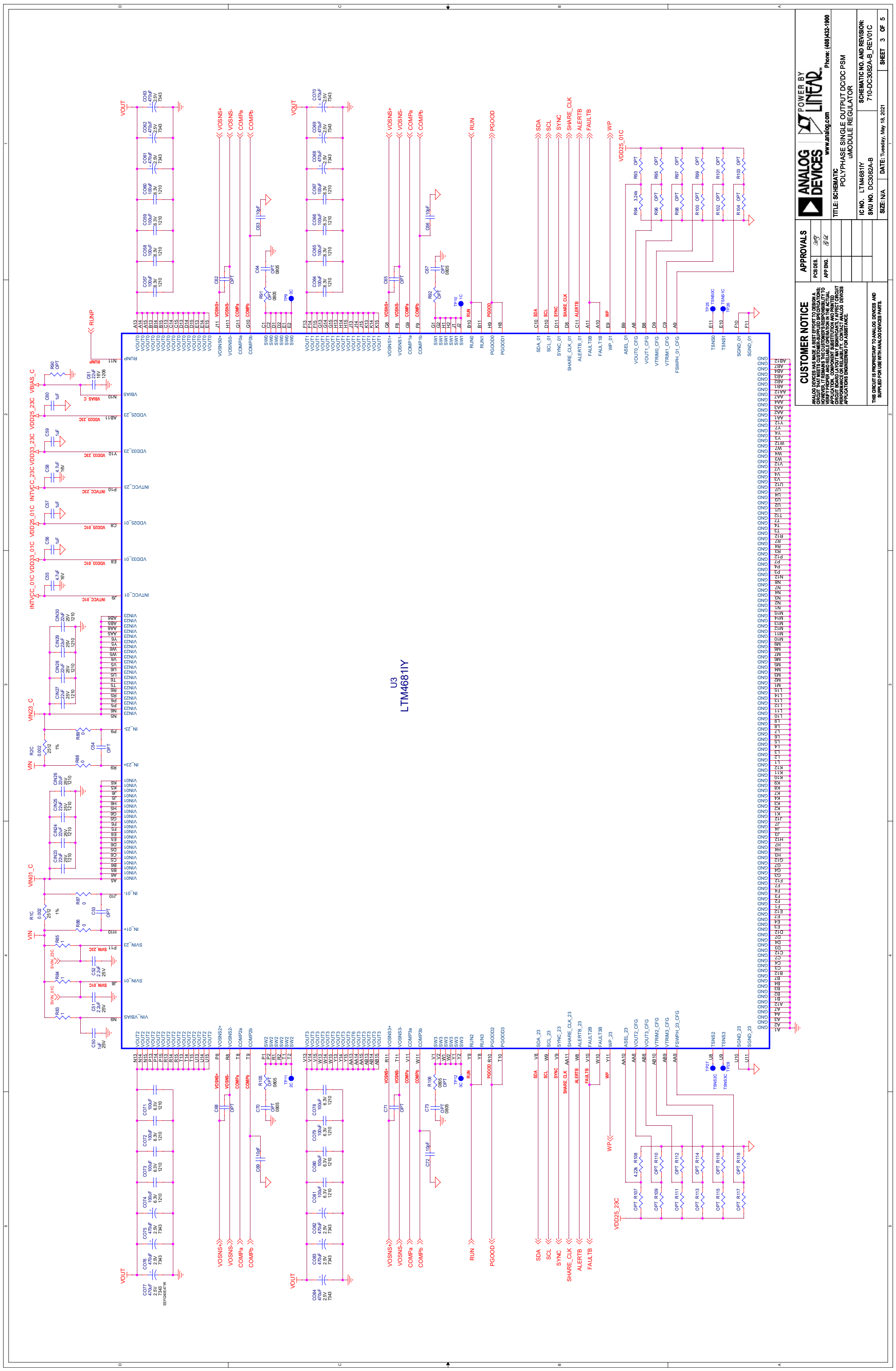
SCHEMATIC DIAGRAM



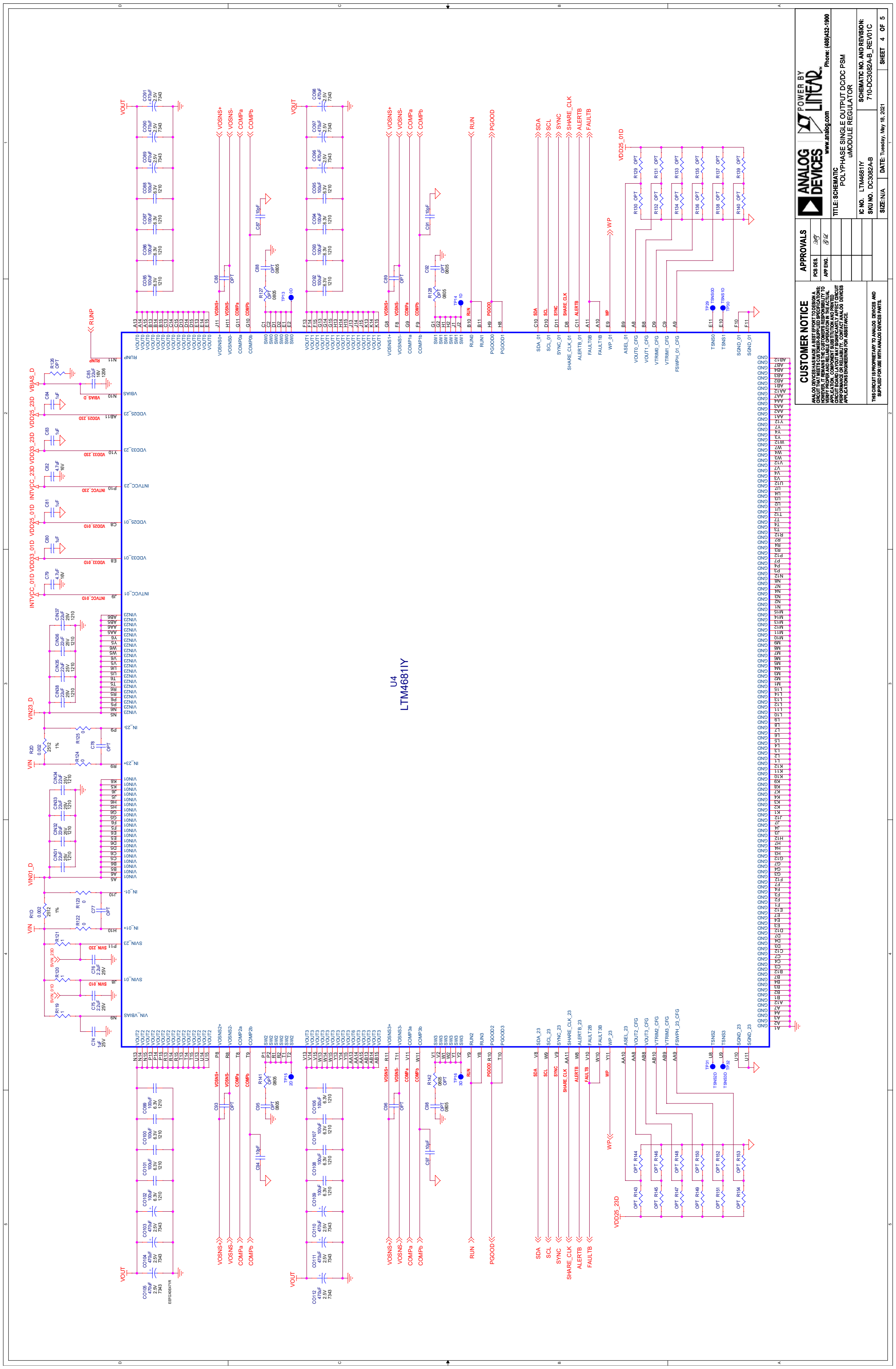
SCHEMATIC DIAGRAM



SCHEMATIC DIAGRAM



SCHEMATIC DIAGRAM



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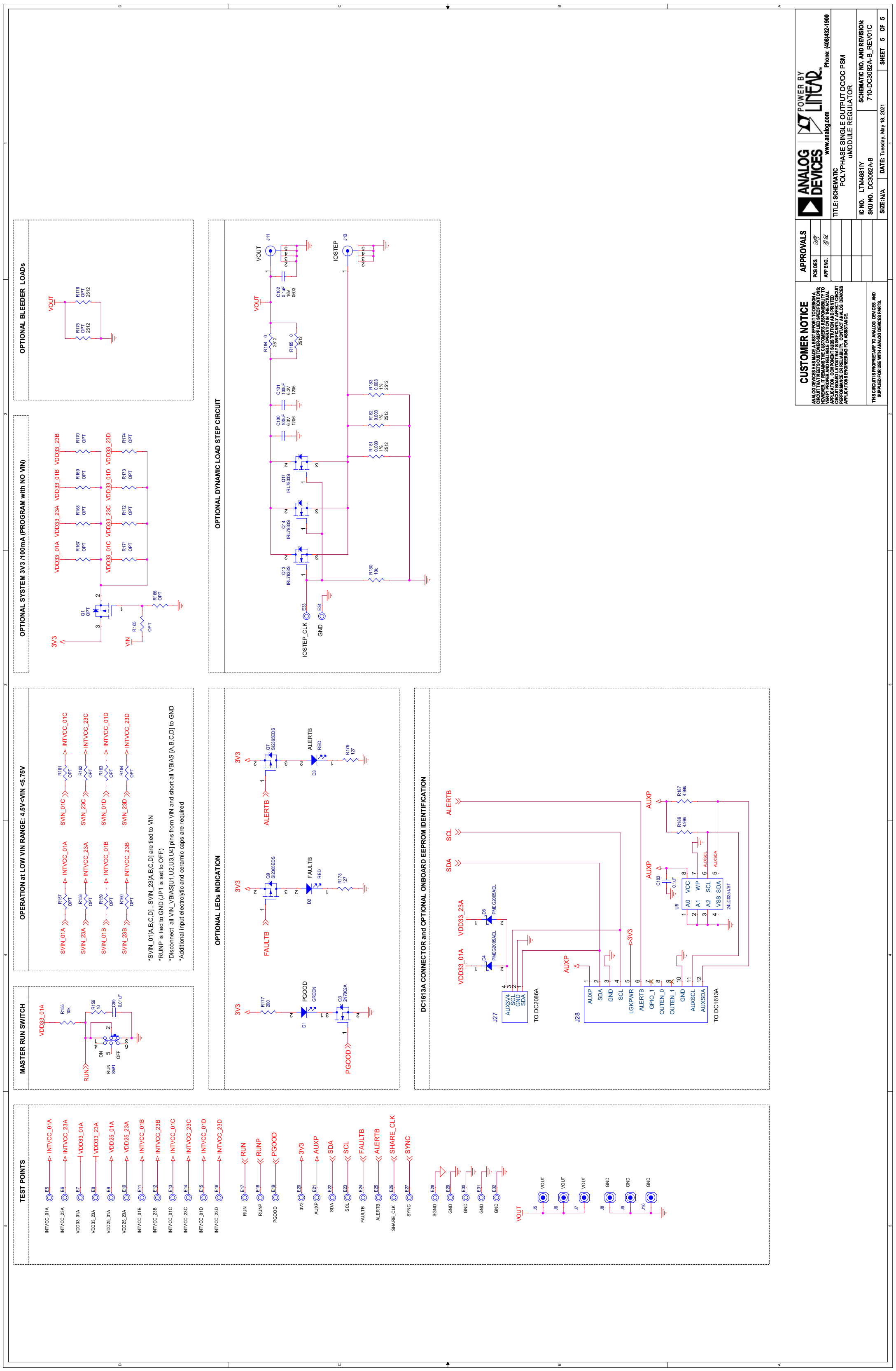
SCHEMATIC DIAGRAM



Rev. 0

ESD Caution
ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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