TI Designs

Less Than 1-W, Quad-Channel, Analog Output Module With Adaptive Power Management Reference Design

Description

This quad-channel, analog output module delivers voltage and current outputs using the highly integrated DAC8775 digital-to-analog converter (DAC). Integrated adaptive power management, along with the LM5166 buck converter, reduces the total power dissipation of the reference design to less than 1 W, even when driving all four channels at 20 mA simultaneously.

Resources

TIPD215	Design Folder
DAC8775	Product Folder
LM5166	Product Folder

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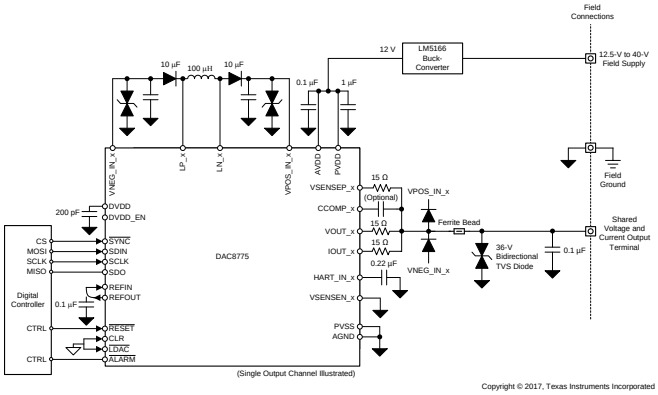
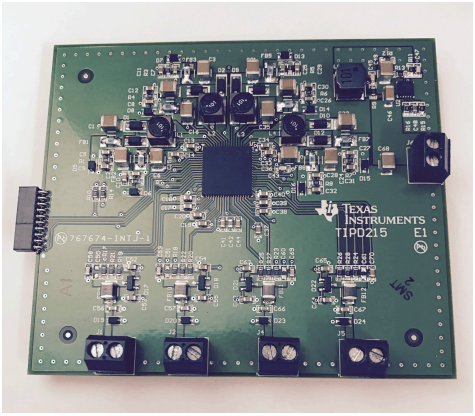
Features

- Quad-Channel Analog Outputs for Factory Automation & Control
- 4-mA to 20-mA Current Outputs
- ±10-V Voltage Outputs
- 12.5-V to 40-V Input Supply Range
- Less than 1 W of Onboard Power Dissipation
- Adaptive Power Management for Current Outputs

Applications

- Factory Automation & Control
- Building Automation
- Motor Drives





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 System Overview

1.1 System Description

This system accepts supply voltages in the range of 12.5 V to 40 V which accommodates common industrial supply voltages and produces four independent voltage or current sources with programmable ranges commonly used in factory automation and control applications. The 16-bit voltage and current outputs each realize less than 0.1% full-scale range (FSR) of total unadjusted error (TUE) at room temperature. The system uses adaptive power management and highly-efficient switch-mode power supplies to maintain onboard power dissipation under 1 W in all operating conditions.

1.1.1 Analog Front End

The following subsections show simplified versions of each of the subcircuits inside the DAC8775 used to deliver the voltage and current outputs common for analog output modules. A similar scheme can be used to implement a discrete solution. A 5-V digital-to-analog converter (DAC) drives the inputs for both the voltage (V_{OUT}) and current (I_{OUT}) output stages. The DAC uses an accurate, low-drift reference voltage (V_{REF}) for strong DC performance.

1.1.2 I_{OUT} Circuitry

Figure 1 shows a simplified version of the I_{OUT} circuit which consists of a bidirectional, precision current source. The circuit is composed of a high-side current source and a low-side current sink using amplifiers A1 and A2, two MOSFETs, and two sense resistors (R_{SENSE}). This stage provides a current output according to the 16-bit DAC code and is supplied by dual buck-boost converters with adaptive power management to minimize the power dissipation of the chip. Only one of the current stages are active at any given time, for example when sourcing current the sinking NMOS node is driven to high-impedance while the sourcing PMOS is driven to source current

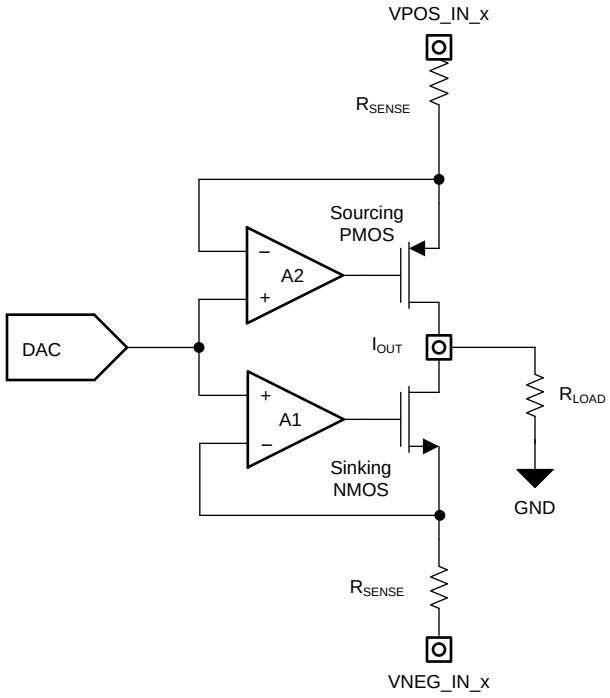


Figure 1. DAC8775 Current Output

1.1.3 V_{OUT} Circuitry

The V_{OUT} circuit is composed of amplifiers A3 and A4. The resistor network consisting of RFB, RG1, RG2, R0, R1, R2, R3, and R4 determine the gain. The DAC controls the non-inverting input and the inverting input has one path to GND and a second path to reference voltage REFIN. This configuration allows the single-ended DAC to create both the unipolar 0- to 5-V and 0- to 10-V outputs and the bipolar ±5-V and ±10-V outputs. The resistor switching network is used to change the values of RG1 and RG2 depending on the selected voltage output range.

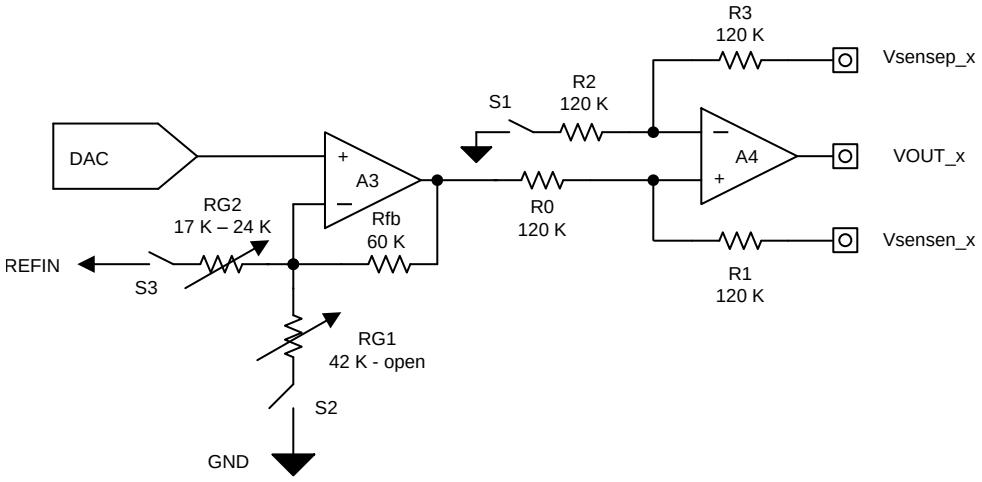


Figure 2. DAC8775 Voltage Output

1.1.4 Buck-Boost Converter

The DAC8775 includes a buck-boost converter to minimize the power dissipation of the chip and provide significant system integration. The buck-boost converter is based on single-inductor multiple output (SIMO) architecture. The converter requires a single inductor per channel to generate all the required analog power supplies.

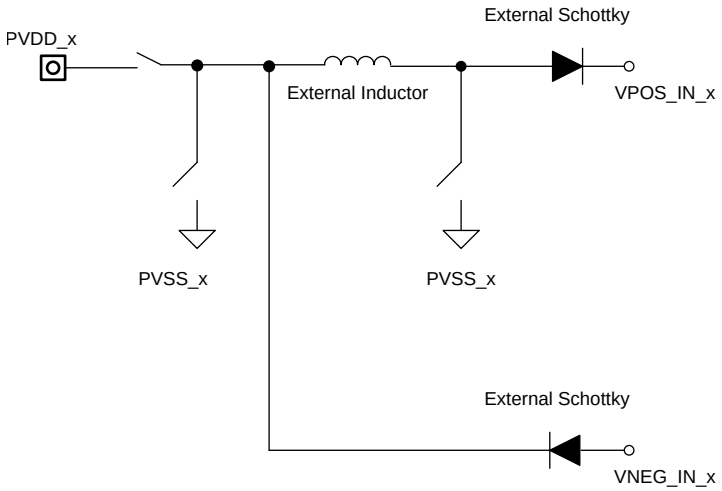


Figure 3. DAC8775 Buck-Boost Converter

1.1.5 Protection Circuitry

An output protection circuit for IEC61000-4 immunity is included in this design for completeness. The IEC61000-4 transients have two main components: a high-frequency component and a high-energy component. These two properties can be leveraged with a strategy of attenuation and diversion by the protection circuitry to deliver robust immunity.

Attenuation uses passive components, primarily resistors and capacitors, to attenuate high-frequency transients and to limit series current. Ferrite beads can also be used and are useful to maintain DC accuracy while still delivering the ability to limit current from high-frequency transients. This circuit utilizes capacitors placed at each of the voltage and current output terminals. A resistor is placed on the current output to limit current flowing into the IOUT terminal of the DAC8775 during exposure to high-voltage transients. The voltage output stage uses a similar strategy with two resistors in the voltage-output feedback loop in addition to a ferrite bead outside of the loop.

Diversion capitalizes on the high-voltage properties of the transient signals by using diodes to clamp the transient within supply voltages or to divert the energy to ground. Transient voltage suppressor (TVS) diodes are helpful to protect against the IEC transients because they break down very quickly and often feature high power ratings, which are critical to survive multiple transient strikes. Schottky diodes feature very-low forward voltage drop and are used to clamp the voltage on the input and output (I/O) lines to within the absolute maximum ratings of the DAC8775.

For more information concerning the design and performance of the protection circuitry in this design, refer to the TIPD216 reference design [1].

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	GOAL	MEASURED
Total power dissipation (4-20-mA current mode, all outputs enabled, all DAC data 0xFFFF)	< 1 W (max)	0.98 W (max)
Current output: Total unadjusted error	0.1 %FSR (max)	0.09%FSR (max)
Voltage output: Total unadjusted error	0.1 %FSR (max)	0.015%FSR (max)
Peak-to-peak current output ripple	8 µA (typical)	$\frac{2.04\ \text{mV}}{250\ \Omega} = 8.16\ \mu\text{A}$.
Peak-to-peak voltage output ripple	2 mV (typical)	0.176 mV

1.3 Block Diagram

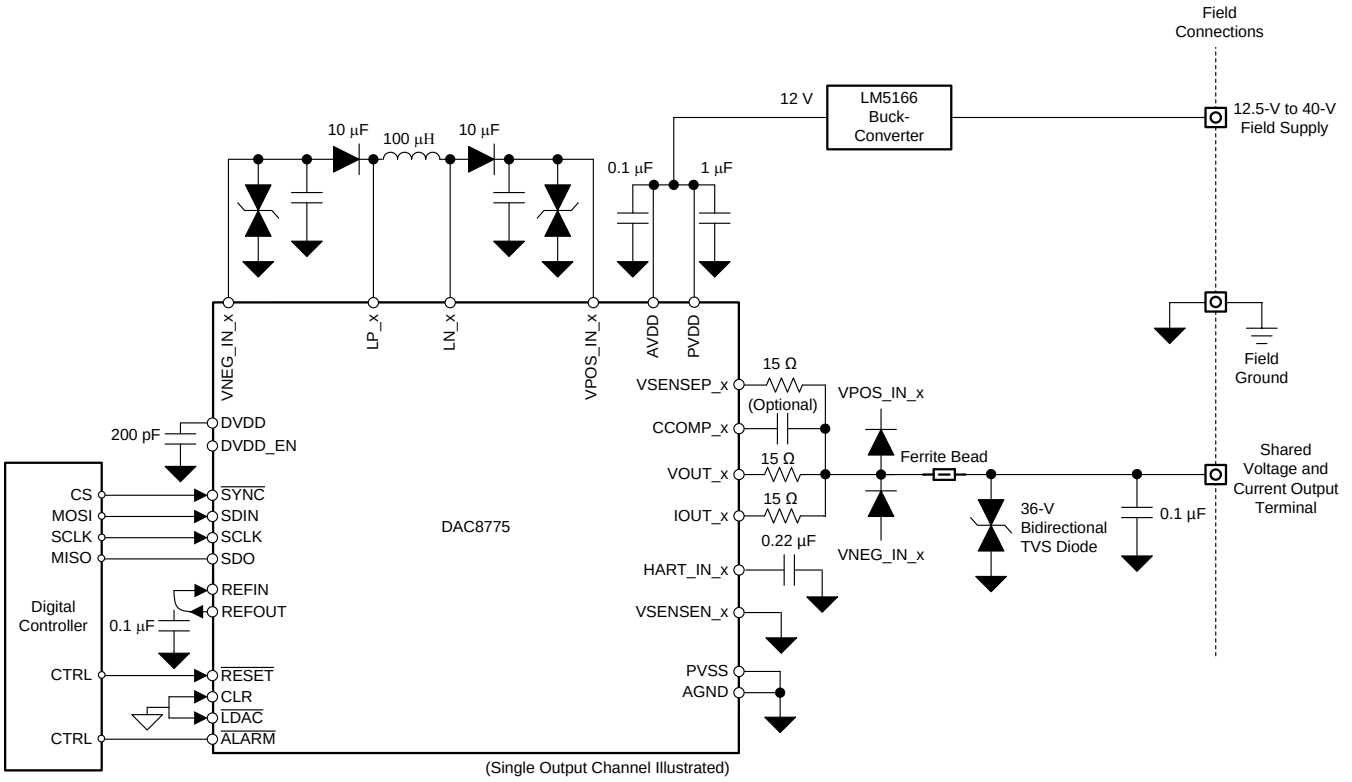


Figure 4. Reference Design Block Diagram

1.4 Design Considerations

The design requirements are as follows:

- Supply voltage: 12.5 V to 40 V
- Input: Four-wire serial peripheral interface (SPI)
- Voltage output: ±10 V
- Current output: 4 mA to 20 mA

The primary objective for this design is to provide less than 1-W total power dissipation on the DAC8775 device, LM5166 device, and power management components when driving 20 mA across an external load up to 1 kΩ simultaneously on all four-channels, while maintaining a very high degree of device precision. The preceding Table 1 summarizes the specific design goals and performance.

1.5 Highlighted Products

1.5.1 DAC

The DAC8775 device has been chosen for this design for its high level of integration, which is helpful to simplify the design of an electromagnetic compatibility (EMC) and electromagnetic interference (EMI) protection solution.

The DAC8775 includes the DAC, current and voltage amplifiers, regulated voltages, and all of the switches, transistors, and resistors required to create a configurable integrated solution for industrial voltage and current output drivers. The DAC8775 features a max 0.1% full-scale range (FSR) total-unadjusted-error (TUE) specification, which includes offset error, gain error, and integral non-linearity (INL) errors at 25°C. The 0.1% FSR TUE is valid for all of the voltage and current output stages and provides a baseline for the final system accuracy. The max differential non-linearity (DNL) specification of ±1 least significant bit (LSB) provides fully-monotonic operation for both V_{OUT} and I_{OUT}.

1.5.2 Buck-Converter

The DAC8775 internal buck-boost converter is most efficient across all operating conditions when using a 12-V input supply. The LM5166 device has been selected to efficiently take a standard industrial supply voltage and regulate the voltage to 12 V to power the DAC8775 device and maintain the overall system power dissipation to a minimum.

The LM5166 has an ultra-low I_Q that utilizes a synchronous buck converter to maintain a very-low efficiency loss with output currents up to 500 mA.

1.5.3 Inductor

A single inductor per channel of the DAC8775 is required for the internal buck-boost converter to generate the positive and negative rails. The recommended inductor value is 100 µH with a peak current of 500 mA or greater with 20% inductance tolerance at the peak current. Inductor values as small as 80 µH may be used; however, this limits the buck-boost converter efficiency, increases output ripple, and reduces the effective output voltage range.

2 Hardware, Software, Testing Requirements, and Test Results

2.1 Required Hardware and Software

The reference design was designed and fabricated, and only requires an external supply and load resistors to perform the tests as outlined in Table 1. The exception is performing the voltage and current ripple test, which requires a first-order filter with fc = 50 kHz and an external operational amplifier (op amp) to gain the voltage ripple by 10x so it can be measured on an oscilloscope.

2.2 Testing and Results

The preceding Table 1 specifies the tests performed for the design.

2.2.1 Test Setup

2.2.1.1 Total Power Dissipation (TPD)

An external load of 0 Ω, 250 Ω, 500 Ω, 750 Ω, and 1 kΩ was applied to each current output set at 20 mA each. The supply voltage was swept 12.5 V to 40 V. The total current consumption was measured at the supply and the power dissipated across the external load was subtracted from the input power to calculate the power dissipation result.

2.2.1.2 Current Mode TUE

An external load of 250 Ω was applied to each current output individually and the supply was set to 24 V. The DAC8775 was set to 4-mA to 20-mA current output mode and then swept from zero code to 0xFFFF and the current was measured at each code. The result was normalized to the internal V_{REF} on the DAC8775 device.

2.2.1.3 Voltage Mode TUE

An external load of 10 kΩ was applied to each voltage output individually and the supply was set to 24 V. The DAC8775 was set to ±10-V voltage output mode and then swept from zero code to 0xFFFF and the voltage was measured at each code. The result was normalized to the internal V_{REF} on the DAC8775 device.

2.2.1.4 Peak-to-Peak Output Ripple

An external load of 250 Ω was applied to each current output individually and the supply was set to 24 V. The DAC8775 was set to 4-mA to 20-mA current output mode using the full-scale code (0xFFFF). A first-order RC filter with fc = 50 kHz was applied to the output before capturing the output ripple on an oscilloscope.

2.2.1.5 Peak-to-Peak Voltage Output Ripple

An external load of 10 kΩ was applied to each current output individually and the supply was set to 24 V. The DAC8775 was set to ±10-V voltage output mode using the full-scale code (0xFFFF). A first-order RC filter with fc = 50 kHz was applied to the output before going to a 10x op amp circuit and then on to an oscilloscope.

2.2.2 Test Results

2.2.2.1 Total Power Dissipation

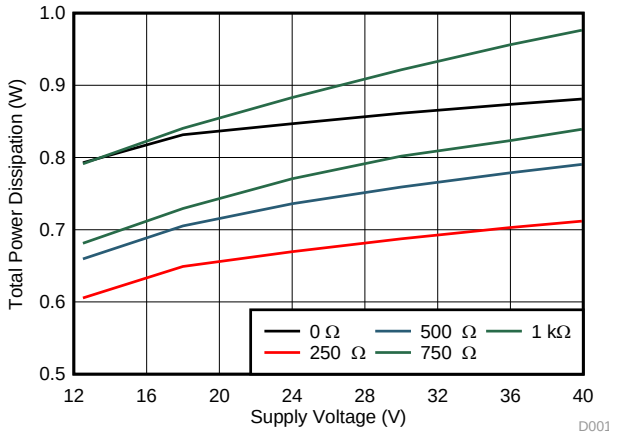


Figure 5. Measured Total Power Dissipation versus Supply at 20 mA—All Channels

2.2.2.2 Current Mode TUE

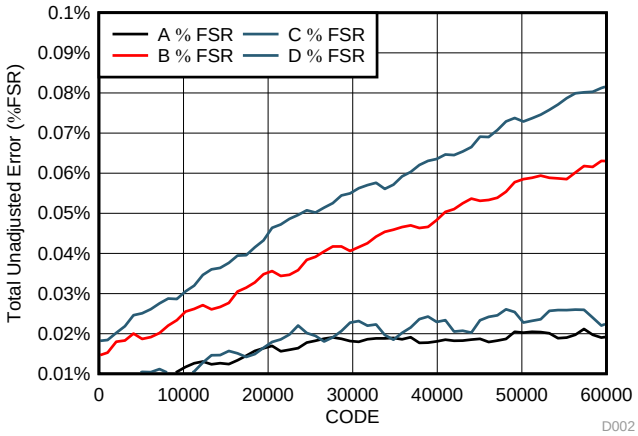


Figure 6. Measured Current Output Total Unadjusted Error (%FSR)

2.2.2.3 Voltage Mode TUE

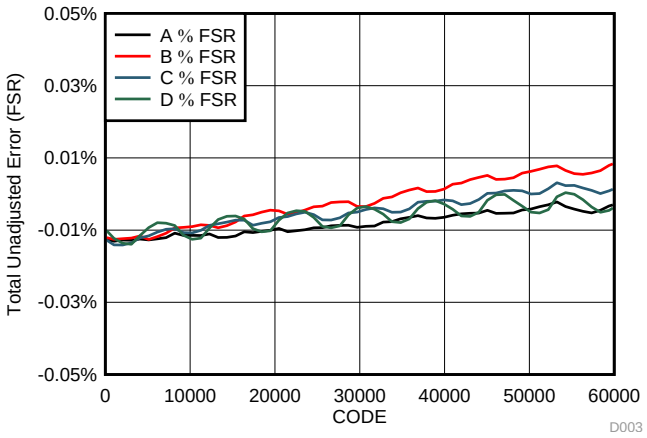


Figure 7. Measured Voltage Output Total Unadjusted Error (%FSR)

2.2.2.4 Peak-to-Peak Current Output Ripple into 250-Ω Load

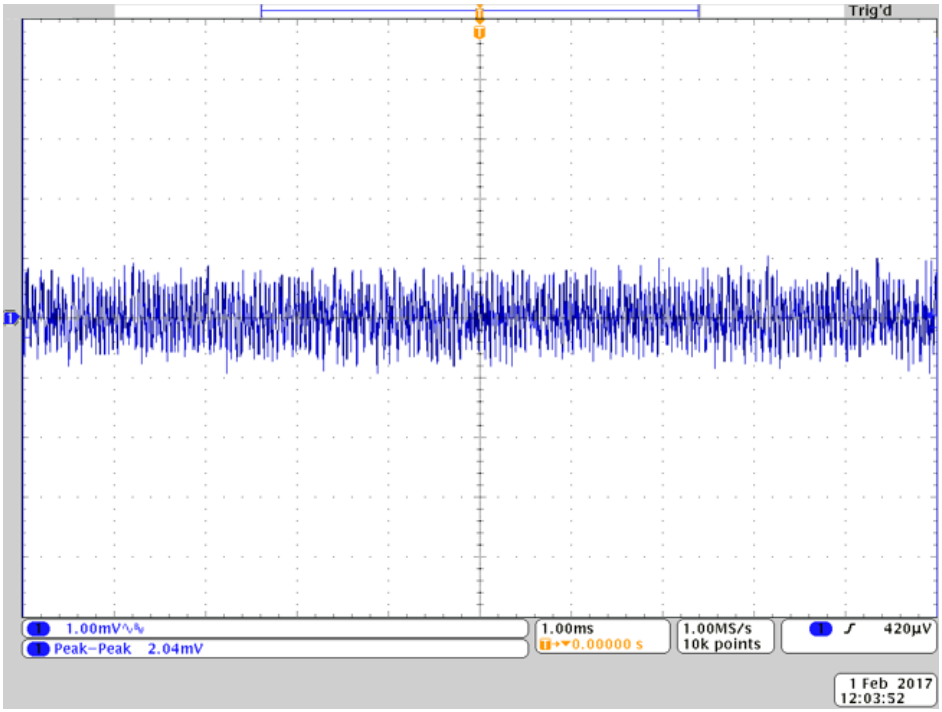


Figure 8. Measured Output Current Ripple

2.2.2.5 Peak-to-Peak Voltage Output Ripple (10x Multiplied)

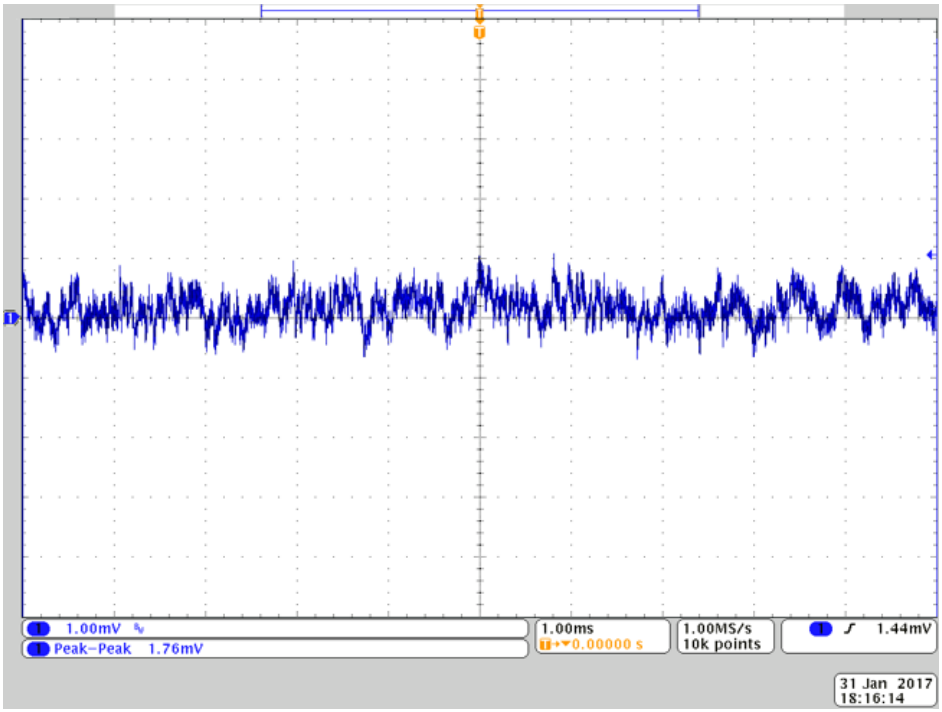


Figure 9. Measured Output Voltage Ripple

3 Design Files

3.1 Schematics

The following figures show the schematics. To download the schematics, see the design files at TIPD215.

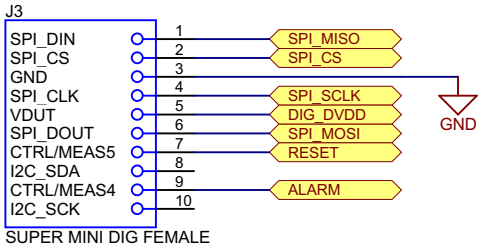


Figure 10. DAC8775 Digital Input Schematic

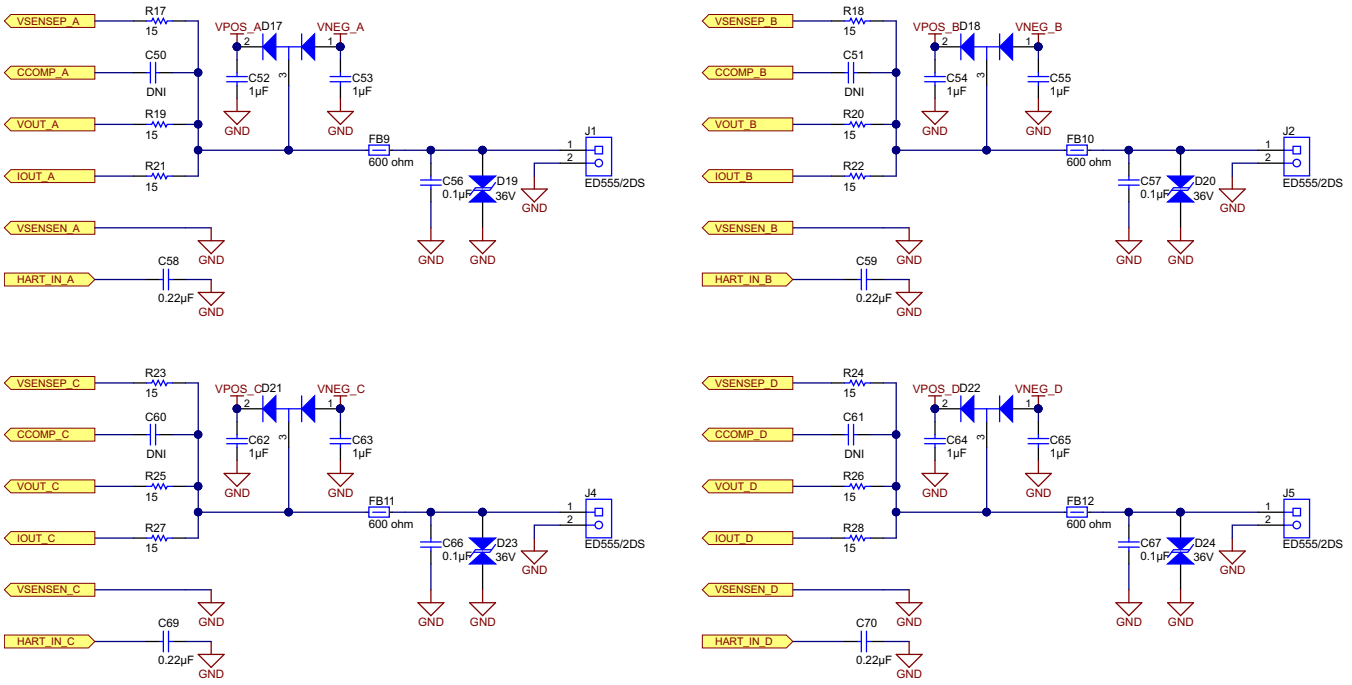


Figure 11. DAC8775 Outputs Schematic

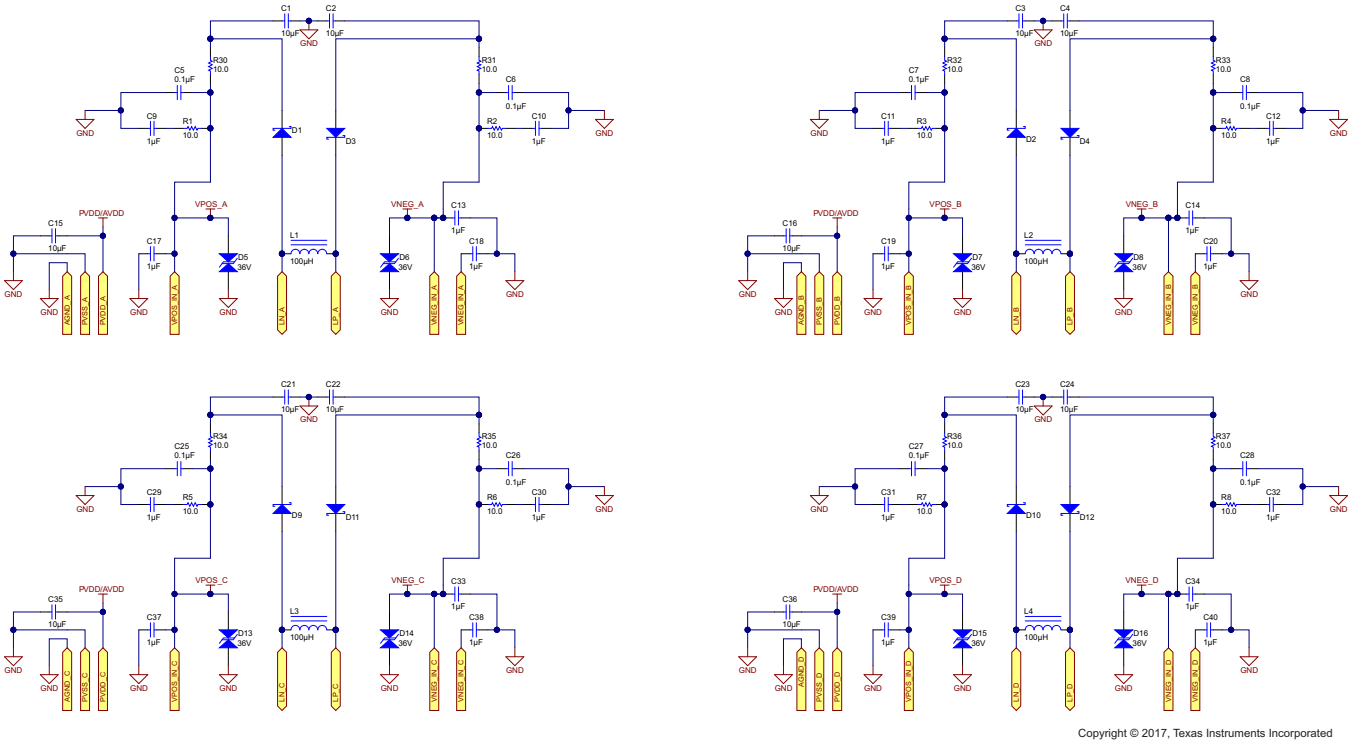


Figure 12. DAC8775 DC-DC Schematic

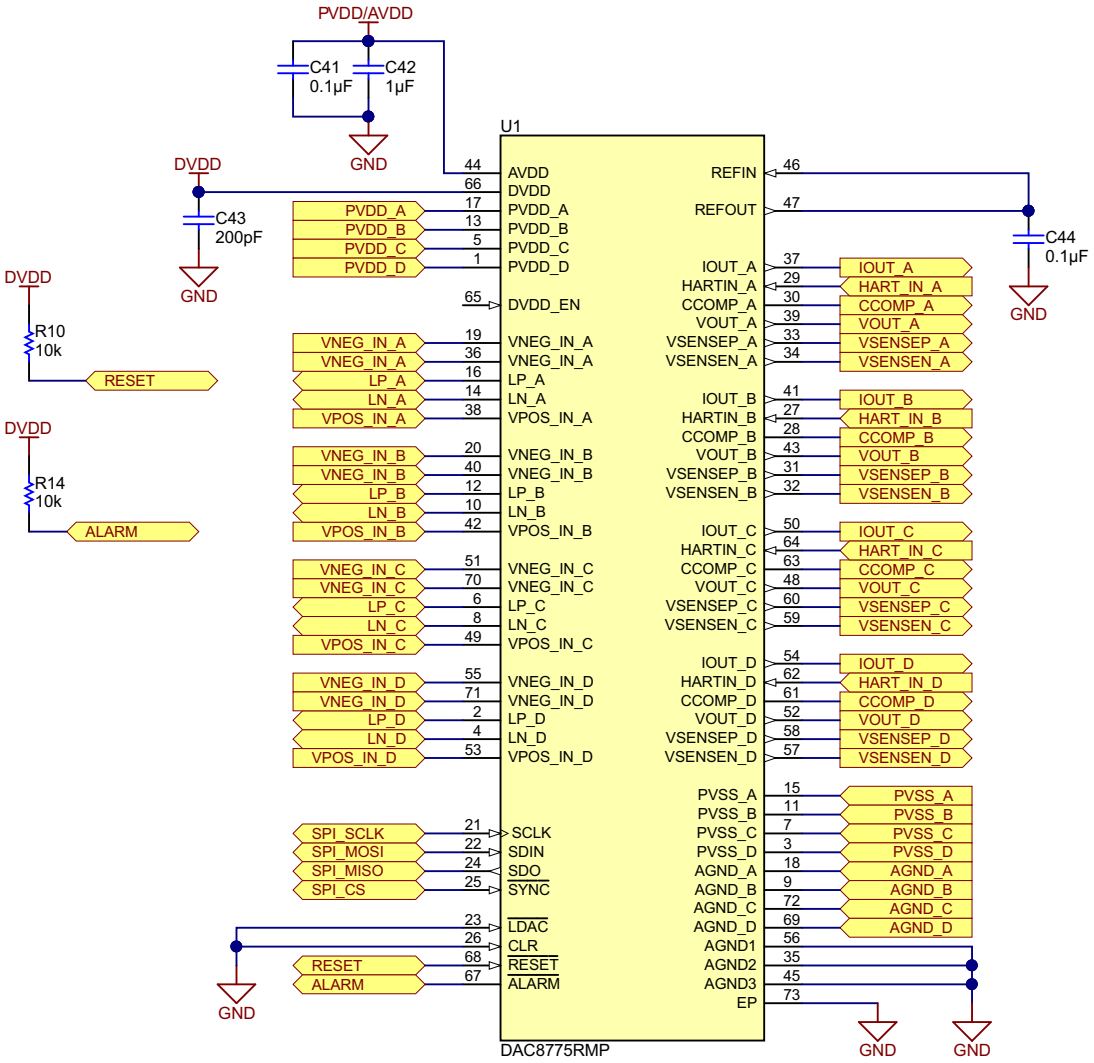


Figure 13. DAC8775 IC Schematic

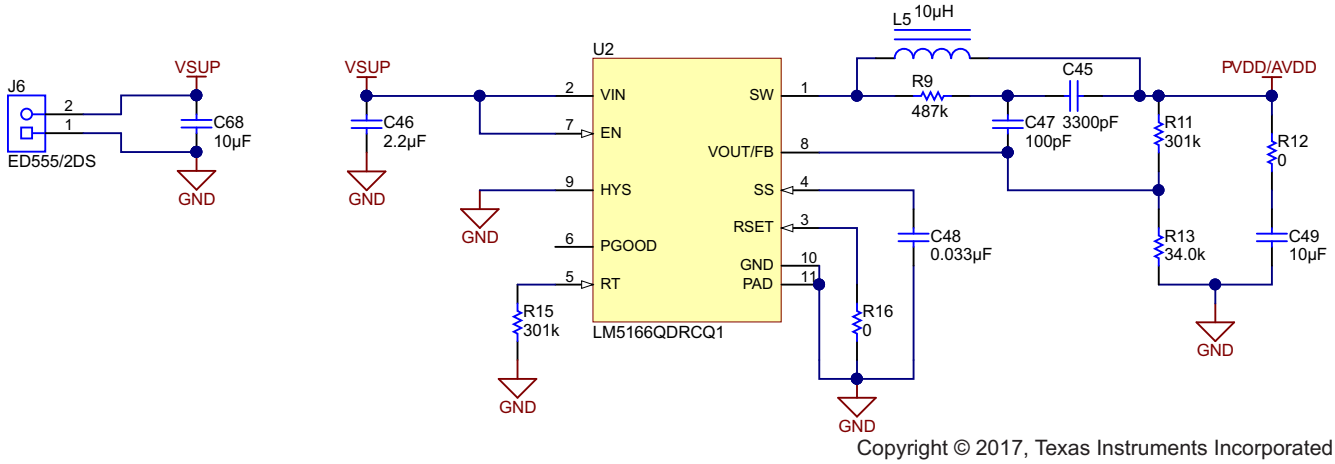


Figure 14. LM5166 IC Schematic

3.2 Bill of Materials

Table 2 shows the bill of materials (BOM). To download the BOM, see the design files at TIPD215.

Table 2. BOM

ITEM #	DESIGNATOR	QUANTITY	VALUE	PART NUMBER	MANUFACTURER	DESCRIPTION	PACKAGE REFERENCE
1	!PCB1	1		TIPD215	Any	Printed Circuit Board	
2	C1, C2, C3, C4, C15, C16, C21, C22, C23, C24, C35, C36, C49, C68	14	10uF	UMK325AB7106KM-T	Taiyo Yuden	CAP, CERM, 10 µF, 50 V, +/- 10%, X7R, 1210	1210
3	C5, C6, C7, C8, C25, C26, C27, C28, C41, C44, C56, C57, C66, C67	14	0.1uF	GRM188R71H104KA93D	MuRata	CAP, CERM, 0.1uF, 50V, +/- 10%, X7R, 0603	0603
4	C9, C10, C11, C12, C13, C14, C17, C18, C19, C20, C29, C30, C31, C32, C33, C34, C37, C38, C39, C40, C42, C52, C53, C54, C55, C62, C63, C64, C65	29	1uF	UMK107AB7105KA-T	Taiyo Yuden	CAP, CERM, 1uF, 50V, +/- 10%, X7R, 0603	0603
5	C43	1	200pF	GRM1885C1H201JA01D	MuRata	CAP, CERM, 200pF, 50V, +/- 5%, C0G/NP0, 0603	0603
6	C45	1	3300pF	06031C332JAT2A	AVX	CAP, CERM, 3300 pF, 100 V, +/- 5%, X7R, 0603	0603
7	C46	1	2.2uF	CL31B225KCHSNNE	Samsung Electro-Mechanics	CAP, CERM, 2.2 µF, 100 V, +/- 10%, X7R, 1206_190	1206_190
8	C47	1	100pF	GCM1885C2A101JA16D	MuRata	CAP, CERM, 100 pF, 100 V, +/- 5%, C0G/NP0, AEC-Q200 Grade 1, 0603	0603
9	C48	1	0.033uF	GRM188R71H333KA61D	MuRata	CAP, CERM, 0.033 µF, 50 V, +/- 10%, X7R, 0603	0603
10	C50, C51, C60, C61	4					0603
11	C58, C59, C69, C70	4	0.22uF	C1608X7R1H224K080AB	TDK	CAP, CERM, 0.22 µF, 50 V, +/- 10%, X7R, 0603	0603
12	D1, D2, D3, D4, D9, D10, D11, D12	8	60V	MBRX160-TP	Micro Commercial Components	Diode, Schottky, 60V, 1A, SOD-123	SOD-123
13	D5, D6, D7, D8, D13, D14, D15, D16, D19, D20, D23, D24	12	36V	CDSOD323-T36SC	Bourns	Diode, TVS, Bi, 36V, 400W, SOD323, 2-Leads, Body 1.9x1.45mm, No Polarity Mark	SOD323, 2-Leads, Body 1.9x1.45mm, No Polarity Mark
14	D17, D18, D21, D22	4	75V	BAV99-7-F	Diodes Inc.	Diode, Switching, 75V, 0.3A, SOT-23	SOT-23
15	FB9, FB10, FB11, FB12	4	600 ohm	FBMH3225HM601NT	Taiyo Yuden	Ferrite Bead, 600 ohm @ 100 MHz, 3 A, 1210	1210

Table 2. BOM (continued)

ITEM #	DESIGNATOR	QUANTITY	VALUE	PART NUMBER	MANUFACTURER	DESCRIPTION	PACKAGE REFERENCE
16	FID1, FID2, FID3	3		N/A	N/A	Fiducial mark. There is nothing to buy or mount.	Fiducial
17	J1, J2, J4, J5, J6	5		ED555/2DS	On-Shore Technology	Terminal Block, 3.5mm Pitch, 2x1, TH	7.0x8.2x6.5mm
18	J3	1		851-43-010-20-001000	Mill-Max	Receptacle, 50mil 10x1, R/A, TH	receptacle 10x1, 50mil
19	L1, L2, L3, L4	4	100uH	74408943101	Wurth Elektronik	Inductor, Shielded Drum Core, Ferrite, 100 µH, 0.52 A, 0.77 ohm, SMD	4.8x3.8x4.8mm
20	L5	1	10uH	74404064100	Wurth Elektronik	Inductor, Wirewound, Ferrite, 10 µH, 2.45 A, 0.048 ohm, SMD	SMD, Body 6x6mm
21	R1, R2, R3, R4, R5, R6, R7, R8, R30, R31, R32, R33, R34, R35, R36, R37	16	10.0	CRCW060310R0FKEA	Vishay-Dale	RES, 10.0 ohm, 1%, 0.1W, 0603	0603
22	R9	1	487k	CRCW0603487KFKEA	Vishay-Dale	RES, 487 k, 1%, 0.1 W, 0603	0603
23	R10, R14	2	10k	CRCW060310K0JNEA	Vishay-Dale	RES, 10k ohm, 5%, 0.1W, 0603	0603
24	R11, R15	2	301k	CRCW0603301KFKEA	Vishay-Dale	RES, 301 k, 1%, 0.1 W, 0603	0603
25	R12, R16	2	0	CRCW06030000Z0EA	Vishay-Dale	RES, 0, 5%, 0.1 W, 0603	0603
26	R13	1	34.0k	CRCW060334K0FKEA	Vishay-Dale	RES, 34.0 k, 1%, 0.1 W, 0603	0603
27	R17, R18, R19, R20, R21, R22, R23, R24, R25, R26, R27, R28	12	15	CRCW060315R0JNEA	Vishay-Dale	RES, 15 ohm, 5%, 0.1W, 0603	0603
28	U1	1		DAC8775RMP	Texas Instruments	Quad-Channel, 16-Bit Programmable Current Output and Voltage Output Digital-to-Analog Converter with Adaptive Power Management, RMP0072A	RMP0072A
29	U2	1		LM5166QDRCQ1	Texas Instruments	3.5-V to 65-V Input, 500-mA Output, Ultra-Low Quiescent Synchronous Step-Down DC/DC Voltage Regulator, DRC0010J	DRC0010J

3.3 PCB Layout Recommendations

For optimal performance of this design, follow standard printed-circuit board (PCB) layout guidelines, including proper decoupling close to all integrated circuits and adequate power and ground connections with large copper pours. Additional considerations must be made for providing robust EMC and EMI immunity. All protection elements should be placed as close to the output connectors as possible to provide a controlled return path for transient currents that does not cross sensitive components. Wide, low-impedance, low-inductance traces should be used along the output signal path and protection elements to allow optimum current flow . When possible, use copper pours in place of traces. Stitching the pours provides an effective return path around the PCB and helps reduce the impact of radiated emissions.

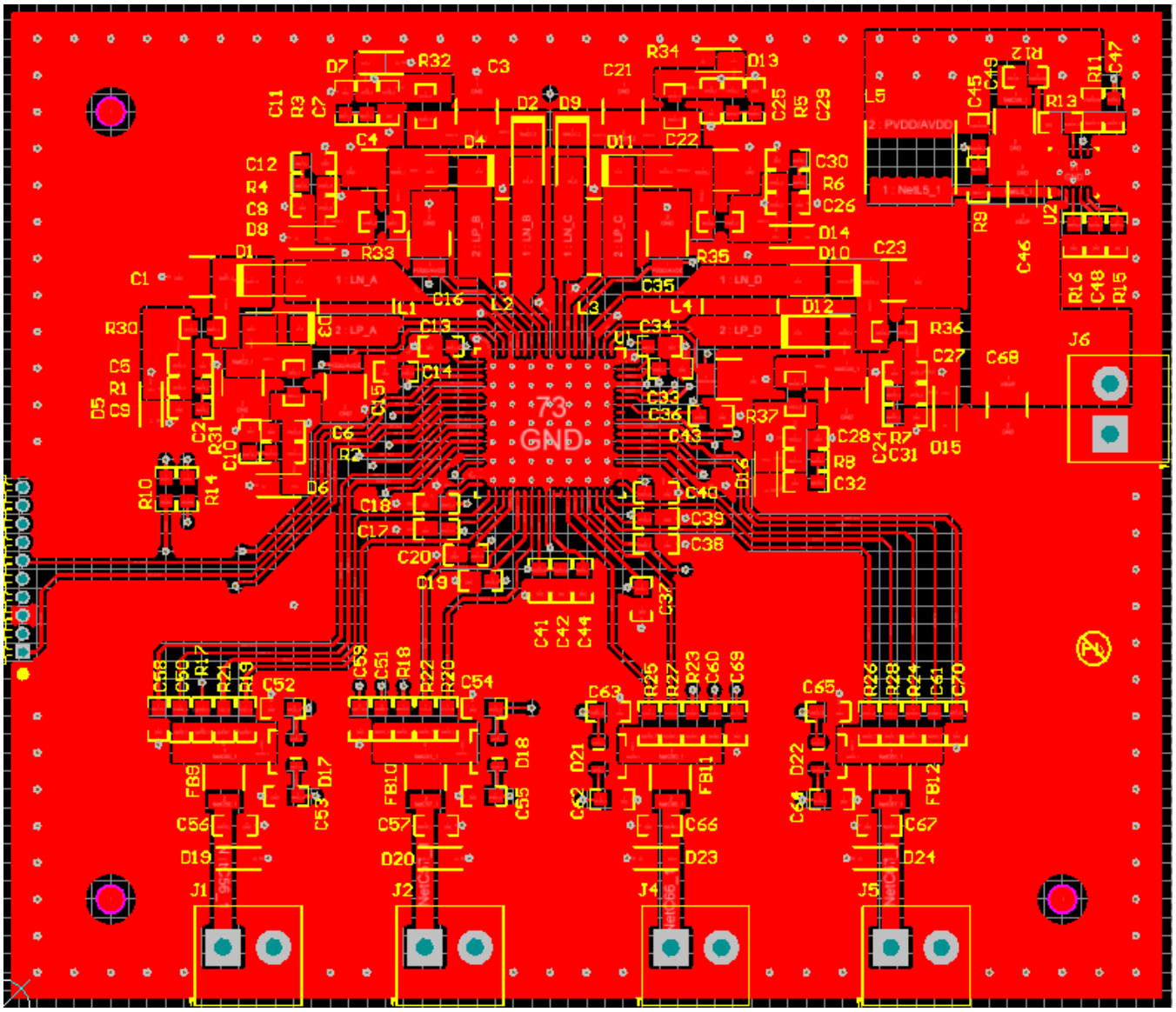


Figure 15. PCB Layout

3.3.1 Layout Prints

To download the layer plots, see the design files at TIPD215.

3.4 Altium Project

To download the Altium project files, see the design files at TIPD215.

3.5 Gerber Files

To download the Gerber files, see the design files at TIPD215.

3.6 Assembly Drawings

To download the assembly drawings, see the design files at TIPD215.

4 Software Files

To download the software files, see the design files at TIPD215.

5 Related Documentation

1. Texas Instruments, *Quad-Channel Industrial Voltage and Current Output Driver, EMC/EMI Tested* , TIPD216 Design Guide (TIDUCV6)
2. Texas Instruments, *DAC8775 Quad-Channel, 16-Bit Programmable Current Output and Voltage Output Digital-to-Analog Converter with Adaptive Power Management* , DAC8775 Datasheet (SLVSBY7)
3. Texas Instruments, *LM5166 3-V to 65-V Input, 500-mA Synchronous Buck Converter with Ultra-Low I_Q* , LM5166 Datasheet (SNVSA67A)

5.1 Trademarks

6 About the Author

KEVIN DUKE is a Systems Engineer in the precision digital-to-analog converters group at Texas Instruments where he is responsible for industrial automation DAC product definition and development. Kevin received his BSEE from Texas Tech University in 2010.

BRYCE SINCLAIR is Sr. Silicon Validation Engineer at Texas Instruments where he is responsible for new product validation for the DAC Group. Bryce has had over 16 years in test and characterization. He received his MSEE from Texas Tech in Lubbock, Texas and his BSCS from the Midwestern State University, Wichita Falls, Texas.

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