

# Design Guide: TIDA-020026

## Stepper-Motor Driver Reference Design for Adaptive Front Lights and Dynamic Headlight Leveling



### Description

This reference design details a solution to drive and control two stepper motors for dynamic headlight leveling and swiveling in automotive headlight applications such as an adaptive LED driving module or a high-resolution DLP module. It uses a local interconnect network (LIN) system basic chip with integrated 3.3-V linear voltage regulator, two stepper motor drivers with serial peripheral interface (SPI), and a microcontroller LaunchPad™.

### Features

- Up to 1-A motor current
- CISPR25 compliant
- Fully-integrated solution

### Applications

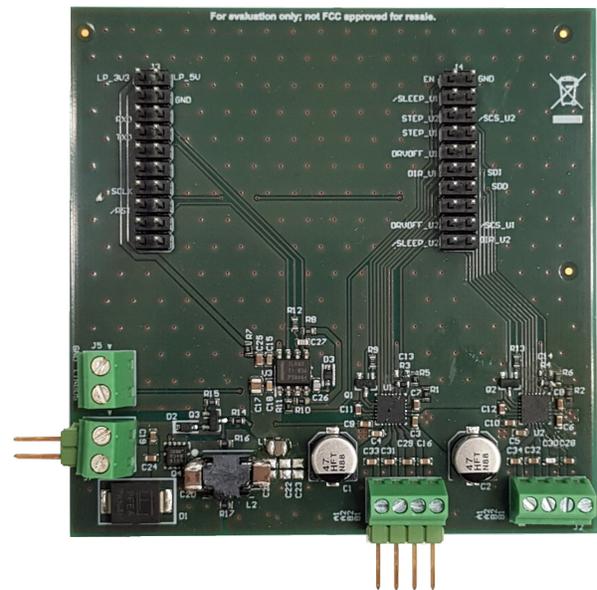
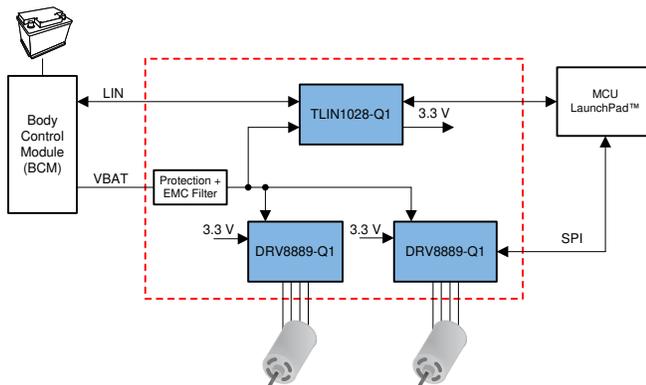
- Headlight - adaptive LED driving module
- Headlight - high resolution DLP module

### Resources

<a href="#">TIDA-020026</a>	Design Folder
<a href="#">DRV8889-Q1</a>	Product Folder
<a href="#">TLIN1028-Q1</a>	Product Folder



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## 1 System Description

A headlamp-leveling system adjusts the height of the cut-off line to the load condition of the vehicle. This is supposed to avoid blinding oncoming traffic. Many modern cars are equipped with dynamic headlamp leveling systems which also react to driving conditions such as acceleration and braking. A stepper motor is typically used for dynamic headlamp leveling applications. The adaptive front-lighting systems (AFS) provide an optimized vision to the driver during night time and other poor-sight road conditions by adapting the headlight angle and intensity using different parameters like the speed of the car, the steering wheel angle, and weather conditions.

This reference design details a solution to drive and control two stepper motors for automotive headlight applications like AFS, dynamic headlamp leveling, and curve light. It uses a LIN system basic chip with integrated 3.3-V linear voltage regulator, two stepper motor drivers with serial peripheral interface (SPI), and a microcontroller LaunchPad.

### 1.1 Key System Specifications

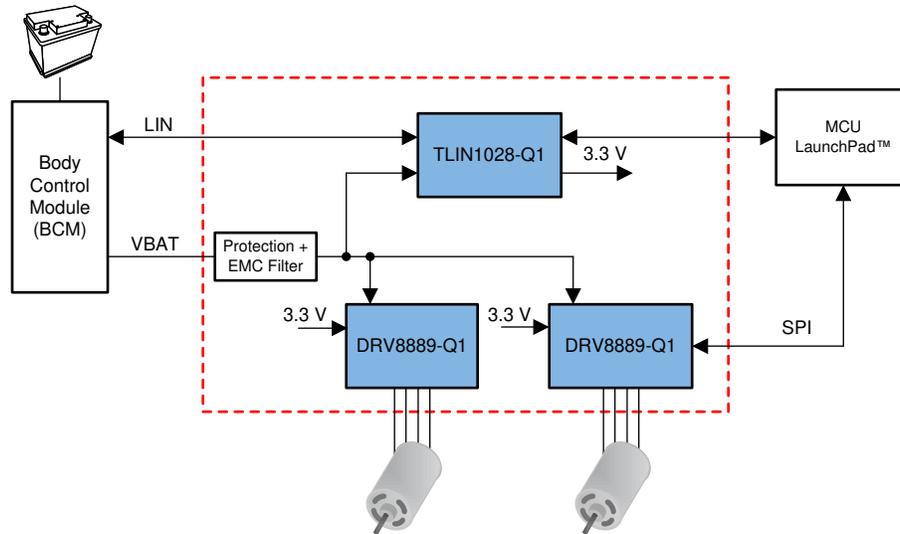
**Table 1. Key System Specifications**

PARAMETER	SPECIFICATIONS
DC input voltage range	6 V to 18 V
Motor current	1 A max
Operating ambient temperature	-40 to 85°C
PCB form factor	75 × 75 mm (2 layers with 1.5 oz)

## 2 System Overview

### 2.1 Block Diagram

**Figure 1. TIDA-020026 Block Diagram**



### 2.2 Design Considerations

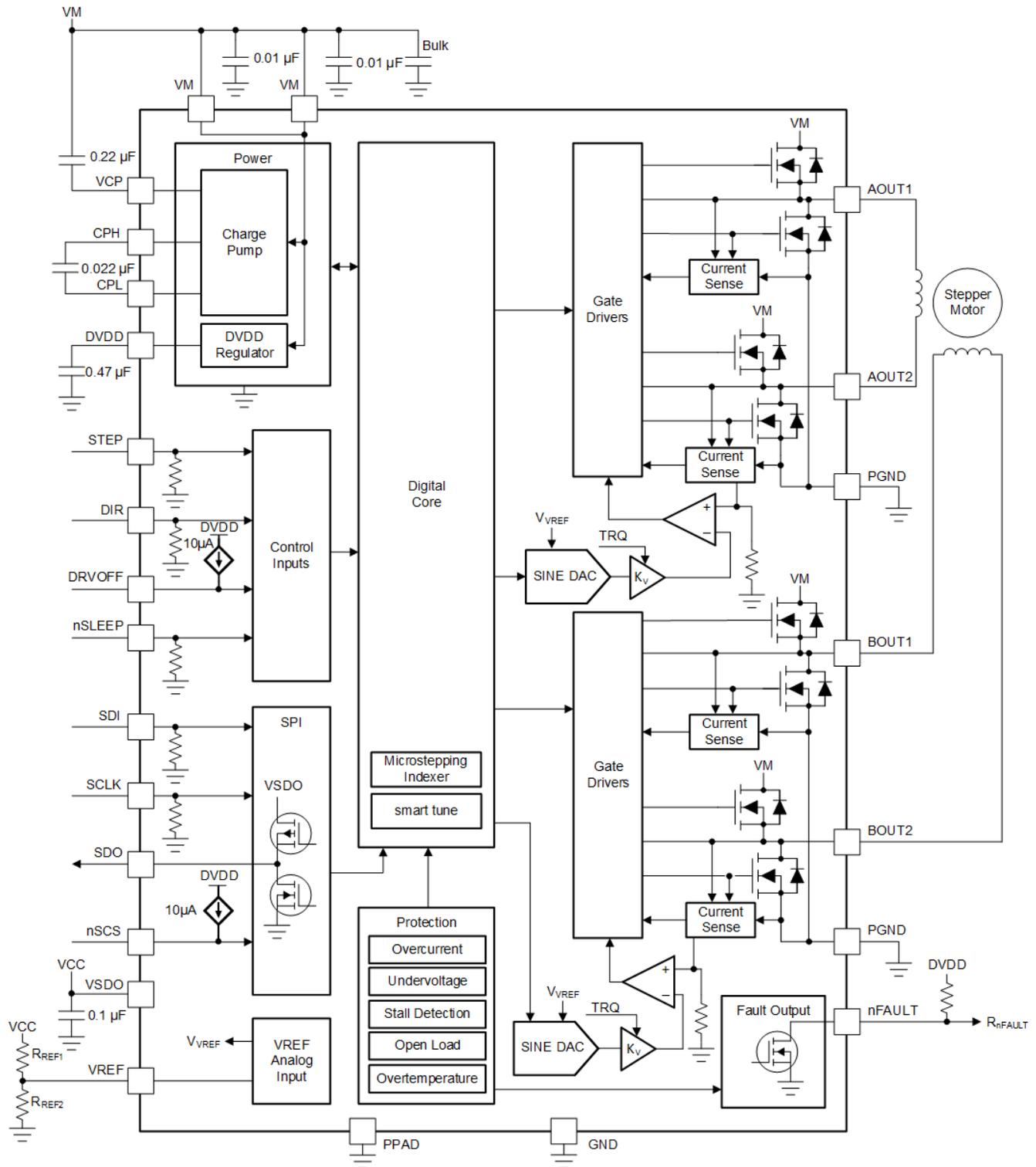
To simplify this reference design and make the design more adaptable to a variety of microcontroller units (MCUs), the board is implemented in the BoosterPack™ format. This board format has a simple connector interface to the external LaunchPad MCU board, which allows this reference design to be evaluated with a wide selection of MCUs. The LaunchPad plus BoosterPack implementation also has the advantage that code development and design testing are facilitated with existing tools such as Code Composer Studio™ or Energia, thus speeding up optimization of the design for any specific operating conditions. While the BoosterPack format does allow flexibility in using different MCU boards, the format also creates constraints on the size and layout of the board. In a production version of this design, the MCU would likely be installed on the same board with the chips and other components with a significant reduction in board size.

### 2.3 Highlighted Products

#### 2.3.1 DRV8889-Q1

The DRV8889-Q1 is a stepper motor driver for automotive applications. The device is fully-integrated with two N-channel power MOSFET H-bridge drivers, a microstepping indexer, and integrated current sensing. The DRV8889-Q1 device is capable of driving up to 1.5-A full scale or 1.1-A<sub>RMS</sub> output current (13.5 V and T<sub>A</sub> = 25°C, dependent on PCB design). The DRV8889-Q1 device uses an internal current sense architecture to eliminate the need for two external power sense resistors, saving PCB area and system cost. It uses an internal PWM current regulation scheme selectable between smart tune, slow, and mixed decay options. Smart tune decay technology automatically adjusts for optimal current regulation performance and compensates for motor variation and aging effects. A torque DAC feature allows the controller to scale the output current without needing to scale the VREF voltage reference. A simple STEP/DIR interface allows an external controller to manage the direction and step rate of the stepper motor. The device can be configured in different step modes ranging from full-step to 1/256 microstepping. A low-power sleep mode is provided for very low standby quiescent current using a dedicated nSLEEP pin. The device features full duplex, 4-wire synchronous SPI communication, with daisy chain support for up to 63 devices connected in series, for configurability and detailed fault reporting.

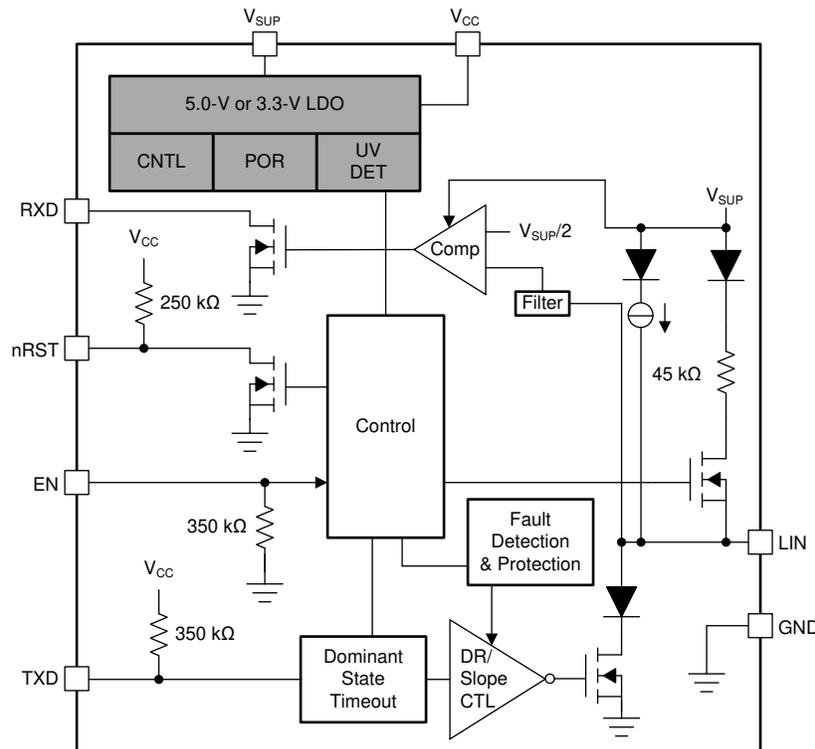
Figure 2. DRV8889-Q1 Functional Block Diagram



### 2.3.2 TLIN1028-Q1

The TLIN1028 LIN transceiver is a local interconnect network (LIN) physical layer transceiver, compliant to LIN 2.0, LIN 2.1, LIN 2.2, LIN 2.2A, ISO/DIS 17987-4.2 and IBEE Zwickau, with integrated wake-up and protection features. The LIN bus is a single-wire, bidirectional bus that typically is used in low speed in-vehicle networks with data rates that range up to 20 kbps. The TLIN1028 LIN receiver works up to 100 kbps supporting in-line programming. The TLIN1028 device converts the LIN protocol data stream on the TXD input into a LIN bus signal using a current-limited wave-shaping driver which reduces electromagnetic emissions (EME). The receiver converts the data stream to logic level signals that are sent to the microprocessor through the open-drain RXD pin. Ultra-low current consumption is possible using the sleep mode which allows wake-up via LIN bus or EN pin. The LIN bus has two states: dominant state (voltage near ground) and recessive state (voltage near battery). In the recessive state, the LIN bus is pulled high by the internal pullup resistor (45 k $\Omega$ ) and a series diode. The device provides two methods to wake up from sleep mode, EN pin and from the LIN bus. The device has integrated a low dropout voltage regulator with a wide input from  $V_{SUP}$  providing 5 V  $\pm 2\%$  or 3.3 V  $\pm 2\%$  with up to 100 mA of current depending upon system implementation. nRST is asserted high when  $V_{CC}$  increases above VIT and stays high as long as  $V_{CC}$  is above this threshold. The delay time ( $t_d$ ) is 4 ms typical and starts after  $V_{CC}$  rises above VIT.

**Figure 3. TLIN1028-Q1 Functional Block Diagram**

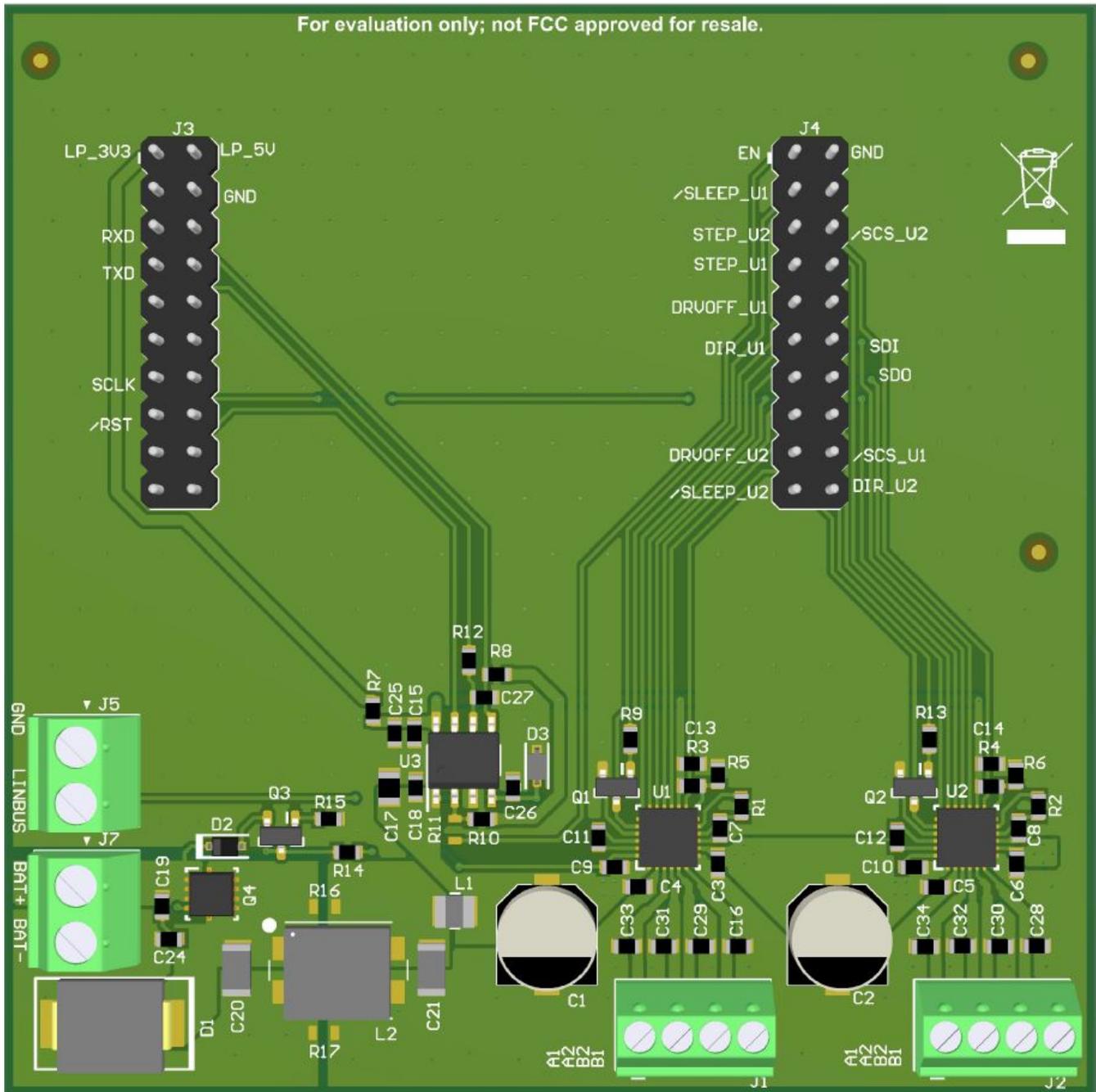


## 2.4 System Design Theory

### 2.4.1 PCB and Form Factor

This reference design uses a two-layer printed-circuit board (PCB) with 1.5 oz of copper where all components are placed on the top layer. The PCB is not intended to fit any particular form factor and has a dimension of 75 mm  $\times$  75 mm. The primary objective of the design with regards to the PCB is to make a solution that is compact while still providing a way to test the performance of the board. In a final production version of this reference design, the size of the solution can be further reduced. [Figure 4](#) shows a 3D rendering of the PCB.

Figure 4. 3D Render of TIDA-020026 PCB

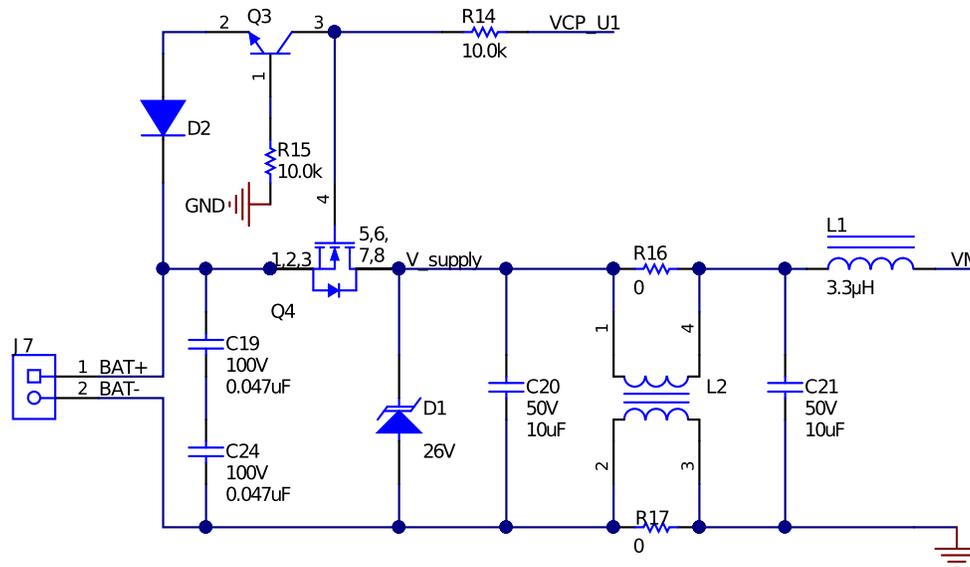


### 2.4.2 Input Protection

In this reference design, ESD protection is implemented by series capacitors C19 and C24 as [Figure 5](#) shows. Two capacitors in series were used to allow for redundancy in the case of mechanical failure of a single capacitor. The diode D1 is a TVS diode which is clamping the supply voltage in the case of positive voltage transients.

The reverse polarity protection makes use of a power NMOS Q4, an NPN bipolar junction transistor (BJT) Q3, diode D2 and current-limiting resistor R14, R15. Resistor R14 is used to limit current flow into the gate of Q4, R15 is used to limit the current into the base of the BJT, and diode D2 prevents current from entering the BJT when the battery is connected correctly. If the battery is connected in reverse, the body diode of the NMOS will not conduct current nor will the NMOS turn on, thereby protecting the system from the reverse polarity condition. When the battery is connected correctly, the circuit permits current to flow with very little power lost because of the low  $R_{DS(on)}$  of the NMOS. For more details, see the [Protecting Automotive Motor-Drive Systems From Reverse Polarity Conditions](#) Application Report. Figure 5 shows the schematic of the input protection.

Figure 5. Input Protection Schematic



### 2.4.3 EMC Filter

There are two forms of conducted emissions. Common-mode noise and differential-mode noise. To attenuate conducted common mode noise, a common-mode choke is placed on the input whereas an LC filter is used to attenuate differential-mode noise. The whole filter consists of C20, C21, L1 and L2 as Figure 5 shows.

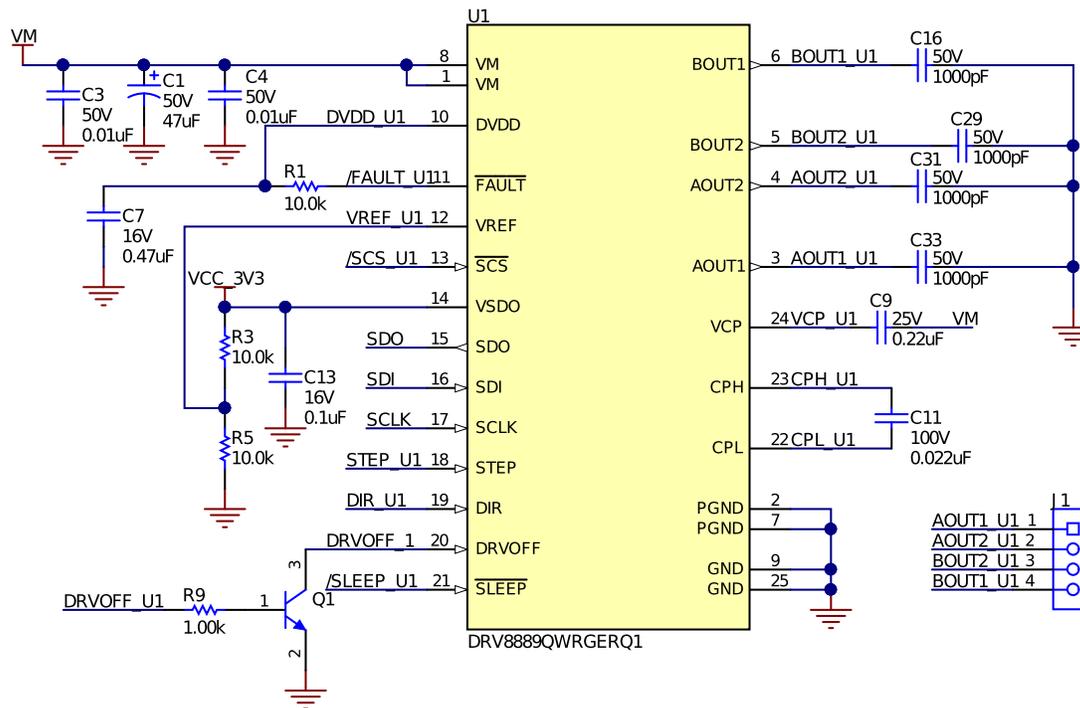
### 2.4.4 DRV8889-Q1 Stepper Driver

In this design, two DRV8889-Q1 devices are used to drive two stepper motors. Figure 6 shows the schematic of the driver. The input capacitor C1 provides a low impedance source to the IC in addition to supplying the ripple current. It must be rated for at least the maximum input voltage that the application requires. This capacitance can be increased to help reduce input voltage ripple, maintain the input voltage during load transients, or both. In addition, small case size ceramic capacitors C3 and C4 must be used at the input, as close a possible to the IC. This provides a high-frequency bypass to the device. Place 1-nF ceramic capacitors C15, C29, C31, and C33 on the driver outputs to filter high-frequency noise. Resistors R3 and R5 set the motor current. This current can be also changed by an integrated digital-to-analog converter (DAC).

A low-ESR ceramic capacitor C11 must be placed in between the CPL and CPH pins. A value of 0.022  $\mu\text{F}$  rated for VM is recommended. A low-ESR ceramic capacitor C9 must be placed in between the VM and VCP pins. A value of 0.22  $\mu\text{F}$  rated for 16 V is recommended. Bypass the DVDD pin to ground with a low-ESR ceramic capacitor C7. A value of 0.47  $\mu\text{F}$  rated for 6.3 V is recommended. Place these bypassing capacitors as close to the pins as possible.

For further details, see the [DRV8889-Q1 Automotive Stepper Driver with Integrated Current Sense, 1/256 Micro-Stepping, and Stall Detection Data Sheet](#).

Figure 6. DRV8889-Q1 Stepper Driver Schematic

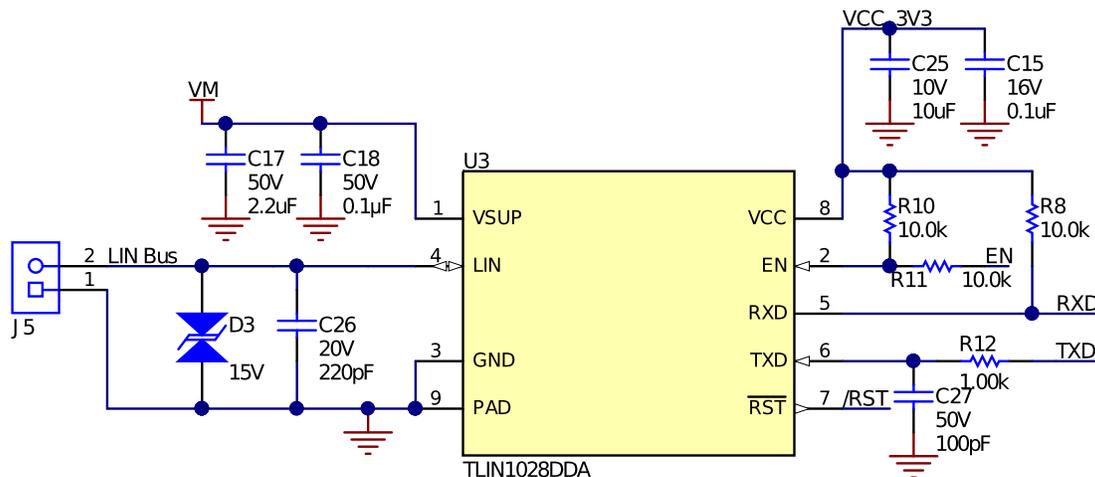


### 2.4.5 TLIN1028-Q1 LIN SBC

The TLIN1028-Q1 IC in this design is a LIN transceiver SBC which is used as communication interface with the MCU and provides a 3.3-V rail. Figure 7 shows the schematic of the LIN transceiver.

For component selection and layout guidelines see the [TLIN1028-Q1 Automotive Local Interconnect Network \(LIN\) Transceiver with Integrated Voltage Regulator Data Sheet](#).

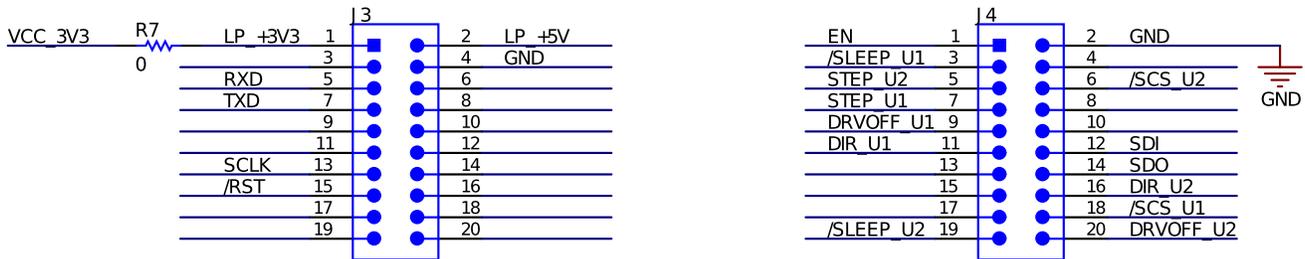
Figure 7. TLIN1028-Q1 LIN Transceiver Schematic



### 2.4.6 MSP430F5529 MCU LaunchPad™

An MSP430 LaunchPad is used to control the DRV8889-Q1 stepper drivers in this design. The MSP430F5529LP (or the F5529 LaunchPad) is an inexpensive and simple development kit for the MSP430F5529 USB MCU. It offers an easy way to begin developing on the TI MSP430 MCU, with onboard emulation for programming and debugging. There are two 20-pin connectors (J3 and J4) on the reference design PCB that allow for connection to the MSP-EXP430F5529LP. Figure 8 shows the connectors. The headers allow the connection of any other microcontroller as well to test the reference design.

**Figure 8. Connectors to MCU LaunchPad™**

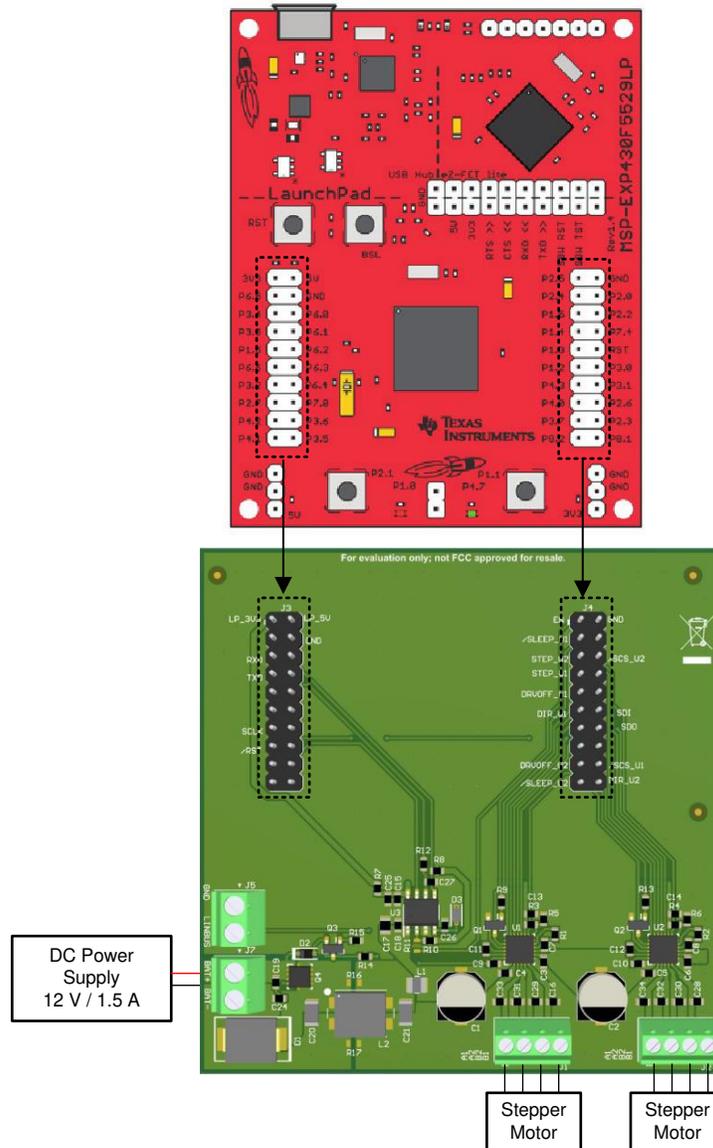


### 3 Hardware, Software, Testing Requirements, and Test Results

#### 3.1 Required Hardware and Software

The MSP430 LaunchPad can be connected to the PCB using the headers J3 and J4 (see Figure 9). Connect a DC power supply to the input terminal J1 and a stepper motor to J1 or J2. A simple code was created for the MSP430F5529 MCU for testing the design.

Figure 9. Hardware Test Setup



### 3.2 Testing and Results

#### 3.2.1 Electromagnetic Compatibility (EMC)

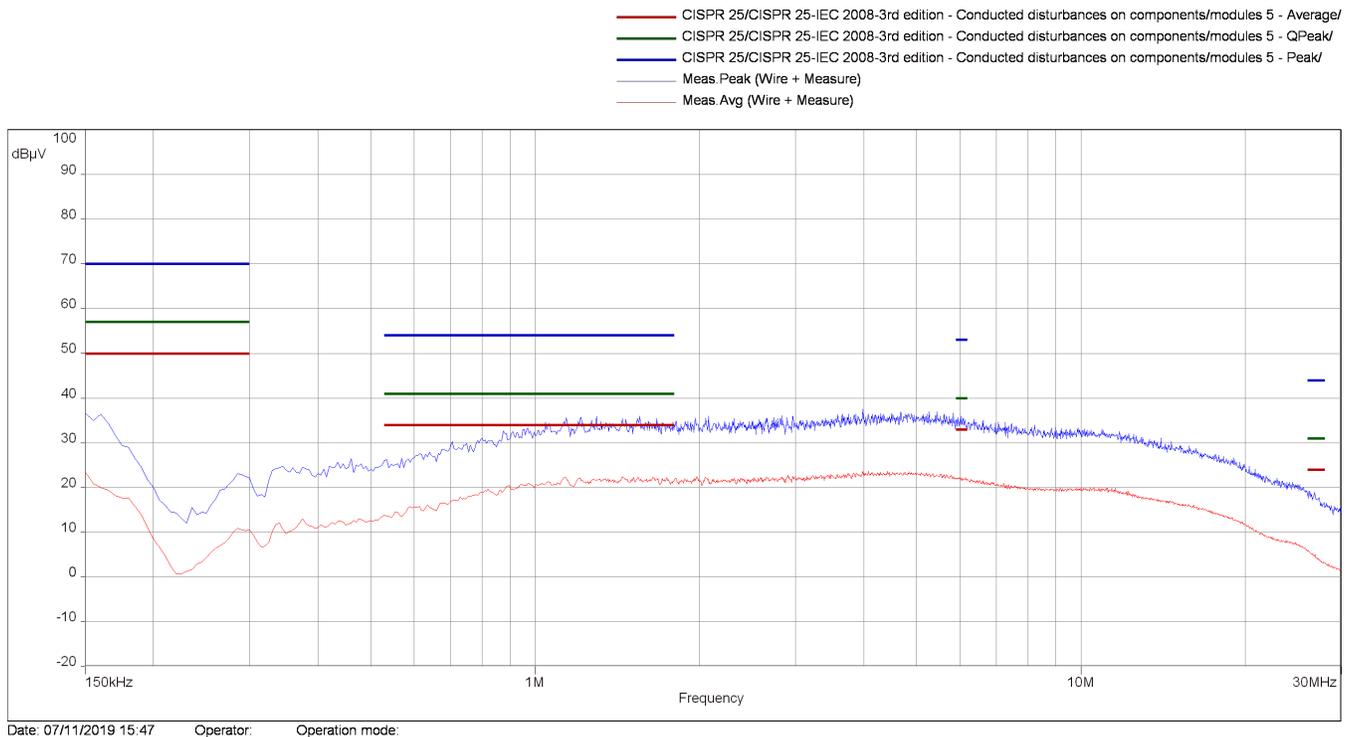
All tests in this section are performed according to the CISPR 25 standard. During the tests, the TIDA-020026 PCB was placed 5 cm above the reference ground plane.

Conditions:

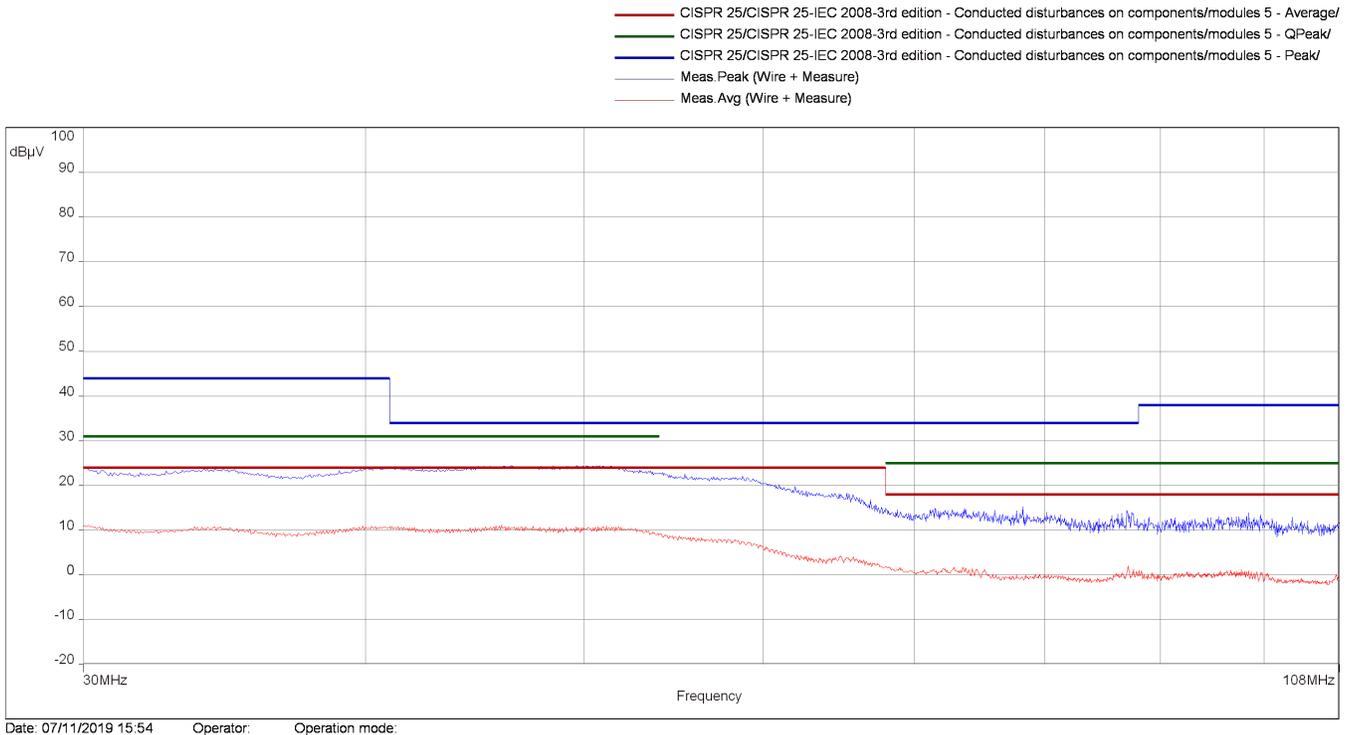
- Output slew rate: 105 V/μs
- Motor current: 1 A
- Step signal: 1000 PPS
- Decay mode: Smart tune ripple control
- Stepping: Full step (2-phase excitation)
- Motor cable length: 50 cm

Figure 10 through Figure 13 show the conducted and radiated emissions of the design.

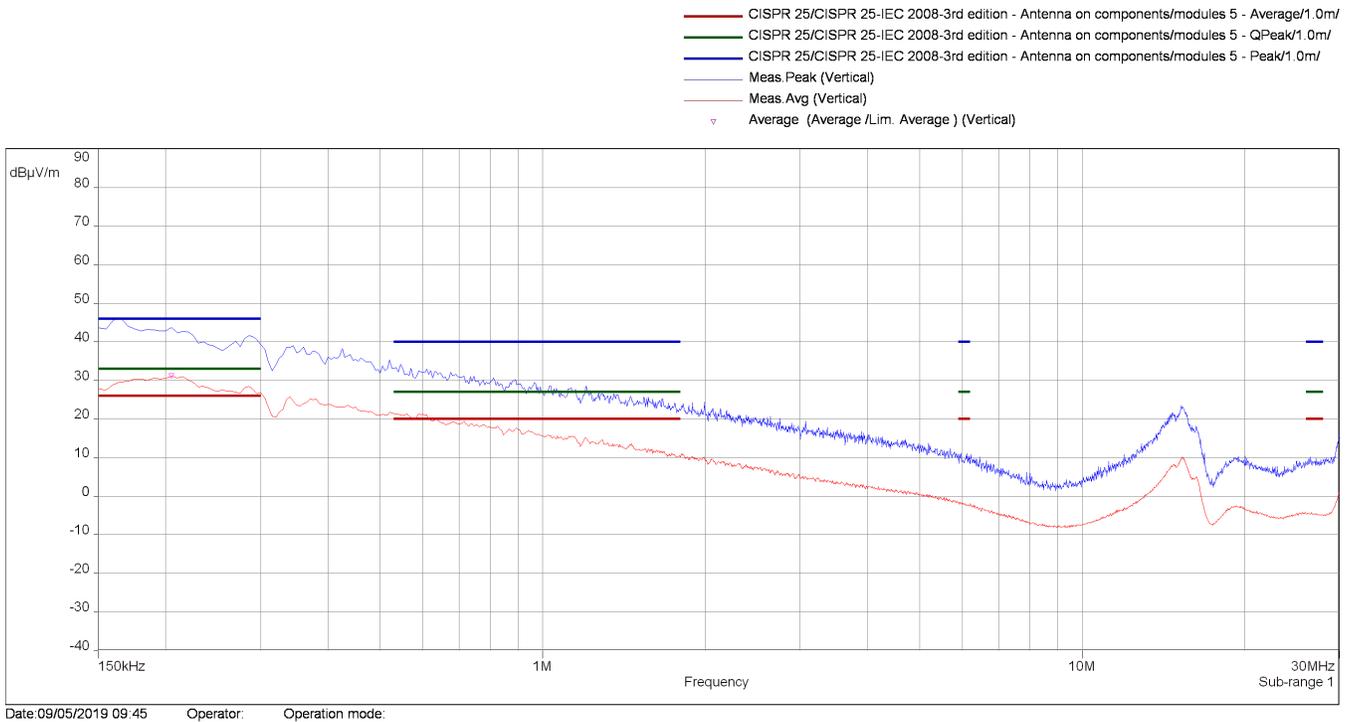
**Figure 10. Conducted Emissions: 0.15 MHz to 30 MHz**



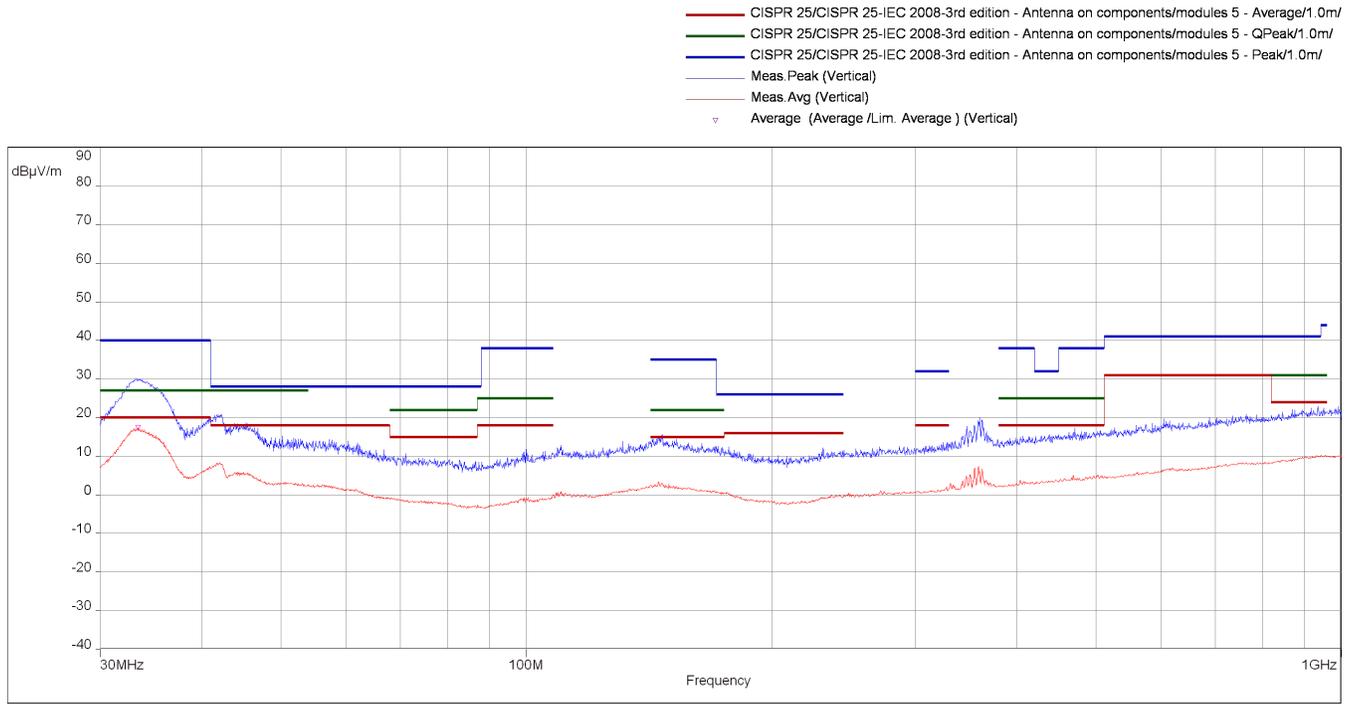
**Figure 11. Conducted Emissions: 30 MHz to 108 MHz**



**Figure 12. Radiated Emissions: 0.15 MHz to 30 MHz**



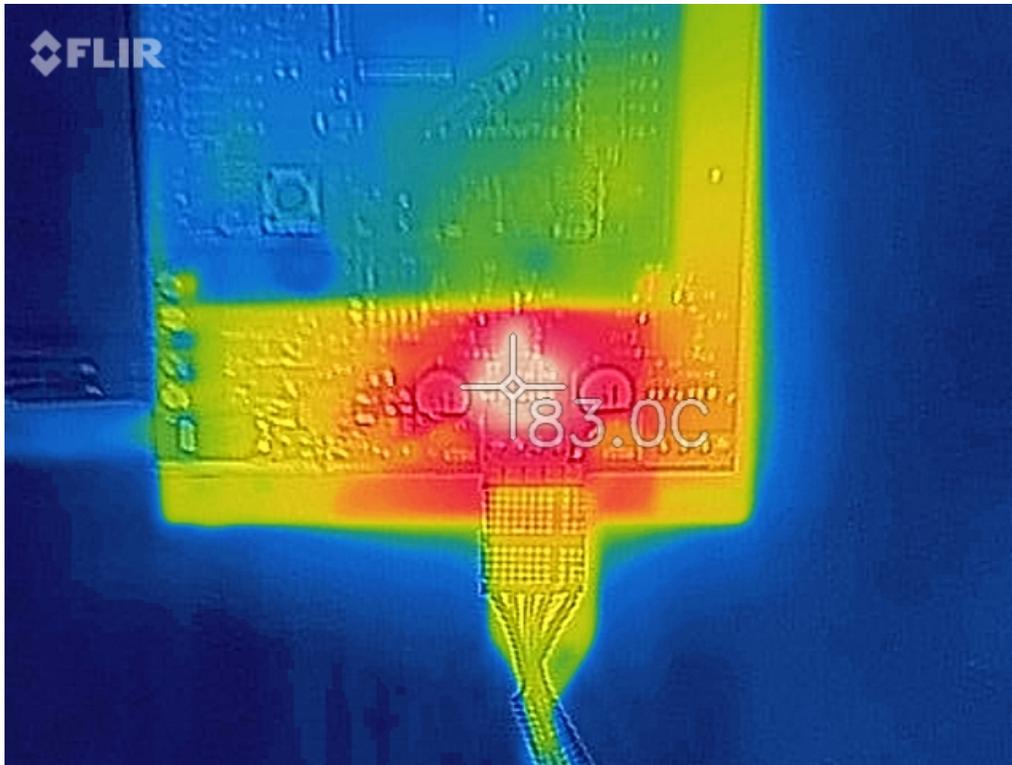
**Figure 13. Radiated Emissions: 30 MHz to 1 GHz**



### 3.2.2 Thermal Performance

Figure 14 shows the thermal behavior of the TIDA-020026. The same conditions are used as for the previous EMC tests in Section 3.2.1.

**Figure 14. Temperature on DRV8889-Q1 With 1-A Current**



## 4 Design Files

### 4.1 Schematics

To download the schematics, see the design files at [TIDA-020026](#).

### 4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-020026](#).

### 4.3 PCB Layout Recommendations

The layout of the reference design is created by following the layout examples and guidelines in the devices DS.

#### 4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-020026](#).

### 4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-020026](#).

### 4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-020026](#).

### 4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-020026](#).

## 5 Software Files

To download the software files, see the design files at [TIDA-020026](#).

## 6 Related Documentation

1. Texas Instruments, [DRV8889-Q1 Automotive Stepper Driver with Integrated Current Sense, 1/256 Micro-Stepping, and Stall Detection Data Sheet](#)
2. Texas Instruments, [TLIN1028-Q1 Automotive Local Interconnect Network \(LIN\) Transceiver with Integrated Voltage Regulator Data Sheet](#)

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## 7 About the Author

MICHAEL HELMLINGER is a systems engineer on the Automotive Body Electronics and Lighting team with more than 5 years of experience in analog power design. He works on various types of end equipment in the field of body electronics especially automotive lighting, creating and testing reference designs for automotive manufacturers.

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