

TI Designs

Status Indication Reference Design With LED and Audio Feedback



Description

This reference design's functionality emulates status indication subsystems in various end equipments. By putting multiple LED drivers in parallel, an array of RGB LEDs can be synchronized to blink, pulse, and breathe, enhancing customer experience. Audio feedback is also integrated to show a combined status indication solution with LEDs and audio. Applications include IP phones, building automation, home automation, white goods, and automotive infotainment and cluster.

Resources

TIDA-03026	Design Folder
TLC59116	Product Folder
TPS22918	Product Folder
TPA6211A1	Product Folder
MSP430G2452	Product Folder
TPD1E1B04	Product Folder
LMR14030	Product Folder
TLV1117-33	Product Folder

Features

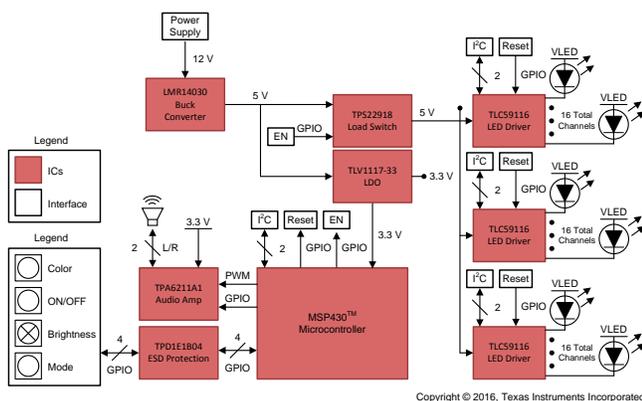
- Sync Multiple LED Drivers to Create Unique Pulsing, Blinking, and Breathing Effects
- I²C Control Makes Adding Additional LEDs simple by Enabling User Experience Customization Across Multiple Platforms
- TPA6211A1 Audio Amplifier Simplifies Audio Design for Faster Time-to-Market
- TPS22918 Load Switch Saves Power for Efficient System Design

Applications

- IP Phones
- Clothes Washer and Dryer
- Dish Washers
- Ovens (Microwave and Other)
- Refrigerators & Freezers
- Fire Alarm Control Panel
- Security Intrusion Control Panel
- Heating, Ventilating, Air Conditioning (HVAC) System Controller
- Remote Annunciator
- Network Video Controller (NVR)



ASK Our E2E Experts



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

All trademarks are the property of their respective owners.

1 System Overview

1.1 System Description

This TI Design showcases a status indication solution, incorporating 16 red-green-blue (RGB) LEDs and a miniature speaker that responds to button presses on the printed circuit board (PCB). The RGB LEDs can change color, brightness, and effects (blinking, pulsing, and breathing) depending on the buttons pressed and how far the brightness knob is turned.

To achieve the LED control, three 16-channel TLC59116 LED drivers are used. Each driver is responsible for one of the colors of the LEDs (red, green, or blue) and all three can be communicated to using I²C. The TLC59116 provides a constant current pulse width modulation (PWM) output for each LED channel, which can be modified to change brightness by varying the duty cycle. Using this adjustable brightness, the colors of each LED can be changed and effects such as blinking, pulsing, and breathing are possible.

When the LED drivers are in a standby state and no LEDs are powered, each LED driver consumes between 25 and 37 mA. To cut power from these devices and reduce the standby leakage to 0.5 μ A, the TPS22918 load switch is placed between the 5-V power rail and the Vcc pins of all the TLC59116 devices.

To generate the 1-kHz audio tone for the miniature speaker, the MSP430™ microcontroller (MCU) outputs a 50% duty cycle square wave to a second order filter. The square wave goes through the second order filter and a buffer to be converted into a sine wave with the same amplitude. This sine wave is fed into the TPA6211A3, which amplifies the signal and sends it to the speaker. Whenever a button is pressed, the MSP430 outputs the PWM signal and the 1.2-kHz tone is heard at the speaker.

This reference design's functionality emulates status indication subsystems in various end equipments. For example, an IP speakerphone will play a tone every time a button is pressed. Once a call has started, there may be LED indication to let the user know that the call is active. When the call is put on mute, the LEDs may turn red and begin to blink. If another line is trying to call in, there may be a notification using a yellow LED color with a pulsing effect. These different notifications allow a user to easily visualize what state the IP speakerphone is in.

Likewise, for a washing machine, there are several settings each wash can have (normal, delicates, colors, whites, and so forth). Like this reference design, when the user presses a button, an audible cue will indicate that the press was registered. When the user looks at the washing machine's buttons they can tell which settings are turned on because of the status indication LEDs. When the washing machine starts, the LEDs may begin to blink or pulse to notify the user. Building automation panels have a similar use case since the LEDs are present to indicate to the user which subsystems or settings are turned on or off.

Automotive qualified versions of the TLC59116 LED driver, TPS22918 load switch, TPS6211A1 audio amplifier, and LMR14030 buck converter are available. These devices can be paired to control the LED lighting in a cluster or infotainment application in the dashboard of a car.

1.2 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
VISUAL STATUS INDICATION		
Channel current (forward current through each LED)	—	20 mA
Typical LED forward voltage	$V_{FWD,RED}$	2.1 V
	$V_{FWD,GREEN}$	3.2 V
	$V_{FWD,BLUE}$	3.2 V
I ² C communication	—	Important I ² C commands and rest function
Blink, breathe, and pulse frequency	—	Adjustable through I ² C
AUDIO STATUS INDICATION		
Sine wave output to speaker	—	130 Hz
Second order filter cutoff frequency	—	1 kHz
Amplifier gain	—	1
POWER DELIVERY - SWITCHING REGULATOR		
Input voltage range	—	5 to 40 V
Output voltage	—	5 V
Output voltage ripple	—	50 mV
Switching frequency	—	375 kHz
Max output current	—	2 A
POWER DELIVERY - LDO		
Input voltage range	—	4.7 to 15 V
Output voltage	—	3.3 V
POWER DELIVERY - LOAD SWITCH		
Shutdown current	—	0.5 μ A
Maximum inrush current	—	500 mA
V_{OUT} rise time	—	242 μ s

1.3 Block Diagram

The image below illustrates the complete functional block diagram for this reference design.

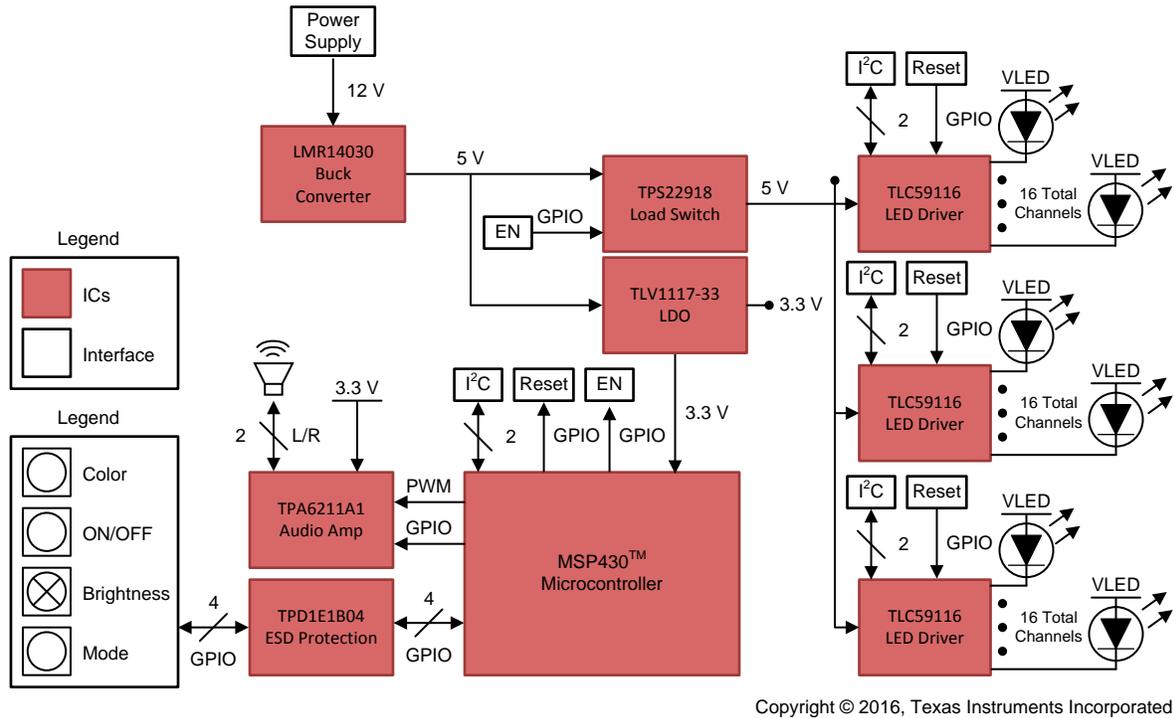


Figure 1. Functional Block Diagram

1.4 Highlighted Products

1.4.1 TLC59116

The TLC59116 is an I²C bus controlled 16-channel LED driver that is optimized for red-green-blue-amber (RGBA) color mixing and backlight application. Each LED output has an 8-bit resolution, fixed-frequency PWM controller that operates at 97 kHz with an adjustable duty cycle from 0 to 99.6%.

1.4.2 TPS22918

The TPS22918 is a 5.5-V, 2-A load switch in a 6-pin SOT-23 package. To reduce voltage drop for low-voltage and high-current rails, the device implements a low-resistance N-channel MOSFET, which reduces the drop out voltage across the device.

The device has a configurable slew rate that reduces or eliminates power supply droop due to large inrush currents. The device also features a quick output discharge (QOD) pin, which allows for the configuration of the discharge rate of V_{OUT} . Quick output discharge occurs once the switch is disabled. The device has very low leakage currents during shutdown, which also helps mitigate leakage for downstream modules during standby. The integrated control logic, driver, charge pump, and output discharge FET eliminates the need for any external components, which reduces solution size and bill of materials (BOM) count.

1.4.3 TPA6211A1

The TPA6211A1 is a 3.1-W mono fully-differential amplifier designed to drive a speaker with at least 3-Ω impedance while utilizing only 20 mm² total PCB area. The device operates from 2.5 V to 5.5 V, drawing only 4 mA of quiescent supply current. The TPA6211A1 is available in the space-saving 3-mm × 3-mm small outline non-leaded (SON) package (DRB) and the 8-pin MSOP- PowerPAD™ integrated circuit package (DGN).

Features like –80-dB supply voltage rejection from 20 Hz to 2 kHz, improved RF rectification immunity, small PCB area, and fast startup with minimal pop makes the TPA6211A1 ideal for PDA and smart phone applications.

1.4.4 LMR14030

The LMR14030 is a 40-V, 3.5-A step down regulator with an integrated high-side MOSFET. With a wide input range from 4 to 40 V, the device is suitable for various applications from industrial to automotive for power conditioning from unregulated sources. The regulator's quiescent current is 40- μ A in sleep mode, which suits battery powered systems. An ultra-low 1- μ A current in shutdown mode can further prolong battery life. The wide adjustable switching 2.5-MHz frequency range allows either efficiency or external component size to be optimized. Internal loop compensation allows the user freedom from loop compensation design, which minimizes BOM count. A precision enable input allows simplification of regulator control and system power sequencing. Additionally, the device also has built-in protection features such as cycle-by-cycle current limit, thermal sensing and shutdown due to excessive power dissipation, and output overvoltage protection.

1.4.5 TLV1117-33

The TLV1117 device is a positive low-dropout voltage regulator designed to provide up to 800 mA of output current. The device is available in 1.5, 1.8, 2.5, 3.3, and 5-V and has adjustable-output voltage options. All internal circuitry is designed to operate down to 1-V input-to-output differential. Dropout voltage is specified at a maximum of 1.3 V at 800 mA, which decreases at lower load currents.

1.4.6 TPD1E1B04

The TPD1E1B04 is a bidirectional transient voltage suppression (TVS) based electrostatic discharge (ESD) protection diode featuring low R_{DYN} (dynamic resistance) and low clamping voltage. The TPD1E1B04 is rated to dissipate ESD strikes at the maximum level specified in the IEC 61000-4-2 international standard (level 4). The ultra-low dynamic resistance (0.15 Ω) and extremely-low clamping voltage (8.5 V at 16-A transmission line pulse) ensure system level protection against transient events. This device features a 1-pF IO capacitance making it ideal for protecting interfaces such as USB 2.0. The TPD1E1B04 is offered in the industry standard 0402 (DPY) package.

2 Getting Started Hardware

2.1 System Setup

To power the board, a 12-V supply must be connected to the positive and negative terminals as shown in [Figure 2](#). The power supply and cables used for connection must be rated for 2 A. Shunts must be connected to the jumpers listed in table for full functionality. The figure below also illustrates jumper placement for default functionality.

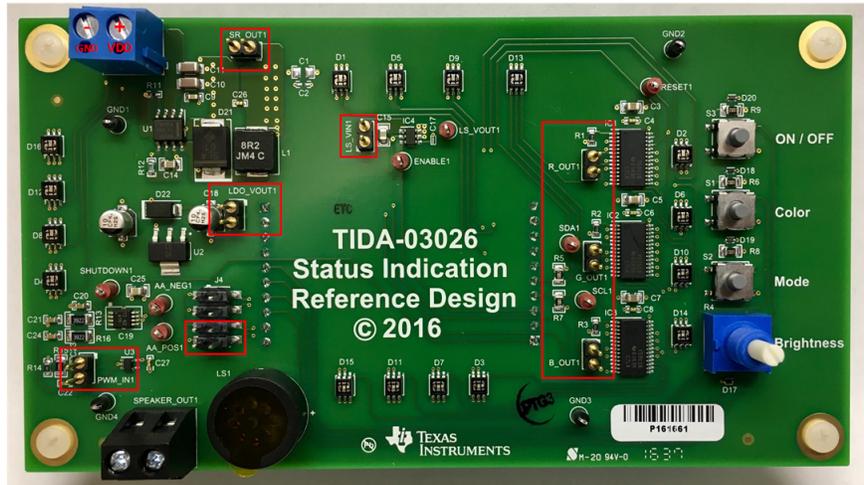


Figure 2. Default Board Setup

[Table 2](#) shows the default jumper settings.

Table 2. Default Jumper Settings

JUMPER NAME	SHUNT CONNECTION	FUNCTION
SR_OUT1	1 to 2	Allows 5 V from LMR14030 to system
LS_VIN1	1 to 2	Allows 5 V across the TPS22918 input voltage pin
LDO_VOUT	1 to 2	Allows 3.3 V from the TLV1117-33 to the system
R_OUT1 G_OUT1 B_OUT1	1 to 2	Allows current to flow to channel 0 of each TLC59116
PWM_IN1	1 to 2	Allows the filtered PWM signal into the TPA6211A1
J4	1 to 2 3 to 4	Allows the differential output of the TPA6211A1 into an externally connected speaker
	5 to 6 7 to 8	Allows the differential output of the TPA6211A1 into the onboard speaker

2.2 Button and Knob Functions

Once the board is powered, each of the buttons can be used to control the function of the LEDs. The function of each button is in [Table 3](#).

Table 3. Button and Knob Functions

BUTTON OR KNOB	FUNCTION
ON or OFF	This turns the LEDs on and off. When pressed, the enable of the TPS22918 load switch is toggled activating and deactivating the LED circuitry.
Brightness	This potentiometer knob controls the brightness of the LEDs by adjusting the duty cycle of the PWM output of the TLC59116 LED drivers.
Color	By pushing this button, the colors of the LEDs can toggle between red, green, and blue. This is done by turning on the appropriate channels of each LED driver.
Mode	There are three modes the LEDs can switch between: <ul style="list-style-type: none"> • Blinking: This mode will turn the LEDs on and off at a slow rate. • Pulsing: This mode will turn the LEDs on and off at a fast rate. • Breathing: This mode will ramp up and down the brightness of the LEDs, which creates a smooth transitioning effect from on to off.

3 Testing and Results

3.1 Overview

This TI Design is characterized for both visual and audible status indication. [Table 4](#) denotes the test points used for system testing.

Table 4. Test Point Descriptions

TEST POINT	FEATURE
RESET1	MSP430 → TLC59116, reset signal
LS_OUT1	TPS22918, input voltage → output voltage
ENABLE1	MSP430 → TPS22918, enable signal
SDA1 SCL1	MSP430 ↔ TLC59116, I ² C interface
SHUTDOWN1	MSP430 → TPA6211A1, shutdown signal
AA_POS AA_NEG	TPA6211A1 → speaker, differential output
GND1 to GND4	Ground

The following subsections detail the procedures, results, and test setup for the visual status indication, audio status indication, and power delivery subsystems.

3.2 Visual Status Indication

The visual status indication subsystem of this TI Design offers visual indication through the 16 RGB LEDs and 3 TLC59116s.

Refer to [Section 3.2.2](#) through [Section 3.2.6](#) for discussion and test results.

3.2.1 Test Setup

The visual indication tests apply probes on the following test points and jumpers:

- R_OUT1
- G_OUT1
- B_OUT1
- SCA1
- SCL1
- ENABLE1

As per default instructions, apply shunts to the necessary jumpers. Connect the power supply to the board and apply 12 V with 2-A current limit. [Table 5](#) summarizes the overall functionality of the visual indication subsystem. Through the button interface, the user is able to transition from several different functionality states.

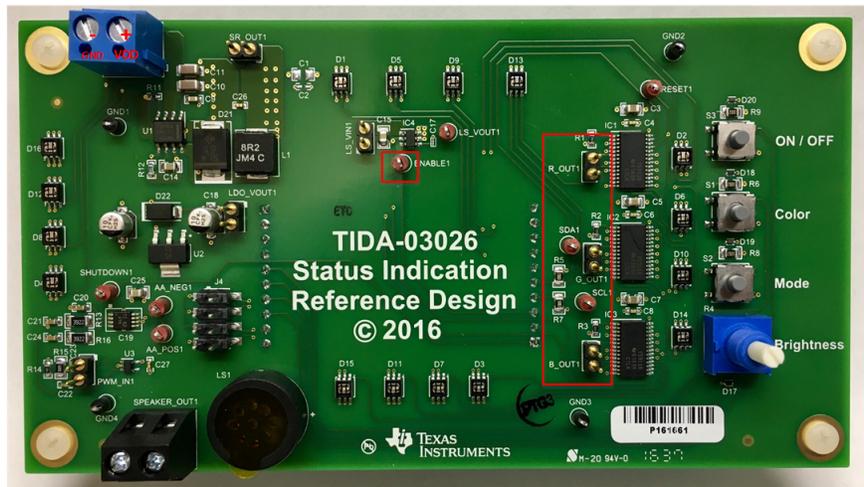


Figure 3. Visual Status Indication Test Setup

The table below details the test parameters and their significance in regards to the test results in Section 3.2.2 through Section 3.2.6. These parameters are seen in the scope shots, which accompany the test results.

Table 5. Visual Status Indication Scope Shot Waveforms

PARAMETER	SIGNIFICANCE
SCL SDA	Indicates I ² C Communication between the LED drivers and the MSP430
R/G/B_OUT1	Indicates the voltage output signal on channel 0 of each LED driver
RESET	Indicates when the LED drivers are reset to maintain synchronization between red, green, and blue
I _{CHANNEL}	Indicates the channel current signal of the LED driver

3.2.2 Color Functionality Results

Color mixing and switching is a must-have for any visual status indication design using LEDs. Used in this design and as described in Section 1.1, the system shall switch between red, green, and blue. Figure 4 shows each state of the color functionality. From left to right, the design produces white, red, green, and blue lights.

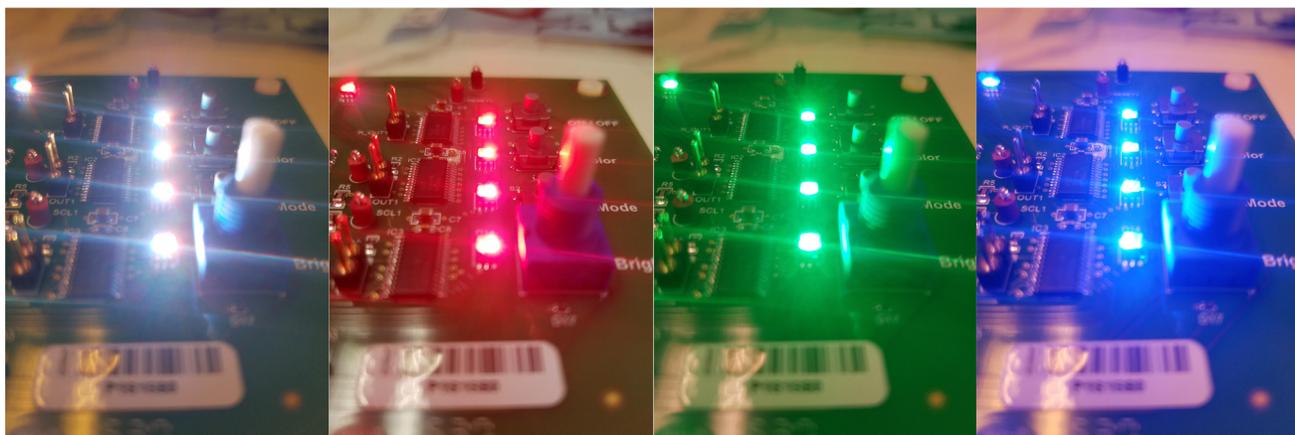


Figure 4. Visual Indication Subsystem Color Settings

Each of the TLC59116 LED drivers has an internal oscillator, which can vary due to process variation. Therefore, when using multiple TLC59116 devices to control one RGB LED, the difference in timing between each LED driver can be visually noticed. To fix this issue, the LED drivers need to be periodically reset so that all devices are in sync. The reset and reinitialization happens so quickly that it is visually undetectable. A scope shot of all colors in sync can be seen in [Figure 5](#).

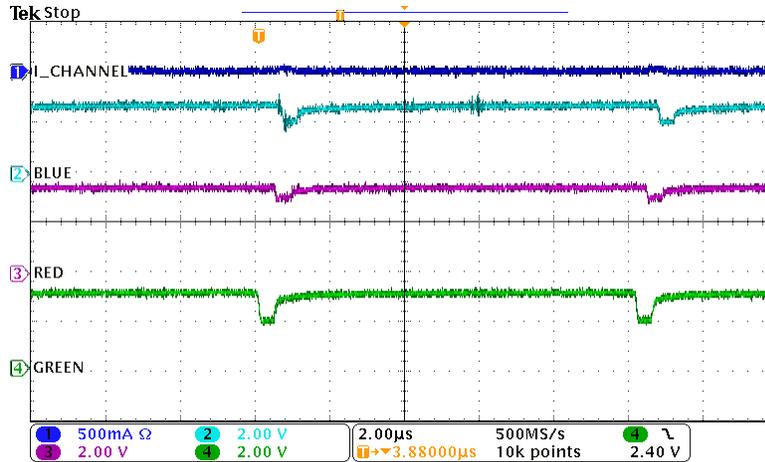


Figure 5. Synchronous LED Operation Across LED Drivers

3.2.3 Brightness Functionality Results

Adjustable brightness settings for status indication are becoming more commonplace. The TLC59116 uses a 190-Hz fixed-frequency signal with programmable duty cycle to provide global brightness control functionality. [Table 6](#) shows the different brightness settings as well as the PWM duty cycle for the current through each LED.

Table 6. Brightness Settings

BRIGHTNESS SETTING	BRIGHTNESS LEVEL	PWM DUTY CYCLE
1	25%	24.9%
2	50%	49.8%
3	75%	74.7%
4	100%	99.6%

3.2.4 Blink Functionality Results

The LED drivers implement a *blink* function for visual status indication. [Figure 6](#) shows a screen capture of the blinking pulse width and frequency for each color. The pulse width is characterized as 1.5 s and a blinking frequency of 0.29 Hz.

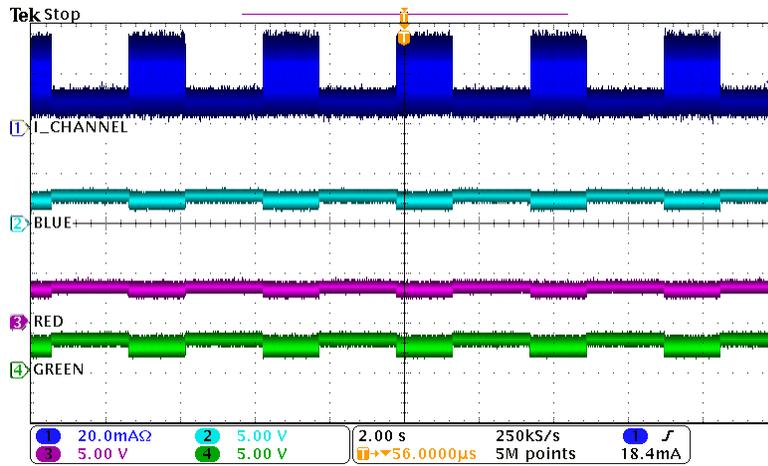


Figure 6. Blink Functionality

3.2.5 Pulse Functionality Results

The *pulse* function indicates blinking at a higher frequency. Figure 7 yields the blinking pulse width and frequency for each color. The pulse width is characterized as 250 ms and a frequency of 1 Hz.

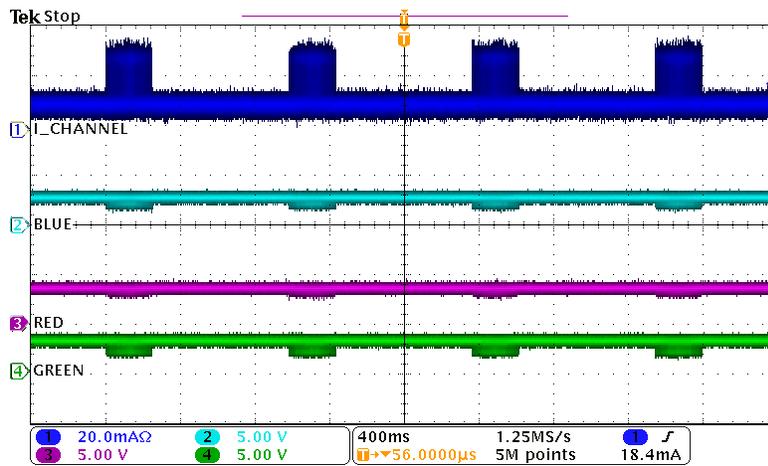


Figure 7. Pulse Functionality

3.2.6 Breathe Functionality Results

The *breathe* mode on the status indication design implements an increasing and decreasing brightness function. Figure 8 shows an example of this behavior.

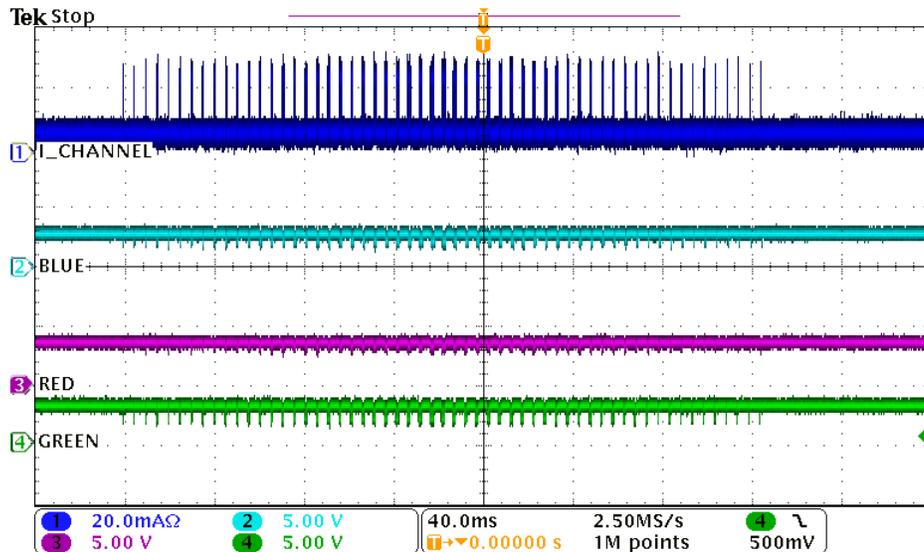


Figure 8. Breathe Functionality

As visible in Figure 8, the voltage and current duty cycle increases and then decreases showing a ramp in brightness from dim to bright to dim.

3.3 Audio Status Indication

The audio status indication subsystem of the *Status Indication Reference Design with LED and Audio Feedback* offers audio indication via the: MSP430, 2nd Order Filter, TPA6211A1, and onboard speaker. An optional speaker can be attached to the board with the proper J4 jumper connections.

Refer to section 3.3.2 for discussion and test results.

3.3.1 Test Setup

The audio indication tests apply probes on the following test points and jumpers:

- LDO_VOUT1
- POINT A
- AA_NEG, AA_POS
- SHUTDOWN1
- PWM_IN1

As per default instructions, apply shunts to the necessary jumpers. Connect the power supply to the board and apply 12 V with 2-A current limit.

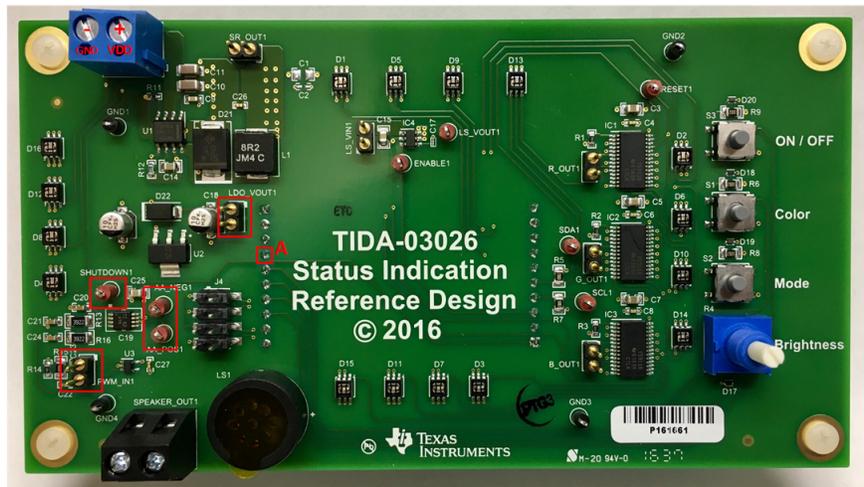


Figure 9. Audio Status Indication Test Setup

3.3.2 Audio Indication Results

Several end equipments achieve audio status indication through various means. The audio status indication subsystem produces an audio tone through an MSP430-generated PWM signal. By passing this PWM signal through a second order filter, the audio status indication subsystem produces a 130-Hz tone as seen in Figure 10 .

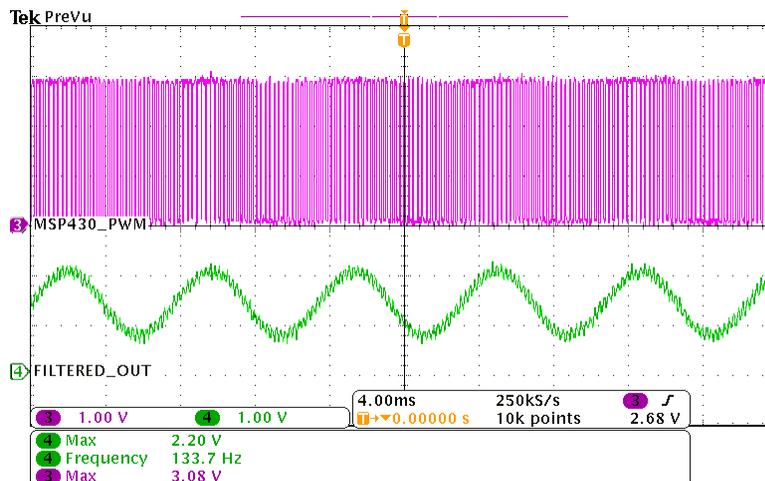


Figure 10. Audio Tone Generation Through PWM Signal and Second Order Filter

TPA6211A1 is configured for a single-ended input using the filtered PWM signal. Volume, for example, amplifier gain, is adjustable through the TPA6211A1's input resistors. Note that end equipment placed in a high-noise floor environment should readjust the gain where applicable. For this subsystem, the gain is currently set to 1. Figure 11 illustrates the single-ended TPA6211A1 input and its differential signal output.

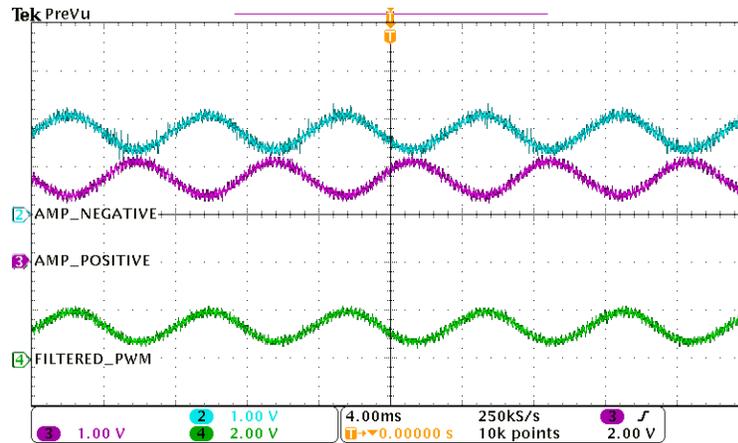


Figure 11. Filtered Input TPA6211A1 Input Signal and Differential Output Signals

3.4 Power Delivery

The power delivery subsystem of this TI Design shows two different advantages of the TPS22918 load switch:

- System power savings
- Inrush current control

Refer to [Section 3.4.2](#) and [Section 3.4.3](#) for discussion and test results.

3.4.1 Test Setup

The power delivery system tests apply probes on the following test points and jumpers:

- LS_VIN1
- LS_VOUT1
- RESET1
- ENABLE1

Operation with the load switch requires a shunt on the LS_VIN1 jumper. As per default instructions, apply shunts to necessary jumpers. Once the proper connections are made, connect the power supply to the board and apply 12 V with 2-A current limit.



Figure 12. Power Delivery Test Setup

3.4.2 Power Savings Results

Power budgets are often critical requirements for systems that operate in different functional modes. For example, during an active status indication event, indication LEDs may consume a large portion of the power budget. However during standby mode, reduction of power dissipation is paramount. Systems whose components have several milliamps of leakage current in their standby mode can achieve power savings through the TPS22918, whose shutdown current is nearly 0.5 μ A. The power dissipated by the LED driver subsystem in standby mode can be represented by the Equation 1:

$$P_{STBY} = V_{IN} \times I_{STBY} \tag{1}$$

Because V_{IN} is constant, reducing the standby current (I_{STBY}) of the system will reduce the standby power dissipation. Figure 13 shows how disabling the LED drivers using the TPS22918 load switch can help reduce the amount of system standby current.

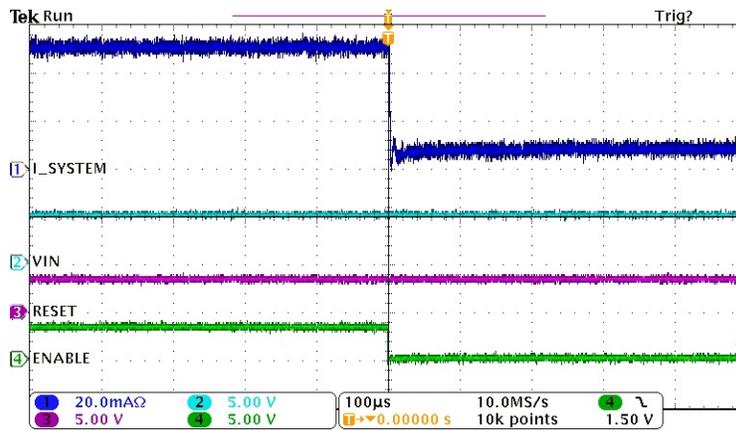


Figure 13. Power Savings

Table 7. Power Savings Parameter Description

PARAMETER	DESCRIPTION
V_{IN}	Indicates steady input voltage with no dips or sag
I_{SYSTEM}	Indicates total leakage current of the visual indication subsystem
ENABLE	Indicates event when load switch is disabled
RESET	Indicates the standby state of the LED drivers

On the left side of the scope shot, the load switch is enabled and the LED drivers are in standby mode (RESET toggled high). When the load switch is disabled, the standby current of the LED drivers is reduced from about 40 mA to 0.5 μ A.

3.4.3 Inrush Current Control Results

Subsystems in any status indication equipment can experience inrush current events from quickly charging load capacitors due to a lack of voltage slew rate control. The voltage dip imposed by the inrush current event is burdensome for subsystems whose power is supplied by the load switch. For example, a 3.3-V rail biasing status LEDs, whose forward voltage is 3.2 V, now dips to 3.1 V. This voltage dip could desynchronize status indication functionality across multiple status LEDs. As such, the goal is to control the rise time of the output voltage.

Inrush current caused by the visual indication subsystem’s capacitive load is determined by Equation 2:

$$I_{INRUSH} = C_{LOAD} \times \frac{dV}{dt} \tag{2}$$

Where C_{LOAD} is the load capacitor being charged, dV is the voltage being applied on the capacitor, and dt is the rise time of the voltage. The rise time of the output voltage for the TPS22918 is set by an external capacitor on the CT pin of the device. The relationship between rise time and the external CT capacitor is below.

$$t_R = V_{OUT} \times (0.55 \times CT + 30) \tag{3}$$

The units for the constants are $\mu\text{s}/\text{V}$ for 30 and $\mu\text{s}/(\text{V} \times \text{pF})$ for 0.55. This equation accounts for 10 to 90% measurement on V_{OUT} and does not apply for $CT = 0 \text{ pF}$. The LED driver subsystem is designed to have a maximum inrush current of 500 mA, which translates into a minimum rise time of 242 μs (using Equation 3). To satisfy this rise time requirement, a CT capacitor of 100 pF was chosen.

Figure 14 shows how modifying the CT capacitor can affect the inrush current for the TPS22918. The scope shot on the left shows that enabling the load switch with a CT capacitor of 0 pF will result in a fast rise time and an inrush current of 1.88 A. The scope shot on the right shows that with a CT capacitor of 100 pF, the inrush current is reduced to 360 mA.

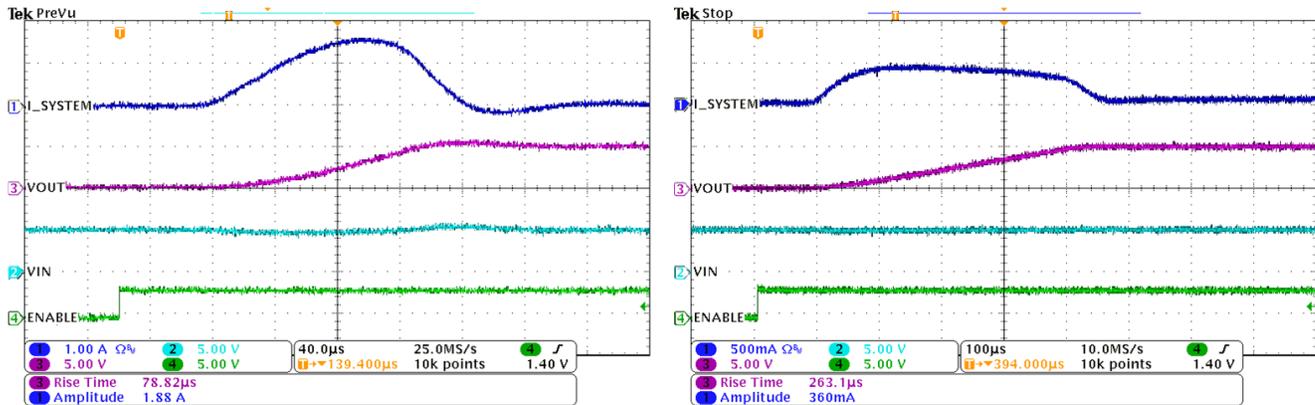


Figure 14. Inrush Current - No CT Capacitor (Left) and 100pF CT Capacitor (Right)

Table 8. Inrush Current Parameter Description

PARAMETER	DESCRIPTION
V_{IN}	Indicates steady input voltage signal with no dips or sag
V_{OUT}	Indicates controlled slew rate output voltage signal
I_{SYSTEM}	Indicates inrush current caused by the capacitive load
ENABLE	Indicates event when load switch is enabled

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-03026](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-03026](#).

4.3 PCB Layout Recommendations

For each device, the layout recommendations in the datasheet were followed. All power traces were made thick enough to handle the maximum current for each power rail and all differential audio signals were routed to be the same length. All bypass capacitors were placed as close to each device as possible.

4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-03026](#).

4.4 Altium Project

To download the Altium project files, see the design files at [TIDA-03026](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-03026](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-03026](#).

5 References

1. Texas Instruments, *Enhance your home automation project with an LED driver*, Blog ([link](#))
2. Texas Instruments, *Managing Inrush Current*, Application Report ([SLVA670](#))
3. Texas Instruments, *Load Switches: What Are They, Why Do You Need Them And How Do You Choose The Right One?*, Application Report ([SLVA652](#))

6 About the Author

ALEK KAKNEVICIUS is an applications engineer at TI, where he answers technical questions about load switches from the TPS229xx family. He received his Bachelor of Science in Electrical Engineering (BSEE) and Master of Science in Electrical Engineering (MSEE) at the University of Florida in Gainesville, FL.

SAMANTHA WATKINS is a product marketing engineer at TI, where she promotes load switches from the TPS229xx family. She received her Bachelor of Science in Computer Engineering (BSCpE) and her Master of Science in Computer Engineering (MSCpE) at Southern Methodist University in Dallas, TX.

HARRY KENNEDY is an applications engineer at TI, where he answers technical questions about LED drivers from the TLC59xxx family. He received his Bachelor of Science in Electrical Engineering (BSEE) at the Ohio University in Athens, OH.

DANIEL FONCANNON is an applications engineer at TI, where he focuses on driving new products and TI designs. He received his Bachelor of Science in Electronic Systems Engineering Technology (BSESET) at the Texas A&M University in College Station, TX.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers ("Designer(s)") who are developing systems that incorporate TI products. TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.

TI's provision of reference designs and any other technical, applications or design advice, quality characterization, reliability data or other information or services does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such reference designs or other items.

TI reserves the right to make corrections, enhancements, improvements and other changes to its reference designs and other items.

Designer understands and agrees that Designer remains responsible for using its independent analysis, evaluation and judgment in designing Designer's systems and products, and has full and exclusive responsibility to assure the safety of its products and compliance of its products (and of all TI products used in or for such Designer's products) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to its applications, it has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any systems that include TI products, Designer will thoroughly test such systems and the functionality of such TI products as used in such systems. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

Designers are authorized to use, copy and modify any individual TI reference design only in connection with the development of end products that include the TI product(s) identified in that reference design. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of the reference design or other items described above may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS AND OTHER ITEMS DESCRIBED ABOVE ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNERS AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS AS DESCRIBED IN A TI REFERENCE DESIGN OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

TI's standard terms of sale for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>) apply to the sale of packaged integrated circuit products. Additional terms may apply to the use or sale of other types of TI products and services.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated