Application Report
SLVA672–December 2014

Low-Noise CMOS Camera Supply

Juergen Neuhaeusler

ABSTRACT

In an automotive environment, cameras replace or extend the function of mirrors enabling the driver to monitor the surroundings of the vehicle. Automated control of a vehicle requires cameras as well. Under automated control, only a computer may see the picture. Cameras which operate reliably without human control and interaction are required. Multiple types of cameras will also be used.

Although it is convenient to use the functionality of the camera, the cameras should not be visible or occupy too much space. If, for example, many cameras are used in a car, they should not dominate the design of the car or its interior or interfere with the car design at all. Cameras in cars must be small and lightweight. The sensor and image processing parts must be power efficient. The power-supply architecture must also be designed. Small solutions consuming lowest power possible are preferable. For the power-supply solution, the smallest components are needed to achieve highest efficiency at highest energy density.

Achieving high efficiency generally means using switching regulators, unfortunately switching generates noise which can interfere with the operation of the CMOS sensors in the cameras. To be on the safe side, many designs still use linear regulators for the power management or for additional filtering. Additional filter components, like resistors or ferrite beads are very common at the output of switching regulators to reduce the risk of noise problems in the camera design.

This application note describes how to design a highly-efficient, low-noise power-supply solution based on switching regulators without the need of any additional filtering.

1 Overview

The power-supply solution in this example is designed for a camera module with a block structure like the one shown in Figure 1. The solution, based on the TPS62170, provides all the required power rails in the system. This solution is designed for highest total efficiency without the need of additional filtering on any of the rails. An example of an implementation is in the TI reference designs library.

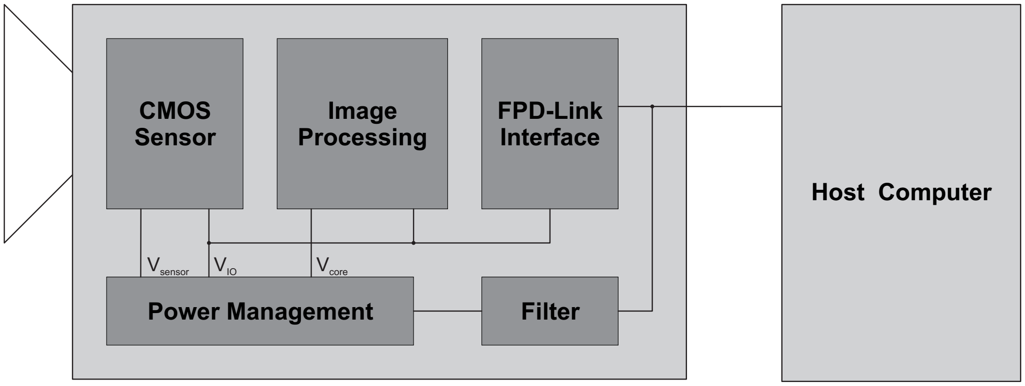

Figure 1. Block Structure

2 Detailed Description

Figure 1 shows the block structure of a typical camera module. The power management solution needs to generate 3 voltage rails for the camera. The supply voltage for the power management solution is provided through the same cable as used for data transmission. A low-pass filter on the input of the power-supply solution filters the DC power provided through the cable from the AC data communication signal.

The level of this supply voltage defines the current which needs to be provided through the cable and handled in the low-pass filter components on both ends of the cable. To be able to design a small filter with small components, low currents flowing through the cable and the filter are desirable. Due to a hard-to-predict voltage drop along the cable connection and the filtering on both ends of the cable, it is most likely that this supply voltage cannot be used directly to supply one of the voltage rails of the camera. The power consumption of the camera module can be estimated to be constant.

Generating 3 different output voltage rails from one supply voltage rail can be done in different architectures. Figure 2 and Figure 3 show the block structure of two different options. In the block structure in Figure 2, an intermediate voltage rail V_{SYS} is generated to supply the DCDC converters 1–3 which are supplying the required camera voltage rails. If the voltage of the intermediate voltage rail V_{SYS} is set to the same voltage as one of the output voltages of the subsequent DCDC converters and if it is regulated well enough to that voltage level, this specific rail can be supplied directly and the one DCDC converter can be saved. So a solution can be implemented using 3 DCDC converters only.

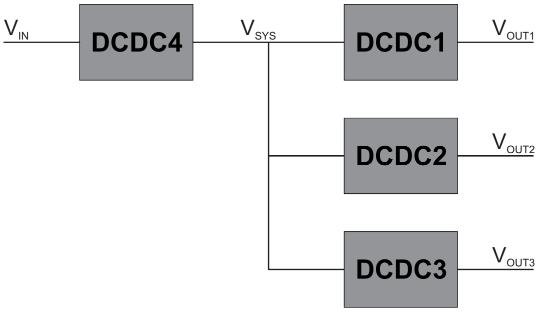

Figure 2. Cascaded Converter Structure

Calculate the required input power of the cascaded converter structure P_{INC} with Equation 1.

$$P_{INC} = \frac{1}{\eta_4}\left(\frac{P_1}{\eta_1} + \frac{P_2}{\eta_2} + \frac{P_3}{\eta_3}\right) \tag{1}$$

In Equation 4, P_{OUT1} is the output power required at the V_{OUT1} rail, P_{OUT2} is the output power required at the V_{OUT2} rail, and P_{OUT3} is the output power required at the V_{OUT3} rail. η_1, η_2, η_3, and η_4 are the power conversion efficiencies of the DCDC converters 1–4.

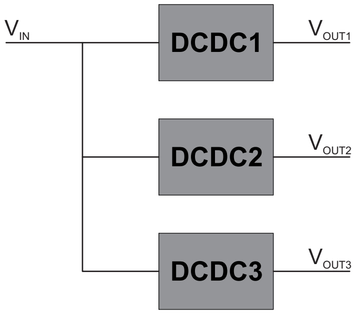

Figure 3. Parallel Converter Structure

Calculate the required input power of the parallel converter structure P_{INP} with Equation 2.

$$P_{INP} = \frac{P_1}{\eta_1} + \frac{P_2}{\eta_2} + \frac{P_3}{\eta_3} \quad (2)$$

The parameters in Equation 2 are defined similar to the parameters of Equation 1.

In case of a linear regulator, the power conversion efficiency η_{LDO} mainly depends on the input and output voltage as shown in Equation 3. This assumes that the quiescent current of the linear regulator is negligible compared to its output current.

$$\eta_{LDO} = \frac{V_{OUT}}{V_{IN}} \quad (3)$$

In Equation 3, V_{IN} is the voltage at the input of the linear regulator and V_{OUT} is its output voltage.

This means that there will be no difference in the required amount of input power of the cascaded and the parallel converter structure. If using linear regulators, the required input power, P_{INLDO}, is calculated using Equation 4 for both options.

$$P_{INLDO} = V_{IN} \left(\frac{P_{OUT1}}{V_{OUT1}} + \frac{P_{OUT2}}{V_{OUT2}} + \frac{P_{OUT3}}{V_{OUT3}} \right) \quad (4)$$

If the power management solution is implemented based on switching regulators independent of the architecture, higher efficiency can be achieved. Due to the switching operation of the regulators, the regulated supply voltage has a characteristic ripple. This ripple is not desirable for a supply rail requiring a low noise supply. For this reason, the regulators need to be designed for a minimum output voltage noise.

Camera sensor circuits usually are sensitive for noise at frequencies below 1 MHz. So, switching regulators supporting switching frequencies above 1 MHz are preferred. This also helps when designing small solutions, since the inductor size strongly depends on the switching frequency of the converter. To not interfere with the AM radio band, staying above 2 MHz is desirable in automotive applications.

Make sure the switching frequency stays constant for the output power which must be regulated by operating the regulator at continuous inductor current.

This avoids a wider noise spectrum at lower frequencies since the switching frequency is typically only controlled by oscillators or timer circuits in the converter. In discontinuous operation, additional parameters come into play, like inductance variations or comparator thresholds in the control loop. They usually generate a wider variation of the switching frequency and with this, a broader noise spectrum.

Since input voltage and output voltage are fixed and the output current is almost constant and can be predicted easily, the minimum inductance, *L*, for the converter to operate with continuous inductor current can be calculated using Equation 5:

$$L = \frac{V_{OUT} \left(V_{IN} - V_{OUT} \right)}{2 \times V_{IN} \times I_{OUT} \times f} \quad (5)$$

In Equation 5, V_{IN} is the voltage at the input of the switching regulator and V_{OUT} is its output voltage. *f* is the minimum switching frequency of the converter which should be maintained.

3 Example

The camera in this example uses 3 separate rails for powering the different functional blocks of the system. The main and most sensitive rail is a 3.3-V rail (V_{OUT1}) requiring 60-mA current (P_{OUT1} = 198 mW). The other two rails are 1.8 V (V_{OUT2}) with 110 mA (P_{OUT2} = 198 mW) and 3.3 V (V_{OUT3}) with 15 mA (P_{OUT3} = 50 mW). So the functional blocks in the camera module in total consume about 450 mW.

In a case linear regulators are used for powering the camera blocks, the input power would be 925 mW if the supply voltage is at 5 V. This would introduce 475 mW additional losses in the camera module. Using a higher supply voltage simply increases the additional losses.

To reduce the additional losses and to be able to benefit from a higher supply voltage to reduce the module supply current in the current example, highly-efficient step-down converters are used for all 3 rails of the camera system. To be able to cover a wide input supply voltage range while still maintaining a small solution size, TPS62170 has been chosen for all 3 rails as a suitable switching regulator.

According to the TPS62170 datasheet (SLVSAG7), in its default configuration at 3.3-V output voltage, it can provide 100-mA output current at 92% efficiency, if the input voltage is 5 V. At an input voltage of 10 V the efficiency is still 85%. For 1.8-V output voltage and 100-mA output current, the efficiency is 86% and at 10 V it is 78%.

Using the efficiency numbers in Equation 2, the required input power for the module would be 500 mW at a 5-V supply and 546 mW at a 10-V supply. This would mean 100-mA supply current at a 5-V input and 55-mA supply current at 10-V input, a significant reduction to the 185 mA required for the linear regulator based solution.

Using Equation 5 gives the required minimum inductance of the converter for the most sensitive rail V_{OUT1} at 5-V input (4.7 µH) and 10-V input (10 µH). For the measurements 10 µH inductors were chosen in all 3 converters to cover all options discussed in this document.

To get good results for output voltage noise of the converters, it is important to select appropriate components for the critical passive components of the step-down converter. Critical components are the capacitor on the input and the output. At the input it is most important to use capacitors which are still behaving like capacitors at the corner frequency of the switching edges of the converter. Those frequencies are in the range of several 100 MHz. It is good practice to use different sizes of capacitors in parallel to achieve filtering at a wide bandwidth. For the inductor, it is important to have a properly shielded structure to avoid interference of the inductor current with other parts of the circuit.

If suitable components are selected, they must be placed and connected properly on the PCB. Guidance for that can be found in the datasheet of the TPS62170 (SLVSAG7) as well as in the PMP9758 reference design documentation.

4 Test Results

Since the configuration of the TPS62170 has changed from the default in the datasheet with the different inductor value, updated measurement data for the efficiency is required. Figure 4 shows the efficiency of the 3.3-V rail at several different input voltages. Figure 5 and Figure 6 show the efficiency for 1.8- and 1.5-V output voltage accordingly. As it can be seen on all the different output voltages, the smaller inductors with the higher inductance value and the lower current rating cause the efficiency to drop slightly compared to the default configuration.

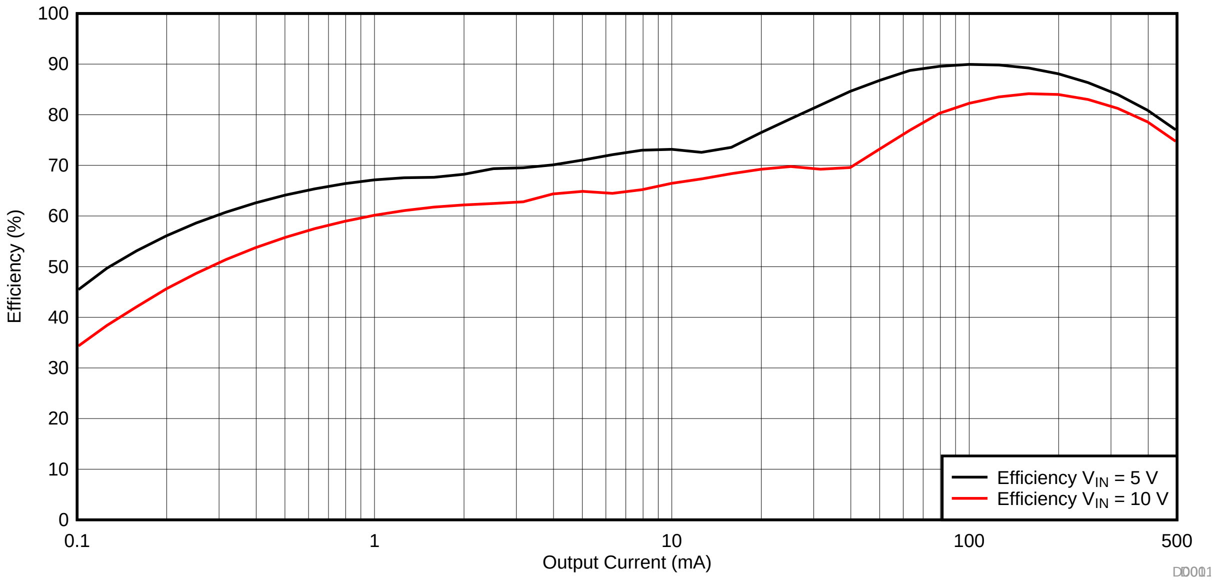

Figure 4. Efficiency vs Output Current V_{OUT} = 3.3 V

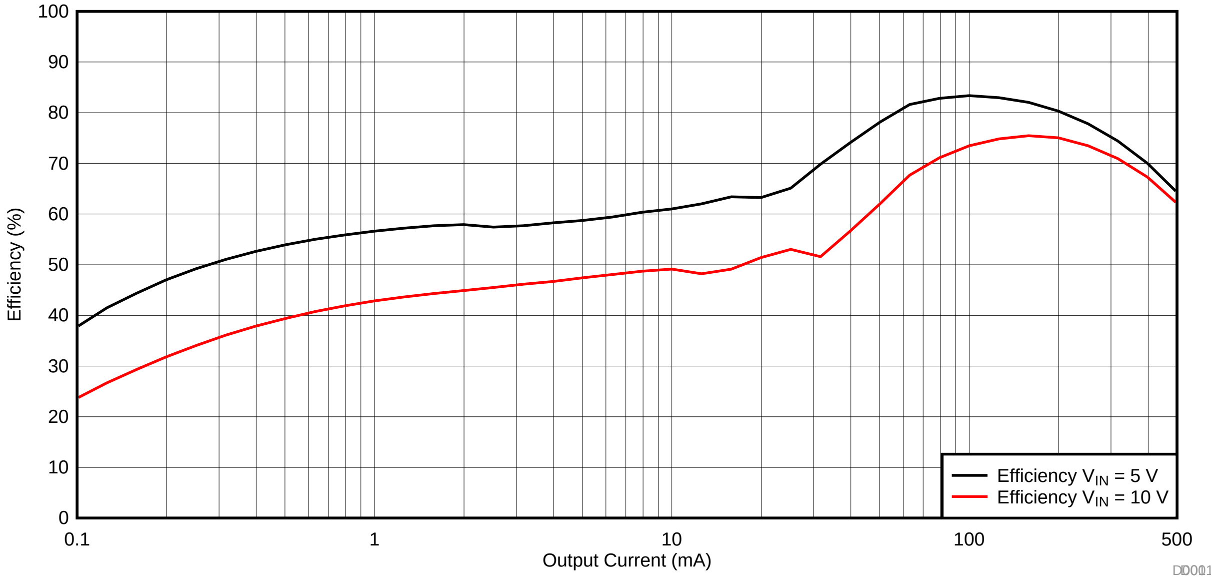

Figure 5. Efficiency vs Output Current V_{OUT} = 1.8 V

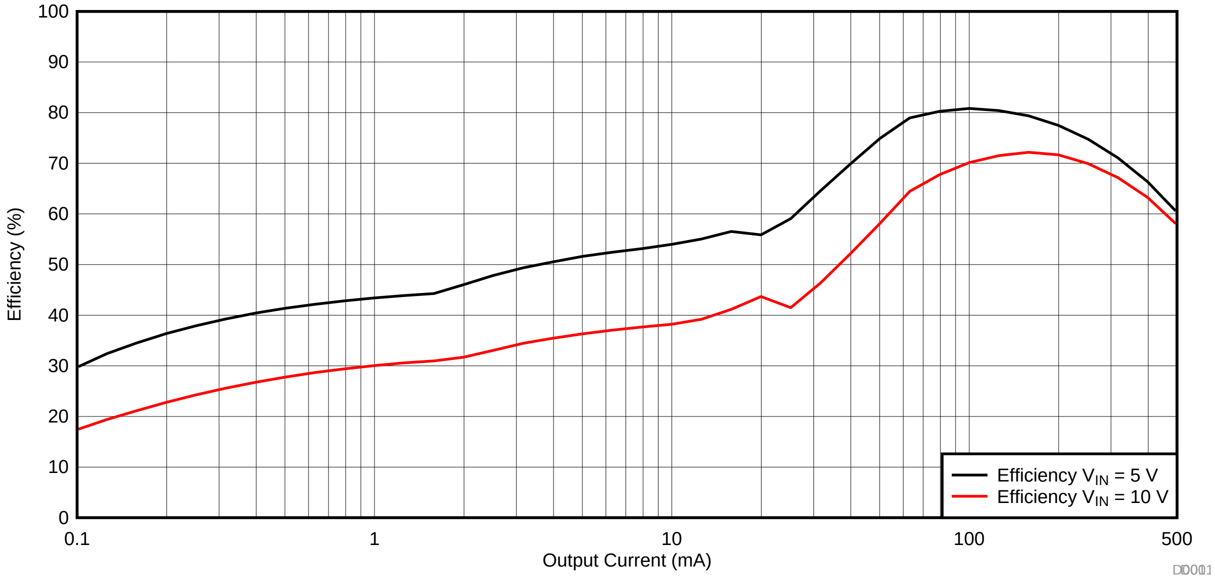

Figure 6. Efficiency vs Output Current V_{OUT} = 1.5 V

As calculated, the inductor current stays continuous at the operating conditions for the high sensitive camera supply rail. Figure 7 shows the measured waveform of the inductor current and the output voltage at the 3.3-V converter while supplying the highly sensitive voltage rail of the camera.

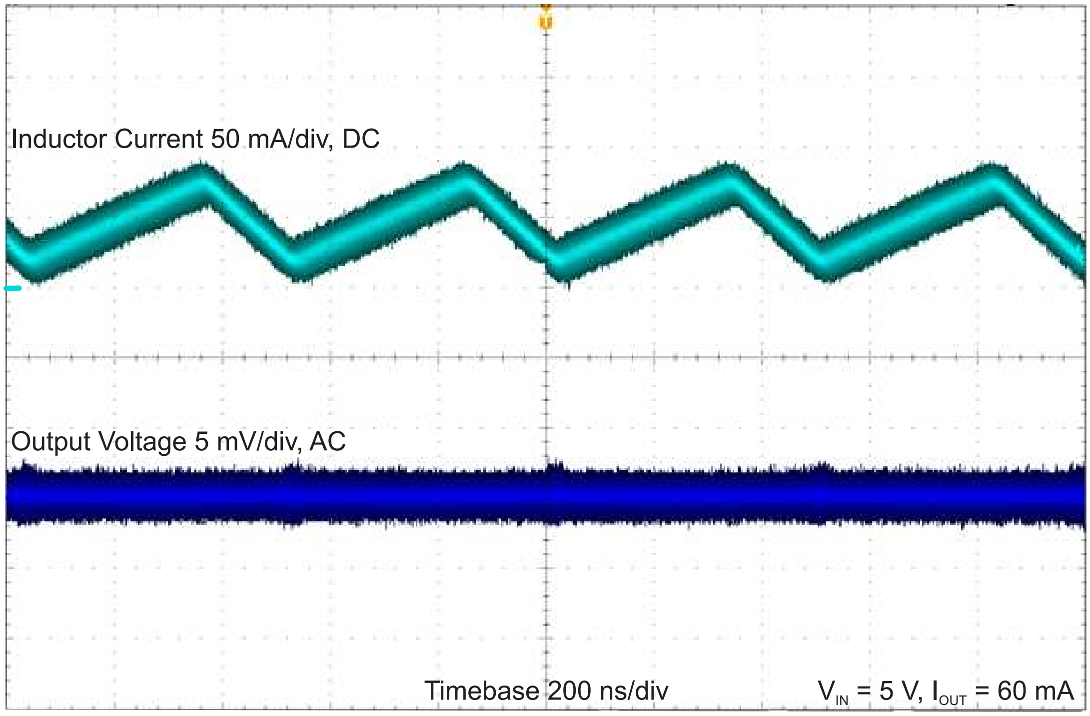

Figure 7. Inductor Current and Output Voltage

Since noise is critical on the 3.3-V rail, the spectrum of the output voltage of the sensitive 3.3-V rail has been measured as well. Figure 8 shows the curve. There is only a small peak with a noncritical level at the switching frequency. The peak is narrow indicating that the switching frequency is stable with a very low amount of jitter.

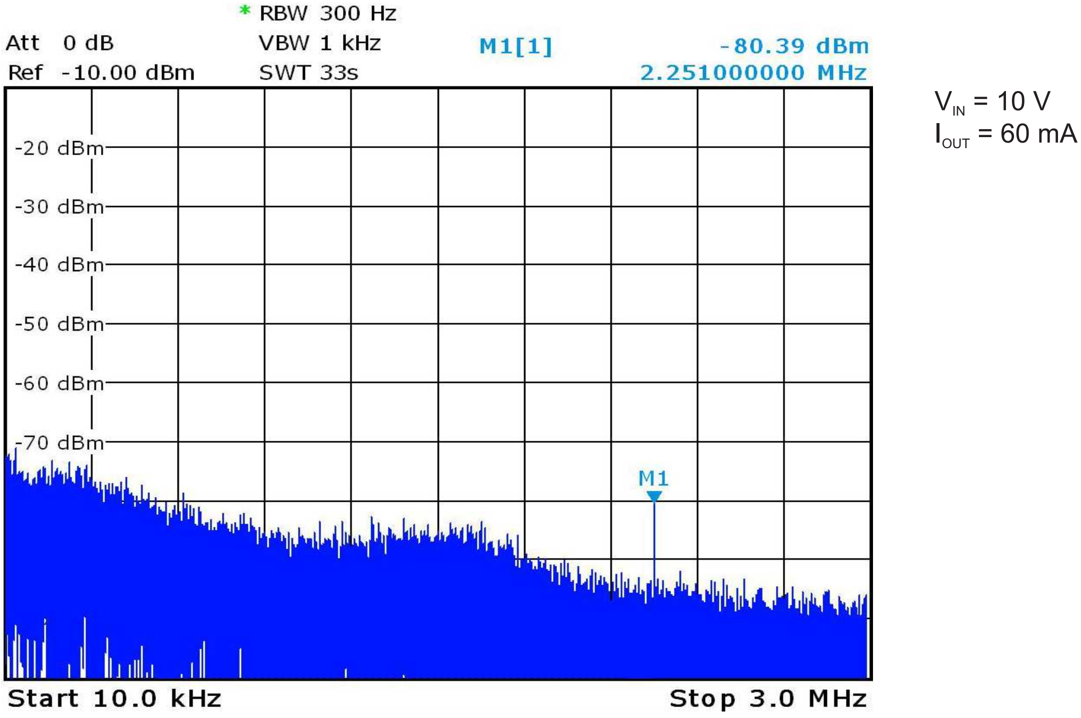

Figure 8. Output Voltage Spectrum

5 Conclusion

This application note is focusing on the parallel structure of the power supply for powering a camera. If appropriate components are available for the desired input voltage range, this is the solution providing the highest conversion efficiency.

In case of the TPS62170, this also includes a very small power supply implementation. The complete supply can be placed on a PCB area of less than 170 mm^2 while still supporting lower cost manufacturing environments. If a wider input voltage range needs to be covered which exceeds the input voltage range and the solution size of the TPS62170 a cascaded power-supply structure may be more suitable to keep the solution small. Lower input voltage converters can have a similar solution size like the TPS62170 or are even smaller. The power conversion efficiency of the total solution will be lower as it can be calculated using the equations provided in Section 2.

In the TI reference design library there are several complete camera power solutions for different camera sensors and different use cases. One example for a camera using a cascaded converter structure is shown in the reference design *Optimized Automotive 1M Pixel Camera Module Design for Uncompressed Digital Video over Coax* (TIDA-00262).

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components 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 such information 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.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265