Bring True-Black and High-Fidelity Colors to Your Automotive TFT-LCD Display

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Abstract

True black and high-fidelity colors in TFT-LCD systems require state-of-the-art system solutions. A 12.3-inch backlight panel that houses a full array of 256 LEDs implements local dimming for true-black using only four chips. A gamma buffer IC delivers 16 voltage references with 10-bit resolution, providing the least amount of gamma variation from panel to panel. A complete TFT bias chip provides the panel with all the necessary rails. Finally, a slew of standby, low-noise, and POL voltage regulators provide the necessary high-voltage and low-voltage rails for a complete TFT-LCD display system solution.

Introduction

With local dimming, deeper blacks and more impressive contrast in the picture are obtained

TFT-LCD displays are ubiquitous in modern cars, from instrument clusters (Figure 1) to center-stacked touchscreens, rear-seat entertainment, and more. With displays playing an increasingly critical role in helping the driver navigate the road, their ability to accurately report information is critical for the safety of car occupants. Concurrently, rear-seat entertainment displays require high-quality images that do not diminish the movie's intended dramatic effects.

While the size and resolution of automotive displays have grown, their electronics have become more complex yet limited in both PCB size and cost. Many examples of increasing complexity are found in the array of power rails that bias the TFT-LCD (thin-film transistor liquid-crystal display) panel, the multiple voltage references for gamma correction and the backlight power.

One shortcoming of traditional LCD displays has been the use of edge-lit backlights. Since the backlight LEDs are located along the edges of the panel, the LEDs cannot be completely turned off because PWM is set globally. This will make the display not truly black but dark gray.

New LCD displays solve the problem by reengineering the backlight, from edge-lit to full-array LEDs (Figure 2). Now the LEDs are uniformly distributed along the panel surface and each LED, or a small zone comprised of a few LEDs (one to four), can be individually controlled from full luminosity to full darkness. With local dimming, deeper blacks and more impressive contrast in the picture are obtained. In turn, they consume a large amount of power, requiring careful power management implementations that maximize the LED driver's efficiency in conjunction with powerful regulated power sources.

Figure 1. Local dimming for true black display.

In this white paper, we see how a novel local dimming LED driver IC provides a high-contrast and high-dimming ratio, high current, high accuracy, low EMI, and a small solution size. A gamma buffer IC delivers 16 voltage references with 10-bit resolution, providing the least amount of gamma variation from panel to panel with low offset error at low cost. A complete TFT bias IC includes a current-mode boost converter, two push-pull charge-pump drivers and a VCOM buffer driving the LCD backplane. Finally, a slew of standby, low-noise and POL voltage regulators provide the necessary high-voltage and low-voltage rails for a complete TFT-LCD display system solution.

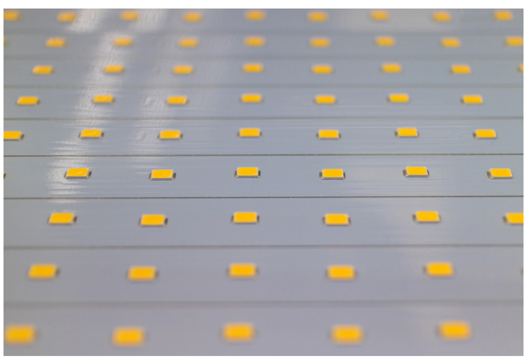

Figure 2. A detailed view of a full-array backlight LED panel.

The TFT-LCD Display System

The standard display used in automotive systems is the active-matrix color TFT-LCD which has become ubiquitous due to its high brightness, high resolution, reasonable cost, and demonstrated reliability in the challenging automotive environment. Liquid crystals have the ability to change their transmissivity with applied voltage. Each sub-pixel in an active-matrix TFT-LCD display receives its bias voltage (which sets its transmissivity) through a TFT transistor that acts as a switch. A pixel is made up of three sub-pixels, one for each of the primary colors: red, green, and blue. Figure 3 shows the main elements of the TFT-LCD display. The local dimming driver IC (LED BACKLIGHTING) drives the backlight LEDs. The TFT BIAS powers the source and gate drivers and the Gamma buffer, while all the power sequencing is driven by a microcontroller. A number of ancillary voltage regulators (HL/LV LDOs, HV/LV DCDC) provide the necessary intermediate voltage rails.

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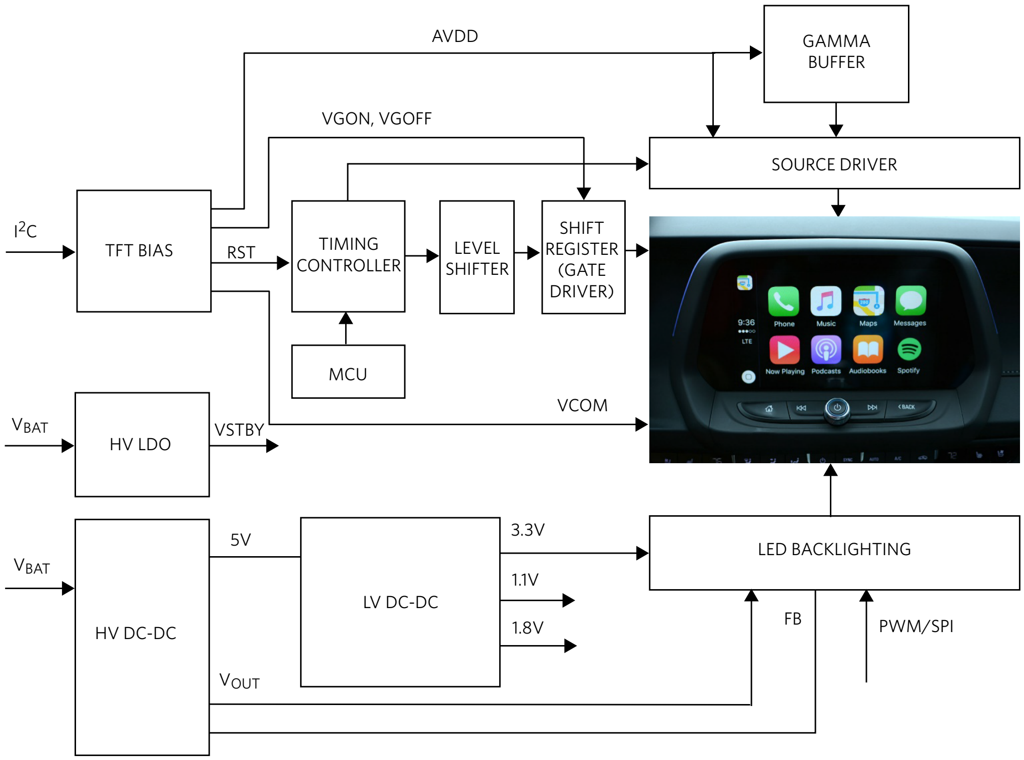

Figure 3. A block diagram of a TFT-LCD display power system.

Full-Array Backlight Example

As an example, a 12.3-inch instrument cluster display backlight panel is populated with a matrix of 256 LEDs. By dividing the 256 LEDs into 64 four-LED zones, local dimming can be accomplished with only four 16-channel LED driver ICs. A 2s2p configuration of four LEDs in a zone assures string continuity even if one diode in each parallel element is open. Each diode has a maximum drop of 3.5V and a mismatch between diodes of ±50mV.

One of 16 channels is shown in Figure 4. The MOSFET/op amp/resistor ensemble is the current sink that powers the 2s2p LED string, which can be dimmed with a switch via the op amp (OA) or shutoff. Two comparators provide overvoltage (V_{THH}) and short-to-ground protection (V_{THL}). The minimum channel output voltage V_{OUT} (OUT16 in Figure 4) is 0.8V.

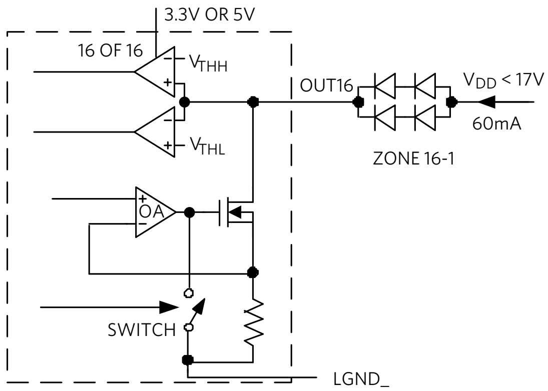

Figure 4. A diagram of an LED driver showing one of 16 channels.

Local dimming can be accomplished with only four 16-channel LED driver ICs

Each IC must operate under different conditions, including dissipating the power associated with 16 channels operating all at once. As an example, the IC has a junction-to-ambient thermal resistance (R) of 29°C/W with T_A = +85°C. V_{DD} must be set as low as possible and accommodate a ±50mV mismatch between diodes. In a worst case, the 2s mismatch will be 100mV.

The worse-case scenario for power dissipation is if one single 2s2p diode string develops a 7V drop while the other 15 develop 6.9V. If the DC-DC output is set to 7.9V, then V_{OUT} will be at 0.9V (0.1V above $V_{OUT(MIN)}$ = 0.8V) and all the other 15 channels will be at 1V. Accordingly, the worst-case power dissipation is:

$$P = (15 \times 1 + 0.9) \times 60mA = 0.954W$$

The IC junction temperature is well below our 150°C limit:

$$T_J = T_A + R \times P = 85 + 29 \times 0.954 = 112.7°C$$

A feedback output pin (FB in Figure 5) is necessary to control the external DC-DC converter so that voltage headroom can be optimized, and the overall system power dissipation reduced.

Integrated Backlight Driver Solution

As an example, the **MAX21610** is a 16-channel modular backlight driver for use with automotive displays (Figure 5). The integrated current outputs can sink up to a 100mA LED current, depending on the ambient temperature. Device power comes from an external 3.3V or 5V supply, while the LED current-sink outputs can operate up to 17V. The global LED current for all strings is set through a serial peripheral interface (SPI), with individual PWM settings for each of the channels. Up to 10 devices can also be daisy-chained to reduce connection complexity. The IC is available in a 5mm x 5mm, 32-pin TQFN package and operates in the -40°C to +125°C temperature range.

The backlight driver's integrated current outputs can sink up to a 100mA LED current, depending on the ambient temperature

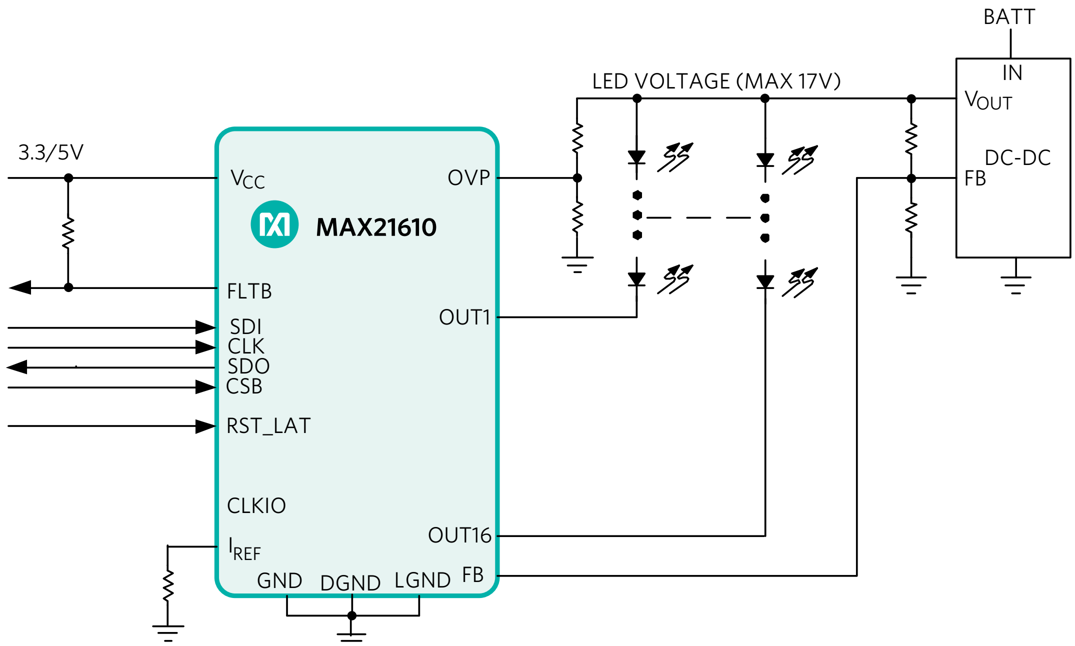

Figure 5. Backlight local dimming application diagram.

When mounted on a four-layer board, the junction-to-ambient thermal resistance is a low 29°C/W, allowing for power dissipation in excess of 2W. A 15-bit dimming ratio allows for up to 32,768 PWM dimmings steps at 200Hz, which achieves the high dynamic range (HDR) display specification. Other important features of this IC include open and short LED string detection and protection, overvoltage protection, thermal warning, and thermal shutdown. Spread spectrum and channel phase-shifting minimize EMI, while a 1% current-setting accuracy yields high color fidelity. Local dimming increases display contrast by making the black look deeper.

High Current DC-DC Converter

The DC-DC converter in Figure 5 can be implemented with **MAX20006**, a small, synchronous, automotive buck converter device with integrated high-side and low-side MOSFETs (Figure 6). The device can deliver up to 6A with input voltages (SUPSW, SUP) from 3.5V to 36V, while using only 25µA quiescent current at no load. The state of the output voltage can be monitored by observing the active-low RESET signal. The device can operate in dropout by running at 98% duty cycle, making it ideal for automotive applications. The IC is housed in a small 3.5mm x 3.75mm, 17-pin FC2QFN package.

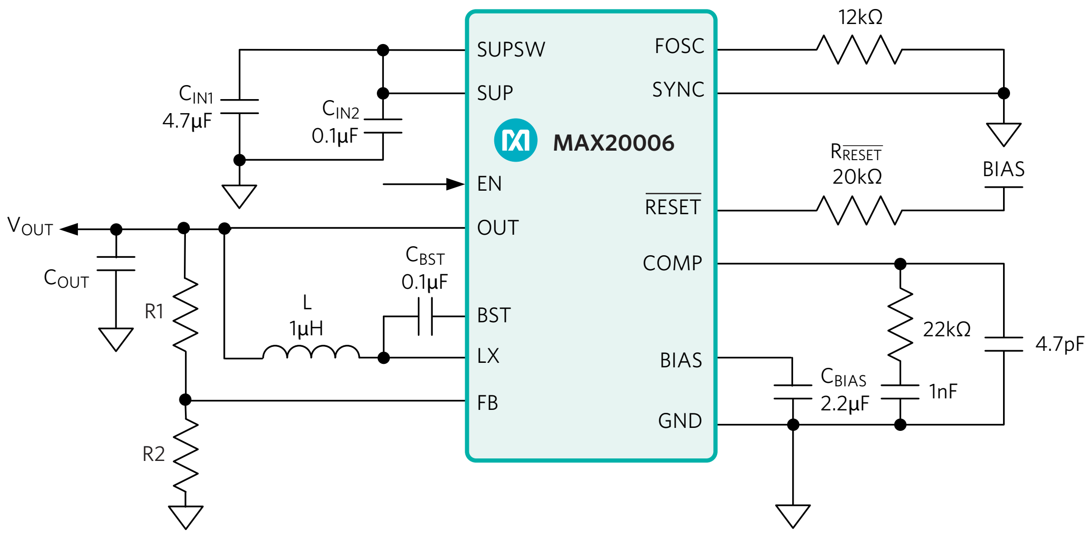

Figure 6. A high-current and high-voltage buck converter.

With the car battery power varying from less than 6V to 16V, the best topology is the buck-boost

High-Power Buck-Boost Controller

With the car battery power varying from less than 6V (warm crank) to 16V, the best configuration for delivery of intermediate voltages and high power is the buck-boost controller (Figure 7). Here only one inductor is utilized, versus a buck + boost that need two inductors. Additionally, small solution size and lower BOM cost is achieved with high-frequency operation up to 2.2MHz in a small 4mm x 4mm 24-pin TQFN-EP SW package. For efficiency and flexibility, this device has synchonous rectification and a low I_Q of 55μA, and its output is adjustable from 4V to 25V or is a fixed 5V. It has pin-selectable spread spectrum for better EMI performance and both a sync-in and sync-out pin which allow for dual-phase operation when using multiple devices. For robust performance, both the enable and input pin can support 40V operation. Another great feature is a $V_{IN(MIN)}$ of 2V after startup that handles severe cold-crank operation. The IC operates from -40°C to 125°C ambient and 150°C junction.

A standby voltage regulator connects directly to the battery and has ultra-low quiescent current and wide input voltage operation

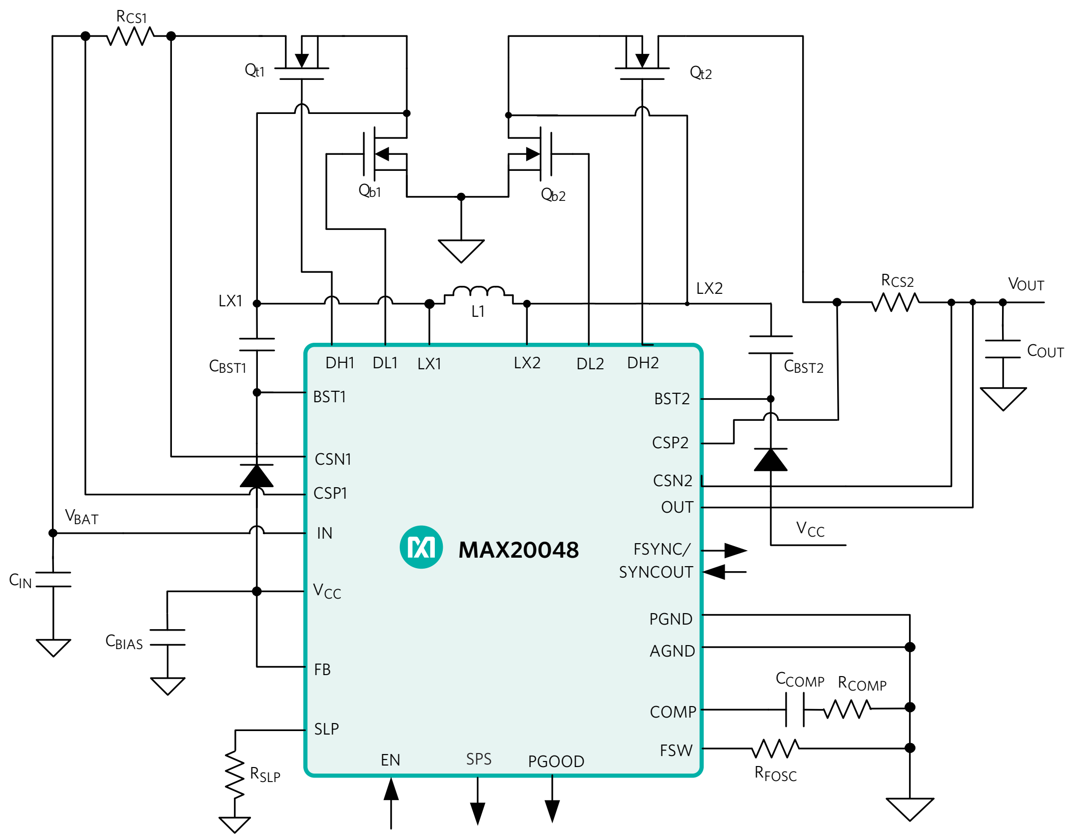

Figure 7. High-power buck-boost controller.

Standby Voltage

A standby voltage regulator connects directly to the battery and has ultra-low quiescent current and wide input voltage operation. The **MAX16910** linear regulator is ideal for use in automotive and battery-operated systems (Figure 8). The device operates from a 3.5V to 30V input voltage, delivers up to 200mA of load current, and consumes only 20µA of quiescent current at no load. A 10kΩ resistor between SETOV and OUT is recommended if line transients are expected to be faster than 0.03V/µs. The device is available in a space-saving, thermally enhanced, 3mm x 3mm, 8-pin TDFN package and a 5mm x 4mm, 8-pin SO package.

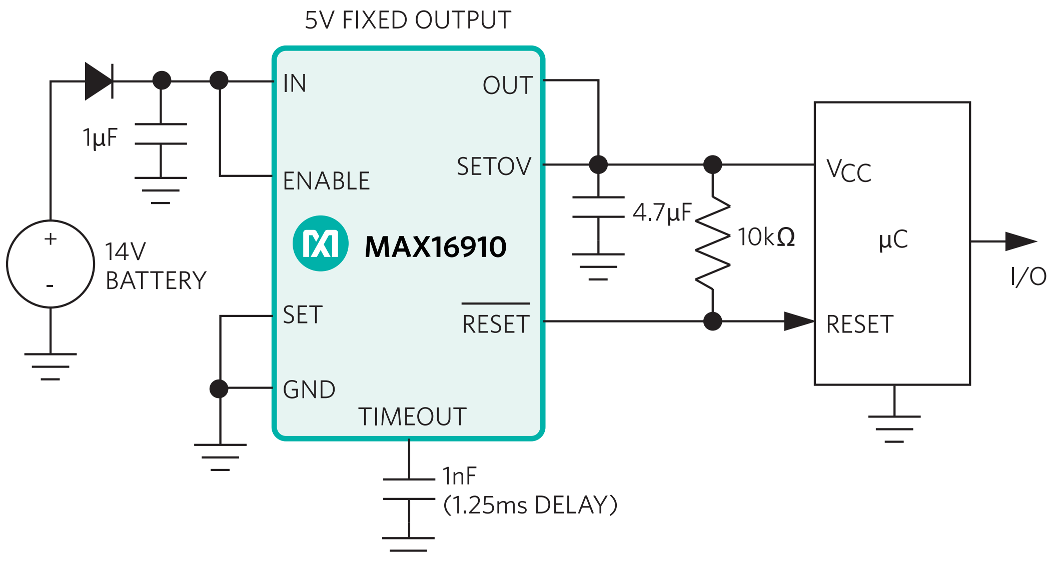

Figure 8. Ultra-low quiescent current and wide input voltage LDO.

Gamma Buffer

While backlight local dimming is necessary for true-black display, gamma correction includes the full range of colors perceived by the human eye. Gamma correction of a digitally encoded image consists of allocating the available bandwidth according to the nonlinear perception of light and color by the human eye. The **MAX9669** outputs 16 voltage references for gamma correction in TFT-LCDs and one voltage reference for VCOM (Figure 9). Each gamma reference voltage has its own 10-bit digital-to-analog converter (DAC) and buffer to ensure a stable voltage. The VCOM reference voltage has its own 10-bit DAC and an amplifier to ensure a stable voltage when critical levels and patterns are displayed. The IC features integrated multiple time-programmable (MTP) memory to store gamma and VCOM values on the chip, eliminating the need for external EEPROM. It supports up to 100 write operations to the on-chip nonvolatile memory. The gamma outputs can drive 200mA peak transient current and settle within 1µs. The VCOM output can provide 600mA peak transient current and also settles within 1µs. The analog supply voltage range extends from 9V to 20V, and the digital supply voltage range extends from 2.7V to 3.6V. Gamma values and the VCOM value are programmed into registers through the I^2C interface. The IC is housed in a 5mm x 5mm, 28-pin TQFN package.

Gamma correction allocates the available bandwidth according to the nonlinear perception of light and color by the human eye

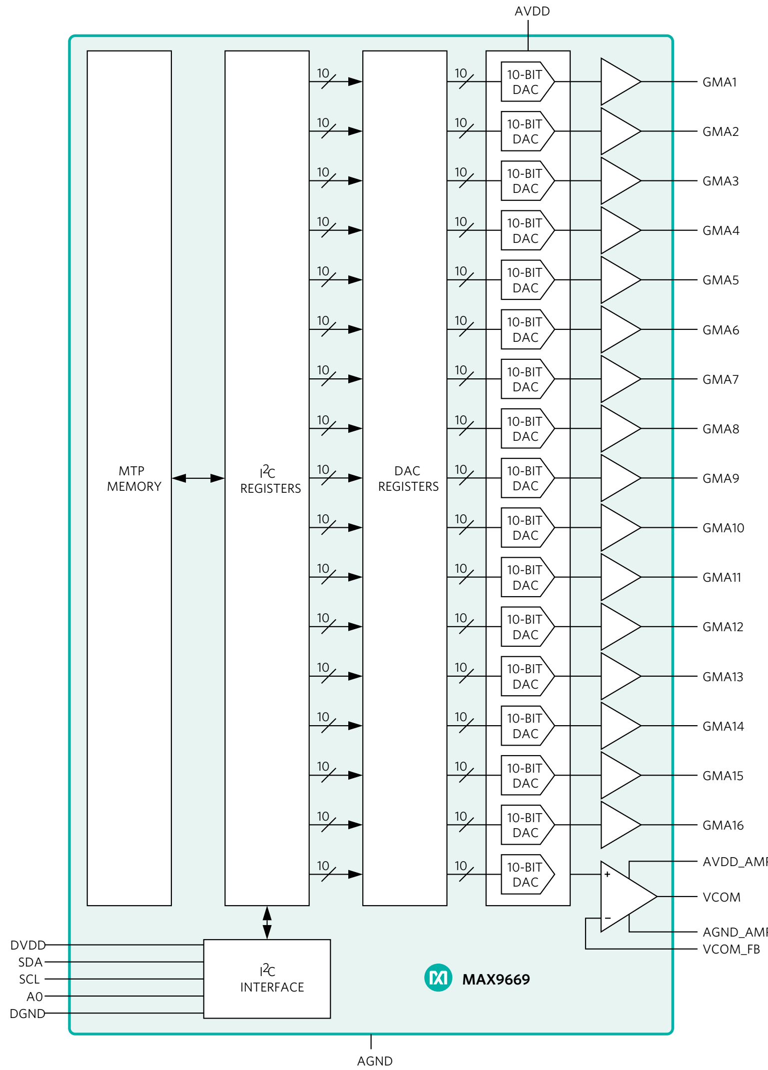

Figure 9. Gamma buffer and VCOM solution.

TFT Bias

The TFT bias provides the several voltage rails needed by the LCD display. As an example, the **MAX20067** 3-channel display bias IC is a complete TFT bias solution for automotive applications (Figure 10). It includes a current-mode boost converter (HVINP) and two push-pull charge-pump drivers (VGON and VGOFF). The IC also includes a gate-shading push-pull level shifter that can be used to improve display uniformity (when needed), and a DAC and VCOM buffer. All blocks on the IC can be used in stand-alone mode or through the I^{2}C interface. The MAX20067 is available in a 4mm x 4mm, 32-pin TQFN package.

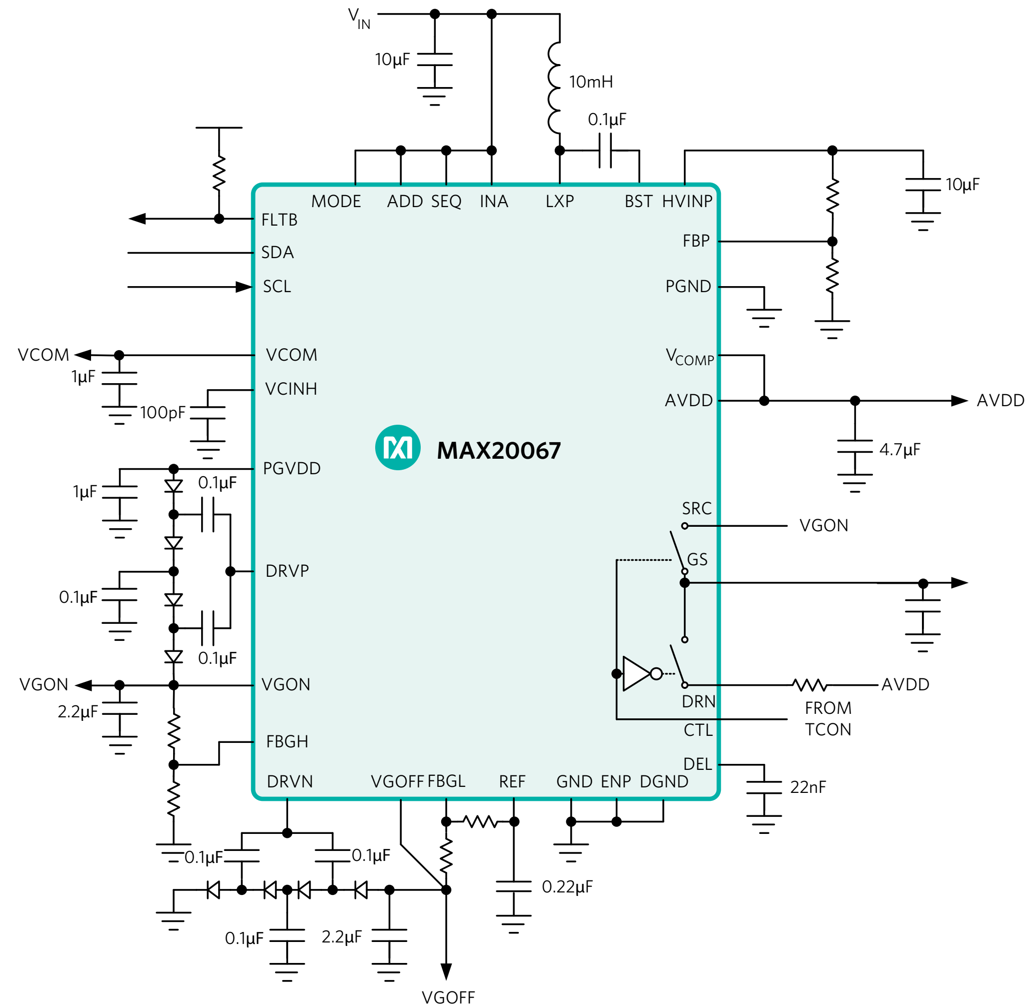

Figure 10. A TFT 3-channel bias IC for automotive solutions.

The TFT bias provides the several voltage rails needed by the LCD display

Another highly integrated TFT bias chip is the **MAX25221**. The four-channel IC includes symmetrical positive AVDD and negative NAVDD supplies as well as VGON and VGOFF gate supplies. It has a VCOM buffer range below ground and a temperature measurement block that can measure the temperature optionally allowing the VCOM output voltage to be adjusted depending on the measured temperature (Figure 11). Programming is carried out using the built-in I^2C interface which can also be used to read back diagnostic information. A stand-alone mode is available after the device has been programmed. The IC is housed in a compact, 5mm x 5mm, 32-pin TQFN package. We also have **MAX25222** device available, which is an ASIL B version of MAX25221.

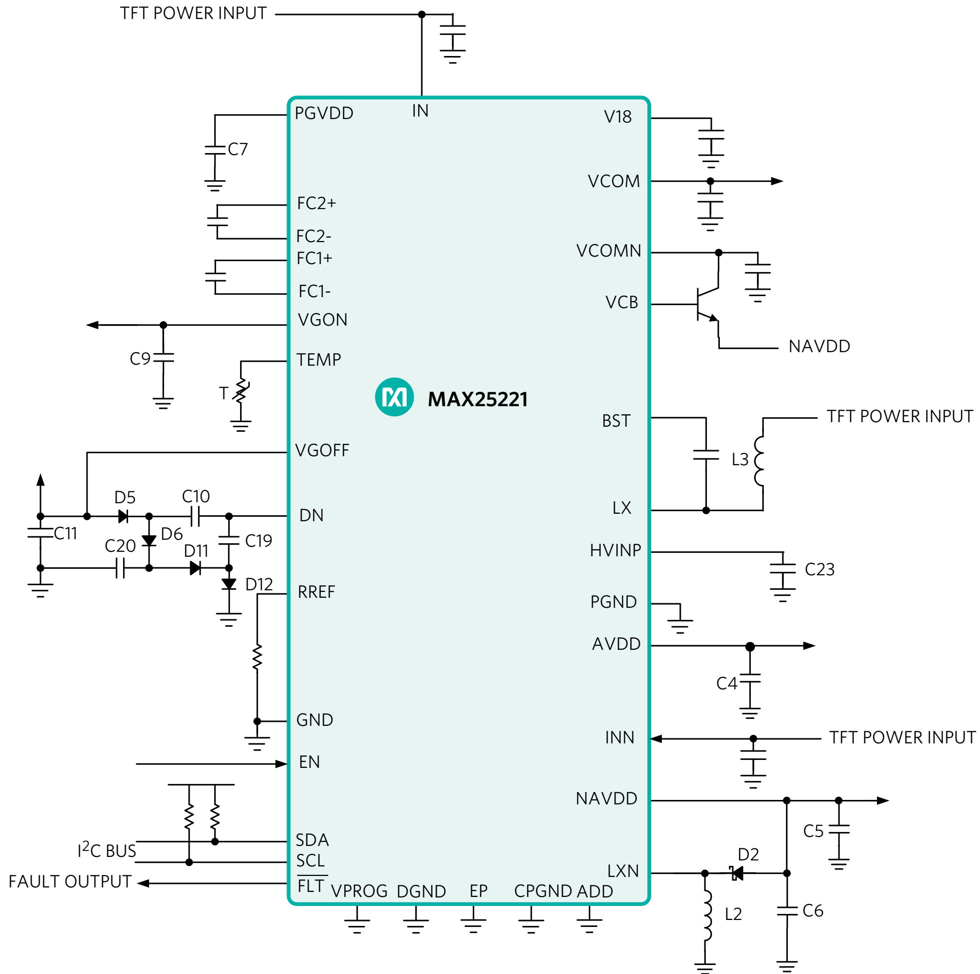

Figure 11. TFT 4-channel bias solution.

Low-Voltage, High-Efficiency POLs

The backlight local dimming system requires several low-voltage, high-efficiency, point-of-load (POL) voltage regulators. The **MAX20416** is a high-efficiency, dual-output, low-voltage DC-DC converter. The synchronous step-down converters operate from a 3.0V to 5.5V input voltage range and provide a 0.8V to 3.8V output voltage range up to 3A. The buck converters achieve ±1.5% output error over line, load, and temperature range.

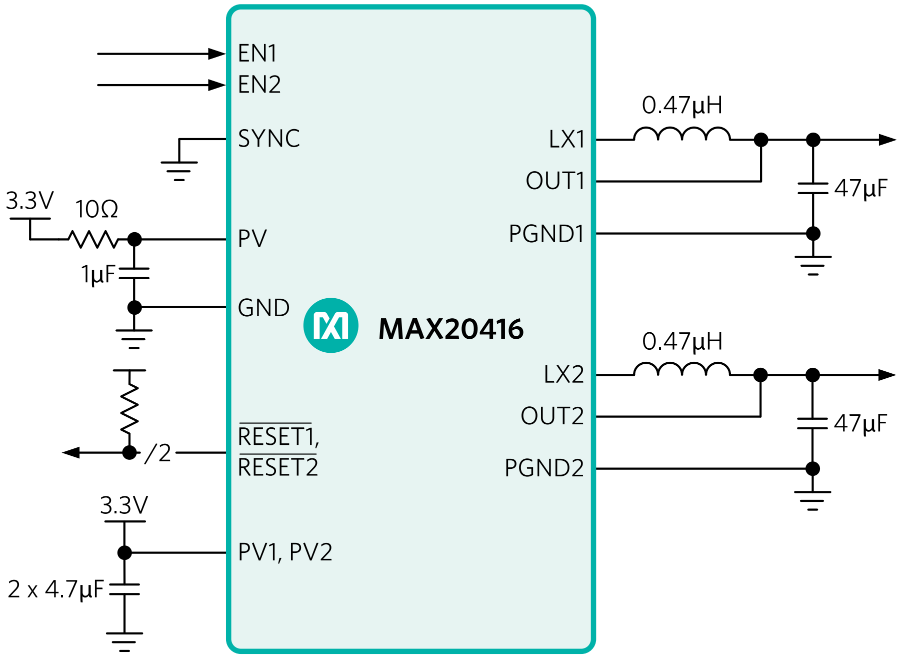

Figure 12. Dual POL voltage regulator IC.

The backlight local dimming system requires several low-voltage, high-efficiency, point-of-load (POL) voltage regulators

Low-Noise LDO

The **MAX8902A**/**MAX8902B** low-noise linear regulators deliver up to 500mA of output current with only 16µV_{RMS} of output noise in a 100kHz bandwidth. These regulators maintain their output voltage over a wide input range (1.7V to 5.5V), requiring only 100mV of input-to-output headroom at full load. These LDOs maintain a low 80µA typical supply current, independent of the load current and dropout voltage. The regulator control circuitry includes a programmable soft-start circuit and short circuit, reverse current, and thermal-overload protection. Other features include an enable input and a power-OK output (MAX8902B only). The MAX8902A output voltage can be set to 1.5V, 1.8V, 2.0V, 2.5V, 3.0V, 3.1V, 3.3V, 4.6V, or 4.7V using the SELA and SELB inputs. The MAX8902B output voltage can be set between 0.6V and 5.3V with an external resistor voltage-divider.

An LDO provides low-noise voltage regulation

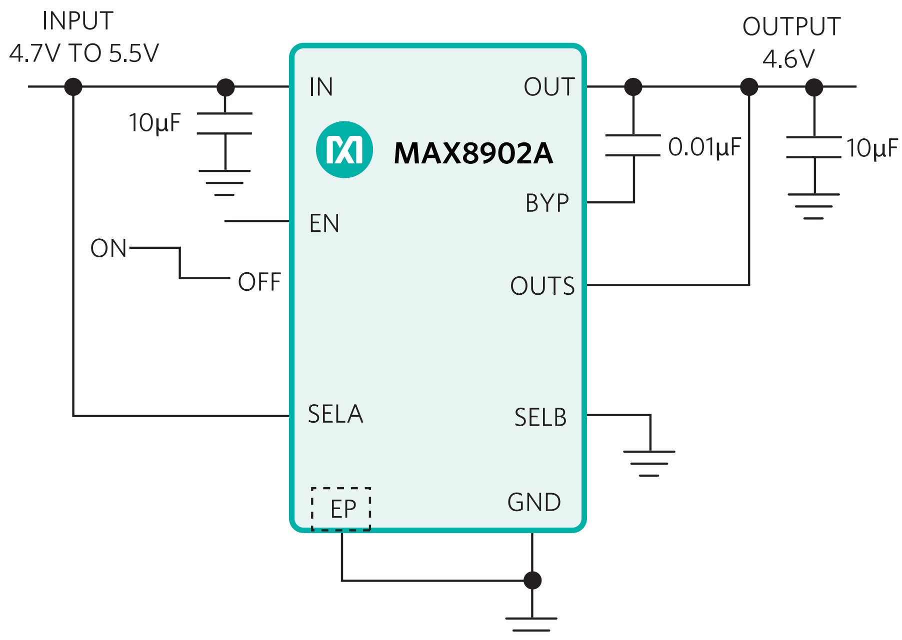

Figure 13. Low-noise LDO application diagram for 100mV headroom minimum operation.

Conclusion

Automotive TFT-LCD displays require true-black and high-fidelity colors. The search for true, deep black in LCD displays is driving the transition from edge-lit to full-array LED backlights. In this white paper, we showed that a 12.3-inch LCD display backlight panel, populated with an array of 256 LEDs, can be effectively driven with just four daisy-chained LED driver ICs. Low IC and PCB thermal resistance assure maximum power delivery capability. A feedback loop that connects the LED driver ICs and a DC-DC voltage source that powers the LED strings assure proper voltage headroom to the four LED drivers' output. This helps minimize the overall system power dissipation. The backlight solution is complemented by a Gamma buffer that delivers 16 voltage references with 10-bit resolution. The TFT bias IC and a slew of standby, low-noise, and POL voltage regulators provide the necessary high-voltage and low-voltage rails for a complete TFT-LCD display system solution that delivers true black and high-fidelity colors.

Summary

Figure 14 shows a state-of-the-art backlight local dimming system solution using Maxim ICs.

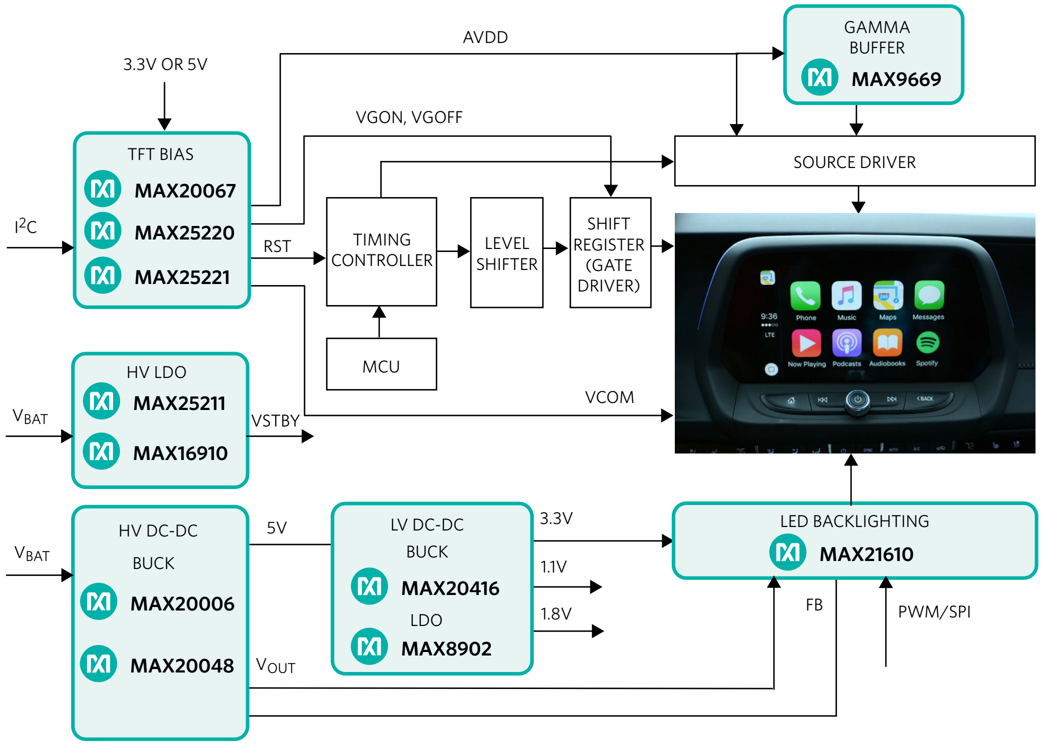

Figure 14. Backlight local dimming system solution.

Learn More

MAX21610 Automotive 16-Channel 100mA Local Dimming Backlight Driver with SPI Interface

MAX20004/MAX20006/MAX20008 36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Automotive Step-Down Converters

MAX20048 Automotive 40V, 55µA I_Q, 2.2MHz, H-Bridge Buck-Boost Controller

MAX16910 200mA, Automotive, Ultra-Low Quiescent Current, Linear Regulator

MAX9669 10-Bit Programmable Gamma Reference System with MTP for TFT LCDs

MAX20067 Automotive 3-Channel Display Bias IC with VCOM Buffer, Level Shifter, and I²C Interface

MAX25220/MAX25221 Automotive 4-Channel TFT-LCD Power Supply with VCOM Buffer

MAX20416 2.2MHz Dual-Output, Low-Voltage Step-Down Converters

MAX8902A/MAX8902B Low-Noise 500mA LDO Regulators in a 2mm x 2mm TDFN Package

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