

APPLICATION NOTE 1845

Choosing the Right DC-DC Converter for Automotive Applications

Abstract: Choosing the right DC-DC converter for automotive applications can be a challenging task when one considers all the requirements that need to be met. Power management in automobiles has come a long way from being the ubiquitous load-dump-protected 5V linear regulator. This article provides an insight into what is required in some common automotive applications and provides solutions.

Introduction

Power-supply requirements for automotive applications can be complex. Designs may have nonstandard restrictions imposed by the nature of the automotive environment and call for a large number of output voltages. This article reviews some of the special cases encountered in automotive applications and suggests some starting-point designs.

Table 1 lists a set of system requirements for an in-car infotainment-system power supply. Each requirement will be examined. Circuit details are available in the identified product data sheets.

Table 1. Power-Supply Requirements for In-Car Infotainment System

System Requirements	Reason	Suggestions
Multiple output voltages: 1.9V, 2.5V (0.3A to 0.5A), 5V, 3.3V (0.3A to 1A), 8V, 9V (0.3A to 3A)	μP (core, I/O), CD/DVD drive, tuner module, alarm, GPS system, displays	Combination of switching and linear regulators
Wide input-voltage range: 3.5V to 28V, depending upon the car manufacturer's requirements	Cold-cranking causes unwanted system reset. Load dump and battery jumping require protection from high voltage	Buck-boost converter
Low quiescent current: < 300μA	Prevents battery drain from standby systems when car ignition is off	Idle Mode™ operation for high-efficiency at light loads
Low noise	EMI interferes with radio reception and video displays	Fixed frequency or linear post regulators
Low cost	Carmaker requirement	Low parts count and/or system solution

5V/3.3V Outputs

This requirement can be conveniently implemented with the dual buck synchronous regulator of **Figure 1**. The [MAX1634](#) is an appropriate IC, as it is capable of operation with input voltages up to 30V to satisfy the high-input-voltage-range requirement.

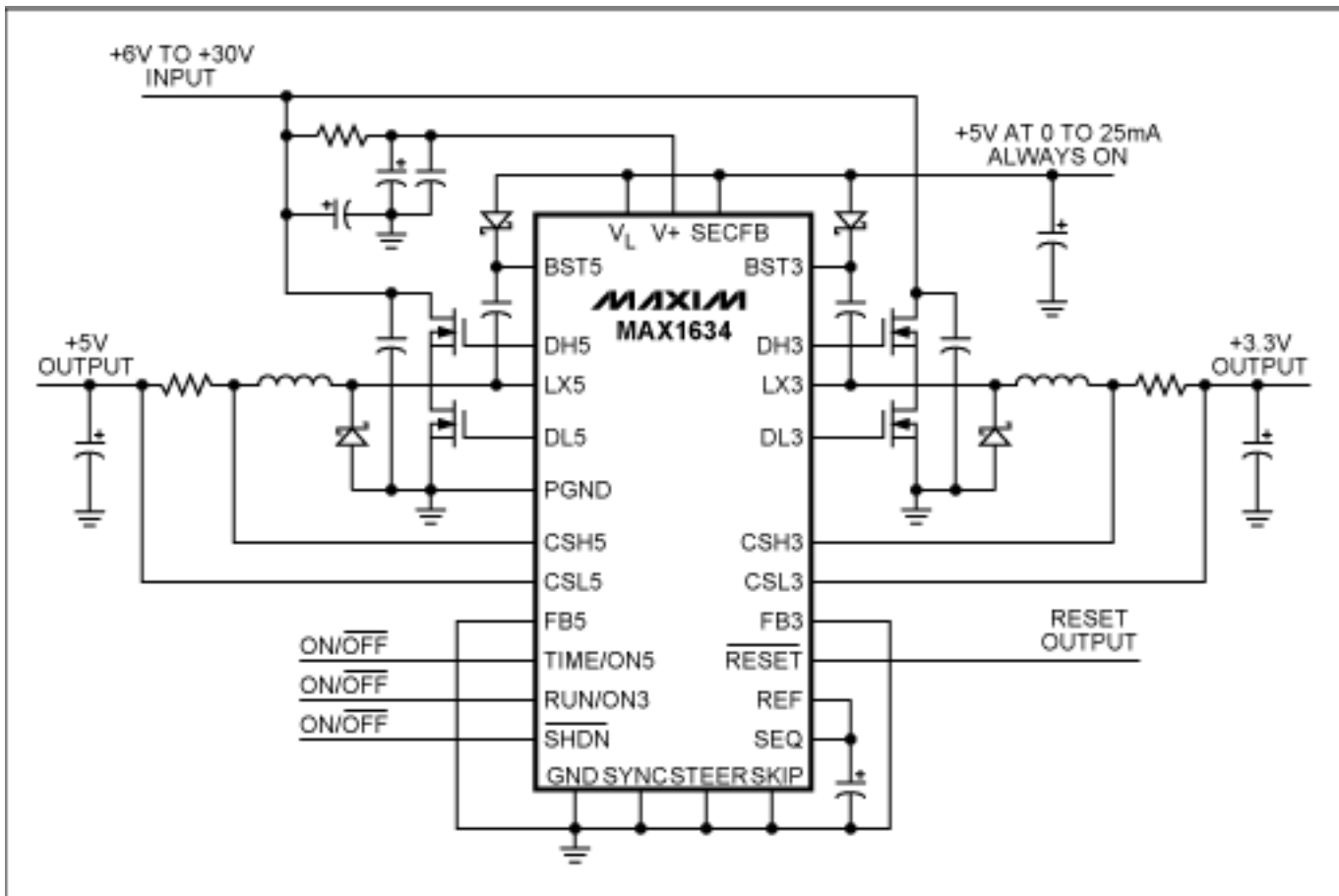


Figure 1. Circuit for implementing 5V and 3.3V with a dual buck regulator.

Low Noise and Quiescent Current

The MAX1634 operates at a constant frequency, making it easy to filter out switching noise. It offers external synchronization, which can be advantageous when selectively tuning the switching frequency to minimize RF interference. The average noise may also be reduced by dithering the synchronizing frequency. At very light loads, in which noise is usually not a problem, the MAX1634 switches automatically to a pulse-frequency modulation (PFM) mode of operation. In this mode, the power switches are turned on only when the output voltage drops out of regulation. The quiescent current in this case becomes so low that the 300 μ A idle-current requirement is easily met. In special cases where the switching frequency must remain constant despite light-load conditions, the SKIP pin on the MAX1634 can accomplish this. For minimum standby current, either output may be individually disabled, or the part may be placed in shutdown mode by a microprocessor after completing certain tasks.

For circuits or components sensitive to sudden changes in load or input voltage (noise may be noticeable on a video panel while displaying a white screen), linear post regulators may be used to further reduce switching noise. A ripple-rejecting regulator like the [MAX1857](#) is suitable for output currents to 500mA. Generally, for currents above 1A, it is worth optimizing the PCB layout or adding secondary filters to reduce switching regulator noise.

8V Outputs

The 8V outputs can be addressed either by using coupled inductor windings on the MAX1634 or by using a separate switching regulator. The use of synchronous rectifiers in this output-voltage range is unprofitable because they contribute little to overall efficiency for their additional cost. The standard buck converter of **Figure 2** may be a better choice—the [MAX1745](#) with an external logic-level pFET has very low quiescent current, uses few external components, occupies less space, and costs less than does an equivalent synchronous buck-regulator circuit. Its wide input-voltage range (achieved by using a variable-frequency mode), high efficiency,

and low quiescent current make this part ideal for automotive applications.

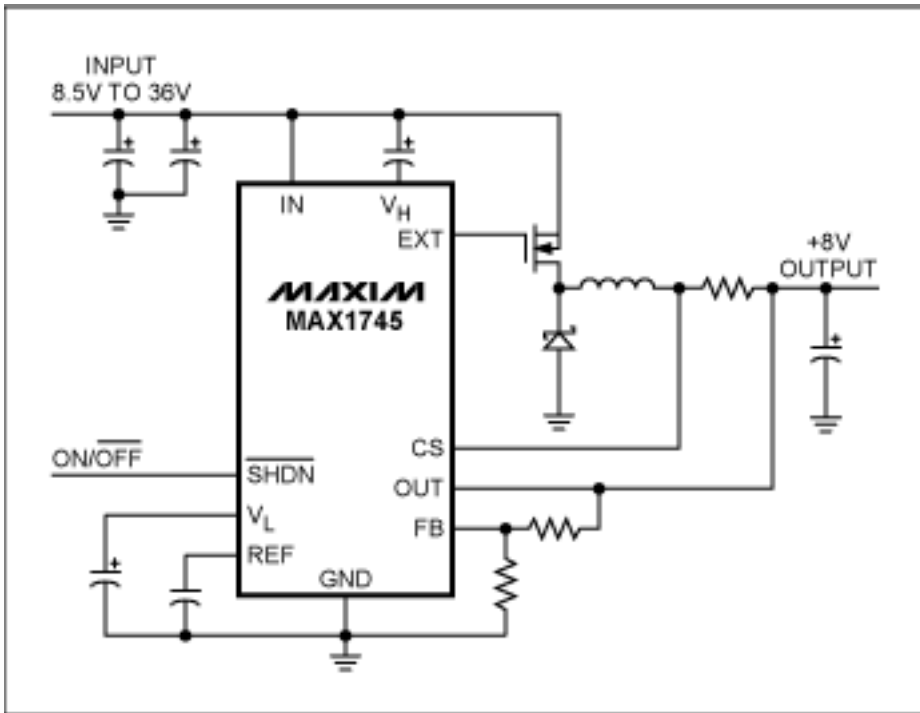


Figure 2. Circuit for implementing output voltages above 5V.

3.5V Input

The 3.5V input-voltage requirement is a troublesome one, as one may be tempted to use a buck-boost topology to create the higher output voltages. However, before doing this, the merits of such a converter should be examined.

The buck-boost topology in its simplest form (see **Figure 3**) produces an inverted output voltage. A very popular buck-boost circuit, which requires more components but produces a noninverting output, is the single-ended primary-inductance converter (SEPIC) of **Figure 4**. Both of these converters have the limitation that the capacitors in the power path must pass a very high ripple current as compared to that in the output capacitor in a buck converter operating at the same load. Because the current through SEPIC capacitors is always discontinuous, the resultant large RMS capacitor current causes high power dissipation. The current through their buck-converter counterparts, on the other hand, is continuous in most applications. As a rule of thumb, SEPIC converters are practical only for output currents typically below 2A, regardless of the output voltage.

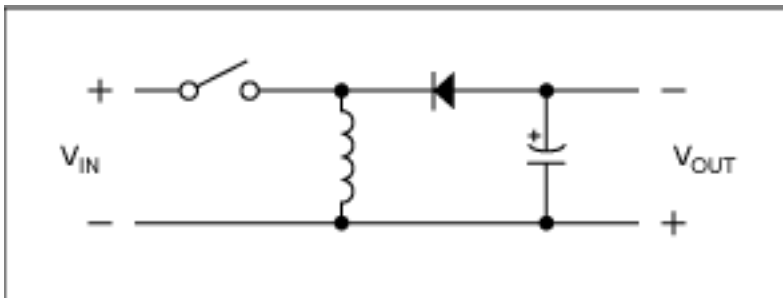


Figure 3. Basic buck-boost converter topology.

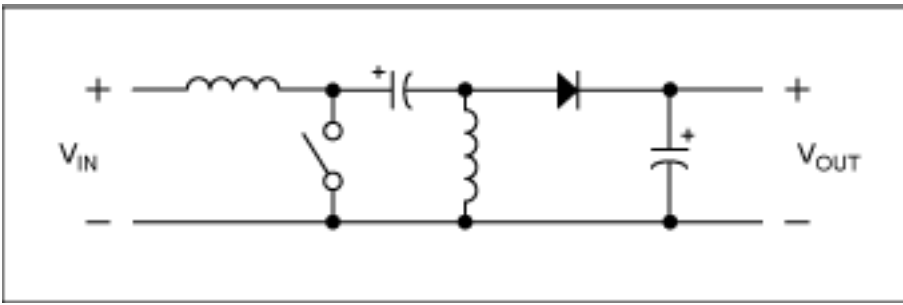


Figure 4. The SEPIC topology.

In solving the low-input-voltage problem, it is well worth determining which parts of the entire infotainment system are required to be functional during cold-cranking conditions. A driver attempting a winter cold start is likely to be less concerned with CD-player operation than he is with the actual cold-start performance. On the other hand, a user would find it unacceptable if the system were reset to the point where program settings must be re-entered. In other words, only the critical components of the system (microprocessor, RAM) need be operational during this short period of low input voltage, as opposed to noncritical components like the CD drive. Because the critical components usually represent a load of no more than 100mA to 200mA, one can simply add an auxiliary boost DC-DC converter ahead of the main buck converter block as shown in **Figure 5**. The [MAX1523](#) is a good choice for this auxiliary output; in this circuit, it only turns on only when the input voltage to the main buck stage drops below its set regulation point of, for example, 9V. Otherwise, it remains off. The typical quiescent current of the MAX1523 is only 25 μ A.

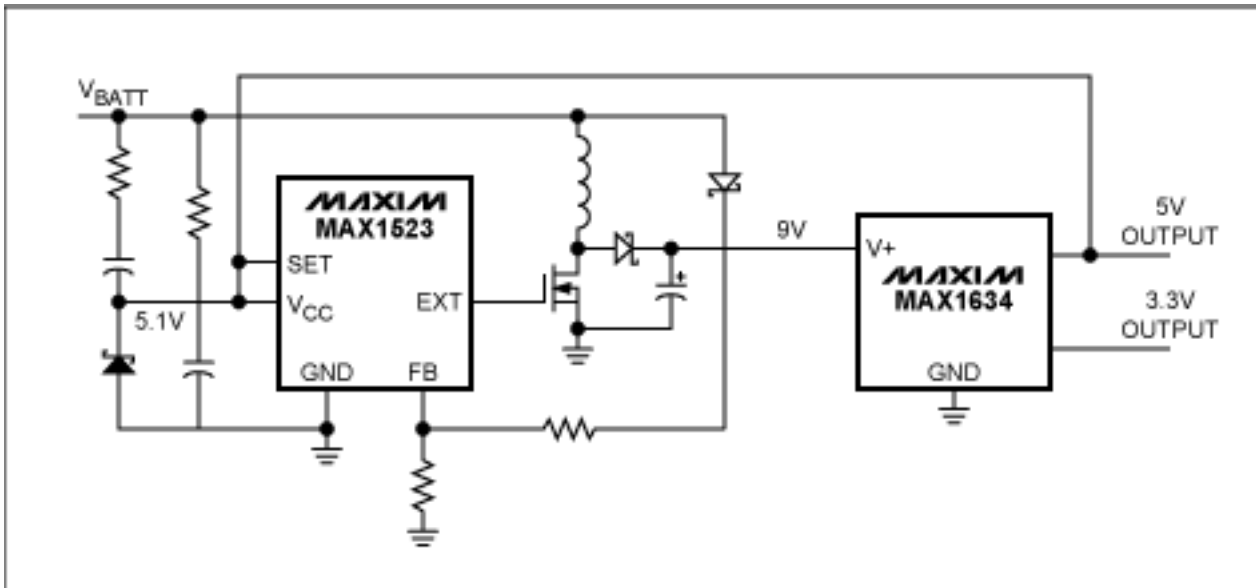


Figure 5. Cold-cranking conditions can be met by adding a low-input-voltage-enabled boost stage ahead of the main buck converter.

1.9V and 2.5V Outputs

The 2.5V and 1.9V outputs can be implemented using linear regulators like the [MAX1806](#) for up to 500mA or a [MAX8881](#) for up to 200mA. If a lower output voltage such as 1.5V is required, efficiency can be improved by deriving the linear regulator's input voltage from the next higher output voltage (1.9V in this case). The MAX1983 low-dropout (LDO) linear regulator is recommended in this application; note that it requires a 5V bias input, which is readily available in this and most every infotainment system.

For higher currents or higher efficiency, one can use a dual buck regulator like the [MAX1845](#) as shown in **Figure 6**, or the similar [MAX1844](#) single-output regulator. These regulators operate with a constant-on-time current-mode control in which valley current is accurately sensed to provide a well-controlled current limit. Finally, it is recommended to derive the lower voltages from either 5V or 3.3V instead of the car-battery voltage because these, like most switching regulators, are limited by minimum duty-cycle constraints to no more than an approximately 10:1 range between input and output voltage. Note that these converters, like the [MAX1983](#), also

require a 5V bias supply.

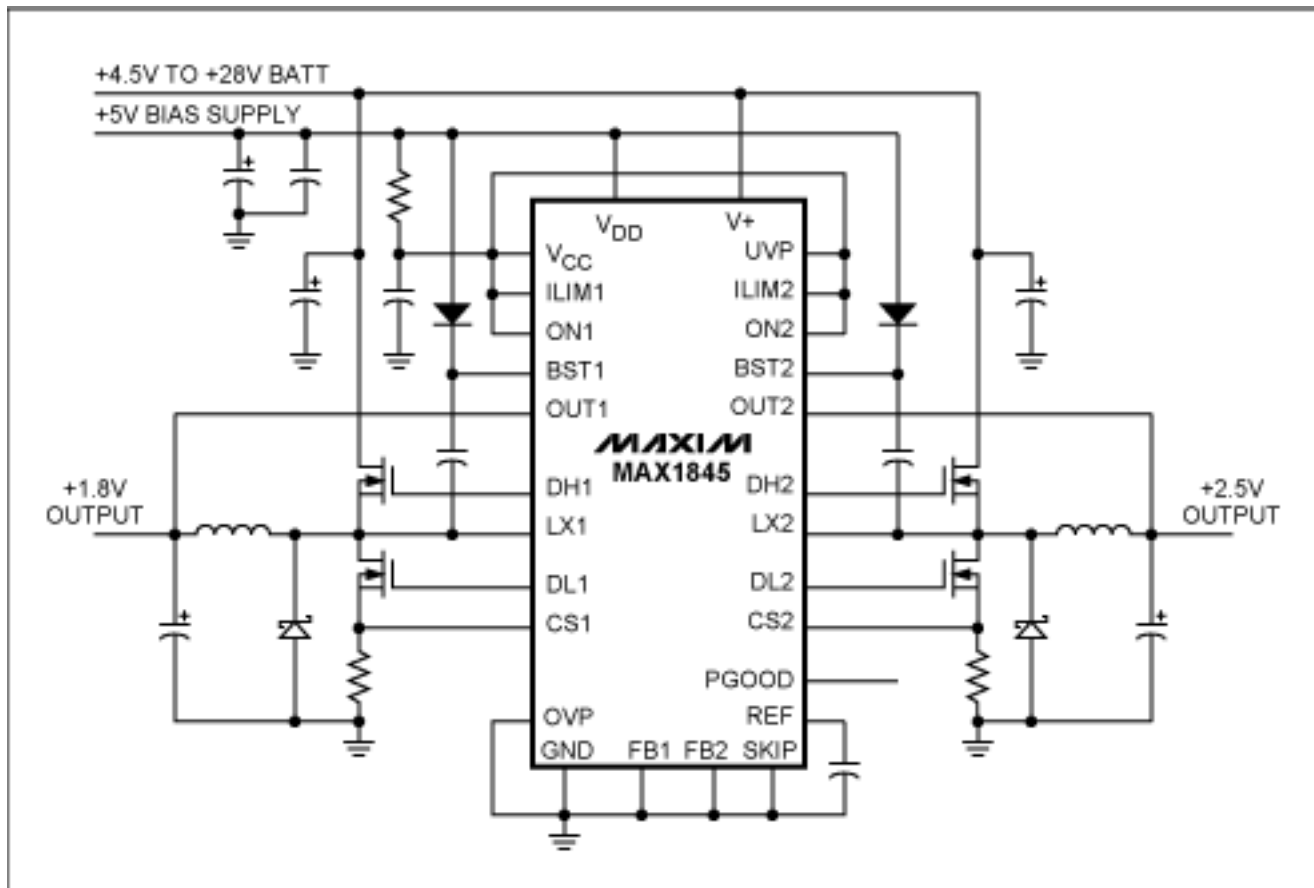


Figure 6. Controller for generating low output voltages with very-high efficiency.

42V Battery Systems

Some newer automobiles include additional batteries either as redundant sources of energy or auxiliary energy sources to help optimize power management. The 42V battery has long been considered as a possible substitute to the 12V battery. Using the 42V battery would result in new system requirements, as shown in **Table 2**.

Table 2. 42V Battery System Requirements

System Requirements	Reason	Suggestions
$18V < V_{IN} < 58V$, $V_{OUT} = 5V, 3.3V$ with various loads	42V battery system	Step-down switching regulator
Quiescent current $< 100\mu A$	To prevent battery drain from standby systems when car ignition is OFF	Controller with quiescent current under $100\mu A$
High efficiency	Heat reduction	Switching regulator

When stepping 42V down to 5V and below at currents greater than a couple of amperes, a standard buck converter cannot be used in a practical sense. To generate a 5V output from a 42V input, the switching waveforms would look very much like the waveforms seen in a typical buck converter with its output shorted. This is because the ratio of the output to the input voltage is equal to the converter's duty-cycle min/max range. There is very little control range left in order to reduce the duty cycle any further when the input voltage increases to its maximum of 58V, let alone a case in which a short occurs on the output during a worst-case condition. The inherent propagation delays in the control IC impose a minimum duty cycle on a converter IC operating in constant frequency. The only way to work around this problem is to slow down the switching frequency, thus turning the problem around into one of reducing controller EMI. Last but not least, a short duty-cycle utilizes the switching element very poorly. For these and other reasons, it is recommended to use either a two-stage buck converter, or a transformer-coupled single-stage converter. The duty-cycle range of a two-stage

converter is split between the two stages, but the number of external components is doubled. Thus, a transformer-coupled converter is a better choice; isolation is not required, so the coupling between the windings can be optimized for minimum leakage inductance.

Low Quiescent Current

The quiescent-current requirement imposes a severe limitation in the choice of converter. There is a limited choice of DC-DC converters in the market with $< 100\mu\text{A}$ quiescent-current levels. The MAX1523 in **Figure 7** is a good choice because it can meet the above requirements with a quiescent current of under $100\mu\text{A}$. This converter operates with variable frequency, but its high frequency and its small size allows the switching noise to be confined to a small area of the board.

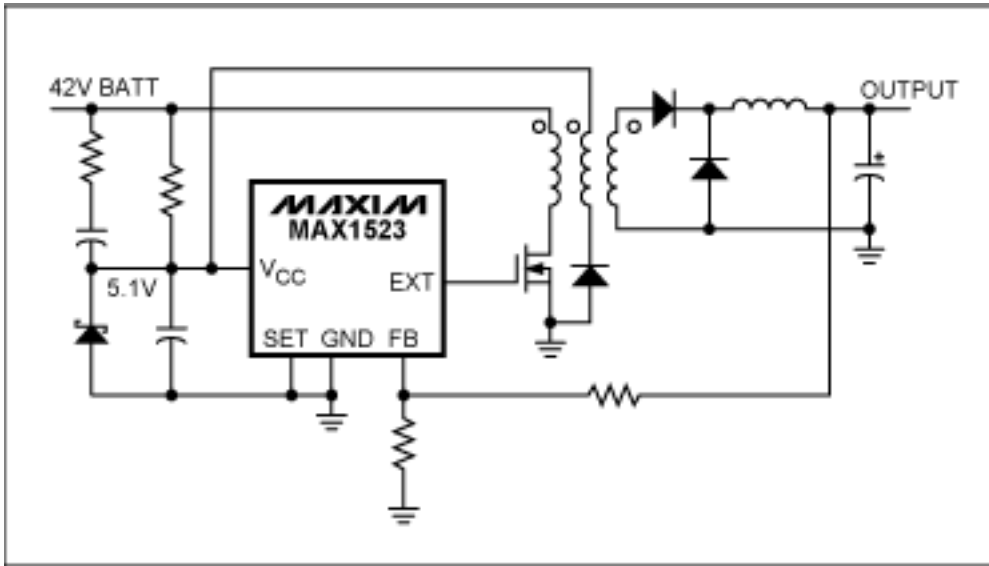


Figure 7. Using a transformer for 42V battery systems.

High Efficiency

The high-efficiency requirement imposes another severe constraint to the choice of regulator—it virtually eliminates the use of linear regulators. Linear regulators containing a MOSFET pass element usually exhibit a very low quiescent current. Their use may be practical for currents of below 10mA, although the power/price performance ratio becomes very low. Maxim offers linear regulators that can withstand up to 80V and provide shutdown for better control of power management. They can be used for RTCs, SRAMs, alarm system detection circuits, and other circuits that require very small amounts of current to operate. Such devices include the [MAX6765–MAX6774](#) automotive micropower linear regulators that include overtemperature and short-circuit protection.

Electrochrome Glass

Electrochrome glass has the ability to adjust the amount of light passing through it when you apply a DC voltage across it. This type of glass is currently used in rear-view mirrors, and may eventually be used in sunroofs and car windows. At the time of this writing, the requirements were as given in **Table 3** and may vary significantly from one glass manufacturer to another. A combination of two synchronous regulators can be used to meet the output requirements. **Figure 8** shows a practical implementation using the MAX1634. One output is fixed at 3.3V while the other is made variable from 2.8V to 5.3V through a [MAX5468](#) 32-tap FleaPoT™. (For a nonvolatile digital potentiometer, refer to the [DS1804](#). For a higher-frequency upgrade to the MAX1634, please refer to the [MAX1904](#).)

Table 3. Electrochrome-Glass Power Requirements

Requirement	Reason	Suggestion
$-0.5V < V_{OUT} < 2V$ at 5A	Requirements of the glass	Synchronous buck

Displays

There are many variances in displays, depending on the LCD manufacturer. Today's display market in automobiles is dominated by LCDs, as in the CCFL lamps that provide most of today's background lighting. The unique requirements for this application are perfectly addressed by the [DS3881](#) single-channel and [DS3882](#) dual-channel CCFL inverter controllers. Newer generation LCDs will have LED backlighting, as LEDs are more environment friendly and their cost is decreasing. Maxim offers a wide selection of LED drivers for this application. The [MAX868](#) regulated inverting charge pump is well suited where a negative voltage is required.

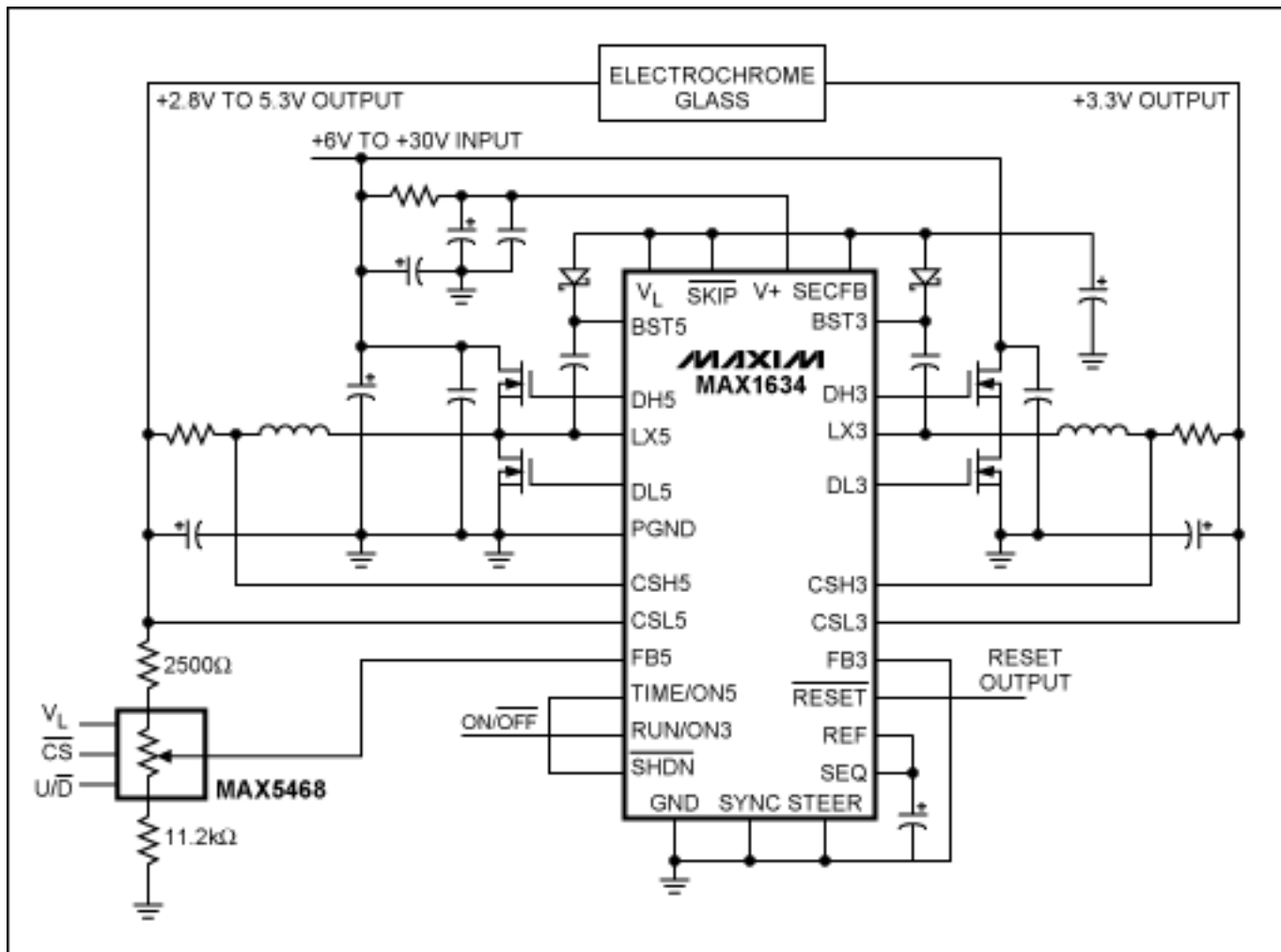


Figure 8. The MAX1634 converter is adjustable from $-0.5V$ to $+2.0V$ for V_{OUT} .

Summary

This article has addressed some of the common stumbling blocks encountered in automotive applications and has proposed solutions. Where a single supply is required, the IC manufacturer's product selector guide is a good place to look for the right part. It is important to reconsider the reasons given here as to why some circuits are not able to perform correctly in an application despite being the likely choice at first sight.

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Application Note 1845: <http://www.maxim-ic.com/an1845>

More Information

For technical questions and support: <http://www.maxim-ic.com/support>

For samples: <http://www.maxim-ic.com/samples>

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Related Parts

MAX1523: [QuickView](#) -- [Full \(PDF\) Data Sheet](#) -- [Free Samples](#)

MAX1634: [QuickView](#) -- [Full \(PDF\) Data Sheet](#) -- [Free Samples](#)

MAX1745: [QuickView](#) -- [Full \(PDF\) Data Sheet](#) -- [Free Samples](#)

MAX1763: [QuickView](#) -- [Full \(PDF\) Data Sheet](#) -- [Free Samples](#)

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MAX1844: [QuickView](#) -- [Full \(PDF\) Data Sheet](#) -- [Free Samples](#)

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