# Constant Frequency, Synchronous, Triple Output DC/DC Converter 

## DESCRIPTIOn

Demonstration circuit board DC125 is a 200 kHz , constantfrequency, triple-output, 2\% tolerance power supply using a low noise dual switching regulator controller. A $5 \mathrm{~V} / 4 \%$ accurate standby internal regulator capable of powering external system wake-up circuitry is also available and active when the switching controllers are shut down. The first two outputs are set for $5 \mathrm{~V} / 3 \mathrm{~A}$ and $3.3 \mathrm{~V} / 3 \mathrm{~A}$ and the third output is a low noise $12 \mathrm{~V} / 200 \mathrm{~mA}$ linear regulator powered from a secondary winding of the 5 V output. Refer to the LTC ${ }^{\circledR}$ 1438/LTC1439 and LTC1538-AUX/LTC1539 data sheets for other possible configurations. A secondary feedback input to the first controller guarantees 12 V Ioad regulation regardless of the load on the primary 5 V output.

The controllers operate at a constant frequency until the output current falls to less than $10 \%$ of rated current, thereby providing low sporadic noise operation. This feature minimizes audible or unpredictable radiation. Burst Mode ${ }^{\text {TM }}$ operation is invoked below $10 \%$ of rated load to maximize efficiency at low currents. The controller can operate at up to $99 \%$ duty cycle for very low dropout conditions. The demonstration board operates on an input supply of from 5.2 V to 28 V , but 12 V output power is limited at low input voltages. Gerber files for this circuit board are available. Call the LTC factory.

[^0] Burst Mode is a trademark of Linear Technology Corporation.

## PGRFORMANCE SUMmARY

(continued on page 3) Operating temperature range $0^{\circ} \mathrm{C}$ to $50^{\circ} \mathrm{C}$.

| PARAMETER | CONDITIONS | LIMITS |
| :--- | :--- | ---: |
| Input Voltage Range | Input Voltage Limited by External MOSFET Drive and Breakdown Requirements | 5.2 V to 28 V |
| Outputs | Output Voltage: Controller 1 (J1 to J6) | $5 \mathrm{~V} \pm 0.10 \mathrm{~V}$ |
|  | Output Voltage: Controller 2 (J5 to J8) | $3.3 \mathrm{~V} \pm 0.08 \mathrm{~V}$ |
|  | Max Output Current (Continuous): 5V Output | 3 A |
|  | Max Output Current (Continuous): 3.3V Output | 3 A |
|  | Typical Output Ripple at 10MHz BW (Continuous): $I_{0}=1 \mathrm{~A}, 3.3 \mathrm{~V}$ and 5 V Outputs; $\mathrm{V}_{\mathrm{IN}}=10 \mathrm{~V}$ | 20 mV P-P |
| Frequency | C $_{\text {OSC }}=56 \mathrm{pF}$, PLLIN Open | 200 kHz |
| Line Regulation | $\mathrm{V}_{\text {IN }}=6 \mathrm{~V}$ to 20V: 3.3V/5V Outputs | $\pm 5 \mathrm{mV}$ |
| Load Regulation | $I_{0}=0.01 \mathrm{~A}$ to 3A: 3.3V/5V Outputs | -30 mV |

## TYPICAL PERFORMANCE CHARACTERISTICS AND BOARD PHOTOS



Front


Back


## PACKAGE ARD SCHEmATIC DIAGRAMS



## PGRFORMANCE SUMMARY

(continued from page 1)

| PARAMETER | CONDITIONS | LIMITS |
| :--- | :--- | ---: |
| Supply Current | $\mathrm{V}_{\text {IN }}=15 \mathrm{~V}, 5 \mathrm{~V} / 3.3 \mathrm{~V}$ On, 12V Off, EXTV ${ }_{\text {CC }}=\mathrm{V}_{0 \text { OT1 }}$ | $320 \mu \mathrm{~A}$ |
| Shutdown Current | $\mathrm{V}_{I N}=15 \mathrm{~V}$, RUN/SS1 and RUN/SS2 $=0 \mathrm{~V}$ | $70 \mu \mathrm{~A}$ |
| 5 V Standby Voltage | $\mathrm{V}_{I N}=15 \mathrm{~V}$, RUN/SS1 and RUN/SS2 $=0 \mathrm{~V}$ | $5 \mathrm{~V} \pm 0.2 \mathrm{~V}$ |
| $\mathrm{~V}_{12 \mathrm{~V}}$ | SW2B in the ON Position; $\mathrm{I}_{\text {LOAD }}=0.1 \mathrm{~mA}$ to 100 mA | $12 \mathrm{~V} \pm 5 \%$ |

## PARTS LIST

| REFERENCE DESIGNATOR | QUANTITY | PART NUMBER | DESCRIPTION | VENDOR |
| :---: | :---: | :---: | :---: | :---: |
| C1 | 1 | 6SL150M | 150uF 6.3V 20\% OS-CON Capacitor | Sanyo |
| C2, C10, C13, C15, C20 | 5 | 08055A102KAT1A | 1000pF 50V 20\% NPO Capacitor | AVX |
| C3 | 1 | 08055A560JAT1A | 56pF 50V 5\% NPO Capacitor | AVX |
| C4 | 1 | TAJC335M035R | 3.34F 35V 20\% Tantalum Capacitor | AVX |
| C5 | 1 | TAJC106M025R | 10¢F 25V 20\% Tantalum Capacitor | AVX |
| C6, C11, C14, C23, C27 | 5 | 08055C104MAT1A | 0.14F 50V 20\% X7R Capacitor | AVX |
| C7 | 1 | 08055A471KAT1A | 470pF 50V 10\% NPO Capacitor | AVX |
| C8, C9 | 2 | 08055A221KAT1A | 220pF 50V 10\% NPO Capacitor | AVX |
| C12 | 1 | 08055A560KAT1A | 56pF 50V 10\% NPO Capacitor | AVX |
| C16, C19, C28, C29 | 4 | TPSD107M010R0080 | 100 F F 10V 20\% Tantalum Capacitor | AVX |
| C17-Option | 1 | 10SL100M | 100uF 10V 20\% OS-CON Capacitor Option | Sanyo |
| C18 | 1 | 08055A220KAT1A | 22pF 50V 10\% NPO Capacitor | AVX |
| C21, C22, C25, C26 | 4 | TPSE226M035R0300 | 22 $\mu \mathrm{F} 35 \mathrm{~V}$ 20\% Tantalum Capacitor | AVX |
| C24 | 1 | TAJB475M016R | 4.7 1 F 16V 20\% Tantalum Capacitor | AVX |
| D1, D3 | 2 | MBRS140T3 | 40V 1A Schottky Diode | Motorola |
| D2, D4 | 2 | CMDSH-3TR | 30V 0.1A Schottky Diode | Central |
| D5, D7 | 2 | MMBD914LT1 | 100V General Diode | Motorola |
| D6 | 1 | MBRS1100T3 | 100V 1A Schottky Diode | Motorola |
| J1 to J8 | 8 | 1502-2 | 2-Turrent Terminal | Keystone |
| J9 | 1 | 38015-06G1 | 6-Pin 1-Row 0.100cc Connector | Comm Con |
| L1 | 1 | CDRH125-100MC | 10 $\mu \mathrm{H} 4 \mathrm{~A}$ 20\% SMT Inductor | Sumida |
| M1 | 1 | Si4936DY | Dual N-Channel MOSFET Transistor | Siliconix |
| M2, M3 | 2 | Si4412DY | N-Channel MOSFET Transistor | Siliconix |
| Q1 | 1 | MMBT2907ALT1 | PNP Transistor | Motorola |
| R1, R7, R8 | 3 | CR21-100J-T | 10Л 1/10W 5\% Chip Resistor | AVX |
| R2, R11 | 2 | CR21-101J-T | 100 $1 / 10 \mathrm{~W} 5 \%$ Chip Resistor | AVX |
| R3 | 1 | CR21-1004F-T | 1M 1/10W 1\% Chip Resistor | AVX |
| R4 | 1 | CR21-9092F-T | 90.9k 1/10W 1\% Chip Resistor | AVX |
| R5 | 1 | CR21-3923F-T | 392k 1/10W 1\% Chip Resistor | AVX |
| R6, R10 | 2 | LR2010-01-R033-F | 0.033 $21 / 2 \mathrm{~W}$ 1\% Chip Resistor | IRC |
| R9 | 1 | CR21-473J-T | 47k 1/10W 5\% Chip Resistor | AVX |
| R12 | 1 | CR21-102J-T | 1k 1/10W 5\% Chip Resistor | AVX |
| R13, R15 | 2 | CR21-103J-T | 10k 1/10W 5\% Chip Resistor | AVX |
| R14 | 1 | CR21-2213F-T | 221k 1/10W 1\% Chip Resistor | AVX |
| R16 | 1 | CR21-105J-T | 1M 1/10W 5\% Chip Resistor | AVX |
| SW1 | 1 | 90HBW03S | 3-Position SPST SMT Switch | Grayhill |
| T1-Gapped E-Core | 1 | LPE-6562-A262; Gapped E-Core | 10んH 3A 1:1.8 Transformer | Dale |
| T1-Gapped SMT Toroid | 1 | 501-0657; Gapped SMT Toroid | 10uH 3A 1:1.8 Transformer | BH Electronics |
| U1 | 1 | LTC1538-AUXCG28 | LTC1538-AUX IC | LTC |

3

# DEMO MANUAL DC125 <br> DESIGN-READY SWITCHERS 

## manufacturer telephone directory

| MANUFACTURER | USA | EUROPE | JAPAN | HONG KONG | SINGAPORE | TAIWAN/KOREA |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| AVX <br> Ceramic Capacitors Resistors | (803) 448-9411 (803) $946-0362$ (803) 9460524 | (0252) 336868 |  | 3633303 |  |  |
| BH Electronics | (612) 894-9590 |  |  |  |  |  |
| Central | (516) 435-1110 | 49816143963 |  |  |  | 8222689795 |
| Comm Con | (818) 301-4200 |  |  |  |  |  |
| Dale | (605) 665-9301 | 49928771434 |  |  | 657472767 |  |
| Grayhill | (708) 354-1040 |  |  |  |  |  |
| IR | (310) 322-3331 | 44883713215 |  | (852) 8037380 |  |  |
| IRC | (512) 992-7900 |  |  |  |  |  |
| Keystone | (718) 956-8900 |  |  |  |  |  |
| LTC | (408) 432-1900 |  |  |  |  |  |
| Motorola | (602) 244-5768 | 4989921030 |  | (852) 4808333 |  |  |
| Siliconix (Temic) | (408) 970-5700 | 4907131 67-0 |  | (852) 23-789-789 |  |  |
| Sanyo | (619) 661-6835 |  | 0720-70-1005 |  |  |  |
| Sumida | (708) 956-0666 |  | 03-3607-5111 | 8806688 | 2963388 | 02-726-2177-9 |

## PUICK START GUIDE

The demonstration board is easily set up to evaluate the performance of the LTC1538-AUX. Please follow the procedure outlined below for proper operation.

- Refer to Figure 2 for board orientation and proper measurement equipment setup.
- Set the three DIP switches, (SW1a, SW1b and SW1c) to the left position (switches closed).
- Connect the desired loads between $\mathrm{V}_{\text {OUT1, }}, \mathrm{V}_{\text {OUT2, }}, \mathrm{V}_{12 \mathrm{~V}}$ and their closest PGND terminals on the board. The loads can be up to 3A for $V_{\text {OUT1 }}, 3 \mathrm{~A}$ for $\mathrm{V}_{\text {OUT2 }}$ and up to 200 mA for $\mathrm{V}_{12 \mathrm{~V}}$. Soldered wires should be used when the load current exceeds 1 A in order to achieve optimum performance.
- Connect the input power supply to the $\mathrm{V}_{\mathrm{IN}}$ and $\operatorname{PGND}$ terminals on the top, center of the board. Do NOT increase $\mathrm{V}_{\text {IN }}$ over 28 V or the MOSFETs MAY BE DAMAGED.
- Switch on the desired channel(s) by moving SW1a, SW1b and SW1c to the open position ( $12 \mathrm{~V}_{0 \mathrm{~N}}, 3.3 \mathrm{~V}_{\text {RUN }}$ and $5 \mathrm{~V}_{\text {RUN }}$ ) allowing the soft start capacitors to ramp positive.
- Measure $\mathrm{V}_{\text {OUT1 }}$ and $\mathrm{V}_{\text {OUT2 }}$ to verify output voltages of $5 \mathrm{~V} \pm 0.1 \mathrm{~V}$ and $3.3 \mathrm{~V} \pm 0.08 \mathrm{~V}$, respectively, at load currents of 1 A each.
- Measure $\mathrm{V}_{12 \mathrm{~V}}$ to verify output voltage of $12 \mathrm{~V} \pm 5 \%$ at a load current of 0.1A.


## OPERATION

The circuit shown in Figure 1 provides fixed voltages of 5 V , 3.3 V and 12 V . It provides 5 V and 3.3 V output voltages at currents up to 3 A . The 12 V output can deliver up to several hundred milliamps limited only by the thermal dissipation available to Q1 in DC125. Figure 2 illustrates the correct measurement setup in order to verify the typical numbers found in the Performance Summary table. Small spring clip leads are very convenient for small-signal bench
testing butshould not be used atthe current and impedance levels associated with this switching regulator. Soldered wire connections are required to properly ascertain the performance of this demonstration PC board.
The LTC1538-AUX switching regulator performs high efficiency DC-to-DC voltage conversion while maintaining constant frequency over a wide range of load current, using a current mode architecture. The oscillator fre-

## OPERATION



Figure 2. Proper Measurement Setup
quency is set by the selection of the external capacitor on Pin 7. The demonstration board is set up with a 56 pF capacitor to run at 200 kHz . High efficiency is made possible by using a new Burst Mode operation architecture employing pulse skipping at low output currents. At very light loads and with an input-to-output voltage differential of 2 V or less, the device will go into a voltage mode of operation in order to recharge the boost capacitors periodically. The first controller can be forced into continuous operation by tying the SFB1 input pin to signal ground.
The demonstration board is shipped in a standard configuration of $5 \mathrm{~V} / 3.3 \mathrm{~V} / 12 \mathrm{~V}$.

The secondary winding of transformer T1 develops a voltage on capacitor C4. This voltage is divided down by the resistive divider comprising R3 and R4. This divided down voltage is compared against the internal 1.19 V reference voltage at the SFB1 pin and forces the first regulator's output stage to be activated for as long as required to support the 12 V load. The inductor current will even be allowed to reverse, in order to provide enough flyback period to charge the secondary winding's filter capacitor.
An internal attenuator set for a 12 V output is connected in series with the AUXFB pin when the voltage applied to the AUXDR pin is greater than 9.5 V . The secondary winding on the transformer T 1 , in conjunction with the feedback control loop, produces a regulated flyback voltage of 14 V , provided that the duty cycle of the 5 V regulator is not too high. Current flows in the secondary winding only during the off time of the first controller's top MOSFET. As the
voltage decreases, the duty cycle increases, meaning that there is less off time for the secondary winding to operate. Ultimately, it will not be able to supply the average current required by the 12 V auxiliary regulator. The demonstration board will provide 12 V at its 200 mA rated output current with the input supply at 7 V or greater.
If fully loaded 12 V operation is required all the way down to the dropout point of the 5 V regulator, controller 1 could be set to 3.3 V , controller 2 could be set to 5 V and a transformer with a higher turns ratio could be used. Consult the factory for assistance or refer to the LTC1538-AUX/ LTC1539 data sheet for a typical application circuit.

The auxiliary regulator drive output can typically sink 15 mA , providing enough external PNP base drive for a 500 mA regulator. Power dissipation must be considered for the PNP output device as well as for the IC. A circuit adding a low-sat NPN can be configured for currents in the 0.5 A to 5 A range if a higher current linear regulator is desired. See the LTC1538-AUX/LTC1539 data sheet for additional information.

Efficiency measurement depends on the operating conditions of all three regulators and must be performed with care. Efficiency figures should ideally be taken with only the minimum required circuitry operating on an individual regulator. Since there is much common circuitry operating when more than one regulator is running, overall efficiency numbers will actually increase when the two switching regulators are active. The increase is not significant at high output currents but can become very significant at low output currents, when the IC supply current becomes an appreciable part of the total input supply current.
Refer to the LTC1538-AUX/LTC1539 data sheet for further information on the internal operation and functionality descriptions of the IC.

## Physical Design

The demonstration board is manufactured using a typical 4-layer/1oz copper PC board. The board is available with a choice of two different types of inductors. The first, pictured in the front page photo, is a Dale LPE6562-A262 gapped E-core. The second is a BH Electronics 501-0657

# DEMO MANUAL DC125 <br> DESIGN-READY SWITCHERS 

## OPGRATION

gapped toroid. The turns ratio is the same for both transformers at 1:1.8, providing the proper unregulated 14 V output for the auxiliary internal linear regulator. The Dale inductor supplies slightly more output current prior to saturating than the BH unit, but the toroid will be offered in a significantly smaller package than shipped with the demonstration board (consult the manufacturer). The Dale and BH transformers shipped with the demo board are released part numbers from the manufacturers.

## PC Board Layout Hints

Switching power supply printed circuit layouts are certainly among the most difficult analog circuits to design. The following suggestions will help to get a reasonably close solution on the first try.

The output circuits, including the external switching MOSFETs, inductor, secondary windings, sense resistor, input capacitors and output capacitors all have very large voltage and/or current levels associated with them. These components and the radiated fields (electrostatic and/or electromagnetic) must be kept away from the very sensitive control circuitry and loop compensation components required for a current mode switching regulator.

The electrostatic or capacitive coupling problems can be reduced by increasing the distance from the radiator, typically a very large or very fast moving voltage signal. The signal points that cause problems generally include the "switch" node, any secondary flyback winding voltage and any nodes that also move with these nodes. The switch, MOSFET gate and boost nodes move between $\mathrm{V}_{\mathrm{IN}}$ and PGND each cycle with less than a 100ns transition time. The secondary flyback winding output has an AC signal component of $-V_{\text {IN }}$ times the turns ratio of the transformer, and also has a similar <100ns transitiontime. The control input signals need to have less than a few millivolts of noise in order for the regulator to perform properly. A rough calculation shows that 80 dB of isolation at 2 MHz is required from the switch node for low noise switcher operation. The situation is worse by a factor of the turns ratio for the secondary flyback winding. Keep these switch-node-related PC traces short and away from the "quiet" side of the IC (not just above and below each other on the opposite sides of the board).

The electromagnetic or current-loop induced feedback problems can be minimized by keeping the high AC current (transmitter) paths and the feedback circuit (receiver) path small and/or short. Maxwell's equations are at work here trying to disrupt our clean flow of current and voltage information from the output back to the controller input. It is crucial to understand and minimize the susceptibility of the control input stage as well as the more obvious reduction of radiation from the high current outputstage(s). An inductive transmitter depends upon the frequency, current amplitude and the size of the current loop to determine the radiation characteristic of the generated field. The current levels are set in the output stage once the input voltage, output voltage and inductor value(s) have been selected. The frequency is set by the output stage transition times. The only parameter over which we have some control is the size of the antenna we create on the PC board, that is the loop. A loop is formed with the input capacitance, the top MOSFET, the Shottky diode and the path from the Shottky diode's ground connection and the input capacitor's ground connection. A second path is formed when a secondary winding is used, comprising the secondary output capacitor, the secondary winding and the rectifier diode or switching MOSFET (in the case of a synchronous approach). These "loops" should be kept as small and tightly packed as possible in order to minimize their "far field" radiation effects. The radiated field produced is picked up by the current comparator input filter circuit(s), as well as by the voltage feedback circuit(s). The current comparator's filter capacitor placed across the sense pins attenuates the radiated current signal. It is important to place this capacitor immediately adjacent to the IC sense pins. The voltage sensing input(s) minimizes the inductive pickup component by using an input capacitance filter to SGND. The capacitors in both cases serve to integrate the induced current, reducing the susceptibility to both the "loop" radiated magnetic fields and the transformer or inductor leakage fields.

The PGND/SGND tie point for the dual switching regulators in the LTC1438/LTC1439/LTC1538-AUX/LTC1539 family is optimized by connecting the grounds directly under the IC on a dedicated grounding plane.

The capacitor on INT $V_{C C}$ acts as a reservoir to supply the high transient currents to the bottom gates and to re-

## OPERATION

charge the boost capacitor. This capacitor should be a 4.7 $\mu$ Ftantalum capacitor placed as close as possible to the INTV $V_{C C}$ and PGND pins of the IC. Peak currents exceed 1A when charging the gates of the bottom MOSFETS.
The oscillator capacitor should be separately connected to the SGND pin to minimize any ground current effects on the frequency of the oscillator.

Capacitor C5, used on the 12 V output, should return to SGND to minimize any switching noise on the switching regulator PGND node.

The traces that sense the voltage across the currentsensing resistor can be long but should run parallel to each other and be spaced with the minimum separation allowed in order to experience the same electrostatic and electromagnetic fields from radiating sources. Keep these traces on a PC board plane furthest from the high current and large switching voltage plane.

PCB LAYOUT AND FILM All views shown through the top.


Component Side Silkscreen Top


Copper Layer 1


Component Side Silkscreen Bottom


Ground Plane Layer 2

PCB LAYOUT A@D FILIn All views shown through the top.


Copper Layer 3


Solder Mask Top


Copper Layer 4


Solder Mask Bottom

## PC FAB DRAWING




[^0]:    $\overline{\mathbf{Q}}$, LTC and LT are registered trademarks of Linear Technology Corporation.

