

Low-cost, minimum-size solution for powering future-generation Celeron™-type processors with peak currents up to 26 A

By Rais Miftakhutdinov, System Engineering, Power Management Products and Philip Rogers, System Engineering, Power Management Products

Introduction

Next-generation microprocessors continue to challenge power system designers by increasing system power consumption. The latest design guidelines from Intel (Reference 4) require a maximum core current of up to 26 A for future processors in a PGA-370 package. The new TPS5211EVM-154 evaluation module with the TPS5211 hysteretic controller has been designed as a low-cost, minimum-size solution for this application. The TPS5211EVM-154 evaluation module includes a synchronous DC-DC buck converter, a socket for a PGA-370 microprocessor package with high-frequency decoupling capacitors, and a load-current transient tester. This module is a high-current modification of the TPS5210EVM-147 that is described in Reference 2. The DC-DC converter has a 5-V input and 1.65-V output and requires a 12-V, 40-mA supply voltage for the controller itself. The DC-DC converter occupies only 3.7 sq. in., while the temperature of the components does not exceed 80°C at room ambient

temperature with a load current of 22 A. The transient characteristics of the module have been tested by Voltage Transient Test Tool v.2.0 from Intel and by an internal load-current transient tester at a peak load current of 26 A. A four-layer PCB, which is a very popular solution for a desktop main-board, was used in the module to get electrical and temperature conditions close to real conditions.

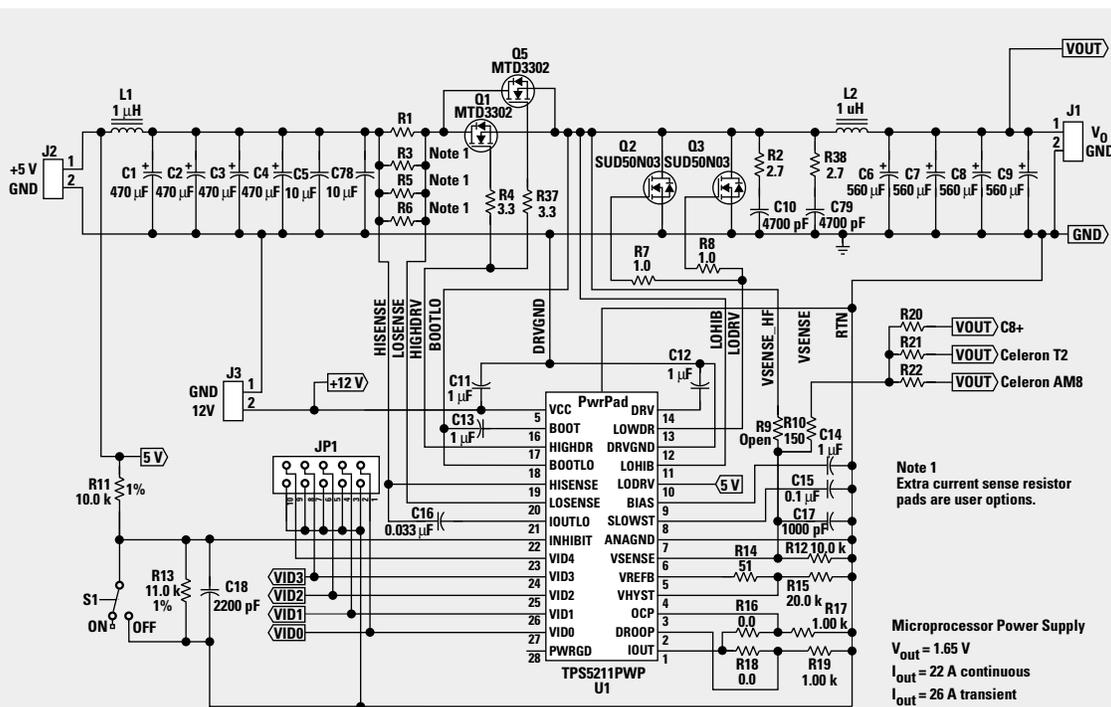
TPS5211EVM-154 evaluation module description

The TPS5211EVM-154 evaluation module (5.67" x 3.19" x 0.8") includes three main parts:

- synchronous DC-DC buck converter,
- socket for a PGA-370 package, allowing use of the Transient Test Tool, and
- additional internal transient tester, which can be used if the Transient Test Tool is not available.

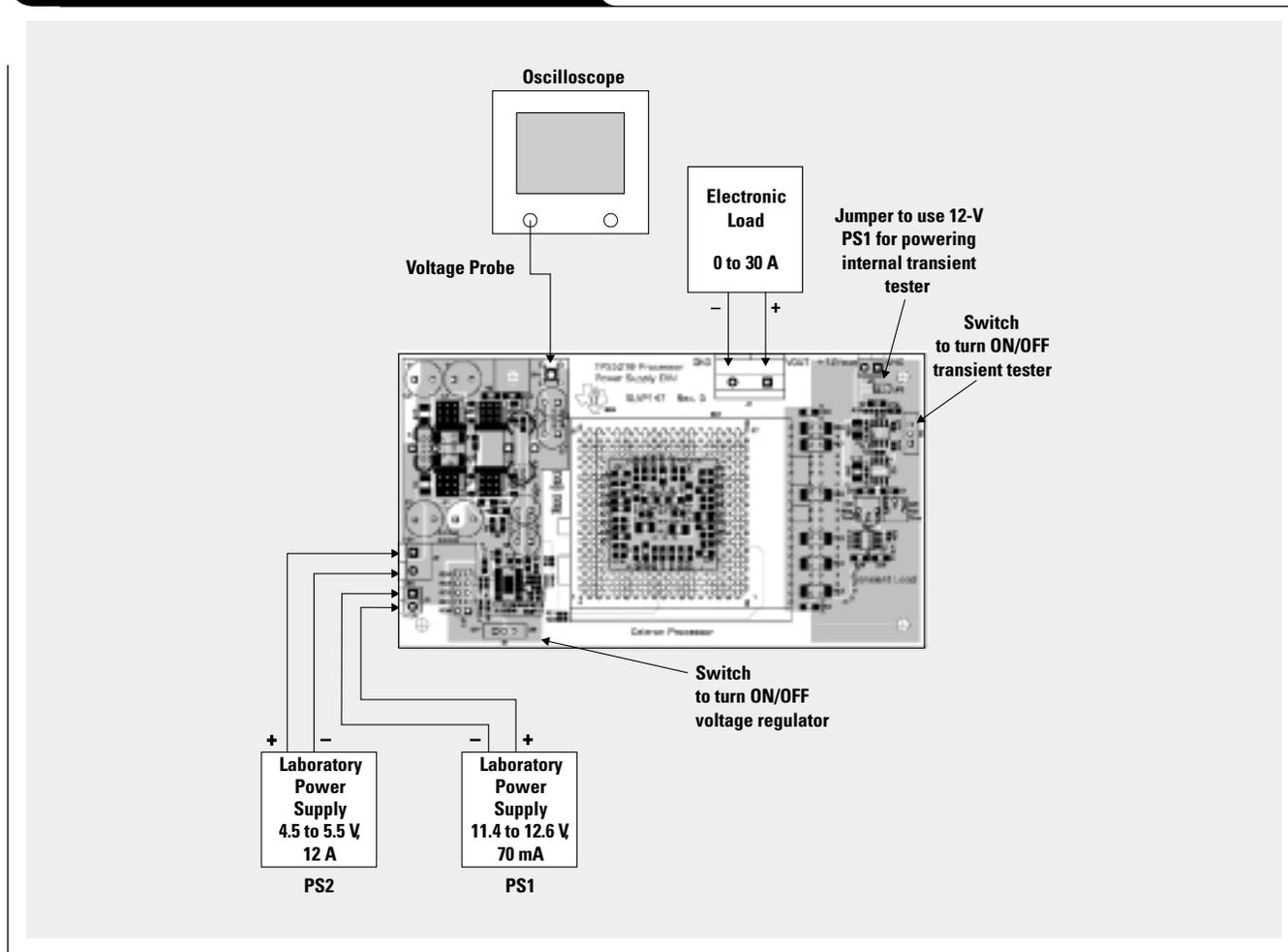
The schematic of the DC-DC synchronous buck converter is shown in Figure 1. The input filter includes four

Figure 1. Synchronous DC-DC buck converter schematic



For this application, R5, R6, and R12 are open; and R1 and R3 are 3 Mohm.

Figure 2. Test set-up for TPS5211EVM-154 EVM



10SP470M capacitors (C1–C4), 10- μ F ceramic capacitors (C5, C78), and a 1- μ H inductor (L1). The input capacitors can handle a total maximum RMS current as high as 18 A to increase the reliability of the power supply. The output filter has four OS-CON type capacitors 4SP560M (C6–C9) and a 1- μ H inductor (L2). The fast hysteretic controller and active droop compensation reduce the number of capacitors while having a reliable margin for dynamic tolerance.

The power stage includes two 10-mohm high-side FETs (MTD3302) and two 7-mohm low-side FETs (SUD50N03) in DPAK packages (Q1, Q2, Q3, and Q5). The surface mount heat sinks from AAVID (part number 573100) have been used to improve temperature characteristics. All functions and features of the TPS5211 hysteretic controller are described in References 1–3.

Test results

The simplified block diagram of the test set-up and the EVM itself are shown in Figure 2.

All measurements were made at room temperature. The electrical and mechanical characteristics of the DC-DC converter are shown in Table 1.

Table 1. Electrical and mechanical characteristics of the DC-DC converter

CHARACTERISTIC	MEASUREMENT
Input voltage	5 V \pm 0.5 V
Input current	12 A max at $V_{in} = 4.5$ V and $I_{out} = 27.5$ A
V_{CC} voltage and current	12 V \pm 0.6 V, 40 mA max
Nominal output voltage	1.65 V
DC and peak output current	22-A DC for temperature measurements and 26-A peak
Output voltage static tolerance	+0% and –3.65% including droop compensation
Output voltage dynamic tolerance	+3% and –4.8% at 25-A load-current step with 20-A/ μ s slew rate
Switching frequency	120 to 145 kHz
Efficiency	>84% at 22 A, 53.8% at 0.5 A
Occupied area	3.7 sq. in.

Continued on next page

Continued from previous page

Efficiency, power losses and temperature through components

The temperatures of components, the efficiency, and power losses were measured after 2 hours of operation when the temperatures of the PCB and components were stabilized. Results of these measurements are presented in Table 2 and Figure 3. The measurements were made at room temperature (22.8°C) with 5-V input voltage and 22-A load current. The cooling conditions were natural air convection in accordance with the specification. The two surface-mount heat sinks from AAVID (part number 573100) have been used for each pair of high- and low-side FETs to improve temperature characteristics. The maximum temperature rise was 56.7°C through the high-side FET, while the temperature rise of the PCB itself was 28.8°C. These are reasonable values because the real motherboard has a much larger cooling area for the components.

One can see that the temperatures of most components are very close to the PCB temperature, except for the FETs and output inductor.

Efficiency at 22.5-A load current is 83.7% and at 0.5 A is 53.8%. This exceeds the specification, which requires 80% and 40%, respectively. The maximum power losses at 22.5-A load current do not exceed 7.1 W.

The electrical requirements and cooling conditions might vary for different applications. To cover more potential applications, the power losses, efficiency, and temperature through high-side FETs have been investigated for different FETs and switching frequencies with and without heat sinks. Results of this investigation are presented in Table 3.

The switching frequency can be decreased using lower ESR (equivalent series resistance) capacitors like OS-CON type 4SP820M or by changing resistor R14 from 51 ohms to 75 ohms. In this case, the hysteresis window increases proportionally.

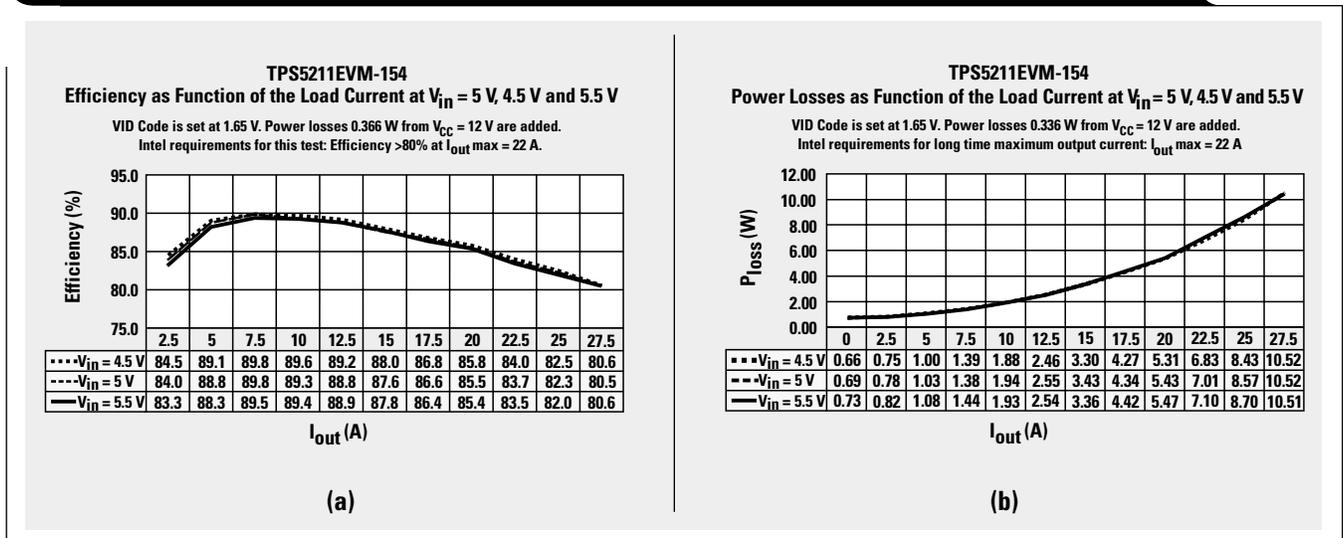
Table 2. Temperature measurement results

COMPONENT	PCB	Q1/Q5 HIGH-SIDE FETs	Q2/Q3 LOW-SIDE FETs	L1, INPUT IND.	L2, OUTPUT IND.	U1, IC	INPUT CAPACITORS				OUTPUT CAPACITORS			
							C1	C2	C3	C4	C6	C7	C8	C9
Temp. (°C)	51.6	78.5/79.5	66.3/70	47	62.3	45	47.8	46.2	43.5	52.5	38.5	45.3	46.8	47.6
Temp. rise (°C)	28.8	55.7/56.7	43.5/47.2	24.2	39.5	23.2	25	23.4	20.7	29.7	15.7	22.5	24	24.8

Table 3. Power losses, efficiency, and high-side FETs temperature for different FETs and frequencies with and without heat sinks. $V_{in} = 5\text{ V}$, $V_{out} = 1.65\text{ V}$, $I_{out} = 22\text{ A}$.

FETs, HIGH-/LOW-SIDE	F _{sw} (kHz)	P _{loss} (W)	EFF (%)	HEAT SINK (With/Without)	TEMPERATURE OF HIGH-SIDE FETs (°C)
MTD3302/SUD50N03-7	130	6.62	84.2	With	79.5
MTD3302/SUD50N03-7	87	6.24	84.9	Without	88
SUD50N03-7/SUD50N03-7	85	6.32	84.8	Without	89
PSMN005-25D/PSMN005-25D	86	5.97	85.5	Without	82

Figure 3. Efficiency (a) and power losses (b) over entire input voltage and output current range



Load-current transient response

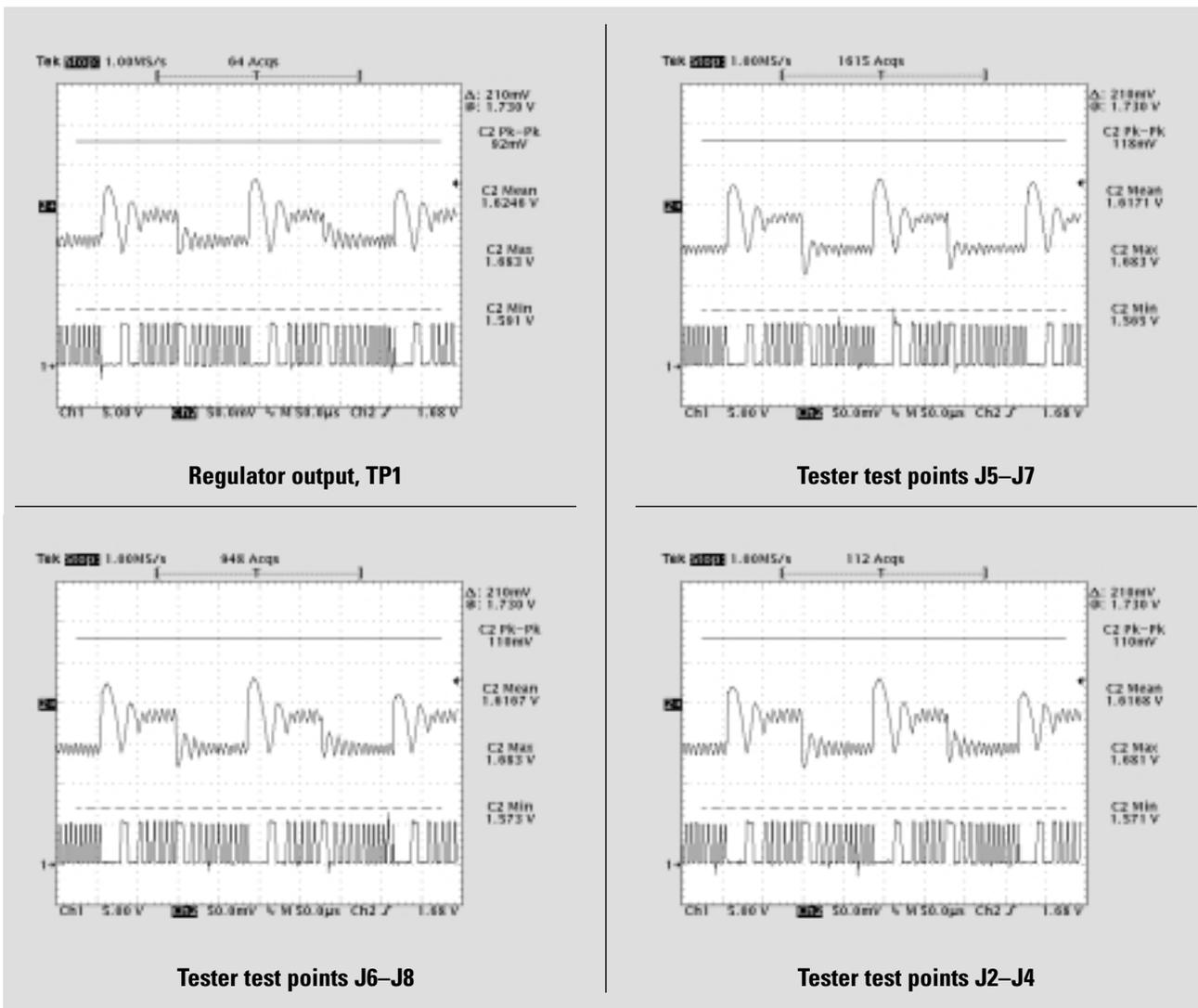
The transient tests using the Voltage Transient Test Tool v.2.0 from Intel have been performed in accordance with the corresponding manual from Intel. The output-voltage transient waveforms during the load-current transitions are shown in Figure 4. The Test Tool was connected to the TPS5211EVM-154 evaluation module through the PGA-370 socket. The transient waveforms were measured near the output filter (TP1 on TPS5211EVM-154 module) and through the special test points J5–J7, J6–J8, and

J2–J4 of the Test Tool, which are located at the micro-processor side of the PGA-370 connector.

The tests were made under the following conditions in accordance with VRM 8.4 requirements: I_{CC} bias = 2.15 A, I_{CC} max = 26 A, slew rate = 22.1 A/ μ s, transient duty cycle = 0.5, and transient frequency = 5.5 kHz. The peak-to-peak output voltage amplitude is 150 mV in the worst case with four OS-CON capacitors 4SP560M. The specification limit is 210 mV for this test.

Continued on next page

Figure 4. The output-voltage transient response with the Intel Transient Test Tool at transient frequency 5.5 kHz



The cursors show the output voltage limits for this test: 1.52 V minimum and 1.73 V maximum. Ch2 shows the output voltage (50 mV/div.), and Ch1 shows the drain-source voltage (5 V/div.).

Continued from previous page

The output-voltage transient response using the internal load-current transient tester is shown in Figure 5. The load-current transition was between 2.2 A and 27.2 A, which corresponds to a 25-A step load. The peak-to-peak output-voltage amplitude for this test is 130 mV, which is also well below the allowable maximum of 210 mV.

Conclusions

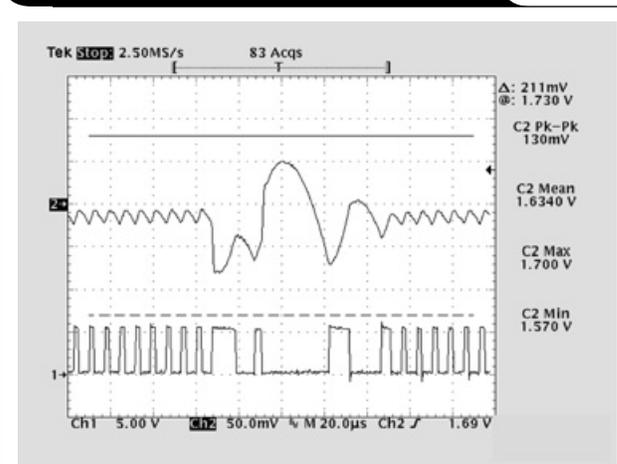
- The TPS5211EVM-154 evaluation module with the TPS5211 hysteretic controller meets the electrical requirements set forth in Reference 4.
- The load-current transient tests using the internal EVM transient tester and the Voltage Transient Test Tool v.2.0 from Intel have shown excellent dynamic characteristics of the TPS5211 hysteretic controller for up to 26-A core current desktop applications with the minimum number of bulk OS-CON capacitors.
- The component temperature measurements in worst-case cooling conditions have given reasonable results.

References

For more information related to this article, you can download an Acrobat Reader file at www-s.ti.com/sc/techlit/litnumber and replace "lit number" with the **TI Lit. #** for the materials listed below.

Document Title	TI Lit. #
1. "TPS5211 High Frequency Programmable Synchronous-Buck Regulator Controller," September 1999slvs243
2. R. Miftakhutdinov and P. Rogers, "Powering Celeron-type Microprocessors Using TI's TPS5210 and TPS5211 Controllers," <i>Analog Applications Journal</i> , February 2000, pp. 20-28slyt178
3. "Designing Fast Response Synchronous Buck Regulator Using the TPS5210," Application Report, March 1999slva044
4. "VRM 8.4 DC-DC Converter Design Guidelines," Rev. No. 1.6, Intel Corporation, November 1999, order number 245335-001.	—
5. R. Miftakhutdinov, "Analysis of Synchronous Buck Converter with Hysteretic Controller at High Slew-Rate Load Current Transients," <i>Proc. of High Frequency Power Conversion Conference</i> , 1999, pp. 55-69.	—

Figure 5. The output-voltage transient response at 25-A load-current step*



*With slew rate of 20 A/μsec during step up and 40 A/μsec during step down, measured at test point TP1.
 The cursors show the output voltage limits for this test: 1.52 V minimum and 1.73 V maximum. Ch2 shows the output voltage (50 mV/div.), and Ch1 shows the drain-source voltage (5 V/div.).

Related Web sites

- www.ti.com/sc/docs/products/msp/pwrmgmt/index.htm
- www.ti.com/sc/docs/tools/analog/powermanagementdevelopmentboards.html

Get product data sheets at:

www.ti.com/sc/docs/products/analog/tps5211.html

To order the TPS5211EVM-154 (SLVP154) evaluation module, call TI's toll-free order desk at 1-800-477-8924, ext. 5800, in North America. To order in other regions, contact the TI Product Information Center for your region (see page 32) or contact your local TI distributor.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

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

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI 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 from TI 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 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. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

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

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products

Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DSP	dsp.ti.com
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com

Applications

Audio	www.ti.com/audio
Automotive	www.ti.com/automotive
Broadband	www.ti.com/broadband
Digital control	www.ti.com/digitalcontrol
Military	www.ti.com/military
Optical Networking	www.ti.com/opticalnetwork
Security	www.ti.com/security
Telephony	www.ti.com/telephony
Video & Imaging	www.ti.com/video
Wireless	www.ti.com/wireless

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page
support.ti.com

TI Semiconductor KnowledgeBase Home Page
support.ti.com/sc/knowledgebase

Product Information Centers

Americas

Phone	+1(972) 644-5580	Fax	+1(972) 927-6377
Internet/Email	support.ti.com/sc/pic/americas.htm		

Europe, Middle East, and Africa

Phone			
Belgium (English)	+32 (0) 27 45 54 32	Netherlands (English)	+31 (0) 546 87 95 45
Finland (English)	+358 (0) 9 25173948	Russia	+7 (0) 95 7850415
France	+33 (0) 1 30 70 11 64	Spain	+34 902 35 40 28
Germany	+49 (0) 8161 80 33 11	Sweden (English)	+46 (0) 8587 555 22
Israel (English)	1800 949 0107	United Kingdom	+44 (0) 1604 66 33 99
Italy	800 79 11 37		
Fax	+(49) (0) 8161 80 2045		
Internet	support.ti.com/sc/pic/euro.htm		

Japan

Fax			
International	+81-3-3344-5317	Domestic	0120-81-0036
Internet/Email			
International	support.ti.com/sc/pic/japan.htm		
Domestic	www.tij.co.jp/pic		

Asia

Phone			
International	+886-2-23786800		
Domestic	Toll-Free Number		
Australia	1-800-999-084	New Zealand	0800-446-934
China	800-820-8682	Philippines	1-800-765-7404
Hong Kong	800-96-5941	Singapore	800-886-1028
Indonesia	001-803-8861-1006	Taiwan	0800-006800
Korea	080-551-2804	Thailand	001-800-886-0010
Malaysia	1-800-80-3973		
Fax	886-2-2378-6808	Email	tiasia@ti.com
Internet	support.ti.com/sc/pic/asia.htm		ti-china@ti.com

C011905

Safe Harbor Statement: This publication may contain forward-looking statements that involve a number of risks and uncertainties. These "forward-looking statements" are intended to qualify for the safe harbor from liability established by the Private Securities Litigation Reform Act of 1995. These forward-looking statements generally can be identified by phrases such as "TI or its management believes," "expects," "anticipates," "foresees," "forecasts," "estimates" or other words or phrases of similar import. Similarly, such statements herein that describe the company's products, business strategy, outlook, objectives, plans, intentions or goals also are forward-looking statements. All such forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those in forward-looking statements. Please refer to TI's most recent Form 10-K for more information on the risks and uncertainties that could materially affect future results of operations. We disclaim any intention or obligation to update any forward-looking statements as a result of developments occurring after the date of this publication.

Trademarks: Celeron is a trademark of Intel Corporation. All other trademarks are the property of their respective owners.

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

© 2005 Texas Instruments Incorporated