Application Report
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High-Speed Load / Line Transient Jigs and App Report for Testing Fast Response POL Regulators

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ABSTRACT

These days, high-speed and communication portable systems employ voltage regulators that demand faster response time. It is necessary to generate steps in line voltage and load current that are fast with respect to the regulator's control loop response time. Lab equipment and many apparatus that use op-amps, passives, and large driver chains are limiting the rise and fall times of the stimulus signals at large excursions. No off-the-shelf products are currently available to obtain high-speed edge rates for load transient (> 1A/µs) and line transients (> 100 mV/µs, that includes input caps), and none capable in the labs. A slow transient stimulus can make a poor regulator look good. In response, this document suggests some simple solutions low in parasitic inductance (L) and capacitance (C) designed to be readily built and duplicated for use in design and application labs.

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1 Introduction

These days, high-speed and communication portable systems employ voltage regulators that demand faster response time. It is necessary to generate steps in line voltage and load current that are fast with respect to the regulator's control loop response time. Lab equipment and many apparatus that use op-amps, passives, and large driver chains are limiting the rise and fall times of the stimulus signals at large excursions. No off-the-shelf products are currently available to obtain high-speed edge rates for load transient (> 1A/µs) and line transients (> 100 mV/µs, that includes input caps), and none capable in the labs. A slow transient stimulus can make a poor regulator look good. In response, this document suggests some simple solutions low in parasitic inductance (L) and capacitance (C) designed to be readily built and duplicated for use in design and application labs.

Moreover, rigging up a respectable test jig is only half of the solution; the device under test ("DUT") must also be properly “wired” onto the PCB with optimal ground and supply conduits, bypassing capacitors, charge reservoirs, etc. The input and output capacitors selection and their proximity to the DUT have profound influence on the response of the DUT. After all, the DUT merits are what need to be evaluated, not the parasitic or the unwanted effects from improper external supporting components and physical layout.

This application note discusses good practice and fundamentals for transient analysis in the lab, and describes the construction of some improved transient test devices. Several jigs were built and used in characterizing new TI regulators and PMUs for advanced applications. The jigs have shown significant enhancement in the resolution and speed of signal injection and capturing. They also facilitated test set up and bench analysis.

2 Load Transient Jig

There are different means to create and monitor load transient. The basic idea is depicted in Figure 1 below -- here regulator output is rapidly switched between a light and heavy loading conditions. Current probe is used to monitor the stimulus waveform while a voltage probe is used to monitor the output response.

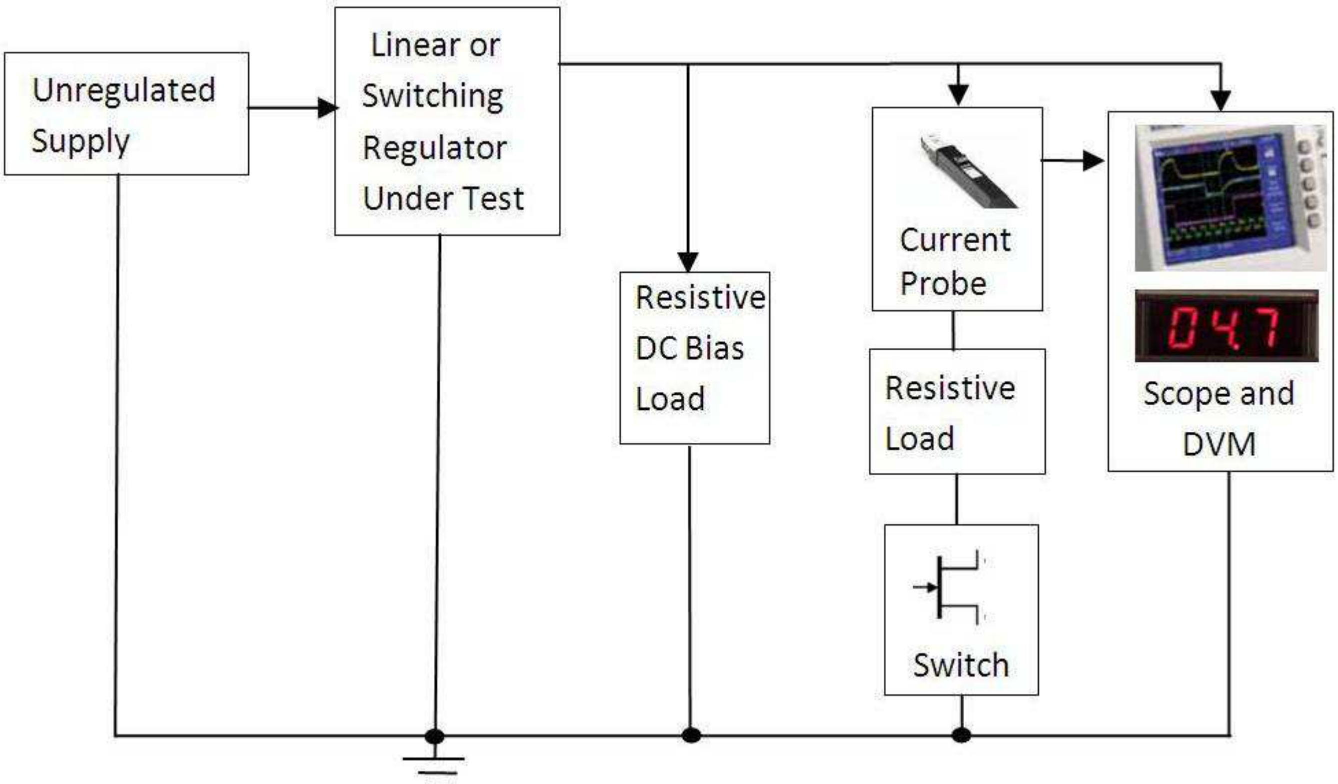

Figure 1. Principle of a Load Transient Test Circuit

Sometimes one uses a closed-loop current control to effect variable current steps. However, incorporating control circuitry may complicate the jig and may limit the slew rate. Alternatively, one can use a variable resistor as a convenient way to ascertaining data points over the range of a regulator's load current. However, if a rheostat is used be aware of contact bounce issue at heavy load; its inductance might introduce side effects that can affect the performance data sought. In general it is desirable to keep the jig simple to minimize the variables involved. The diagram in Figure 2 below illustrates a compact load transient test setup for a switching regulator that mimics the simplicity of the conceptual test jig shown in Figure 1. A passive scope probe is usually adequate, though any probe may be used. The pulse generator can be replaced by an LM555 chip that uses external passives to obtain frequency and duty cycle adjustments, which further compacts the test jig design for test and characterization. A pulse generation is preferable for R & D lab use. Gate drive and damping/speeding network can be used, as needed, for high-current and speed applications. The current probe (IP) can be any AC/DC high bandwidth hybrid sensor snap-on type.

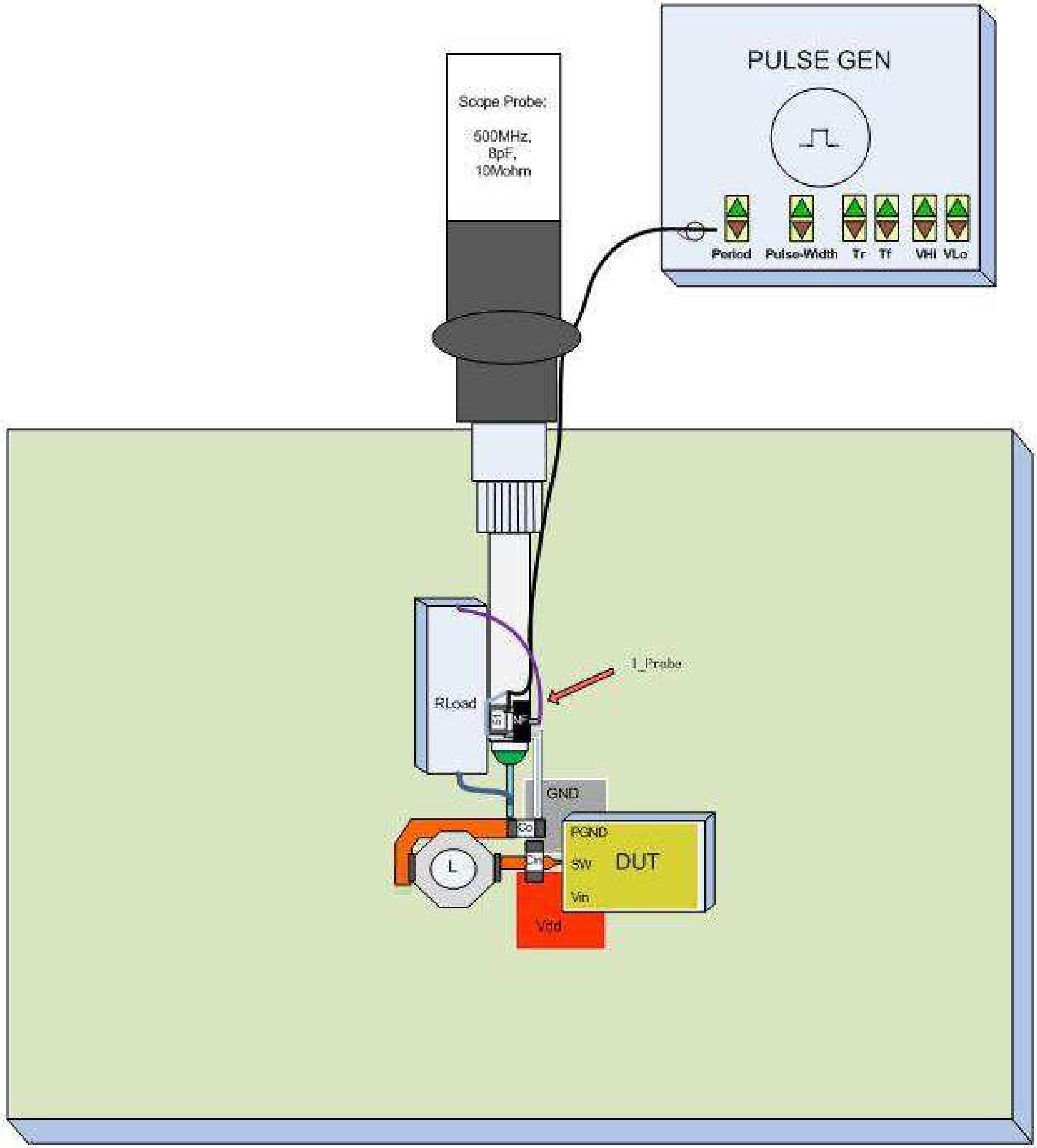

Figure 2. Improved Load Transient Jig

Ideally a 4-point probe would be used to allow better segregation between the stimulus and sense probe tips. However, as will be demonstrated, the added complexity might not worth the minute potential gain in performance. As in any high-edge rate test setup care should be taken in selecting the switch (e.g., the proper voltage, current, R_{DSON}, and switching ratings should be considered per application needs); good board layout is essential to achieve optimal speed and loading targets for the desired transient response. Furthermore, one should always use a star single-point ground technique and keep all wiring and probing connections as short as practical to obtain the best response result.

3 Interpreting the Transient Waveform Phenomena

Sometimes it may not be apparent how a regulator works in a system when checked on a bread board -- one may observe the undershoot diving way below ground, and its overshoot may be volts above the equilibrium level! The fact is one often neglects to use “good” high-frequency practice in the test setup. Thus, excessive parasitic inductance (capacitance, ESR, etc.) may corrupt the observation. Figure 3 below shows a typical transient response waveform of a regulator from a step in the load. Note that the amplitude of overshoot and undershoot relate proportionally to the parasitic. For example, long scope ground wire, lengthy and high-impedance board traces, probe capacitance, capacitor impedance, etc., all affect the transient waveform excursions. Hence, the elements that pertain to the “real” response of the regulator must be clearly distinguished from those from the parasitic of one's setup.

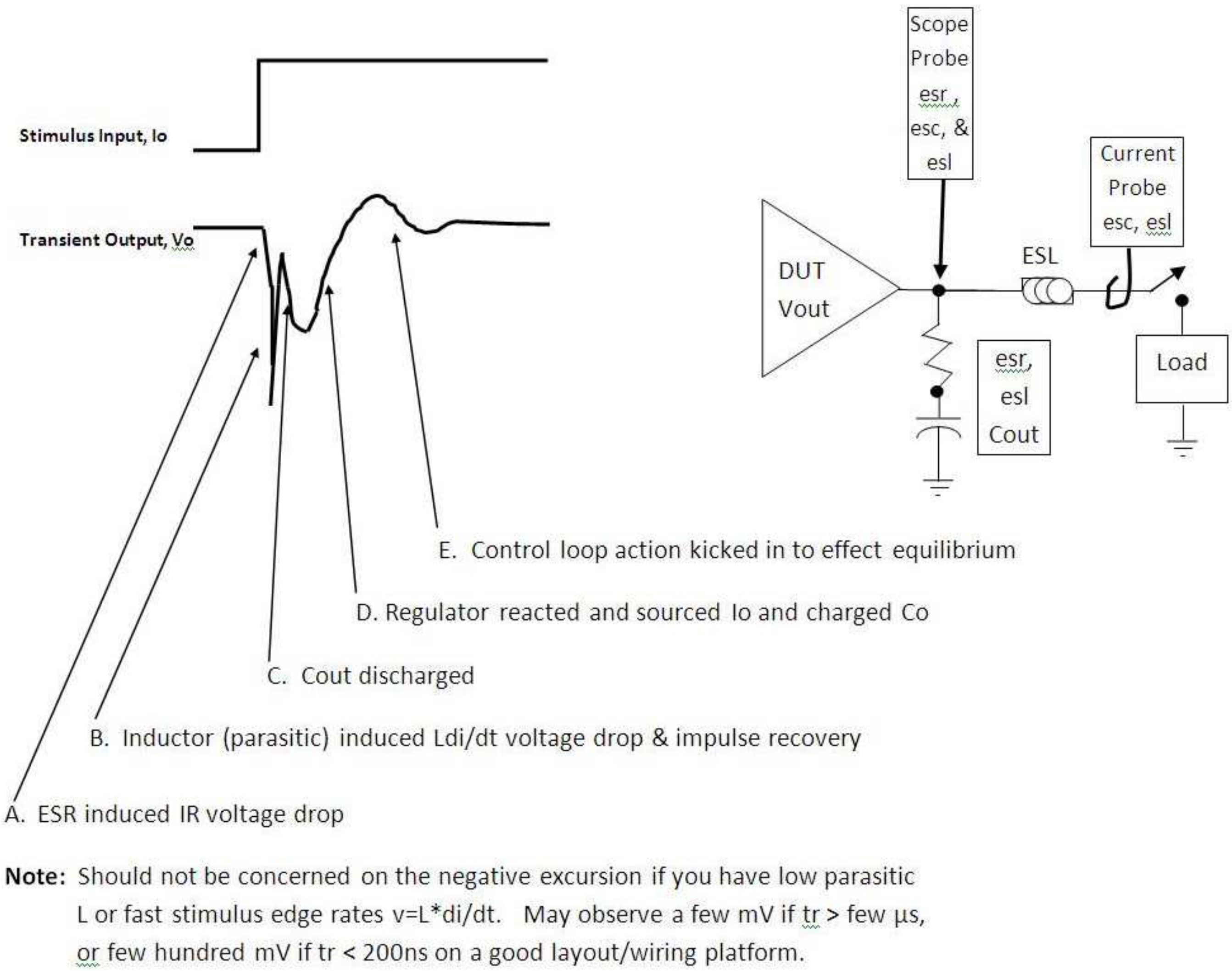

Figure 3. Typical Characteristics of Load Transient Response

3.1 Two Typical Load Transient Test Setups used in the Labs

1. Electronic Load (or E-load as it's often called) is a device or assembly that simulates loading on an electronic circuit. It is used as substitute for a conventional ohmic load resistor (see Figure 4). Many industrial E-load makers spec their high slew rates capable of 30A/μs and 50A/μs. But if a couple amps is needed, the maximum slew rate obtainable is, unfortunately, about 1A/μs.

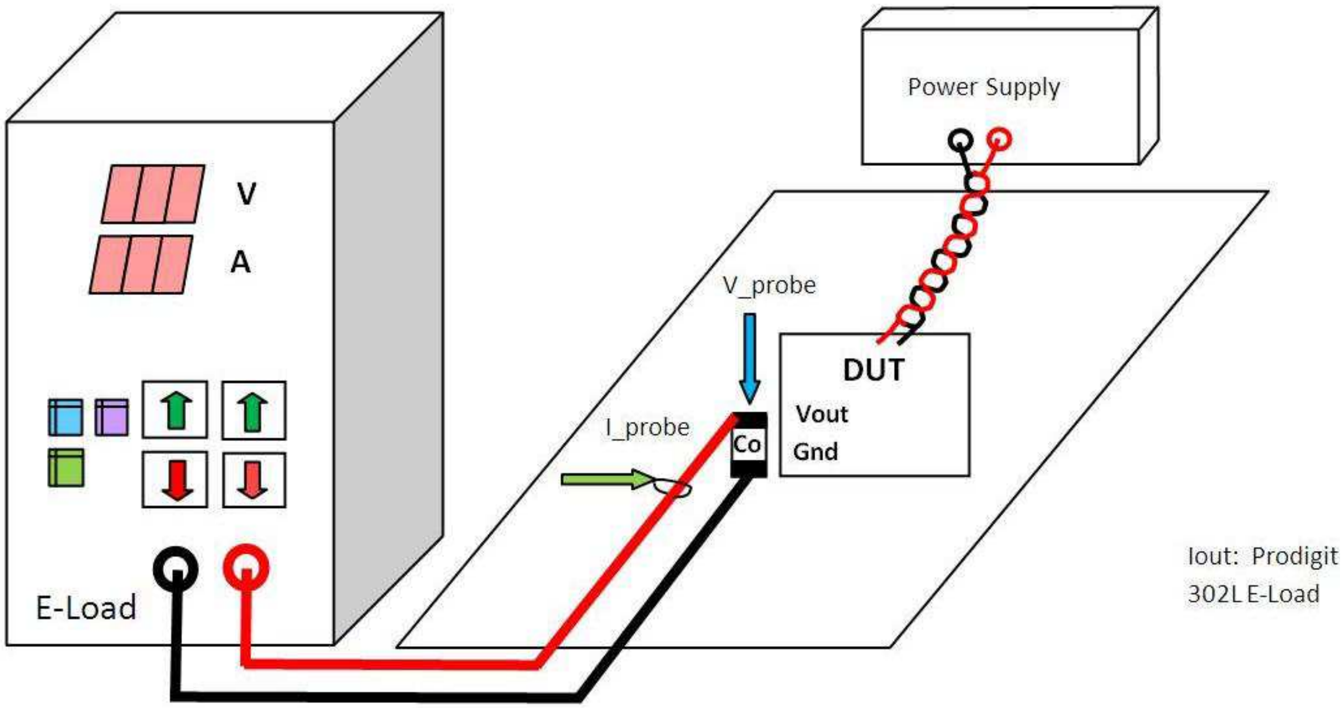

Figure 4. Using a Commercial Electronic Load Test Setup

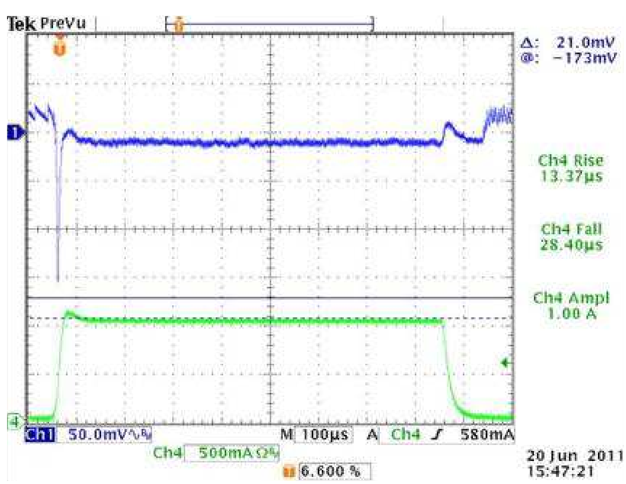

Figure 5. Load Transient Using an E-Load

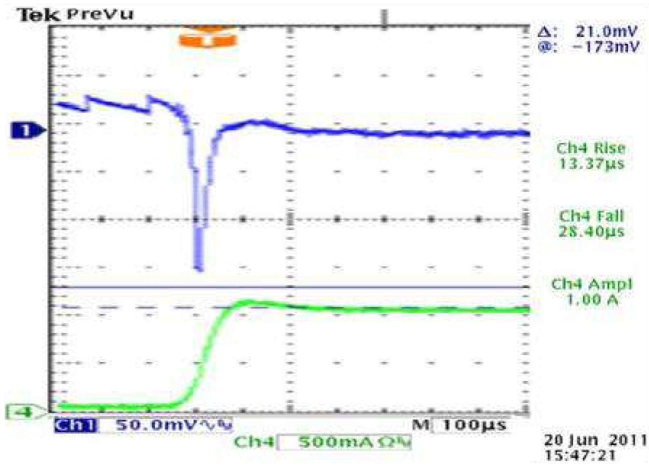

Figure 6. Expanded View of E-Load Transient Figure

The load transient using an E-Load Figure 5 shows the waveforms of a commercial Electronic Load used on an LP3906 buck EVB platform, I_{OUT} = 0 <-> 1A load transient from PFM to PWM; probes: voltage P6139A (8.0 pf/10 mΩ/500 MHz), current probe is Tek-TCP202.

Note that with this commercial E-load, typical current edge rates faster than 75 mA/µs are not obtainable with the LP3906 1.5A EVB platform for load transient test. Figure 6 is an expanded view of the same waveform at the rising edge portion of Figure 5.

2. Pulse Generator Switching a NMOSFET (MTB20N20E rated at 20A and R_{DSON} = 160 mΩ) is shown in Figure 7 below:

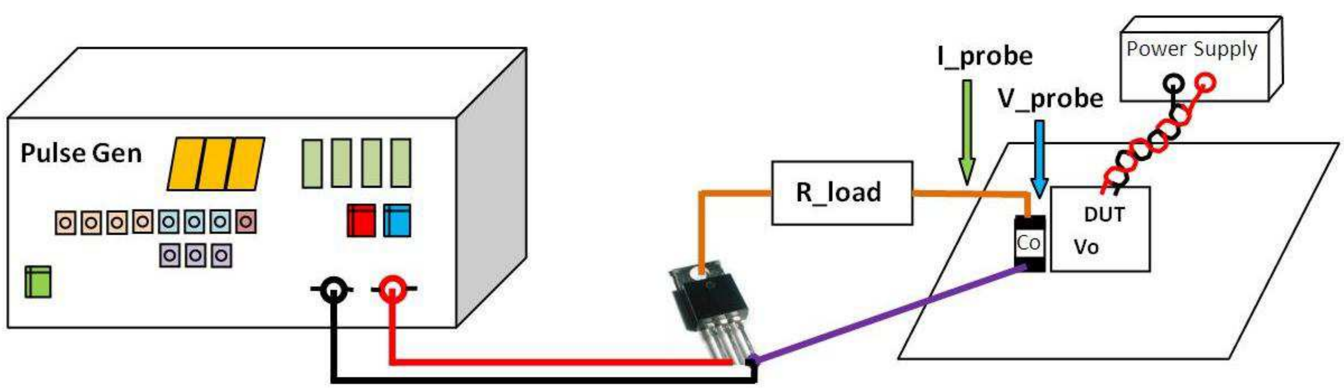

Figure 7. A Typical Lab Load Transient Jig Using an NFET Switching a Resistive Load

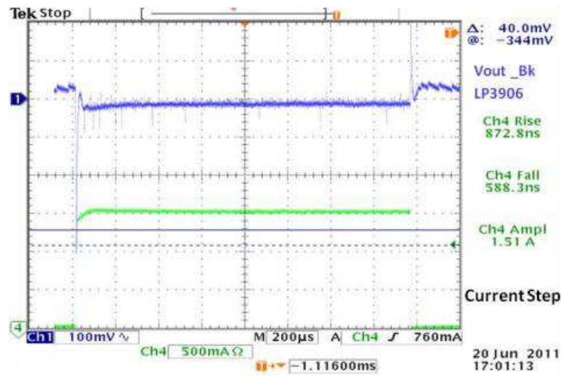

Figure 8. Load Transient I/V Test Waveforms on an LP3906

Figure 8 shows the Load transient I/V test waveforms on a LP3906 EVB, I_{OUT} = 0 ↔1.5A using a NMOSFET, MT0N20E and a HP8112A pulse generator. The result is a faster current step achievable with this discrete MOS setup compared to the previous E-load setup.

NOTE: Faster load current slew rates of Tr ~1.73A/µs and Tf ~2.56A/µs are obtainable with this setup while employing the same LP3906 test platform.

NOTE: Infrequently some regulators will not tolerate E-loads and may result in instability or noisy response. Then R_load should be used. A rheostat is convenient for ease-of-load adjustment. But, at heavy loading, heating may cause contact issues, and, while the coil winding is also an effective inductor, it is not a desirable feature for transient analysis (see Figure 9). A low-inductance decade box is the preferred adjustable Resistive Load, built with non-wire wound or surface-mount power components with short and wide metal interconnects (see Figure 10).

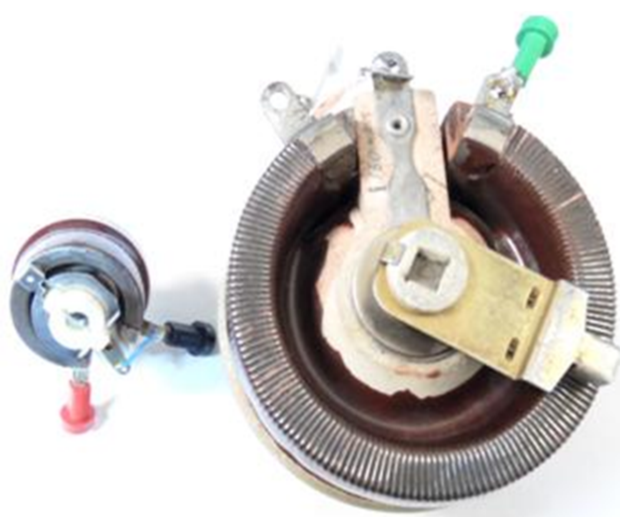

Figure 9. A Rheostat Variable Resistor

NOTE: The rheostat above is commonly used as a variable resistive load in the labs, but it is not a desirable component for transient analysis due to its potential contact bounce issues and the fact that it is a coil of inductance.

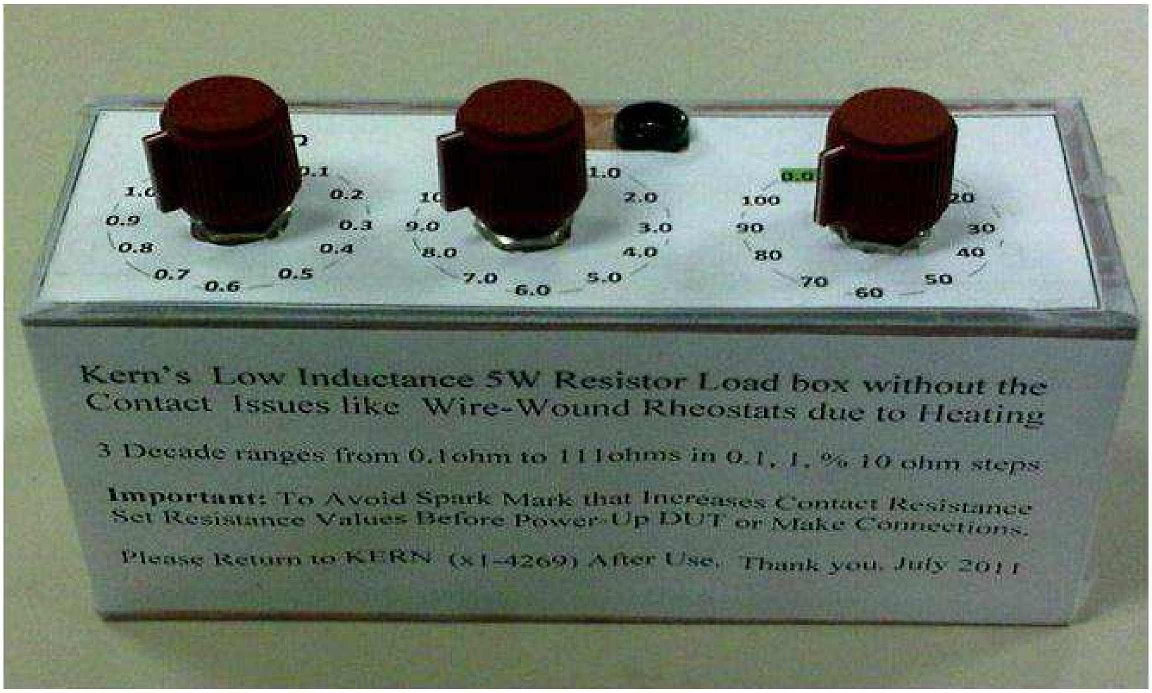

Figure 10. A Low-Inductance Decade Box

NOTE: Waveform exhibits excessive under-shoot and/or ringing are often caused by long return ground lead from the scope probe. A centimeter of ground lead length can manifest many millivolts of unwanted signal with fast edge signals. The spring coil, like ground straps from probe manufacturers, are not good; similarly, those hand-modified short tips with many turns of coiling wrapped on the probe sleeve have the same deficiency. Soldering or welding a short piece of wire at the tip of the sleeve is the best, if using a passive probe. Simplicity is the trick; with more control, it is easier to tame a test setup. (See example of modified probes and tips in Figure 11.)

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4 A Self Contained Load Transient Jig

An improved and integrated load transient test jig as illustrated in Figure 2. The electronic switch and load resistor are embedded right at the scope probe tip. This arrangement not only compacts the jig design and facilitates the test setup. Above all it minimizes the wiring and parasitic significantly. This enables setting faster slew rate parameter figure of merits for one's custom and optimization needs. See the crafted probe-jig shown in Figure 12 below.

Figure 11. Scope Probes with Short Ground Tips

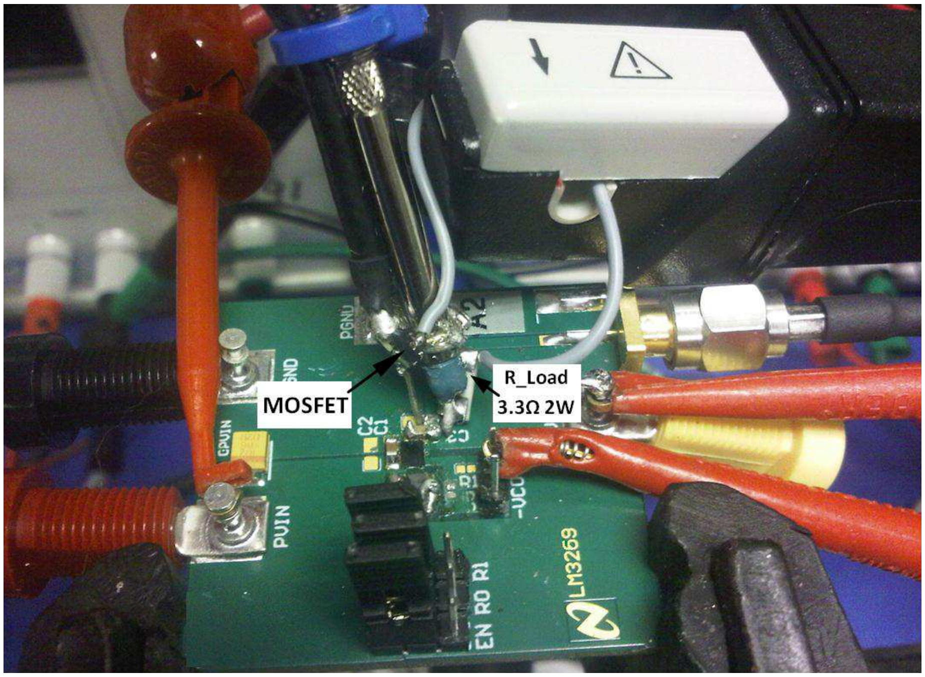

Figure 12. Load Transient Scope Probe Jig Assembly

The Load Transient graphics below show the faster current step stimuli and response using the novel compact load transient jig with a NFET, NDT451AN, 20A pulsed, R_{DSON} = 90 mΩ and an HP8112A pulse generator. Notice that faster current step slew rates of 5.71A/µs rising edge, and 9.70A/µs falling edge, are achievable with this setup, which can satisfy some of the most demanding regulators in the field today. (Top trace step is buck transition from PFM to PWM left, and PWM to PFM, right.) As shown below, the arrows point to the region where the regulator control loop response to the load step in terms of time and magnitude for this aggressive slew rate is employed.

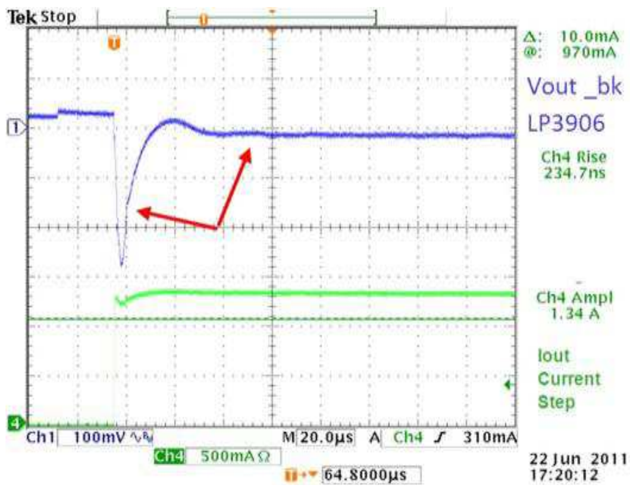

Figure 13. Load Transient Using Probe Jig

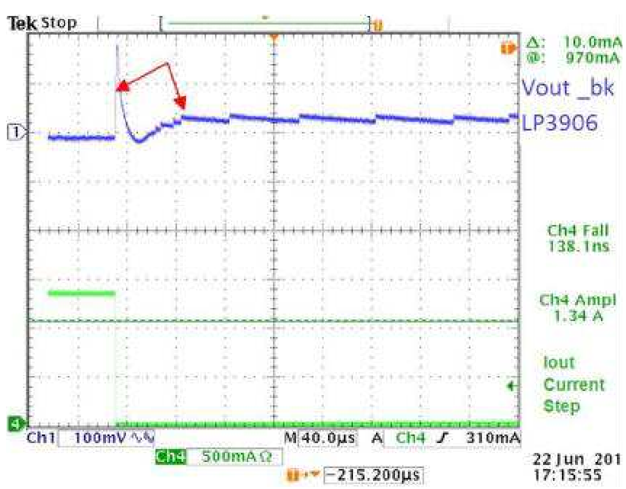

Figure 14. Load Transient Using Probe Jig

5 Very Fast Edge Rates in the ns Range for the Demanding Applications

To demonstrate the improved speed and fidelity of the stimulus and capture capability of the integrated load transient probe jig, a higher bandwidth LM3269 buck-boost switcher designed for powering RF PA application is used as an evaluation platform.

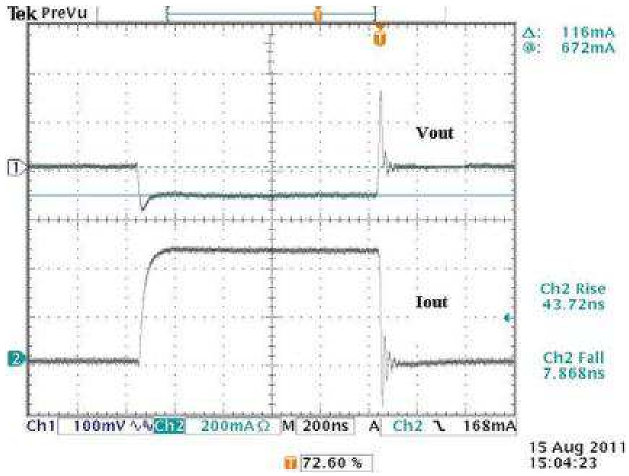

Figure 15. Integrated Load Transient Probe Jig @ Tr = 43. 7 ns

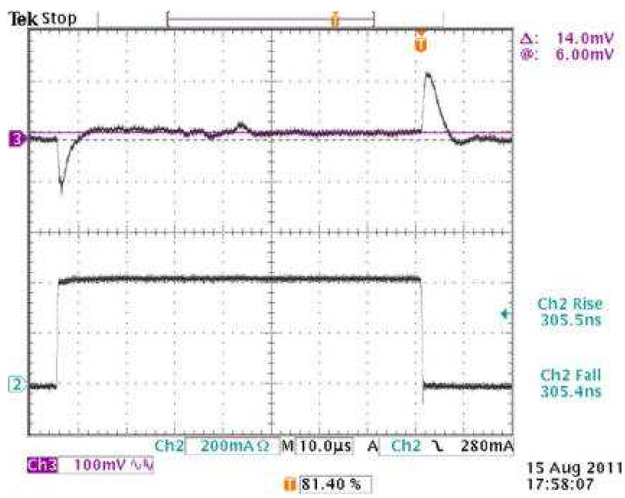

Figure 16. Integrated Load Transient Probe Jig @ Tr = 305 ns

Figure 15 shows a step from 0A to 500 mA with Tr = 43.7 ns and Tf = 7.8 ns, very fast-edge rates times. Figure 16 shows the input step and the output response when the edge rates are reduced to Tr = Tf = 305 ns in 400 mA step.

Figure 17 and Figure 18 below show the regulator output peaking and DC response improved as the current step stimulus function uses much slower edge rates of approximately 1µs and 10 µs, respectively. Current step from 0A to 400 mA is the same as in the case shown in Figure 16 above.

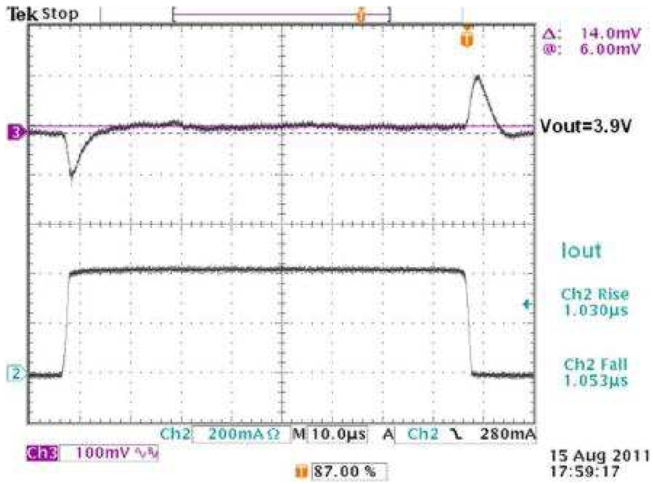

Figure 17. Integrated Load Transient Probe Jig @ Tr = 1µs

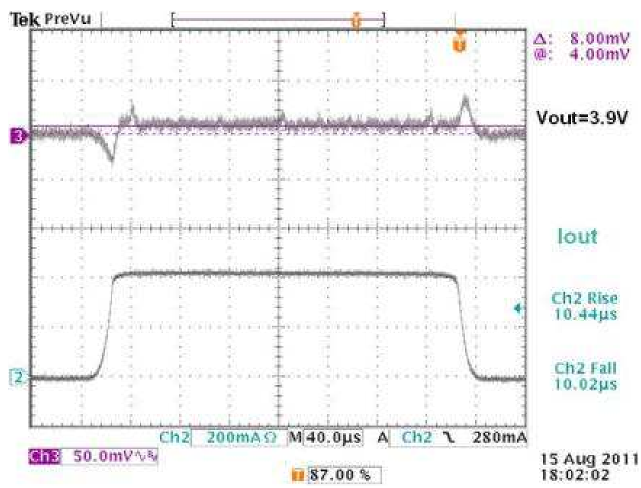

Figure 18. Integrated Load Transient Probe Jig @ Tr = 10 µs

Notice the effects of V_{OUT} peaking from the current pulse edge rate in the above waveforms. Using the same setup and conditions, it can be seen the peaking is very much influenced by inductive parasitics. Peaking is substantially reduced when the edge rate of the current steps is reduced. Thus, V = Ldi/dt is attenuated when the rate of current change di/dt is reduced, while L is fixed. Note the clean current waveforms with little overshoot/undershoot from the integrated setup.

6 Line Transient Jig

A line transient test jig is no more than a variable power supply source, except that can step between two voltage levels rapidly. Typical line transient setups either use a power op-amp based supply source or a complementary symmetry emitter followers circuit. The latter is more widely used due to its simplicity and ease of interface. These circuits generate an output which is a step function delivering the high and low voltage levels required by the device under test for evaluation.

It used to be adequate for the above line step slew rate to be approximately 200 mV/µs. With the advent of new digital devices and complex SoC designs, 5V/µs and better has become typical. Seldom can one find some op-amp-based jig that comes close to these edge rates. The follower scheme may issue faster slew rate, but might not perform well with large steps and at high edge rates. Unity gain amplifier stage design may be vulnerable to marginal instability and care must be taken avoid undesirable ringing.

The prevalent line transient jigs for general use today are either the emitter followers as shown in Figure 19 or a pair of NMOSFET or CMOSFET switches toggling the output between two well bypassed power supplies as depicted by Figure 20. With any choice, bypassing caps should be used liberally with a broad value of capacitances ensuring low impedance over frequencies of interest.

6.1 Complementary Symmetry Emitter Followers Line Transient Jig

The emitter followers circuit depicted in Figure 19 is among the simplest apparatus to use for line transient application. However, the Vbe (typically 0.6v to 0.7V) difference between the input and output should be carefully factored in the setup. In particular, with present core voltages operating down to 0.6V and below, variation in Vbe can be a nuisance such as in over-temperature testing where the drift due to its tempco becomes a larger percentage of the output. One needs to make provision for sensing and adjustment in order to properly compensate it. Another concern is the follower operates without feedback. It is an amplifier stage with a gain of 1 which inherently operates at about unity gain. However, if the amplifier has insufficient phase margin overshoot, ringing and instability may occur.

Care must be exercised in working with follower circuits to ensure clean and stable operation over temperature by applying good layout practice and implement degenerative feedback as needed.

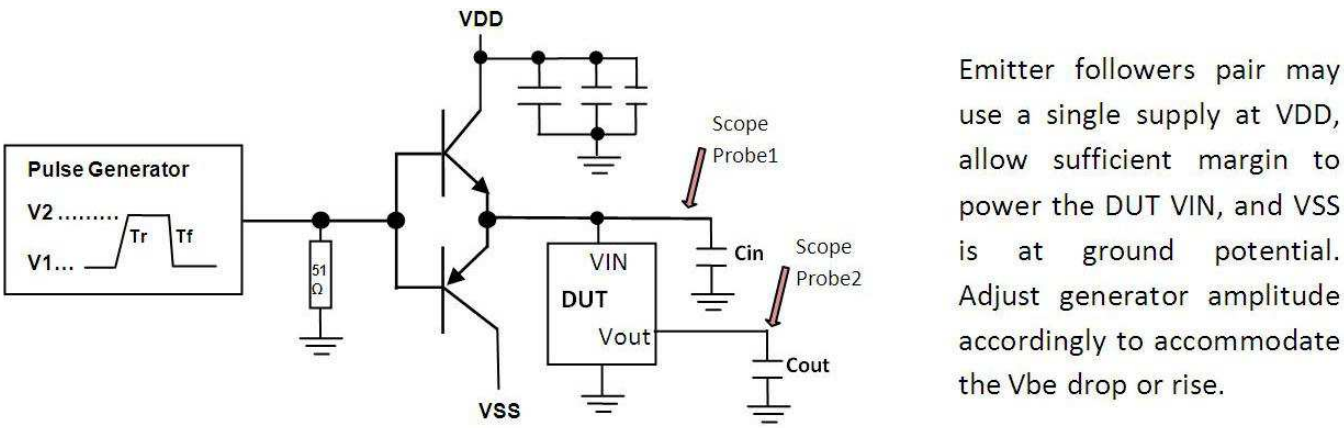

Figure 19. Line Transient Test Jig via Emitter Followers

6.2 Commuting Supplies Line Transient Test Jig

This is achieved by essentially a CMOS power inverter switch as shown in Figure 20. Like the followers jig, a pulse generator is also used in the setup. There are several advantages in this implementation, albeit it requires two power supplies. First, the heart of the operation is only switches, which obviates the potential instability issue and thermal voltage offset as in the emitter follower jig. Second, the gate drive amplitude and edge rates can be independently adjusted to drive the FET switches to obtain wider dynamic range on slew rates and may introduces damping to mitigate potential ringing.

As with a load transient test, setup precautions should be applied. One should try to use a near zero-length scope probe ground lead, if passive using passive probes like those shown in Figure 11. Moreover, keep all wiring among the power supplies, switches, and DUT as short as practical.

6.3 Myth

It has been observed the engineers commonly remove the DUT C_{IN} bypass capacitors to achieve the slew rate required to test their regulators. However, best practice guides that if one's jig cannot drive 10 or 22 uF of C_{IN}, a better line-transient jig should be obtained. If the recommended charge-reservoir and high-frequency bypass capacitors at the VIN pins of the DUT (as dictated by design and datasheet) are not incorporated, the device might not operate properly or optimally. These capacitors are necessary for line transient performance qualification test and to reflect actual operation conditions. A good test jig with adequate drive capability should always be employed to perform line transient test on POL voltage regulators.

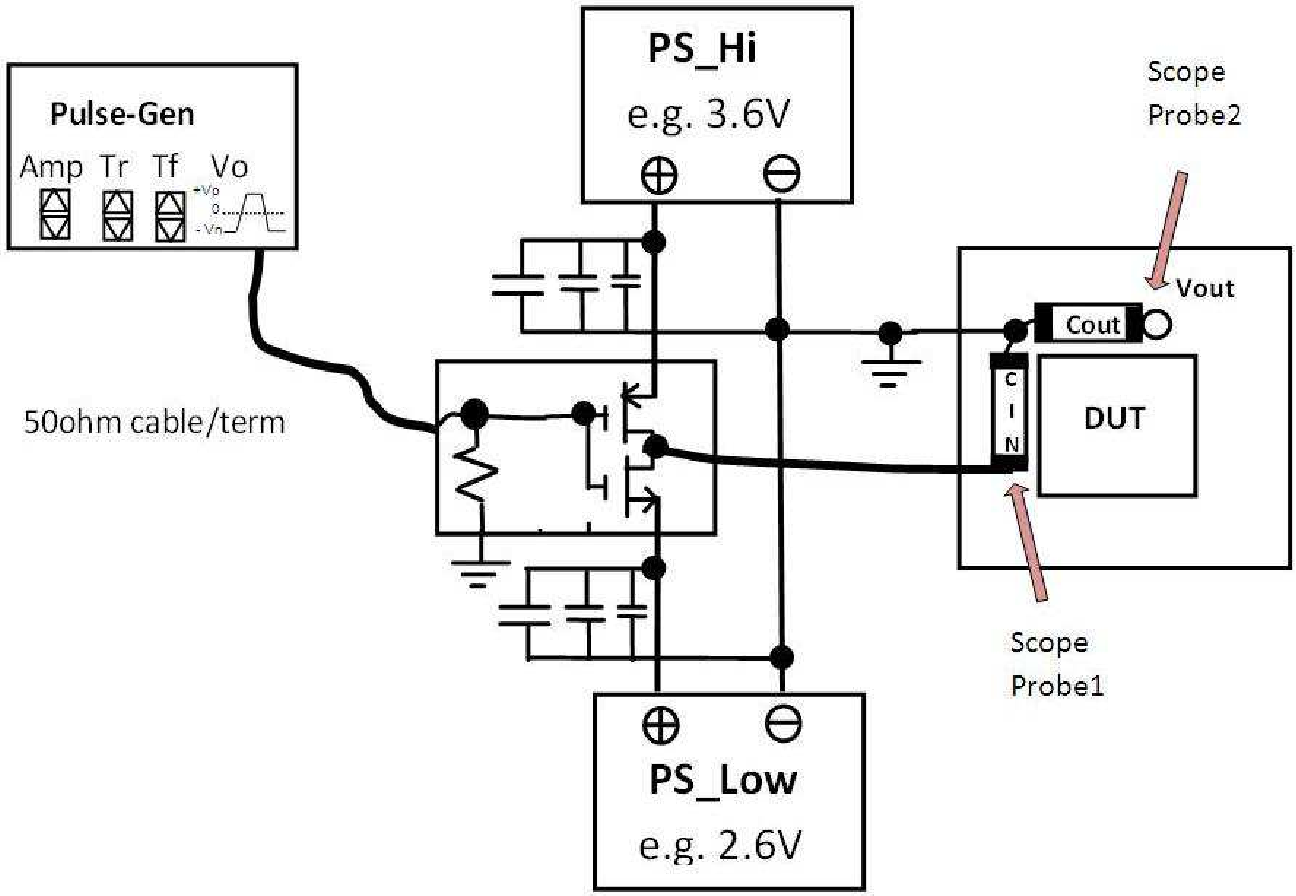

Figure 20. Line Transient Jig via Commutating Supplies Capable of Clean High-Slew Rate and Drive

7 Line Transient Jig With CMOS Switches Driving Two Power Supplies

The inherent slew rates of the switched supplies jig is quite fast with suitable selection of the MOSFETs, layout, and interconnection. Refer to the figures below that show the resultant waveforms of this line transient jig output driving a **purely resistive load** at various example step levels settings. Voltage developed across the resistor by the current step and the edge rates are measured. The data below indicate the switched supplies line transient jig can slew at 13V/µs.

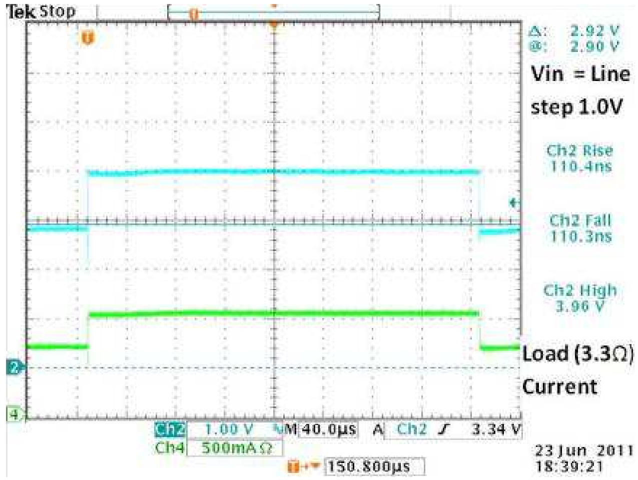

Figure 21. Line Transient Jig 1.0V Step Driving a Resistor

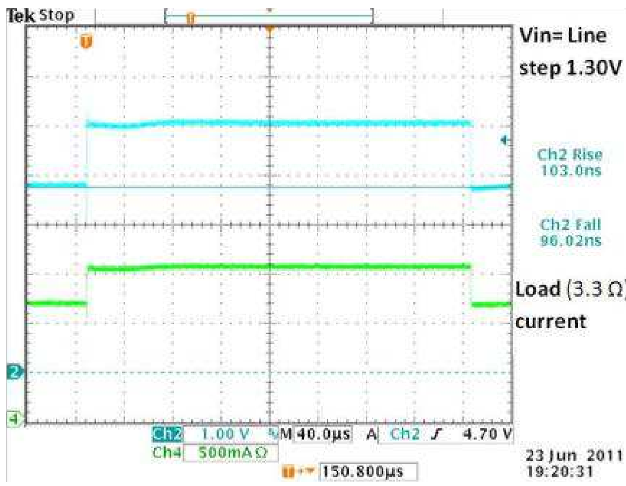

Figure 22. Line Transient Jig 1.3V Step Driving a Resistor

8 Line Transient Test Includes DUT C_{IN}

The LP3906 evaluation board is again used in this demonstration, since it has a larger on board C_{IN} = 12 µF. The DC supply is replaced by the line transient test jig of Figure 19. The NDS8858H integrated complementary CMOS switches and Agilent E3633A supplies are used in driving the buck VIN pins. There is at least 12 µF of capacitance on-board supporting the switcher, plus other distributed impedance between the jig and the evaluation board that the line transient jig circuit must drive. Hence, the edge rate can be seen decreased appreciably with capacitive loading as shown in at the right. Nevertheless, the jig delivers very good slew rate of about 500 mV/µs on both edges for this capacitor-loaded application.

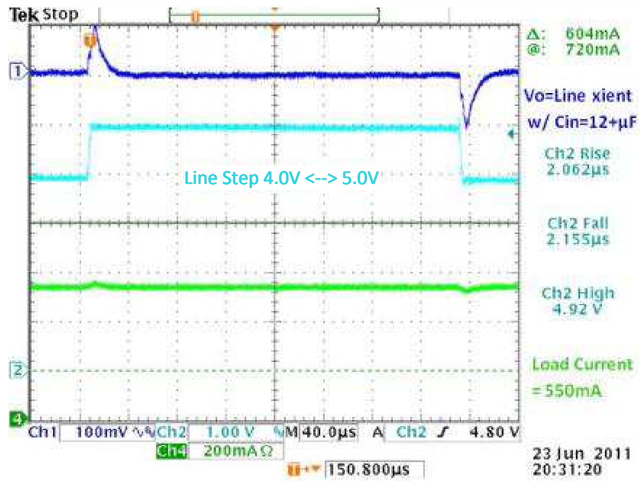

Figure 23. Line Transient Jig 1.0V Step Driving a Buck w/C_{IN}=12 µF

9 Summary

High-performance regulators are currently available, as well as in development, for mobile applications for which load transient must be characterized with stimulus at better than 1A/µs (1mA/ns) for low-output voltage and 20 mA/µs at 5V V_{OUT}. Similarly, for line transient tests high-performance regulators for mobile devices are using 200 mV/µs at low V_{OUT} (< 2V) and I_{OUT} (< 300 mA), and 67 mV/µs for high V_{OUT} (> 3.3V) and I_{OUT}(> 1.5A). Thus, the improved and simplified test jigs illustrated herein are quite suitable for use with demanding applications for the foreseeable future generation of new integrated regulators. Meeting the target needs, lab data confirms fast slew rates on load step at >1A and V_{OUT} = 3.3V can be achieved at better than 5A/us (T_R) and 9A/µs (T_F). Similarly, slew rates on line step of 1V with 12 µF loading at 500 mV/µs can be attained. Table 1 below tabulates a brief summary of the figure of merits comparing the various types of load transient jigs evaluated.

Last but not least, an element that frequently masks line/load transient tests is an unwanted parasitic in the test setup. By reducing the extraneous elements via compact layout design and shorter traces on interconnects and probes, the example jigs should made significant improvement to one's load transient test results. Furthermore, by having more robust drives from the line transient jig, bulk capacitive loading can be accommodated for proper testing.

Table 1.

Load Transient Jigs and Figure of Merit	Typical E-load	NMOS Lab Jig +	NMOS Lab Jib -	Integrated Probe-jig +	Integrated Probe-jig -
Slew Rate (AMP/µs)	75 mA/µs)	1.7A/µs - 2.5	2.5A/µs	5.7A/µs	9.7A/µs
Slew at 1A	1A in 13.3/µs	1A in 588 ns	1A in 400 ns	1A in 175 ns	1A in 103 ns

10 References

1. Load-transient-response testing for voltage regulators, Jim Williams EDN September 28, 2006.
2. The Effects of Load Switch Slew Rate vs Output Transient on LP3972 Buck Regulators, Kern Wong, NSC Portable Power August 10 , 2006.
3. Load Transient Testing Simplified, NSC AN-1733 Chester Simpson Nov, 7, 2007.
4. Line and load transient jig setups, Kern Wong, NSC MDP March 8, 2011.

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Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

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This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

For EVMs annotated as IC – INDUSTRY CANADA Compliant

This Class A or B digital apparatus complies with Canadian ICES-003.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

Concerning EVMs including radio transmitters

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concerning EVMs including detachable antennas

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication.

This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada.

Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l'autorité de l'utilisateur pour actionner l'équipement.

Concernant les EVMs avec appareils radio

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

【Important Notice for Users of this Product in Japan】

This development kit is NOT certified as Confirming to Technical Regulations of Radio Law of Japan

If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or
3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

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【ご使用にあたっての注】

本開発キットは技術基準適合証明を受けておりません。

本製品のご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

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EVALUATION BOARD/KIT/MODULE (EVM)
WARNINGS, RESTRICTIONS AND DISCLAIMERS

For Feasibility Evaluation Only, in Laboratory/Development Environments. Unless otherwise indicated, this EVM is not a finished electrical equipment and not intended for consumer use. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

Your Sole Responsibility and Risk. You acknowledge, represent and agree that:

1. You have unique knowledge concerning Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the EVM for evaluation, testing and other purposes.
2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using the EVM. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.
3. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.
4. You will take care of proper disposal and recycling of the EVM’s electronic components and packing materials.

Certain Instructions. It is important to operate this EVM within TI’s recommended specifications and environmental considerations per the user guidelines. Exceeding the specified EVM ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings please contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, some circuit components may have case temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use these EVMs.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the EVM that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if the EVM fails to perform as described or expected.

Safety-Critical or Life-Critical Applications. If you intend to evaluate the components for possible use in safety critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify TI of such intent and enter into a separate Assurance and Indemnity Agreement.

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

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