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SUCCESSFULLY IMPLEMENTING FLASH LAMPS INVOLVES UNDERSTANDING NUMEROUS PRACTICAL CONSIDERATIONS.

Simple circuitry for cellular-telephone/camera-flash illumination

NEXT-GENERATION CELLULAR TELEPHONES will include high-quality photographic capabilities. To support their improved image sensors and optics, they will need high-quality "flash" illumination, which requires special design attention. This lighting is crucial for yielding good photographic performance and requires careful consideration.

Two practical choices exist for flash illumination: LEDs and flash lamps (**Table 1**). LEDs feature continuous operating capability and low-density support circuitry, among other advantages. Flash lamps, however, have some important characteristics for high-quality photography. Their line-source light output is hundreds of times greater than point-source LEDs, which results in dense, easily diffused light over a wide area. Additionally, the flash lamp's color temperature of 5500° to 6000°K is close to the temperature of natural light, which eliminates the color correction needed by a so-called white LED's blue-peaked output.

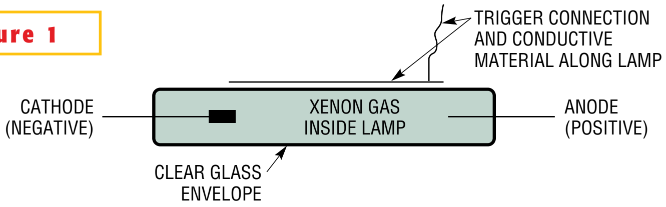
Figure 1 shows a conceptual flash lamp, with a cylindrical glass envelope that is filled with xenon. Anode and cathode electrodes directly contact the gas; the trigger electrode, distributed along the lamp's outer surface, does not. The gas breakdown potential voltage is in the multikilovolt range; once breakdown occurs, lamp impedance drops to less than 1Ω. High current flow in the broken-down gas produces intense visible light. Practically, the large current necessary requires that the circuitry must put the lamp into its low-impedance state before it emits light.

The trigger electrode serves this function. It transmits a high-voltage pulse through the glass envelope, ionizing the xenon along the lamp length. This ionization breaks down the gas, placing it into a low-impedance state. The low impedance permits large current to flow between anode and cathode, producing intense light. The energy involved is so high that current flow and light output are limited to pulsed operation. Continuous operation would quickly produce extreme temperatures, damaging the lamp. When the current pulse decays, lamp voltage drops to a low point, and the lamp reverts to its high-impedance state. It then needs another trigger event to initiate conduction.

SUPPORT THOSE HOT FLASHES

Figure 2 diagrams conceptual support circuitry for flash-lamp operation. A trigger circuit and a storage capacitor that generates the high transient current service the flash lamp. In operation, the flash capacitor is typically charged to 300V. Initially, the capacitor cannot discharge, because the lamp is in its high-impedance state. A command to the trigger circuit produces the multikilovolt trigger pulse at the lamp. The lamp breaks down, allowing the capacitor to discharge. (Strictly speaking, the capacitor does not fully discharge, because the lamp reverts to its high-impedance state when the potential across it decays to some low value—typically, 50V.)

Figure 1

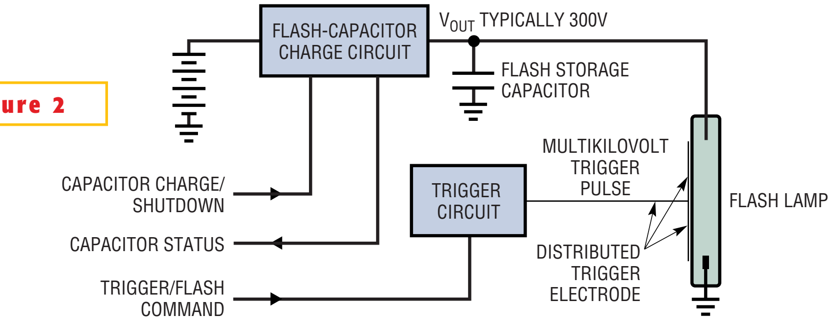


The flash lamp consists of xenon gas-filled glass cylinder with anode, cathode, and trigger electrodes.

Capacitor, wiring, and lamp impedances typically total a few ohms, resulting in transient current flow in the 100A range. This large current pulse produces the intense flash of light.

The ultimate limitation on flash-repetition rate is the lamp's ability to safely dissipate heat. A secondary limitation is the time required for the charging circuit to fully charge the flash capacitor. The large capacitor charging toward a high voltage combines with the charge circuit's finite output impedance, limiting how quickly charging can occur. Charge times of 1 to 5 sec are possible, depending upon available input power, capacitor value, and charge-circuit characteristics.

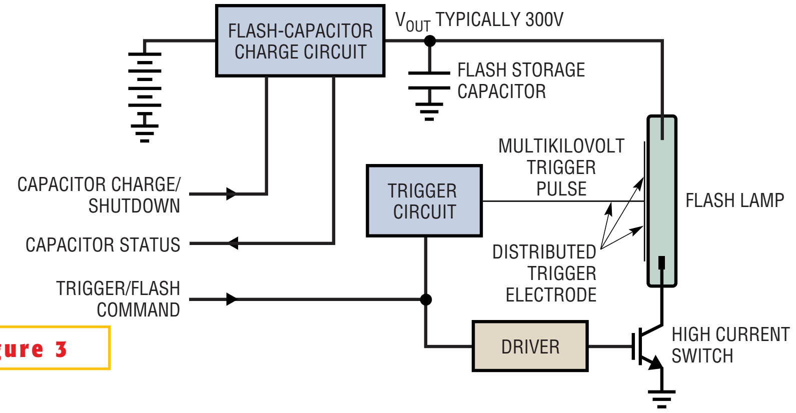
Figure 2



Conceptual flash-lamp circuitry includes a charge circuit, storage capacitor, trigger, and lamp.

The scheme shown in **Figure 2** discharges the capacitor in response to a trigger command. It is sometimes desirable to have a partial discharge, resulting in less intense light flashes. Such operation permits "redeye" reduction, in which one or more reduced-intensity flashes immediately precede the main flash. (Redeye in a photograph is caused by the human retina reflecting the light flash with a distinct red color. You eliminate it by causing the eye's iris to constrict in response to a low-intensity flash immediately preceding the main flash.) The modifications of **Figure 3** provide this operation, where you might have added a driver and a high-current switch to **Figure 2**.

Figure 3

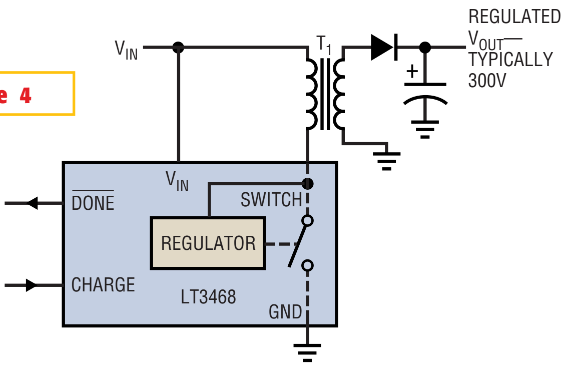


Adding a driver/power switch to Figure 2 permits partial capacitor discharge, allowing pulsed low-level light before main flash, thus minimizing "redeye" phenomena.

These components permit stopping flash-capacitor discharge by opening the lamp's conductive path. This arrangement allows the "trigger/flash-command" control-line pulse width to set current-flow duration and, hence, flash energy. The low-energy, partial capacitor discharge allows rapid recharge, permitting several low-intensity flashes in rapid succession immediately preceding the main flash, without lamp damage.

The flash-capacitor charger of **Figure 4** is basically a transformer-coupled step-up converter with some special capabilities. When the "charge" control line goes high, the regulator clocks the power switch, allowing step-up transformer T_1 to produce high-voltage pulses. These pulses are rectified and filtered, producing the 300V-dc output, with conversion efficiency of about 80%. The circuit regulates by stopping the drive to the power switch when it reaches the desired output. It also pulls the "done" line low, indicating that the capacitor is fully charged. Intermittent power-switch cycling compensates for any capacitor-leakage-induced loss.

Figure 4



A flash-capacitor charger circuit includes an IC regulator, a step-up transformer, a rectifier, and a capacitor.

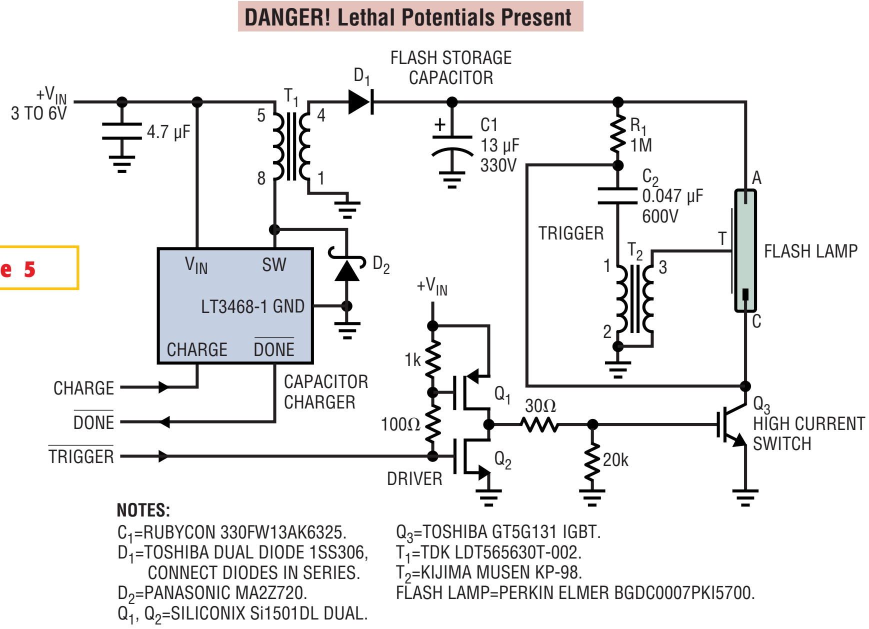
Normally, the circuit would obtain feedback by resistor-chain-dividing down the output voltage. This approach is unacceptable here, because it would require excessive switch cycling to offset the feedback resistor's constant power drain. Although this action would maintain regulation, it would also drain excessive power from the primary source, presumably a battery. Instead, the circuit obtains its regulation by monitoring T_1's flyback-pulse characteristic, which reflects T_1's secondary amplitude. The output voltage is set by T_1's turns ratio. This feature permits tight capacitor-voltage regulation, necessary to ensure consistent flash intensity without exceeding lamp-energy or capacitor-voltage ratings. Also, the capacitor value conveniently determines flash-lamp energy without any other circuit alterations.

THE NEXT CHALLENGE IS THE DETAILS

Figure 5 is a complete flash-lamp circuit based on the previous discussion. **WARNING: This circuit contains high-voltage, lethal potentials. Use extreme caution in its construction, testing, and usage.** The capacitor-charging circuit, similar to **Figure 4**, appears at the upper left. Diode D_2 has been added to safely clamp reverse-transient-voltage events, which originate at T_1. FETs Q_1 and Q_2 drive high-current switch Q_3. Step-up transformer T_2 forms the high-voltage trigger pulse. Assuming that C_1 is fully charged, when Q_1 and Q_2 turn on Q_3, C_2 deposits current into T_2's primary winding. T_2's secondary winding delivers a high-voltage trigger pulse to the lamp, ionizing it to permit conduction. C_1 discharges through the lamp, producing light.

Figure 6 details the capacitor-charging sequence. In Trace A, the "charge" input goes high, which initiates T_1 switching, causing C_1 to ramp up (Trace B). When C_1 arrives at the regulation point, switching ceases, and the resistively pulled-up "done" line drops low (Trace C), indicating C_1's charged state. The "trigger" command (Trace D), resulting in C_1's discharge via the lamp-Q_3 path, may occur any time (in this case, approximately 600 msec) after "done" goes low. Note that this **figure**'s trigger command is lengthened for photographic clarity; it is normally 500 to 1000 µsec in duration for a complete C_1 discharge. Short trigger-input commands facilitate low-level flash events, such as for redeye reduction.

Figure 5



NOTES:
C_1=RUBYCON 330FW13AK6325.
D_1=TOSHIBA DUAL DIODE 1SS306, CONNECT DIODES IN SERIES.
D_2=PANASONIC MA2Z720.
Q_1, Q_2=SILICONIX Si1501DL DUAL.
Q_3=TOSHIBA GT5G131 IGBT.
T_1=TDK LDT565630T-002.
T_2=KIJIMA MUSEN KP-98.
FLASH LAMP=PERKIN ELMER BGDC0007PKI5700.

A complete flash-lamp circuit includes capacitor-charging components (left side), flash capacitor C_1, trigger (R_1, C_2, T_2), Q_1-Q_2 driver, Q_3 power switch, and flash lamp.

Figure 7 shows a high-speed detail of the high-voltage trigger pulse (Trace A) and resultant flash-lamp current (Trace B). Some amount of time is required for the lamp to ionize and begin conduction after triggering. Here, 10 µsec after the 8-kV p-p trigger pulse, flash-lamp current begins its rise to nearly 100A. The current rises smoothly in 5 µsec to a well-defined peak before beginning its descent. The resultant light produced, **Figure 8**, rises more slowly and peaks in about 25 µsec before decaying. Slowing the oscilloscope sweep permits capturing all the current and light events. **Figure 9** shows that the light-output (Trace B) profile follows the lamp-current (Trace A) profile, although current-peaking is more abrupt. Total event duration is approximately 500 µsec, with most of the energy expended in the first 200 µsec. The leading edge's discontinuous presentation is due to the oscilloscope's chopped-display-mode operation.

LAMP, LAYOUT, AND RFI ISSUES

Several lamp-related issues require your attention. First, you must thoroughly understand and adhere to lamp-triggering requirements. Otherwise, you can end up with an incomplete flash or even no lamp flash. Most trigger-related problems involve trigger-transformer selection, drive, and physical location with

TABLE 1—PERFORMANCE CHARACTERISTICS FOR LED- AND FLASH-LAMP-BASED ILLUMINATION

Performance category	Flash lamp	LED
Light output	High—typically 10 to 400× higher than LEDs. Line source output makes even light distribution relatively simple.	Low—point source output makes even light distribution somewhat difficult.
Illumination versus time	Pulsed--good for sharp, still picture.	Continuous--good for video.
Color temperature	5500 to 6000°K—very close to natural light. No color correction necessary.	8500°K—blue light requires color correction.
Solution size	Typically 3.5×8×4 mm for optical assembly; 27×6×5 mm for circuitry--dominated by flash capacitor (6.6 mm in diameter, may be remotely mounted).	Typically 7×7×2.4 mm for optical assembly; 7×7×5 mm for circuitry
Support-circuitry complexity	Moderate	Low
Charge time	1 to 5 sec, depending on flash energy	None—light always available.
Operating voltage and currents	Kilovolts to trigger, 300V to flash. I_{SUPPLY} to charge is approximately 100 to 300 mA, depending on flash energy. Essentially zero standby current.	Typically 3.4 to 4.2V at 30 mA per LED continuous, 100 mA peak. Essentially zero standby current.
Battery power consumption	200 to 800 flashes per battery recharge, depending on flash energy.	Approximately 120 mW per LED (continuous light) and 400 mW per LED (pulsed light).

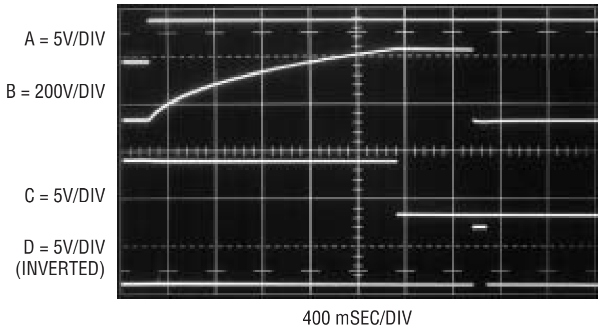


Figure 6 Capacitor-charging waveforms include charge input (Trace A), C_1 (Trace B), "done" output (Trace C), and "trigger" input (Trace D).

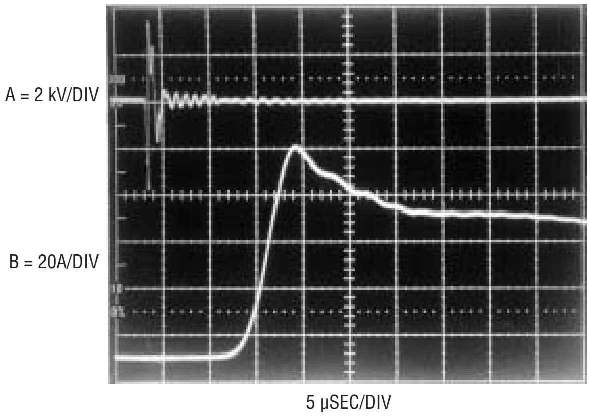


Figure 7 High-speed detail of the trigger pulse (Trace A) and resultant flash-lamp current (Trace B) show that some amount of time is required for the lamp to ionize and begin conduction after triggering.

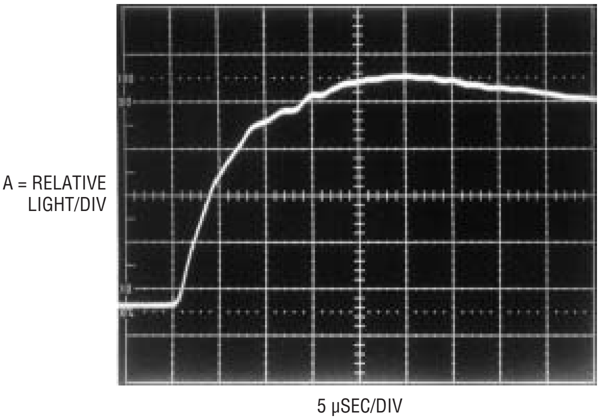


Figure 8 The smoothly ascending flash-lamp light output peaks in 25 µsec.

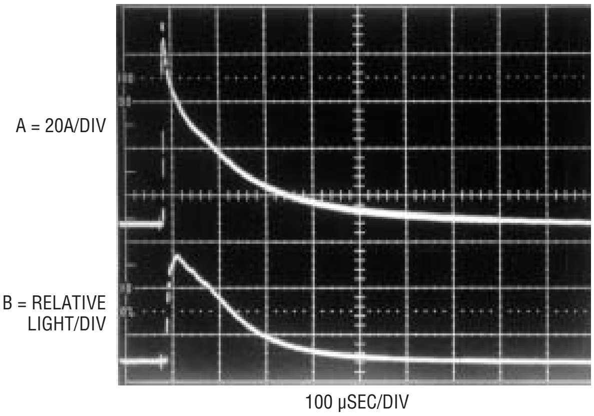


Figure 9 A photograph captures all current (Trace A) and light (Trace B) events; light output follows current profile, although peaking is less defined.

respect to the lamp. Some lamp manufacturers supply the trigger transformer, lamp, and light diffuser as a single, integrated assembly (**Reference 3**). This type of offering obviously implies trigger-transformer approval by the lamp vendor, assuming that you trigger it properly. When the lamp is triggered with a user-selected transformer and drive scheme, it is essential that you obtain lamp-vendor approval before going to production.

The lamp's anode and cathode have access to the lamp's main discharge path. The circuit must respect electrode polarity, or the lamp's lifetime will be severely reduced. Similarly, respect the lamp-energy dissipation restrictions, so lamp lifetime doesn't suffer. Severe lamp-energy overdrive can result in lamp cracking or disintegration. Energy is easily and reliably controlled by selecting capacitor value and charge voltage and restricting flash-repetition rate. As with triggering, lamp-flash conditions promoted by the user's circuit require lamp-manufacturer approval before production.

Assuming proper triggering and flash energy, you can expect lamp lifetimes of approximately 5000 flashes. Lifetimes for various lamp types do differ from this typical figure, but all vendors specify the lifetime of their particular lamps. Note that lifetime is typically defined as the point at which lamp luminosity drops to 80% of its original value.

The high voltages and currents of lamp-related circuits mandate layout planning. Referring back to **Figure 5**, C_1's discharge path is through the lamp, Q_3, and back to ground. The approximately 100A peak current means you must maintain this discharge path at low impedance. Conduction paths between C_1, the lamp, and Q_3 should be short and well below 1Ω.

Additionally, Q_3's emitter and C_1's negative terminal should be directly connected—the goal being a tight, highly conductive loop between C_1's positive terminal, the lamp, and Q_3's return back to C_1. Avoid abrupt trace discontinuities and vias, as the high current flow can cause conductor erosion in local high-resistivity regions. If you must employ vias, they should be filled, verified for low resistance, or used in multiples. Unavoidable capacitor ESR, lamp, and Q_3 resistances typically total 1 to 2.5Ω, so total trace resistance of 0.5Ω or less is adequate. Similarly, the relatively slow rise time of the high current (**Figure 7**) means trace inductance does not have to be tightly controlled.

C_1 is the largest component in the circuit; space considerations may make it

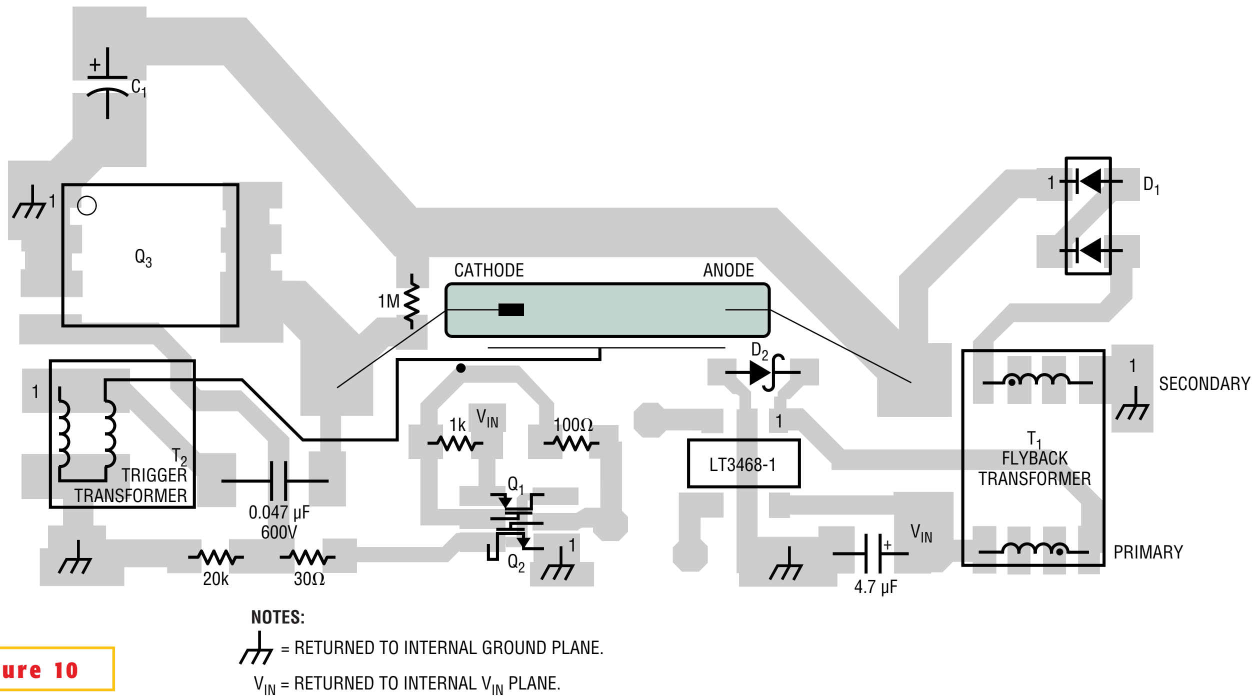


Figure 10

In this magnified demonstration layout for Figure 6, lamp connections are wires, not traces, and wide T_1 secondary spacing accommodates 300V output.

desirable to remotely mount it. You can facilitate this mounting with long traces or wires, as long as you maintain interconnect resistance within the limits stated above.

Capacitor charger-IC layout is similar to conventional switching-regulator practice. The electrical path formed by the IC's V_{IN} pin, its bypass capacitor, the transformer primary, and the switch pin must be short and highly conductive. The IC's ground pin should directly return to a low-impedance, planar ground connection. The transformer's 300V output requires larger than minimum spacing for all high-voltage nodes to meet circuit-board breakdown requirements. Verify board-material-breakdown specifications and ensure that board-washing procedures do not introduce conductive contaminants.

T_2's multikilovolt trigger winding must connect directly to the lamp's trigger electrode, preferably with less than ¼-in. of conductor. You must employ adequate high-voltage spacing. In general, what little conductor there is should not contact the circuit board. Excessive T_2 output length can cause trigger-pulse degradation or RFI; therefore, modular flash-lamp-trigger transformer assemblies are excellent choices.

Figure 10 contains a demonstration layout for **Figure 5**, showing its topside component layer. Power and ground are distributed on internal layers. The LT3468 layout is typical of the switching-regulator practice previously described, although its wide trace spacing accom-

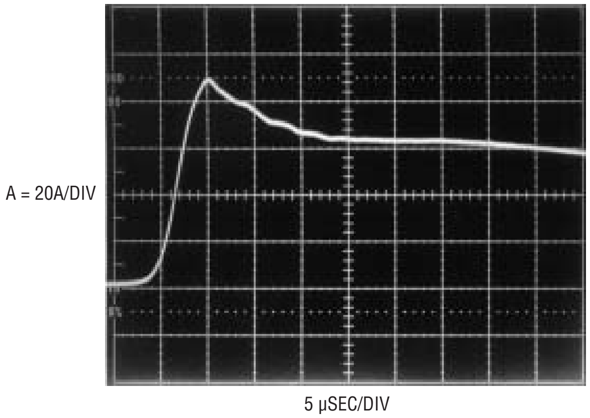


Figure 11

The peak current of 90A is confined within 70-kHz bandwidth by 5-µsec rise time, minimizing noise concerns.

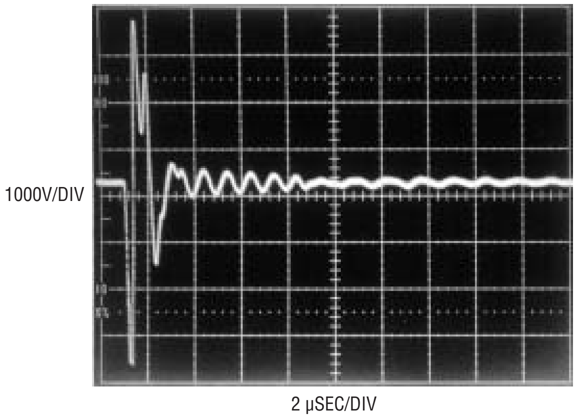


Figure 12

Trigger pulses with high amplitude and fast rise time promote RFI, but energy and path exposure are small, simplifying radiation management.

modates T_1's 300V output. The approximately 100A pulsed current flows in a tight, low-resistance loop from C_1's positive terminal, through the lamp, into Q_3, and back to C_1. In this case, lamp connections are made with wires, although modular flash-lamp-trigger transformers allow trace-based connections (**Reference 3**).

The flash circuit's pulsed high voltages and currents make RFI a concern. The capacitor's high-energy discharge is actually far less offensive than you might suppose. **Figure 11** shows that the 90A current peak of the discharge is confined to a 70-kHz bandwidth by its 5-µsec rise time. Therefore, there is little harmonic energy at radio frequencies, easing the RFI concern. Conversely, **Figure 12**'s T_2 high-voltage output has a 250-nsec rise time (bandwidth is approximately 1.5 MHz), qualifying it as a potential RFI source. Fortunately, the energy involved and the exposed path length are small, making interference management possible.

The simplest interference management you can use involves placing radiating components away from sensitive circuit nodes or employing shielding. Another option takes advantage of the predictable time when the flash circuit operates. You can blank sensitive circuitry within the telephone during flash events, which typically last much less than 1 msec.□

You can find a table listing standard transformers available for LT3468 circuits on the Web version of this article at www.edn.com.

REFERENCES

1. Linear Technology Corporation, "LT3468/LT3468-1/LT3468-2 Data Sheet."
2. Wu, Albert, "Photoflash Capacitor Chargers Fit Into Tight Spots," Linear Technology.
3. Perkin Elmer, "Flashtubes."
4. Perkin Elmer, "Everything you always wanted to know about flashtubes."
5. Rubycon Corporation, Catalog 2004, "Type FW Photoflash Capacitor," pg 187.

AUTHORS' BIOGRAPHIES

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STANDARD TRANSFORMERS AVAILABLE FOR LT3468 CIRCUITS

For use with	Transformer name	Size (W×L×H, mm)	L_{PRI} (µH)	$L_{PRI\text{-}LEAKAGE}$ (nH)	N	R_{PRI} (mΩ)	R_{SEC} (Ω)	Vendor
LT3468/LT3468-2/	SBL-5.6-1	5.6×8.5×4.0	10	200 max	10.2	103	26	Kijima Musen, Hong Kong Office
LT3468-1	SBL-5.6S-1	5.6×8.5×3.0	24	400 max	10.2	305	55	852-2489-8266, kijimahk@netvigator.com
LT3468	LDT565630T-001	5.8×5.8×3.0	6	200 max	10.4	100 max	10 max	TDK, Chicago Sales Office
LT3468-1	LDT565630T--002	5.8×5.8×3.0	14.5	500 max	10.2	240 max	16.5 max	847-803-6100, www.components.tdk.com
LT3468-2	LDT565630T-003	5.8×5.8×3.0	10.5	550 max	10.2	210 max	14 max	
LT3468/LT3468-1	T-15-089	6.4×7.7×4.0	12	400 max	10.2	211 max	27 max	Tokyo Coil Engineering, Japan Office
LT3468-1	T-15-083	8.0×8.9×2.0	20	500 max	10.2	675 max	35 max	0426-56-6336, www.tokyo-coil.co.jp