Simple Circuitry for Cellular Telephone/Camera Flash Illumination

A Practical Guide for Successfully Implementing Flashlamps

Jim Williams and Albert Wu

INTRODUCTION

Next generation cellular telephones will include high quality photographic capability. Improved image sensors and optics are readily utilized, but high quality "Flash" illumination requires special attention. Flash lighting is crucial for obtaining good photographic performance and must be quite carefully considered.

FLASH ILLUMINATION ALTERNATIVES

Two practical choices exist for flash illumination—LEDs (Light Emitting Diode) and flashlamps. Figure 1 compares various performance categories for LED and flashlamp approaches. LEDs feature continuous operating capability and low density support circuitry among other advantages. Flashlamps, however, have some particularly important characteristics for high quality photography.

Their line source light output is hundreds of times greater than point source LEDs, resulting in dense, easily diffused light over a wide area. Additionally, the flashlamp color temperature of 5500°K to 6000°K, quite close to natural light, eliminates the color correction necessitated by a white LED's blue peaked output.

FLASHLAMP BASICS

Figure 2 shows a conceptual flashlamp. The cylindrical glass envelope is filled with Xenon gas. Anode and cathode electrodes directly contact the gas; the trigger electrode, distributed along the lamp's outer surface, does not. Gas breakdown potential is in the multikilovolt range; once breakdown occurs, lamp impedance drops to $\leq 1\Omega$. High

$\boldsymbol{\mathcal{L}\mathcal{T}}$, LTC and LT are registered trademarks of Linear Technology Corporation.

PERFORMANCE CATEGORY	FLASHLAMP	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 vs Time	Pulsed—Good for Sharp, Still Picture	Continuous—Good for Video
Color Temperature	5500°K to 6000°K—Very Close to Natural Light. No Color Correction Necessary	8500°K—Blue Light Requires Color Correction
Solution Size	Typically 3.5mm × 8mm × 4mm for Optical Assembly. 27mm × 6mm × 5mm for Circuitry—Dominated by Flash Capacitor (≈6.6mm Diameter; May be Remotely Mounted)	Typically 7mm × 7mm × 2.4mm for Optical Assembly, 7mm × 7mm × 5mm for Circuitry
Support Circuit Complexity	Moderate	Low
Charge Time	1 to 5 Seconds, Dependant Upon Flash Energy	None—Light Always Available
Operating Voltage and Currents	Kilovolts to Trigger, 300V to Flash. I_{SUPPLY} to Charge ≈ 100mA to 300mA, Dependant Upon Flash Energy. Essentially Zero Standby Current	Typically 3.4V to 4.2V at 30mA per LED Continuous—100mA Peak. Essentially Zero Standby Current
Battery Power Consumption	200 to 800 Flashes per Battery Recharge, Dependent Upon Flash Energy	≈120mW per LED (Continuous Light) ≈400mW per LED (Pulsed Light)

Partial Source: Perkin Elmer Optoelectronics

Figure 1. Performance Characteristics for LED and Flashlamp-Based Illumination. LEDs Feature Small Size, No Charge Time and Continuous Operating Capability; Flashlamps are Much Brighter with Better Color Temperature
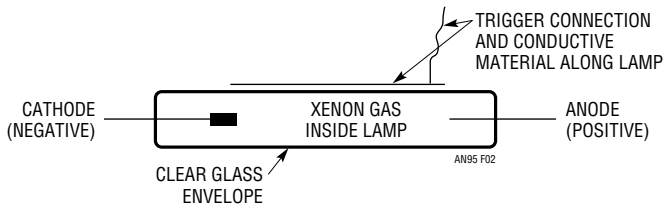
an95f

Figure 2. Flashlamp Consists of Xenon Gas-Filled Glass Cylinder with Anode, Cathode and Trigger Electrodes. High Voltage Trigger Ionizes Gas, Lowering Breakdown Potential to Permit Light Producing Current Flow Between Anode and Cathode. Distributed Trigger Connection Along Lamp Length Ensures Complete Lamp Breakdown, Resulting in Optimal Illumination

current flow in the broken down gas produces intense visible light. Practically, the large current necessary requires that the lamp be put into its low impedance state before emitting light. The trigger electrode serves this function. It transmits a high voltage pulse through the glass envelope, ionizing the Xenon gas 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, necessitating another trigger event to initiate conduction.

SUPPORT CIRCUITRY

Figure 3 diagrams conceptual support circuitry for flashlamp operation. The flashlamp is serviced by a trigger circuit and a storage capacitor that generates the high

transient current. 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 applied to the trigger circuit results in a multikilovolt trigger pulse at the lamp. The lamp breaks down, allowing the capacitor to discharge[1]. Capacitor, wiring and lamp impedances typically total a few ohms, resulting in transient current flow in the 100A range. This heavy 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 towards a high voltage combines with the charge circuit's finite output impedance, limiting how quickly charging can occur. Charge times of 1 to 5 seconds are realizable, depending upon available input power, capacitor value and charge circuit characteristics.

The scheme shown discharges the capacitor in response to a trigger command. It is sometimes desirable to effect partial discharge, resulting in less intense light flashes. Such operation permits "red-eye" reduction, where the main flash is immediately preceded by one or more reduced intensity flashes[2]. Figure 4's modifications provide this operation. A driver and a high current switch have been added to Figure 3. These components permit

---

Note 1. 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.

Note 2. "Red-eye" in a photograph is caused by the human retina reflecting the light flash with a distinct red color. It is eliminated by causing the eye's iris to constrict in response to a low intensity flash immediately preceding the main flash.
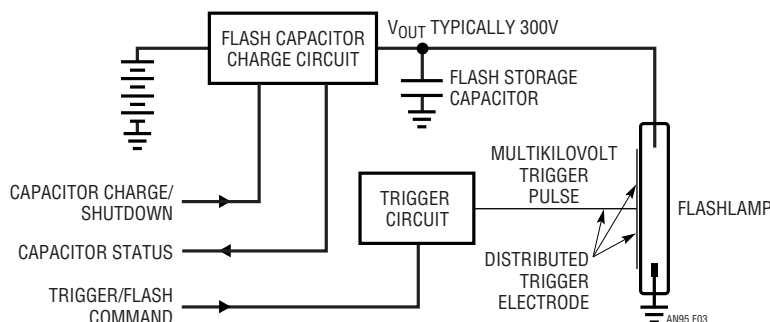

Figure 3. Conceptual Flashlamp Circuitry Includes Charge Circuit, Storage Capacitor, Trigger and Lamp. Trigger Command Ionizes Lamp Gas, Allowing Capacitor Discharge Through Flashlamp. Capacitor Must be Recharged Before Next Trigger Induced Lamp Flash Can Occur
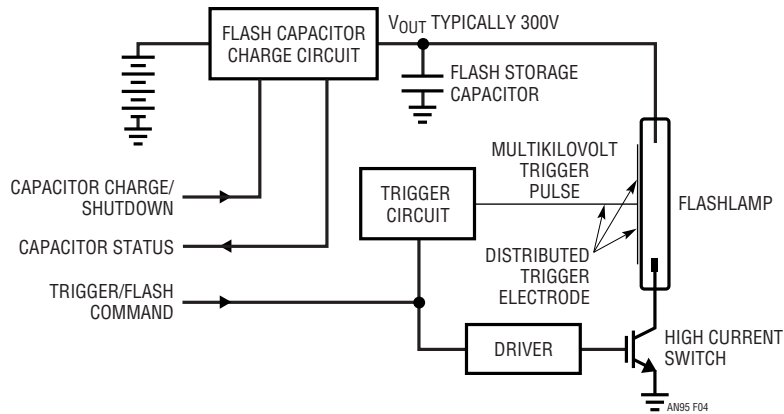
an95f

Figure 4. Driver/Power Switch Added to Figure 3 Permits Partial Capacitor Discharge, Resulting in Controllable Light Emission. Capability Allows Pulsed Low Level Light Before Main Flash, Minimizing "Red-Eye" Phenomena

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 preceeding the main flash without lamp damage.

FLASH CAPACITOR CHARGER CIRCUIT CONSIDERATIONS

The flash capacitor charger (Figure 5) is basically a transformer coupled step-up converter with some special capabilities[3]. When the "charge" control line goes high, the regulator clocks the power switch, allowing step-up transformer T1 to produce high voltage pulses. These pulses are rectified and filtered, producing the 300V DC output. Conversion efficiency is about 80%. The circuit regulates by stopping drive to the power switch when the desired output is reached. It also pulls the "$\overline{\text{DONE}}$" line low, indicating that the capacitor is fully charged. Any capacitor leakage-induced loss is compensated by intermittent power switch cycling. Normally, feedback would be provided by resistively dividing down the output voltage. This approach is not acceptable because it would require excessive switch cycling to offset the feedback resistor's constant power drain. While this action would maintain regulation, it would also drain excessive power from the primary source, presumably a battery. Regula-
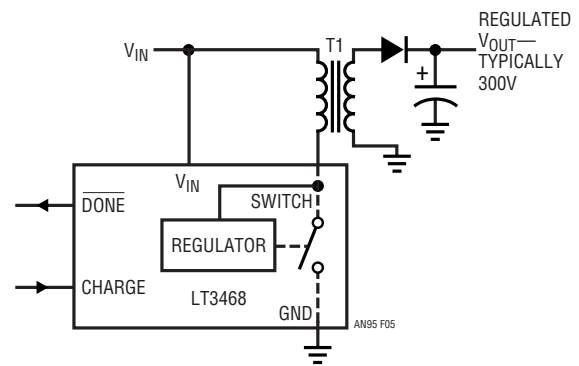

Figure 5. Flash Capacitor Charger Circuit Includes IC Regulator, Step-Up Transformer, Rectifier and Capacitor. Regulator Controls Capacitor Voltage by Monitoring T1's Flyback Pulse, Eliminating Conventional Feedback Resistor Divider's Loss Path. Control Pins Include Charge Command and Charging Complete ("$\overline{\text{DONE}}$") Indication

tion is instead obtained by monitoring T1's flyback pulse characteristic, which reflects T1's secondary amplitude. The output voltage is set by T1's turns ratio[4]. This feature permits tight capacitor voltage regulation, necessary to ensure consistent flash intensity without exceeding lamp energy or capacitor voltage ratings. Also, flashlamp energy is conveniently determined by the capacitor value without any other circuit alterations.

Note 3. Details on this device's operation appear in Appendix A, "A Monolithic Flash Capacitor Charger."
Note 4. See Appendix A for recommended transformers.

DETAILED CIRCUIT DISCUSSION

BEFORE PROCEEDING ANY FURTHER, THE READER IS WARNED THAT CAUTION MUST BE USED IN THE CONSTRUCTION, TESTING AND USE OF THIS CIRCUIT. HIGH VOLTAGE, LETHAL POTENTIALS ARE PRESENT IN THIS CIRCUIT. EXTREME CAUTION MUST BE USED IN WORKING WITH, AND MAKING CONNECTIONS TO, THIS CIRCUIT. REPEAT: THIS CIRCUIT CONTAINS DANGEROUS, HIGH VOLTAGE POTENTIALS. USE CAUTION.

Figure 6 is a complete flashlamp circuit based on the previous text discussion. The capacitor charging circuit, similar to Figure 5, appears at the upper left. D2 has been added to safely clamp T1-originated reverse transient voltage events. Q1 and Q2 drive high current switch Q3. The high voltage trigger pulse is formed by step-up transformer T2. Assuming C1 is fully charged, when Q1-Q2 turns Q3 on, C2 deposits current into T2's primary. T2's secondary delivers a high voltage trigger pulse to the lamp, ionizing it to permit conduction. C1 discharges through the lamp, producing light.

Figure 7 details the capacitor charging sequence. Trace A, the "charge" input, goes high. This initiates T1 switching, causing C1 to ramp up (trace B). When C1 arrives at the regulation point, switching ceases and the resistively pulled-up "DONE" line drops low (trace C), indicating C1's charged state. The "TRIGGER" command (trace D), resulting in C1's discharge via the lamp-Q3 path, may occur any time (in this case ≈600ms) after "DONE" goes low. Note that this figure's trigger command is lengthened for photographic clarity; it normally is 500µs to 1000µs in duration for a complete C1 discharge. Low level flash events, such as for "red-eye" reduction, are facilitated by short duration trigger input commands.

DANGER! Lethal Potentials Present — See Text

C1: RUBYCON 330FW13AK6325
D1: TOSHIBA DUAL DIODE 1SS306, CONNECT DIODES IN SERIES
D2: PANASONIC MA2Z720
Q1, Q2: SILICONIX Si1501DL DUAL

Q3: TOSHIBA GT5G131 IGBT
T1: TDK LDT565630T-002
T2: KIJIMA MUSEN KP-98
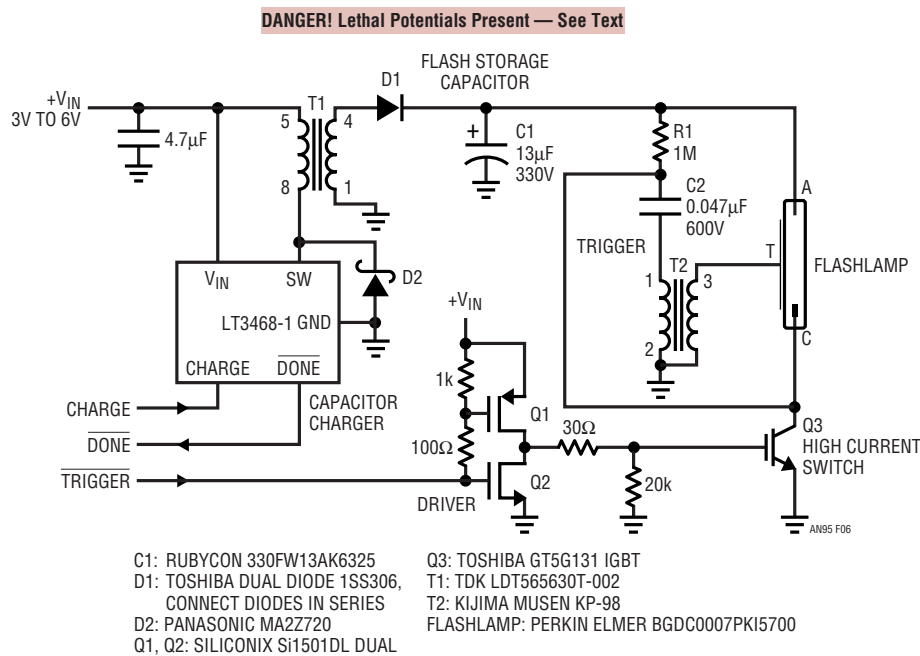FLASHLAMP: PERKIN ELMER BGDC0007PKI5700

Figure 6. Complete Flashlamp Circuit Includes Capacitor Charging Components (Figure Left), Flash Capacitor C1, Trigger (R1, C2, T2), Q1-Q2 Driver, Q3 Power Switch and Flashlamp. TRIGGER Command Simultaneously Biases Q3 and Ionizes Lamp via T2. Resultant C1 Discharge Through Lamp Produces Light
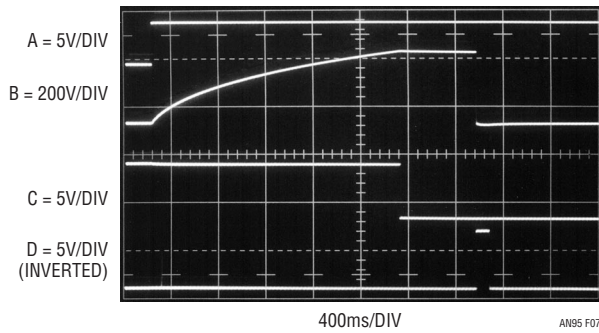
Figure 7. Capacitor Charging Waveforms Include Charge Input (Trace A), C1 (Trace B), DONE Output (Trace C) and TRIGGER Input (Trace D). C1's Charge Time Depends Upon Its Value and Charge Circuit Output Impedance. TRIGGER Input, Widened for Figure Clarity, May Occur any Time After DONE Goes Low

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

LAMP, LAYOUT, RFI AND RELATED ISSUES

Lamp Considerations

Several lamp related issues require attention. Lamp triggering requirements must be thoroughly understood and adhered to. If this is not done, incomplete or no lamp flash may occur. Most trigger related problems involve trigger transformer selection, drive and physical location with respect to the lamp. Some lamp manufacturers supply the trigger transformer, lamp and light diffuser as a single, integrated assembly[5]. This obviously implies trigger transformer approval by the lamp vendor, assuming it is driven properly. In cases where the lamp is
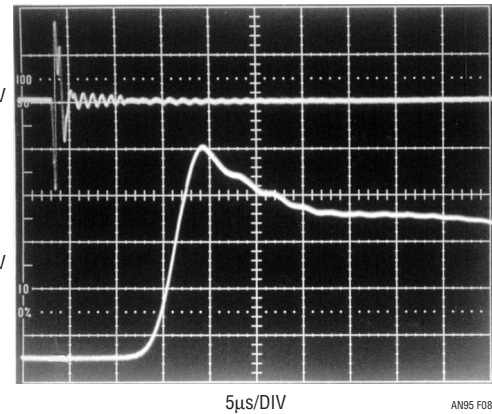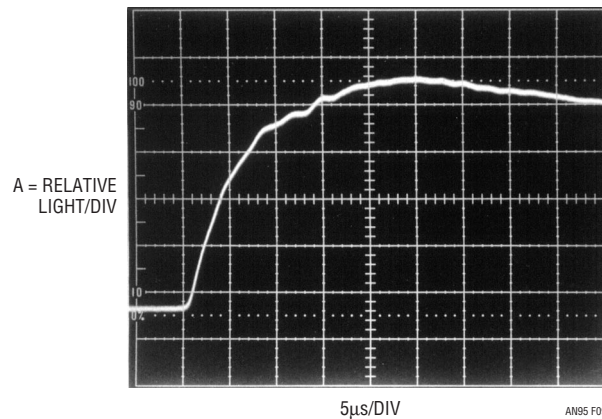
Note 5. See Reference 1.

Figure 8. High Speed Detail of Trigger Pulse (Trace A) and Resultant Flashlamp Current (Trace B). Current Approaches 100A After Trigger Pulse Ionizes Lamp

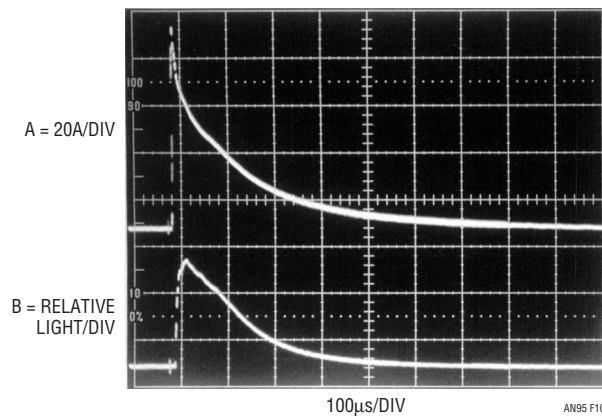Figure 9. Smoothly Ascending Flashlamp Light Output Peaks in 25μs

Figure 10. Photograph Captures Entire Current (Trace A) and Light (Trace B) Events. Light Output Follows Current Profile Although Peaking is Less Defined. Leading Edges Dashed Presentation Derives from Oscilloscope's Chopped Display Operation

an95f

triggered with a user-selected transformer and drive scheme, it is essential to obtain lamp vendor approval before going to production.

The lamp's anode and cathode access the lamp's main discharge path. Electrode polarity must be respected or severe lifetime degradation will occur. Similarly, lamp energy dissipation restrictions must be respected or lifetime will 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, lamp lifetimes of ≈5000 flashes may be expected. Lifetime for various lamp types differs from this figure, although all are vendor specified. Lifetime is typically defined as the point where lamp luminosity drops to 80% of its original value.

Layout

The high voltages and currents mandate layout planning. Referring back to Figure 6, C1's discharge path is through the lamp, Q3 and back to ground. The ≈100A peak current means this discharge path must be maintained at low impedance. Conduction paths between C1, the lamp and Q3 should be short and well below 1Ω. Additionally, Q3's emitter and C1's negative terminal should be directly connected, the goal being a tight, highly conductive loop between C1's positive terminal, the lamp and Q3's return back to C1. Abrupt trace discontinuities and vias should be avoided as the high current flow can cause conductor erosion in local high resistivity regions. If vias must be employed they should be filled, verified for low resistance or used in multiples. Unavoidable capacitor ESR, lamp and Q3 resistances typically total 1Ω to 2.5Ω, so total trace resistance of 0.5Ω or less is adequate. Similarly, the high

current's relatively slow risetime (see Figure 8) means trace inductance does not have to be tightly controlled.

C1 is the largest component in the circuit; space considerations may make remotely mounting it desirable. This can be facilitated with long traces or wires so long as interconnect resistance is maintained 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. T2's multikilovolt trigger winding must connect *directly* to the lamp's trigger electrode, preferably with less than 1/4" of conductor. Adequate high voltage spacing must be employed. In general, what little conductor there is should not contact the circuit board. Excessive T2 output length can cause trigger pulse degradation or radio frequency interference (RFI). Modular flashlamp-trigger transformer assemblies are excellent choices in this regard.

A demonstration layout for Figure 6 appears in Figure 11. The topside component layer is shown. Power and ground are distributed on internal layers. LT3468 layout is typical of switching regulator practice previously described, although wide trace spacing accomodates T1's 300V output. The ≈100A pulsed current flows in a tight, low resistance loop from C1's postive terminal, through the lamp, into Q3 and back to C1. In this case lamp connections are made with wires, although modular flashlamp-trigger transformers allow trace-based connections[6].
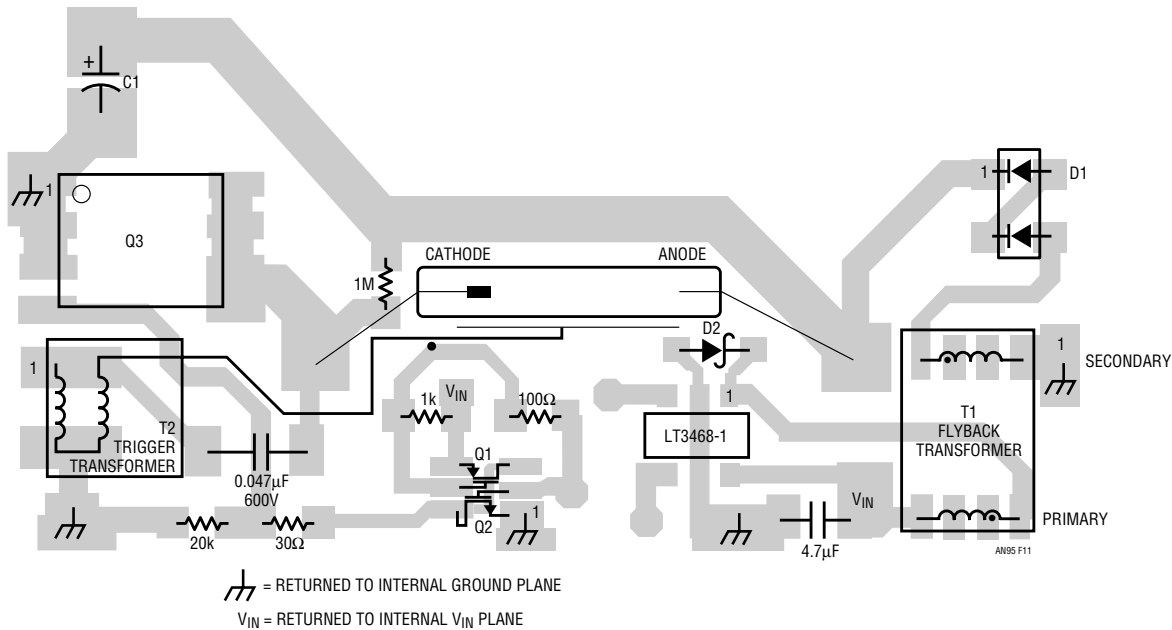
Note 6. See Reference 1.

Figure 11. Magnified Demonstration Layout for Figure 6. High Current Flows in Tight Loop from C1 Positive Terminal, Through Lamp, Into Q3 and Back to C1. Lamp Connections are Wires, Not Traces. Wide T1 Secondary Spacing Accommodates 300V Output

Radio Frequency Interference

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 might be supposed. Figure 12 shows the discharge's 90A current peak confined to a 70kHz bandwidth by its 5µs risetime. This means there is little harmonic energy at radio frequencies, easing this concern. Conversely, Figure 13's T2 high voltage output has a 250ns risetime (BW ≈ 1.5MHz), qualifying it as a potential RFI source. Fortunately, the energy involved and the exposed path length (see layout comments) are small, making interference management possible.

The simplest interference management 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. Sensitive circuitry within the telephone can be blanked during flash events, which typically last well under 1ms.

Note: *This application note was derived from a manuscript originally prepared for publication in* EDN *magazine.*
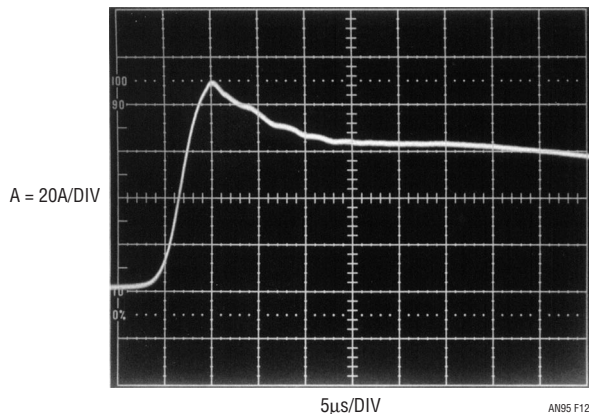
Figure 12. 90A Current Peak is Confined Within 70kHz Bandwidth by 5µs Risetime, Minimizing Noise Concerns
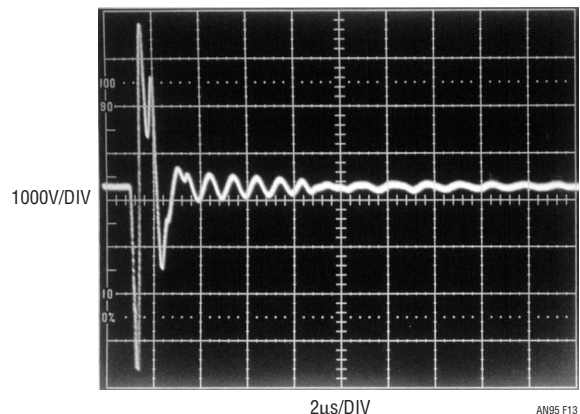
Figure 13. Trigger Pulses High Amplitude and Fast Risetime Promote RFI, but Energy and Path Exposure are Small, Simplifying Radiation Management

REFERENCES

1. Perkin Elmer, "Flashtubes."

2. Perkin Elmer, "Everything You Always Wanted to Know About Flashtubes."

3. Linear Technology Corporation, "LT®3468/LT3468-1/ LT3468-2 Data Sheet."

4. Wu, Albert, "Photoflash Capacitor Chargers Fit Into Tight Spots," Linear Technology, Vol. XIII, No. 4, December, 2003.

5. Rubycon Corporation. Catalog 2004, "Type FW Photoflash Capacitor," Page 187.

an95f

APPENDIX A

A MONOLITHIC FLASH CAPACITOR CHARGER

The LT3468/LT3468-1/LT3468-2 charge photoflash capacitors quickly and efficiently. Operation is understood by referring to Figure A1. When the CHARGE pin is driven high, a one shot sets both SR latches in the correct state. Power NPN, Q1, turns on and current begins ramping up in T1's primary. Comparator A1 monitors switch current and when peak current reaches 1.4A (LT3468), 1A(LT3468-2) or 0.7A (LT3468-1), Q1 is turned off. Since T1 is utilized as a flyback transformer, the flyback pulse on the SW pin causes A3's output to be high. SW pin voltage must be at least 36mV above V_{IN} for this to happen.

During this phase, current is delivered to the photoflash capacitor via T1's secondary and D1. As the secondary current decreases to zero, the SW pin voltage begins to collapse. When the SW pin voltage drops to 36mV above V_{IN} or lower, A3's output goes low. This fires a one shot which turns Q1 back on. This cycle continues, delivering power to the output.

Output voltage detection is accomplished via R2, R1, Q2 and comparator A2. Resistors R1 and R2 are sized so that when the SW voltage is 31.5V above V_{IN}, A2's output goes high, resetting the master latch. This disables Q1, halting

LT3468: $R_{SENSE} = 0.015\Omega$
LT3468-2: $R_{SENSE} = 0.022\Omega$
LT3468-1: $R_{SENSE} = 0.03\Omega$

AN95 FA1

Figure A1. LT3468 Block Diagram. Charge Pin Controls Power Switching to T1. Photoflash Capacitor Voltage is Regulated by Monitoring T1's Flyback Pulse, Eliminating Conventional Feedback Resistors Loss Path

power delivery. Q3 is turned on, pulling the $\overline{DONE}$ pin low, indicating the part has finished charging. Power delivery can only be restarted by toggling the CHARGE pin.

The CHARGE pin gives the user full control of the part. Charging can be halted at any time by bringing the CHARGE pin low. Only when the final output voltage is reached will the $\overline{DONE}$ pin go low. Figure A2 shows these various modes in action. When CHARGE is first brought high, charging commences. When CHARGE is brought

low during charging, the part shuts down and V_{OUT} no longer rises. When CHARGE is brought high again, charging resumes. When the target V_{OUT} voltage is reached, the $\overline{DONE}$ pin goes low and charging stops. Finally, the CHARGE pin is brought low again, the part enters shutdown and the $\overline{DONE}$ pin goes high.

The only difference between the three LT3468 versions is the peak current level. The LT3468 offers the fastest charge time. The LT3468-1 has the lowest peak current capability, and is designed for applications requiring limited battery drain. Due to the lower peak current, the LT3468-1 can use a physically smaller transformer. The LT3468-2 has a current limit between the LT3468 and the LT3468-1. Comparative plots of the three versions charge time, efficiency and output voltage tolerance appear in Figures A3, A4 and A5.

Standard off-the-shelf transformers, available for all LT3468 versions, are available and detailed in Figure A6. For transformer design considerations, as well as other supplemental information, see the LT3468 data sheet.
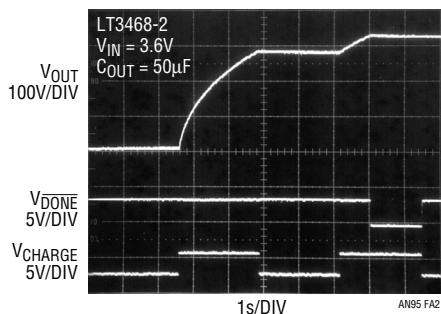

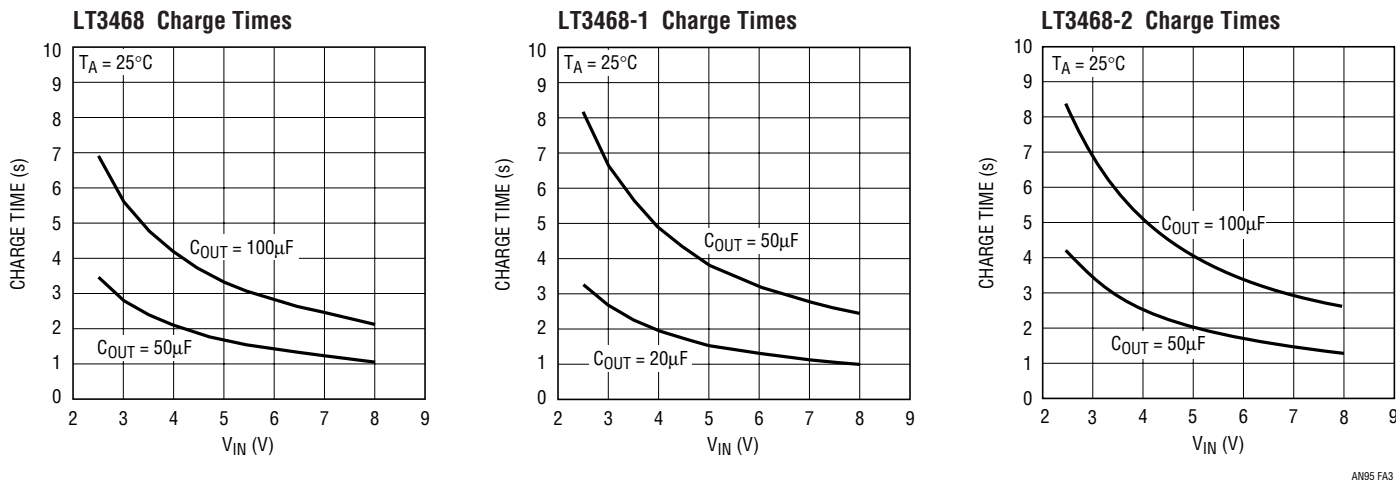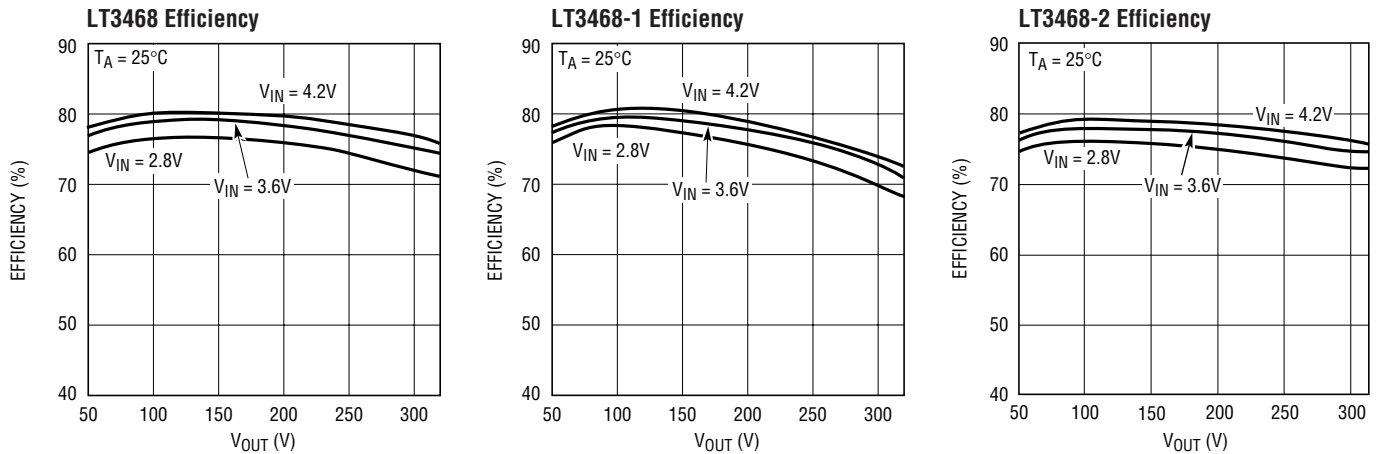**Figure A2. Halting the Charging Cycle with the CHARGE Pin**

Figure A3. Typical LT3438 Charge Times. Charge Time Varies with IC Version, Capacitor Size and Input Voltage

LT3468 Efficiency

LT3468-1 Efficiency

LT3468-2 Efficiency

AN95 FA4

Figure A4. Efficiency for the Three LT3468 Versions Varies with Input and Output Voltages

LT3468 Output Voltage

LT3468-1 Output Voltage

LT3468-2 Output Voltage
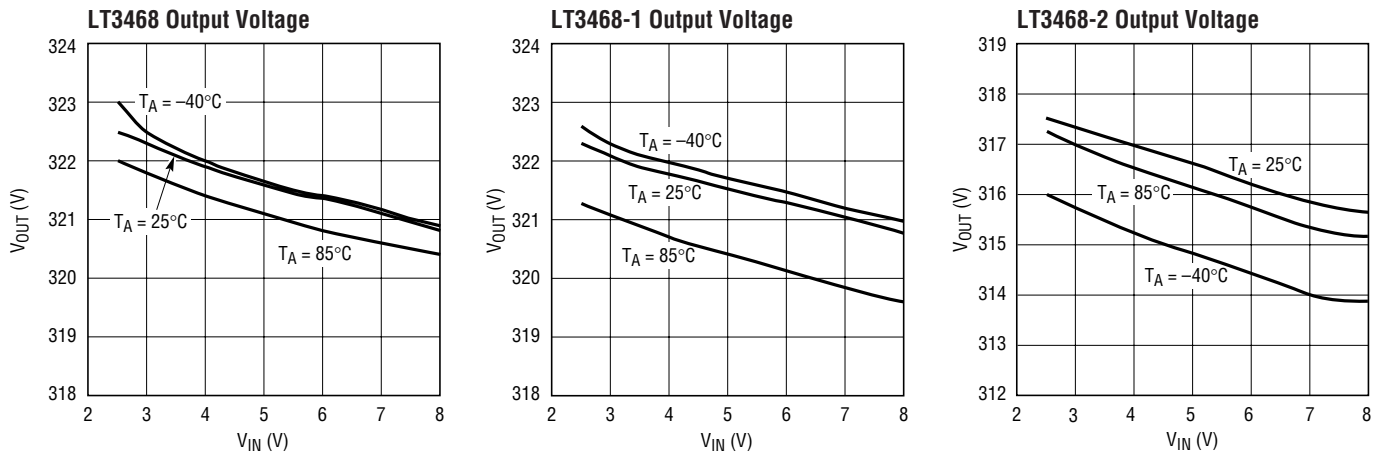
AN95 FA5

**Figure A5. Typical Output Voltage Tolerance for the Three LT3468 Versions.
Tight Voltage Tolerance Prevents Overcharging Capacitor, Controls Flash Energy**

FOR USE WITH	TRANSFORMER NAME	SIZE (W × L × H) mm	L_{PRI} (μH)	$L_{PRI-LEAKAGE}$ (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
LT3468-1	SBL-5.6S-1	5.6 × 8.5 × 3.0	24	400 Max	10.2	305	55	Hong Kong Office 852-2489-8266 (ph) kijimahk@netvigator.com (email)
LT3468	LDT565630T-001	5.8 × 5.8 × 3.0	6	200 Max	10.4	100 Max	10 Max	TDK
LT3468-1	LDT565630T-002	5.8 × 5.8 × 3.0	14.5	500 Max	10.2	240 Max	16.5 Max	Chicago Sales Office
LT3468-2	LDT565630T-003	5.8 × 5.8 × 3.0	10.5	550 Max	10.2	210 Max	14 Max	(847) 803-6100 (ph) www.components.tdk.com
LT3468/LT3468-1	T-15-089	6.4 × 7.7 × 4.0	12	400 Max	10.2	211 Max	27 Max	Tokyo Coil Engineering
LT3468-1	T-15-083	8.0 × 8.9 × 2.0	20	500 Max	10.2	675 Max	35 Max	Japan Office 0426-56-6336 (ph) www.tokyo-coil.co.jp

Figure A6. Standard Transformers Available for LT3468 Circuits. Note Small Size Despite High Output Voltage