ISOLUX POWER SUPPLIES

ENGINEERING GUIDE

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2.0 Electrical Characteristics

The electrical characteristics of quartz xenon arc lamps and CeraLux lamps are complex.24 Characteristics such as the voltage-current (V-I) curve, triggerability, dynamic resistance, and so on, are affected by a large number of lamp variables that result from numerous interactions between plasma and materials inside the lamp. In addition, electrical characteristics vary slightly from lamp to lamp and with lamp age. These characteristics are nonlinear and many exhibit memory effects.

Fortunately, the best xenon lamp power supplies and electrical interfaces are robust and are tolerant of slight lamp-to-lamp variations, so most of the complex interactions are not important to practical circuits. In addition, CeraLux and quartz xenon lamps are not grossly temperature-sensitive, so their electrical characteristics do not change radically during lamp warm-up as they do with mercury and metal halide lamps.

Most of the lamp's electrical variability is attributable to effects at the lamp cathode: either the activation of the cathode tip or the manner of arc attachment. All other electrical lamp variables anode condition, fill pressure, and arc gap are so well controlled that they do not cause problems of variation from lamp to lamp.

2.1 V - I Curves

The primary electrical characteristic of a CeraLux or short arc lamp is the V-I curve. Figure 29 shows the average V-I curve for the CL300BF lamp. This curve is derived from the actual average lamp voltage and current as measured after lamp ignition and while lamp current is slowly varied. Superimposed on the V-I curve are three asymptotes that explain how the curve results from lamp parameters[25,26,27].

Asymptote 1 arises from the voltage drop at the cathode. It represents the voltage necessary to power the cathode and raise the cathode tip to the necessary temperature - thermionic emission. With a thoriated tungsten cathode, it is very difficult to build a lamp with less than a 10-volt drop, even with a vanishingly small arc gap, because of the need for power to raise the cathode to its operating temperature.

Asymptote 2, which determines the negative resistance portion of the curve, is a measure of the relative ease with which thermionic emission takes place at the cathode. This curve is affected by fill pressure and by the activation at the cathode tip. A high fill pressure causes asymptotes 1 and 2 to intersect at lower currents. A cathode that is new and well activated will also cause the intersection to occur at a low current. As a lamp ages and the cathode tip becomes worn, the minimum in the V-I curve tends to move to higher currents.

Asymptote 3 is primarily determined by the ratio of the electric field to the gas fill pressure. The slope of asymptote 3 is a function of the lamp s cold fill pressure. A higher fill pressure causes a steeper slope.

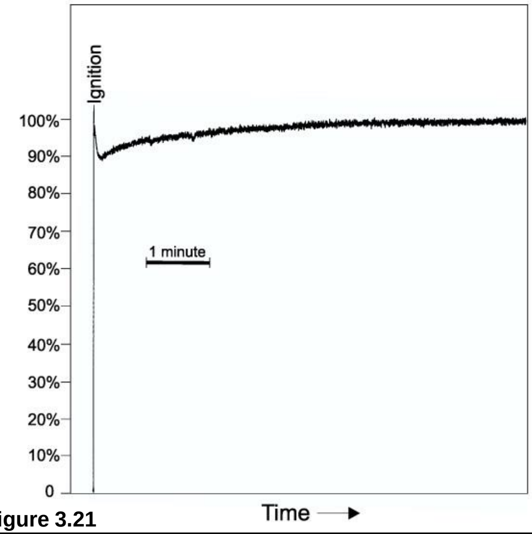


Figure 3.21

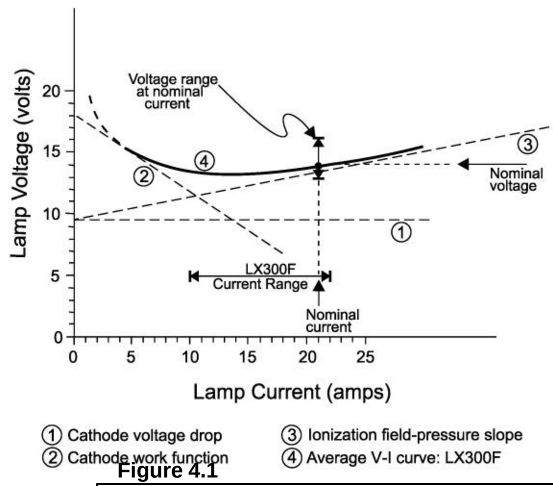


Figure 4.1

As we have mentioned, the upper end of the operating range of a CeraLux lamp is determined by the maximum power loading or the maximum safe operating temperature to achieve rated life. The lower operating current limit is determined by the minimum current needed to keep the lamp cathode activated and free of arc flicker. The minimum current in most lamps tends to correspond roughly to the minimum in the V-I curve. At currents lower than the curve s minimum, the cathode no longer operates at the proper temperature, the cathode hot spot is more diffuse, the arc is less stable at the cathode tip, and, because of the negative resistance, the lamp's operation can be unstable. In addition, the lamp will emit EMI at these low currents.

Figure 30 shows actual individual V-I curves for a number of EX300-10F lamps after 2 hours of operation. Figure 31 shows the equivalent curves for EX900-10F lamps.

As lamps age to their rated lives and the minima of the V-I curves tend to move to higher currents, the lamp voltage distribution tends to spread out to higher voltages, because the cathode tip burns back and becomes slightly less active, causing a longer effective arc gap in some lamps.

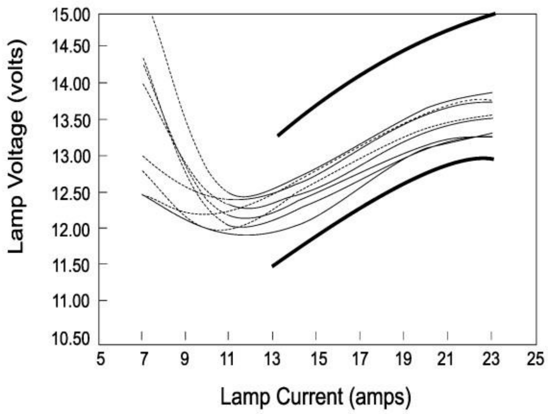
The slopes of the linear operating regions of various lamp types vary with fill pressure. Lamps with a 250-PSI fill pressure (LX125, 175, 300) have an average slope of 0.08 – 0.02 volts per amp. Lamps at 280 to 305 PSI (LX500, LX1000, EX500) have an average slope of 0.12 – 0.02 volts per amp. Lamps at 325 to 350 PSI (EX125, 175, 300, 900) have an average slope of 0.2 – 0.03 volts per amp.

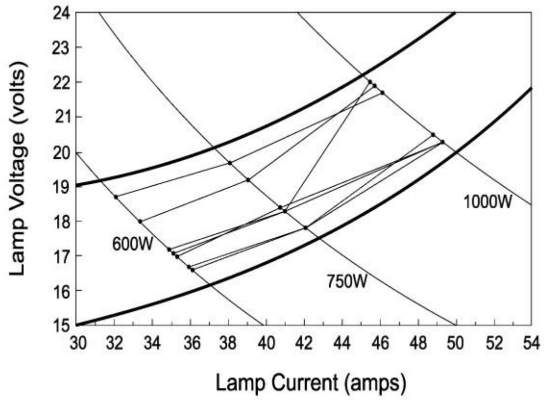
2.2 Lamp Ignition

Lamp ignition is the process by which the initial, cold, non-conducting gas in the lamp is changed by the application of electric fields and current sources to a conducting stable plasma at the lamp s running current. As with other lamp characteristics, calculating anything in the ignition process from plasma parameters is not practical. Most such calculations do not allow advance prediction of useful information.

The ignition process covers many orders of magnitude in voltage and current, from volts to tens of kilovolts and from microamps to tens of amps. For convenience, the process is separated into three sequential stages: trigger, boost, and DC. In section 4.4, on power supplies, a typical circuit for these stages is shown.

The ignition process creates a great deal of electrical noise, sometimes at very high frequencies. This noise is caused by the high voltages and high currents in the process. In cases where sensitive electronics are fairly close to arc discharge lamps, the system should be designed so that either (1) the sensitive electronics are extremely well shielded from radiated and conducted EMI at the lamp and at the lamp power supply, or (2) the sensitive





electronics are turned on only after the lamp has been ignited.

2.2.1 Trigger

Lamp ignition requires the application of a high-voltage DC or trigger pulse to one of the lamp electrodes. The high voltage initiates a trigger streamer between the electrodes and causes the streamer impedance to decrease enough for the next stage in the process, the boost phase, to take over and supply even more energy to the discharge.

It is possible to ignite CeraLux lamps with high-voltage DC, either from a separate DC supply or from a voltage multiplier. Such DC ignition is rarely used because of the economics of circuit design. It is usually easier and less expensive to design a pulsed circuit to supply a short trigger pulse. Also, there is a risk with DC ignition: in CeraLux type lamps it is possible to ignite the gas between the anode and the reflector instead of the gas between the anode and the cathode. Such an arc-over ignition mode, which is ultimately destructive to the lamp, is most often seen in older lamps with either DC ignition systems or systems in which the ignition pulse rises slowly.

The voltage required to trigger the lamp varies with the time over which the voltage is applied. The shorter the time over which the voltage is applied, the higher the voltage required for breakdown. On a DC basis, a CL300BF CeraLux lamp may trigger at 7 to10kV. However, it may require a 13-kV peak pulse with a 250-ns pulse width to break down the gas in the same lamp.

Each CeraLux product specification sheet includes a value for the recommended minimum ignition voltage at the lamp. This value is in the range of 17 to 35 kV. This recommended voltage represents the minimum value that a circuit designer should use in designing a lamp power supply to ensure that the lamps ignite and run throughout their full lifetimes. It is assumed that the designer is using a trigger pulse in the 20-ns to 1- s range. The vast majority of CeraLux lamps produced will actually trigger at voltages much lower than this recommended value. However, conservative designs for igniters go even farther. Additional factors can degrade triggerability so that even a higher trigger voltage design point may be required:

Most trigger circuits vary from unit to unit because of spark gap and transformer variations.

With fast trigger pulses, the lines between the igniter and the lamp can degrade the trigger pulse by capacitively shorting out part of the trigger pulse.

CeraLux lamps require slightly higher than normal trigger voltages for 1 minute after being turned off. If extra trigger voltage is designed into the circuit, it allows the lamp to trigger reliably even in this hot-restrike situation.

One of the possible end-of-life phenomena in CeraLux lamps is failure to trigger. This can be caused by gas contaminants that evolve from interior lamp parts during operation. If a lamp has exceeded its rated lifetime and still provides acceptable light output, yet requires a higher trigger voltage, additional free life can be obtained by making sure that the trigger voltage is high enough to run these lamps.

The only drawback of designing an extremely high trigger voltage is the possibility of arc-over to other components in the system if the lamp fails to trigger. Thirty- to 45-kV peak trigger voltage is a good design range for most lamps if the insulation is sufficient.

Figure 32 shows a typical lamp trigger pulse. When the trigger circuit is connected to a lamp, the rising edge of the first pulse breaks at the lamp trigger voltage and the rest of the ringing waveform is clamped to zero.

The amount of energy in the trigger pulse is not crucial. In fact, low energy is recommended for safety. For example, 0.02 J in the primary discharge circuit is sufficient for low-power CeraLux lamps, and only a small fraction of this energy is actually deposited in the lamp. Likewise, the exact condition of the electrodes making the transition from nonconducting to the point of breakdown of the lamp is unimportant. It is very rare that a lamp does not trigger if the trigger voltage is within specifications.

Either the anode or the cathode of a CeraLux lamp can be triggered as long as:

The trigger polarity matches the electrode potential (i.e., positive pulses if anode triggered and negative pulses if cathode triggered).

The insulation at the triggered electrode is sufficient.

For some applications, anode triggering is favored because it allows optical components closer access to the lamp window (cathode end) without the risk of high voltage arc-over.

Xenon lamps can exhibit triggerability differences that are related to the time between ignitions. Lamps that have been stored for weeks or months may be slightly harder to start the first time. This condition may occur because residual charge carriers inside the lamp, which normally aid ignition, recombine during long periods of inactivity. It may also be caused by very small amounts of oxidation on the cathode tip or by contamination of the xenon with an electronegative gas such as hydrogen.

On a very short time scale, lamp triggerability is subject to an effect termed hold-off. Just after a xenon lamp is turned off there is a time period, usually measured in milliseconds, during which the lamp will still retain some ionization and therefore will be very easy to reignite. The lamp will not be capable of holding off a high voltage. This effect is not very important in xenon arc lamps, because reigniting or holding off a high voltage on such a short time scale is not normal.

In summary, the variables that can affect lamp triggerability are:

Peak voltage
Pulse rise time or pulse width
Capacitive loading of the lamp leads
Hot or cold restrike
Time since last ignition
Age of lamp
Impurities in the gas

2.2.2 Boost

The boost phase of ignition widens the narrow discharge streamer generated in the trigger phase. By depositing more energy in the streamer, the boost drives the impedance of the arc low enough for the DC phase of ignition to take over. The aim is to drive the lamp to the positive portion of the V-I curve.

Figure 33 shows a schematic diagram of the lamp ignition circuit, including the boost and the trigger. The boost and DC phases of ignition interact much more strongly with each other than with the trigger phase. Most problems in lamp ignition are problems in the boost and DC circuits.

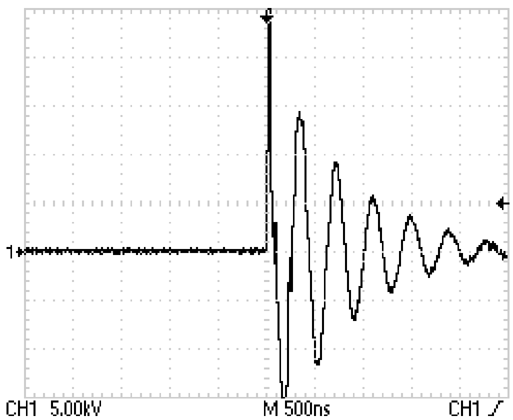


Figure Xa. Rotec ECG300 Xe P.S. Trigger Pulse (no load)

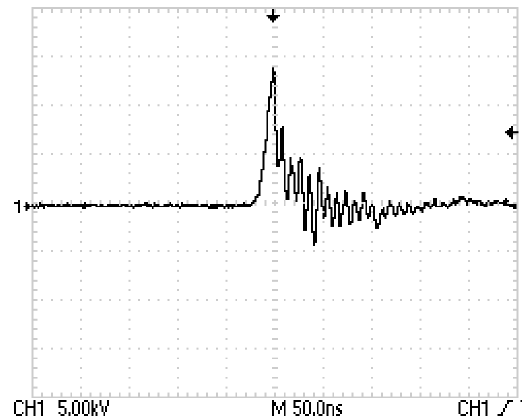


Figure Xb. Rotec ECG300 Xe P.S. Trigger Pulse (lamp connected)

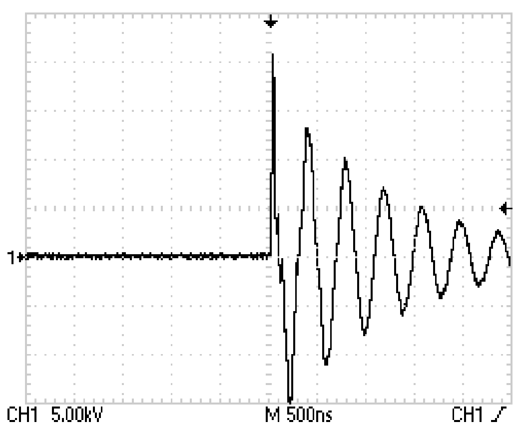


Figure Xc. RotecECG300 DC HE P.S. Trigger Pulse (no load)

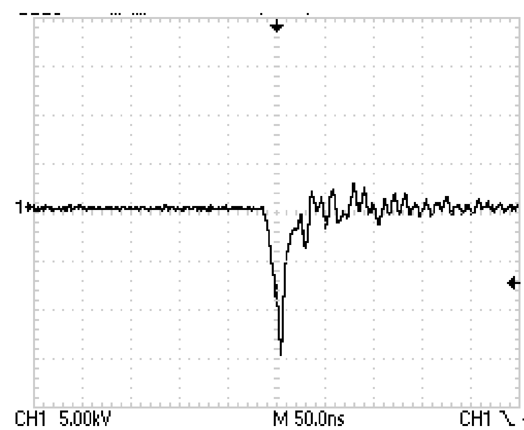


Figure Xd. RotecECG300 DC HE P.S. Trigger Pulse (lamp connected)

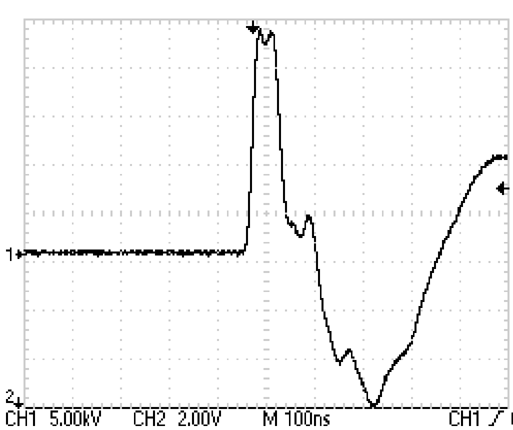


Figure Xe. Laser Drive 7500 P.S. Trigger Pulse (no load)

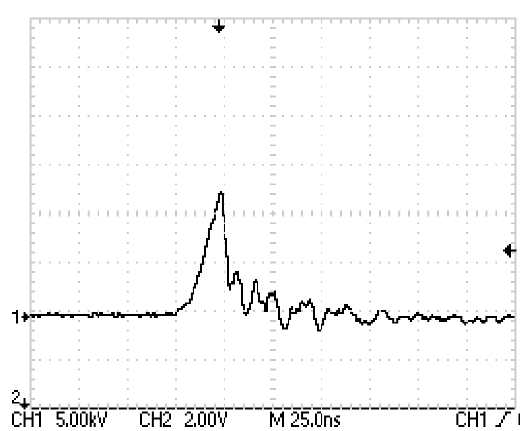
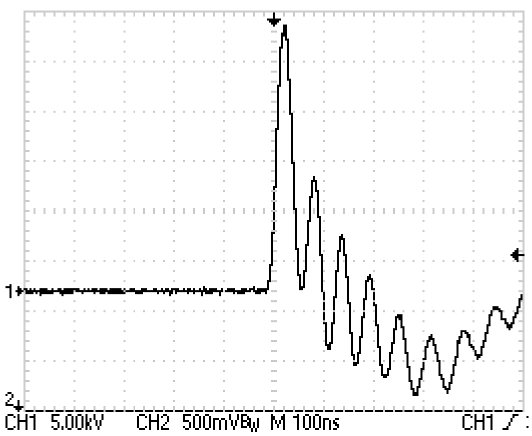


Figure Xf. Laser Drive 7500 P.S. Trigger Pulse (lamp connected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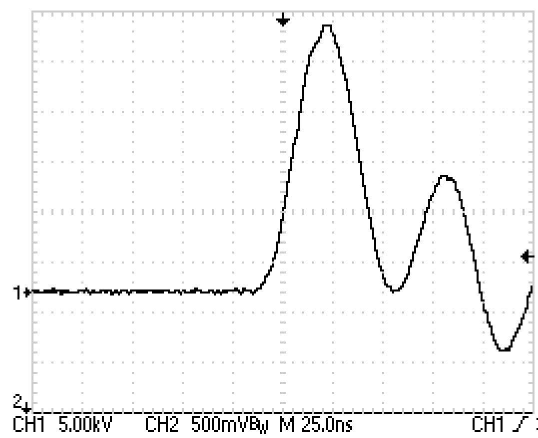
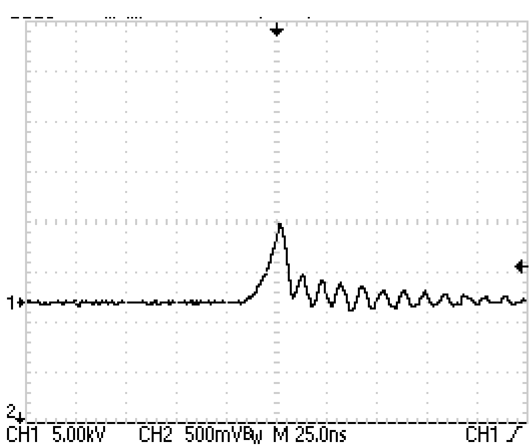
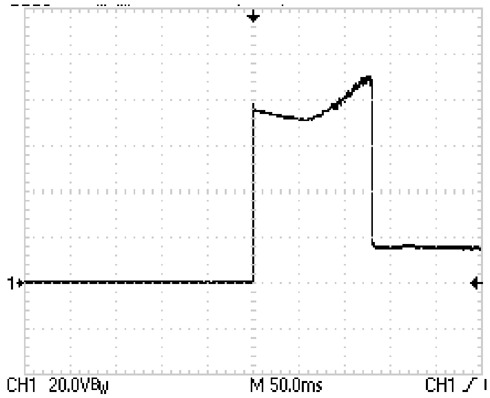
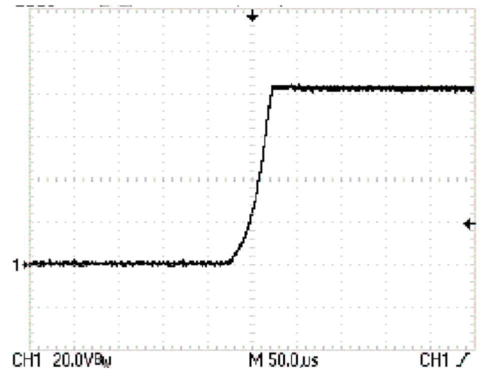

CH1 5.00kV CH2 500mVBW M 25.0ns CH1


CH1 5.00kV CH2 500mVBW M 25.0ns CH1



(a)



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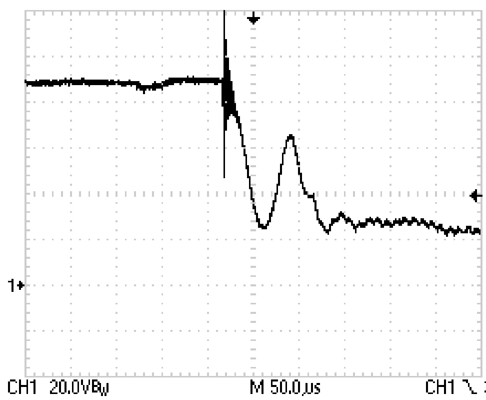

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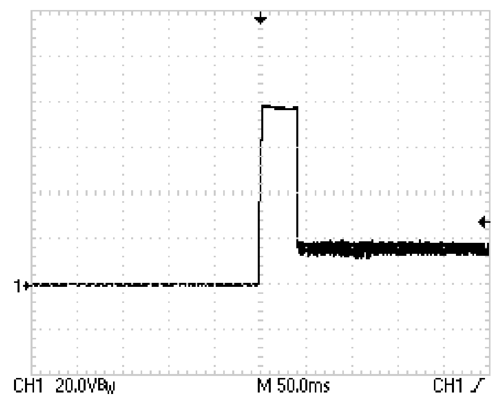

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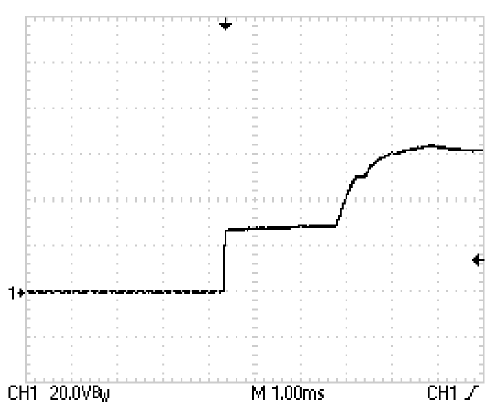

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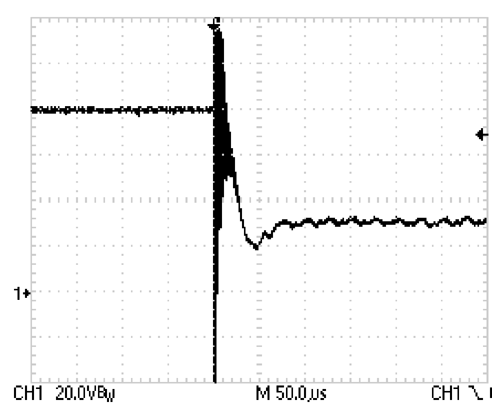
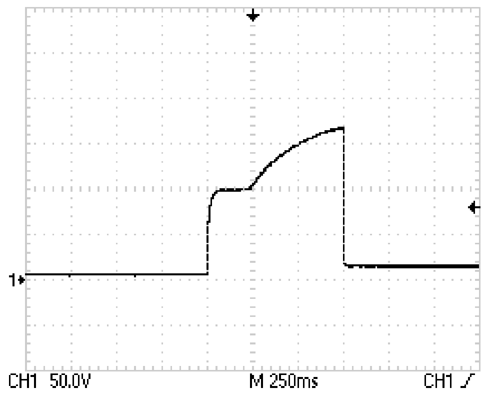
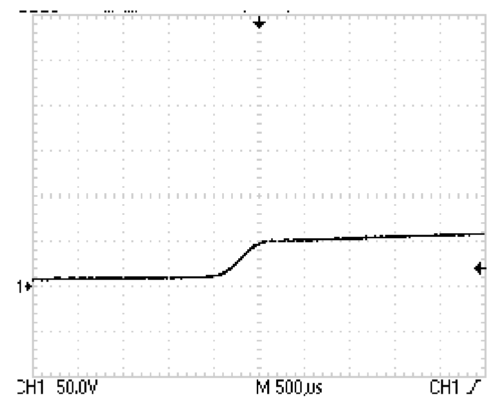


(f)

Figure y. Typical Boost Voltage waveforms: (a) Rotec ECG300 Xe P.S. Boost Voltage, (b) Rotec ECG300 Xe Rise Time, (c) Rotec ECG300 Xe Fall Time, (d) Rotec ECG300 DC HE P.S. Boost Voltage, (e) Rotec ECG300 DC HE Rise Time, (f) Rotec ECG300 DC HE Fall Time.



(g)



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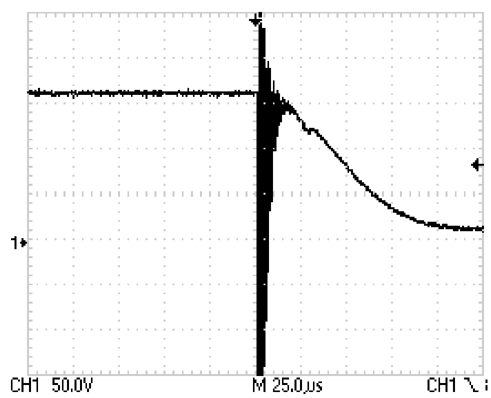
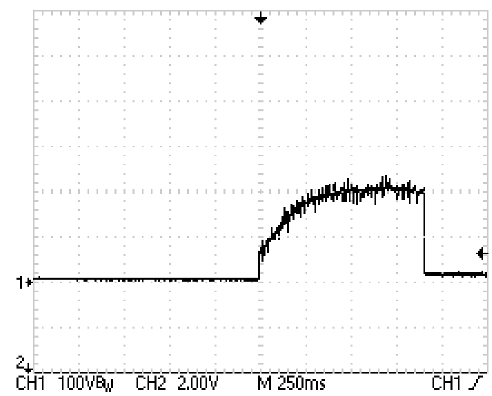


(i)



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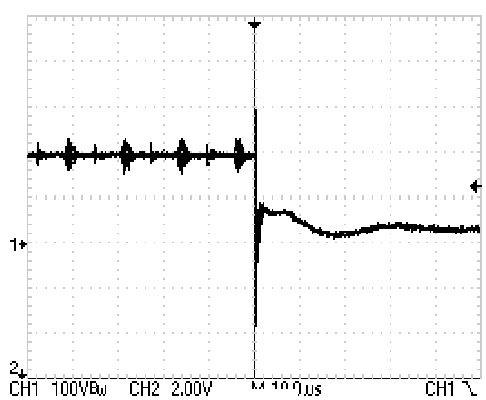

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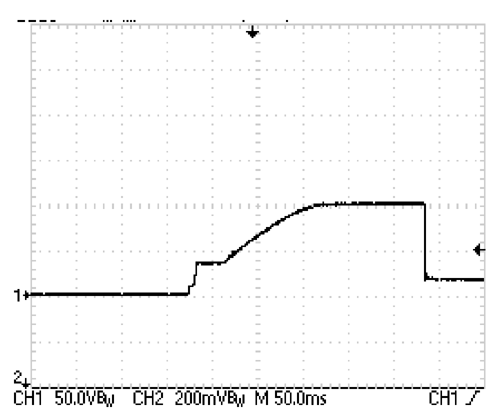


(l)

Figure Y (cont.). (g) Laser Drive 7500 P.S. Boost Voltage Waveform, (h) Laser Drive 7500 Rise Time, (i) Laser Drive 7500 Fall Time, (j) Laser Drive 040-75150 P.S. operating Boost Voltage, (k) Laser Drive 040-75150 Fall Time, (l) ESMC P.S. (operating at 125 Watts) Boost Voltage

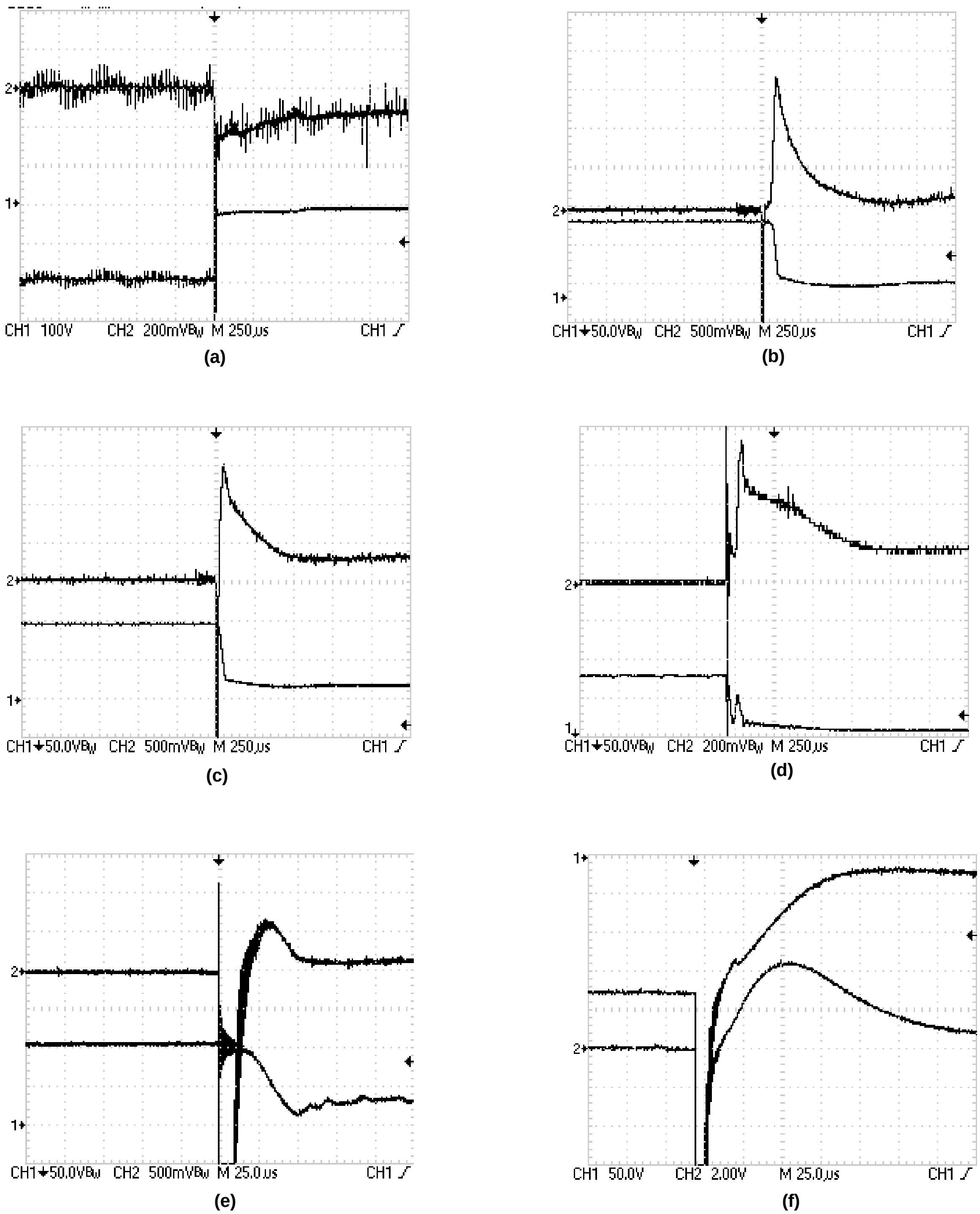


Figure Z. Boost Voltages & Currents: (a) Laser Drive 040-75150, (b) EMSC P.S. operating @ 125 Watts, (c) EMSC P.S. operating @ 300 Watts, (d) Rotec ECG300 Xe P.S., (e) Rotec ECG300 DC HE P.S., (f) Laser Drive 7500 P.S.

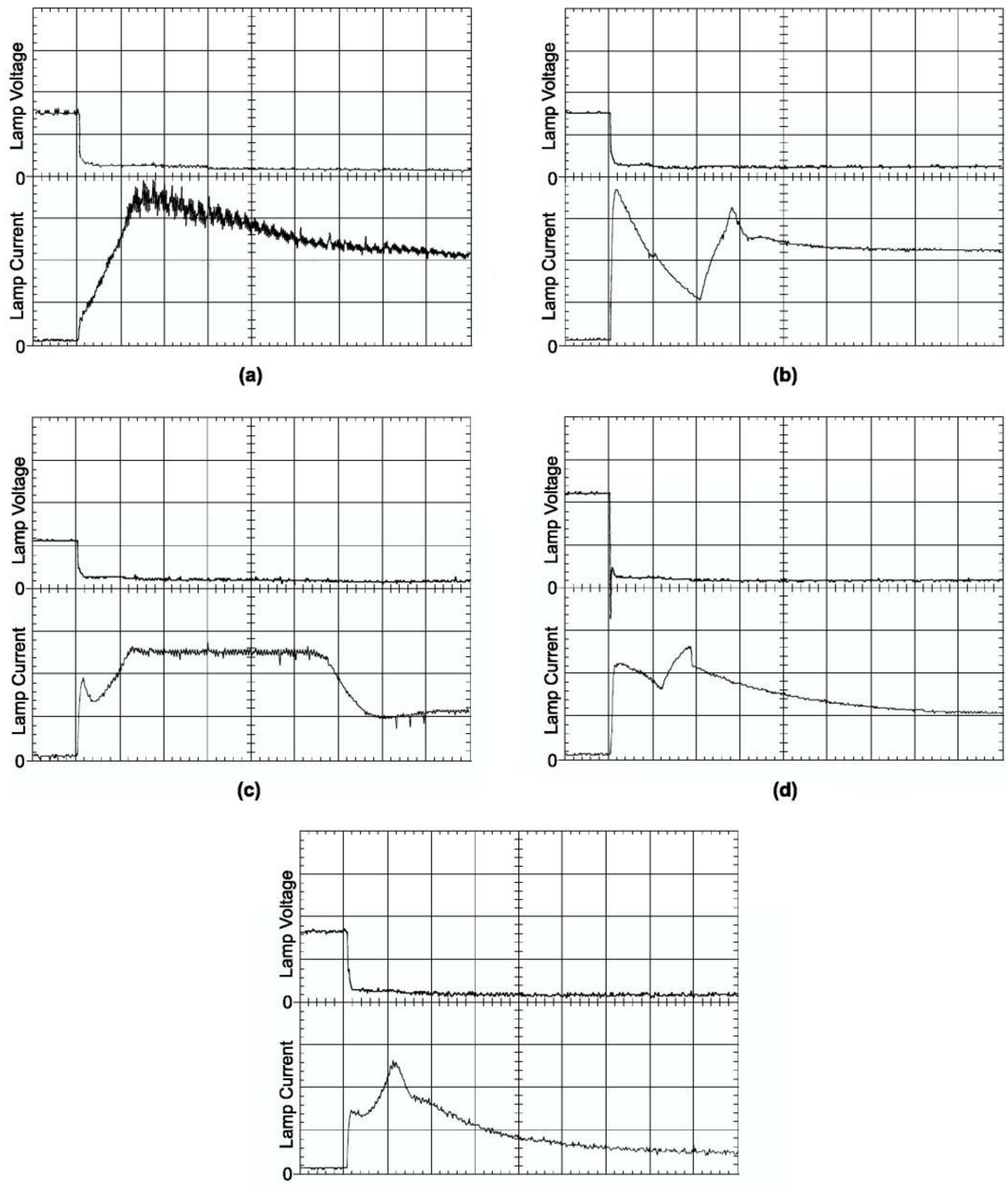
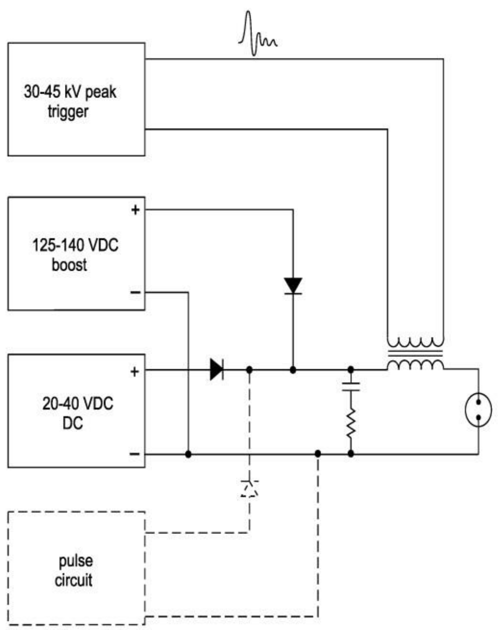


Figure AA. Additional Boost Voltages & Currents of older power supplies, Time Base is 500 msec. per division, Boost Voltage set at 100 volts per division. (a) PS1 75 SW-1 Power Supply (10 Amps / div.), (b) PSC300 (10 Amps / div.), (c) PS300 SW-2 (20 Amps / div.), (d) PS 300-1 linear supply (20 Amps / div.), (e) PS500 –10 (50 Amps / div.)



In practical, economical power supply designs, the boost is rarely a separate circuit. It is usually designed into the DC section. The trigger circuit in practical circuits may be separate, but even the trigger circuit is usually powered by voltage from the DC section.

The boost is usually designed with one of two approaches. In the first approach, voltage is stored on a capacitor that is connected to the lamp with a resistor in series. The lamp then forms an RLC circuit and when the trigger pulse breaks over the arc gap, the RLC circuit discharges through the lamp. This type of circuit is shown in Figure 33. The result is a current pulse through the lamp that reaches a peak current higher than the lamp running current. The circuit values are chosen to reach the optimum peak current and duration. These values are usually determined by trial and error with a number of sample lamps. The goal is a discharge that smoothly makes the transition to the lamp running current on the decreasing current side of the boost pulse.

In the second approach, there is still a voltage source and usually a charged capacitor to supply most of the current, but instead of an RLC circuit, active devices such as FETs or transistors are used to limit and shape the boost discharge into the lamp. In this approach, there may not be an apparent boost pulse, because the current may rise smoothly from zero up to the final lamp running current.

Either of these approaches produces reliable lamp ignition if the design is correct, so a wide range of lamp variation can be accommodated.

A number of factors affect the boost discharge: peak voltage, peak current, stored energy, rise time, fall time, transition to the DC phase, and the impedance of the lamp. The most important parameters are peak voltage, peak current, and the transition to the DC phase.

The minimum recommended peak voltages for reliable boost are 125 VDC for lower-powered CeraLux lamps of 300 watts or less and 140 VDC for the higher powered CeraLux lamps (500 watts and above). It is possible to design reliable boost circuits with values lower than these, but these represent the lowest values for conventional circuits. Higher boost voltages are better as long as the maximum boost current is observed.

Peak boost current is important primarily because excessive peak current can damage the lamp electrodes. Because some successful boost circuits make the transition to the running current smoothly, there is obviously no minimum acceptable boost current. Nevertheless, above a 400-amp peak in a boost current pulse of less than 1 ms, the cathode may be damaged. For boost current pulses of longer than 1 ms, even 400 amps may be excessive. Figure 34 shows some typical boost voltage and current waveforms from commercially available power supplies.

2.2.3 Transition to DC operation

The DC power supply must satisfy four primary requirements to successfully take the lamp from the boost phase into steady DC operation. First, the DC supply must either be current-regulated or change from voltage regulation to current regulation as it takes over from the boost circuit. Voltage regulation in normal operation is not recommended because the lamp V-I curve is too flat.

Second, the rise time of the DC circuit must match the time constant of the boost circuit. The DC circuit must take over the supply of lamp current in a smooth manner. For instance, if the boost current decays away in 1 ms, the DC circuit must have a rise time of at least 1 ms. If there is a pronounced dip in current between the boost and the DC, the lamp voltage may go up and the lamp may be extinguished.

Third, the DC circuit must have sufficient open circuit voltage. From Figure 34, it is apparent that even with sufficient current, the lamp voltage is higher than the normal operating voltage for a short time after lamp trigger and boost. For low-wattage lamps, 20 volts are often needed for a few milliseconds after the boost. For higher-wattage lamps (500 watts and above), 35 to 40 volts are often needed. The exact requirement is a function of the energy and time constants in the boost circuit, the particular lamp type and lamp age, and the load characteristics of the DC supply.

The last requirement is low-ripple current at mains line frequencies. This is not really a requirement for reliable lamp ignition, but for achieving rated lamp life. Fifty- to 120-Hz current ripple should be limited to 10% or less. Above 10% low-frequency ripple, the lamp s lifetime is usually reduced, because the lamp cathode temperature cannot stay constant for good thermionic emission. Five percent ripple is a good design goal. However, high frequency ripple can be greater than 10%. At normal switching power supply frequencies (40 kHz and above), the cathode is not disturbed as much by the fast oscillation in power and can, therefore, tolerate higher ripple. The exact limits are unknown, but a 15% ripple current at 50 kHz does not seem to affect lamp life.

2.3 Lamp Power Supplies and Igniters

Sections 4.1 and 4.2 provide the necessary information for a power supply designer to design a reliable CeraLux or xenon arc lamp power supply. Most such power supplies are not made by modifying existing low-voltage power supplies. Most arc lamp supplies are custom designed[34]. Engineering Note 229 includes representative schematics for commercial CeraLux power supplies and a checklist of specification items to be addressed when such supplies are designed.

Before the advent of large-scale integrated circuits, power-regulated arc lamp power supplies were difficult to design and lamp-power supplies tended to be current regulated.
Current-regulated supplies work very well and most xenon arc lamp supplies today are current regulated. However, power regulation is slightly preferable. When a CeraLux lamp ages, it tends toward higher voltage operation because the cathode tip wears and the arc gap lengthens. Therefore, if the power supply is current-regulated, there is a slight chance that later in life the lamp will run at a power that is higher than its original setting or higher than its maximum power rating. Power regulation avoids this problem. Under no circumstances should a voltage-regulated supply be used unless a large ballast resistor is included in the lamp circuit.

2.4 Electromagnetic Interference (EMI)

EMI generated by the lamp and power supply is important for two related reasons:

1. The noise often interferes with nearby equipment, particularly video circuits.

2. Various safety and governmental agencies limit the conducted and radiated emissions from equipment that contains the lamp and power supply.

The noise that results from the power supply switching frequency is usually low enough in frequency (20 to 500 kHz) that the conducted emission can be handled with normal line filters, and the radiated emission wavelength is long enough that the equipment chassis does not need special EMI shielding.

However, the lamp can generate very high-frequency EMI if it is operated at low currents. Even with a very well regulated supply and with RF bypass capacitors, the lamp plasma can generate noise in the 1 to 500 MHz range if it is operated below its noise threshold current. The noise threshold current is a current level below which the plasma generates noise and above which the lamp is quiet. Each lamp has a noise threshold current that is about 80% of the maximum lamp current. This noise threshold is easily detectable with an oscilloscope voltage probe fairly close to the lamp. The noise threshold varies by an amp or two from lamp to lamp of the same model number. The threshold increases slightly as the lamp ages. This plasma noise does not harm the lamp, but presents problems for the system designer and can be avoided by operating the lamp above the threshold.