The Use of High Voltage Disc Capacitors in Half Wave Voltage Doublers / Quadruplers and Excimer Laser Systems

By Mark Walsh

INTRODUCTION

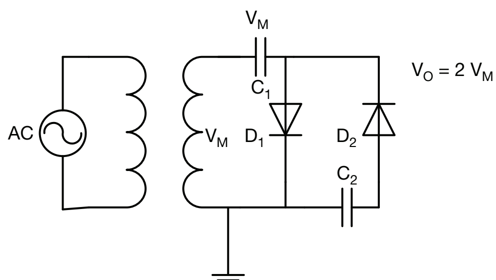
High voltage disc capacitors are used in a number of applications that require operating voltage capability up to 50 kV, capacitance of over 5000 pF, low inductance, and a dissipation factor (DF) well under 0.5 %. In this white paper we will focus on their use for energy storage and discharging in laser system applications.

In addition, half wave voltage doublers, which are voltage multiplier circuits consisting of two diodes, two capacitors, and an AC input voltage source will be considered. Found in a host of applications including X-ray systems, high voltage power supplies, particle accelerators, and ion pumps, the output voltage amplitude of these circuits is twice that of the input voltage amplitude. In addition, we will explore their use in voltage quadruplers which include an additional diode-capacitor stage.

HALF WAVE VOLTAGE DOUBLER

The circuit diagram of a half wave voltage doubler is shown in the figure below. During the positive half cycle, diode D_1 is forward biased so current flows through it. This current will flow to the capacitor C_1 and charge it to the peak value of input voltage V_M.

However, current does not flow to the capacitor C_2 because the diode D_2 is reverse biased. So, the diode D_2 blocks current flowing to the capacitor C_2. Therefore, during the positive half cycle, capacitor C_1 is charged, whereas capacitor C_2 is uncharged.



Half Wave Voltage Doubler

During the negative half cycle, diode D_1 is reverse biased. Therefore, during the negative half cycle, the capacitor C_1 will not be charged. However, the charge (Q_m) stored in the capacitor C_1 is discharged.

D_2 is forward biased during the negative half cycle, so capacitor C_2 charges to a value of 2 V_M because the input voltage V_M and capacitor C_1 voltage V_M are added to the capacitor C_2. Hence, during the negative half cycle, the capacitor C_2 is charged by both input supply voltage V_M and the voltage on capacitor C_1.

Therefore, capacitor C_2 is charged to 2 V_M.

If a load is connected to the circuit at the output side, the charge (2 V_M) stored in the capacitor C_2 is discharged and flows to the output.

During the next positive half cycle, diode D_1 is forward biased and diode D_2 is reverse biased. So, the capacitor C_1 charges to V_M, whereas capacitor C_2 will not be charged. However, the charge (2 V_M) stored in the capacitor C_2 will be discharged and flow to the output load. Thus, the half wave voltage doubler drives a voltage of 2 V_M to the output load.

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DESIGN EXAMPLE

Diodes: 2CL74 (download datasheet at https://datasheetspdf.com/datasheet/2CL74.html)

Capacitors: HVCC103Y6P202KEAX (download datasheet at www.vishay.com/doc?23144)

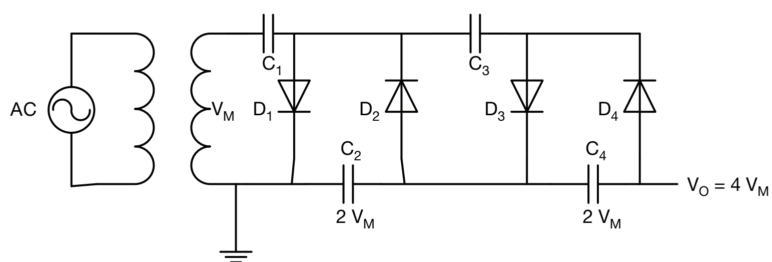
For V_M = 1000 V_{peak} input we have:

$$\mathbf{V_o = 2(1000\ V) = 2\ kV}$$

ADDING ADDITIONAL STAGES - VOLTAGE QUADRUPLER

The voltage quadrupler can be obtained by adding one more diode-capacitor stage to the voltage doubler circuit. Thus, with this configuration, one can add N number of stages to get an output voltage of $V_o = V_M N$, where N is the number of stages added to the initial voltage doubler. The circuit operation is as follows.

During the first positive half cycle of the input AC signal, the diode D_1 is forward biased, whereas diodes D_2, D_3, and D_4 are reverse biased. Hence, the diode D_1 allows current through it. This current will flow to the capacitor C_1 and charge it to the peak value of the input voltage V_M.



Voltage Quadrupler

During the first negative half cycle, diode D_2 is forward biased and diodes D_1, D_3, and D_4 are reverse biased. Hence, the diode D_2 allows current through it. This current will flow to the capacitor C_2 and charge it. The capacitor C_2 is charged to twice the peak voltage of the input signal (2 V_M). This is because the charge (V_M) stored in the capacitor C_1 is discharged during the negative half cycle. Therefore, the capacitor C_1 voltage (V_M) and the input voltage (V_M) is added to the capacitor C_2. Capacitor voltage + input voltage = $V_M + V_M = 2\ V_M$. As a result, the capacitor C_2 charges to 2 V_M.

During the second positive half cycle, the diode D_3 is forward biased and diodes D_1, D_2, and D_4 are reverse biased. Diode D_1 is reverse biased because the voltage at the node of C_1 and D_1 is negative due to the voltage V_M across C_1, and diode D_2 and D4 are reverse biased because of their orientation. As a result, the voltage (2 V_M) across capacitor C_2 is discharged. This charge will flow to the capacitor C_3 and charge it to the same voltage of 2 V_m.

During the second negative half cycle, diodes D_2 and D_4 are forward biased, whereas diodes D_1 and D_3 are reverse biased. As a result, the charge (2 V_M) stored in the capacitor C_3 is discharged. This charge will flow to the capacitor C_4 and charge it to the same voltage (2 V_M).

The capacitors C_2 and C_4 are in series and the output voltage is taken across the two series-connected capacitors C_2 and C_4. The voltage across capacitor C_2 is 2 V_M and capacitor C_4 is 2 V_M. So, the total output voltage is equal to the sum of capacitor C_2 voltage and capacitor C_4 voltage.

$$2\ V_M + 2\ V_M = 4\ V_M = V_O$$

DESIGN EXAMPLE

Diodes: 2CL74 (download datasheet at datasheetspdf.com/datasheet/2CL74.html)

Capacitors: HVCC103Y6P202KEAX (download datasheet at www.vishay.com/doc?23144)

For V_M = 1000 V_{peak} input we have:

$$\mathbf{V_O = 2(1000\ V) + 2(1000\ V) = 4\ kV}$$

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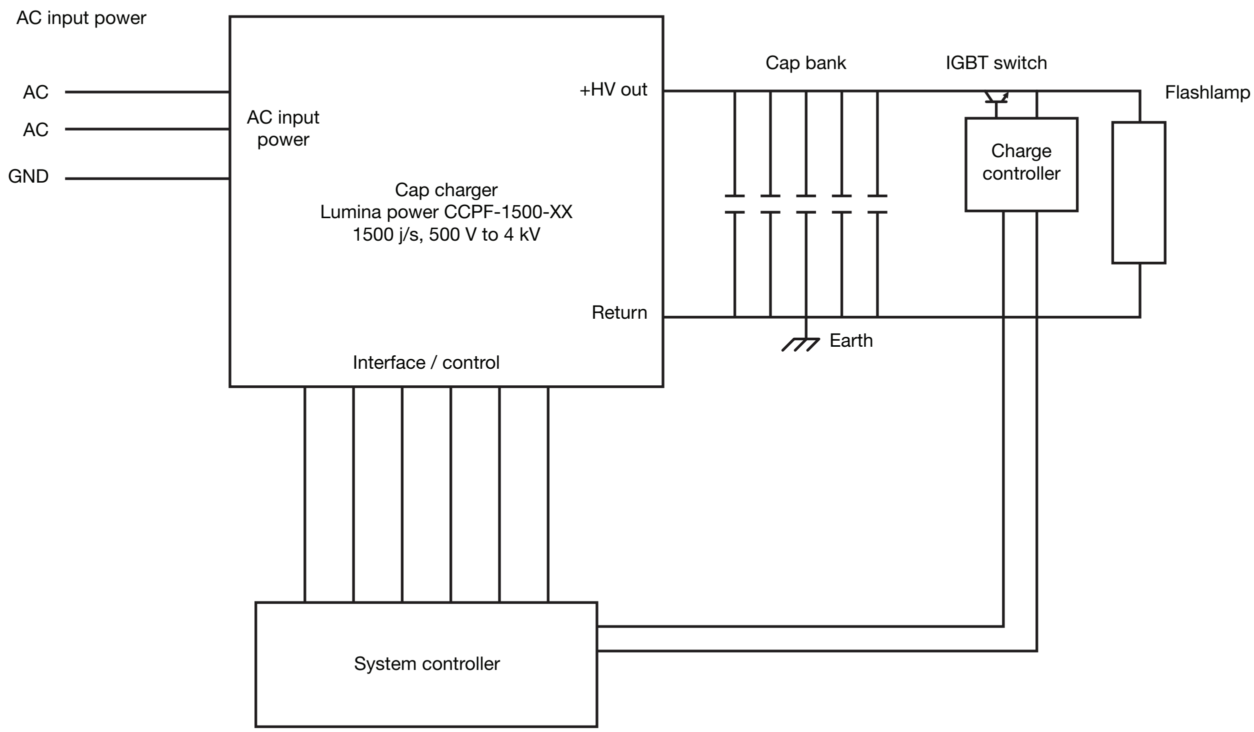
EXCIMER LASERS

Laser action in an excimer molecule occurs because it has a bound (associative) excited state, but a repulsive (dissociative) ground state. Noble gases such as xenon and krypton are highly inert and do not usually form chemical compounds. However, when in an excited state (induced by electrical discharge or high energy electron beams), they can form temporarily bound molecules with themselves (excimer) or with halogens (exciplex) such as fluorine and chlorine. The excited compound can release its excess energy by undergoing spontaneous or stimulated emission, resulting in a strongly repulsive ground state molecule which very quickly (on the order of a picosecond) dissociates back into two unbound atoms. This forms a population inversion.

In the case of initiating the excited state with electrical discharge, the basic circuit topology is shown below where the storage capacitor, typically a storage bank, is used in a flash lamp.



The capacitor bank mentioned can be configured with Vishay's 715C series class 2 ceramic disc capacitors, when selected with the appropriate capacitance value, voltage rating, and ceramic type.

The most commonly used methods for charging capacitors in pulsed applications are full discharge and partial discharge. Full discharge, as the name implies, allows the capacitor to be discharged to zero for each shot. The power supply is then enabled, the capacitor is charged to the set voltage, and the discharge cycle is repeated. The high voltage switch is usually an SCR, or a Thyraton for higher voltage applications.

The partial discharge method takes advantage of semiconductor switches to turn on and off the discharge from the capacitor to the load, allowing the designer to vary the pulse width along with the energy delivered. The specified capacitor is usually large enough so that only a small percentage of the energy is taken from it during each shot. Hence the name "partial discharge."

In both cases, standard formulas can be used to determine the power supply size and calculate the charge time. The simplest way to estimate the amount of energy needed for an application is to use these formulas.

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DESIGN EXAMPLE: 2.5 kV PULSE

Power supply: Lumina CCPF-1500-XX (download datasheet at luminapower.com/ccpf-capacitor-charging-power-supplies/)

Capacitors: Vishay 715C10KTD80 (download datasheet at www.vishay.com/doc?22210)

For a system utilizing a 20-capacitor bank with 8000 pF per capacitor, we have C = 0.16 μF. And, charging this bank to 2.5 kV results in the following energy per pulse:

$$\text{Energy/pulse} = 1/2\ CV^2 = 0.5(1.6 \times 10^{-5}\text{F})(2500\ \text{V})^2 = 50\ \text{j}$$

The capacitors will be charged and then discharged into the system’s flash lamp. The frequency of this charge / discharge process is the rep rate. Thus, the charge rate is calculated as follows:

$$\text{Charge rate} = (\text{energy/pulse})(\text{rep-rate})$$

When:

C is the capacitor in farads

V is the charge voltage required

Rep-rate in Hz

For a 20 Hz system with the above energy per pulse, we have:

$$\text{Charge rate} = (50\ \text{j})(20\ \text{Hz}) = 1000\ \text{j/s}$$

This formula does not allow for any dead time (settling time), which is usually required in most systems. So, in most low rep rate applications, selecting a slightly larger supply is the best choice. In this case, the 1500 j/s power supply would be a good model to specify.

In the case of a partial discharge application, the length of time the capacitor is allowed to discharge determines the amount of energy needed to recharge the capacitor to the set voltage. Pulse widths can vary from several hundred microseconds to tens of milliseconds, with a corresponding droop in voltage. In general, calculating the recharge energy can be done using the formula:

$$\mathbf{E_{Recharge} = 1/2C_L\ (V^2_{max.} - V^2_d)}$$

When:

$V_{max.}$ is the maximum voltage

V_d is the lowest droop voltage

Now, for the above system, assuming a drop to 1 kV, we have:

$$E_{Recharge} = 0.5(1.6 \times 10^{-5}\text{F})(25002\text{-}10002)\text{=}42\ \text{j}$$