Technical Note: 4

Designing Helium-Neon Laser Power Supplies

The task of designing a power supply for helium neon (He-Ne) laser could range from a routine exercise of designing a high voltage, low current power supply with a moderate current regulation requirement to a highly complex one involving current stabilization of a very high order. The design of a He-Ne laser power supply varies from a moderate exercise meeting the twin objectives of plasma excitation and sustenance in laboratory use lasers to a highly complex job in the case of He-Ne laser based systems such as a ring laser gyroscope.

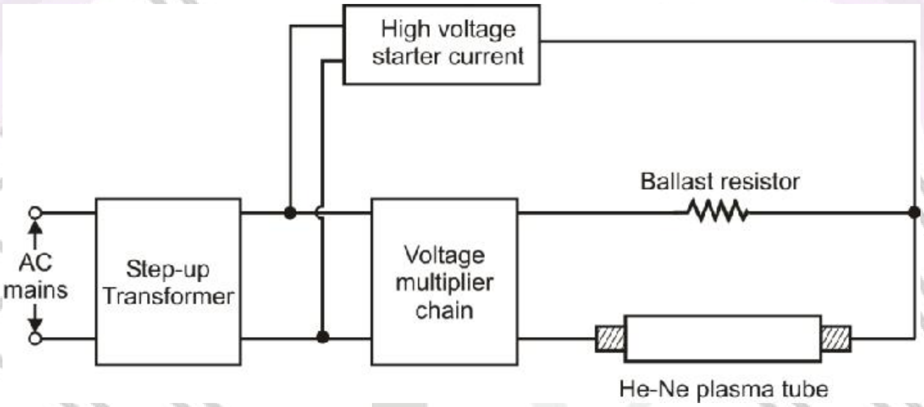

Figure 4.1
Generalized block schematic of power supply for a DC excited gas discharge laser

The He-Ne laser uses a low pressure helium-neon mixture predominantly helium with about 10% neon contained in a narrow bore glass tube with nearly 100 per cent reflectance mirror forming one end of the resonator and another mirror with about 1% transmission forming the other end. With a proper choice of gas mixture, processing technique and resonator optics, this laser can be made to emit at any of the four wavelengths, i.e. 0.6328, micron (red), 0.5435 micron (green), 1.523 micron (infrared) and 3.391 micron (infrared).

He-Ne laser is pumped by an electric discharge through the gas mixture thus creating He-Ne plasma. Commercial He-Ne lasers are almost invariably DC excited, though excitation by RF means, which is more popular in the case of CO_2 lasers, is also possible. The process of excitation in the case of a He-Ne laser involves application of high voltage of the order of 10 kV initially across the electrodes of the plasma tube to initiate the plasma. Once the plasma is initiated, the voltage required to sustain the same is usually of the order 2500 V or so.**Figure 4.1** shows generalized block schematic of power supply for a DC excited gas discharge laser.

Both the excitation voltage as well as the sustaining voltage is mainly the function of the intended laser power output of the tube which in turn depends upon several He-Ne plasma tube parameters. Plasma current that needs to be supplied at the plasma tube sustaining voltage is in the range of 5 mA to 10 mA.

Another important requirement is that of providing an appropriate ballast resistance to be connected in series with the plasma discharge impedance and wired as close to the electrode as possible as shown in **Figure 4.2.Figure 4.3** shows the current-voltage characteristics of the He-Ne discharge. The plasma I-V characteristics exhibit a negative resistance as shown in the I-V curve of Fig.8.3. The ballast resistance ensures that the power supply sees a positive resistance while delivering current to the plasma discharge. This is necessary condition to initiate stable plasma discharge. The negative resistance offered by the plasma is given by the reciprocal of the slope of the tangent drawn at the operating point in the curve of **Figure 4.3**.

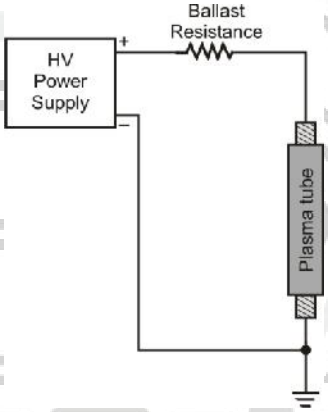

Figure 4.2
Use of Ballast resistance

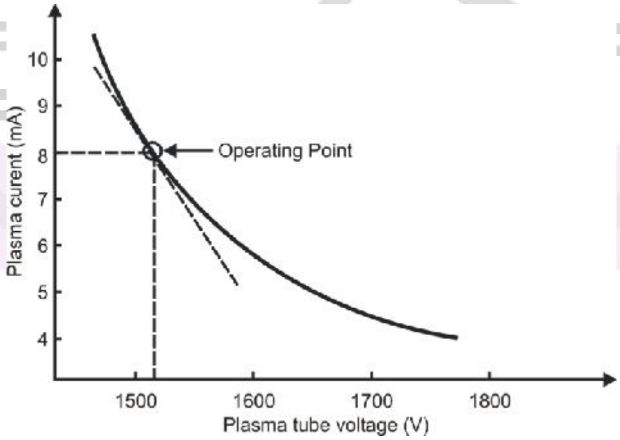

Figure 4.3
I-V characteristics of He-Ne plasma discharge

8.3.1. Power Supply Design

One design approach, which is also the most commonly used one in the case of commercial He-Ne laser power supplies, is to use a voltage multiplier chain to generate the required high voltage for plasma excitation from a relatively much lower input voltage. The power supply in this case is usually designed for a power output capability equal to the product of the voltage, which is the plasma tube voltage at the operating current plus the expected drop across the ballast resistance and the plasma current. In a supply like this, the multiplier chain raises the output voltage to a magnitude needed for initiating the discharge. The moment plasma is struck and the current is drawn from the power supply, the output voltage falls to a lower value required to sustain the plasma.

One possible circuit configuration using a step-up power transformer followed by a cascade type voltage multiplier chain is shown in **Figure 4.4**. The step-up ratio and the multiplying factor are chosen so as to produce an output DC voltage of about 10 kV required for initiating the plasma. One could possibly use for the circuit of Fig.8.6 step-up transformer that produces an output voltage of 1000 V RMS followed by a cascade type voltage multiplier chain with a multiplication factor of 8. Such a circuit would produce at its output a DC voltage equal to $8V_m$ where V_m is peak AC voltage across the secondary of the transformer. For a 1000V RMS across the transformer secondary, the no-load output voltage would be about 11 kV, which is just the right voltage for exciting the He-Ne plasma.

In the circuit of **Figure 4.4**, the multiplication factor of the cascade multiplier chain needs to be an even number. A similar circuit configuration with an odd multiplication factor is shown in **Figure 4.5**. The designer is free to exercise this flexibility in choosing the transformer step-up ratio and the multiplier's multiplication factor depending upon what is optimum in a given situation. In the circuit configuration of **Figure 4.5**, the multiplication factor is 7.

Once the plasma is struck and current is drawn from the power supply, the output voltage falls due to voltage drops in the transformer windings and diodes in the multiplier chain. Ideally, this voltage should drop to a value equal to the required power supply voltage for plasma sustenance, which is the sum of the plasma tube voltage at the desired plasma current plus the voltage drop across the ballast resistance. If the voltage does no fall to the required value and is instead higher than that, then the excess voltage would have to be dropped across an additional resistance is series with the ballast resistance in order to get the desired plasma current. Otherwise, the plasma current would be more than the desired operating value for the right value of the ballast resistance.

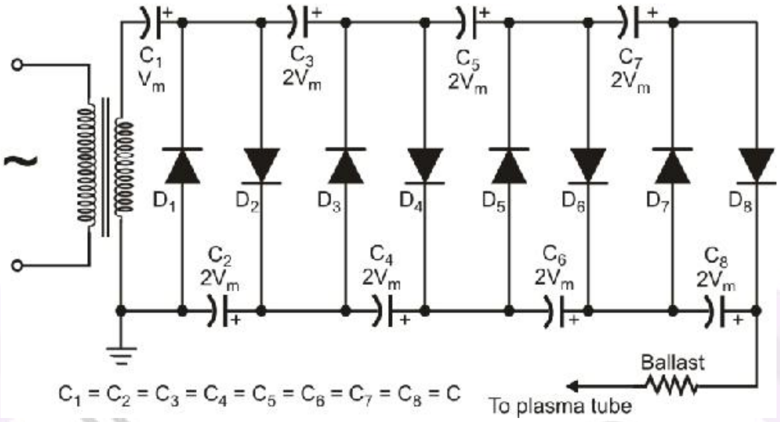

Figure 4.4

He-Ne power supply with a cascade multiplier chain having even multiplication factor

It may be mentioned here that most of the voltage drop occurs across the multiplier chain. The components of the chain have to be so chosen as to drop the required voltage across it. Now, for a multiplier chain with an even multiplication factor, the output voltage (V_O) can be expressed by equation 8.1.

$$V_O = \frac{nV_P}{1+\left[n\left(n^2/2+1\right)/6\,fCR_L\right]} \tag{8.1}$$

Where, (n) is the multiplication factor

V_p is the peak value of the voltage at the input to the multiplier chain

f is the frequency of the AC input

C is the capacitance of each capacitor in the chain

R_L is the load resistance

In case the multiplication factor is odd, the output voltage (V_O) can be expressed by equation 8.2.

$$V_O = \frac{nV_P}{1+\left[n\left(n^2-1\right)/12\,fCR_L\right]} \tag{8.2}$$

In both cases, as is clear from the above equations, the output voltage is ‘n’ times the input voltage to the multiplier chain only when the factor within the brackets in the denominator is zero. For this to happen, the denominator of the bracketed term needs to be much greater than the numerator. For the given values of frequency and load resistance, this can be achieved by using large value capacitors.

As the desired multiplication factor increases, it can be visualized that the capacitance value becomes prohibitively large even for moderate values of load current. That is why the multiplier chain of this type is inherently poorly regulated. But this can be used to advantage in the case of a He-Ne laser power supply design. For instance, for the given values of load resistance (which is decided by the required power supply output voltage for plasma sustenance and the plasma current) and the frequency of the input to the chain (50 Hz in case of chain operating from the AC mains), value of C can be so chosen as to get an output voltage that equals the required output voltage for plasma sustenance.

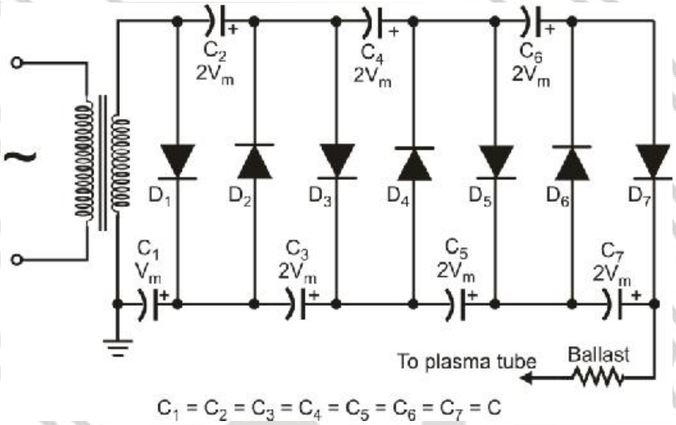

Figure 4.5

He-Ne power supply with a cascade multiplier chain having odd multiplication factor

For a multiplication factor of ‘8’ and frequency equal to 50 Hz, the value of capacitance would be about 0.04 μF if the laser power supply output had to produce an output voltage of 2000 V for a plasma current of 5 mA, assuming that the input AC signal to the multiplier chain input is 1000 V RMS or about 1400 V peak. So, for the circuit of **Figure 4.4**, if the capacitance value is 0.04 μF, the output voltage would automatically fall from an initial no-load value of about 11 kV to about 2000 V when a plasma current of 5 mA is drawn from it.

In fact, the multiplier chain as a whole offers a series resistance which drops a voltage across it when current is drawn from it. The multiplier chain may be represented by an equivalent circuit of the type shown in **Figure 4.6**. This equivalent series source resistance to a very good approximation increases as the cube of the multiplication factor. This implies that if the multiplication factor is doubled, then for a given operating frequency, the capacitance will have to be increased by a factor of eight if the multiplier circuit were to maintain the same output voltage on load.

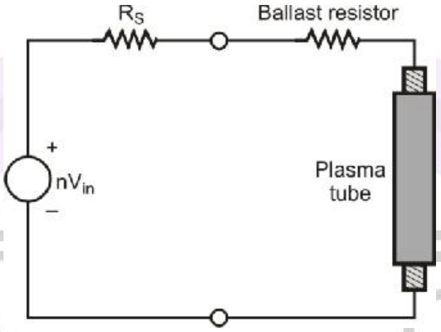

Figure 4.6
Equivalent circuit of cascade multiplier chain

Another multiplier circuit configuration that offers superior performance in terms of efficiency is shown in Figure 4.7. The configuration shown here is that of a multiplier with even multiplication factor. The circuit works at an efficiency that is better than that of the circuit using equal value capacitances. The circuits shown in Figures4.4, 4.5 and 4.7 are half-wave circuits. A full-wave voltage multiplier that gives a far better ripple performance is shown in Figure 4.8. The circuit shown is a quadrupler.

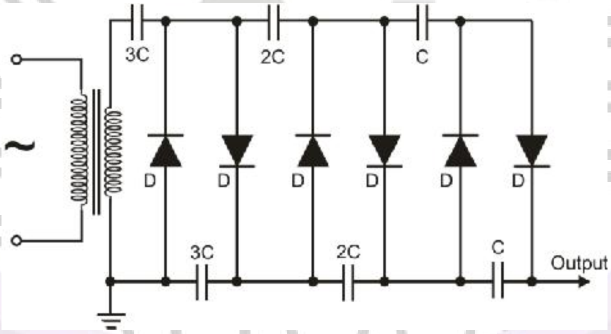

Figure 4.7
Multiplier chain with unequal capacitors

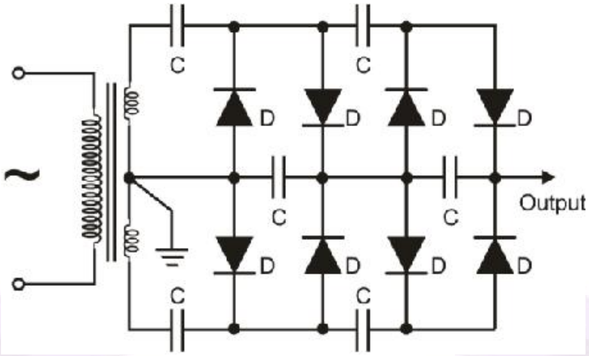

Figure 4.8
Full wave voltage multiplier

4.3.2. Switched Mode Power Supply Configurations

The concept of using a multiplier chain fed at the input by an AC signal can be implemented far more effectively and efficiently by using a switched mode power supply to drive the voltage multiplier chain. The most obvious SMPS configuration for such an application is the push-pull circuit as it generates a square wave AC signal across the secondary of the switching transformer. Both, self-oscillating as well as externally driven configurations can be used. The latter configuration has better control over various performance parameters.

A variety of switched mode IC controllers are available that are suitable for driving the two transistors (BJT or MOSFET) of the push-pull configuration. ICs LM/SG3524, TL494, TL594 and TL497 are a few of them. The peak value of the square wave output across the transformer secondary equals the input DC voltage applied to the centre tap of the transformer primary, multiplied by the step-up ratio of the transformer. Again, the converter could operate off-line where a bridge circuit transforms the AC mains input into a proportional DC, which in turn feeds the centre tap of the push-pull transformer primary.

In case the converter is off-line, there is no isolation transformer for the mains. In such a case the feedback loop must have isolation so that the DC output is cut off from the AC line. This is usually accomplished by using an opto-isolator.

The other option is to operate the converter from a relatively lower DC voltage of say, 24V DC, which could be generated from a step-down transformer, rectifier and filter combination. The transformer here provides isolation, which eliminates the need for using additional isolation on the output side. It may be mentioned that a typical He-Ne power supply needs to deliver about 10 W of power. The use of step-down transformer, rectifier and filter does not really add significantly to the size, while it allows the designer to use much lower voltage switching devices.

The switched mode version has all the advantages associated with switched mode power supplies like higher efficiency, small size and so on. To use a push-pull converter with a voltage multiplier chain for designing a He-Ne power supply, the required capacitance value would be much smaller for a given multiplication factor due to high frequency operation. On the other hand, if the operating frequency is, say, 50 kHz for a given value of the chosen capacitance it would be possible to use a multiplication factor which is 10 times the one possible in case of a multiplier circuit operating at 50 Hz.

A typical He-Ne laser power supply configuration built around an externally driven push-pull inverter driving a voltage multiplier chain is shown in **Figure 4.9**. The controller IC used here is LM3524. Here the components R and C decide the switching frequency. R_1 and R_2 constitute the voltage sense loop whereas R_3 and R_4 potential divider arrangement makes use of the internal reference of + 5V (available at pin 16 of the IC) to generate reference for the voltage sense loop. Any other suitable IC can also be used with associated minor changes in the external circuit. The data sheets of these ICs come with basic application circuits. In the absence of availability of the controller IC, the same configuration could be implemented using two 555 timer ICs or one 556 timer IC as shown in **Figure 4.10**.

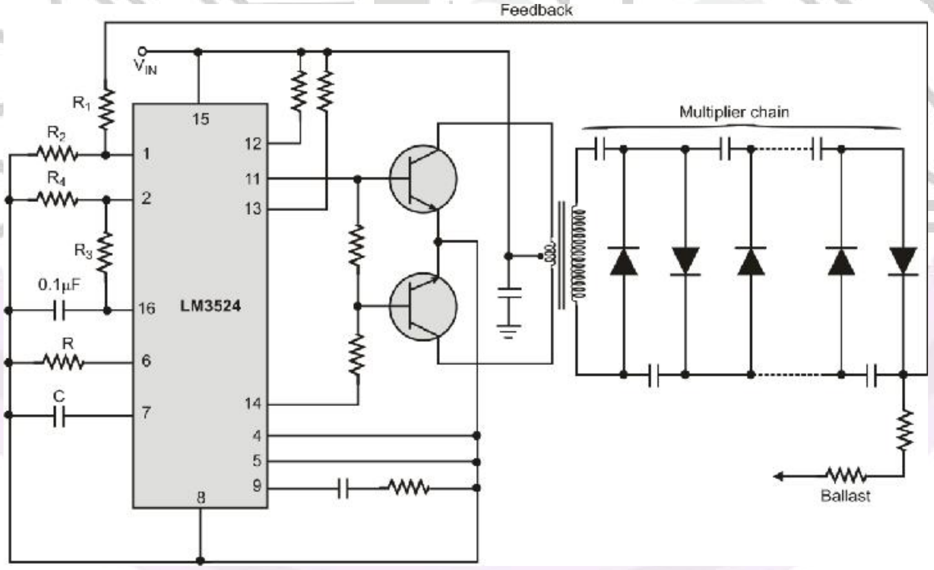

Figure 4.9
He-Ne power supply using push-pull inverter and multiplier chain

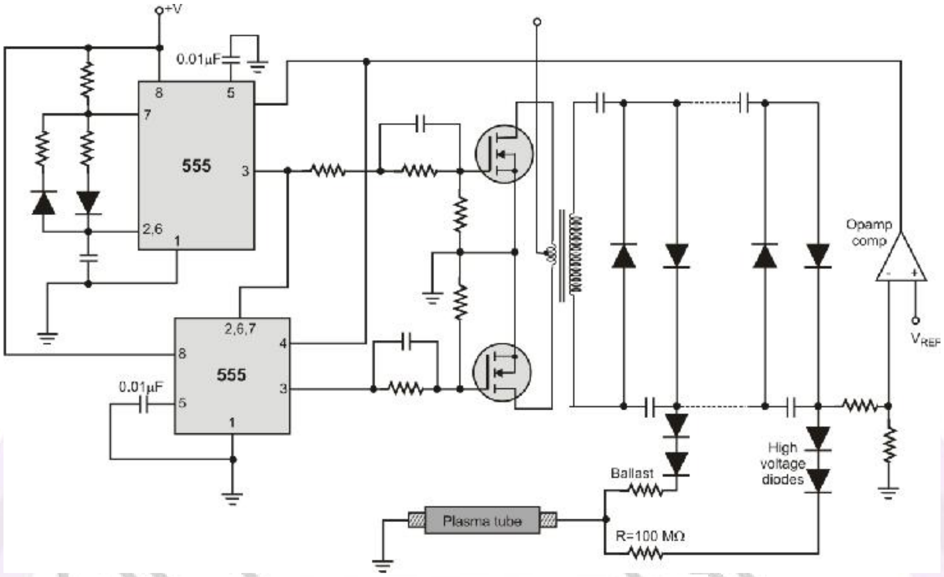

Figure 4.10
Push-pull converter with 555 timer IC based drive circuit

A close examination of the circuit shown in **Figure 4.10** reveals an interesting variation from the circuit of **Figure 4.9** on the output side. As discussed earlier, the capacitance value has to be chosen as to ensure that the power supply output voltage falls to the level of the sustaining voltage when plasma current is drawn from the power supply. Such a circuit inherently lacks good regulation. Now, if we choose the capacitance value in such a way that the power supply output voltage on load is either equal to or slightly less than the open circuit voltage, the excess voltage would need to be dropped across an additional series resistance.

In the configuration of **Figure 4.10**, the plasma tube is initially fed from the output of the multiplier chain, and the moment the plasma is struck, the tube draws its current from a point where the push-pull output is only doubled. The current drawn through the rest of the multiplier chain is almost negligible. In the circuit shown, this current is of the order of 80 µA for a multiplied output voltage of 10 kV, assuming a voltage of about 2 kV across the plasma tube.

8.3.3. Other Possible Configurations

A self-oscillating flyback converter, which is inherently a constant output power DC/DC converter, is another supply configuration particularly attractive for use with He-Ne lasers. **Figure 4.11**shows the basic circuit. The converter circuit in this case is designed to deliver an output power equal to the product of the required sustaining voltage at the power supply output and the plasma current. Since it is a constant output power converter, the output voltage would increase without limit in the ideal case in the event of zero current drawn from the power supply. When the output voltage exceeds the required initiating voltage, the plasma current drawn from the power supply forces the output voltage to fall to the sustaining voltage governed by the output power capability of the converter.

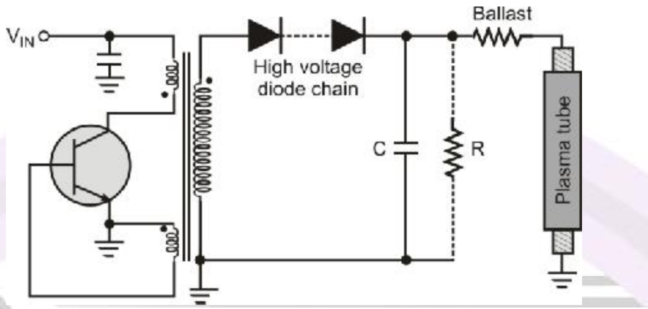

Figure 4.11
Constant output power self-oscillating flyback converter based power supply

It is advisable to have a fixed value high voltage resistor across the output as shown in the diagram. The resistance of this resistor can be computed from R = V^2/W, where 'V' is the required initiating voltage, typically 10 kV, and 'W' is the power output capability of the converter. This resistance would ensure that the output voltage does not rise without limit.

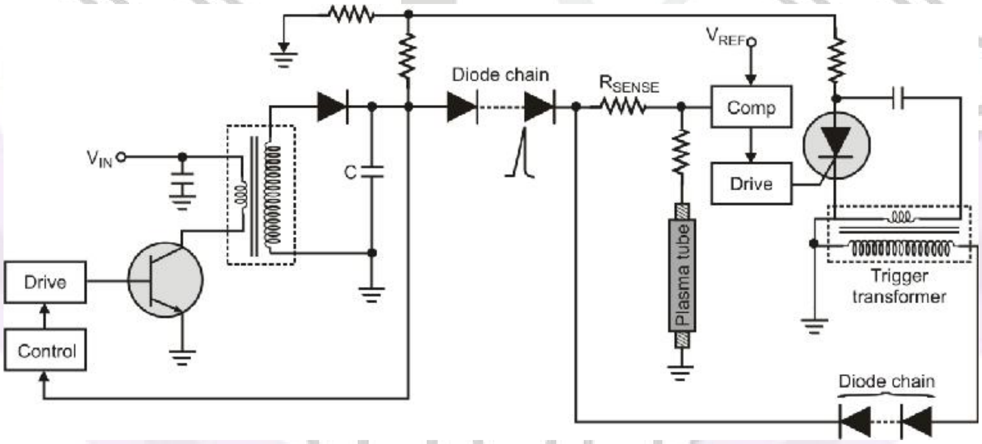

Figure 4.12
Externally driven flyback converter based power supply

Another configuration, as shown in **Figure 4.12**, makes use of an externally driven flyback converter. It generates an output voltage equal to the required sustaining voltage. The power output capability is equal to the product of the sustaining voltage and the desired plasma current. A voltage feedback loop ensures the right voltage at output. The output of the power supply feeds the plasma tube through a ballast resistance. The ballast resistance here is split into two parts. The voltage present after the first resistance is used to sense the status of the plasma tube to ascertain if the plasma has been struck. In the absence of plasma, this voltage equals the power supply output voltage. In case the plasma is struck, the voltage falls by an amount equal to the product of the plasma current and the resistance value.

A fraction of this voltage is compared with a reference voltage in a comparator whose output is used to enable or disable an astable multivibrator. The multivibrator circuit in turn triggers an SCR-based capacitive charge/discharge circuit. In the absence of plasma, the SCR circuit generates high voltage pulses at a repetition rate of typically 20 Hz to 30 Hz. The trigger pulses are withdrawn when the plasma is struck.