



Low vs High Frequency Plasma Excitation

We have frequently been asked to document why lower frequency plasma (40-50 kHz) provides demonstrably superior cleaning action than achieved at higher frequencies (13.56 Mz or GHz).^{1,2}

To provide a basis for discussion let us define a typical plasma system as follows:

- Electrode dimensions: 16 inches (0.4 meters) square (area of 0.16 meters)
- Number of electrodes: 4
- Spacing between electrodes: 1.5 inch (.012 meters)
- Power Supply: 400 Volts

Now let's look at how low and high frequencies will affect the energy delivered to the sample surface.

Basic Circuit/System Capacitance

First, if we look at the basic circuit of a typical plasma system, we see it is one (or more) capacitors arranged in parallel as shown in Figure 1.

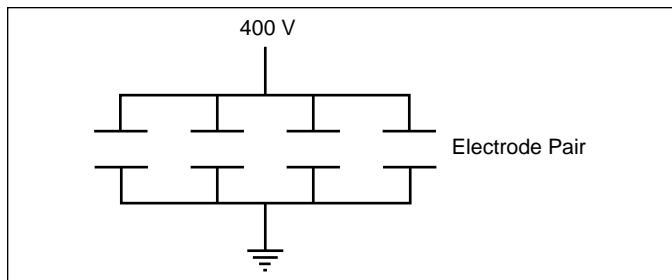


Figure 1.

The actual capacitance of a parallel plate capacitive system is given by the formula

$$C = \frac{AKE_0}{d}$$

Equation 1

where:

- C = Capacitance in Farads
- A = Area of one of the plates in sq. meters (0.16)

- K = Relative dielectric constant if the dielectric between the plates (Unity for most gases)
- E₀ = Permittivity of empty space (8.85 x 10⁻¹² coul²/newton-m²)
- d = Distance between the Capacitor plates in meters (0.012)

Substituting the these values we get a typical system capacitance of

$$C = \frac{16 \times 1 \times 8.85 \times 10^{-12}}{.012} = 118 \times 10^{-12} \text{ Farads}$$

System Efficiency

The "efficiency" of a plasma system is the ratio of the energy used in producing the plasma vs the energy dissipated in such losses as heat.

An ideal system should act like a perfect capacitor with infinite Capacitive Impedance, or zero current drain in the standby mode. Then as current applied across the capacitive pair (electrodes) causes the plasma gas to ionize, the impedance will be bridged causing current flow (or plasma) between the electrodes.

The Capacitive Impedance of a parallel plate capacitive system is given by the formula

$$X_c = \frac{1}{2\pi f c}$$

where:

- X_c = Capacitive Impedance
- f = Frequency in Hz
- C = Capacitance as calculated above

1. Mitsuo Shimozuma, Gen Tochitani and Hiroaki Tagashira, "Optical Emission diagnostics of H₂ + CH₄ 50 Hz - 13.56 MHz Plasma for Chemical Deposition". *J. Appl. Phys.*, Vol. 70, No. 2, 15 July 1991.
2. Y. Khairallah, F. Arefi, J. Amouroux, D. Leonard and P. Bertrand, "Surface fluorination of polyethylene films by different glow discharges. Effects of frequency and electrode configuration". *J. Adhesion Sci. Technol.* Vol. 8, No. 4, pp 363-381 (1994).

Relative Efficiencies - 40kHz vs 13.56 MHz

To review the relative efficiencies of 40kHz vs 13.56 MHz for the above typical system, we simply substitute these frequencies into the preceding formula.

Then for a system operating at a frequency of **40kHz** (40×10^3 Hz), we get:

$$X_c = \frac{1}{2\pi \times 40 \times 10^3 \times 118 \times 10^{-12}} = 340,000 \text{ Ohms}$$

and for a system operating at a frequency of **13.56 MHz** (13.56×10^6 Hz), we get:

$$X_c = \frac{1}{2\pi \times 13.56 \times 10^6 \times 118 \times 10^{-12}} = 400 \text{ Ohms}$$

As you will note, the Capacitive impedance is 850 times greater for the 40kHz system.

To find how this impacts system performance let us consider Ohms Law.

$$I = E/R$$

where I = Current; E = Voltage; R = Impedance (Xc).

Substituting known values we get for the **40kHz system**:

$$I = 400/340,000 = 1.176 \times 10^{-3}$$

and for the **13.56 MHz system**:

$$I = 400/400 = 1$$

Substituting these values into the standard power equation

$$P = I^2 R$$

where P = System Power in watts
I = Current in amps
R = Xc in ohms

We get:

$$\begin{aligned} \text{Energy Loss for a 40kHz System} &\leq I^2 R = \\ (1.176 \times 10^{-3})^2 \times 340,000 &= 1.38 \times 10^{-6} \times 340 \times 10^3 \\ &= \mathbf{0.47 \text{ watts}} \end{aligned}$$

$$\begin{aligned} \text{Energy Loss for a 13.56 MHz System} &= I^2 R = 1^2 \times \\ 400 &= \mathbf{400 \text{ watts}} \end{aligned}$$

Note that the energy loss with a 13.56 MHz system is 850 times higher than with the 40kHz system.

These calculations are very real and show that with a spacing of 0.05 inch between the capacitive plates of a plasma system operating at 400 watts and a frequency of 13.56 MHz, almost all the energy will go into heat loss and no plasma will occur. If the 13.56 MHz system is to work at all, the capacitance of the system must be artificially increased with substantial electrode spacing ("d" in Equation 1). Thus it will be noted that a high frequency system operating in the downstream mode must be configured as shown in Figure 2 for the system to work.

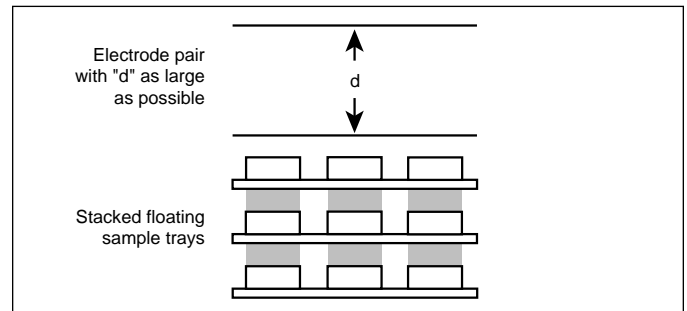


Figure 2. High frequency system configuration showing "shadowing" that occurs when sample trays are stacked.

The space between the electrodes MUST be as large as possible for plasma to occur and it is then necessary to stack all sample shelves in the chamber space remaining. In this configuration, samples on the upper shelves form a very effective mask to prevent plasma reaching the samples on the shelves below (referred to as "shadowing").

On the other hand, a low frequency system operating in the downstream mode can be configured as shown in Figure 3. Since Xc is large, the electrode pairs can be positioned close together (small "d"), allowing each floating sample tray to have a dedicated set of electrodes to provide uniform plasma across each sample tray.

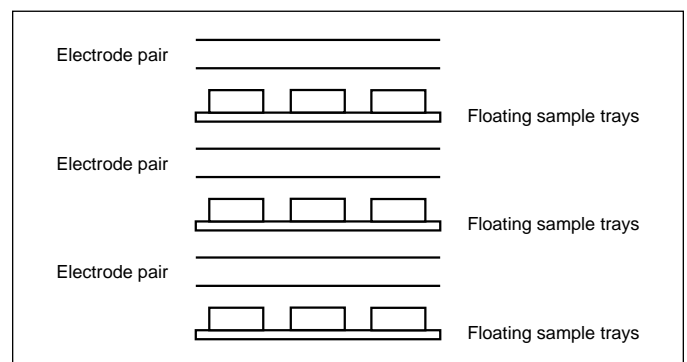


Figure 3. Low frequency system showing close proximity of the electrode pairs and even energy distribution with no shadowing.



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