Electrical Model of Capacitively coupled plasma

Prepared by
Yara Saad

Supervised by
Dr . Mohammed Shihab

Outlines:

- Motivation.
- Electric model
- Experiment and results.
- Outlook.

Motivation:

This is a comprehensive study of the electrical model of radio-frequency capacitively-coupled plasma (RF-CCP). The plasma is simplified into an RLC circuit. Its solution indicates the non linear behaviour of the plasma sheath, this non linearity led to the formation of harmonics in the plasma; i.e., a number of frequencies is excited. this was contrary to the assumption that expected the existence of the frequency of the driven RF source only. The model was solved using Mathematica program. The solution of the model gave the instantaneous discharge current as a function of time. We also calculated the instantaneous power dissipation and the accumulated power as a function of time. These calculations were repeated at different pressure values to get the optimum results. As outlook, the problem should be calculated analytically to give more physical understanding of the interplay between the sheath and the plasma bulk.

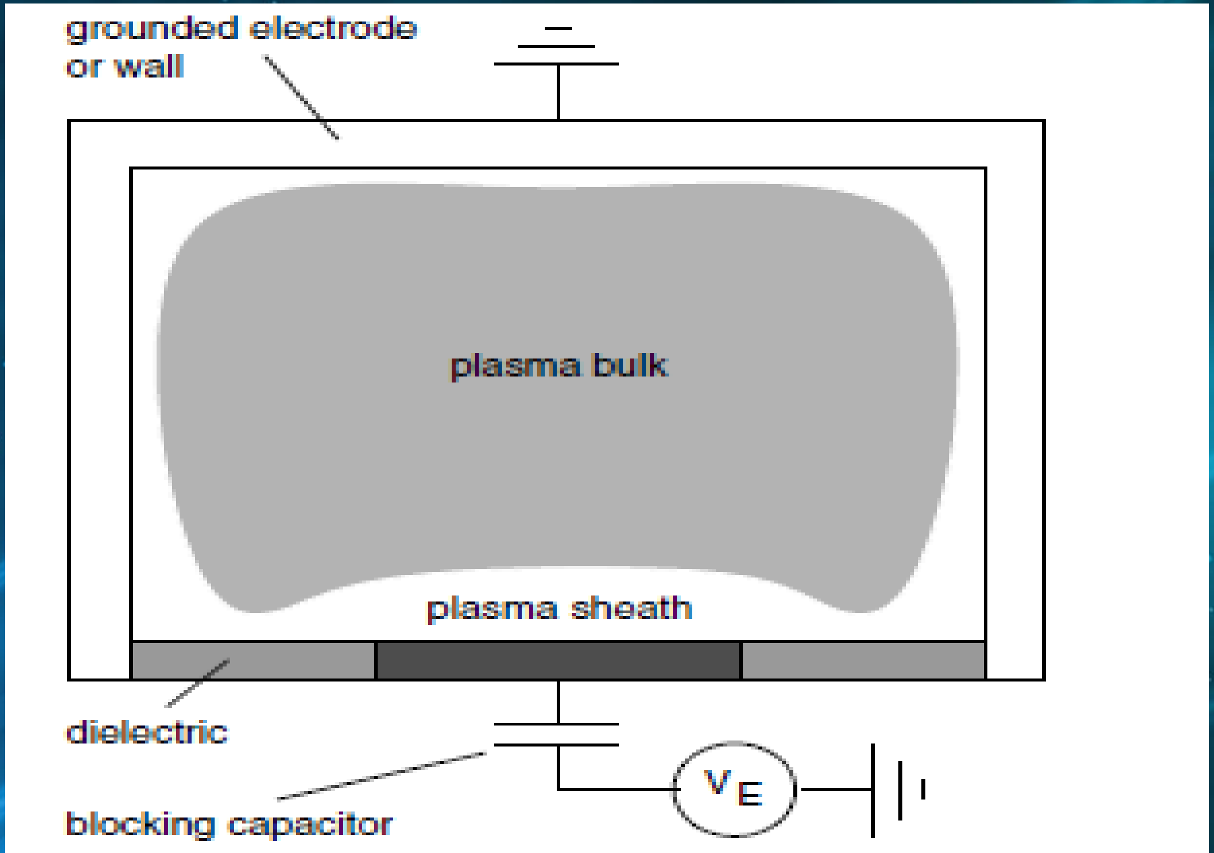
Harmonics in a power system:

In an electric power system, a harmonic of a voltage or current waveform is a sinusoidal wave whose frequency is an integer multiple of the fundamental frequency.

Capacitance of the capacitor is the ability of it to store electric charge when a potential difference exists between the conductors.
It is inversely proportional to frequency, so the presence of harmonics will lower the charge storage, hence increasing the loss to the plasma power dissipation.

Researches are performed to make limitation to these harmonics to avoid their harmful effects on the power system.

$$J_g = I_{rf}/A_g$$
$$J_p = I_{rf}/A_p$$
$$J_p \gg J_g$$



Capacitively coupled plasma can be analogous to series circuit consisting of an ohmic resistance and a coil of inductance L for the bulk, and capacitor for the sheath all connected in series.

To prove this:

2.2 Sheath dynamics:

assume a constant ion density $n_i(X) = \tilde{n}_s$, and neglect the electron density in the sheath,

$$-\frac{d^2 \varnothing}{d x^2} = -\frac{e}{\varepsilon_0} n_i(X)$$

Integrating over sheath borders 0 'n s (t)

$$\frac{d \varnothing}{d x} = -\frac{e n_i}{\varepsilon_0} s$$

$$\therefore \varnothing = -\frac{e n_i}{\varepsilon_0} \frac{s^2}{2}$$

Since surface charge density $\sigma(t) = \int_0^{s(t)} e\, n_i(x)\, dx = e \tilde{n}_i s(t)$

$$\therefore s(t) = \sigma(t) / e \tilde{n}_i$$

$$\therefore \varnothing = -\frac{e\, n_i}{\varepsilon_0} \frac{\sigma^2}{2\, e^2\, n_i^2} = \frac{-\sigma^2}{2\, e\, \varepsilon_0\, n_i}$$

Since $\sigma(t) = Q \setminus A$,

$$\therefore \varnothing = \frac{-Q^2}{2\, e\, \varepsilon_0\, n_i\, A^2}$$

∴ Plasma sheath can be represented by a non- linear capacitor .

2.3 Bulk dynamics:

starting from the momentum equation of electron ,

$$m_e \frac{\partial v_e}{\partial t} + m_e\, v_e \frac{\partial v_e}{\partial x} = -e\, E - m_e v_e f_c$$

Where f_c is electron collision frequency

The forces present are : electric force and collision force ,

Assuming that bulk is homogeneous :

$$\therefore \cancel{m_e \frac{\partial v_e}{\partial t}} + m_e\, v_e \frac{\partial v_e}{\partial x} = -e\, E - m_e v_e f_c$$

$$\therefore \quad m_e \frac{\partial v_e}{\partial t} + m_e v_e f_c = -e\,E = e\,\frac{d\varnothing}{dx}$$

Since $E = -\nabla \varnothing = -\dfrac{d\varnothing}{dx}$,

Integrating over bulk borders,

$$\therefore \int \left(m_e \frac{\partial v_e}{\partial t} + m_e v_e f_c\right) d\,x = e\,\varnothing$$

Where $\varnothing$ is the bulk potential difference ,

$$\therefore \; m_e \frac{\partial v_e}{\partial t}\, L + m_e v_e f_c\, L = e\,\varnothing$$

Where L is bulk limits,

Since current density $= J = \dfrac{I\,(t)}{A} = e\,n_e\,v_e$

$$\therefore \quad v_e = \frac{I\,(t)}{A\,e\,n_e}$$

Since $m_e \dfrac{\partial v_e}{\partial t} + m_e v_e f_c = -e\,E = e\,\dfrac{d\varnothing}{dx}$

$$\therefore \frac{m_e}{e} \int_{x_1}^{x_2} \left(\frac{\partial}{\partial t} + f_c \right) \frac{I(t)}{A\, e\, n_e} dx = \varnothing_{21}$$

$$= \frac{m_e L}{e^2 n_e A} \left(\frac{\partial}{\partial t} + f_c \right) I(t) = \varnothing_{21}$$

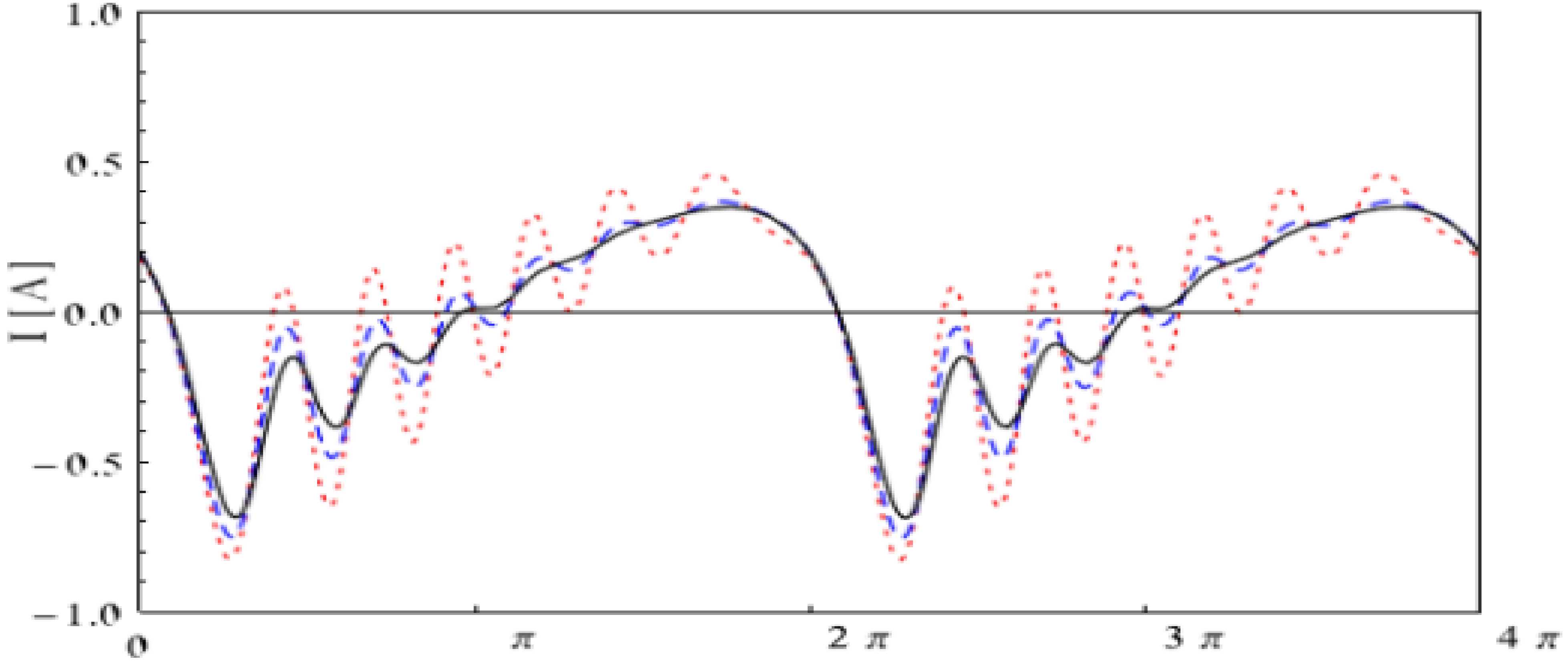
Since $V_{source} = V_{bulk} + V_{sheath}$

$$\therefore V_{source} = \frac{m_e L}{e^2 n_e A} \left(\frac{\partial}{\partial t} + f_c \right) I(t) - \frac{Q^2}{2\, e\, \varepsilon_0\, n_i A^2}$$

$$\therefore V_{source} = \frac{m_e L}{e^2 n_e A} \left(Q'' + f_c Q' \right) - \frac{Q^2}{2\, e\, \varepsilon_0\, n_i A^2}$$

$$\therefore V_{source} = a Q'' + bQ' + c Q^2$$

We examine the model in High frequency regime where source angular frequency is 13.56 MHz.
We carried out the simulation at three gas pressures, 10 mTorr, 30 mTorr, and 50 mTorr,Fig1. shows the discharge current at three pressures 10 mTorr, 30 mTorr, and 50 mTorr. One can easily observe the excited harmonics due to the plasma series circuit. Fourier analysis of the current shows frequency components in the range of 1 MHz to 40 MHz with considerable amplitudes. The amplitude of the self-excited harmonics are diminished by increasing the plasma pressure. On the other hand, increasing the gas pressure increases the collision frequency and, consequently, increases the power dissipation.



The discharge current at 10 mTorr (dotted-red), 30 mTorr (dashed-blue), and 50 mTorr (solid-black).

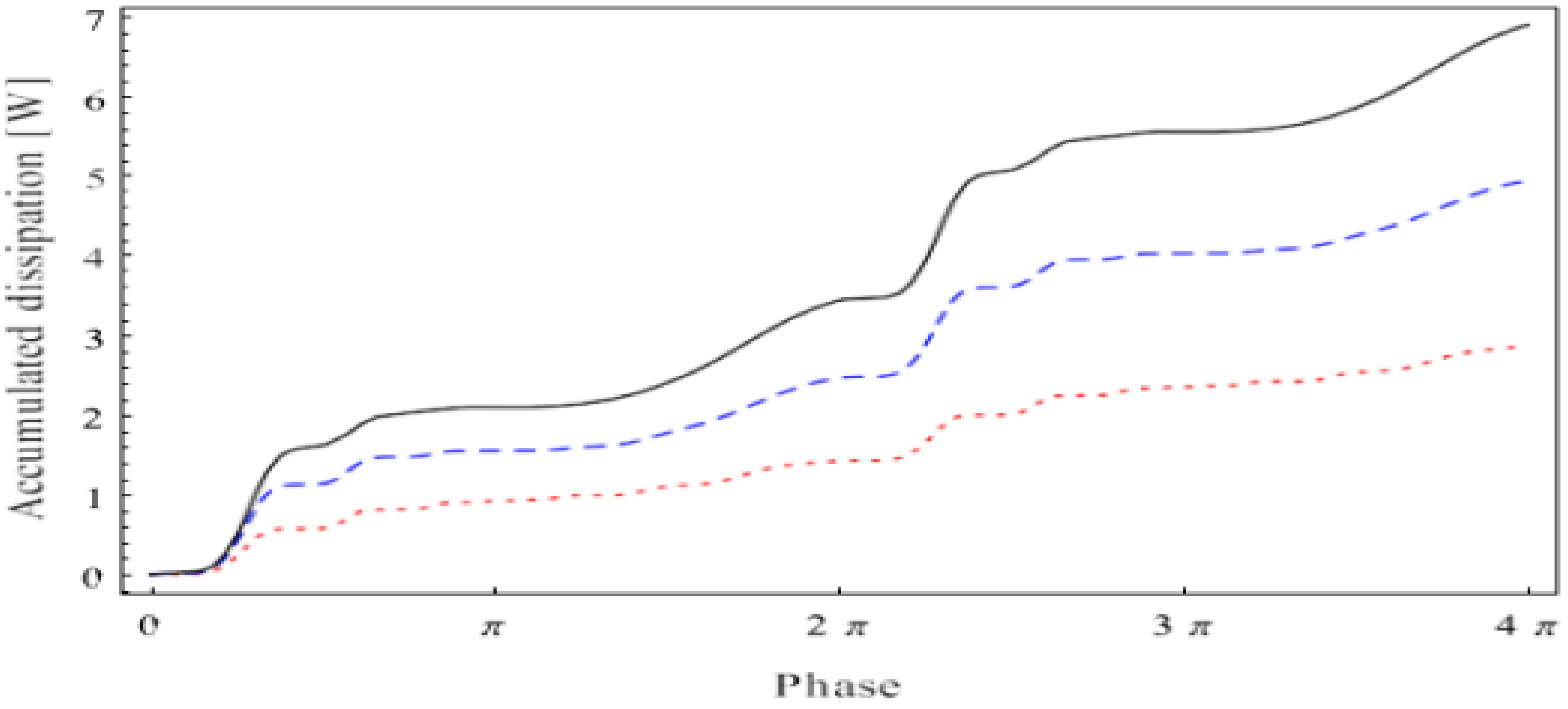


Fig. 3. The phase-accumulated power at 10 mTorr (dotted-red), 30 mTorr (dashed- blue), and 50 mTorr (solid-black).

Outlook

THANK YOU