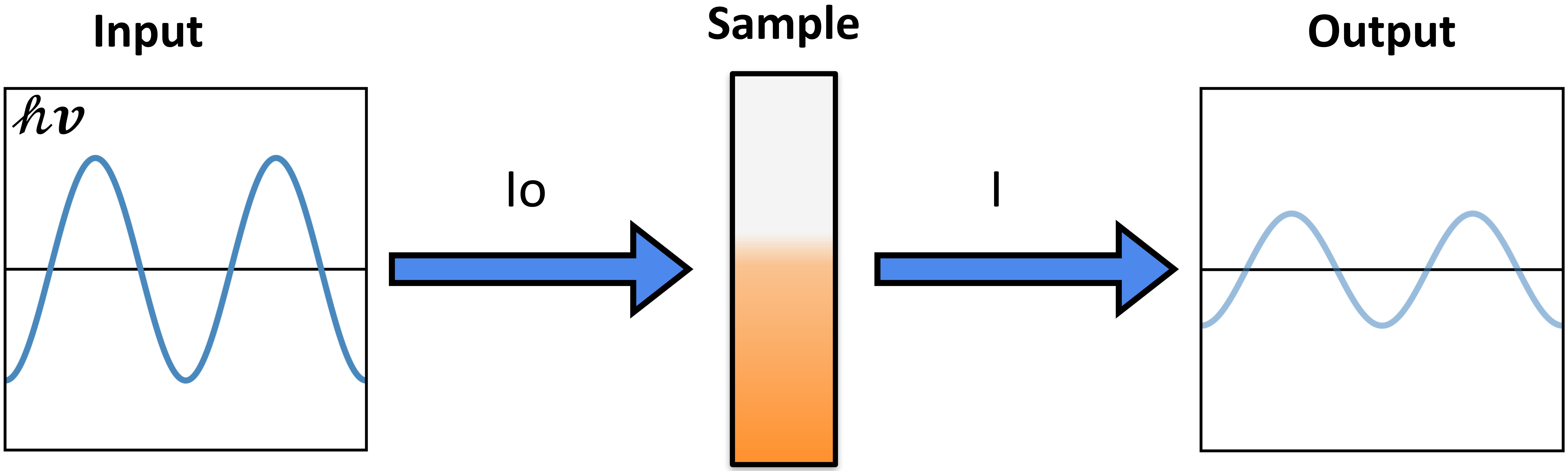
THE OHIO STATE UNIVERSITY

Impedance Tutorial

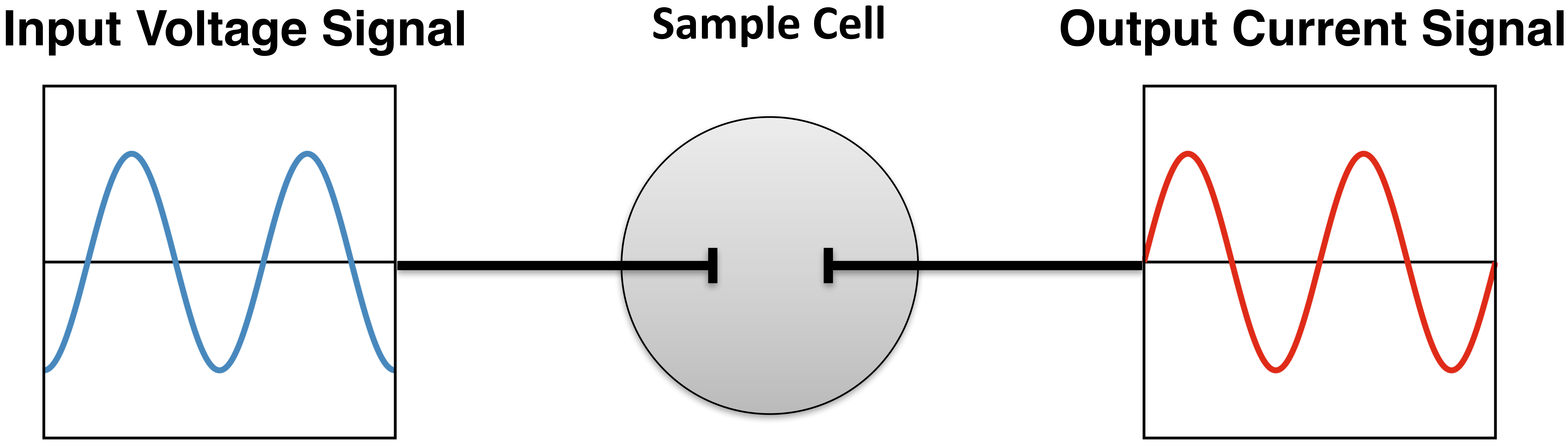
Wu Group
Billy McCulloch

UV-Vis Spectroscopy



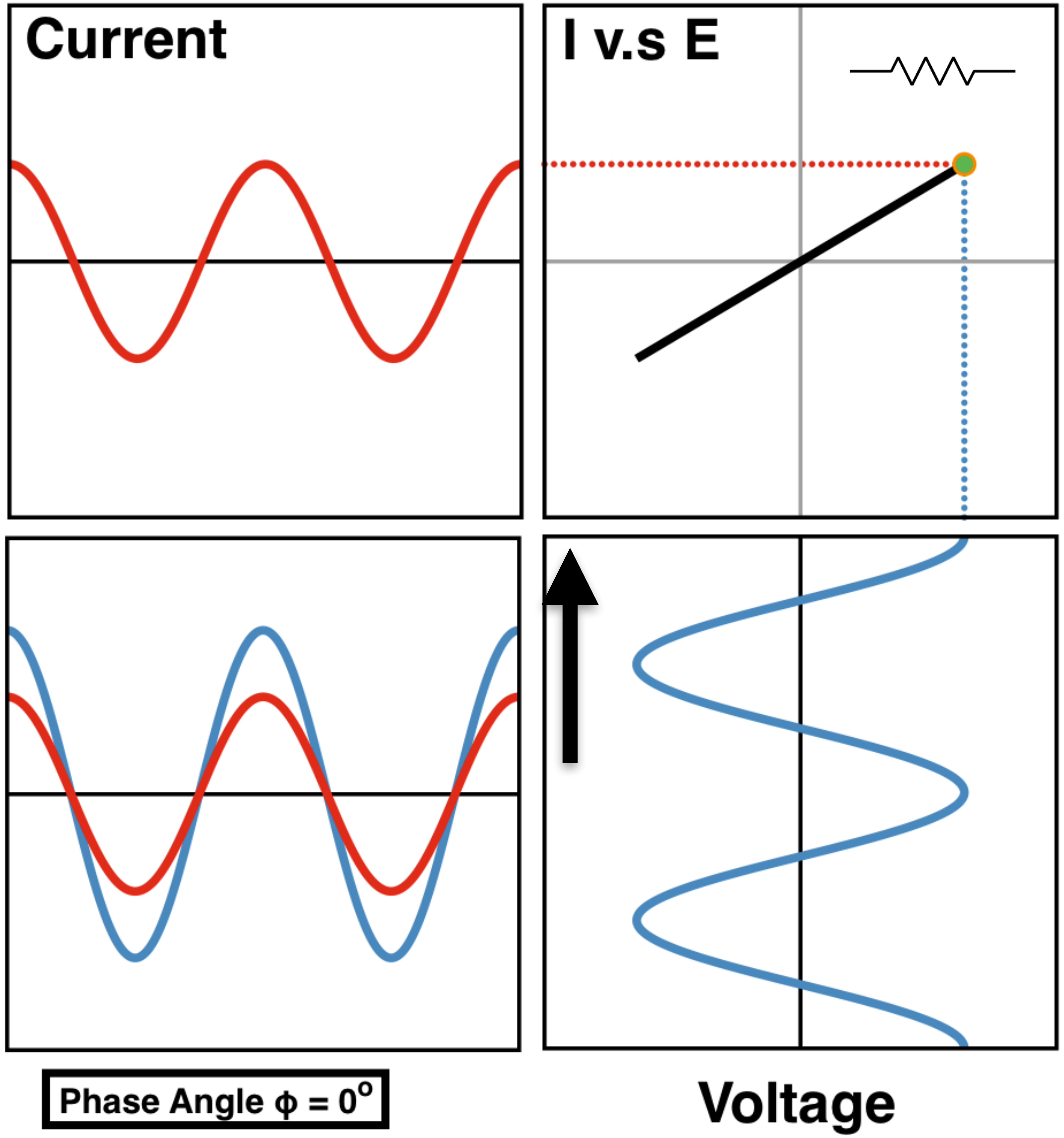
- Scan Frequency: ~ 3-8 x 10^{14} Hz
- Change in Amplitude of signal- Related to the Transmittance(v)
- Gain Information about the effect of frequency on the sample

Impedance Spectroscopy



- Scan Frequency: ~ 0.01 - 1 MHz
- Change in Amplitude and phase related to the Impedance(v)
- Difference elements respond differently to different Frequencies

Dependance of Resistor



Resistor

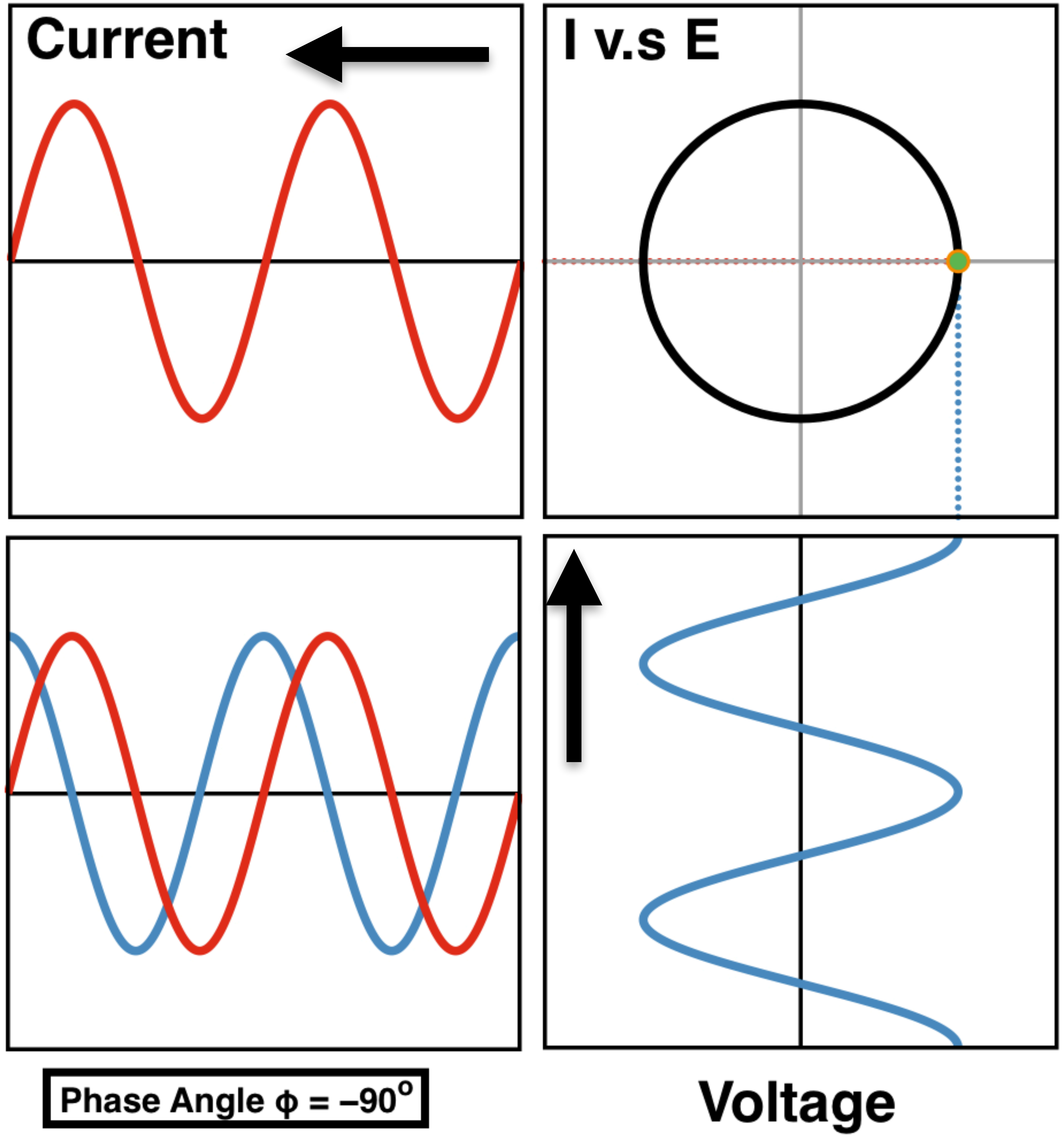
Ohms Law $R = \frac{V}{I}$ $\quad Z = \frac{V(t)}{I(t)}$

$$V(t) = Sin(\omega t)$$ **Input Voltage**

$$I(t) = \frac{Sin(\omega t)}{R}$$ **Output Current**

$$Z_{resistor} = R$$
$$Phase\ \phi = 0^o$$

Dependance of a Capacitor



Capacitor

$$Q = CV$$

$$\frac{dQ}{dt} = C\frac{dV}{dt}$$

$$I(t) = C\frac{dV}{dt}$$

$$V(t) = Sin(\omega t)$$

$$I(t) = C\omega cos(\omega t)$$

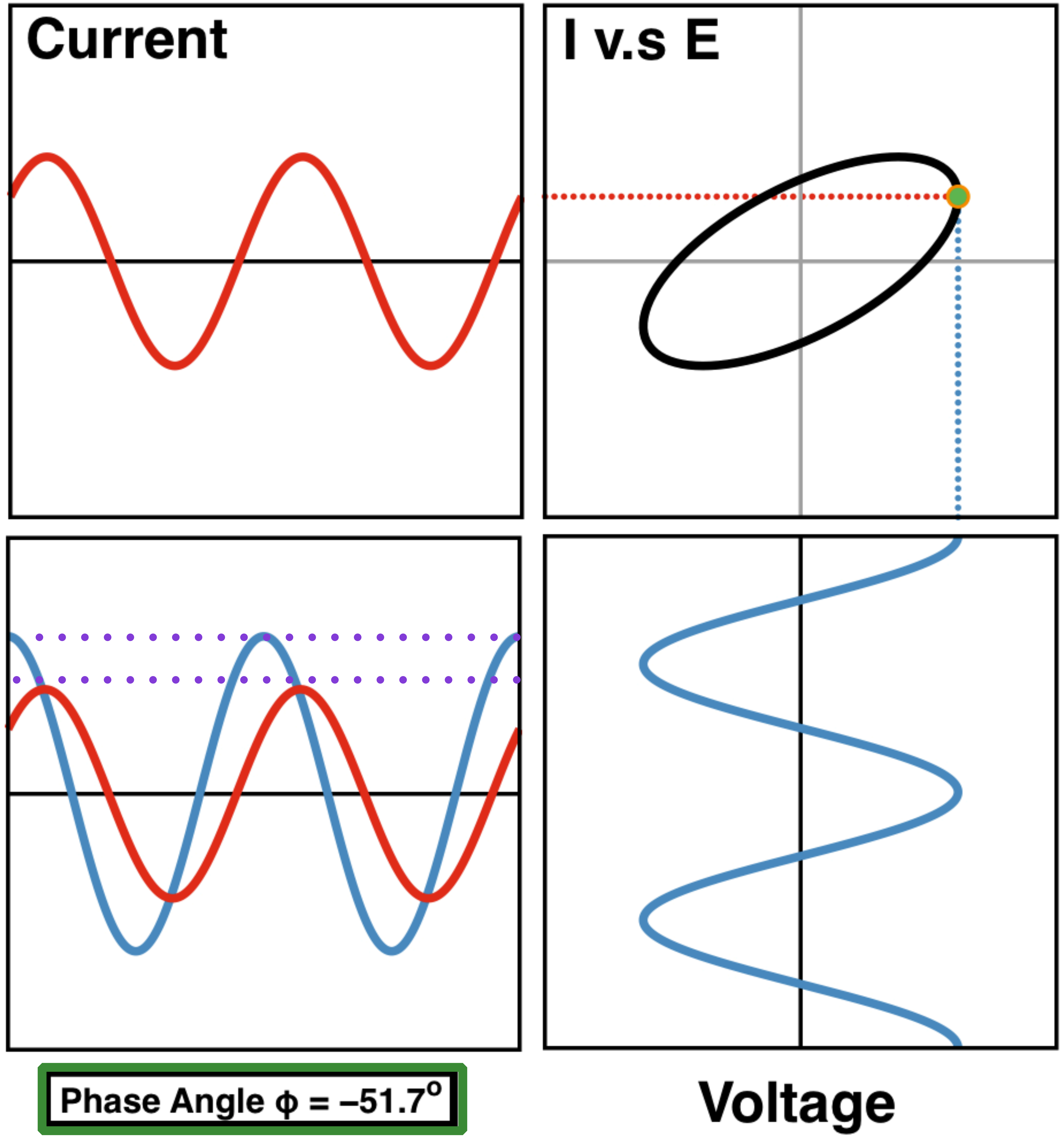
$$I(t) = C\omega sin(\omega t + 90^o)$$

$$Z = \frac{V(t)}{I(t)}$$

$$Z_{Capacitor} = \frac{1}{\omega C}$$

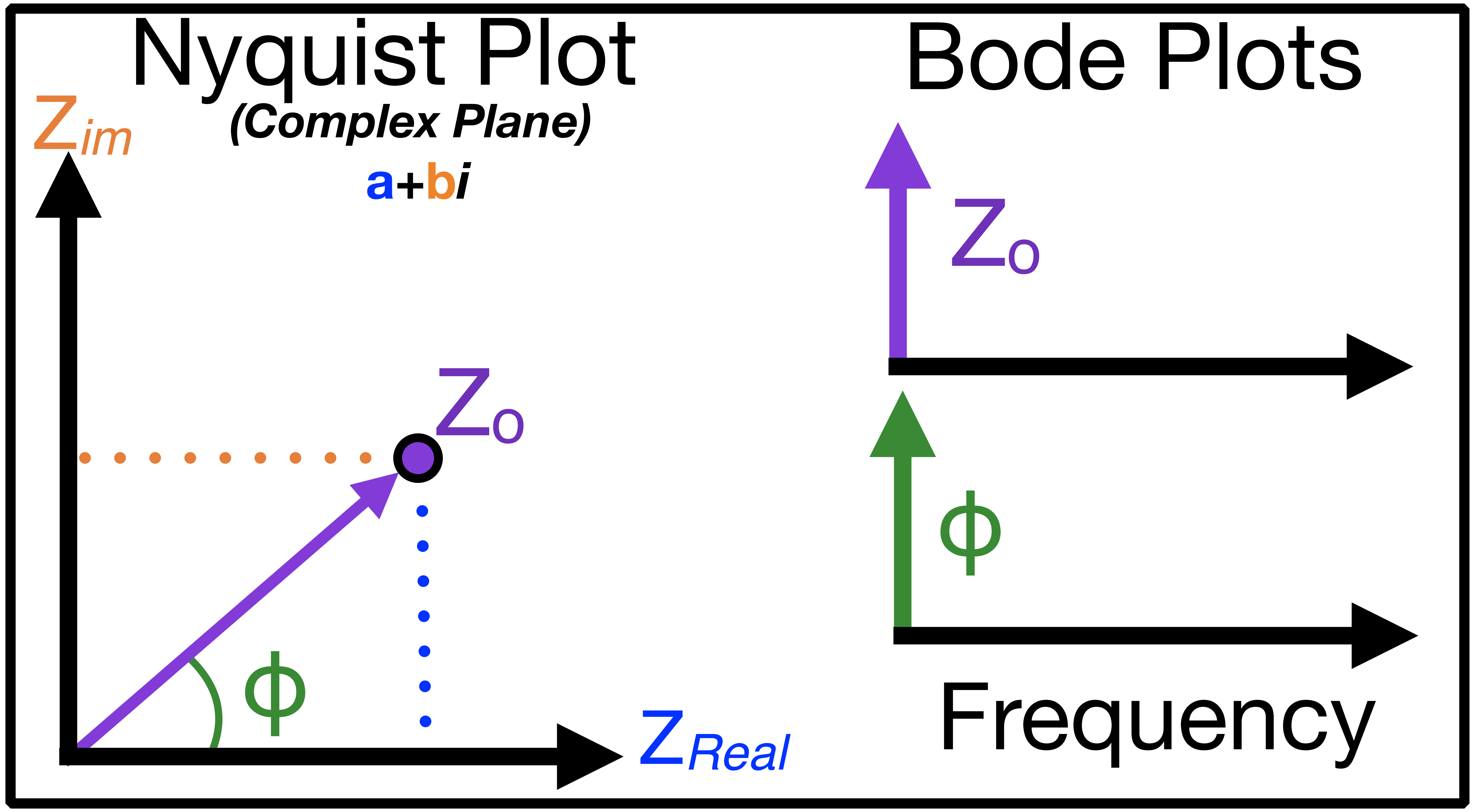
$$Phase \ \phi = 90^o$$

How to Visualize the Data?

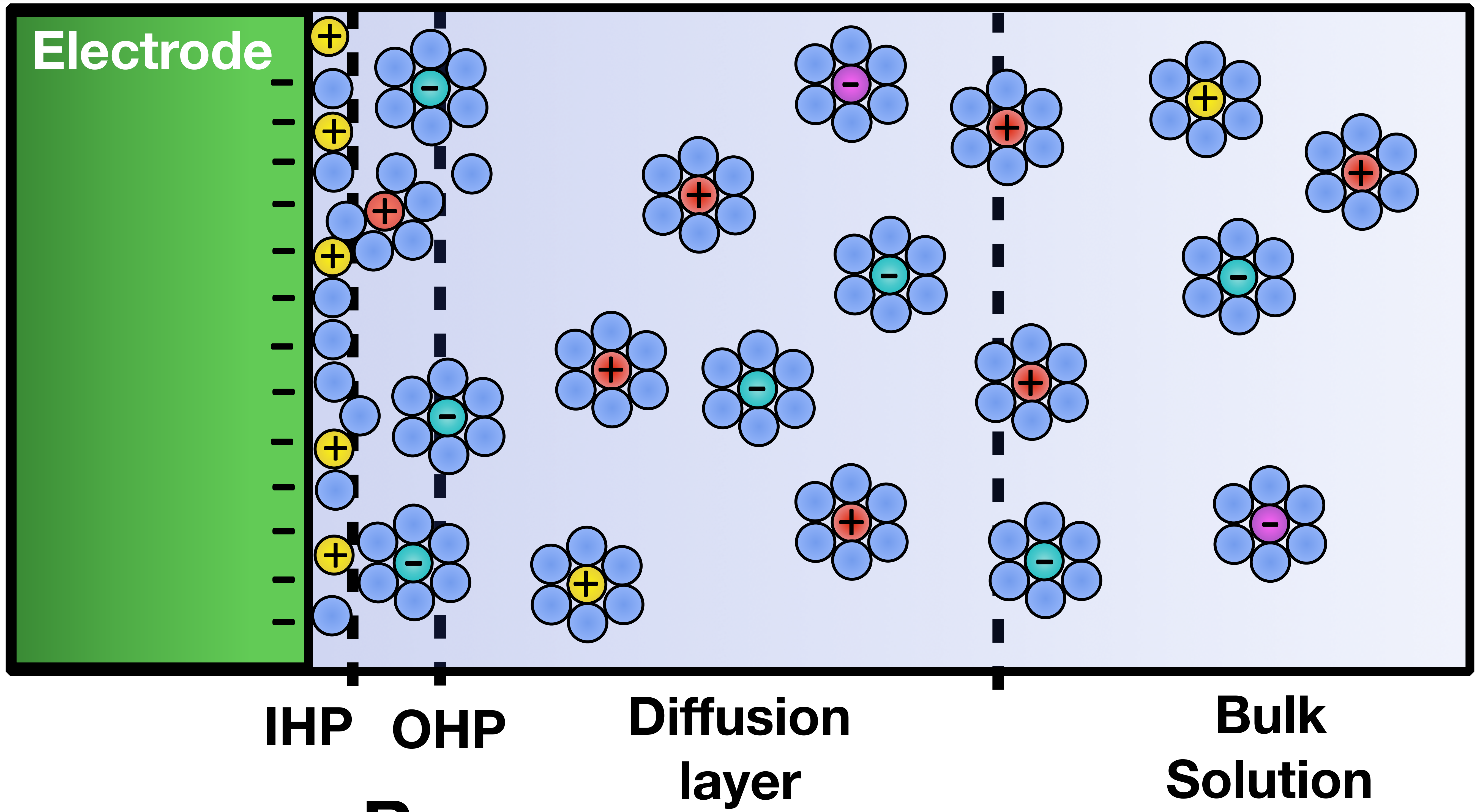


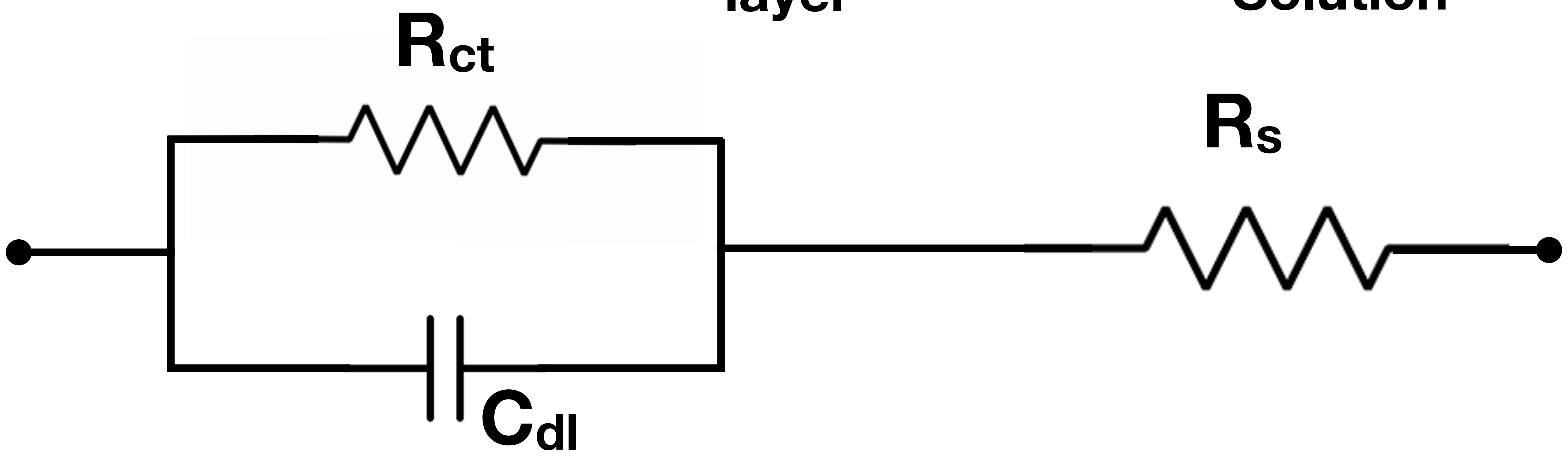
$$Z = \frac{E_t}{I_t} = \frac{E_0 Sin(\omega t)}{I_o Sin(\omega t + \phi)} = Z_o \frac{Sin(\omega t)}{Sin(\omega t + \phi)}$$

Magnitude, Z_o Phase Angle, ϕ

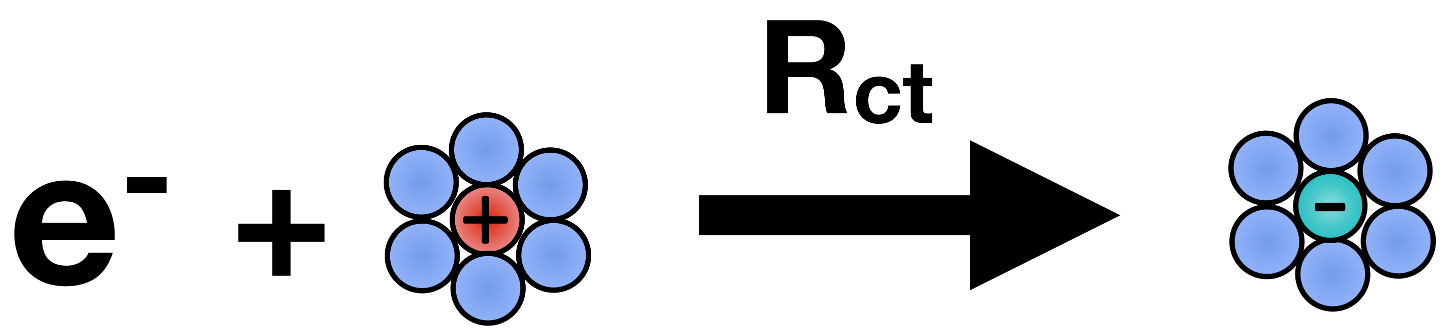


Common Electrode-Electrolyte System

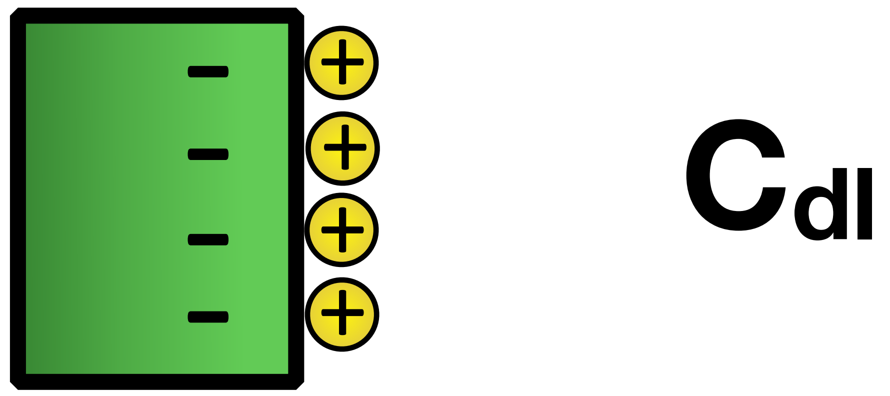




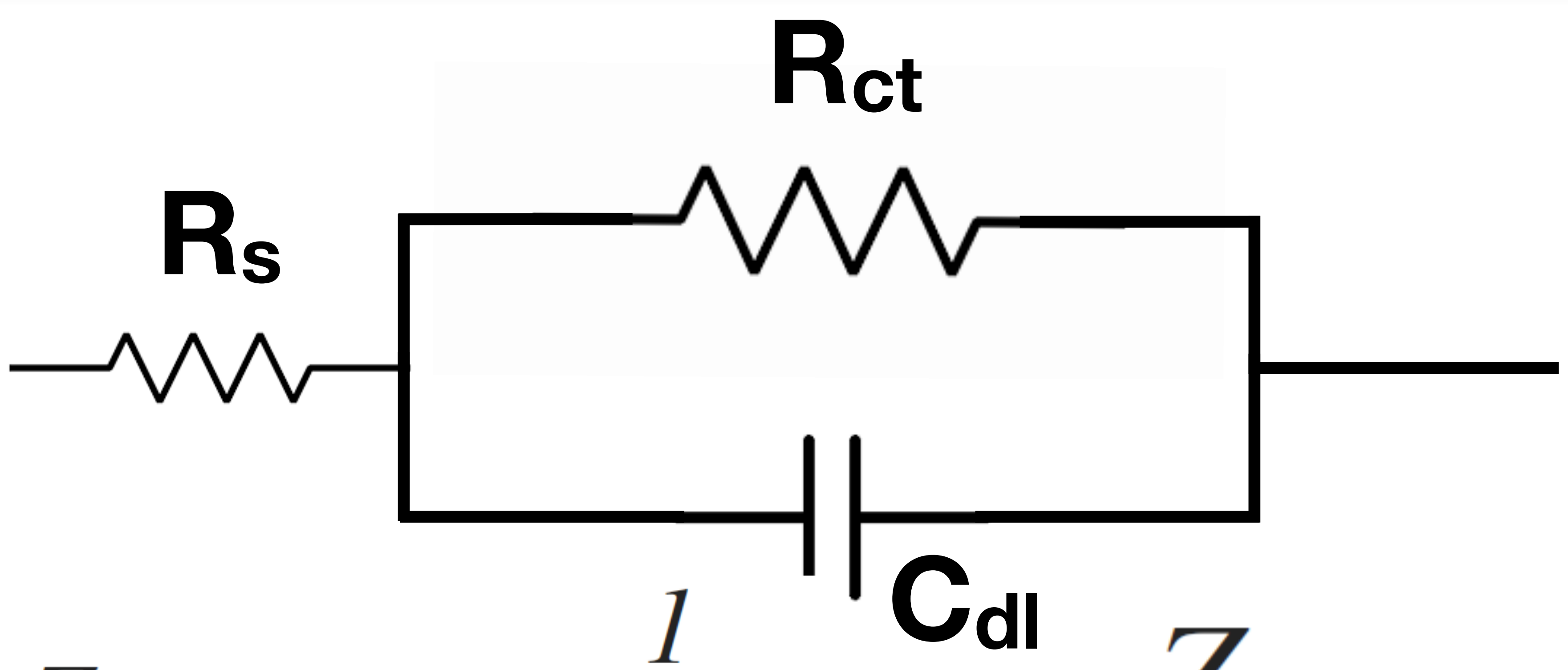
- **Faradaic Current**



- **Nonfaradaic Current** ***(Capacitive Charging)***



Frequency Dependent Circuit



$$Z_{Capacitor} = \frac{1}{i\omega C} \qquad Z_{resistor} = R$$

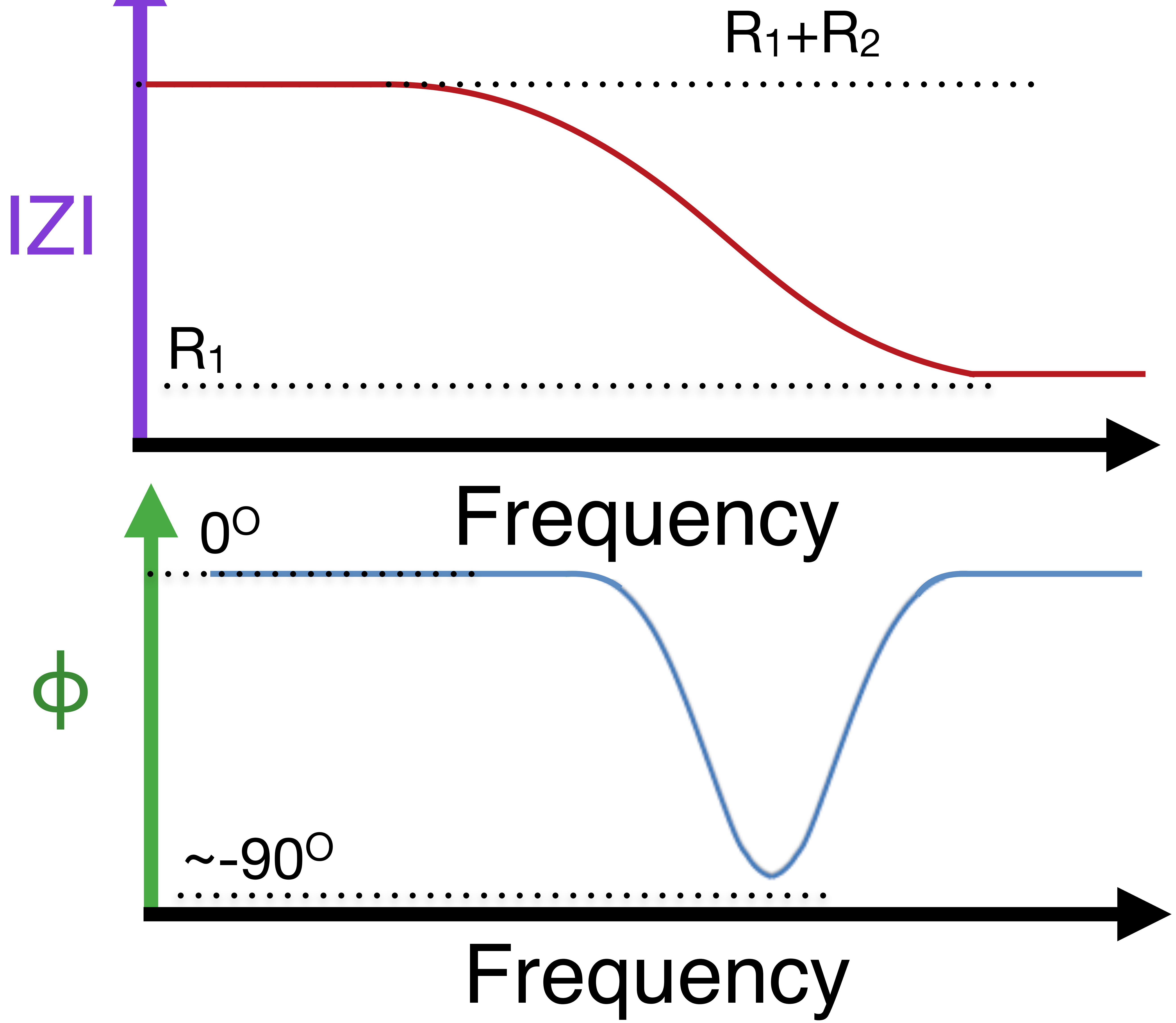
High Frequency $\omega \rightarrow \infty$

$$Z_{Capacitor} \rightarrow 0$$

Low Frequency $\omega \rightarrow 0$

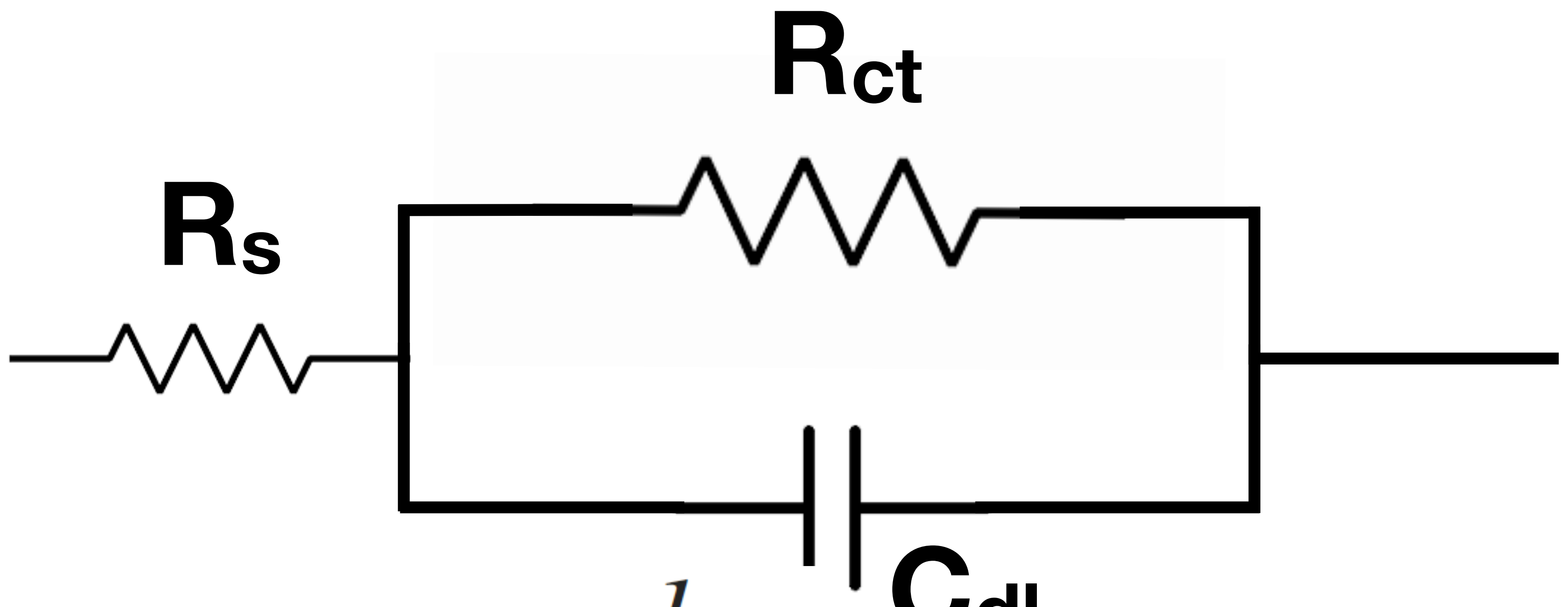
$$Z_{Capacitor} \rightarrow \infty$$

Bode Plots



The Ohio State University
Chemistry and Biochemistry

Frequency Dependent Circuit



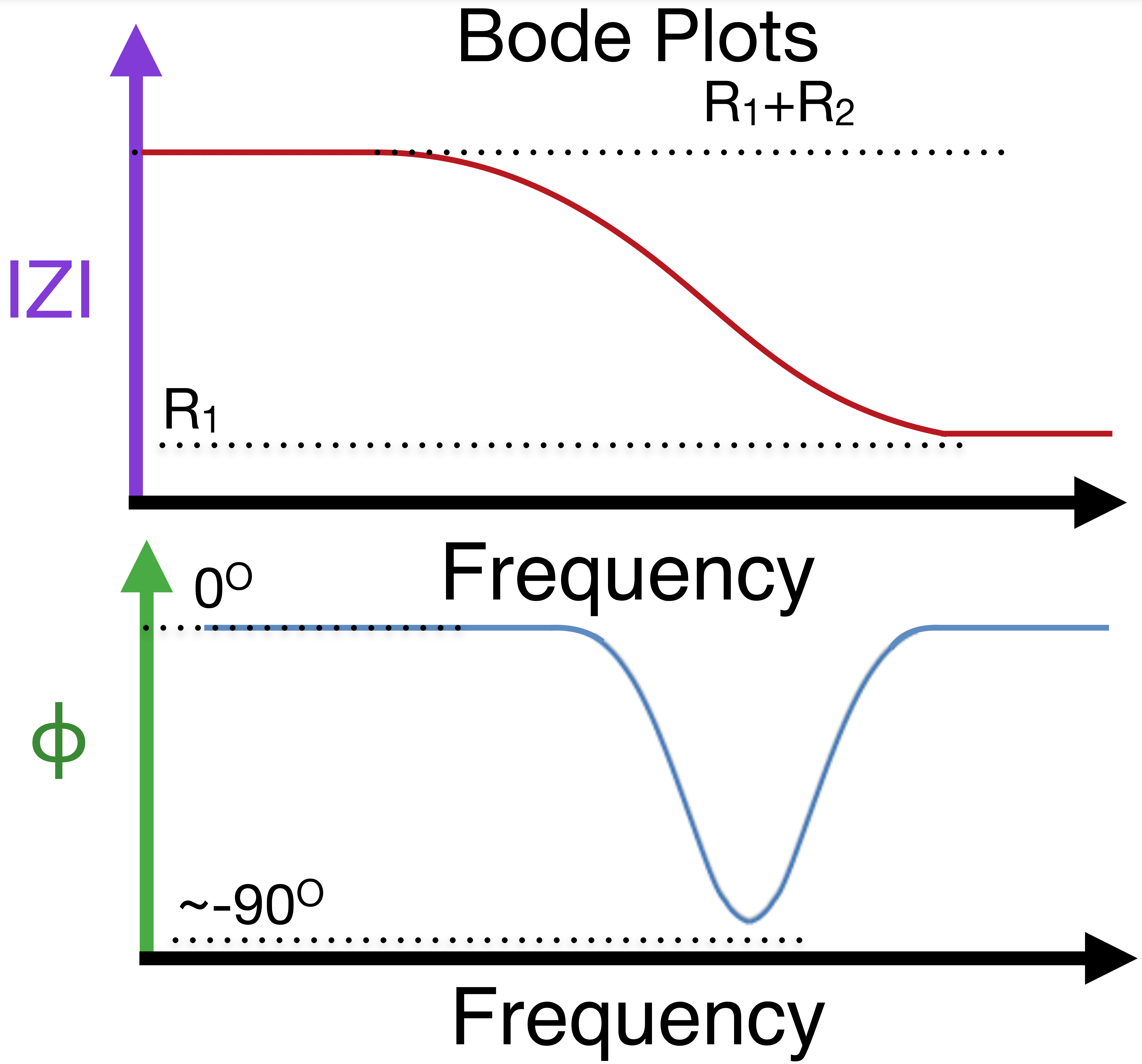
$$Z_{Capacitor} = \frac{1}{i\omega C} \qquad Z_{resistor} = R$$

High Frequency $\omega \rightarrow \infty$

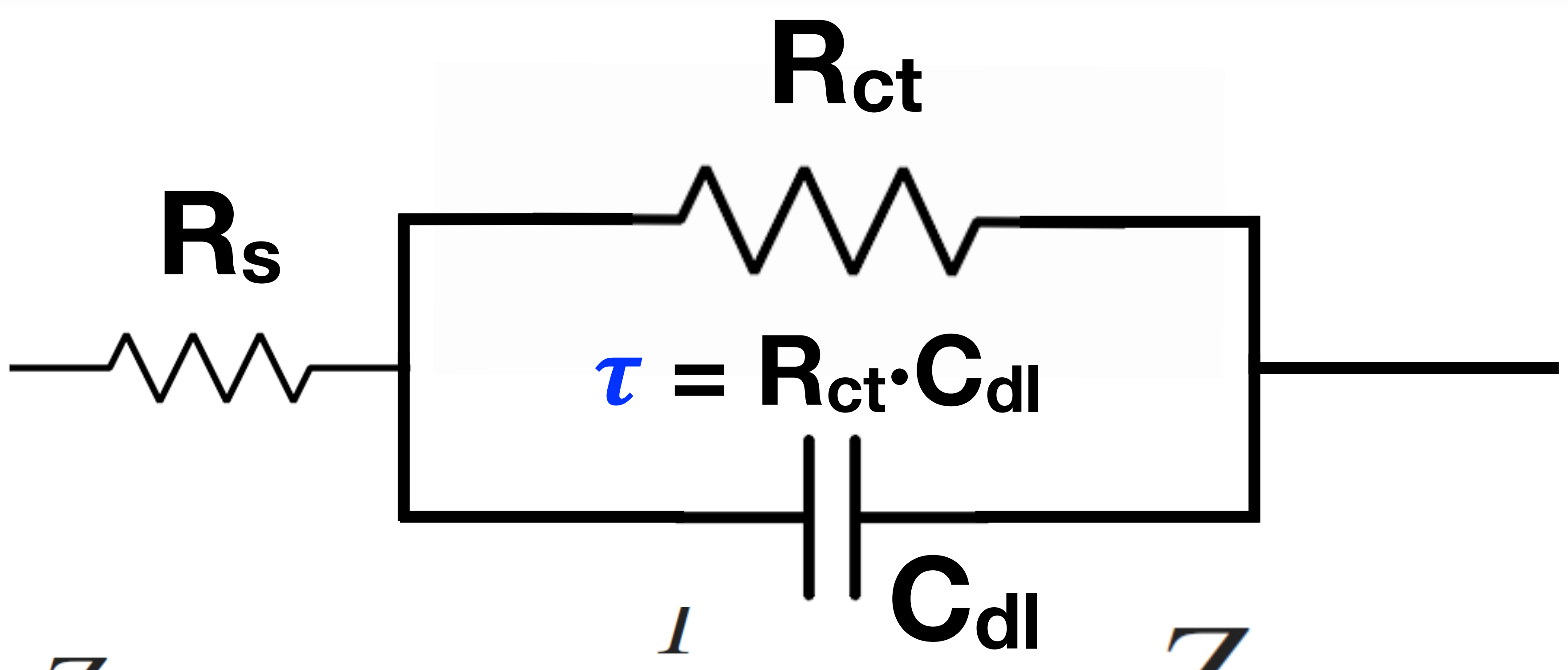
"Looks like" R_s

Low Frequency $\omega \rightarrow 0$

"Looks like" R_s — R_{ct}



Frequency Dependent Circuit



$$Z_{Capacitor} = \frac{1}{i\omega C} \qquad Z_{resistor} = R$$

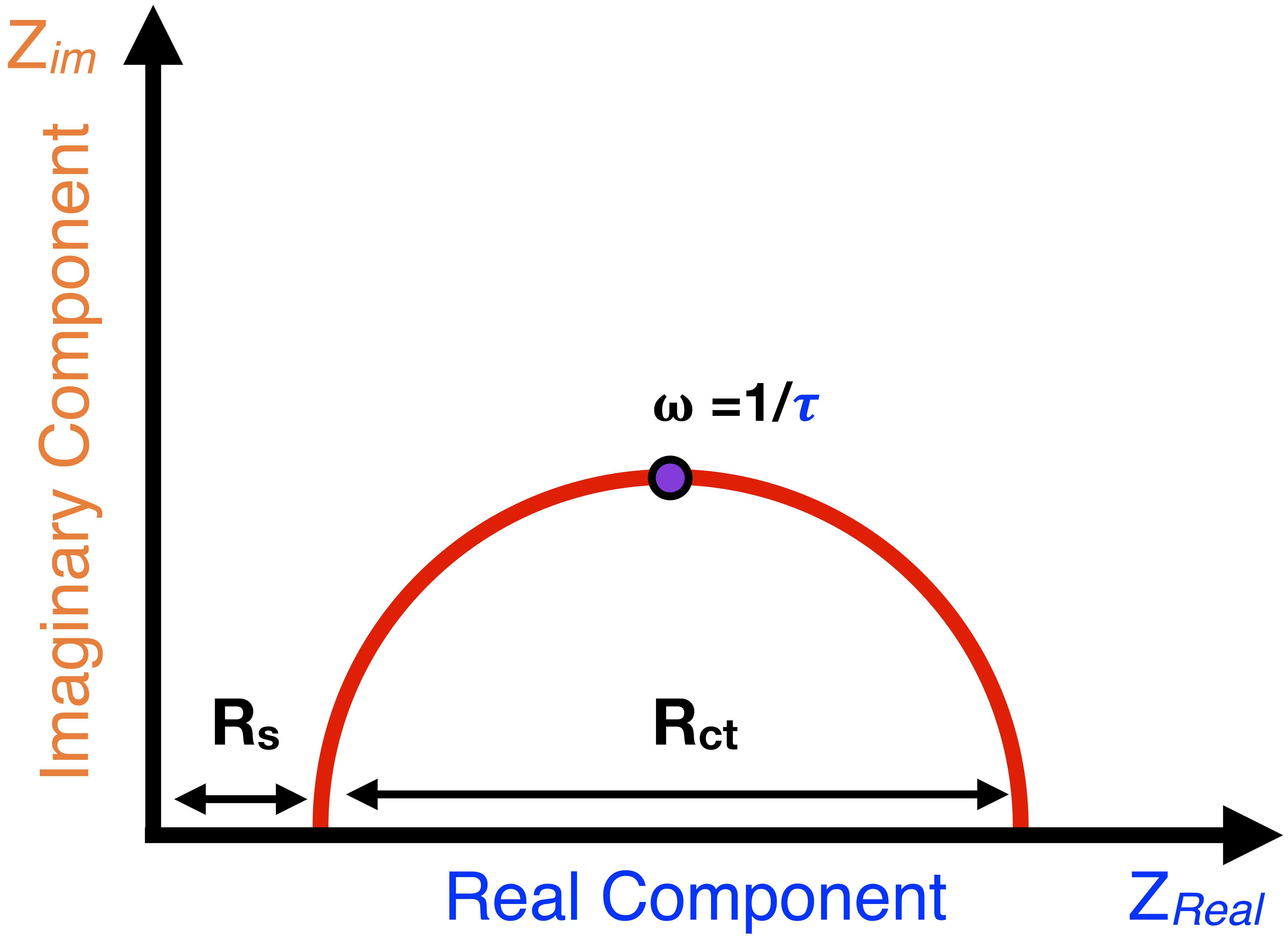
High Frequency $\omega \rightarrow \infty$

$$Z_{Capacitor} \rightarrow 0$$

Low Frequency $\omega \rightarrow 0$

$$Z_{Capacitor} \rightarrow \infty$$

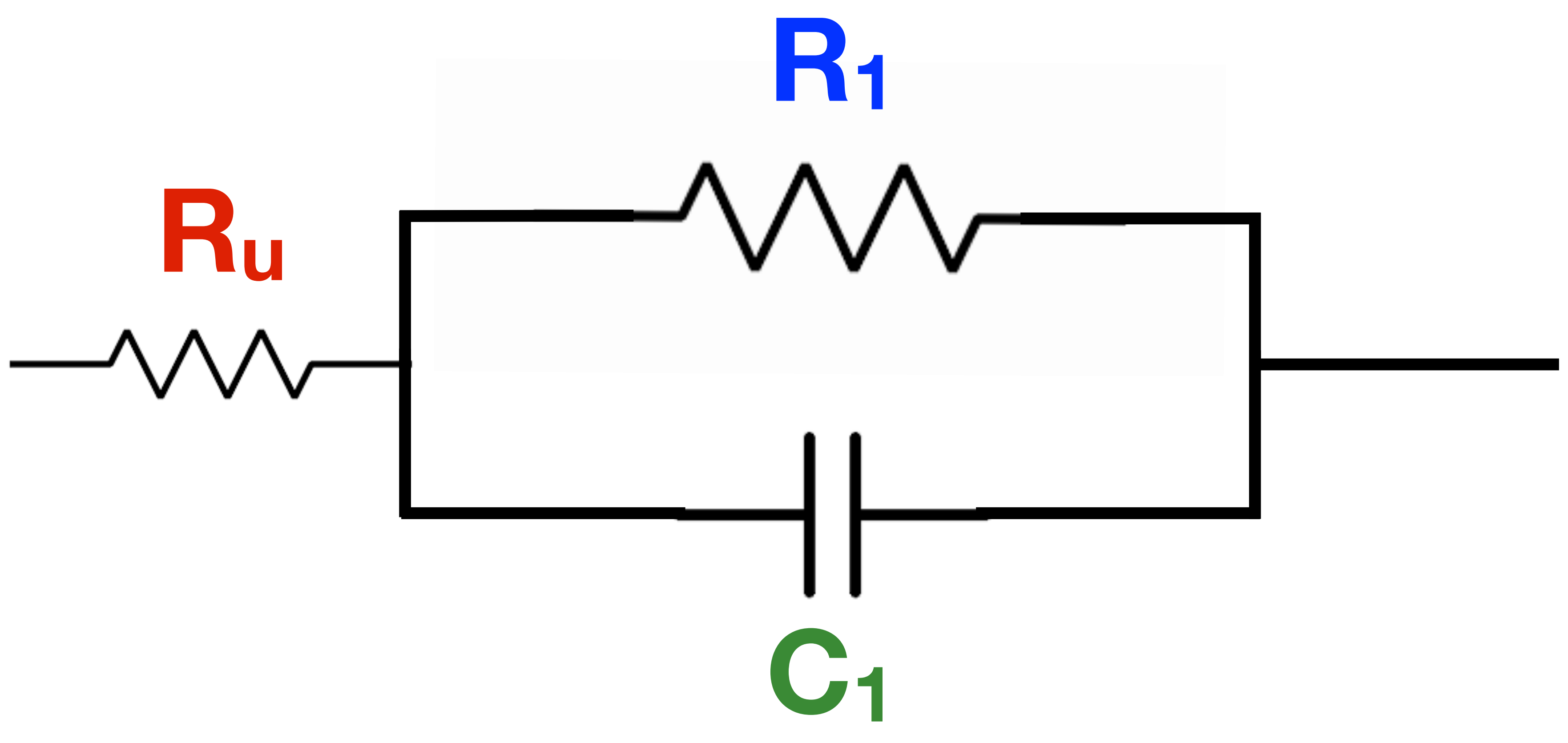
Nyquist Plot

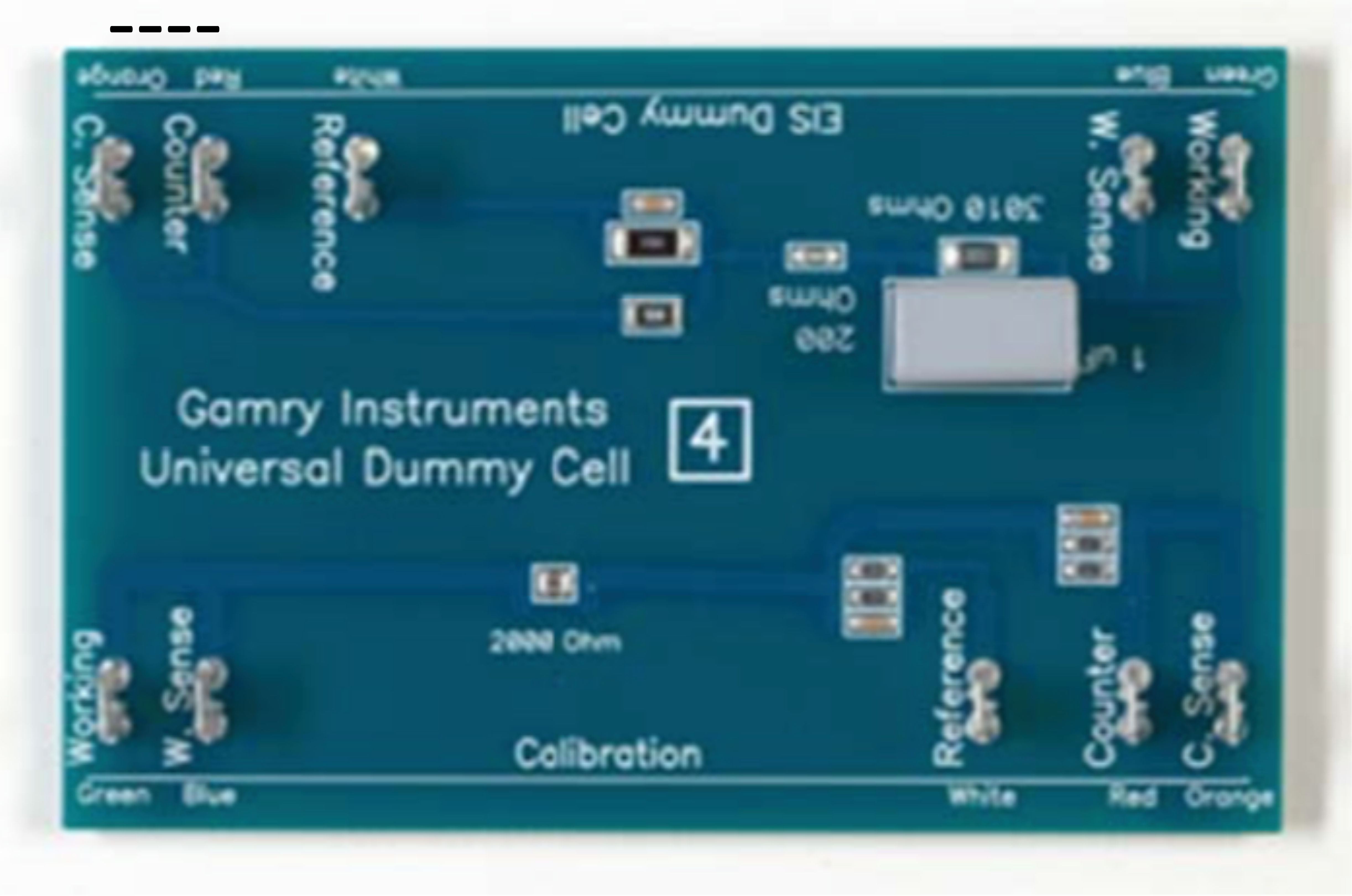


Running The Experiment

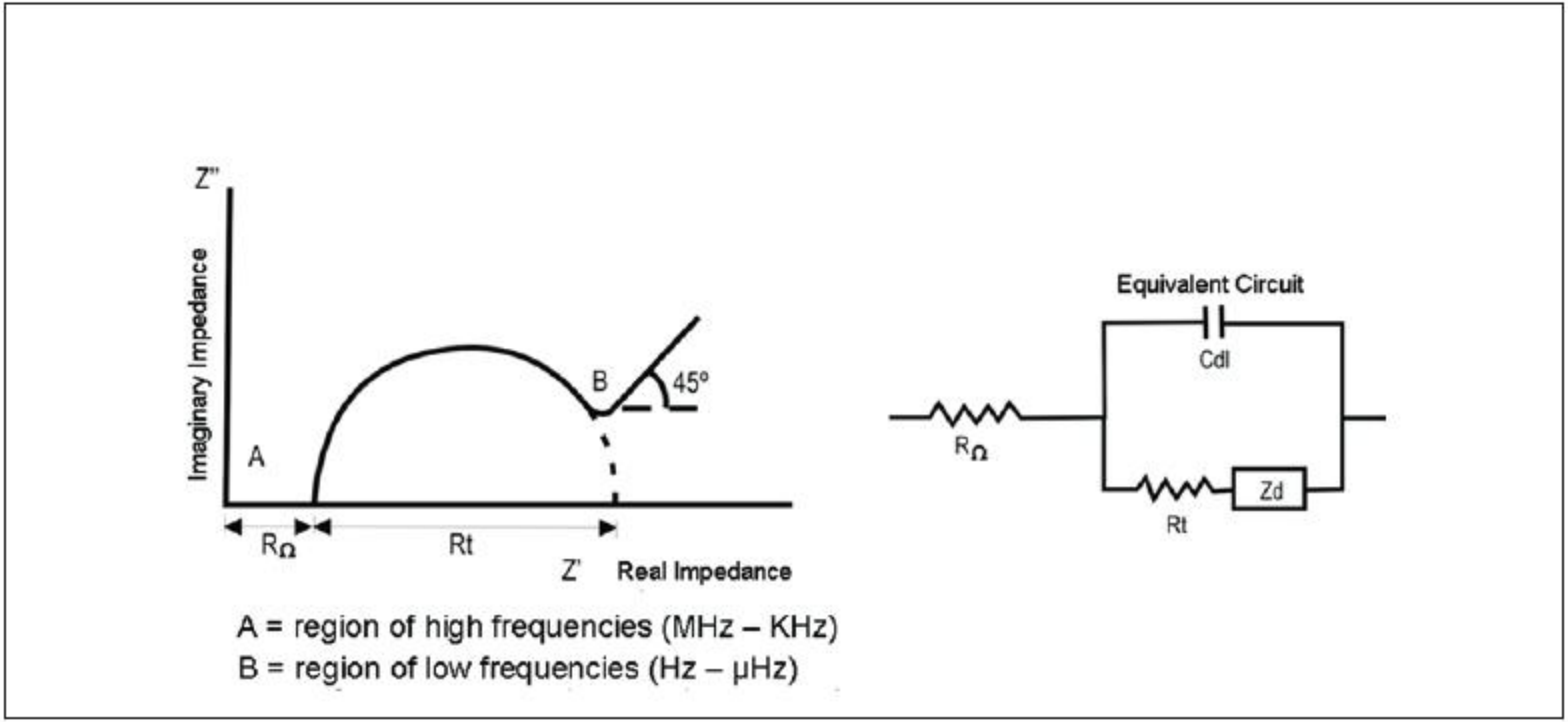
R_u	2.95 kΩ	—	3.07 kΩ
R_1	196 Ω	—	204 Ω
C_1	0.9 μF	—	1.10 μF

DEMO



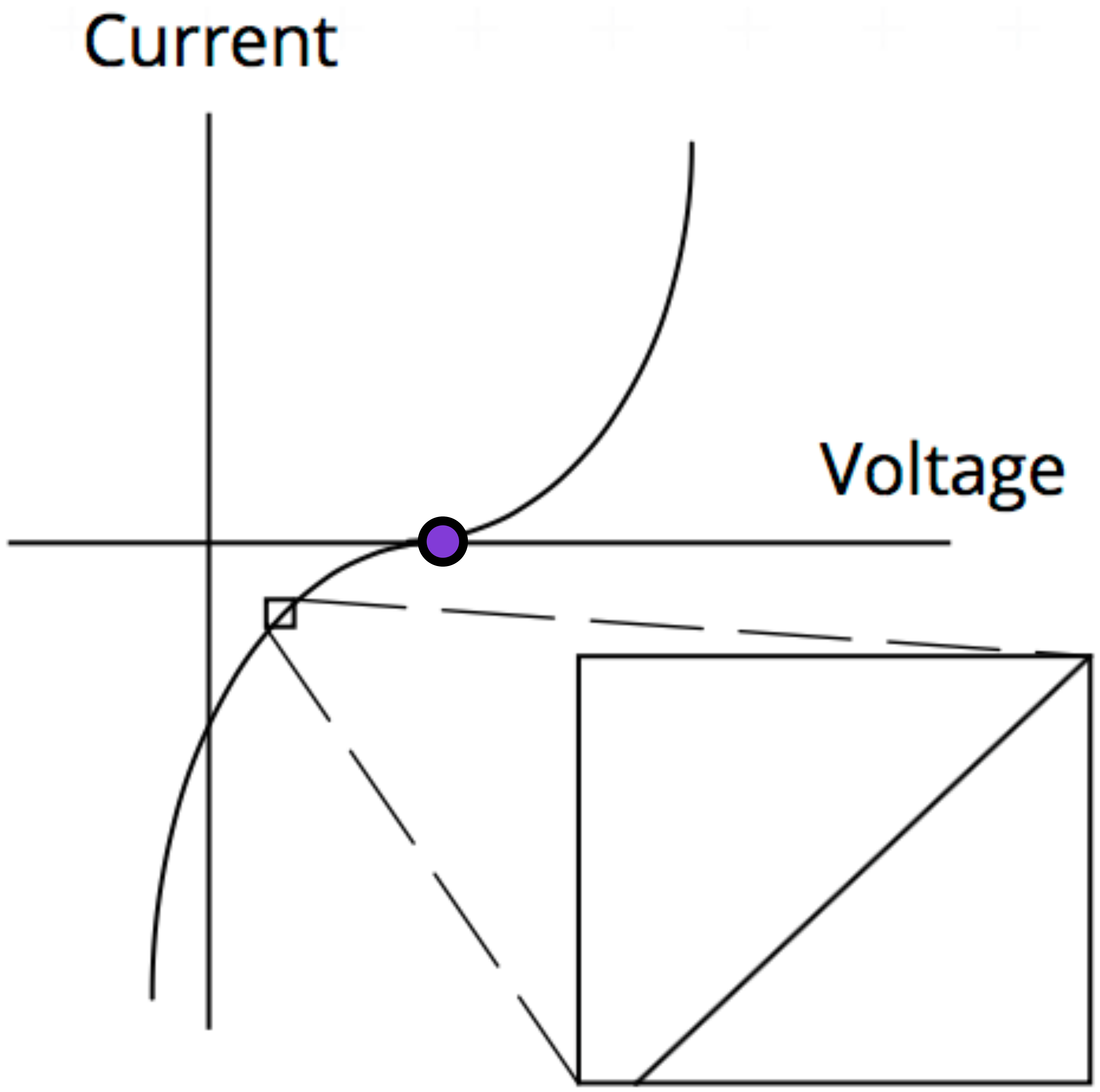


Impedance Applications



http://dx.doi.org/10.1590/S1983-41952015000400007

Impedance Applications



Butler- Volmer Equation

$$i = i_0 \left(\exp\left(\alpha \frac{nF}{RT} \eta\right) - \exp\left(-(1-\alpha)\frac{nF}{RT}\eta\right)\right)$$

Low Overpotential

$e^x \;\; -> \;\; (1 + x)$

$$R_{ct} = \frac{RT}{nFi_0}$$

Used to calculate I_o *(exchange current density)*
Good Representation of catalytic activity of the electrode surface toward a specific redox couple

https://www.gamry.com/application-notes/EIS/basics-of-electrochemical-impedance-spectroscopy/