Exercises

Exercise 2.1.

Generate digitalized function $E(t) = \cos(2\pi t / T_a)$ containing 64 points from 0 to 63 for the sampling time 0.01 s and wave period $T_a = 0.32$ s during 0.63 s. Then use Excel to carry out FFT. What information can be obtained from it?

Exercise 2.2.

Generate digitalized function $E(t) = \sin(2\pi t / T_a)$ containing 64 points from 0 to 63 for the sampling time 0.01 s and for wave period $T_a = 0.32$ s during 0.63 s. Then use Excel to carry out FFT. Show the plots of the function and its FT. What information can be obtained from it?

Exercise 2.3.

Generate digitalized function $E(t) = \cos(2\pi t / T + \pi / 3)$ containing 64 points from 0 to 63 for the sampling time 0.01 s and for $T_a = 0.32$ s during 0.63 s. Then use Excel to carry out FFT. Show the plots of the function and its FT. What information can be obtained from it?

Exercise 2.4.

Generate digitalized function $E(t) = \exp(-3t_i)$ containing 32 points for the sampling time 0.01 s. Use Excel to carry out FFT. What information can be obtained from it?

Exercise 2.5.

Generate digitalized function $E(t) = \sin(2\pi t / T_a)$ containing 256 points for the sampling time 0.2 s and $T_a = 34$ s. Use Excel to carry out FFT. What information can be obtained from it? Is it possible to obtain the studied function frequency from FT analysis?

Exercise 2.6.

Simulate sum of frequencies curve consisting of functions: $\cos(k\, 2\pi t/1024)$ for $k = 1, 3, 7$, and 13 and $\sin(k\, 2\pi t/1024)$ for $k = 5, 9$, and 17, and t from 0 to 1023. Perform FFT and determine the frequencies and compare with the frequencies of assumed individual functions.

Exercise 2.7.

In order to determine the impedance of the system data acquisition of the applied voltage and circulating current were measured during 0.64 s every 0.01 s. To calculate the impedance generate "experimental" data (normally they would be presented as series of numbers) using the following equations: $E(t) = E_0 \cos(\omega t)$ and $I(t) = I_0 \cos(\omega t + \pi / 3)$, where $E_0 = 0.01$ V, $I_0 = 0.002$ A, $\omega = 2\pi f = 2\pi / T_a$, $T_a = 0.32$ s.

Exercise 2.8.

Determine impedance using data obtained from D/A data acquisition of voltage and current. This data containing time, potential and current: t, $E(t)$, $I(t)$ in s, V, and A, respectively, can be found in file Ex2_8.txt. What is the frequency of these functions?

Exercise 2.9.

Make complex plane, Bode, and complex admittance plots of R C connection in series; R = 150 Ω, C = 40 μF.

Exercise 2.10.

Make complex plane, Bode, and complex admittance plots of (RC) connection in parallel; R = 100 Ω, C = 20 μF.

Exercise 2.11.

Make complex plane, Bode, and complex admittance plots of R_s in series with the parallel connection of RC, $R_s(RC)$; R_s = 10 Ω, R = 100 Ω, C = 20 μF.

Exercise 2.12.

Make complex plane and Bode plots for the circuit $R_s(C_{dl}(R_{ct}C_p))$ with the following elements: R_s = 2 Ω, $R_{ct} = 50\,\Omega$, $C_{dl} = 2\times10^{-5}\,F$, and $C_p = 0.01\,F$.

Exercise 2.13.

Simulate using ZView impedance of the two models displayed in Fig. 2.37, book, in series $R_0(R_1C_1)(R_2C_2)$ and nested $R_0(C_1(R_1(R_2C_2))$, using the following parameters: R_s = 10 Ω, R_1 = 100 Ω, C_1 = 2×10^{-5} F, R_2 = 100 Ω, C_2 = 10^{-1}, 10^{-3}, 10^{-4}, 2×10^{-5}, 10^{-5} F. Make the approximations of the impedances of the nested circuit by that in series. Compare with the results in Ch2.xlsx, Worksheets Ex2.13 serial, Ex2.13 nested, and Ex2.13 approx.

Exercise 2.14.

Simulate impedances for the circuit RCL in series for R = 1 Ω, C = 0.01 F, and L = 0.01 H. Make simulations using ZView and Excel. Make complex plane and Bode plots.

Exercise 3.1.

Simulate sum of odd harmonic functions $\sum A_i \cos(2\pi v_i t + \pi b_i)$ for:

Frequencies, v, / Hz

1	3	5	7	9	11	13	17	21	25	31
37	44	52	64	75	90	100	110	130	170	210
250	310	370	440	520	640	750	900	1000		

Relative amplitudes, A:

0.25	0.1796024	0.154003	0.1391682	0.1290281
0.1214646	0.1155073	0.1065462	0.09997981	0.09486765
0.08891917	0.08430711	0.08002237	0.0760977	0.07148676
0.06815384	0.06451406	0.0625	0.06073228	0.05775367
0.0532731	0.04998991	0.04743382	0.04445958	0.04215356
0.04001119	0.03804884	0.03574338	0.03407692	0.03225703
0.03125				

Relative phases, b, $\varphi = \pi * b$

0.7055475	0.533424	0.5795186	0.2895625	0.301948
0.7747401	0.01401764	0.7607236	0.81449	0.7090379
0.04535276	0.4140327	0.8626193	0.79048	0.3735362
0.9619532	0.8714458	0.05623686	0.9495566	0.3640187
0.5248684	0.7671117	0.05350453	0.5924582	0.4687001
0.2981654	0.6226967	0.6478212	0.2637929	0.2793421
0.8298016				

Make the simulations in Excel for the total time of one second for $N = 2048$ points, that is for $\Delta t = 1/2048$ s. Calculate the Fourier transform of this function and its amplitude (modulus) versus frequency up to the Nyquist frequency.

Exercise 4.1.

Write a program in Maple or Mathematica for the Randles model and make the corresponding complex plane and Bode plots.

Exercise 4.2.

Construct the model of the Randles' circuit in ZView and make the simulation using data in Fig. 4.2 (book) $R_s(C_{dl}(R_{ct}Z_W))$: $R_s = 10$ Ω, $C_{dl} = 25$ μF, $R_{ct} = 50$ Ω, $\sigma' = 10$ Ω $s^{-1/2}$. Repeat simulations in Maple or Mathematica.

Exercise 4.3.

Write a Maple/Mathematica programs to simulate spherical internal diffusion and the corresponding complex plane and Bode plots using the following parameters: R_s=10 Ω, C_{dl}=2×10^{-5} F, D_O=10^{-5} cm^2 s^{-1}, R_{ct}=50 Ω, C_O=2×10^{-6} mol cm^{-3}, r_0=10^{-3} cm.

Exercise 4.4.

Write a program in Maple or Mathematica to simulate semi-infinite spherical fusion (external) diffusion and the corresponding complex plane and Bode plots. The parameters as in Exercise 4.3 except r_0=0.01 cm

Exercise 4.5.

Write a program in Maple/Mathematica to simulate transmissive impedance and the corresponding complex plane and Bode plots. The parameters as in Exercise 4.3 with l=0.01 cm.

Exercise 4.6.

Write a program in Maple/Mathematica to simulate reflective impedance and the corresponding complex plane and Bode graphs. Use data as in Exercise 4.5.
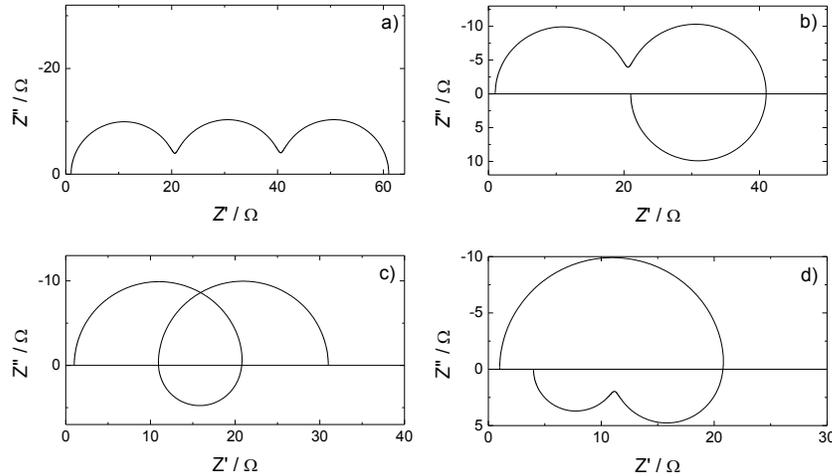
Exercise 4.7.

Write a Maple/Mathematica program to simulate cylindrical diffusion and the corresponding complex plane and Bode plots, use parameters as in Exercise 4.5 and r_0=0.01 cm.

Exercise 4.8.

Write a program to calculate Φ_4 and Φ_5 for diffusion to disk electrode.

Exercise 5.1.

Simulate in ZView plots in Fig. 5.6 (book).

Fig. 5.6. Examples of the complex plane plots obtained in the presence of two adsorbed species assuming the following parameters: $R_s = 1\ \Omega$, $C_{dl} = 20\ \mu F$, $R_{ct} = 20\ \Omega$ a) $R_{p1} = R_{p2} = 20\ \Omega$, $C_{p1} = 0.02\ F$, $C_{p2} = 2\ F$; b) $R_{p1} = 20\ \Omega$, $R_{p2} = -20\ \Omega$, $C_{p1} = 0.02\ F$, $C_{p2} = -2\ F$; c) $R_{p1} = -10\ \Omega$, $R_{p2} = 20\ \Omega$, $C_{p1} = -0.02\ F$, $C_{p2} = 2\ F$; d) $R_{p1} = -10\ \Omega$, $R_{p2} = -7\ \Omega$, $C_{p1} = -0.02\ F$, $C_{p2} = -2\ F$.

Exercise 9.1.

Using Maple or Mathematica simulate impedance described by Eq. (9.18) using data from Fig. 9.15.

Exercise 9.2.

Simulate impedances defined in Eq. (9.16) using ZView and then approximate them using de Levi's classical model. This model might be found in the new version of ZView only. Use the following parameters: $r_e = 200\ \Omega\ cm^{-1}$, $r_s = 50\ \Omega\ cm^{-1}$, $c_{dl} = 0.001\ F\ cm^{-1}$, $l = 0.05$ cm.

$$\hat{Z}_{pore} = \frac{r_s r_e}{r_s + r_e}\left[l + \frac{2\lambda}{\sinh\left(\dfrac{l}{\lambda}\right)} \right] + \lambda\, \frac{r_s^2 + r_e^2}{r_s + r_e}\coth\left(\frac{l}{\lambda}\right) \qquad (9.16)$$

Exercise 9.3.

Using Maple or Mathematica simulate impedance described by Eqs. (9.16) and (9.30) using data from Fig. 9.20.

Exercise 9.4.

Simulate impedance of the porous electrode in the presence of the solution and electrode resistance and redox system using ZView. Use parameters from Fig. 9.20. Fit the obtained data to the simple de Levie's model.
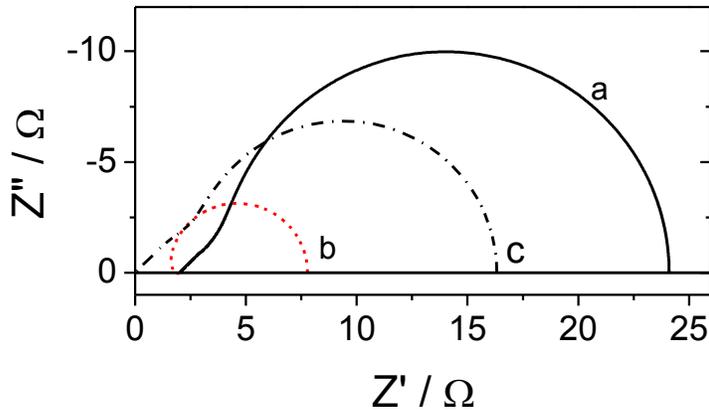
Fig. 9.20. Complex plane plots for the porous electrode in the presence of redox species at equilibrium potential according to Eq. (9.19); a – total impedance, Eq. (9.16), b – impedance of the first term, c – impedance of the second term; $r_{ct} = 1\ \Omega$ cm , $r_e = 200\ \Omega$ cm^{-1}, $r_s = 50\ \Omega$ cm^{-1} $\hat{z} = 1/j\omega c_{dl}$, $c_{dl} = 0.001$ F cm^{-1}, $l = 0.05$ cm.

Exercise 13.1.

Carry out K-K transform of the data in the file 1.z.

Exercise 13.2.

Carry out K-K transform of the data in the file 2.z.

Exercise 13.3.

Carry out K-K transform of the data in the file 3.z.

Exercise 13.4.

Perform K-K transform of the data in the file 4.z.

Exercise 13.5.

Perform K-K transform of the data in the file 5.z.

Exercise 14.1.

Determine the error structure of the impedance in files Z1.z, Z2.z, Z3.z, and Z4.z using Orazem's measurement model approach and determine the impedance parameters for Z1.z using circuit: $R_s(C_{dl}(R_{ct}Z_{FLW}))$ where Z_{FLW} is the finite length transmissive mass transfer impedance.

Exercise 14.2.

Find an electrical equivalent model describing data in file 2.z. Try different weighting techniques. Calculate the sum of squares, S, and reduces sum of squares S_v. Carry out F-test.

Exercise 14.3.

Fit data 3.z into the nested model $R_s(C_{dl}(R_{ct}(C_pR_p)))$. Check if the use of the CPE elements instead of capacitances is statistically justified.

Exercise 14.4.

Fit 4.z into the model $R_s(C_{dl}(R_{ct}C_p))$. Check if the use of the CPE elements instead of capacitances is statistically justified.

Exercise 14.5.

Fit the data in 5.z to the model R(C(RWs)) where Ws is the transmissive mass transfer impedance. Check if the use of the CPE element is justified.