Example Mathcad sheet for extracting the parameters of the lossy voice-coil inductance.

$\mathrm{Data} := \mathrm{READPRN}(\text{"em10resp.prn"})$ Reads the text file em10resp.prn.

Data =

	0	1	2
0	14.7964	6.78455	6.2272
1	18.4955	7.87926	8.37344
2	22.1946	10.00688	11.16913
3	25.8937	14.5691	14.47484
4	29.5928	23.87734	15.59986
5	33.2919	35.50693	6.7749
6	36.991	34.10189	-9.89821
7	40.6901	23.17333	-16.43802
8	44.3892	15.51733	-15.39501
9	51.7874	9.71677	-10.93851
10	55.48651	8.55592	-9.35664
11	62.88471	7.44207	-7.27267
12	70.28291	6.67066	-5.59601
13	81.38021	6.36234	-4.19354
14	88.77841	6.29414	-3.45341

$\mathrm{Data}_{n,0}$ is the frequency. $\mathrm{Data}_{n,1}$ is the real part of the series impedance. $\mathrm{Data}_{n,2}$ is the imaginary part of the series impedance. There are 62 data points in this file. The left column index goes from 0 to 61.

$R_E := 5.078 \quad f_S := 35.178 \quad R_{ES} := 32.034 \quad Q_{MS} := 2.796$

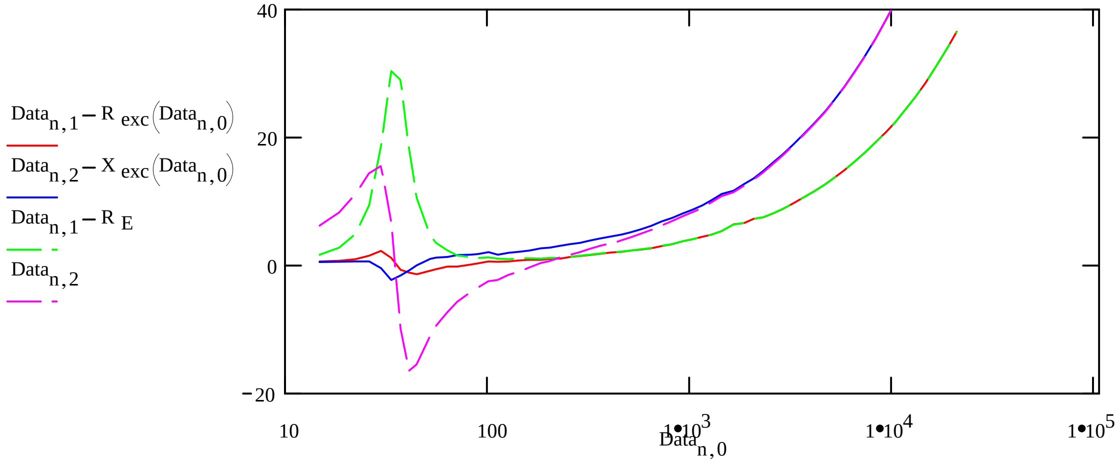
$$Z_{exc}(f) := R_E + R_{ES} \cdot \frac{\frac{1}{Q_{MS}} \cdot \left(\frac{j \cdot f}{f_S}\right)}{1 - \left(\frac{f}{f_S}\right)^2 + \frac{1}{Q_{MS}} \cdot \left(\frac{j \cdot f}{f_S}\right)}$$

$Z_{exc}(x)$ is the impedance of R_E plus the impedance due to Blu_D. It is to be subtracted from the measured impedance to obtain only the impedance of the lossy voice-coil inductance.

$R_{exc}(f) := \mathrm{Re}(Z_{exc}(f)) \qquad X_{exc}(f) := \mathrm{Im}(Z_{exc}(f))$

Now for the plots of the real and imaginary parts of the measured impedance and the impedance after $Z_{exc}(f)$ is subtracted out.

$n := 0 .. 61$



Note that the subtraction is not perfect in the region about f_S. We will only use the data above 1 kHz to calculate the lossy inductance parameters.

$n := 35..61$ These are the values of n to use the data from 1 kHz to 20 kHz.

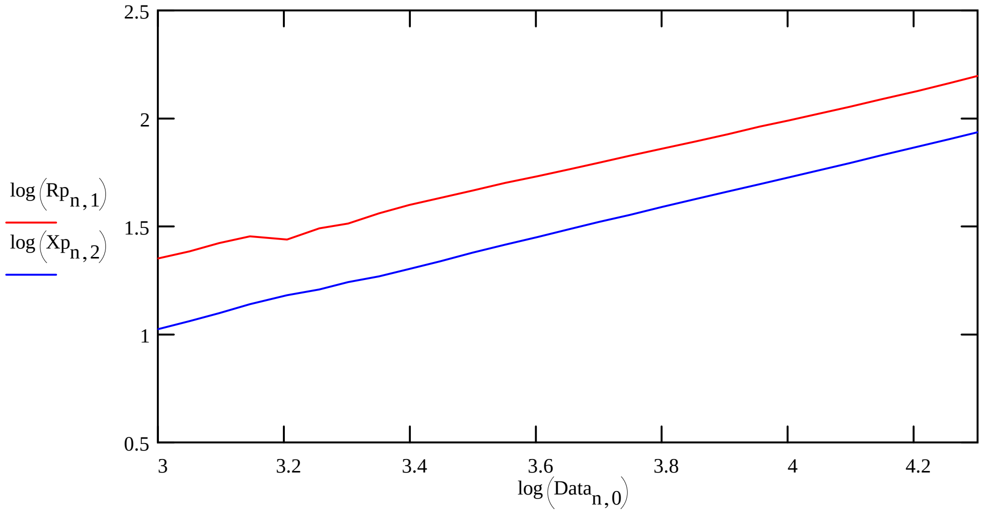
$Rs_{n,1}$ is the real part of the series impedance, and $Xs_{n,2}$ is the imaginary part of the series impedance.

$$Rs_{n,1} := Data_{n,1} - R_{exc}\left(Data_{n,0}\right) \qquad Xs_{n,2} := Data_{n,2} - X_{exc}\left(Data_{n,0}\right)$$

$Rp_{n,1}$ is the real part of the parallel impedance and $Xp_{n,2}$ is the imaginary part of the parallel impedance.

$$Rp_{n,1} := Rs_{n,1} + \frac{\left(Xs_{n,2}\right)^2}{Rs_{n,1}} \qquad Xp_{n,2} := Xs_{n,2} + \frac{\left(Rs_{n,1}\right)^2}{Xs_{n,2}}$$

Now for log-log plots to see if these fall on a straight line.



The lines look straight except for a glitch in the real part.

Next, we perform a linear regression analysis for the curve fits to the real and imaginary parts of the series and parallel impedances. Rp_m is for the real part of the parallel impedance. Xp_m is for the imaginary part of the parallel impedance.

$m := 0 .. 26$ Note that m+35 goes from 35 to 61. The start value of m must be 0 for the linear regression analysis to work.

$f_m := \log\left[Data_{(m+35),0}\right]$ $A_m := \log\left[Rp_{(m+35),1}\right]$ $B_m := \log\left[Xp_{(m+35),2}\right]$

$n_r := \mathrm{slope}(f, A)$ $n_r = 0.65264$ $n_x := \mathrm{slope}(f, B)$ $n_x = 0.69688$

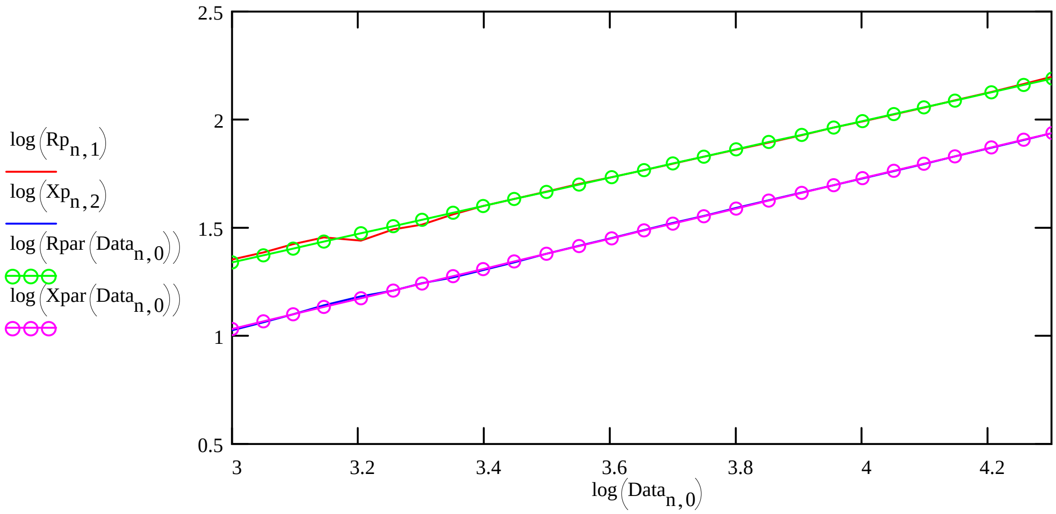
$interA := \mathrm{intercept}(f, A)$ $interA = -0.61713$ $interB := \mathrm{intercept}(f, B)$ $interB = -1.05847$

$$R_e := \frac{10^{interA}}{(2\cdot\pi)^{n_r}} \qquad X_e := \frac{10^{interB}}{(2\cdot\pi)^{n_x}}$$

The following are the approximating functions. Rpar approximates the resistive part of the parallel impedance. Xpar approximates the reactive part of the parallel impedance. x is the frequency in Hertz.

$$Rpar(x) := R_e\cdot(2\cdot\pi\cdot x)^{n_r} \qquad Xpar(x) := X_e\cdot(2\cdot\pi\cdot x)^{n_x}$$

Now for a plot of the approximating functions and the measured data on the same graph.



Note that the measured and the approximating functions fall on top of each other. The circles are the measured values. The real part approximating function goes smoothly through the glitch.

Now to check to see how well the overall impedance is approximated. To do this, we must add the excess impedance to that of the lossy voice-coil inductance.

$n := 0 .. 61$

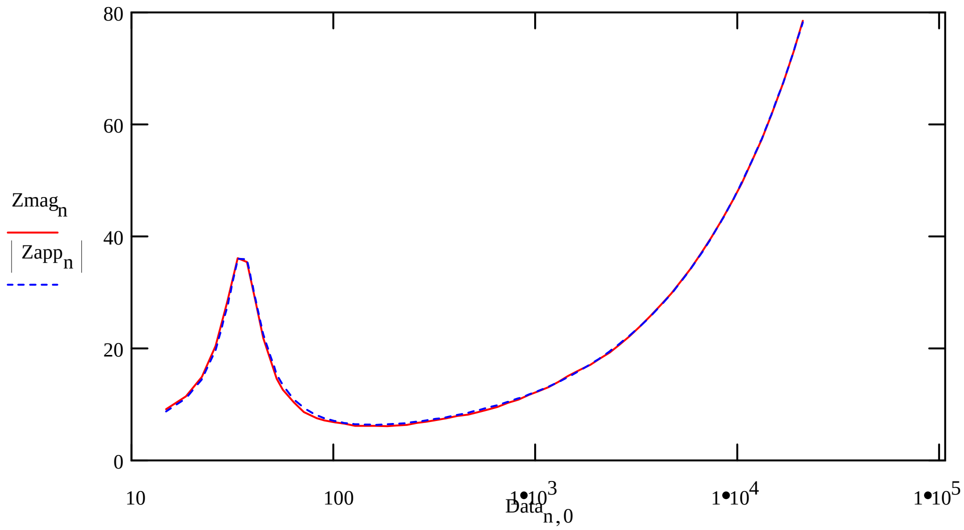
$Zmag_n := \sqrt{\left(Data_{n,1}\right)^2 + \left(Data_{n,2}\right)^2}$ Magnitude of measured impedance.

$\phi meas_n := \frac{180}{\pi} \cdot arg\left(Data_{n,1} + j \cdot Data_{n,2}\right)$ Phase of measured impedance

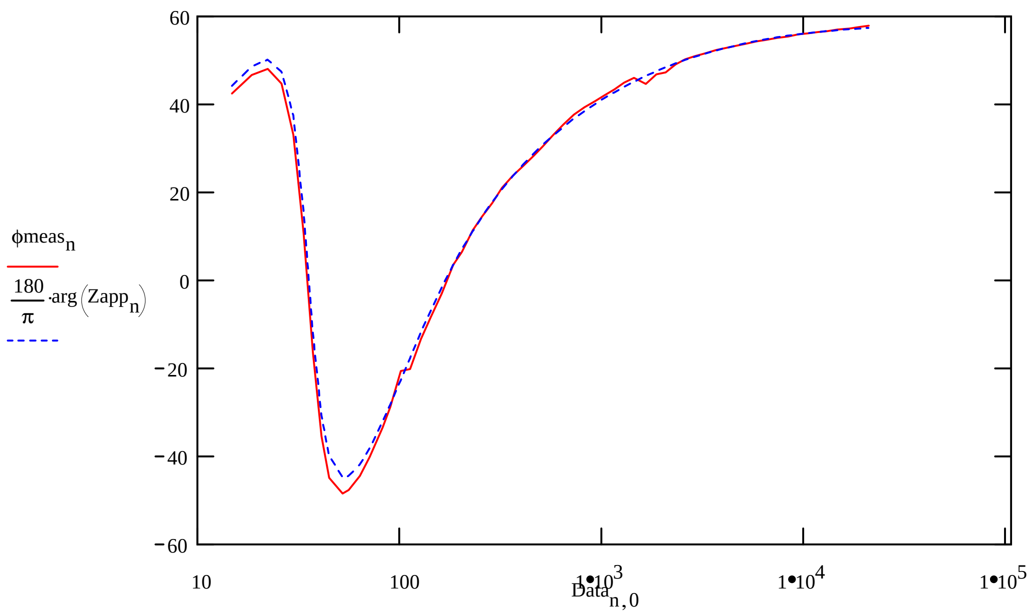
The approximating impedance with the excess impedance added back.

$$Zapp_n := Z_{exc}\left(Data_{n,0}\right) + \left[\frac{1}{R_e \cdot \left(2 \cdot \pi \cdot Data_{n,0}\right)^{n_r}} + \frac{1}{j \cdot X_e \cdot \left(2 \cdot \pi \cdot Data_{n,0}\right)^{n_x}}\right]^{-1}$$

Here are the magnitude plots.



Here are the phase plots.



Notice the excellent agreement between the measured and approximating functions.