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

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

\[ n_0, n_1, n_2 \text{ are the frequency. Data}_{n_0} \text{ is the real part of the series impedance. Data}_{n_1} \text{ is the imaginary part of the series impedance. There are 62 data points in this file. The left column index goes from 0 to 61.} \]

\[
\begin{array}{c|c|c|c}
0 & 1 & 2 \\
0 & 14.7964 & 6.78455 & 6.2272 \\
1 & 18.4955 & 7.87926 & 8.37344 \\
2 & 22.1946 & 10.00688 & 11.16913 \\
4 & 29.5928 & 23.87734 & 15.59986 \\
5 & 33.2919 & 35.50693 & 6.7749 \\
6 & 36.991 & 34.10189 & -9.89821 \\
7 & 40.6901 & 23.17333 & -16.43802 \\
8 & 44.3892 & 15.51733 & -15.39501 \\
9 & 51.7874 & 9.71677 & -10.93851 \\
10 & 55.48651 & 8.55592 & -9.35664 \\
11 & 62.88471 & 7.44207 & -7.27267 \\
12 & 70.28291 & 6.67066 & -5.59601 \\
13 & 81.38021 & 6.36234 & -4.19354 \\
14 & 88.77841 & 6.29414 & -3.45341 \\
\end{array}
\]

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

\[
Z_{exc}(f) := R_E + R_{ES} \cdot \frac{1}{Q_{MS} \cdot f_S} \cdot \frac{j \cdot f}{f_S} \\
Z_{exc}(f) \text{ is the impedance of } R_E \text{ plus the impedance due to Blu D. It is to be subtracted from the measured impedance to obtain only the impedance of the lossy voice-coil inductance.}
\]

\[ R_{exc}(f) := \text{Re}(Z_{exc}(f)) \quad X_{exc}(f) := \text{Im}(Z_{exc}(f)) \]

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.

\[
n := 35, 61 \quad \text{These are the values of } n \text{ to use the data from 1 kHz to 20 kHz.}
\]

\( R_{n,1} \) is the real part of the series impedance, and \( X_{n,2} \) is the imaginary part of the series impedance.

\[
R_{n,1} := \text{Data}_{n,1} - R \text{ exc(Data}_{n,0}) \quad X_{n,2} := \text{Data}_{n,2} - X \text{ exc(Data}_{n,0})
\]

\( R_{n,1} \) is the real part of the parallel impedance and \( X_{n,2} \) is the imaginary part of the parallel impedance.

\[
R_{n,1} := \text{Data}_{n,1} - R \text{ exc(Data}_{n,0}) \quad X_{n,2} := \text{Data}_{n,2} - X \text{ exc(Data}_{n,0})
\]

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.  $R_{P_m}$ is for the real part of the parallel impedance.  $X_{P_m}$ 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.

$$f_m := \log\left[\frac{\text{Data}_{(m+35),0}}{1}\right]$$

$$A_m := \log\left[\frac{R_{(m+35),1}}{1}\right]$$

$$B_m := \log\left[X_{(m+35),2}\right]$$

$n_r := \text{slope}(f, A)$  \hspace{1cm}  $n_r = 0.65264$

$n_X := \text{slope}(f, B)$  \hspace{1cm}  $n_X = 0.69688$

$\text{inter}_A := \text{intercept}(f, A)$  \hspace{1cm}  $\text{inter}_A = -0.61713$

$\text{inter}_B := \text{intercept}(f, B)$  \hspace{1cm}  $\text{inter}_B = -1.05847$

$$R_e := \frac{10^{\text{inter}_A}}{(2 \cdot \pi)^{n_r}}$$

$$X_e := \frac{10^{\text{inter}_B}}{(2 \cdot \pi)^{n_X}}$$

The following are the approximating functions.  $R_{\text{par}}$ approximates the resistive part of the parallel impedance.  $X_{\text{par}}$ approximates the reactive part of the parallel impedance.  $x$ is the frequency in Hertz.

$$R_{\text{par}}(x) := R_e \cdot (2 \cdot \pi \cdot x)^{n_r}$$

$$X_{\text{par}}(x) := X_e \cdot (2 \cdot \pi \cdot x)^{n_X}$$
Now for a plot of the approximating functions and the measured data on the same graph.

![Graph showing approximating functions and measured data](image)

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.

\[ n_0 := 0..61 \]

\[
Z_{\text{mag}}_n := \sqrt{\left(\text{Data}_{n,1}\right)^2 + \left(\text{Data}_{n,2}\right)^2} \quad \text{Magnitude of measured impedance.}
\]

\[
\phi_{\text{meas}}_n := \frac{180}{\pi} \arg\left(\text{Data}_{n,1} + j \cdot \text{Data}_{n,2}\right) \quad \text{Phase of measured impedance}
\]

The approximating impedance with the excess impedance added back.

\[
Z_{\text{app}}_n := Z_{\text{exc}}(\text{Data}_{n,0}) + \left[ \frac{1}{R e^{2 \cdot \pi \cdot \text{Data}_{n,0}}} + \frac{1}{j \cdot X e^{2 \cdot \pi \cdot \text{Data}_{n,0}}} \right]^{-1}
\]
Here are the magnitude plots.

Notice the excellent agreement between the measured and approximating functions.

Here are the phase plots.