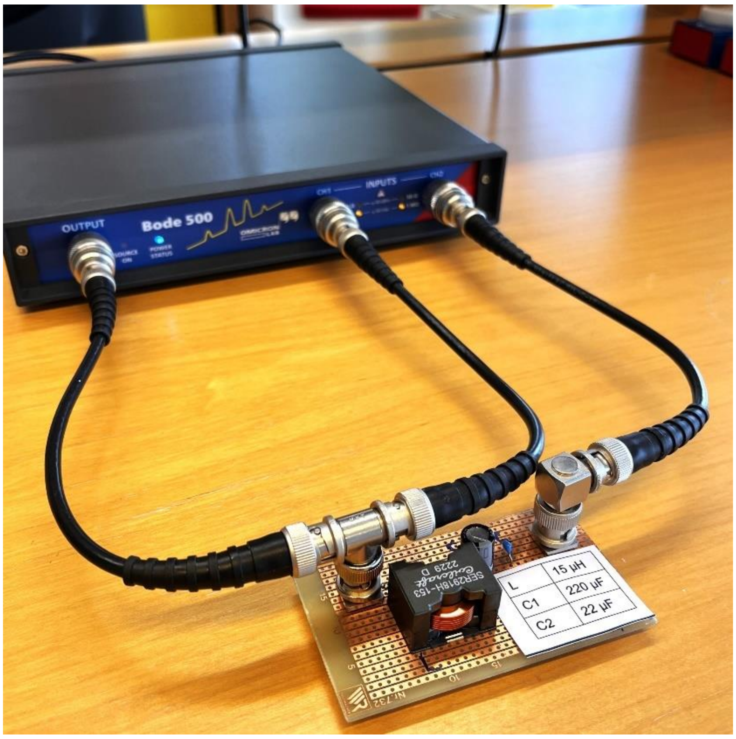
Bode 500 - Application Note

LC Low-Pass Filter Transfer Function Measurement and Simulation

Featuring the BAS Circuit Fit Tool



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Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 500 are described in the Bode 100, Bode 500 user manual available at: https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

Note: All measurements in this application note have been performed using the Bode Analyzer Suite V3.51 Use this version or a newer version to perform the measurements shown in this document. You can download the latest version at https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

1 Executive Summary

Measuring and modeling components individually before assembling a circuit offers advantages. It allows accurate simulations to predict behavior and identify issues early, despite limited datasheet information and components variations.

This Application Note demonstrates the use of the Bode 500 to measure and model the individual component impedances of an LC low-pass filter, and to analyze and compare the transfer function of the modelled filter and the real one. Modelling real components enables the creation of realistic circuit simulations and explains unexpected circuit behavior, leading to better design outcomes.

The Bode Analyzer Suite (BAS) software, with its Circuit Fit feature, models the component’s impedance and exports SPICE netlists for simulation. Following the simulation, the actual LC low-pass filter is built, and the Bode 500 is used to measure its transfer function response. The measured response is then compared with the simulated response to identify discrepancies. As a final step, stray inductances and resistors are added to the simulation to demonstrate the presence of unseen parasitics in the real circuit caused by the connections between the individual components.

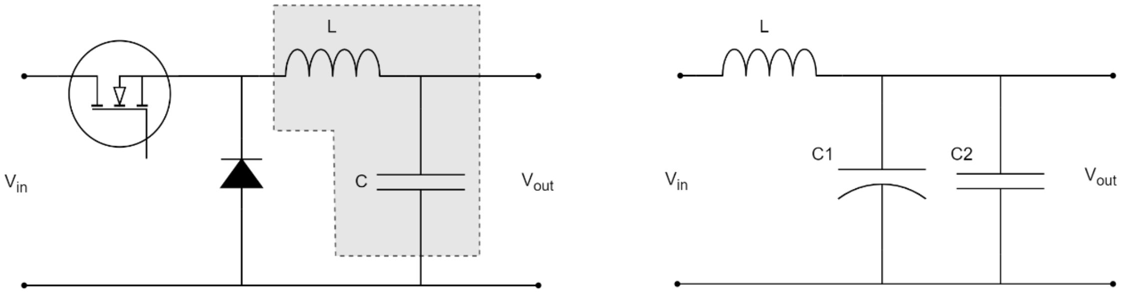
2 Design Parameters

An LC low-pass filter, consisting of an inductor (L) and a capacitor (C), is frequently found at the output stage of DC-DC converters, as illustrated in Figure 1(a). This LC combination filters out the switching ripple to achieve a DC output.

The chosen power inductor, *SER2918H* [1], has an inductance of L = 15 µH, and the selected electrolytic capacitor [2] has a capacitance value of C = 220 µF. The resonance frequency (f_{res}) calculated according to equation (1) is 2.77 kHz.

$$f_{res} = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

To improve the high-frequency filtering, a combination of an electrolytic capacitor (C1=220 µF) and a ceramic capacitor (C2) with smaller capacitance is used, as shown in Figure 1(b) below. [3]



(a) Buck converter LC low pass filter

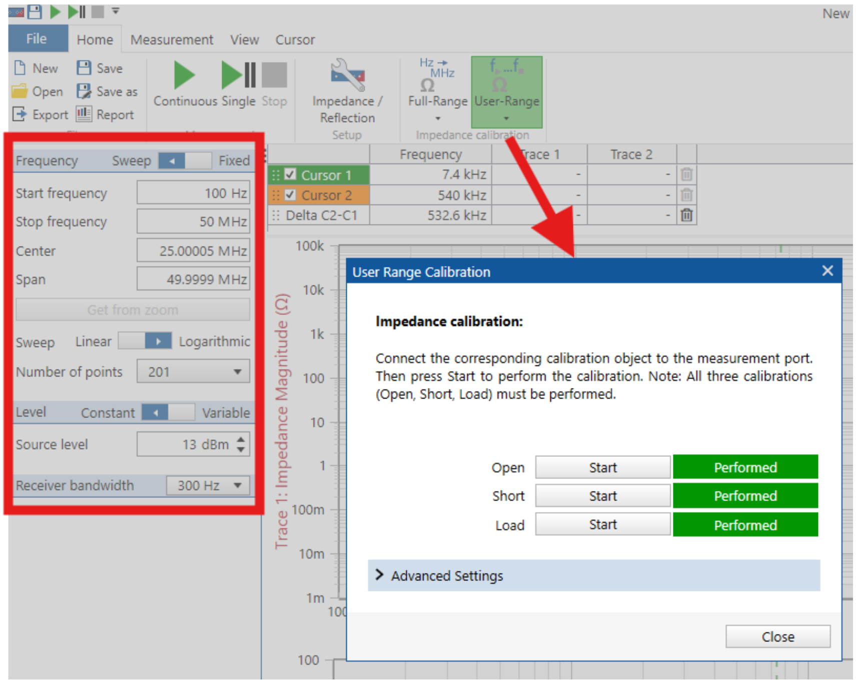
(b) LC low pass filter with electrolytic and ceramic capacitors

Figure 1: Buck converter

The resonance frequency remains nearly unaffected since the electrolytic capacitor dominates at low frequencies due to its larger capacitance value. The ceramic capacitor is 10 times smaller than the electrolytic and has a nominal capacitance value of C2 = 22 µF [4].

3 Components Measurement and Circuit Fit

The impedances of the power inductor, the electrolytic capacitor, and the ceramic capacitor are measured using the B-WIC Test Fixture adapter [5]. The frequency range used to measure the power inductor goes from 100 Hz to 50 MHz, as depicted in Figure 2. The setup for measuring the power inductor impedance is presented in Figure 3.



Frequency: Sweep | Fixed
Start frequency: 100 Hz
Stop frequency: 50 MHz
Center: 25.00005 MHz
Span: 49.9999 MHz
Sweep: Linear | Logarithmic
Number of points: 201
Level: Constant | Variable
Source level: 13 dBm
Receiver bandwidth: 300 Hz

	Frequency	Trace 1	Trace 2
☑ Cursor 1	7.4 kHz	-	-
☑ Cursor 2	540 kHz	-	-
Delta C2-C1	532.6 kHz	-	-

User Range Calibration

Impedance calibration:

Connect the corresponding calibration object to the measurement port. Then press Start to perform the calibration. Note: All three calibrations (Open, Short, Load) must be performed.

Open: Performed
Short: Performed
Load: Performed

> Advanced Settings

Figure 2: B-WIC Measurement setup and calibration.

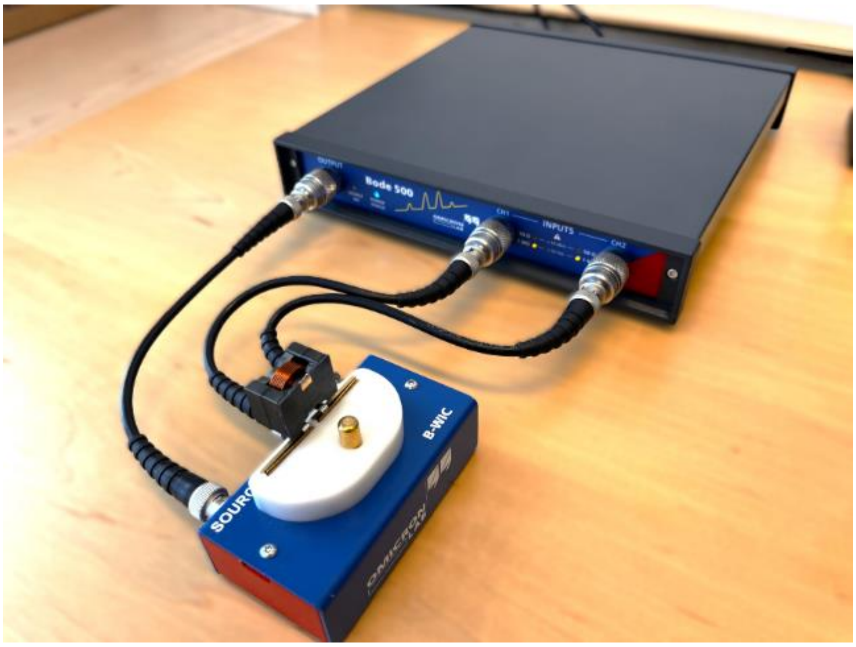
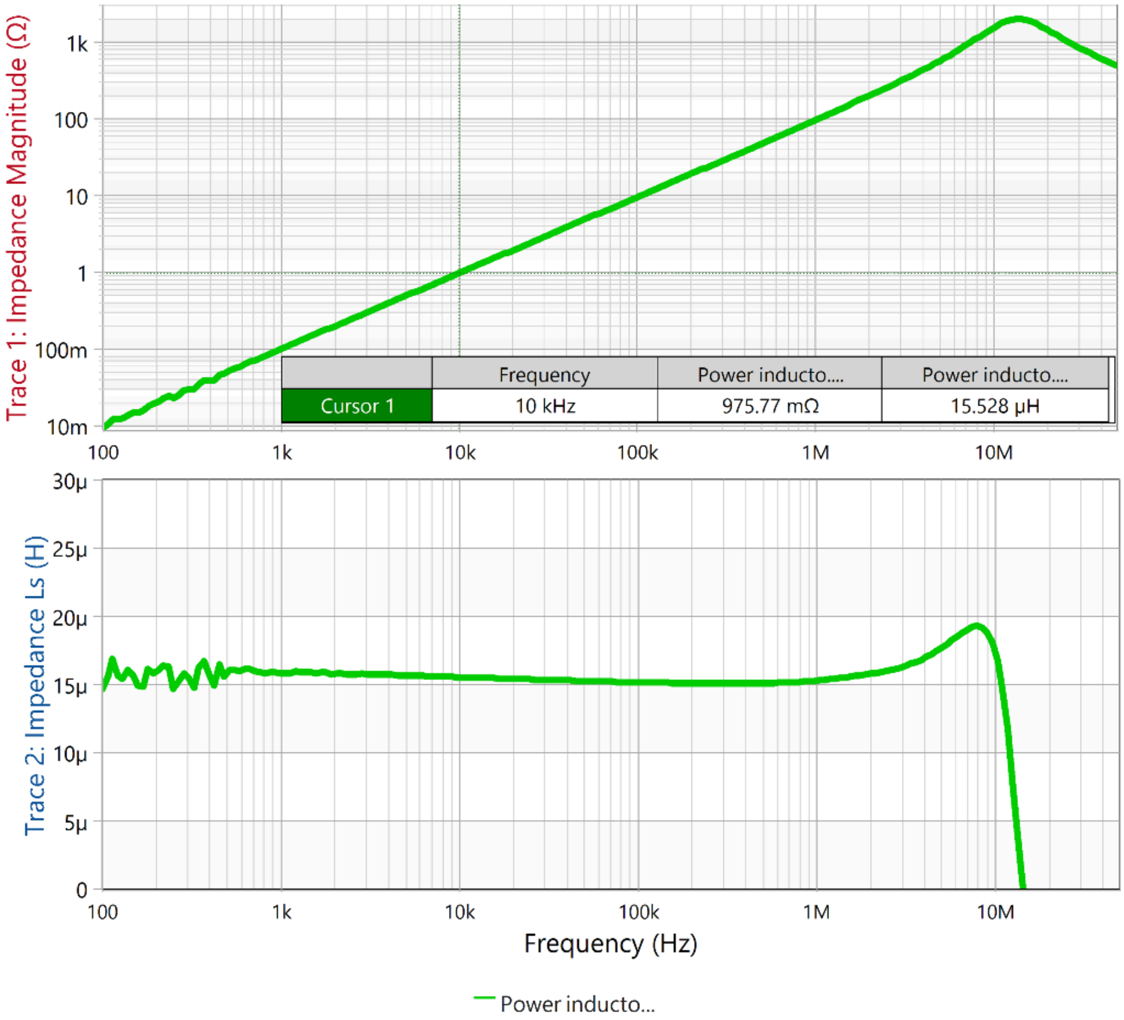


Figure 3: Power inductor measurement setup.

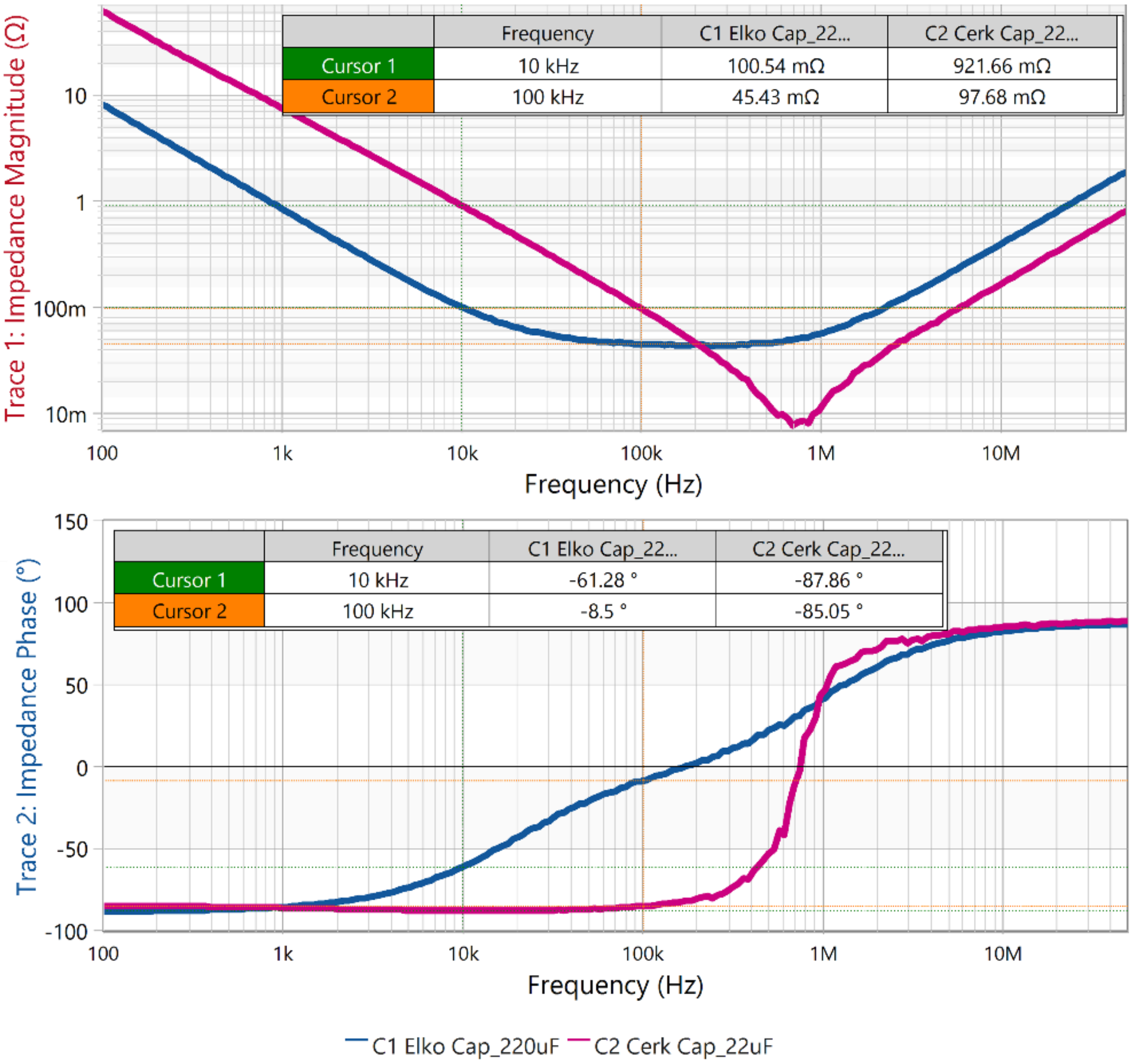
The measurement results for the power inductor and the capacitors are displayed in Figure 4 and Figure 5, respectively. From the measurement of the power inductor, we can see it has a low DC resistance < 10 mΩ and its self-resonance frequency is above 10 MHz.



	Frequency	Power inducto....	Power inducto....
Cursor 1	10 kHz	975.77 mΩ	15.528 µH

Figure 4: Inductor impedance magnitude and inductance over frequency.

The capacitor measurement shows the capacitive slope at low frequencies and the self-resonance frequency as well as the inductive behavior after self-resonance. The aluminum electrolytic capacitor has a higher ESR value around 48 mΩ and quickly loses its capacitive behavior above 10 kHz. The ceramic capacitor has a much lower ESR below 10 mΩ acting in a capacitive manner up to several 100 kHz.



	Frequency	C1 Elko Cap_22...	C2 Cerk Cap_22...
Cursor 1	10 kHz	100.54 mΩ	921.66 mΩ
Cursor 2	100 kHz	45.43 mΩ	97.68 mΩ

	Frequency	C1 Elko Cap_22...	C2 Cerk Cap_22...
Cursor 1	10 kHz	-61.28 °	-87.86 °
Cursor 2	100 kHz	-8.5 °	-85.05 °

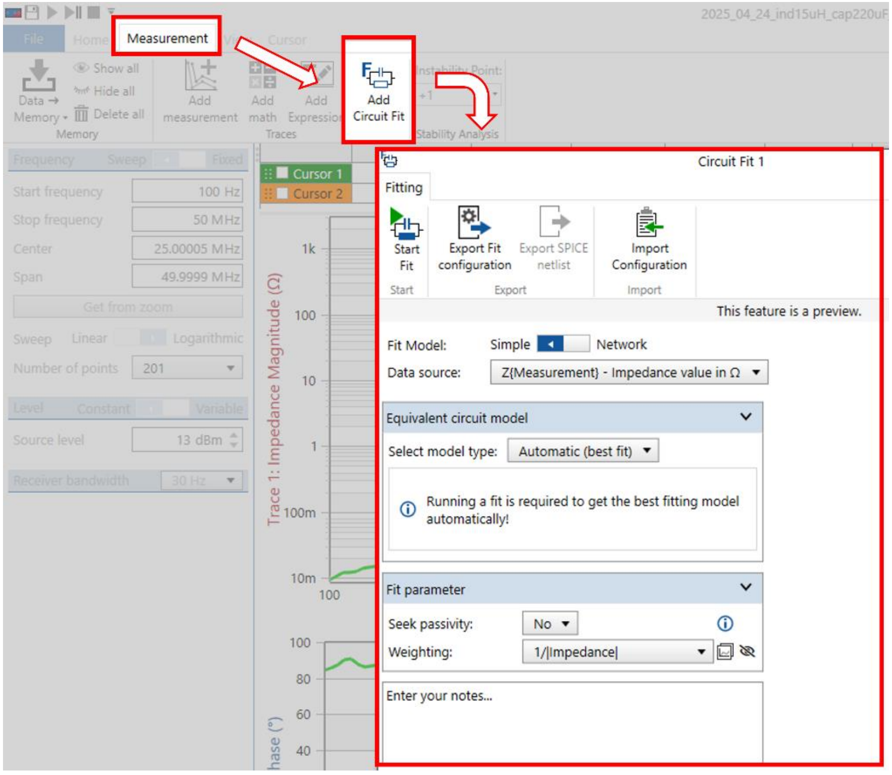
Figure 5: Electrolytic (C1) and ceramic (C2) capacitors' impedance and phase.

3.1 Power Inductor Impedance - Circuit Fit Model

The new Circuit Fit tool [6] in BAS can calculate a model from a measurement. It determines the component values of an equivalent circuit that approximates a measured impedance or admittance curve, supporting predefined models or a more complex network structure. It adjusts the circuit parameters so that the resulting impedance closely matches the measured data.

In this case, the power inductor impedance is measured and then modelled using the Circuit Fit feature using an automatic selected predefined (Simple) model.

To access the Circuit Fit feature, once the impedance of the component has been measured, select the Measurement option in the ribbon and click the Add Circuit Fit icon. A new fit trace, Circuit Fit 1, is added, and the fit window will then appear displaying the fitting settings as it is shown in Figure 6.



Start frequency: 100 Hz
Stop frequency: 50 MHz
Center: 25.00005 MHz
Span: 49.9999 MHz
Sweep: Linear / Logarithmic
Number of points: 201
Source level: 13 dBm
Receiver bandwidth: 30 Hz

This feature is a preview.

Fit Model: Simple / Network
Data source: Z(Measurement) - Impedance value in Ω
Select model type: Automatic (best fit)

Running a fit is required to get the best fitting model automatically!

Seek passivity: No
Weighting: 1/|Impedance|

Enter your notes...

Figure 6: Selection of the Add Circuit Fit feature in the BAS.

For most applications, it is recommended to use the default settings to achieve satisfactory results. For higher accuracy or higher order models, switch the “Fit Model” settings from Simple to Network.

In detail, the following settings are selected for the power inductor Circuit Fit model:

- **Fit model**: The Simple model is selected, as the impedance does not exhibit additional resonances within the 50 MHz frequency range.
- **Data source**: Select the trace containing the power inductor impedance measurement data.
- **Equivalent circuit model**: Choose a model type from a list of eight predefined models or use the Automatic (best fit) option. The latter selects the best fit based on the lowest root-mean-square of the relative errors (RMSRE[1]). In this application, it is kept in Automatic (best fit).
- **Fit parameter**:
  - **Seek passivity**: The mathematical solution of a fitting curve can contain positive and negative values. This option is used to ensure that the circuit model components only take on positive values. The simulation software (i.e. LTspice) can handle also negative values, so no restrictions are required. The setting is left as “No” which usually generates better fitting models.

---

[1] A maximum value of 7% is arbitrarily defined in this application note for all fittings.

  - **Weighting**[2]: It is recommended to use the default **1/|Impedance|** since it ensures that all data points contribute equally to the fitting process.

Pressing the Start Fit model button on the upper left-hand side (see Figure 7) will start the fitting process.

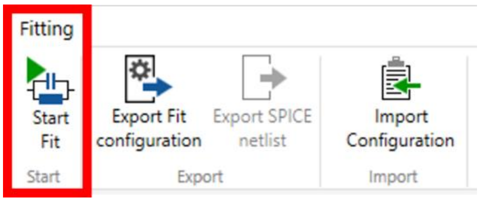
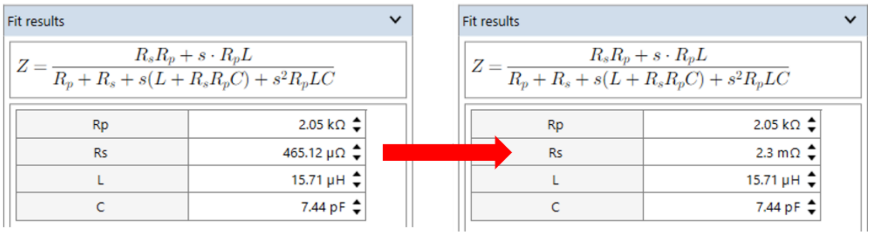


Figure 7: Start Fit button.

The Circuit Fit model results are shown in Figure 9, where the following points are highlighted:

- The Automatic (best fit) selects Model F with a parallel circuit configuration.
- The model transfer function equation, along with its parameters, is presented on the right-hand side. After the fitting it is possible to manually adjust the parameter values. For example, the fitting curve initially yielded a series resistance Rs (DC impedance) of 465.12 µΩ, which differs from the datasheet value of 2.3 mΩ. Therefore, a manual correction was applied, and the fitting curve was adjusted accordingly[3].



Fit results

$$Z = \frac{R_s R_p + s \cdot R_p L}{R_p + R_s + s(L + R_s R_p C) + s^2 R_p L C}$$

Rp	2.05 kΩ
Rs	465.12 µΩ
L	15.71 µH
C	7.44 pF

Fit results

$$Z = \frac{R_s R_p + s \cdot R_p L}{R_p + R_s + s(L + R_s R_p C) + s^2 R_p L C}$$

Rp	2.05 kΩ
Rs	2.3 mΩ
L	15.71 µH
C	7.44 pF

Figure 8: Curve Fitting manual parameter adjustment.

- The Relative Error[4] graph indicates the precision of the model at each evaluated point. The equation (2) describes the calculation of the relative error E for a complex measurement point Z and the complex actual value of the fit Z':

$$E = \left|\frac{Z - Z'}{Z}\right| 100 \qquad (2)$$

- The model achieves a RMSRE of 5.4%, and the yellow curve represents the model. The RMSRE is calculated as the root-mean-square of the relative errors, which as shown in the error plot.

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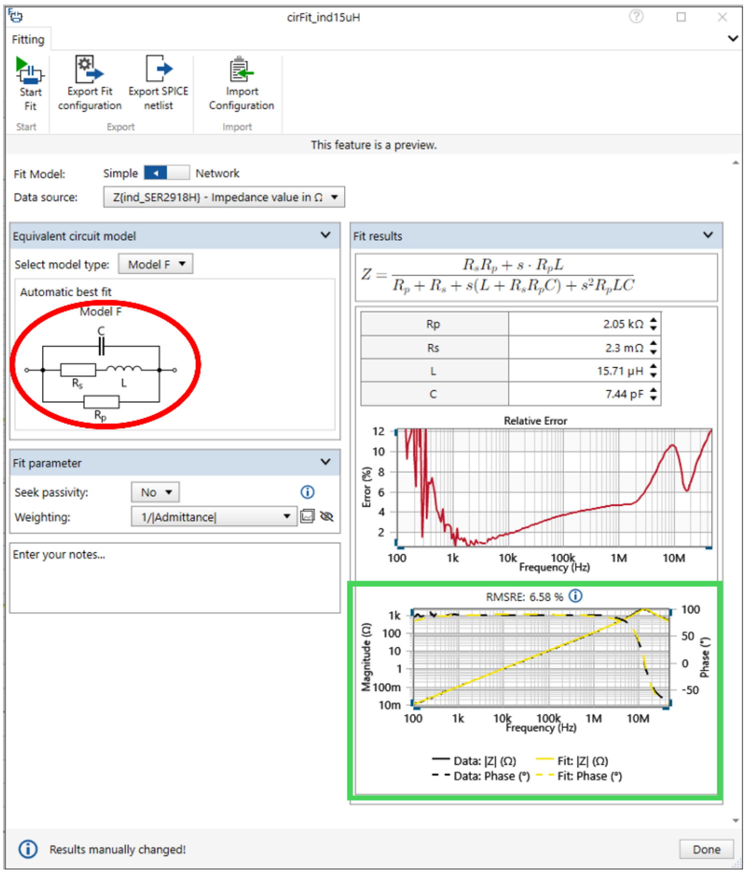
[2] Alternative weighting options, such as the square of the magnitude, emphasize smaller values, while the square root weighting prioritizes larger values.

[3] For relative accuracy of the B-WIC, refer to the B-WIC & B-SMC Impedance Test Fixture User Manual [5].

[4] For more information on relative and RMSRE error calculation refer to the Bode Analyzer Suite user manual [6].



This feature is a preview.

Fit Model: Simple / Network

Data source: Z(ind_SER2918H) - Impedance value in Ω

Select model type: Model F

Automatic best fit

$$Z = \frac{R_s R_p + s \cdot R_p L}{R_p + R_s + s(L + R_s R_p C) + s^2 R_p L C}$$

Rp	2.05 kΩ
Rs	2.3 mΩ
L	15.71 µH
C	7.44 pF

Seek passivity: No

Weighting: 1/|Admittance|

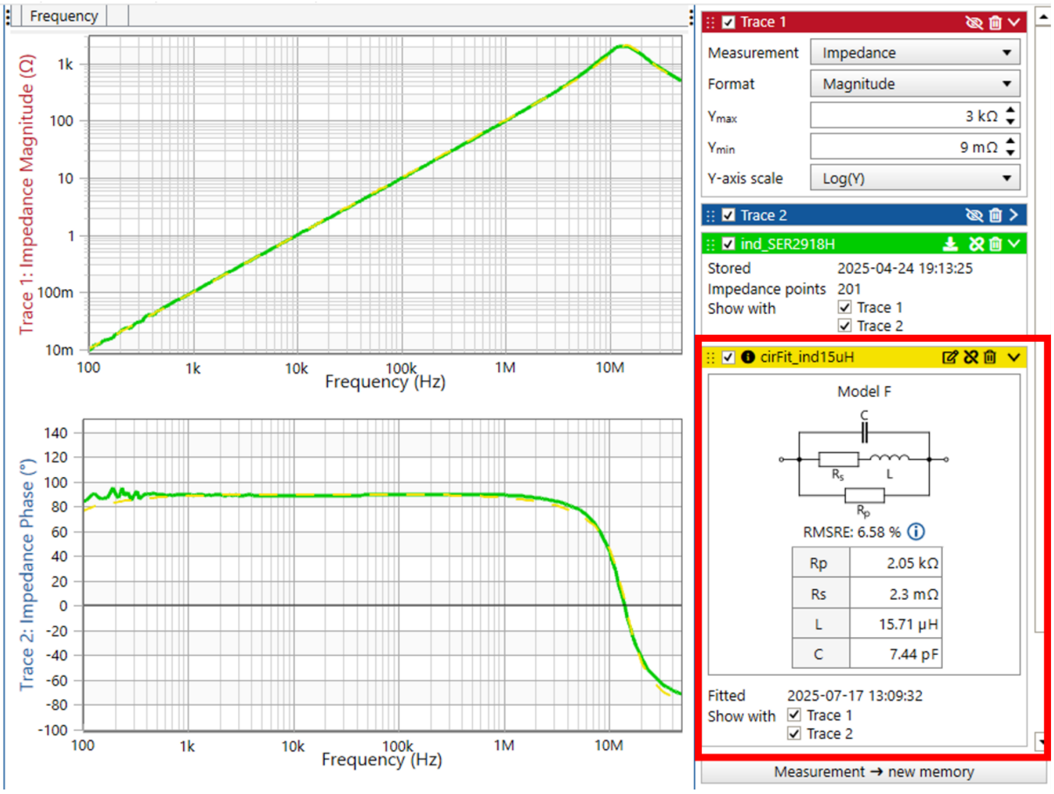
Enter your notes...

RMSRE: 6.58 %

Results manually changed!

Figure 9: Power inductor Circuit Fit results and error plot.

The power inductor circuit fit model is saved as a Memory in the traces panel of the main BAS window as it is presented in Figure 10.



☑ Trace 1

Measurement	Impedance
Format	Magnitude
Y_{max}	3 kΩ
Y_{min}	9 mΩ
Y-axis scale	Log(Y)

☑ Trace 2

☑ ind_SER2918H

Stored	2025-04-24 19:13:25
Impedance points	201
Show with	☑ Trace 1 ☑ Trace 2

☑ cirFit_ind15uH

Model F

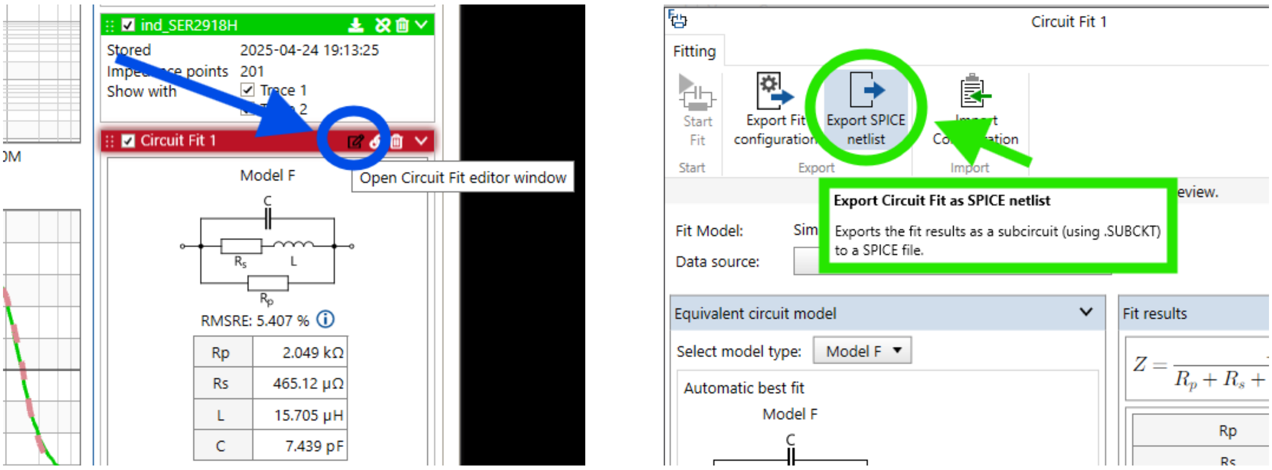
RMSRE: 6.58 %

Rp	2.05 kΩ
Rs	2.3 mΩ
L	15.71 µH
C	7.44 pF

Fitted	2025-07-17 13:09:32
Show with	☑ Trace 1 ☑ Trace 2

Figure 10: Power inductor measurement and Circuit Fit results in BAS main window.

Furthermore, the Circuit Fit model of the component can be exported as a SPICE netlist by selecting the Export SPICE netlist button. See Figure 11(a) and Figure 11(b). Consequently, the power inductor model is exported as a SPICE netlist for further analysis.



☑ ind_SER2918H

Stored	2025-04-24 19:13:25
Impedance points	201
Show with	☑ Trace 1 ☑ Trace 2

☑ Circuit Fit 1

Model F

RMSRE: 5.407 %

Rp	2.049 kΩ
Rs	465.12 µΩ
L	15.705 µH
C	7.439 pF

Export Circuit Fit as SPICE netlist

Exports the fit results as a subcircuit (using .SUBCKT) to a SPICE file.

Fit Model: Sim

Data source:

Equivalent circuit model

Select model type: Model F

Automatic best fit

Model F

Fit results

$Z = R_p + R_s +$

Rp

Rs

(a) Opening Circuit Fit editor.

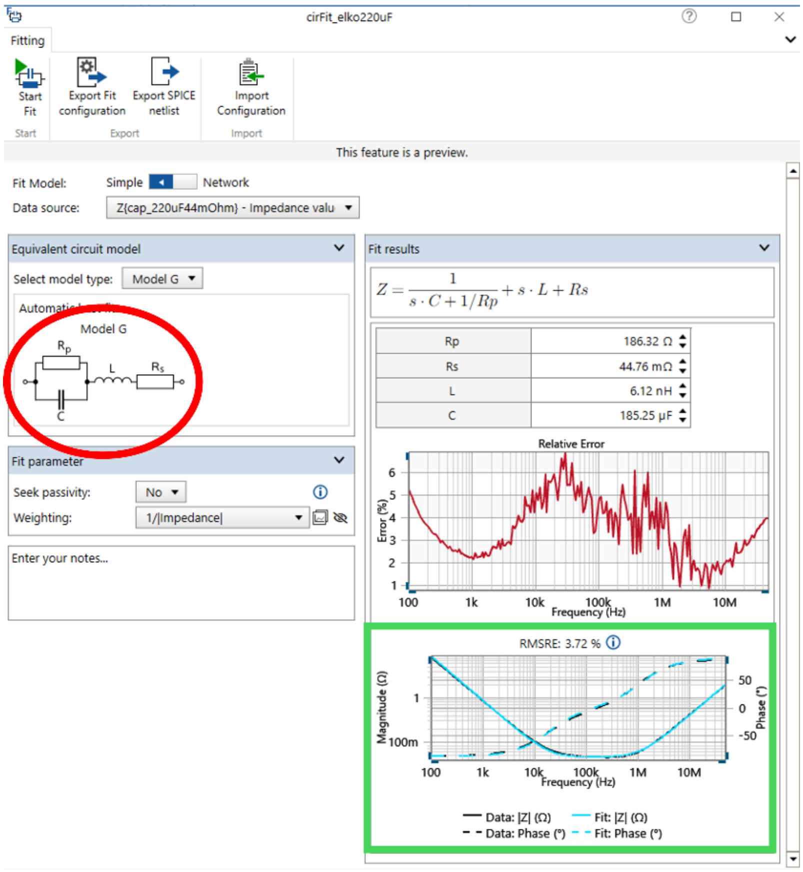
(b) Click on the Export SPICE netlist button.

Figure 11: Exporting to a SPICE netlist.

3.2 Electrolytic Capacitor – Circuit Fit Model

The Circuit Fit setup procedure described in section 3.1 is also applied to the electrolytic capacitor. The Fit Model Simple and the Automatic (best fit) options are chosen. The Seek passivity option is left at “No”, and the default weighting is retained.

The results of the Circuit Fit are shown in Figure 12 and Figure 13, where Fit Model G was chosen and the obtained RMSRE is 3.7%. The electrolytic capacitor model is exported as a SPICE netlist.



This feature is a preview.

Fit Model: Simple / Network

Data source: Z{cap_220uF44mOhm} - Impedance valu

Select model type: Model G

Automatic

$$Z = \frac{1}{s \cdot C + 1/Rp} + s \cdot L + Rs$$

Rp	186.32 Ω
Rs	44.76 mΩ
L	6.12 nH
C	185.25 µF

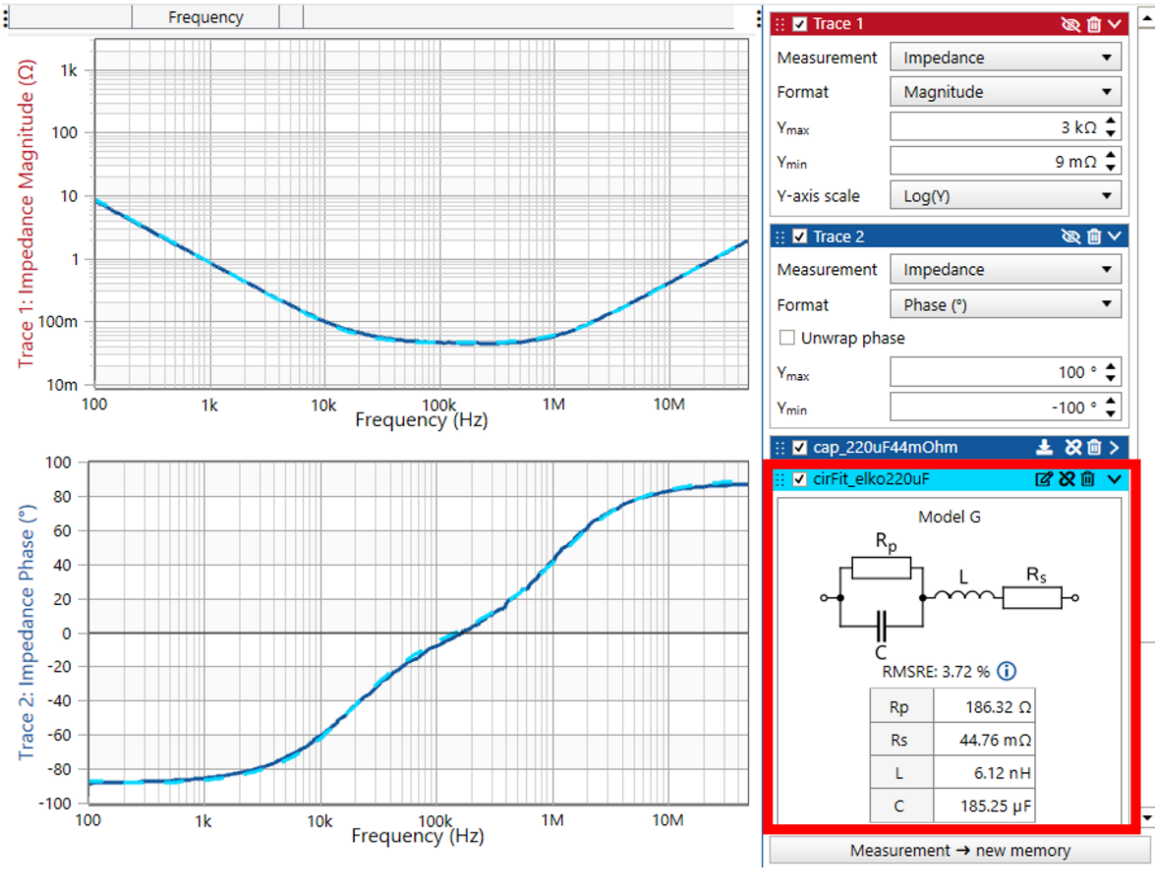
Seek passivity: No

Weighting: 1/|Impedance|

Enter your notes...

RMSRE: 3.72 %

Figure 12: Electrolytic capacitor Circuit Fit results.



☑ Trace 1
Measurement: Impedance
Format: Magnitude
Y_{max}: 3 kΩ
Y_{min}: 9 mΩ
Y-axis scale: Log(Y)

☑ Trace 2
Measurement: Impedance
Format: Phase (°)
☐ Unwrap phase
Y_{max}: 100 °
Y_{min}: -100 °

☑ cap_220uF44mOhm

☑ cirFit_elko220uF
Model G
RMSRE: 3.72 %

Rp	186.32 Ω
Rs	44.76 mΩ
L	6.12 nH
C	185.25 µF

Measurement → new memory

Figure 13: Electrolytic capacitor measurement and Circuit Fit results in BAS main window.

3.3 Ceramic Capacitor - Circuit Fit Model

For the ceramic capacitor impedance, the Network Fit Model is selected because the Simple Fit Model, including the Automatic (best fit), delivered an RMSRE of 14.3%, which exceeds the predefined limitation of 7%.

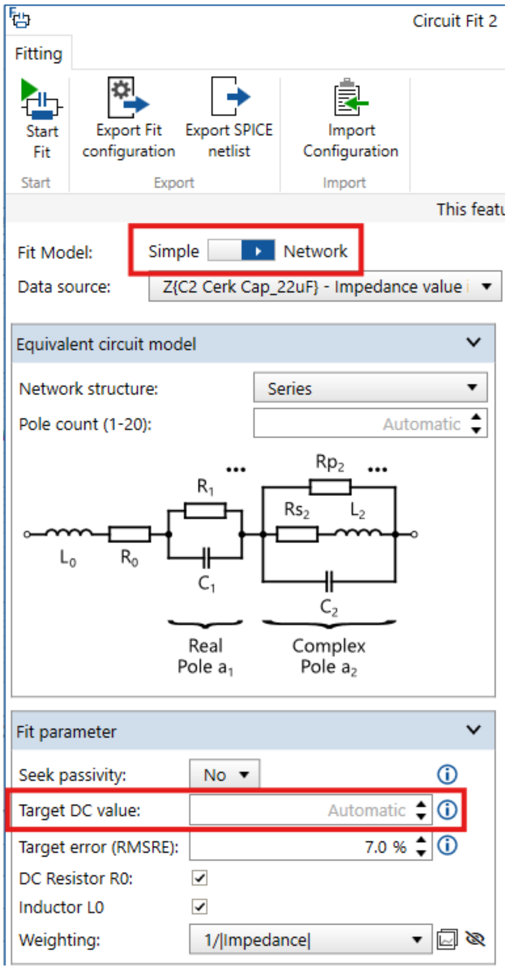
Following the corresponding settings that can be seen also in Figure 14:

- **Equivalent circuit model:**
    - **Network structure**: It can be chosen between Series, Parallel and Automatic. In this case, Automatic was selected.
    - **Pole count (1 – 20)**: As a modeling criterion, the equivalent circuit can contain from 1 to 20 poles. If “Automatic” is selected, the result will have a lower RMSRE than the specified target error or the maximum count of poles[5].

---

[5] If “Seek Passivity” is set to “Yes”, then the result might have a higher RMSRE than the specified target error.

- **Fit parameter:**
    - **Fit Seek passivity**: The mathematical solution of a fitting curve can contain positive and negative values. This option is used to ensure that the circuit model components only take on positive values. The simulation software (i.e. LTspice) can handle such mathematical negative values, so no restrictions are required. The setting is left as “No”.
    - **Target DC value**: One can specify the value of the fit at DC. In this case, it is retained Automatic. If you want to make sure that your capacitor model has high DC resistance, define it here.
    - **Target Error (RMSRE)**: It was set arbitrarily at 7.0% as the algorithm target.
    - **Weighting**: **1/|Impedance|** ensures that all data points contribute equally to the fitting process.



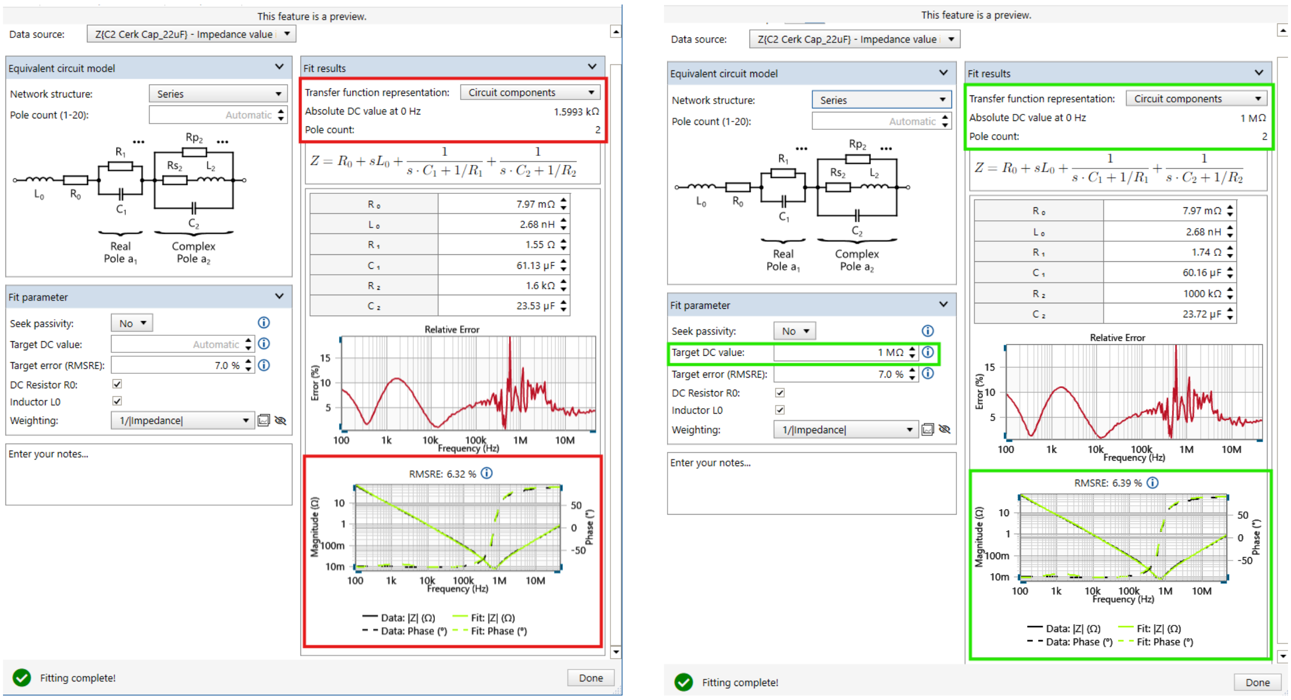
Fit Model: Simple / Network
Data source: Z{C2 Cerk Cap_22uF} - Impedance value
Network structure: Series
Pole count (1-20): Automatic
Seek passivity: No
Target DC value: Automatic
Target error (RMSRE): 7.0 %
DC Resistor R0: ☑
Inductor L0 ☑
Weighting: 1/|Impedance|

Figure 14: Network fit model setting up.

The result of the Network Fit Model is presented in Figure 15 and Figure 16. The following lists some highlights of the result:

- The absolute DC value at 0 Hz is about 1.6 kΩ[6] as seen in Figure 15(a).
- The series network transfer function contains 2 poles.
- The parameters of the transfer function are listed in the table below the transfer function.
- The RMSRE is 6.39%

Similar as the power inductor and electrolytic capacitor, the ceramic capacitor model is exported as a SPICE netlist.



This feature is a preview.

Data source: Z{C2 Cerk Cap_22uF} - Impedance value

Network structure: Series
Pole count (1-20): Automatic

Seek passivity: No
Target DC value: Automatic
Target error (RMSRE): 7.0 %
DC Resistor R0: ☑
Inductor L0: ☑
Weighting: 1/|Impedance|

Enter your notes...

Transfer function representation: Circuit components
Absolute DC value at 0 Hz 1.5993 kΩ
Pole count: 2

$$Z = R_0 + sL_0 + \frac{1}{s \cdot C_1 + 1/R_1} + \frac{1}{s \cdot C_2 + 1/R_2}$$

R_0	7.97 mΩ
L_0	2.68 nH
R_1	1.55 Ω
C_1	61.13 µF
R_2	1.6 kΩ
C_2	23.53 µF

RMSRE: 6.32 %

Fitting complete!

This feature is a preview.

Data source: Z{C2 Cerk Cap_22uF} - Impedance value

Network structure: Series
Pole count (1-20): Automatic

Seek passivity: No
Target DC value: 1 MΩ
Target error (RMSRE): 7.0 %
DC Resistor R0: ☑
Inductor L0: ☑
Weighting: 1/|Impedance|

Enter your notes...

Transfer function representation: Circuit components
Absolute DC value at 0 Hz 1 MΩ
Pole count: 2

$$Z = R_0 + sL_0 + \frac{1}{s \cdot C_1 + 1/R_1} + \frac{1}{s \cdot C_2 + 1/R_2}$$

R_0	7.97 mΩ
L_0	2.68 nH
R_1	1.74 Ω
C_1	60.16 µF
R_2	1000 kΩ
C_2	23.72 µF

RMSRE: 6.39 %

Fitting complete!

(a) Results with 1.6 kΩ DC impedance value.

(b) Results with 1 MΩ DC impedance value as Target.

Figure 15: Ceramic capacitor Circuit Fit using the Network model.

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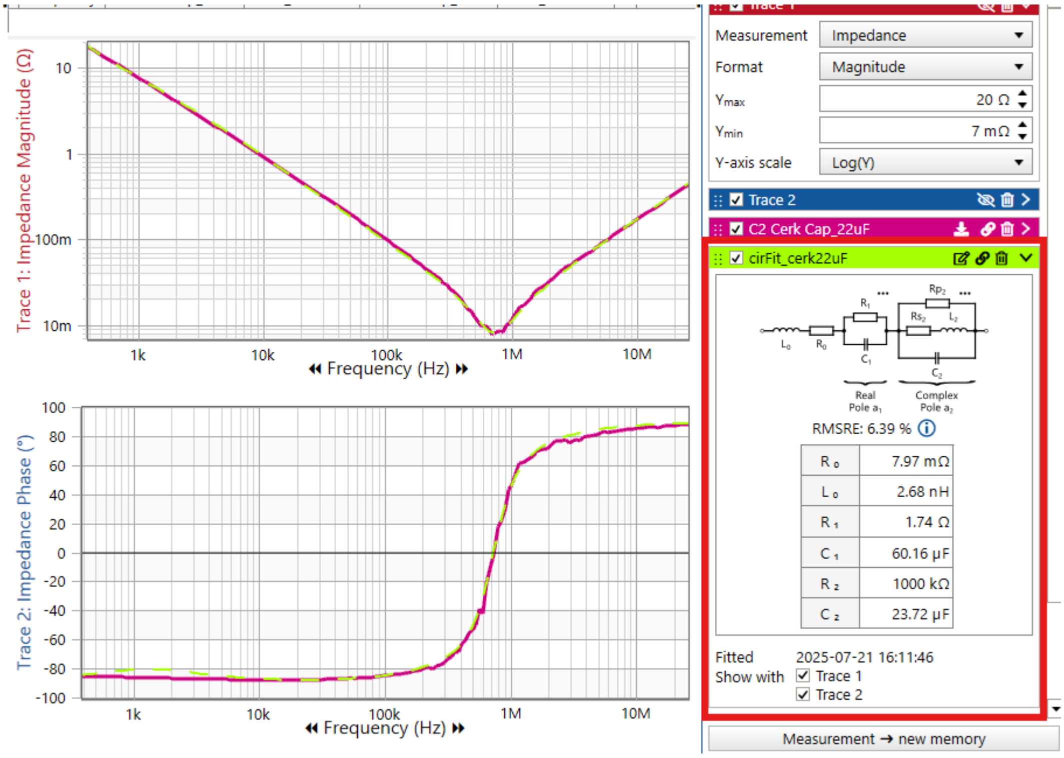
[6] This DC value is low for a ceramic capacitor which is expected to be in the rage of MΩ. This can be solve specifying a DC value in the option: Target DC value in Figure 14 (instead of Automatic) and redoing the fit. The result is shown in Figure 15(b).



Measurement: Impedance
Format: Magnitude
Ymax: 20 Ω
Ymin: 7 mΩ
Y-axis scale: Log(Y)

RMSRE: 6.39 %

R ₀	7.97 mΩ
L ₀	2.68 nH
R ₁	1.74 Ω
C ₁	60.16 µF
R ₂	1000 kΩ
C ₂	23.72 µF

Fitted 2025-07-21 16:11:46
Show with ☑ Trace 1
☑ Trace 2

Figure 16: Ceramic capacitor measurement and Circuit Fit results in BAS main window.

4 LC Low-Pass Filter Simulation

As mentioned in previous sections, LTspice is used for simulating the filter using an AC analysis. Additionally, a theoretical LC low-pass filter with ideal components is considered for comparison purposes.

In sections 3.1 3.2 and 3.3 the three passive components are exported as SPICE netlist. These netlists can be imported into LTspice, and a symbol can be generated[7].

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[7] Open the component Netlist file in LTspice. Then, right-click over the name of the *.SUBCKT and select Create Symbol [7].

The LC low-pass filter schematics are created, as shown in Figure 17.

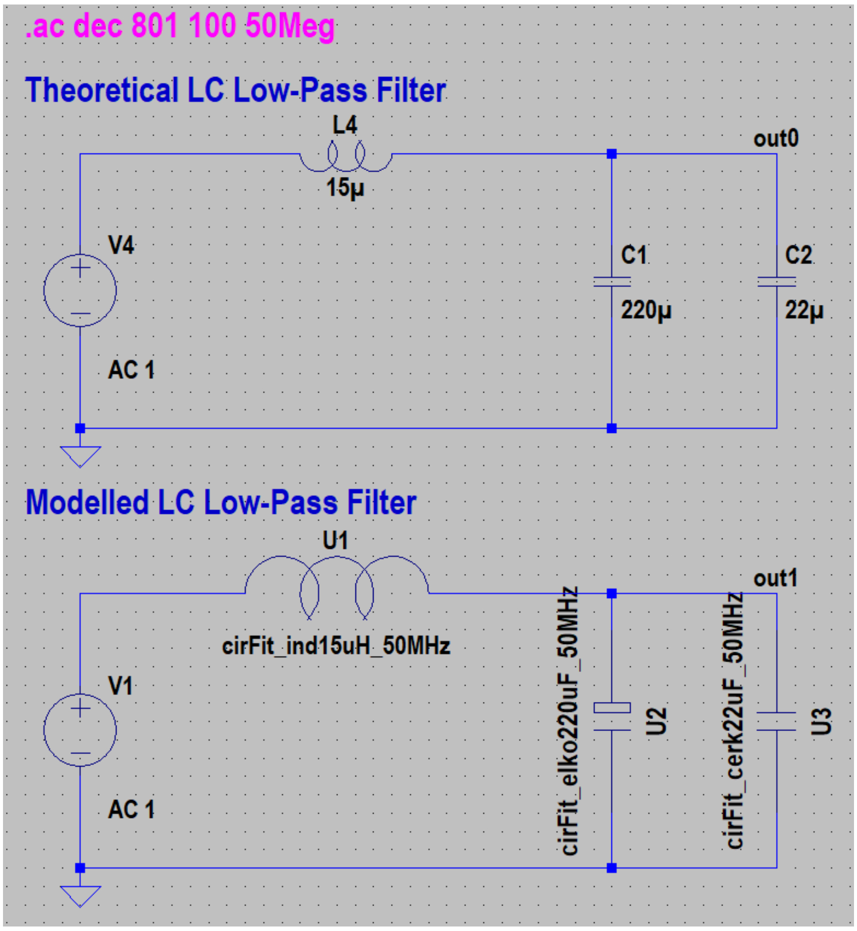

Figure 17: Theoretical and modelled LC low pass filter schematics.

By performing an AC analysis with the voltage sources set to 1 VAC and measuring the voltage at out0 and out1, the gain and phase response of the filters' voltage transfer functions are obtained, as shown in Figure 18.

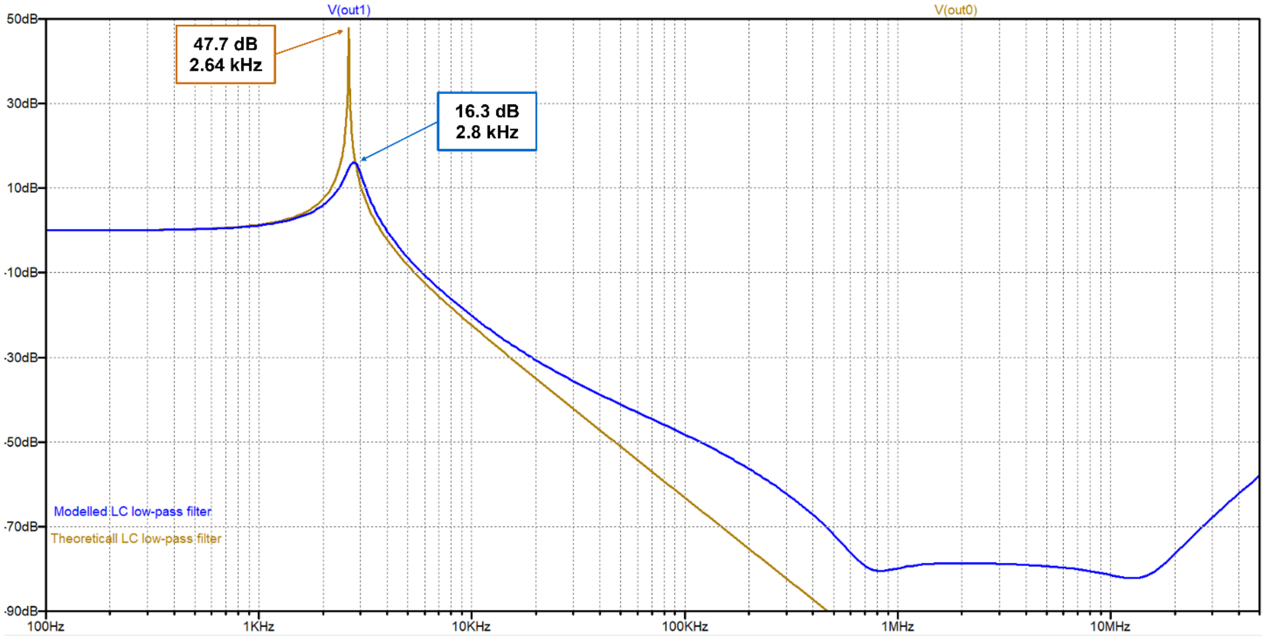

Figure 18: Theoretical and Modelled LC low-pass filter voltage transfer functions response.

The theoretical filter shows a peak value of 47.7 dB at its resonance frequency of 2.64 kHz, while the modelled filter has its peak of 16.3 dB at 2.79 kHz caused by damping from parasitic resistance like the ESR of the electrolytic capacitor.

A higher peak means the LC filter of the converter has a higher Q factor (quality factor)[8], which implies lower damping. Also, it causes ringing or overshoot in the output voltage, especially during load transient or switching events.

The gain and phase response data can be exported, in terms of Cartesian numbers — real and imaginary — versus frequency as a .txt file, as it shows in Figure 19(a) and Figure 19(b). This option allows the plot to be loaded in the BAS.

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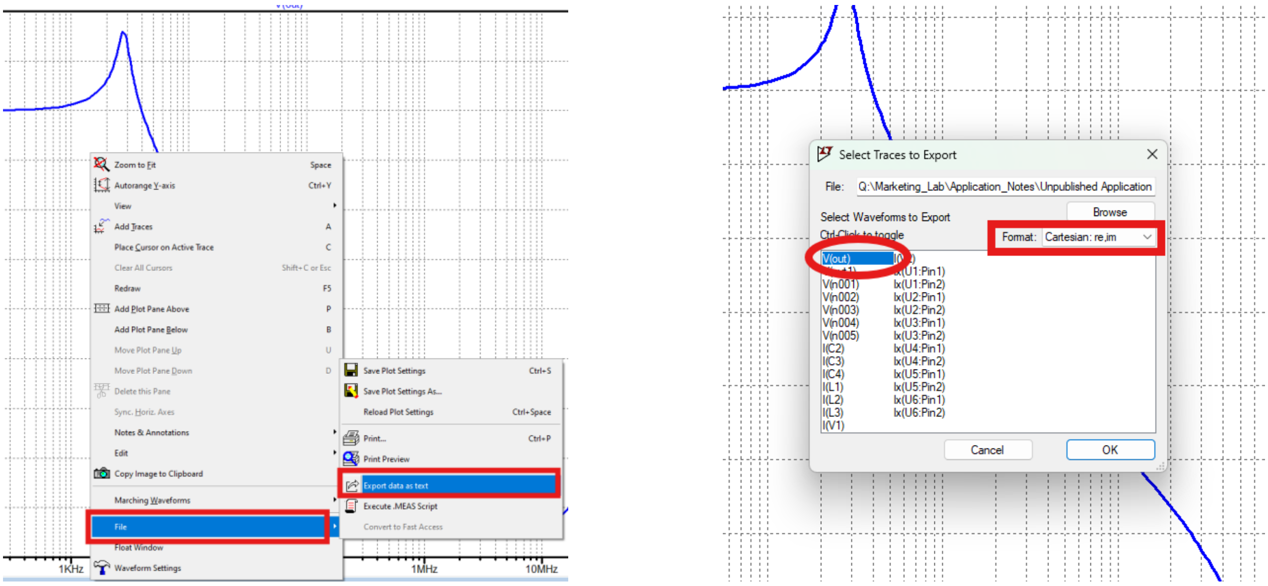
[8] $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$, where L is the inductance, C is the capacitance and R is the ESR.



File: Q:\Marketing_Lab\Application_Notes\Unpublished Application

Format: Cartesian: re,im

(a) Saving gain and phase transfer function response.

(b) Selecting the Cartesian (re, im) format of V(out).

Figure 19: Exporting the LTspice simulation data to import into the BAS.

5 LC Low-Pass Filter Measurement and Comparison

The LC low-pass filter is the Device Under Test (DUT) and is constructed as presented in Figure 20. The circuit board includes two BNC female terminals (input and output) for measuring the voltage transfer function (Gain / Phase).

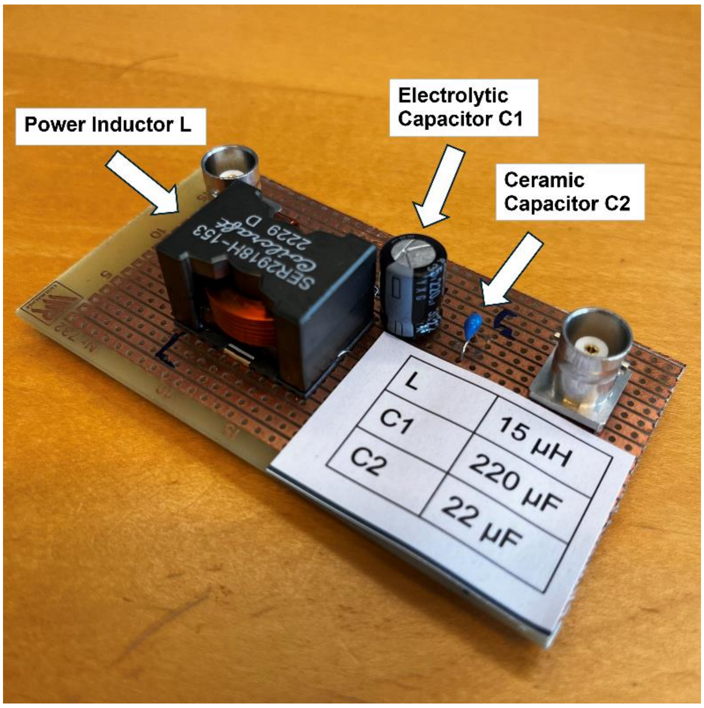
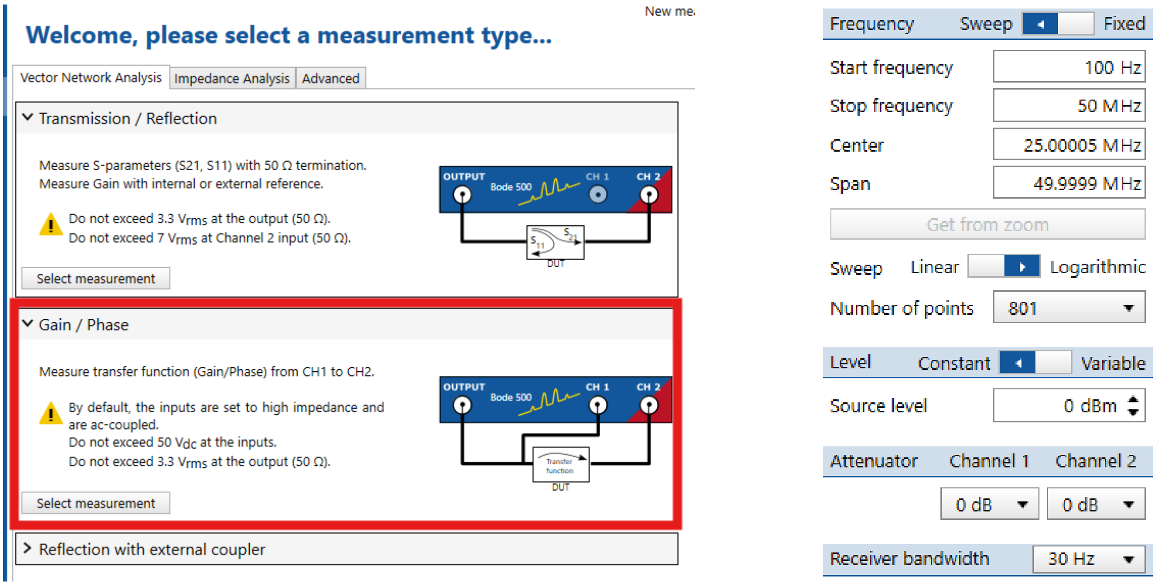


Figure 20: LC Low-pass filter PCB board.

5.1 Voltage Transfer Function Measurement Setup

In the Bode Analyzer Suite, the Vector Network Analysis tab is chosen, and the Gain / Phase measurement selected, as seen in Figure 21(a). The measurement configuration is illustrated in Figure 21(b). This will be used to perform the User-Range Thru calibration as shown in Figure 22(a) and Figure 22(b).



Welcome, please select a measurement type...

Transmission / Reflection

Measure S-parameters (S21, S11) with 50 Ω termination.
Measure Gain with internal or external reference.

Do not exceed 3.3 V_{rms} at the output (50 Ω).
Do not exceed 7 V_{rms} at Channel 2 input (50 Ω).

Gain / Phase

Measure transfer function (Gain/Phase) from CH1 to CH2.

By default, the inputs are set to high impedance and are ac-coupled.
Do not exceed 50 V_{dc} at the inputs.
Do not exceed 3.3 V_{rms} at the output (50 Ω).

Reflection with external coupler

Frequency: Sweep [✓ Sweep] / Fixed
Start frequency: 100 Hz
Stop frequency: 50 MHz
Center: 25.00005 MHz
Span: 49.9999 MHz
Sweep: Linear / Logarithmic [✓ Logarithmic]
Number of points: 801
Level: Constant [✓ Constant] / Variable
Source level: 0 dBm
Attenuator: Channel 1: 0 dB; Channel 2: 0 dB
Receiver bandwidth: 30 Hz

(a) Gain / Phase measurement.

(b) Measurement configuration.

Figure 21: BAS setup.

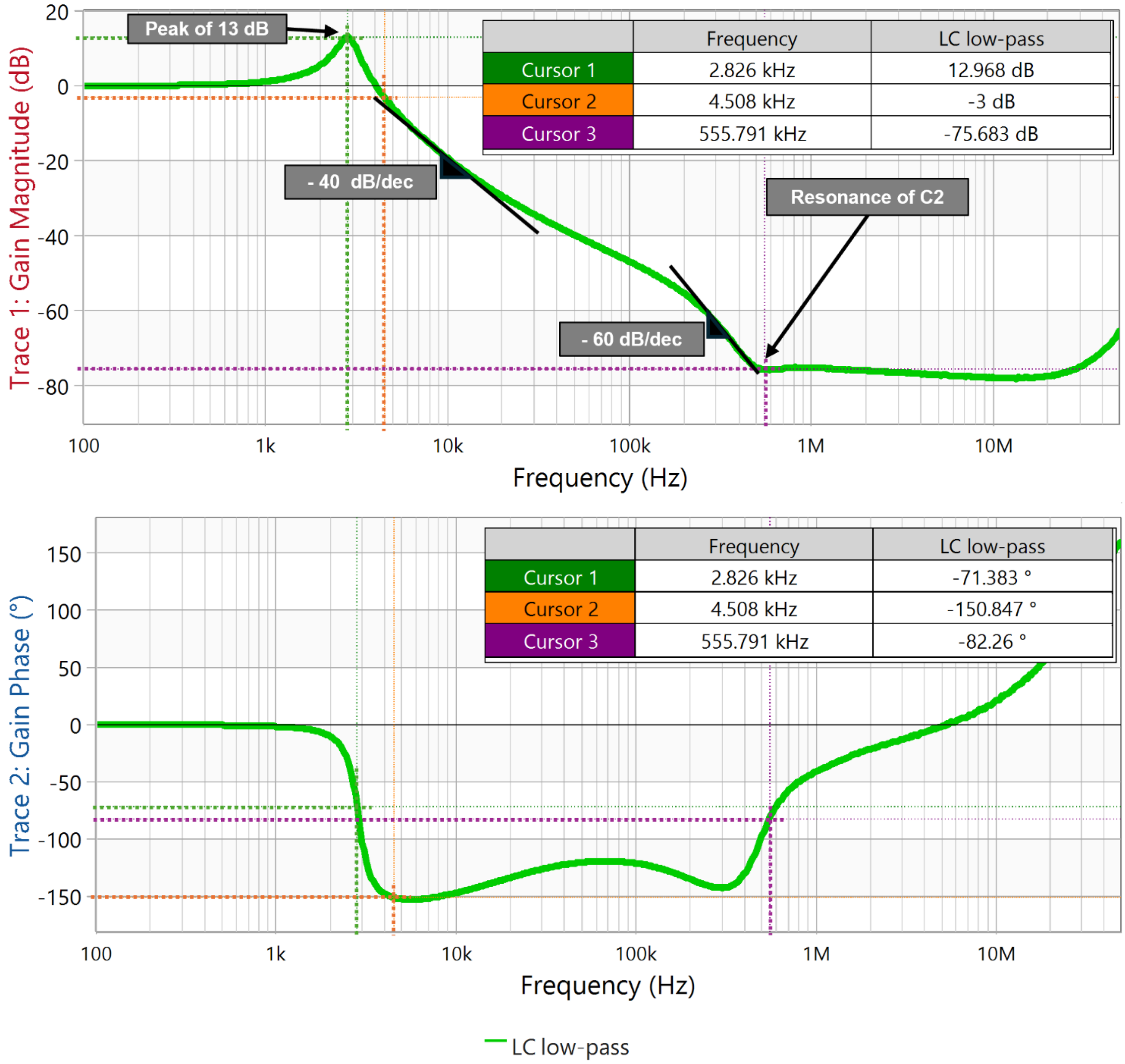
(a) Thru calibration

(b) Measurement setup

Figure 22: Calibration and measurement setup

5.2 Voltage Transfer Function Result

The Gain / Phase response of the LC low-pass filter transfer function in Figure 23 is presented in green.



	Frequency	LC low-pass
Cursor 1	2.826 kHz	12.968 dB
Cursor 2	4.508 kHz	-3 dB
Cursor 3	555.791 kHz	-75.683 dB

	Frequency	LC low-pass
Cursor 1	2.826 kHz	-71.383 °
Cursor 2	4.508 kHz	-150.847 °
Cursor 3	555.791 kHz	-82.26 °

Figure 23: LC low-pass filter gain and phase response.

Out of the curve, it is possible to notice the different slopes indicating the poles and zeros, which kick in at specific frequencies according to the impedance behavior of the components. The LC low-pass filter second-order behavior is highlighted as the slope of -40 dB/dec is presented. The peak of 13 dB at the first resonance frequency (2.83 kHz) as the effect of the electrolytic capacitor ESR takes effect. The pole of the ceramic capacitor comes into play with a slope of -60 dB/dec until about 555 kHz, which is the ceramic capacitor’s resonance frequency. Above 555 kHz, the inductive behavior of both capacitors flatters the gain curve at about -75 dB.

5.3 Comparison with the Simulation

BAS allows plotting gain and phase over frequency from a third-party simulation software (i.e. LTspice). It requires real vs frequency and imaginary vs frequency (x,y) data[9].

Opening the BAS, it will display the option **Clipboard→new memory** at the lower right-hand corner of the screen, as shown in Figure 24. Clicking on it, the data will be copied as a new memory trace to be plotted in the main window.

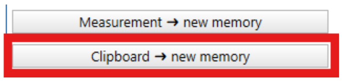
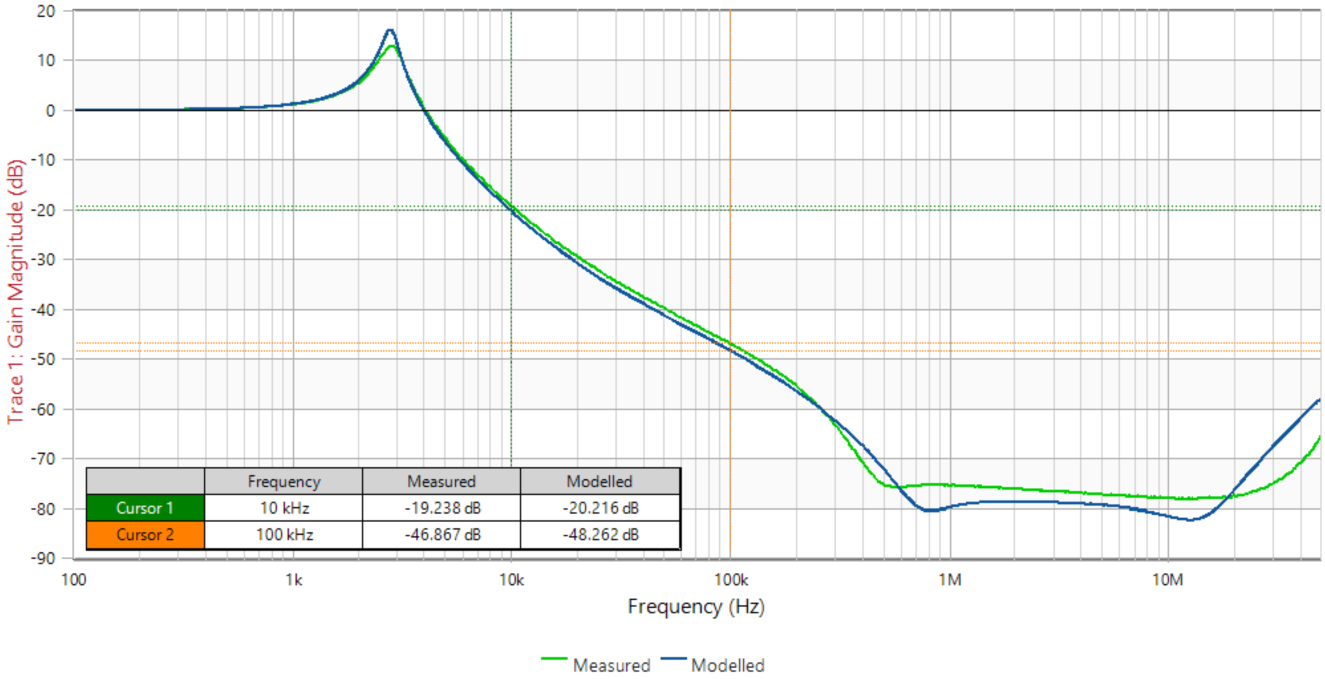


Figure 24: Paste data in BAS as a new memory.

Then, the two gain curves are shown simultaneously as presented in Figure 25.



	Frequency	Measured	Modelled
Cursor 1	10 kHz	-19.238 dB	-20.216 dB
Cursor 2	100 kHz	-46.867 dB	-48.262 dB

Figure 25: Measured vs modelled LC low-pass filter.

The comparison between the modelled and measured curves reveals close approximation at low frequencies. Specifically, at -3 dB, the measured filter frequency is 4.508 kHz, while the modelled frequency is 4.394 kHz. At 10 kHz, the gain difference is approximately 0.978 dB. This difference increases to 1.395 dB at 100 kHz. The growing discrepancy at higher frequencies indicates additional parasitic components.

The model in LTspice does not consider all intrinsic parasitics present in a real DUT. Factors such as copper traces, lead soldering material and the physical component placement add parasitic elements to the measurement such as resistances, inductances, and capacitances.

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[9] From section 4, it is possible to import the *.txt* file containing the data into Excel software and then edit it in three individual columns: frequency in Hz, real part, and imaginary part. Then, copy them in the clipboard (Ctrl + C).

Figure 26 illustrates the LTspice schematic of the filter, including an estimation of parasitic elements. These parasitics are approximated by using 8 nH of inductance and 10 mΩ of resistance per 10 mm of thin PCB trace.

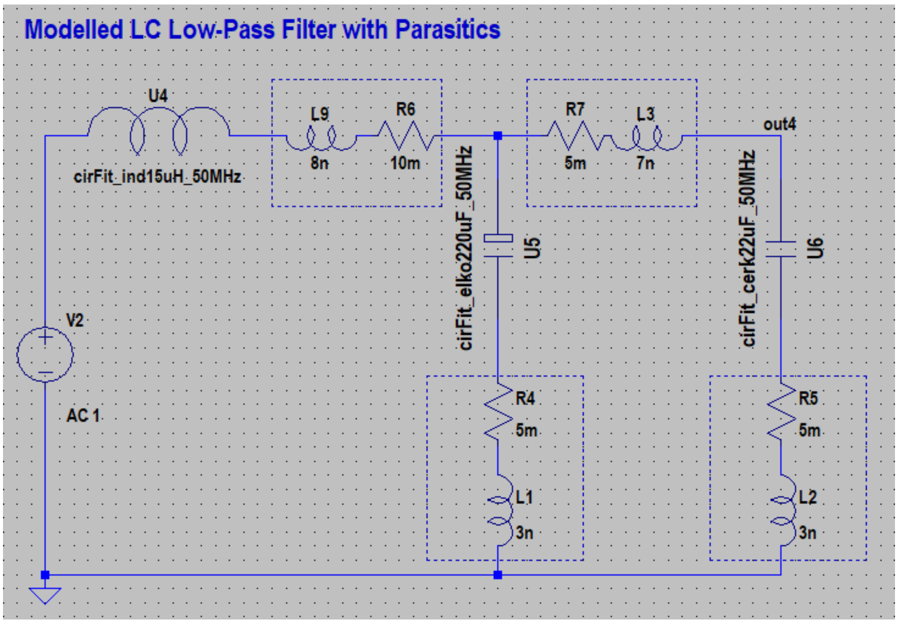

Figure 26: LTSpice model with parasitics.

The result is again exported to the BAS and plotted with the measured filter. Figure 27 represents the gain traces showing a better match between model and measurement.

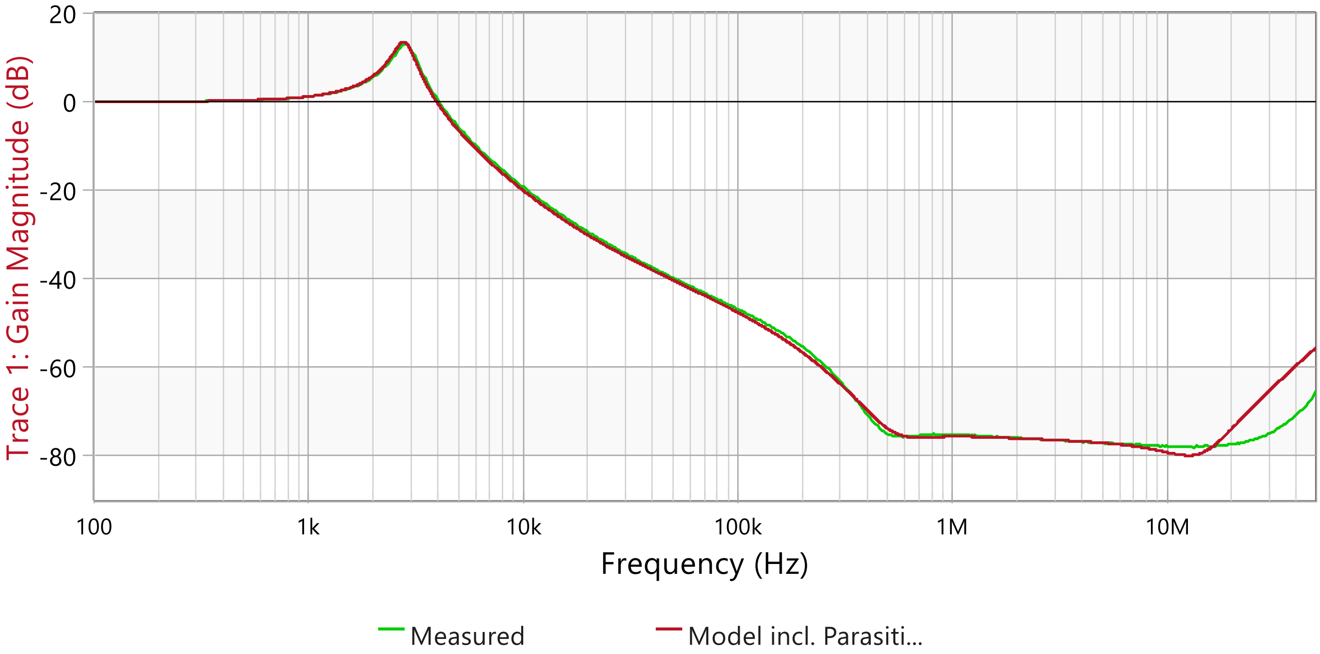

Figure 27: Measured LC low-pass filter vs modelled with parasitics.

6 Summary

This experiment measured and simulated the transfer function of an LC low-pass filter using the Bode 500 and the Circuit Fit feature of the BAS. Key components are modelled and exported as SPICE netlists for simulation.

Modeling components before building the filter offers significant advantages, including the early identification of issues, optimization of the design, and accurate performance prediction. The BAS Circuit Fit feature allows Network models to be calculated according to the desired RMSRE or number of poles. Despite thorough characterization, parasitic components in real assemblies have an additional impact on circuit performance.

The Bode 500 provides precise component characterization, and the BAS allows flexible data comparison, enhancing the accuracy and reliability of the filter design.

7 References

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