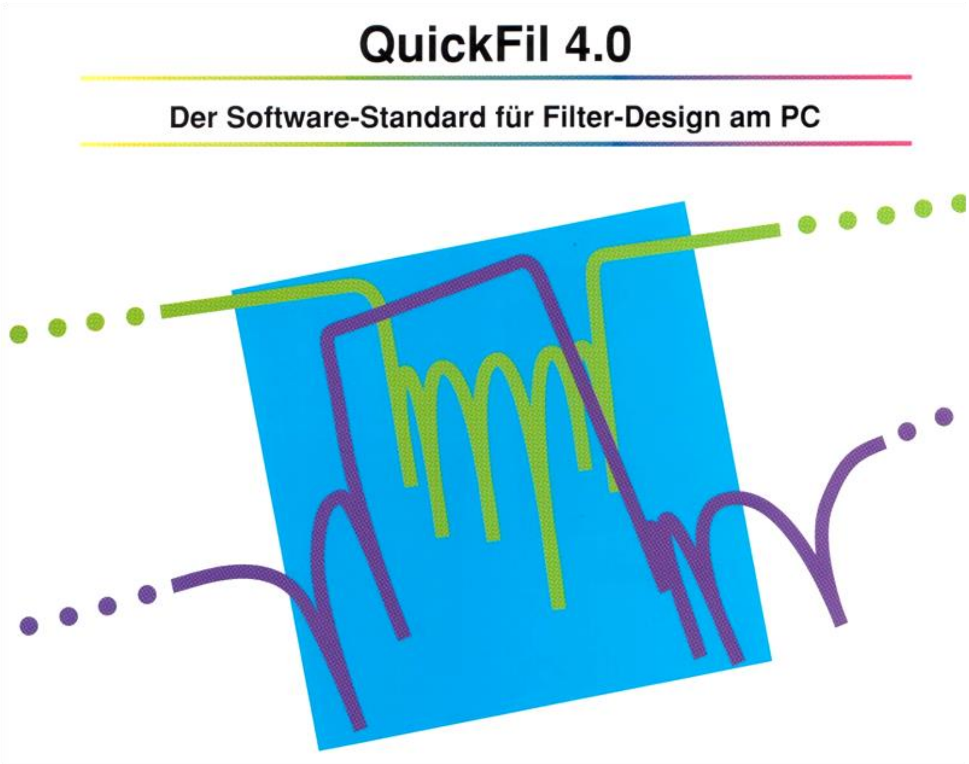
Bode 100 - Application Note

Passive Filter Design with QuickFil and Bode 100



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Visit www.omicron-lab.com for more information.
Contact support@omicron-lab.com for technical support.

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Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual. You can download the Bode 100 user manual at www.omicron-lab.com/bode-100/downloads#3

Note: All measurements in this application note have been performed with the Bode Analyzer Suite V3.23. Use this version or a higher version to perform the measurements shown in this document. You can download the latest version at www.omicron-lab.com/bode-100/downloads

1 Executive Summary

This application note targets the design and analysis of standard filter types such as high pass, low pass and band pass filters.

It is demonstrated how to design a passive bandpass filter using the freeware filter design software QuickFil[1].

The designed filter is realized using standard value components and the filter characteristics are then measured using the Bode 100.
Finally the measured filter characteristics are compared with the calculated values from QuickFil.

2 Task

A passive bandpass filter with the following characteristics shall be designed:

- Centre frequency: $f_c = 230\ \mathrm{kHz}$
- Passband bandwidth: $f_p = 10\% = 23\ \mathrm{kHz}$
- Passband loss $= 0.1\ \mathrm{dB}$
- Filter degree $n = 6$

The designed filter shall be built and the characteristics be measured. The measured characteristics will be compared with the theoretical values.

[1] More information at: https://www.omicron-lab.com/quickfil.html

3 Filter Design with QuickFil

3.1 About QuickFil

QuickFil is a software for designing passive electronic filters. QuickFil supports many types of filters and different approximations:

Types of Filters:

- Lowpass
- Highpass
- Bandpass
- Bandstop
- Allpass
- Asymmetric bandpass filters
- Parametric bandpass filters

Approximations:

- Butterworth (maximally-flat filters)
- Chebyshev (equal-ripple filter)
- Inverse Chebyshev
- Elliptic (Cauer)
- Bessel (maximally flat delay)
- Modified Bessel
- General Equal-ripple approximation
- General maximum-flat approximation

Note:
If you plan to run QuickFil on Windows 10 you have to use a small workaround. Details on this are described in the QuickFil Installation Guideline which is delivered within the QuickFil Folder.

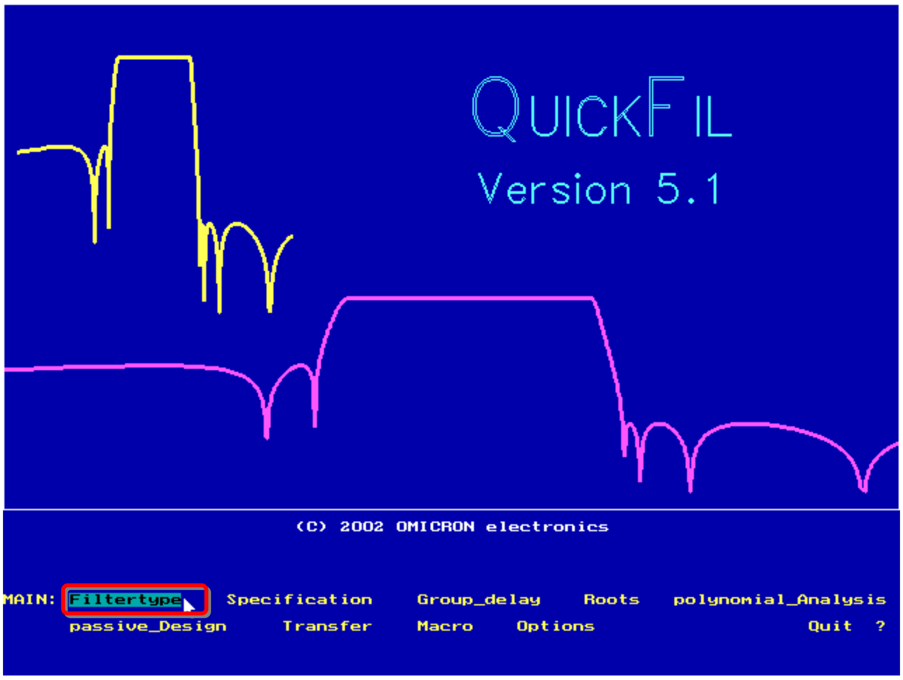
3.2 Bandpass Filter Design

The following chapters are structured like a step by step guideline on how to design a filter using QuickFil.

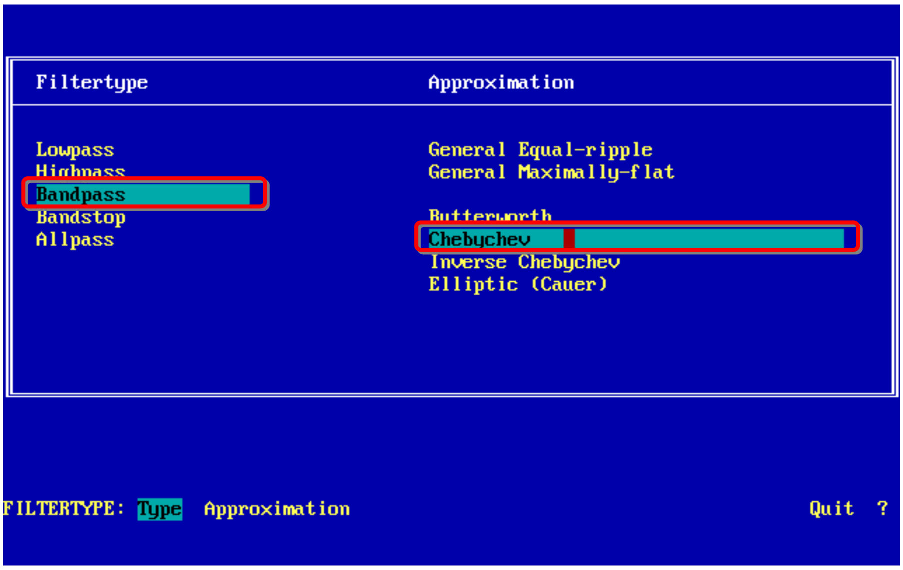
3.2.1 Filter Type and Specifications

The first step is to define the filter type and approximation. After starting QuickFil the main screen is shown. By clicking on <Filtertype> the type of filter and the approximation method can be chosen as shown in the following figures:

In the QuickFil Main screen the option <Filtertype> can be chosen:

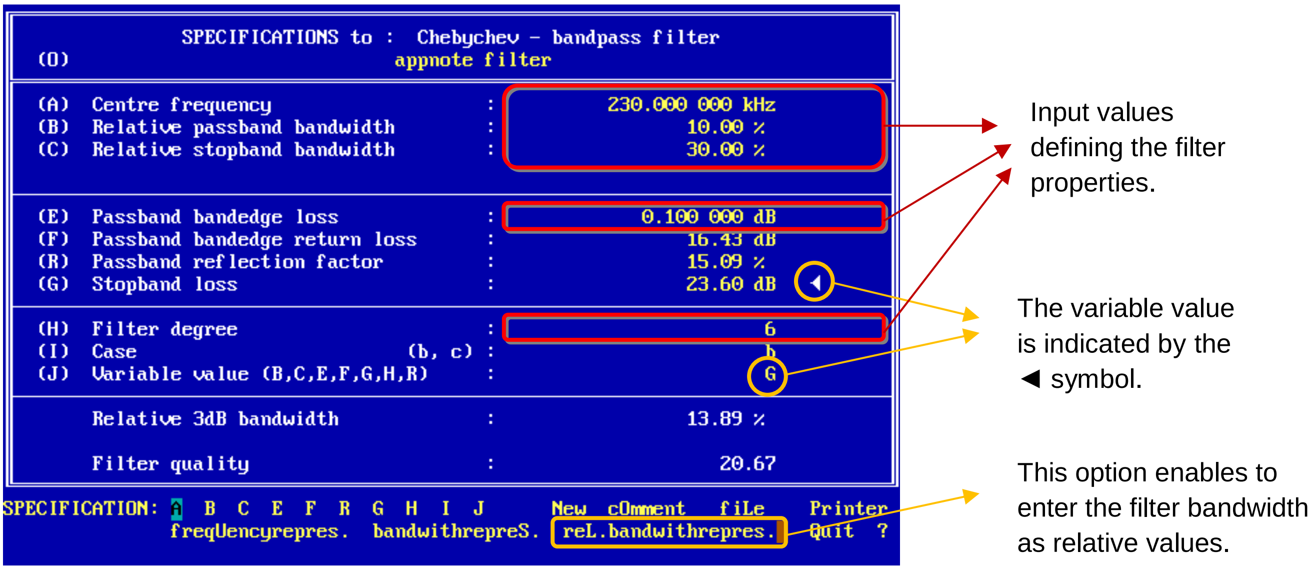


The Filtertype screen appears and the <Type> is set to <Bandpass> and the <Approximation > to <Chebychev>:



Note:
By clicking on <Quit> one can return to the main screen!

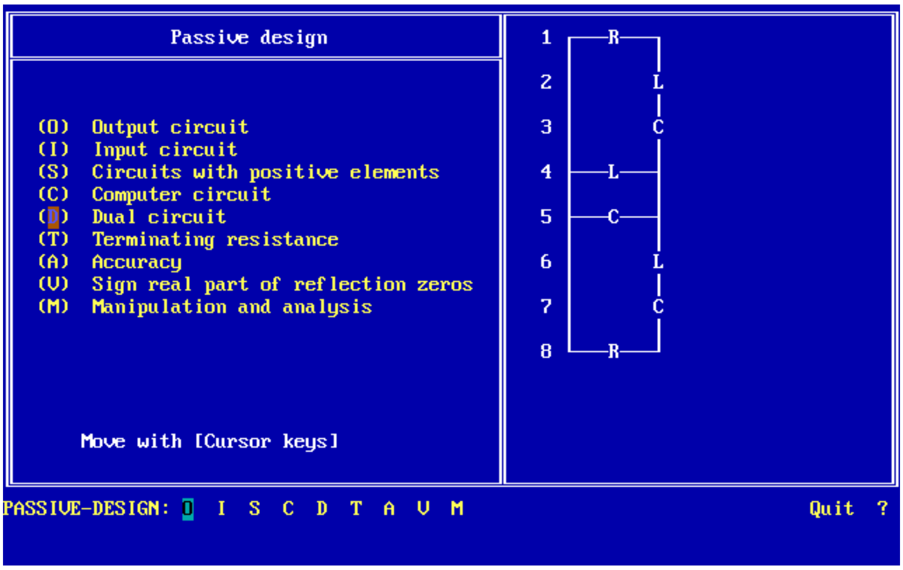
In the Main screen the <Specification> option can be chosen to enter the specification values which define the filter performance:



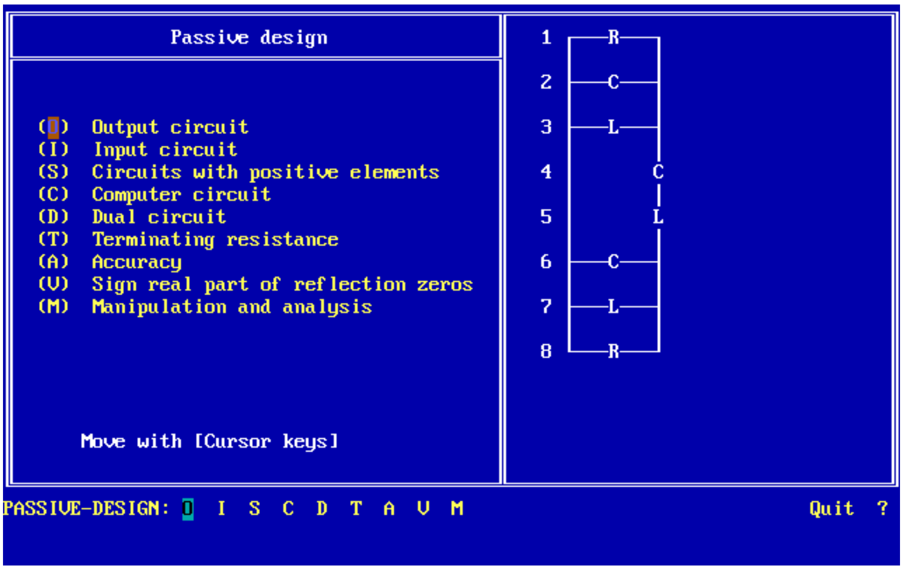
As described in the beginning of the document, a filter with a centre frequency of 230 kHz is defined. The relative passband bandiwdth is defined to be 10% and the relative stopband bandwidth is defined to be 30%.

By defining the <Stopband loss> to be the variable (changing) value the filter degree can be defined to be 6. This results in a calculated stopband loss of 23.6 dB.

<Quit> returns to the Main screen and by choosing the option <passive_Design> in the Main screen, QuickFil proposes the design and values for the passive filter defined in the specification screen:



By clicking on <Dual circuit> QuickFil calculates the component values for the dual design. In this case the dual design has some advantages for later circuit manipulation.



Choosing the option <Output circuit> shows the current design and the calculated component values:

```
appnote filter
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  1 ....R....          50.000 000 Ohm
    .       .
  2 ....C....         142.763 346 nF
    .       .
  3 ....L....           3.354 037 uH
    .       .
  4 .       C           1.206 170 nF
    .       .
  5 .       L         396.986 807 uH
    .       .
  6 ....C....         142.763 346 nF
    .       .
  7 ....L....           3.354 037 uH
    .       .
  8 ....R....          50.000 000 Ohm
```
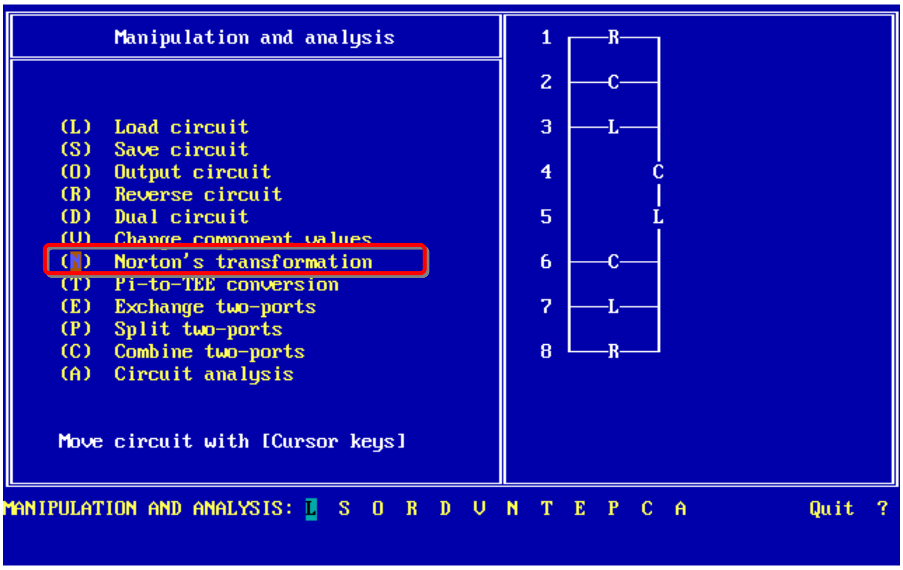

3.2.2 Circuit Manipulation

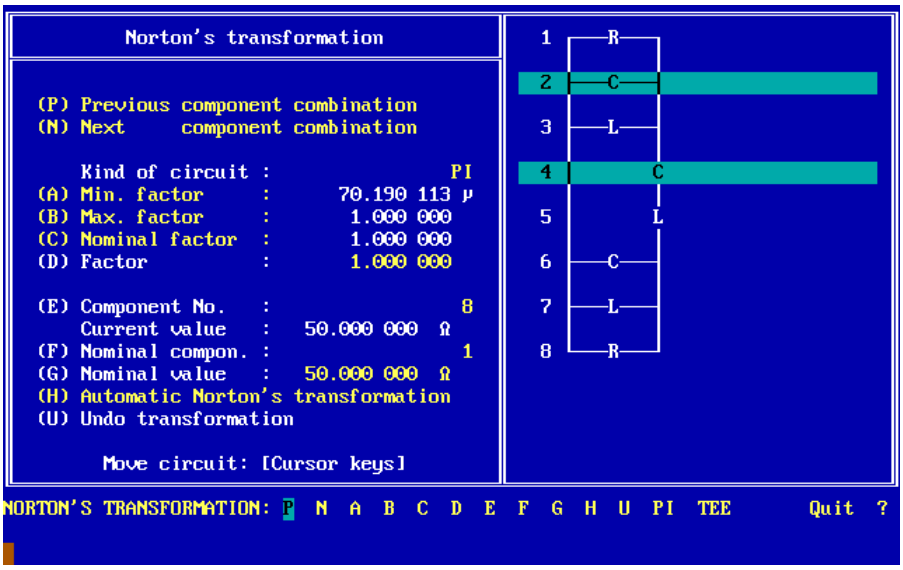
The default design proposed by QuickFil contains three inductors with two different inductance values ($L_3 = L_7 = 3.35\ \mu\mathrm{H}, L_5 = 397\ \mu\mathrm{H}$).

QuickFil offers a Norton's transformation functionality to modify component values without affecting the filter characteristics. In the following is explained how the filter can be modified to achieve three similar inductors.

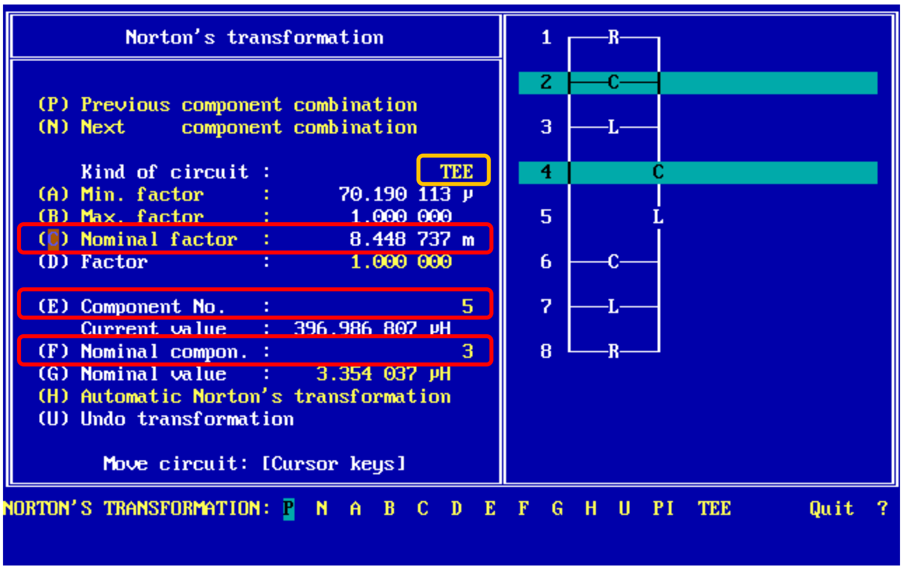
The Norton's transformation option can be found by first choosing the <Manipulation and analysis> option in the Passive design screen.



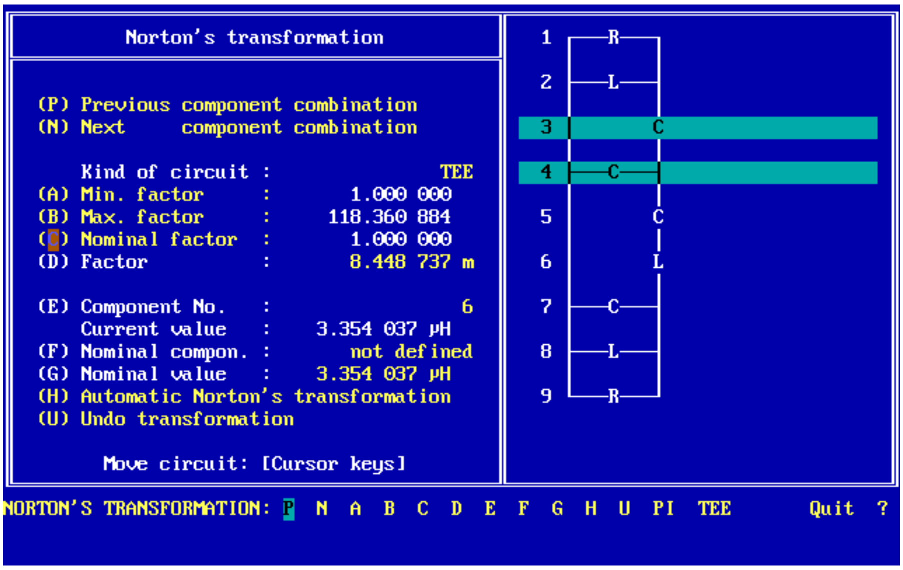
Choosing the <Norton's transformation> option opens the Norton's transformation screen:



The transformation always works from top to down. We now want to perform a transformation in a way that the inductor L5 gets the same inductance value as the inductor L3. This can be done by setting the <Component No.> to 5. This means that component No. 5 will be changed. Since we want the inductor L5 to have the same value as the inductor L3 the <Nominal compon.> has to be set to 3. QuickFil now calculates the transformation factor which is displayed in the <Nominal factor> field:

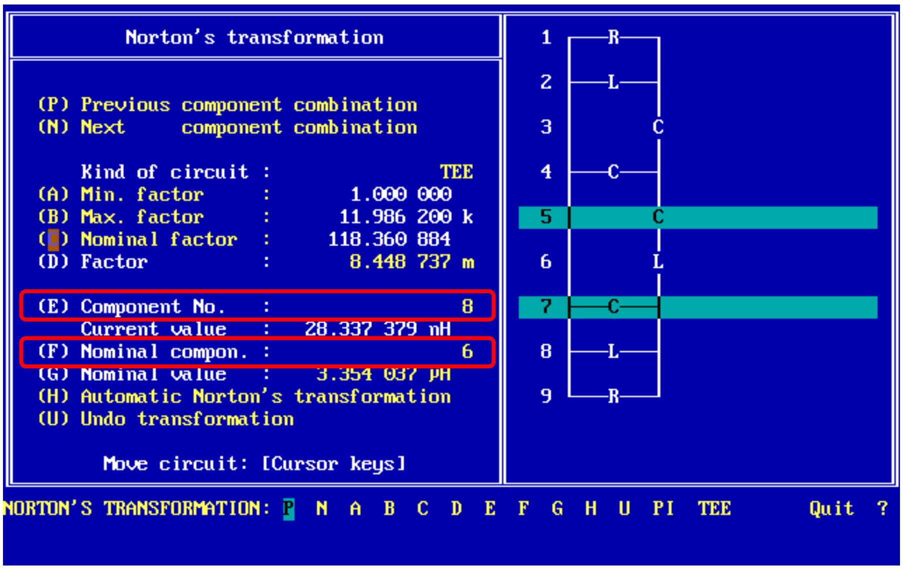


In addition the <Kind of circuit> is set to TEE as this gives a better structure for the second transformation.
The transformation now has to be made active by clicking on <Nominal factor>. This means that the calculated transformation factor is applied to the circuit. This leads to the following screen:



The first two inductors now have the same inductance value. The same transformation can be applied to the third inductor as follows.

Clicking two times on <Next component combination> marks the right components. Now the <Component No.> field is set to 8 as we want to change the value of the last inductor at position 8. The <Nominal compon.> value is set to 6 as we want the inductor 8 to have the same inductance value as the inductor 6.



Performing the transformation by clicking on <Nominal factor> leads to the final circuit design. The circuit and component values can be displayed by clicking on <Quit> and <Output circuit>:

```
appnote filter
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  1 ....R....         50.000 000 Ohm
    .       .
  2 ....L....          3.354 037 uH
    .       .
  3 .       C        157.213 986 nF
    .       .
  4 ....C....          1.553 177 uF
    .       .
  5 .       L          3.354 037 uH
    .       .
  6 .       C        171.371 516 nF
    .       .
  7 ....C....          1.553 177 uF
    .       .
  8 .       C        157.213 986 nF
    .       .
  9 ....L....          3.354 037 uH
    .       .
 10 ....R....         50.000 000 Ohm
```
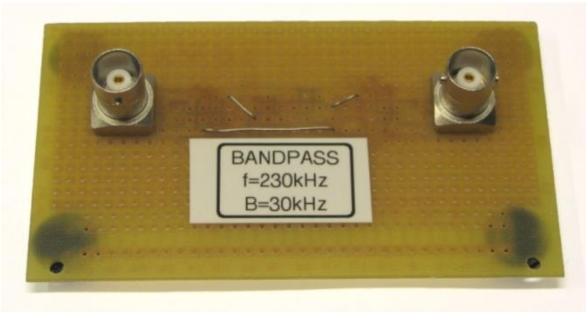
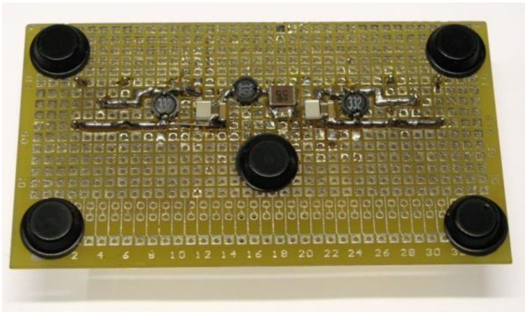

The three inductors now have the same inductance values which can be advantageous for the practical design.

The practical design is built using standard component values. The capacitance values were achieved by series and parallel combination of standard capacitors. The used component values are:

Component	Calculated Value	Used Value
L2, L5, L9	3.354 µH	3.3 µH
C3, C8	157.213 nF	158 nF
C4, C7	1.553 µF	1,55 µF
C6	171.371 nF	172 nF

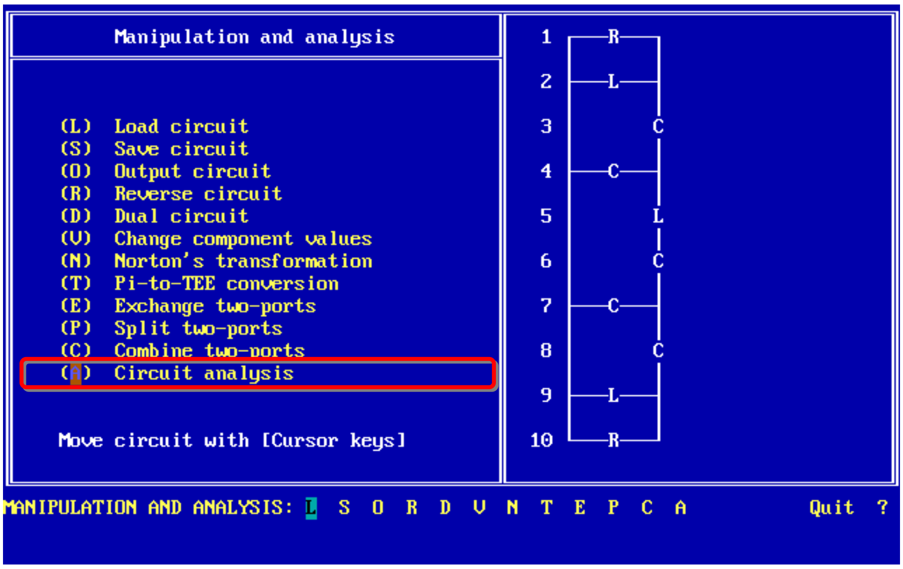
Assembled bandpass filter:



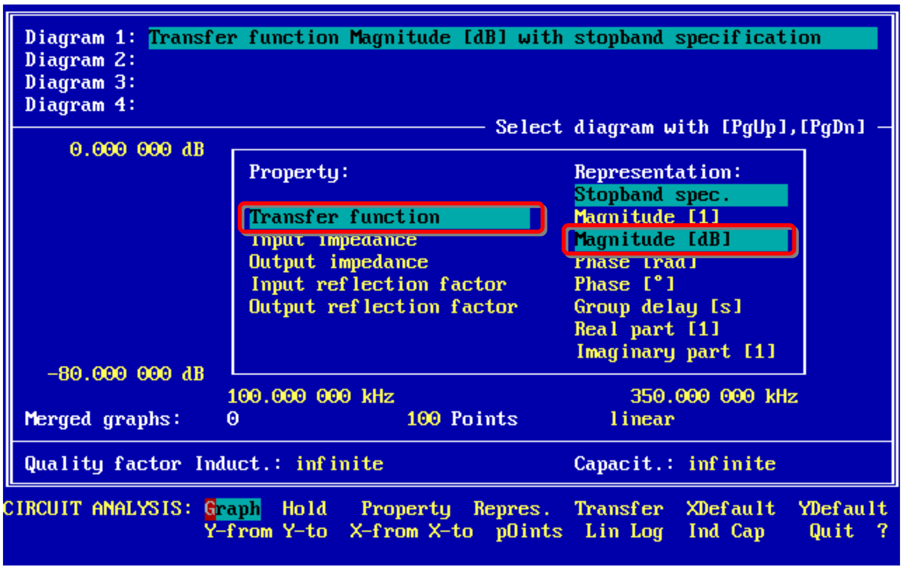


3.2.3 Circuit Analysis

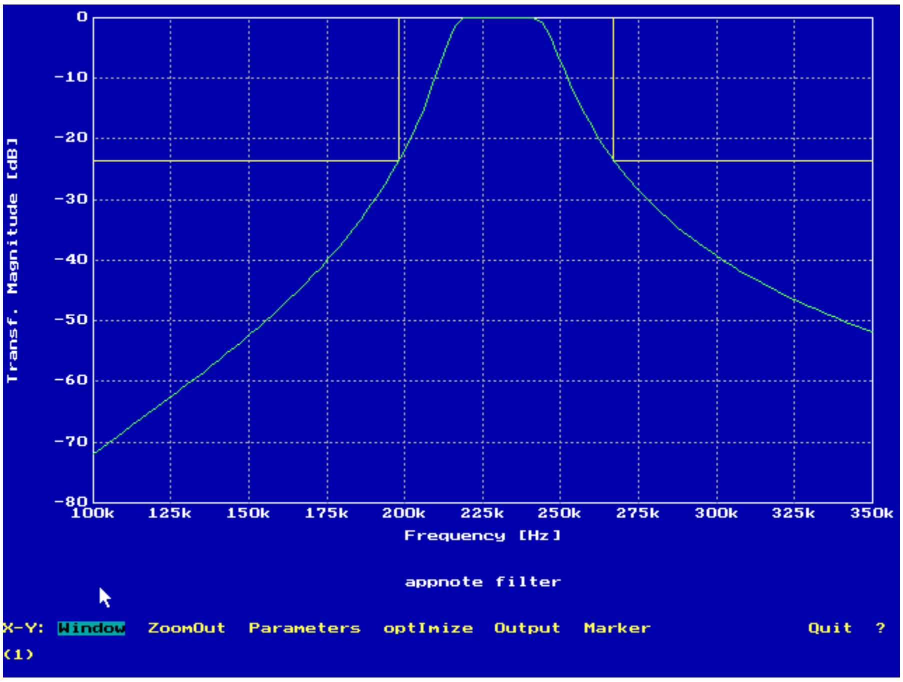
QuickFil offers tools to analyze the designed filter. In the Manipulation and Analysis screen the option <Circuit analysis> can be chosen.



In the Circuit Analysis screen the desired property and plot settings can be set.



Clicking on <Graph> starts the plot window and shows the transfer function as shown in the following figure.



4 Filter Measurement

The assembled bandpass filter transfer function shall be measured with the Bode 100. In the following is shown step by step how to configure and calibrate the Bode 100 for the filter measurement.

4.1 Device Setup

The transfer function of the bandpass filter can be measured in the Transmission / Reflection measurement type of the Bode Analyzer Suite.

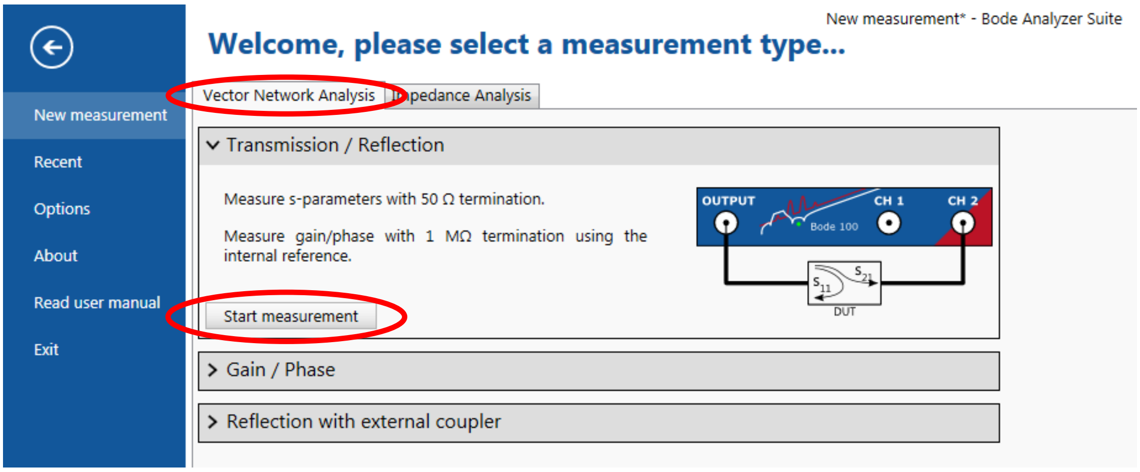


Figure 1: Start menu

We want to measure the magnitude and phase of the filter. Therefore trace 1 is set to Measurement Gain, Format Mag(dB) and trace 2 to Measurement Gain, Format phase(°) as shown in the following figures:

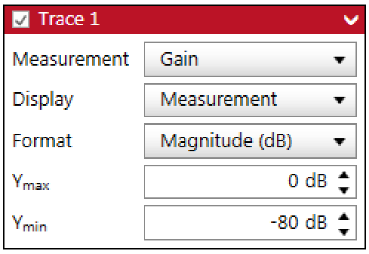


Figure 2: Settings Trace 1

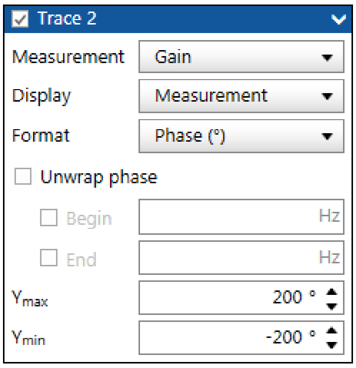


Figure 3: Settings Trace 2

Start and stop frequency are set to 100 kHz and 350 kHz. The attenuator for channel 1 to 0 dB and the attenuator for channel 2 to 10 dB. The receiver bandwidth is set to 30 Hz as in the following figure.

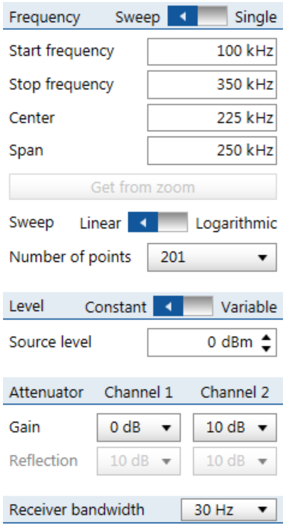


Figure 4: Frequency Settings

The Bode 100 is now ready to perform the measurement. To remove the influence of the connection cables on the measurement results it is advisable to perform a calibration before measuring the filter.

4.2 Calibration

A thru calibration removes the influence of the cables on the measurement. To do so, the two cables from output and channel 2 have to be connected together using the thru connector as shown in the picture below or in the Bode 100 user manual (https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/).

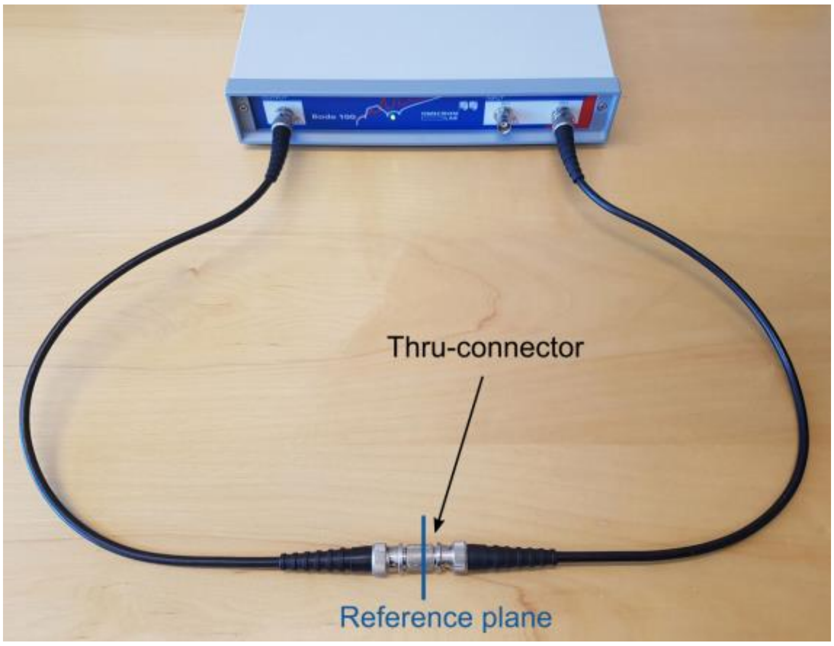


Figure 5: Calibration setup

After connecting the cable the thru calibration can be done by clicking on Gain calibration -> User Range.

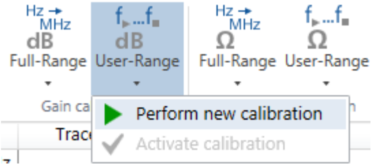


Figure 6: perform calibration

Start the calibration by pressing *Start*.

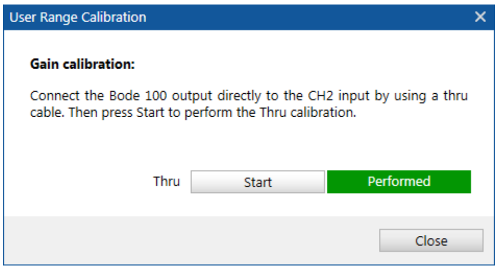


Figure 7: User Range Calibration window

4.3 Measurement

After performing the calibration, the thru connection is replaced by the bandpass filter as shown in the picture below.

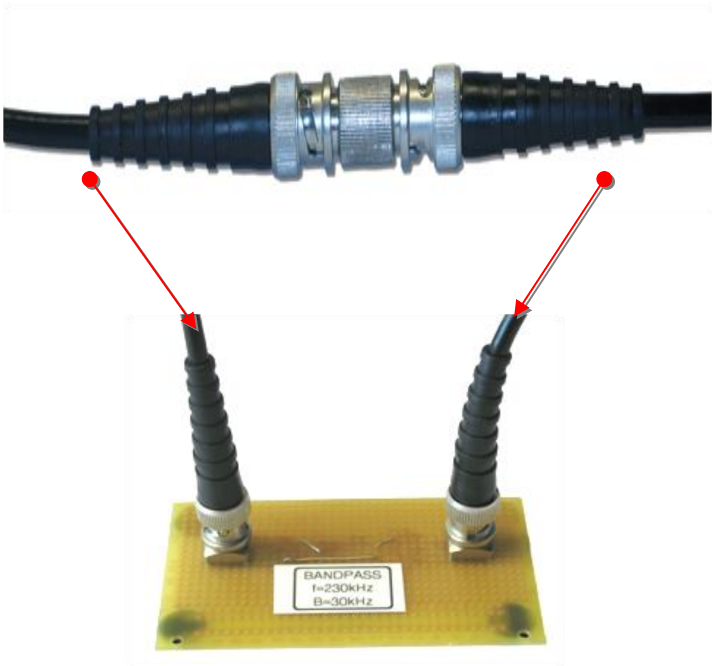


Figure 8: Measurement setup

Now the measurement can be started by pressing the single sweep button.

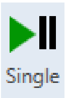


Figure 9: single sweep button

5 Results

Performing the measurement described above leads to results as shown below. The first graph shows the amplitude gain in decibel and the second graph the phase in degree.

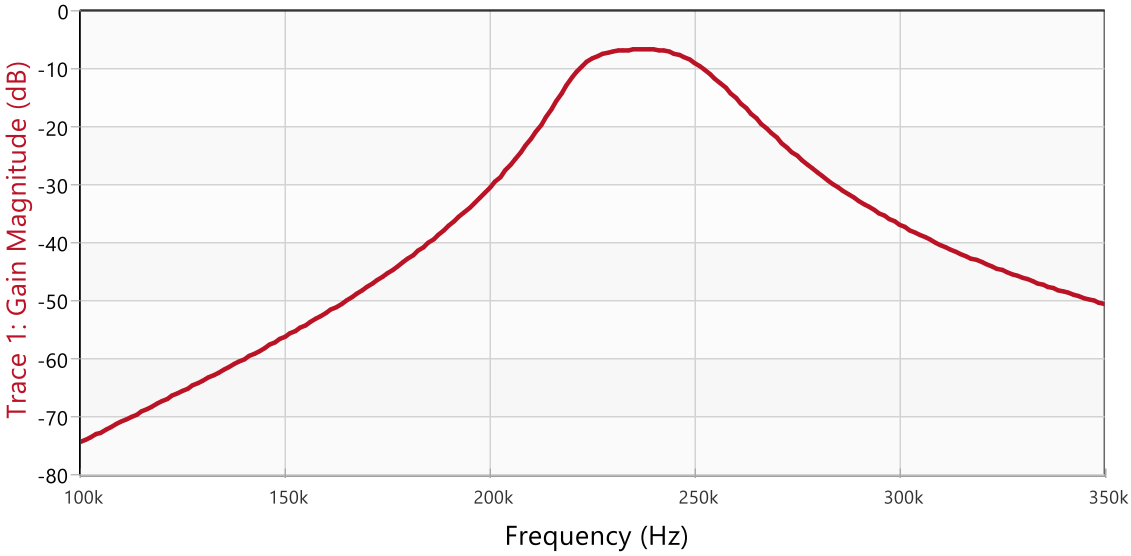


Figure 10: Measurement result - Magnitude (dB)

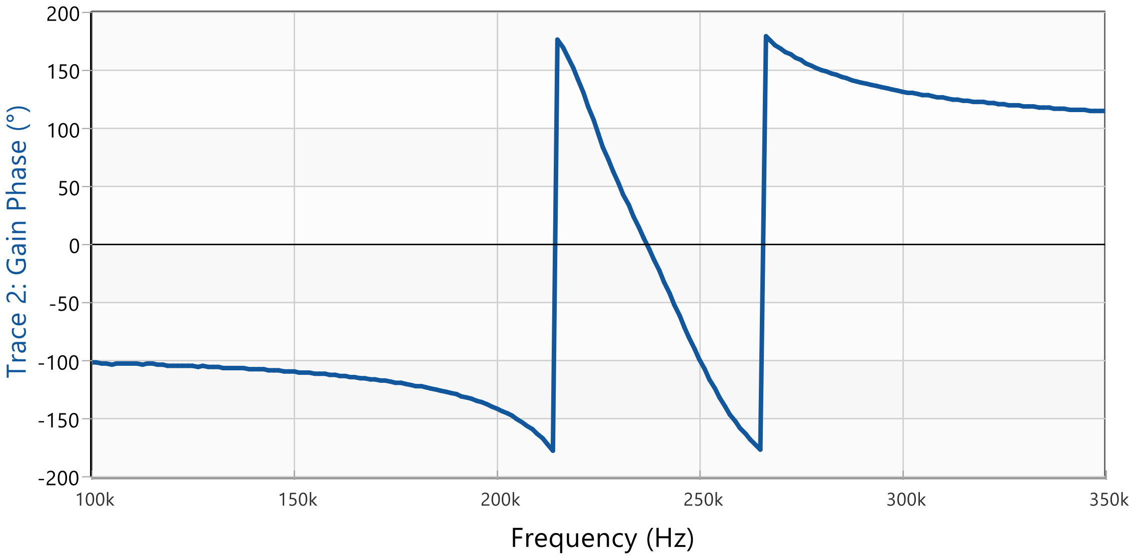
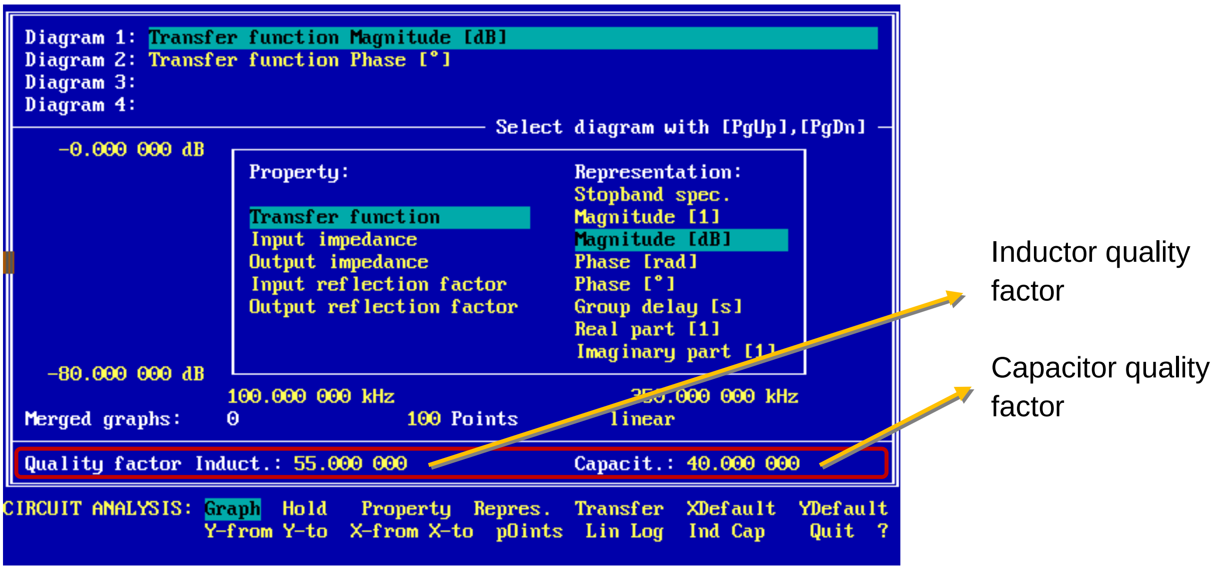


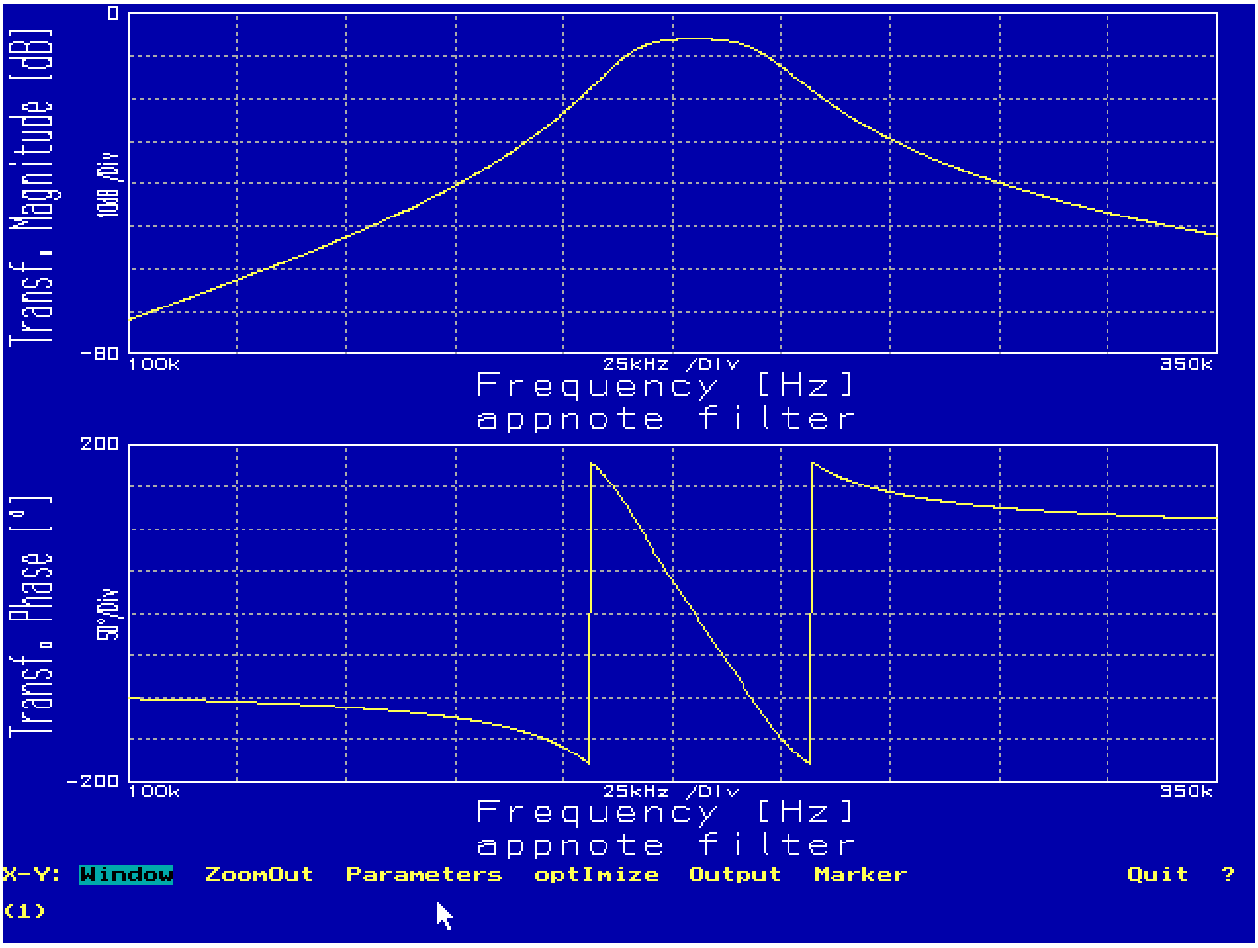
Figure 11: Measurement result - Phase (°)

Comparing these results with the calculations in QuickFil shows that the passband loss is higher than calculated. The reason for this are the limited quality factors of the components used to assemble the filter.
QuickFil offers a feature to estimate this influence. In the circuit analysis screen are input fields for the inductor quality factor and the capacitor quality factor. The components used for the assembled filter have an approximate quality factor of
Inductors: $Q \approx 55$
Capacitor combinations: $Q \approx 40$

The figure below shows how the quality factors are entered into QuickFil.

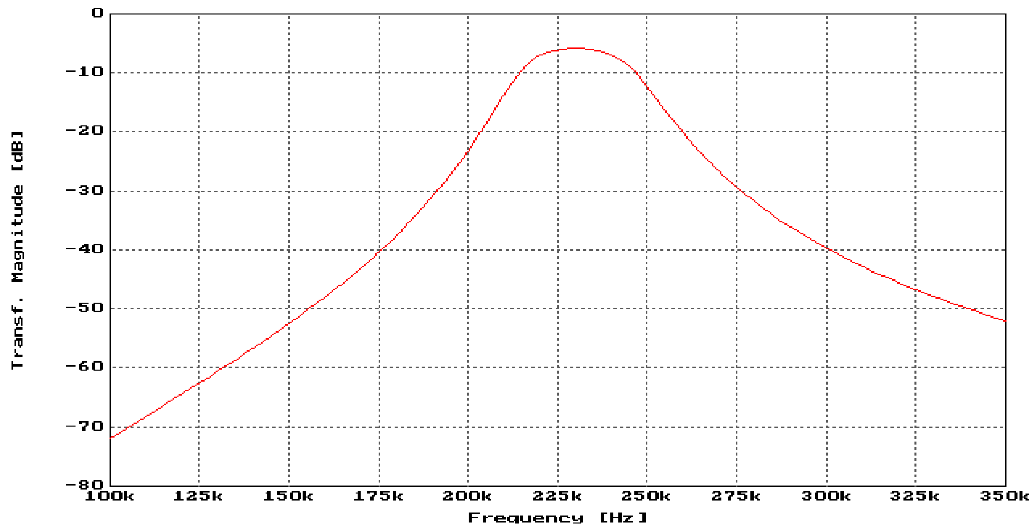


When considering the quality factors of the components the calculated transfer characteristic results as shown in the following graph:

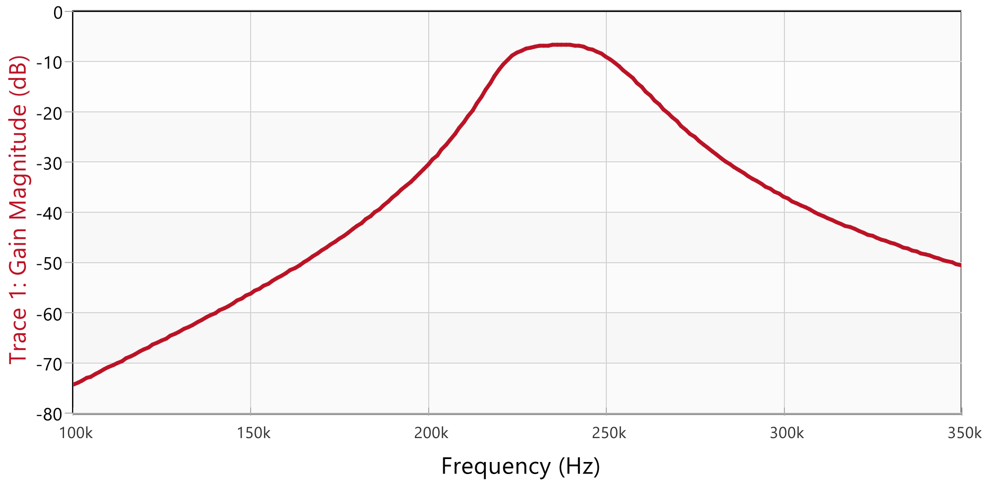


On the next page there is a direct comparison between measured and calculated data where the quality factors are taken into consideration

Calculated gain magnitude in dB:



Measured gain magnitude in dB:



6 Conclusion

The first part of this application note shows how to design passive filters using the filter design software QuickFil. QuickFil offers many functions for passive filter design e.g. Norton's transformation to optimize the filter design.

The second part of the application note shows how to measure the filter characteristics of the designed bandpass filter using the Bode 100. It is shown how to terminate the filter correctly using the internal 50 Ohm resistance of the Bode 100.

The measured and calculated results match very well when the quality factors of the used components are considered for the calculation of the transfer function. It is therefore very important to have high quality components for the passive filter design.

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