Pickup Wizard

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The present article shows how the impedance of electromagnetic guitar pickups can be measured using a regular sound card in comination with a simple passive measurement adapter. If reduced accuracy is acceptable the pickup can even remain mounted on the guitar. The article also describes the automatic estimation of the parameters of an equivalent-circuit model for the pickup, as well as the calculation of the pickup's frequency response. All associated steps and processes are implemented via a GUI driven script designated "Pickup Wizard". It requires MATLAB® or GNU Octave as an interpreter. GNU Octave (https://www.gnu.org/software/octave) is an open-source alternative to the well-known commercial software MATLAB®. The "Pickup Wizard" script is available free of charge from the GITEC homepage. Underlying theory is discussed in order to prove the validity of the process. Advice for putting together the measurement adaptor as well as a user manual for "Pickup Wizard" are provided for those who seek not to deep-dive into theory but simply want to measure and view the results.

1. Introduction

Many guitarists are interested in the frequency response of the electromagnetic guitar pickups on their guitars. However, the required impedance measurements, parameter estimations, and frequency response calculations typically require instrumentation and knowledge not necessarily available to most guitarists. The present paper will show that with merely a regular computer equipped with a normal sound card, the objective of measuring the pickup at hand can be met when running a script designated "Pickup Wizard", and operating in conjunction with a simple passive "do it your self" measurement adaptor, Moreover, the theoretical background of the complete process will also be provided in the following. Those not interested in the theory and just wanting to put the Pickup Wizard to good use may skip ahead to Section 6 below. The measurement process starts with assessing the impedance using an regular sound card in conjunction with the measurement adapter. Further steps estimate the pickup parameters, store them in a database, and calculate the pickup's frequency responses for different load scenarios.

2. Theory of the impedance measurement

The circuit diagram of the measurement setup for the impedance measurement is shown in **Fig. 1**. A sound card generates the test voltage U_0 and simultaneously records the voltages U_1 and U_2 at its two input channels. The latter have the input impedance Z_{1S} and Z_{2S}. The capacities of the cables between the the sound card inputs and the measurement adaptor are connected in parallel to the input impedances. The impedances of these parallel connections are Z_1 and Z_2. A sensing impedance Z_s is used to measure the current flowing into the impedances Z and Z_2. Z is the impedance to be measured. The sensing impedance Z_s is assumed as a parallel connection of a known resistance R_s, and an unknown capacity C_s. The absolute values of source impedance Z_0 are assumed to be about ten thousand times smaller than the absolute values of Z_s, Z_1 and Z_2. The voltage drop across Z_0 is therefore negligible for the present considerations. We assume that Z_2 is a parallel connection of two impedances: an unknown capacity C_i, and a series connection of an unknown capacity C_{DC} and an unknown resistance R_i.

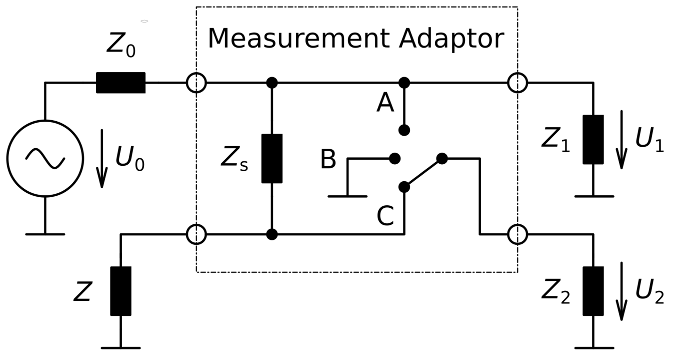


Fig. 1: Impedance measurement setup

The test signal used by the Pickup Wizard is a log-sine sweep, i.e. the logarithm of the frequency of the sinusoidal test signal increases linear over time. The duration of one such sweep is 3 s; it runs from a start-frequency of 16 Hz to a stop-frequency of 22 kHz. In order to avoid broadband transients, fade-in/out sections with a length of 25 ms are included at the beginning and at the end of the sweep. The spectrum of this signal is pink in the frequency range from 20 Hz to 20 kHz. The sample rate of the sound card is set to 48 kHz.

The Pickup Wizard generates a sequence of n_s sweeps for one measurement. The pause between the sweeps is 1 s + t_d. The extra time difference t_d is set to 12.354 ms or 10.292 ms, depending on the local power supply system: t_d is the duration of a 50-Hz- or 60-Hz-cycle divided by the golden ratio, and quantized with the sample interval. The hum-canceling effect across all hum-harmonics therefore is optimal if an averaging over n_s sweeps is done. There is also a pause of 1 s head of the first sweep to ensure that potential transients generated by the sound card at the start of playback and recording cannot influence the measurement. The response to the n_s sweeps is recorded on both input channels. The time domain signals are averaged over the n_s sweeps. This averaging can be used to improve the signal to noise ratio and at the same time also to reduce hum interference generated by power supplies as already mentioned above.

The first 4 s of the averaged time-domain signal are transformed into the frequency domain via a 19200 point DFT. We obtain the two complex spectra U_1 and U_2 in this first step. The ratio of U_2 to U_1 denotes the transfer function from input 1 to input 2; it is calculated in a second step. If so selected by the user, a spectral hum suppression is performed in a third step. In this case, the transfer-function values in the vicinity (± 10 bins) of the first 39 harmonics of the powerline frequencies are not used. Instead, a linear interpolation between the nearest “hum free” bins is used for these values. In a fourth step, the transfer function is resampled with equidistant values on the logarithmic frequency scale. We use 120 frequency points per decade and finally obtain 361 frequency points with corresponding transfer-function values covering the frequency range from 20 Hz and 20 kHz.

The application of a resampling process has two reasons. First, the signal-to-noise ratio becomes independent of frequency. Without resampling the signal to noise ratio would decrease with frequency due to the pink spectrum of the test signal. Second, the magnitudes of the expected transfer functions can be approximated by straight lines only in a double logarithmic scale.

For a necessary sound-card calibration, we set the rotary switch of the measurement adaptor to position A. Now both sound card inputs should receive the same input voltage. Due to different gains and frequency responses of the two inputs the recorded voltages U_{1cal} and U_{2cal} might however differ. We calculate and store the transfer function H_{cal} in order to compensate these differences during the impedance measurement.

$$H_{cal}=\frac{U_{2\,cal}}{U_{1\,cal}} \tag{1}$$

During a regular impedance measurement, we set the rotary switch of the measurement adaptor to position C. The measured impedance Z_m is now obtained:

$$Z_m=\frac{Z\,Z_2}{Z+Z_2}\cdot\left(1+s\,R_s C_s\right)=R_s\cdot\frac{\dfrac{U_2}{U_1 H_{cal}}}{1-\dfrac{U_2}{U_1 H_{cal}}} \tag{2}$$

Wherein:

$$Z_2=\frac{1}{s\cdot\left(C_{DC}+C_i\right)}\cdot\frac{\left(1+s\,R_i C_{DC}\right)}{1+s\,R_i\cdot\dfrac{C_i\cdot C_{DC}}{C_i+C_{DC}}} \tag{3}$$

Note that *s* is the imaginary angular frequency defined as:

$$s=\mathrm{j}\cdot 2\pi f \tag{4}$$

and that j is the imaginary unit and *f* is the frequency.

If we measure the impedance of the setup with *Z* removed, we will obtain:

$$Z_{cal}=Z_2\cdot\left(1+s\,R_s C_s\right). \tag{5}$$

If we use a cable between *Z* and the measurement adaptor during regular impedance measurements this cable must remain connected but *Z* must still be removed during the measurement of Z_{cal}. In this case C_i is the sum of the sound card input capacity, the capacity of the cable to input 2 and the capacity of the cable to Z.

We can now finally calculate *Z* using (2) and (5) with:

$$Z=\frac{Z_2\cdot\dfrac{Z_m}{1+s\,R_s C_s}}{Z_2-\dfrac{Z_m}{1+s\,R_s C_s}}=\frac{Z_{cal}\,Z_m}{Z_{cal}-Z_m} \tag{6}$$

This means that Z could be calculated with only Z_m and Z_{cal}. We do not need to know the four parameters C_s, R_i, C_i and C_{DC}. However, they can be obtained by approximating the measured Z_{cal} with the model of Z_{cal}. The four parameters are required anyway to solve (11). For the sake of simplicity, we never use the measured Z_{cal} directly but always its approximation by model parameters.

If a reduced measurement accuracy is acceptable, and if the pickup is mounted on a passive electric guitar, the pickup may stay in the unmodified guitar during the impedance measurement. In this case there is an additional load Z_g parallel to Z_2. We assume that Z_g is a parallel connection of two impedances. The first one is the resistance of the volume potentiometer R_v ,and the second one is a series connection of the tone capacitor C_t and the resistance of the tone potentiometer R_t.

For many guitar types R_v can be determined jointly with the pickup DC resistance R_0 in the unmodified guitar. This procedure has already been described in [1]. The DC resistance at the output port of the guitar is measured at full volume setting as R_{full}, and a second time at a volume setting were the highest DC resistance, R_{max}, occurs. We can now calculate R_v and R_0:

$$R_v = 2 \cdot \left(R_{max} + \sqrt{R_{max}^2 - R_{max} R_{full}} \right) \tag{7}$$

$$R_0 = 2 \cdot \left(R_{max} - \sqrt{R_{max}^2 - R_{max} R_{full}} \right) \tag{8}$$

R_t can be measured directly if the guitar circuit is accessible.

C_t cannot be measured while the capacitor is fitted to the guitar circuit. However, its nominal value may be read from the marking on the capacitor, or it can be derived from the circuit diagram of the guitar. Since its value has only a minor impact on the accuracy of the impedance measurement, it is acceptable to work with the nominal instead of its real value. The latter typicall differs more or less from the nominal value due to production tolerances.

Compared to the influence of the value C_t, the impact of R_v and R_t on the accuracy of the impedance measurement is much higher. Since the tolerances of the resistance of potentiometers can be up to ± 30 %, the nominal value should only be used if the measurement of the real values is not possible.

There is also a small additional capacity C_g in the guitar which is connected in parallel to Z. We cannot measure C_g in the unmodified guitar, and thus assume that it is a part of the pickup capacity C_0.

We obtain:

$$Z_g = \frac{R_v R_t}{R_t + R_v \cdot \dfrac{s R_t C_t}{1 + s R_t C_t}} \tag{9}$$

$$Z_p = \frac{Z_2 Z_g}{Z_2 + Z_g} \tag{10}$$

Finally, we can calculate Z of the pickup itself:

$$Z = \frac{Z_p \cdot \dfrac{Z_\mathrm{m}}{1+s R_\mathrm{s} C_\mathrm{s}}}{Z_p - \dfrac{Z_\mathrm{m}}{1+s R_\mathrm{s} C_\mathrm{s}}} \tag{11}$$

If the crosstalk from input 1 to input 2 of the soundcard exceeds about -90 dB it might have a negative impact on the accuracy of the impedance measurement. With a crosstalk compensation, however, even soundcards with a poor crosstalk performance can be used for accurate impedance measurements.

For the measurement of the crosstalk H_cross, we set the rotary switch of the measurement adaptor to position B. We obtain:

$$H_\mathrm{cross} = \frac{U_{2\,\mathrm{cross}}}{U_{1\,\mathrm{cross}} H_\mathrm{cal}} \tag{12}$$

For Z_m with crosstalk compensation we obtain:

$$Z_\mathrm{m} = R_\mathrm{s} \cdot \frac{\dfrac{U_2}{U_1 H_\mathrm{cal}} - H_\mathrm{cross}}{1 - \dfrac{U_2}{U_1 H_\mathrm{cal}} + H_\mathrm{cross}} \tag{13}$$

3. Theory of the pickup model

In principle, the electromagnetic guitar pickup is a coil wound around a permanent magnet. A small part of the ferromagnetic string is magnetized in the vicinity of the pickup by the static magnetic field of the pickup. When the string moves, the magnetic flux in the coil changes. The voltage U induced in the coil is proportional to the time derivative of the magnetic flux, and thus to the velocity V_0 of the string at the pickup position.

$$U = k_\mathrm{v} V_0 \tag{14}$$

The coil can be modeled as a series connection of an inductance L_0 and a resistance R_0. The inductance L_0 is proportional to the square of the number of the coil windings, the relative permeability of the magnetic core, the square of the coil diameter, and the reciprocal of the coil height. The resistance R_0 is determined by the length, diameter and conductivity of the coil wire. Connected in parallel to the above coil model, we must also assume a capacity C_0 which represents the capacitive coupling between the coil windings. The equivalent circuit model described so far is only valid if magnetic losses in the magnetic core are negligible.

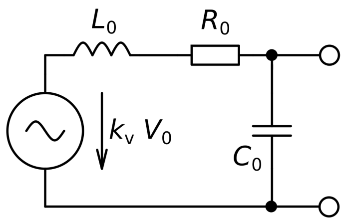


Fig. 2. The equivalent circuit model of electromagnetic pickups without magnetic losses

If there are significant magnetic losses in the magnetic core the inductance of the coil becomes a complex function, and depends on frequency. Thus, L_0 needs to be replaced by an equivalent circuit which approximates the real-world behavior of the coil with sufficient accuracy. As a reasonable approximation, a model with a series connection of n sub-coils is described in [2]. Each sub coil is a parallel connection of an inductance L_i, and a resistance R_i which represents the ferromagnetic losses.

We define the sum of the inductances of all sub-coils as L_0. This definition will help us to understand the differences between a real pickup, and a similar virtual pickup without magnetic losses.

$$L_0 = \sum_{i=1}^{n} L_i \tag{15}$$

The equivalent circuit described above is well known from the approximation of the skin effect of conductors in the radio frequency (RF) range. In [2], the term skin effect is, however, used to describe the frequency-dependent losses in magnetic cores depending on their geometric properties. This is a different effect and should not be confused with the well-known RF skin effect even if there are some similarities between both effects, and even if both effects can be described with the Maxwell equations.

The voltage induced in the equivalent circuit of L_0 is not strictly proportional to the string velocity anymore. A part of the magnetic flux change is absorbed as magnetic losses, and thus the induced voltage at the output terminals of the pickup will be reduced. The reduction factor depends on frequency. The following equivalent circuit model describes the real-world behavior with sufficient accuracy.

Here, a current source is used instead of a voltage source. This current source is connected in parallel with the series connection of the sub-coils. The current I of the current source is proportional to the string velocity divided by the (imaginary) angular frequency s as defined in (2) and L_0. This means that the current is proportional to the magnetic flux but not to its time derivative. The part of I which flows through an inductance of the sub-coils still induces a voltage proportional to the time derivative of the magnetic flux. Conversely, the part of I which flows through a parallel resistance of the sub-coils only causes a voltage drop proportional to the magnetic flux. Thus, with increasing frequency the energy absorption in the parallel resistances increases, as well, and it reduces the magnitude of the time derivative of the magnetic flux which is relevant for the well-known induction law.

$$I = \frac{k_v V_0}{s L_0} \tag{16}$$

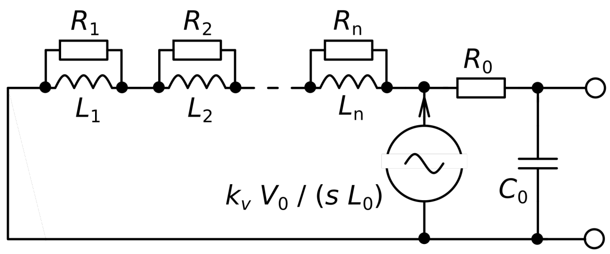


Fig. 3. The equivalent circuit model of electromagnetic pickups with magnetic losses

For the impedance Z at the output port of the pickup we finally obtain:

$$Z = \frac{(R_0 + Z_c) \cdot \frac{1}{s C_0}}{(R_0 + Z_c) + \frac{1}{s C_0}} \tag{17}$$

With:

$$Z_c = \sum_{i=1}^{n} \frac{s L_i}{1 + s \frac{L_i}{R_i}} \tag{18}$$

4. Theory of the estimation of circuit model parameters

In the present article paper we seek to estimate the parameters of an equivalent circuit model for two purposes. First, there is the estimation of the Z_{cal}-parameters, and second we require the estimation of the pickup impedance parameters which are necessary for the calculation of the pickup’s frequency response. In both cases we have a set of complex measurement values measured at a set of frequencies. In other words, we have the measured transfer functions of Z_{cal} or Z. We also have a parametric model description of Z_{cal} and Z with (5) and (15).

We can calculate the gain error ΔG between the model transfer function H_{model} and the measured transfer function H_{meas} with:

$$\Delta G = 20 \log_{10} \frac{H_{model}}{H_{meas}} \tag{19}$$

Note that ΔG is complex. Its real part contains the magnitude error, and its imaginary part contains the phase error. A phase error of 0.1 degree results in a complex gain error of j·0.01516 dB. Note that a magnitude error of 0.01516 dB and phase error of 0.1 degree indeed indicate the same relative absolute vector error of 0.175 %. For higher errors, however, the relationship between linear and logarithmic errors becomes nonlinear. If we would only use the real part of ΔG we would only use half of the available information, and our parameter estimation would be less accurate.

We will arrive at the best approximation if we set the model parameters such that the mean over all frequency points of the squared error magnitude *mse* is as small as possible. Mathematically speaking, we have to minimize *mse*.

In the end, the process of approximation is:

- Define start values for all unknown parameters.
- Define a cost function which calculates *mse* for a given parameter set.
- Use the “fminsearch”-function of GNU Octave or MATLAB® to find the parameter set with minimum *mse*.
- Display the root of *mse* which denotes the RMS error of the approximation in dB.

Like all optimization functions, “fminsearch” may not find the global but rather only a local minimum of *mse*. It therefore is a good idea to use different start values in different approximation runs to check if a smaller RMS error can be achieved with different start values.

The function “fminsearch” does not support constraints of the parameter values. For our purposes we must limit the parameters to positive values. This constraint has to be implemented in the cost function.

5. Theory of the frequency response calculation

We have already derived the equivalent circuit model of the pickup. For the calculation of the frequency response we must define a load for the pickup. For many cases we can assume a parallel connection of a resistance R_l and a capacity C_l as a realistic load. The resistance R_l is a place holder for the parallel connection of the tone potentiometer, the volume potentiometer, and the input resistance of the guitar amp. The capacitance C_l is a place holder for the sum of the cable capacitance and the input capacitance of the guitar amp. We obtain the spectrum of the output voltage U_{pu} and the frequency response H_{pu} of the loaded pickup with:

$$H_{pu}=\frac{U_{pu}}{V_0}=k_V\cdot\frac{Z_c}{sL_0}\cdot\frac{Z_l}{R_0+Z_c+Z_l} \tag{20}$$

With:

$$Z_l=\frac{R_l}{1+sR_l(C_0+C_l)} \tag{21}$$

We cannot determine k_v with impedance measurements thus we normalize H_{pu} to its magnitude at 20 Hz.

6. Construction of the measurement adapter

For the measurement we need a passive measurement adapter. **Fig. 4** shows a possible implementation of the measurement adapter. **Fig. 1** contains the circuit diagram of the adapter.

The adaptor is mounted into a black coated aluminium housing (Hammond 1550 BBK). The holes for the connectors and the rotray switch neeed to be drilled by the maker of the adaptor.

Four quarter inch TS jacks are used for the connections to the sound card inputs (1 and 2), to the sound card output (G) and to the pickup or guitar (Z). Sound card input 1 may also be designated “left input”, or it may have another (odd) number if your sound card has more than one stereo input pair. Sound card input 2 may also be designated “right input” or may have another (even) number if your sound card has more than one stereo input pair. The sound card output should be connected with a TRS cable if it is a symmetrical or a stereo output. This will prevent short cutting the unused output amplifier. Pickups not already built into a guitar can be connected via the “loudspeaker terminal” too.

The rotary switch (Lorlin DS4) has three positions to build up the desired connections for tranfer function calibration (A), crosstalk calibration (B) and impedance calibration or measurement (C).

The resistor R_s determines the minimum achievable measurement uncertainty. It is recommended to use a metal film resistor with a value of 1 MΩ and a tolerance of 0.1 %.

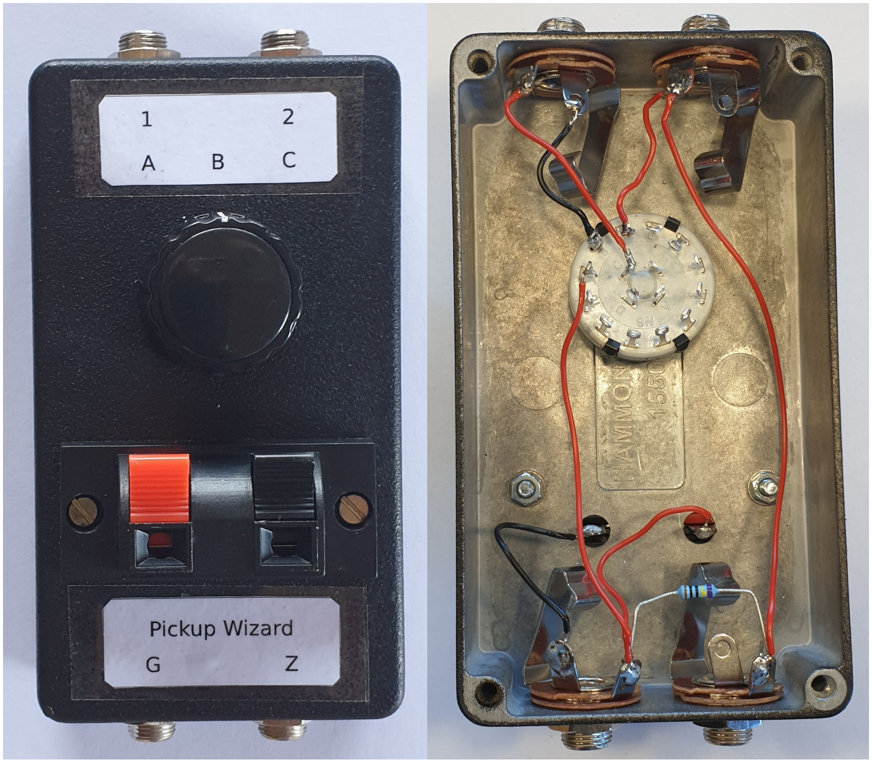


Fig. 4: A possible implementation of the measurement adapter

7. User manual of the Pickup Wizard

The Pickup Wizard is a GUI driven script for the interpreters MATLAB® or GNU Octave. If you do not own a MATLAB® license and want to avoid purchasing one, the latest version of GNU Octave can be donwloaded and installed. GNU Octave is available for the following operating systems: GNU/Linux, BSD, macOS and Microsoft Windows. The Pickup Wizard has been tested by the author only on Windows 11 with the 64-bit versions of MATLAB® version R2021a, and with GNU Octave version 7.1.0. The standard Windows-64 package of GNU Octave should be installed via the downloadable installer. Installing GNU Octave with the "zip"-files is not recommended because it seems to be too confusing for many users.

A sound card (or audio interface) with at least one analog stereo output and one analog stereo input with a nominal input impedance of at least 1 MΩ needs to be connected to the computer before starting Pickup Wizard. The sound card has to support a sample rate of 48 kHz, and a bit depth of 24 bits. Make sure that your operating system does not apply any signal processing to the sound card signals. Also make sure that any direct monitoring and signal processing of your sound card (or interface) is disabled.

Pickup Wizard is downloaded as a zip file. Unpack the zip file to a folder with write permission. The files "PickupWizard.m" and "Gitec Logo.png" are now located in the main directory of the Pickup Wizard folder. This directory will contain the two sub directories "Functions" and "GUI Callback Functions". Both these directories contain necessary function scripts. The sub directory "Pickup Data" is the default directory for measurment data; it will already contain some measurement results taken from the authors guitar collection. The sub directory "Documentation" contains the PDF file of this article, and a marked-up version of the main script of the Pickup Wizard. The best way to start the Pickup Wizard is to double click the file "PickupWizard.m". MATLAB® or GNU Octave will then start and load "PickupWizard.m" into the script editor. If this does not work ".m" files are not assoictated with MATLAB® or GNU Octave. In this case you have to start one of the intepreters manually and load "PickupWizard.m" into the editor. Before you start the script you should disable the usage of native file dialogs in the general settings dialog of GNU Octave in the case that you use GNU Octave as the interpreter. With the native file dialogs enabled, the file dialogs will not work as expected if the Pickup Wizard runs on a GNU Octave Windows installation. At last, you can now start the actual script by clicking on the start button of the interpreters editor. If the current working directory is not the one in which "PickupWizard.m" resides, the interpreter will propose to correspondingly change the current working directory. You should agree with this proposal. Do not select the other option, which is to add its dircetory to the search path.

Once Pickup Wizard is started you will see the following window:

Fig. 5: Start screen of the Pickup Wizard showing its main menu.

On macOS the menu bar may appear at a different position. The Pickup Wizard will create the sub directories “Persistent Parameters” and “Pickup Data” if they don’t already exist in the current working directory. Inside “Persistent Parameters”, some data files with the extension “.mat” will be created. These files contain user input which is stored permanently, and calibration data, as well. At the time they are first generated they will contain default values. The directory “Pickup Data” is the default directory for the storage of Pickup Wizard measurement data.

The main menu of the Pickup Wizard has the following six sub menus:

Settings

- **Audio input device**

  Here you can select the active audio input device and stereo channel pair. Note that the selected output needs to be on the same sound card – this is for a proper synchronization between input and output signals.

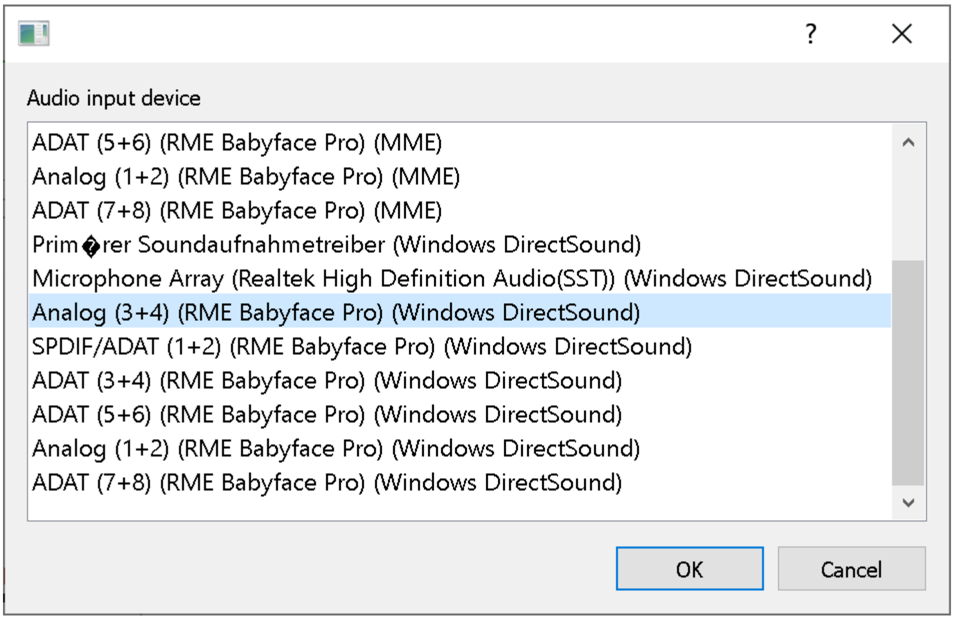


Fig. 6: Audio input device dialog.

- **Audio output device**

  You can select the active audio output device and stereo channel pair here. Note that the selected input needs to be on the same sound card – again for a proper synchronization between input and output signals. The test signal appears on both output channels.

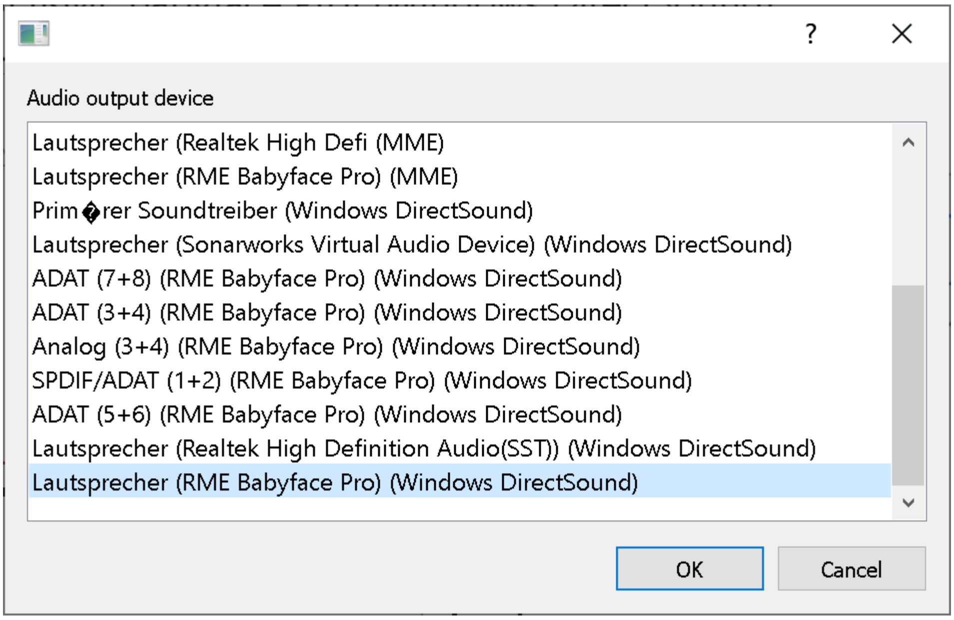


Fig. 7: Audio output device dialog.

- **Basic parameters**

  You can set the following six basic parameters:

  The **signal level** is the level of the test signal (unit: dBFS) and should be set to the highest value which just prevents overloading the inputs when connected directly to the outputs.

Start with a level of – 1 dBFS, and try to adjust the gains of the outputs and the two inputs for maximum-but-still-not-overloaded input levels first. Reduce the test signal level only if you cannot reduce the gains sufficiently, or if there is no other way to prevent clipping of the output amplifiers of your sound card. You can use the Pickup Wizard menu entry "**Calibrate transfer function**" to check the correct level settings.

The **number of sweeps** is the number of log-sine sweeps which are used as a test signal for a single measurement. One sweep with its associated pause has a length of about 4 s. Values greater than one can be used to reduce noise and hum; normally a value of one is sufficient, though.

The **power line frequency** is be entered in the unit Hz for an effective hum suppression. You can measure the hum frequency very accurately with the Pickup Wizard tool "**FFT Analyzer**". In most cases, however, it is sufficient to enter the nominal power line frequency of your location.

The question "**Suppress hum?**" wants to know if a spectral hum suppression is to be carried out. Since this feature has no significant disadvantages, the answer should be "yes".

Rsense is the reference resistance of your measurement adaptor in the unit kΩ. It is highly recommended to use a 0.1%-tolerance metal film resistor with a nominal value of 1000 kΩ (i.e. 1 MΩ). If you have instrumentation at hand that can measure the resistor's DC resistance with a higher accuracy than the given tolerance, you should enter the measured value here. Otherwise just enter the nominal value.

The question "**Compensate crosstalk?**" wants to know if a crosstalk compensation should be applied. For sound cards with crosstalk values greater than -90 dB the answer should be "yes". You can measure the crosstalk of your sound card with the Pickup Wizard menu entry "**Calibrate crosstalk**". Note that if you use crosstalk compensation you need to perform a crosstalk calibration before your regular impedance measurements.

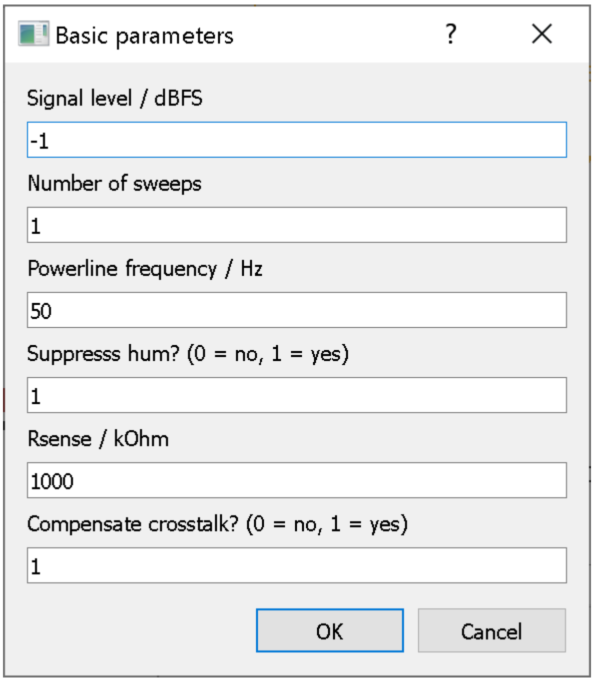


Fig. 8: Basic parameters dialog.

Calibration

- **Calibrate transfer function**

  This performs a calibration of the transfer function from input 1 to input 2 of your sound card. Please read the question of the initial dialog carefully before you answer it. Note that MA is an acronym for measurement adaptor.

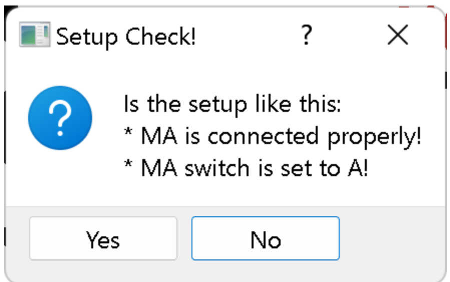


Fig. 9: Setup check dialog for transfer function calibration.

The calibration will be canceled if your answer is “no”. The calibration will start showing the measurement progress bar if your answer is “yes”.

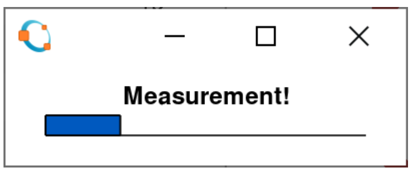


Fig. 10: Measurement progress bar.

The duration of the measurement is about 2 s plus n_s times 4 s. The blue bar shows the progress of the measurement. You can cancel the measurement at any time by closing the measurement progress bar window.

Once the measurement is done the progress bar will show the peak level L_{pk} of both inputs. It should not be smaller than -2 dBFS. If one of the two inputs is overloaded, the text "**Overdriven!**" appears instead. After two seconds the progress bar will disappear.

The measurement is canceled if an input-overload condition is established. Otherwise the complex transfer function data vector H_{cal} is stored as "Hcal.mat" in the sub directory "Persistent Parameters". It will be displayed on the screen, as well. A picture file "Hcal.png" showing the screen content will be stored in the same sub directory.

Note that the gain of H_{cal} should at all frequencies be in the range of ±1dB. Adjust the input gains, and repeat the calibration, until this is the case.

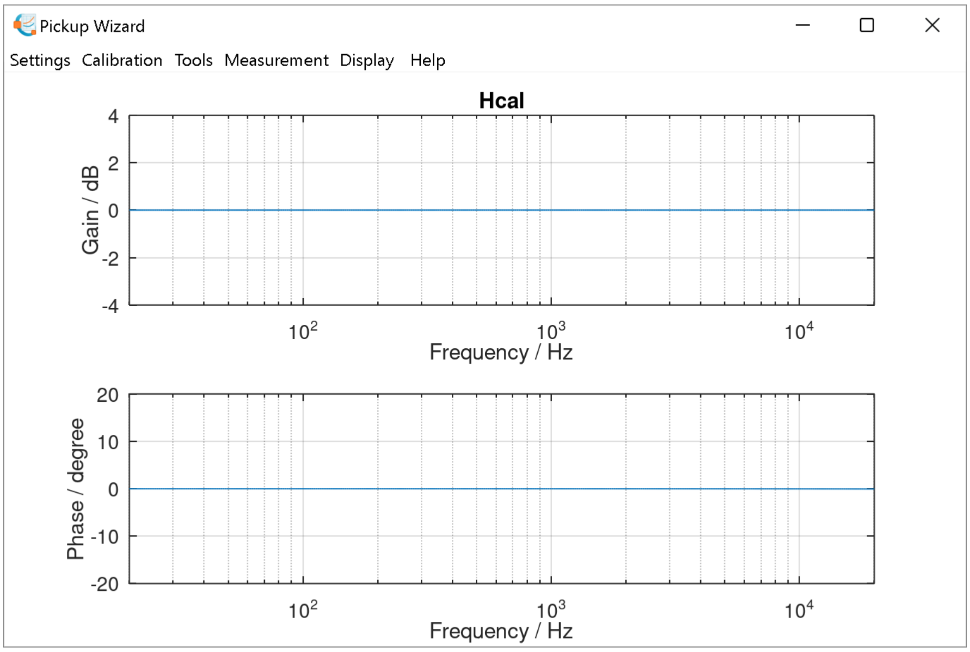


Fig. 11: H_{cal} display.

- **Calibrate crosstalk**

  This performs a calibration of the crosstalk from input 1 to input 2 of the sound card. Please read the question of the initial dialog carefully before you answer it. Note that MA is an acronym for measurement adaptor. Note that the latest transfer function calibration should not be older than a few minutes when you start a crosstalk calibration.

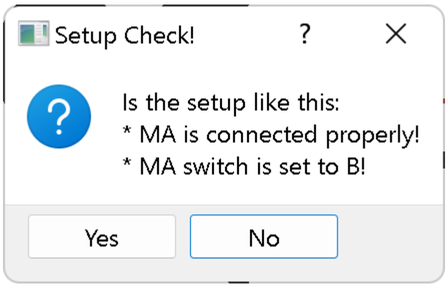


Fig. 12: Setup check dialog for crosstalk calibration.

The calibration will be canceled if your answer is “no”. It will start showing the measurement progress bar if your answer is “yes”.

Once the measurement is done the progress bar will disappear and the complex transfer function data vector H_{cross} will be stored as “Hcross.mat” in the sub directory “Persistent Parameters”. It will be displayed on the screen, as well. A picture file “Hcross.png” showing the screen content will be stored in the same sub directory.

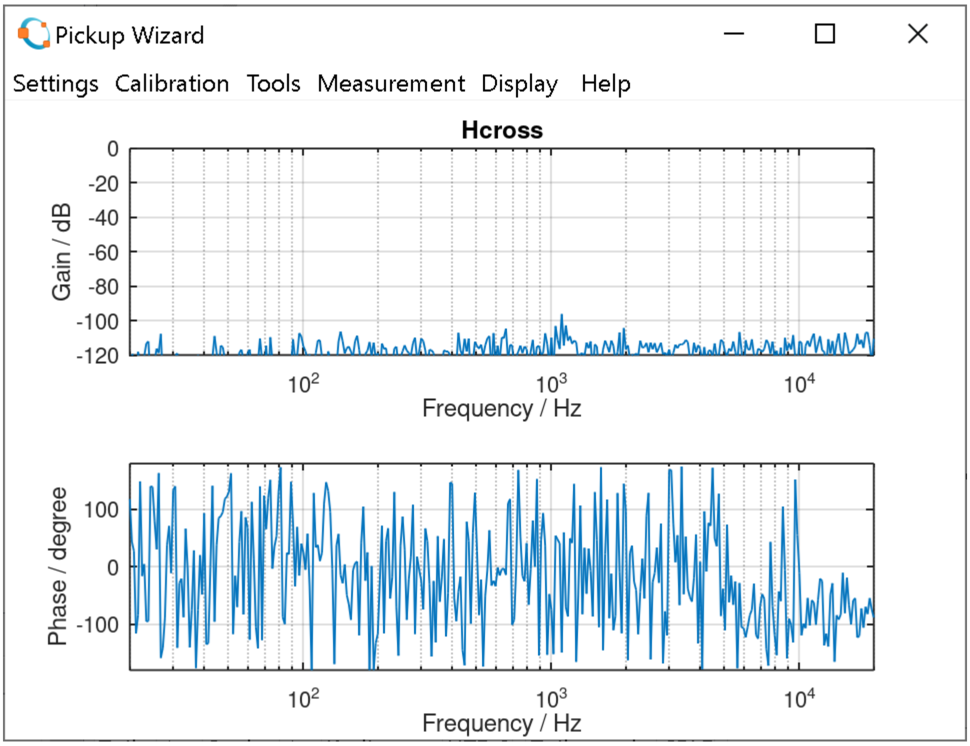


Fig. 13: H_{cross} display.

- **Calibrate impedance**

A calibration of the impedance of your measurement setup, and of input 2 of the sound card is performed here. Please read the question of the initial dialog carefully before you answer it. Note that MA is an acronym for measurement adaptor. If you connect the impedance to be measured directly to the impedance port of the measurement adaptor during a regular impedance measurement, simply keep the impedance port of the measurement adaptor open during the calibration. If, however, you use a cable to connect the impedance to be measured to the impedance port of the measurement adaptor during a regular impedance measurement, you must continue to use this cable during the impedance calibration, as well, but its “other” end needs be open (i.e. without any connection). Note that the latest transfer function calibration should not be older than a few minutes when you start an impedance calibration.

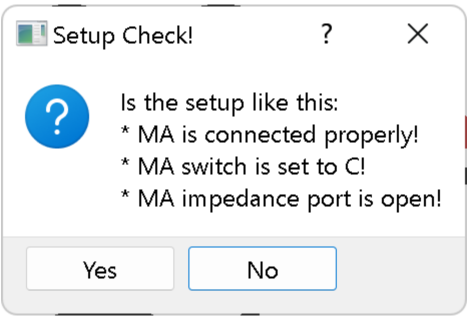


Fig. 14: Setup check dialog for impedance calibration.

The calibration will be canceled if your answer is “no.” The calibration will start showing the measurement progress bar if your answer is “yes”.

Once the measurement is done, the progress bar will disappear and the numeric approximation results will be stored as “zcalParams.mat” in the sub directory “Persistent Parameters”. The numeric results as well as the plots of Z_{cal} and its approximation Z_a will be displayed on the screen, as well. A picture file “Zcal.png” showing the screen content will be stored in the same sub directory.

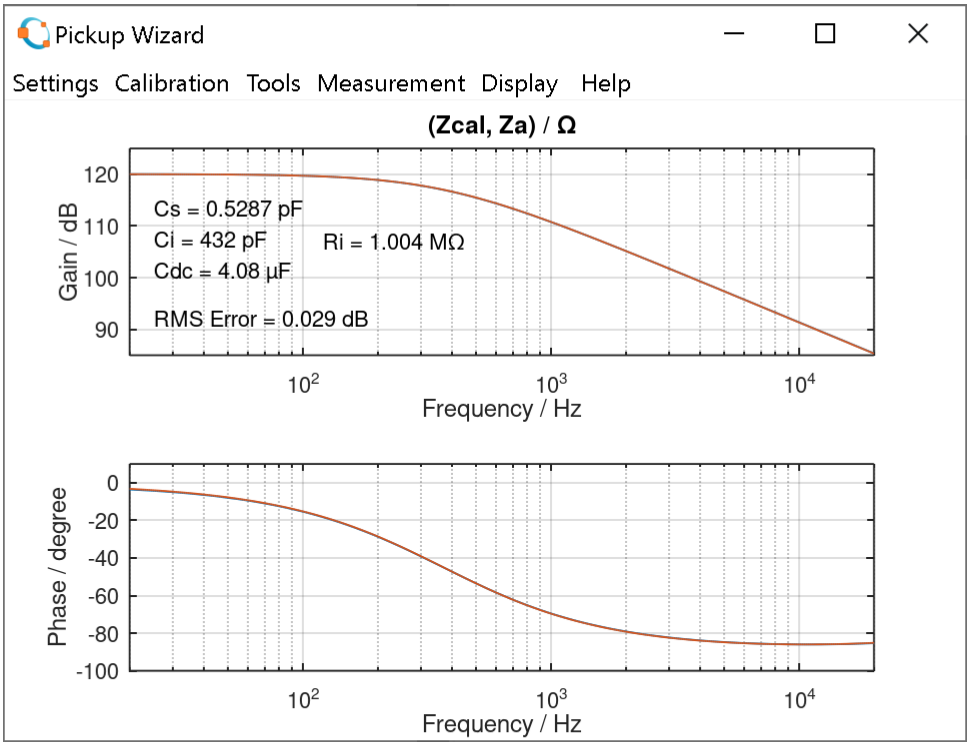


Fig. 15: Z_{cal} display.

Tools

- **FFT Analyzer**

This performs a cylcic FFT Analysis on input 2 of the sound card. FFTs with 16 384 points and a 4-term Nuttall window are done as long as you do not start another measurement, or display other plots, or change the active audio input device. Using the FFT Analyzer you can see whether there is too much hum or noise in your setup. Thanks to an innovative interpolating peak finder you can measure the level L_{peak}, and frequency F_{peak} of the highest spectral line with an extremely high accuracy. The total RMS level L_{RMS} in the frequency range from 20 Hz to 20 kHz is also displayed. A sinusoidal signal with full scale amplitude will result in a L_{RMS} and L_{peak} of 0 dBFS.

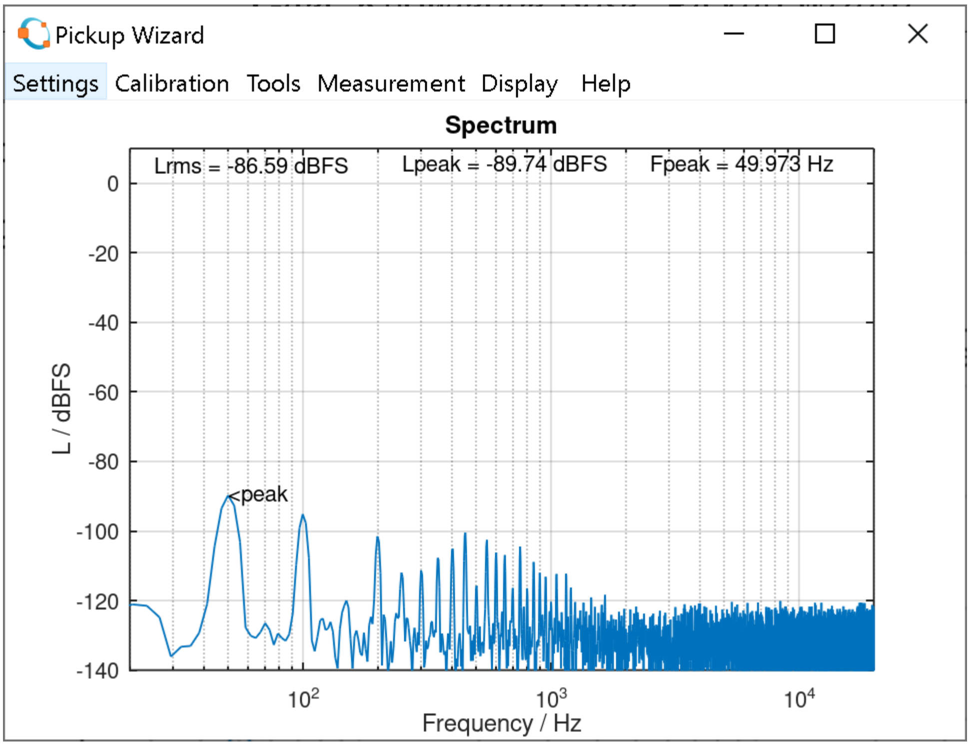


Fig. 16: FFT Analyzer display.

Note that Pickup Wizard sets the bit depths of your sound card to 24 bits. In MATLAB® you will get this resolution if your sound card supports it. In GNU Octave you will never get more than 16 bits resolution due to a buggy audio device implementation.

- **Calculate R0 and Rv**

This is a tool to jointly determine the DC resistance R_0 of a pickup and the volume potentiometer resistance R_v in a passive electric guitar as originally described in [1]. Note that this method works only correctly if there is not more than one volume potentiomter connected to the pickup, if the middle tap of this volume potentiometer is connected to the output of the guitar, and if any present tone potentiometers do not have a DC connection to ground. These conditions will be met for most electric guitars but not for all of them. If in doubt look for a circuit diagram of the guitar to be measured. For a “normal” passive electric guitar both the values R_0 and R_v can be calculated based on the measurement of the DC resistance at the guitar output port for two volume potentiometer settings. The first setting is "volume fully up" (i.e. set to "10"), here R_{full} is measured. For the second setting, the pot needs to set such that the highest measured resistance occurs; it will give R_{max}. Once both the measured values for R_{full} and R_{max} are entered (unit: kΩ), R_0 and R_v are calculated, stored and displayed. R_0 is used as a start value for impedance approximations and R_v is used as a guitar load parameter.

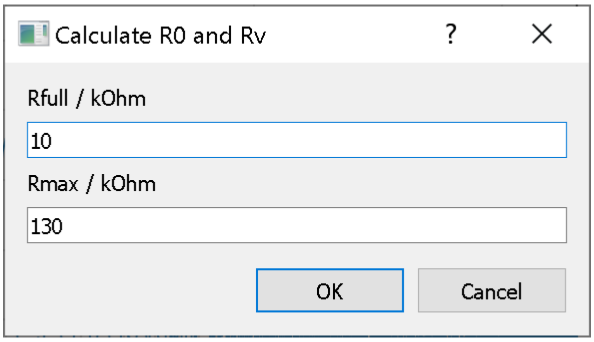


Fig. 17: Rfull and Rmax entry.

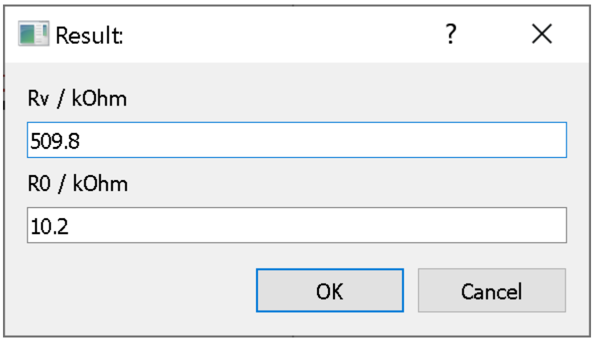


Fig. 18: R0 and Rv result.

Measurement

- **Guitar load**

You can set the following four "Guitar load" parameters:

The resistance **Rv** of the volume potentiometer of the guitar. Enter values in the unit kΩ.

The resistance **Rt** of the tone potentiometer of the guitar. Enter values in the unit kΩ. If there is no tone potentiometer conneceted to the pickup, enter a value of one million kΩ.

The capacitance **Ct** of the tone capacitor of the guitar. Enter values in the unit nF.

The question "**Regard guitar load?**" wants to know whether the guitar load is considered for the impedance calculation. Answer with "no" if the pickup is not mounted in a guitar during the impedance measurement.

Note that the volume potentiometer and the tone potentiometer must be set fully clockwise if you measure a pickup mounted and connected in the guitar.

Note that some bass guitars like the Fender Jazz Bass have a volume potentiometer for each of its two pickups, and a single tone potentiometer – but no switch to select the pickups. In such bass guitars the middle taps of the potentiometers are connected to the pickups rather than to the guitar output (i.e. they are wired “backwards”). In this case you can measure Rv directly by turning down fully both volume potentiometers. Note the value you measure (the result of both potentiometers connected in parallel as it is relevant as the load for the single pickup) and enter it. During the measurement of the impedance you have to fully turn up the pickup to be measured, and likewise the tone potentiometer. Conversely, you need to turn down the other pickup.

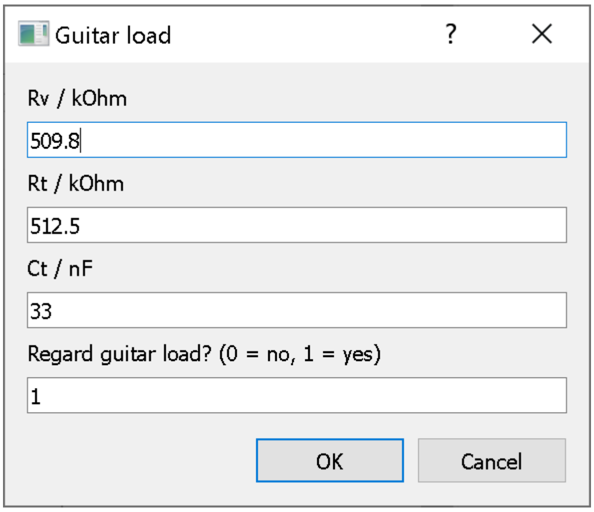


Fig. 19: Set guitar load parameters dialog.

- **Measure impedance**

This performs an impedance measurement. Please read the question of the initial dialog carefully before you answer it. Note that MA is an acronym for measurement adaptor. Note that the latest transfer function calibration should not be older than a few minutes when you start an impedance measurement.

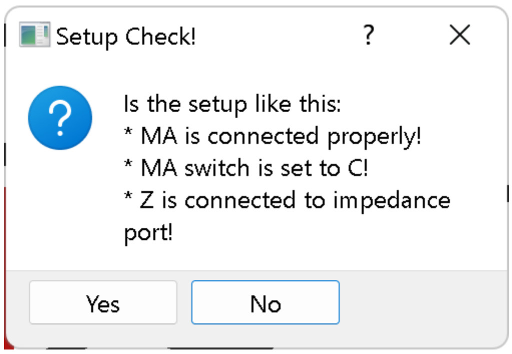


Fig. 20: Setup check dialog for impedance measurement.

The calibration will be canceled if your answer is “no”. The calibration will start showing the measurement progress bar if your answer is “yes”.

Once the measurement is done the progress bar will disappear and a “save file”-dialog will appear:

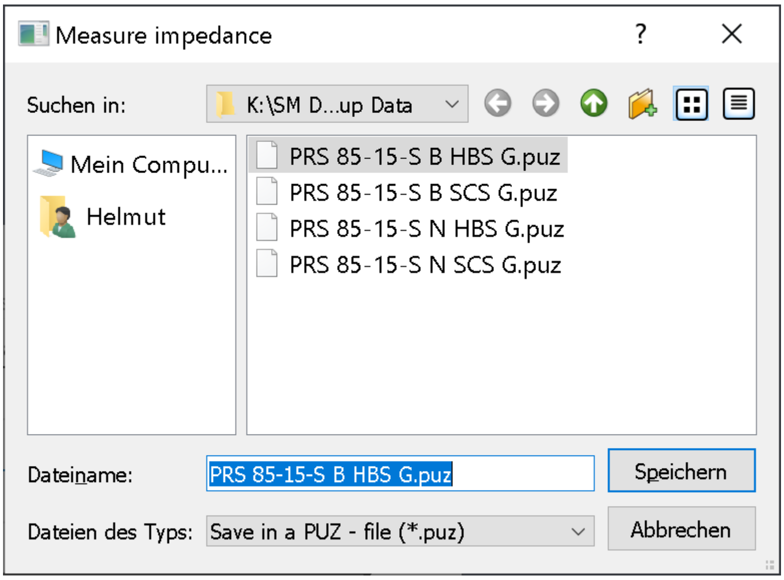


Fig. 21: Save file dialog for impedance measurements.

Once you have selected the destination directory, and have entered a valid filename, the complex impedance data vector Z will be stored in a file with the entered filename and the extension “.puz”. It will be displayed on the screen, as well. A picture file with the same filename and the suffix “ Z.png” showing the screen content will be stored in the same directory. A data file with the same filename and the extension “.mzp” containing information about the load scenario, about impedance calibration, as well as the measurement date will be stored in the same directory. If you overwrite an existing “.puz” file all files in the destination directory which are derived from it are deleted for the sake of data integrity. If you cancel the save file dialog nothing will be stored, and the display will not be updated.

If you observe a steep jump in the phase plot at the resonance frequency (from more than + 100 degree to less than –100 degree), the entered values for Rv, or Rt, or both of them are too low. Measure the real values or find at least a better estimation of these values. The measurement should then be repeated.

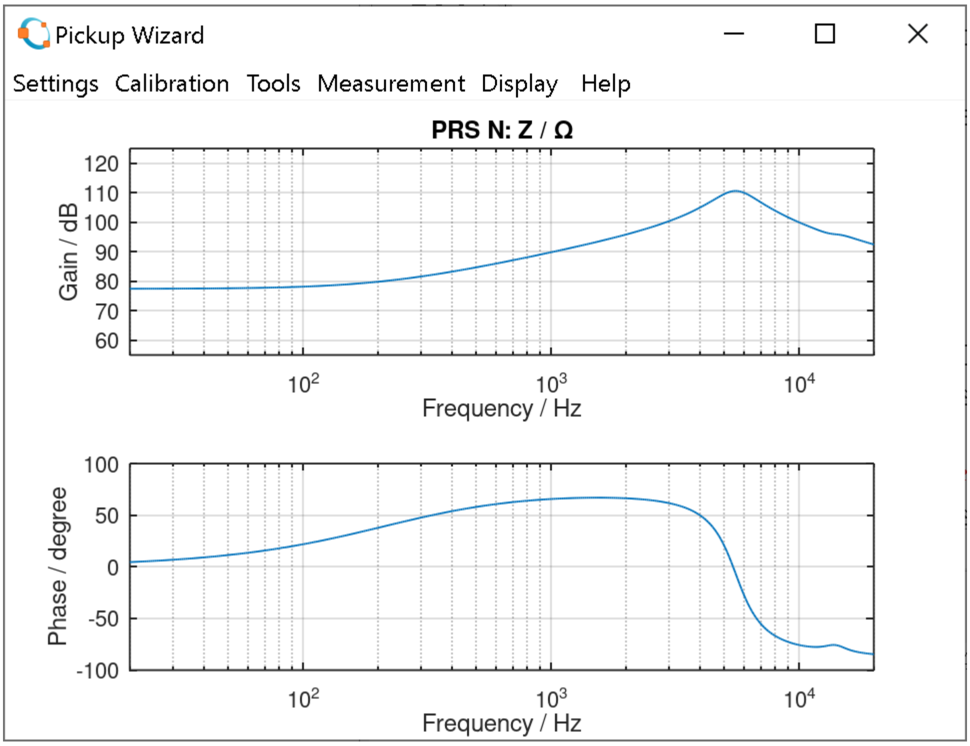


Fig. 22: Z display.

- **Approximation start values**

  You can set the following start values for the pickup impedance approximation:

  R0 is the start value for the DC resistance of the pickup. Enter values in the unit kΩ.

  The question "**Vary R0**?" wants to know if R0 is varied during the approximation process. Answer with "no" if you are sure that you already know the correct value of R0.

  C0 is the start value for the pickup capacitance. Enter values in the unit pF.

  L(i) are the start values for the inductances of up to three sub-coils of the pickup. Enter values in the unit H. You will disable sub-coils 2 and 3 if you enter a value of zero for sub-coil 2. You will disable sub-coil 3 if you enter a value of zero for sub-coil 3.

  R(i) are the start values for the resistances of up to three sub-coils of the pickup. Enter values in the unit kΩ. You will disable sub-coils 2 and 3 if you enter a value of zero for sub-coil 2. You will disable sub-coil 3 if you enter a value of zero for sub-coil 3.

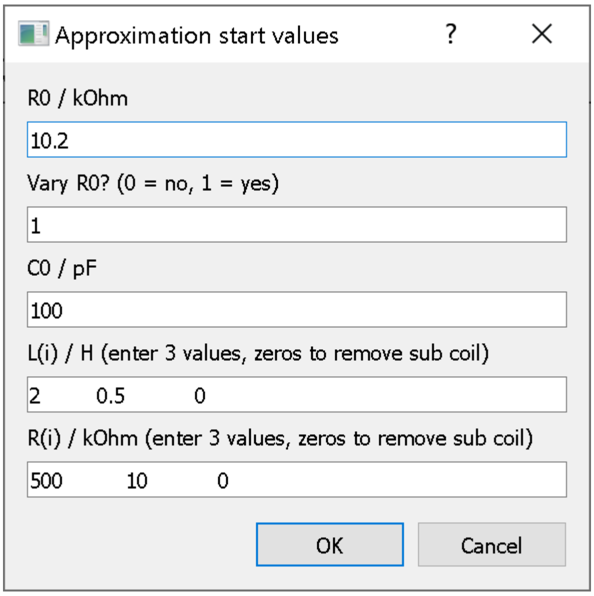


Fig. 23: Approximation start values dialog.

- **Approximate impedance**

  Performs an approximation of the measured pickup impedance to estimate the pickup model parameters (as used in the pickup model) the knowledge of which is necessary for a calculation of the pickup frequency response.

  A file dialog opens first:

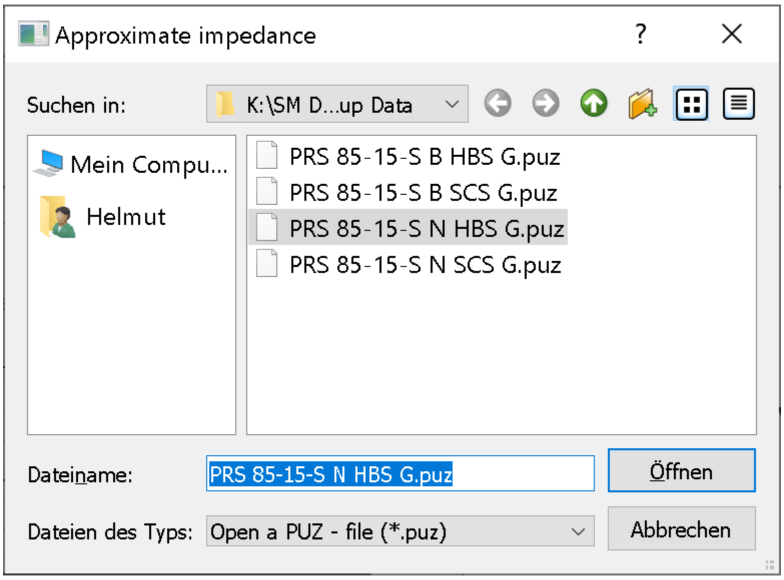


Fig. 24: Open file dialog for the impedance approximation

Cancel the this dialog to go back to the main menu. Open a pickup impedance file with the extension ".puz" to proceed. Now the approximation will be executed and the numeric results will be stored in a ".pup" file with the same filename and in the directory of the impedance file. The numeric results as well as a plot of the pickup impedance Z and the approximated impedance Z_a will be displayed on the screen. A picture file with the same filename and the suffix " Za.png" showing the screen content will be stored in the same directory. If you overwrite an existing ".pup" file by again approximating a ".puz" file, then already existing frequency response plot files based on this file will be deleted for the sake of data integrity.

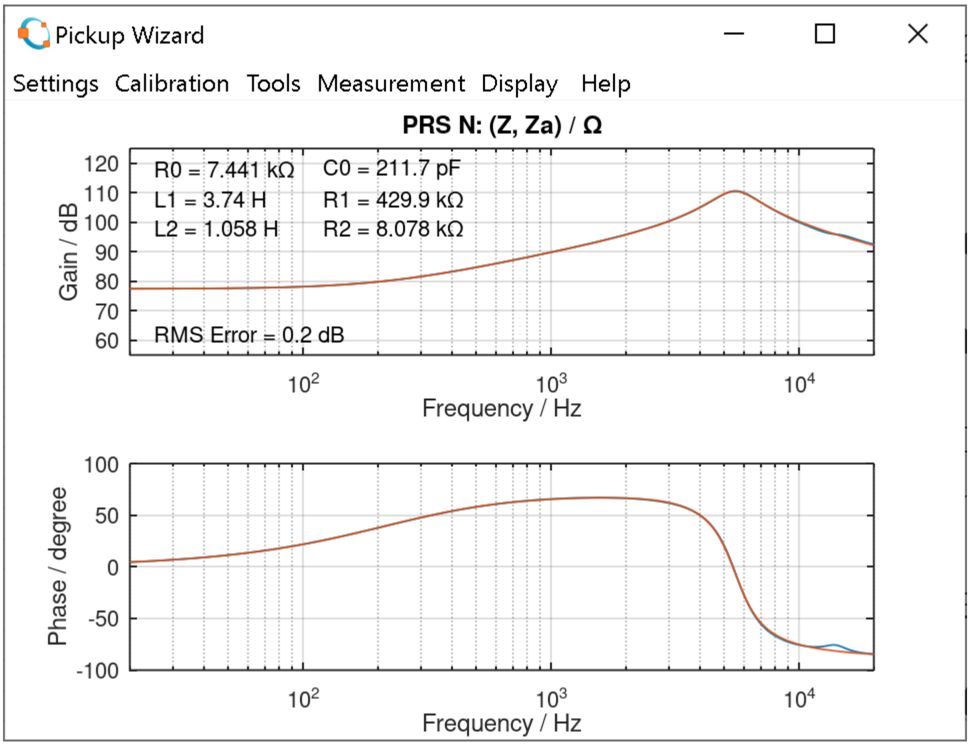


Fig. 25: Z, Z_a display, example 1.

If you are not satisfied with the approximation result you can run new approximations with different start values and numbers of enabled sub-coils until you to get the smallest achievable RMS errors. Don't use more enabled sub-coils than necessary to keep the model as simple as possible.

The kink at 13 kHz in the example above cannot be approximated with the actual pickup model. This would require a model of higher complexity. Since, however, this effect is not relevant for the sound of the pickup, it is not regarded in the used pickup model. The achievable RMS error for pickups (without kinks like the one in the example above) is normally well below 0.1 dB.

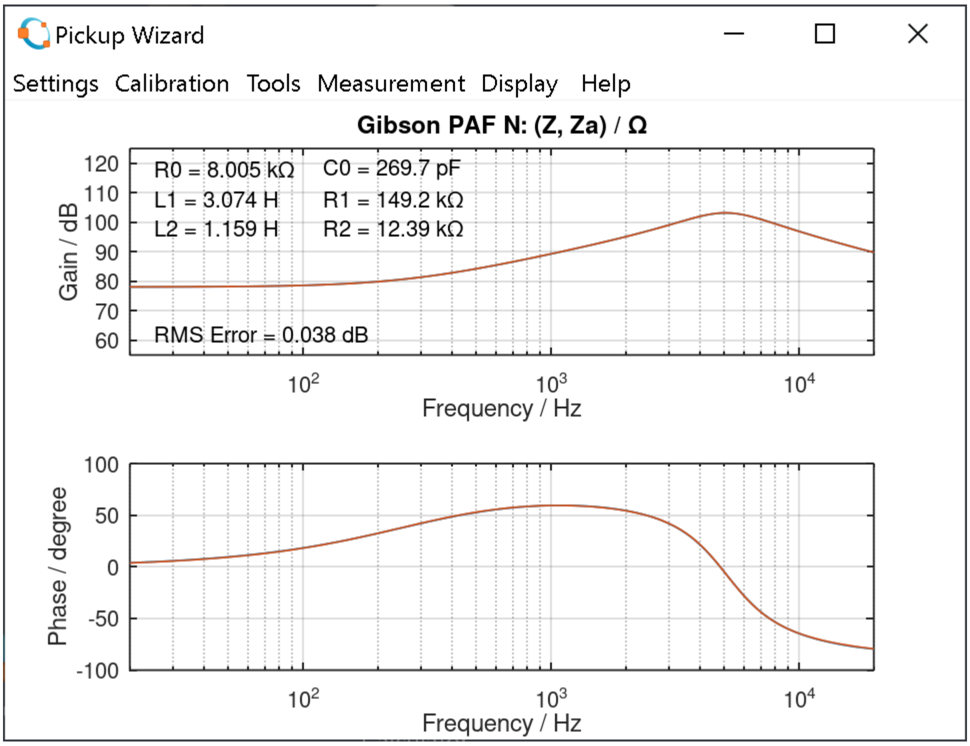


Fig. 26: Z, Z_a display, example 2.

Display

- **Display Z**

  Displays the results of already stored impedance measurements. Open the “.puz” file of interest in the initial file open dialog.

- **Display Z, Za**

  Displays the results of already stored impedance approximations. Open the “.pup” file of interest in the initial file open dialog.

- **Frequency response loads**

  You can enter the following load-parameters for frequency response calculations:

  Rload(i) are the load resistances for three load scenarios. Enter the values in the unit kΩ.

  Cload(i) are the load capacitances for three load scenarios. Enter the values in the unit pF.

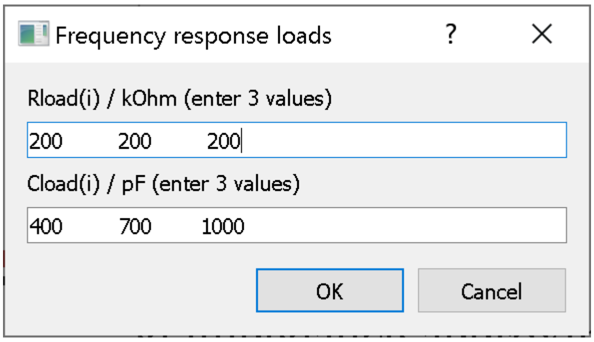


Fig. 27: Frequency response load parameters dialog.

- **Display frequency response**

  Displays the pickup frequency response of pickups with already stored “.pup” files. Open the ”.pup” file of interest in the initial file open dialog. A picture file with the same filename and the suffix “FR.png” showing the screen content will also be stored in the directory of the opened “.pud” file.

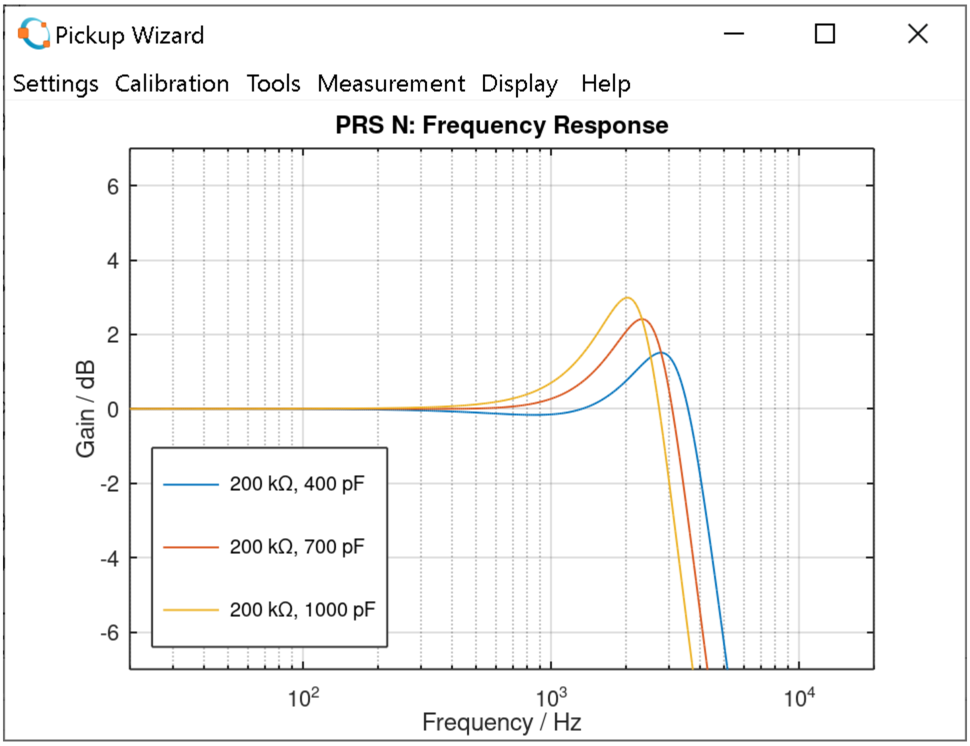
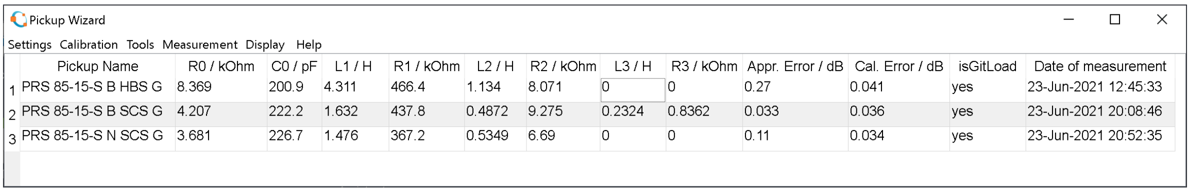


Fig. 28: Frequency response display.

- **Display pickup data table**

  Displays a table with all numeric pickup data stored in the selected directory. Select a directory already containing “.pud” files in the initial get-directory dialog. The selected directory will be scanned and a table with all numeric pickup data currently stored in this directory will be displayed on the screen. A text file “Pickup Data Table.csv” containing the same table will be stored in the selected directory, as well. You can import this file in all common spreadsheet software products for further data processing or visualization.



Pickup Wizard

Settings Calibration Tools Measurement Display Help

	Pickup Name	R0 / kOhm	C0 / pF	L1 / H	R1 / kOhm	L2 / H	R2 / kOhm	L3 / H	R3 / kOhm	Appr. Error / dB	Cal. Error / dB	isGitLoad	Date of measurement
1	PRS 85-15-S B HBS G	8.369	200.9	4.311	466.4	1.134	8.071	0	0	0.27	0.041	yes	23-Jun-2021 12:45:33
2	PRS 85-15-S B SCS G	4.207	222.2	1.632	437.8	0.4872	9.275	0.2324	0.8362	0.033	0.036	yes	23-Jun-2021 20:08:46
3	PRS 85-15-S N SCS G	3.681	226.7	1.476	367.2	0.5349	6.69	0	0	0.11	0.034	yes	23-Jun-2021 20:52:35

Fig. 29: Pickup data table display.

Help

- **About**

  Displays a dialog with some information about your version of the Pickup Wizard

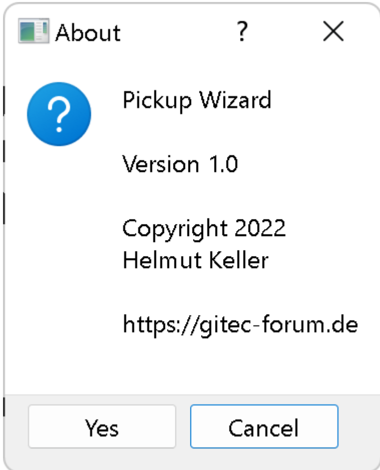


Fig. 30: About dialog.

8. Source code documentation

The Pickup Wizard is distributed as a ".zip" file. In its source directory you will find the script file "PickupWizard.m" and the GITEC logo "Gitec Logo.png". You need both files and two subfolders containing necessary function scripts to execute the Pickup Wizard. In the subfolder "Documentation" you will find the present document "Pickup Wizard.pdf", and the file "PickupWizard.html". The latter contains the marked-up source code which offers significantly easier reading compared to "PickupWizard.m". It is highly recommended to read the marked-up version of the source code if you seek to comprehend it.

9. License conditions

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Programmers who want to use parts of the source code may do so as long as they clearly state that the used source code is part of the Pickup Wizard written by Helmut Keller in 2022 and distributed by https://www.gitec-forum-eng.de, and as long as they do not allow any commercial usage of their code.

10. References

[1] B. C. Meiser, “Potis einmal anders messen”, https://gitec-forum.de

[2] M. Zollner, "Physik der Elektrogitarre", https://www.gitarrenphysik.de