V5.8 Integrator Manual

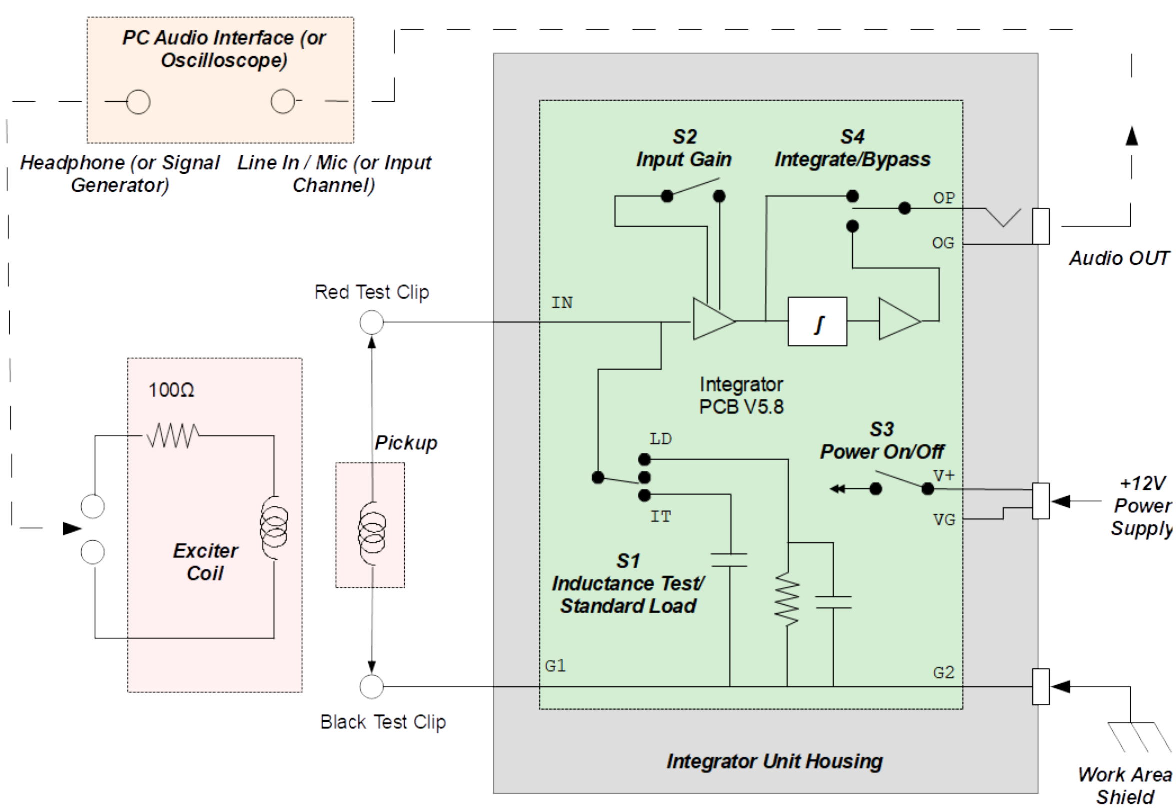
This document explains how to produce the Bode plots for an electromagnetic guitar pickup using the V5.8 Integrator.

Equipment:

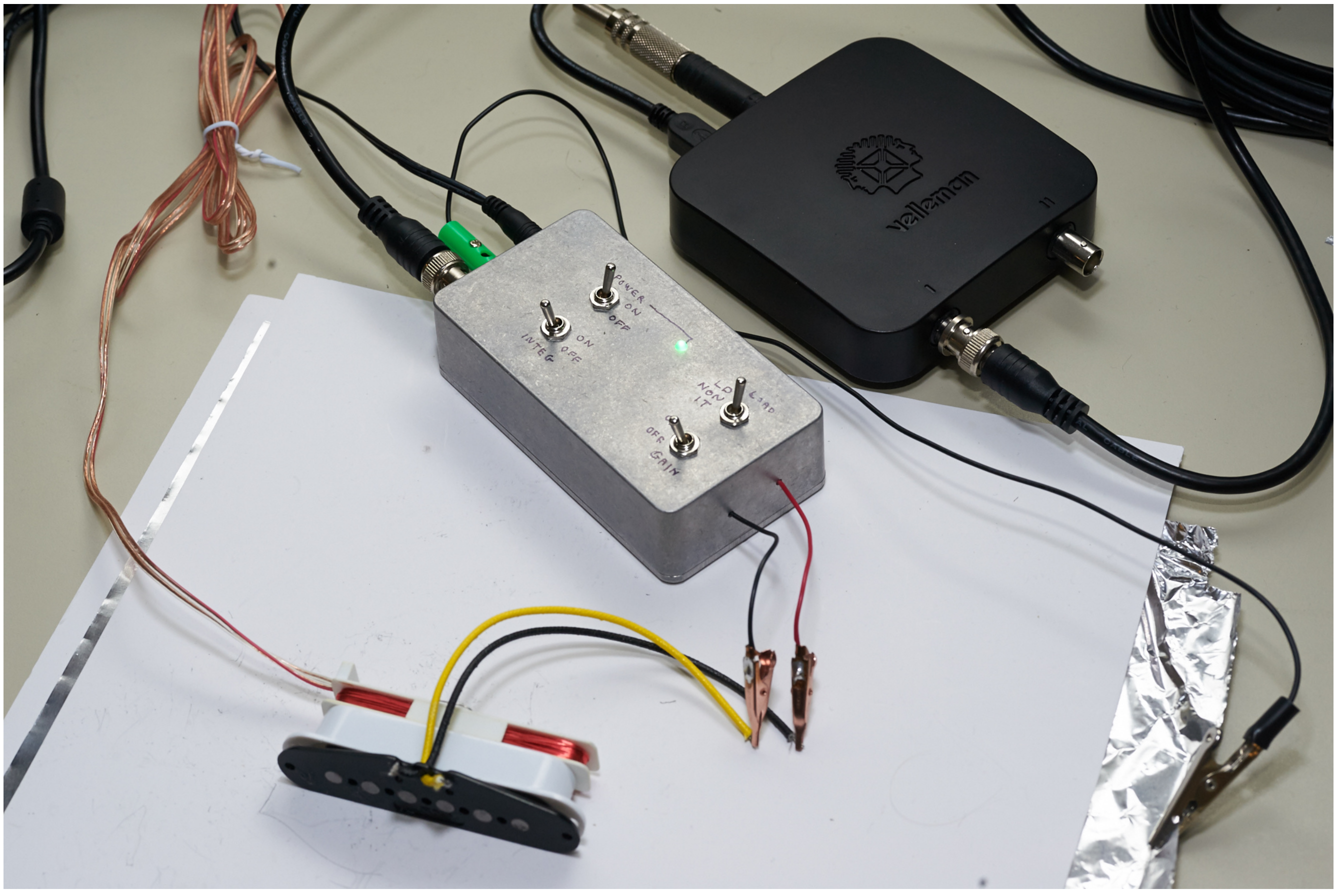
- Test coil – 50-100 turns of 26 AWG coated copper magnet wire on a non-magnetic bobbin such as plastic or wood.
- V5.8 integrator board
- Either one of these:
  1. computer audio interface such as the Scarlett Focusrite 2i2 or equivalent
  2. software oscilloscope
- RightMark audio test software or equivalent

Overview:

The test setup consists of an audio signal loop, where signals produced by the test software suite are sent from the output of the computer interface device, to the test coil. The field from the test coil induces a voltage in the pickup, which is connected to the input of the integrator. The integrator output is connected to the input of the audio device, where it is converted to digital format and returned to the audio test software suite for recording and analysis.



Here is a photograph of a typical test bench layout:



The V5.8 integrator circuit provides a high impedance preamplifier, an integrator, and an output amplifier. It also has terminals for switches to control input gain, and to select between internally provided test loads. One of the loads is a relatively large capacitor, to measure inductance, and the other is an RC load to simulate a typical guitar circuit. A three way switch can select between these two loads, or neither load in order to make an unloaded (actually minimally loaded) measurement. An auxiliary ground wire connects to a workbench shield (not shown). In the photo above, it is a large piece of aluminum foil underneath the paper surface that supports the test apparatus. This is for hum reduction.

To prepare for the test, the test coil must be placed against the pickup housing. The leads are connected to the integrator input. If the pickup is shielded, the shield connection should also be connected to the input ground (black). Connecting IN to the shield will result in bad measurements. Otherwise the polarity does not matter. Ensure that 12V power is applied to the integrator and that connections to and from the computer interface are complete. Launch the software suite and configure the sound interface options, select the option to perform Bode plots, and any other settings that are permanently required. Ensure that any monitor loopback setting in the audio device is disabled.

Procedure:

Launch the analysis software suite. For RightMark, you can click on a "Run Tests" button. It will show you the following display, if no pickup is connected:

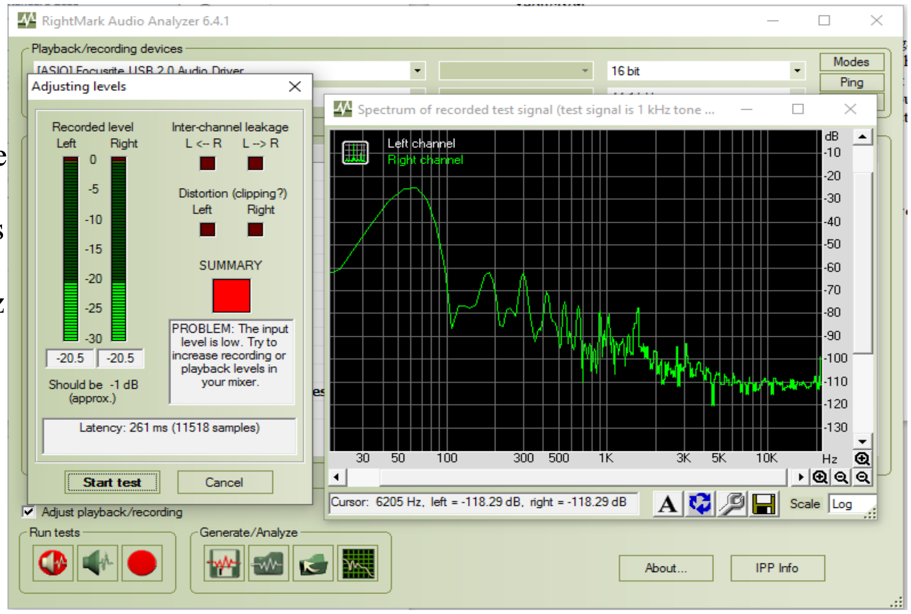


Illustration 1: Input with no valid connections

This is what you would see with no pickup connected to the integrator. The software adjusts levels by sending a 1 Khz pilot tone, which you can see is absent here. Also, you can see a huge 60 Hz signal which is the electrostatic hum picked up by the very high impedance input terminals when they are not connected to anything.

After connecting the pickup, the levels should be adjusted so that the SUMMARY box is green, the "recorded level" bars come up, and the displayed level should be approximately -1 dB as indicated. In practice, a level between -1 and -3 will usually be okay.

First, we will do an unloaded measurement. For this, the load switch should be set to the center position. Here is a resulting calibration screen:

The pilot tone is now visible at 1 Khz. You can see evidence of distortion in the harmonic overtone peaks at multiples of the test tone frequency.

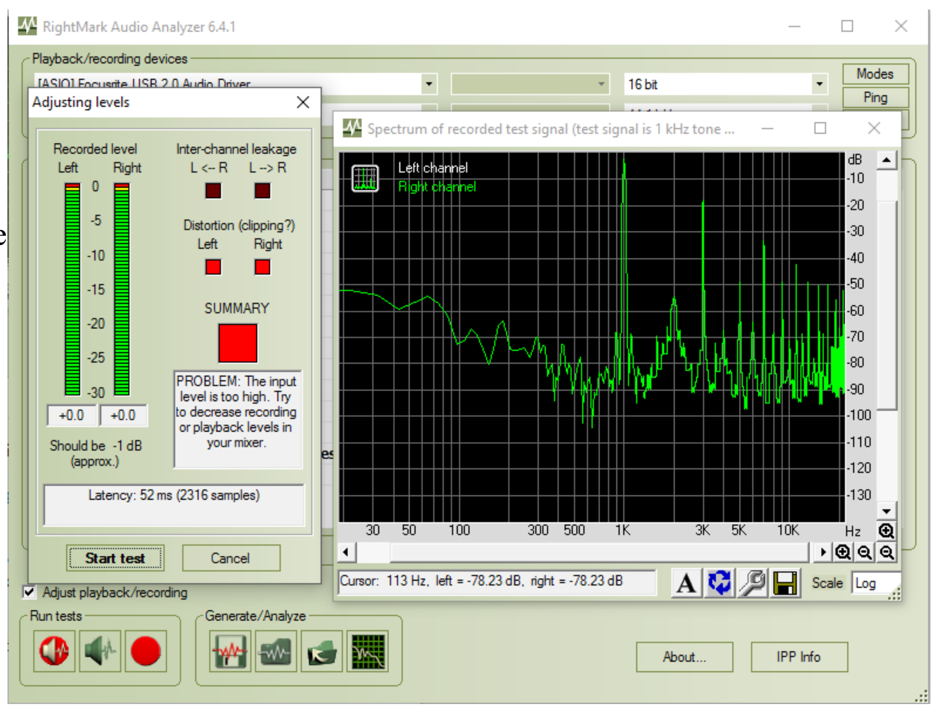


Illustration 2: Distorted Input

To obtain the best signal to noise, it is good to increase the drive to the test coil as much as possible, and then adjust the audio interface input level until the right level is attained, and there is not too much distortion or 60 Hz interference as it appears in the previous two illustrations. As a rule of thumb, neither the distortion products, nor the hum, should exceed -50 dB or so. It is possible to run tests with greater than this, but the accuracy will be impaired.

Here is a good calibration screen, when you see this you can press the "Start Test" button:

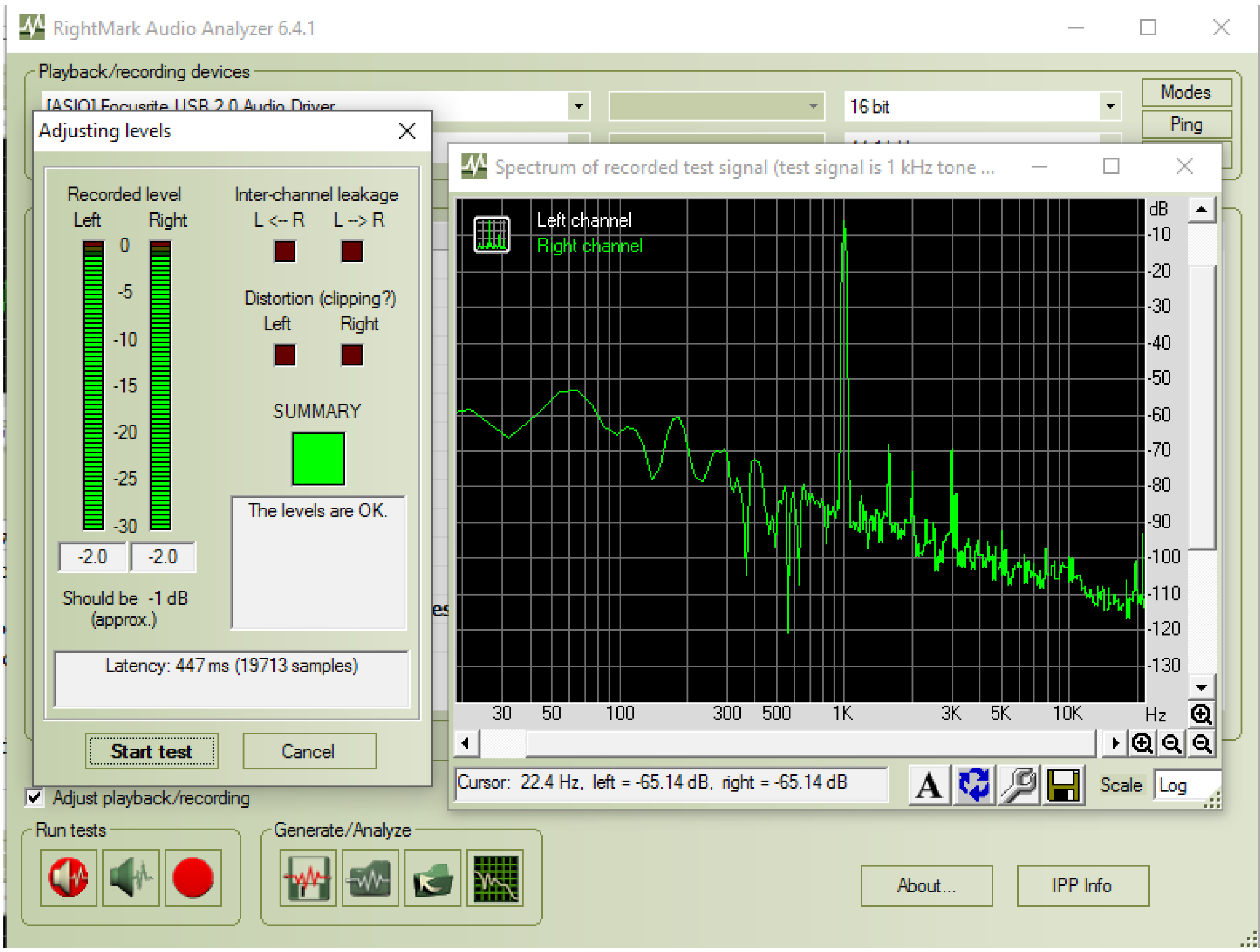


Illustration 3: Typical acceptable calibration screen

When the frequency sweep is completed, you will be prompted to save the plot. It is a good idea to name it at this point by typing in the name field. In this case, I'm calling it "No load".

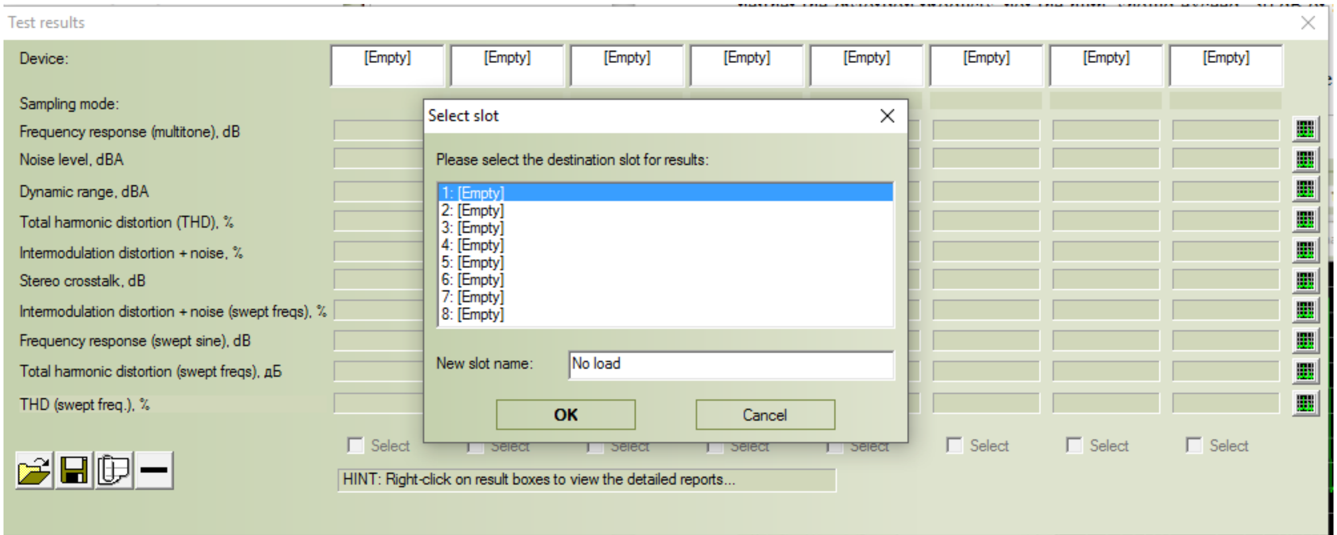


Illustration 4: Name the slot

Click on "OK". Now your first sweep will be recorded in the first of 8 possible slots:

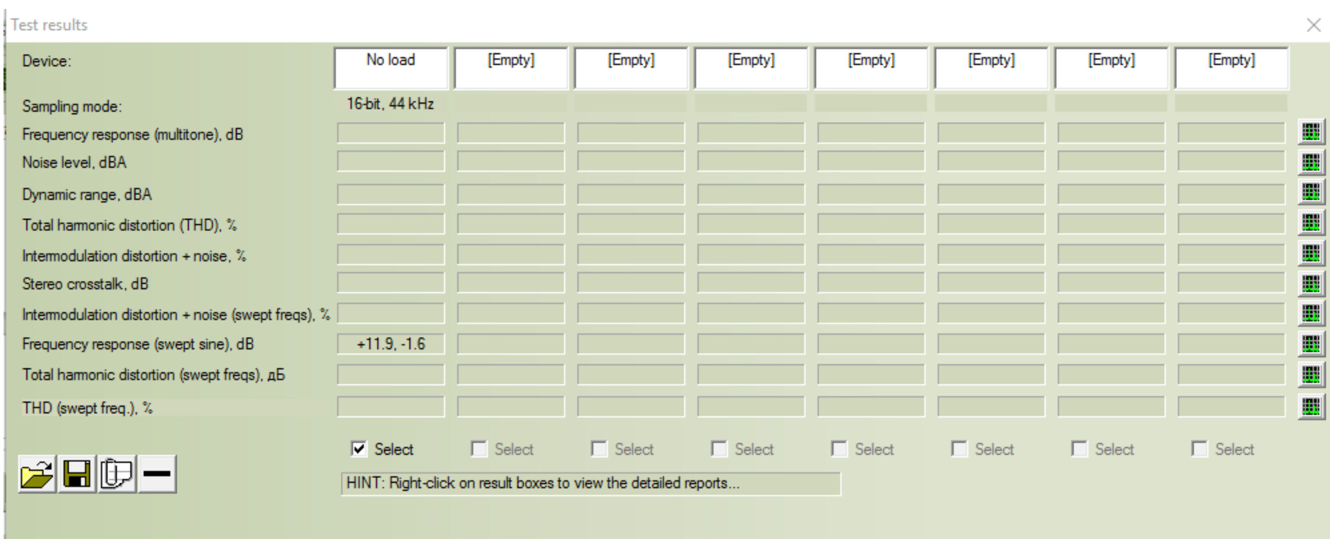


Illustration 5: First slot

Move the load select switch on the integrator to the "test load" position. Click again on the "Run Tests" button. Adjust the levels as before, and complete another sweep. You will again be prompted and you can name this sweep "loaded" for example (You can also include the pickup name or any data you want to appear on the final plot).

Finally, Move the load select switch on the integrator to the "Inductance test" position. Click again on the "Run Tests" button. After running and naming the sweeps, you will now have three sweeps stored:

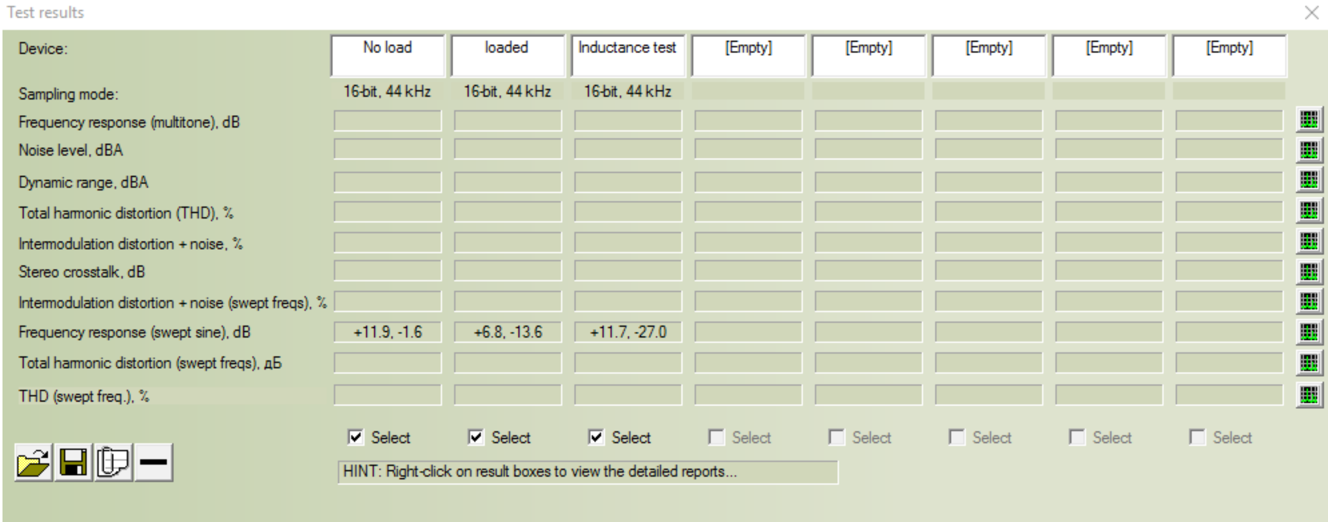


Illustration 6: All test slots filled

The HINT suggests Right clicking, but I find that a normal left click on the results box on the right hand side, will bring up a plot:

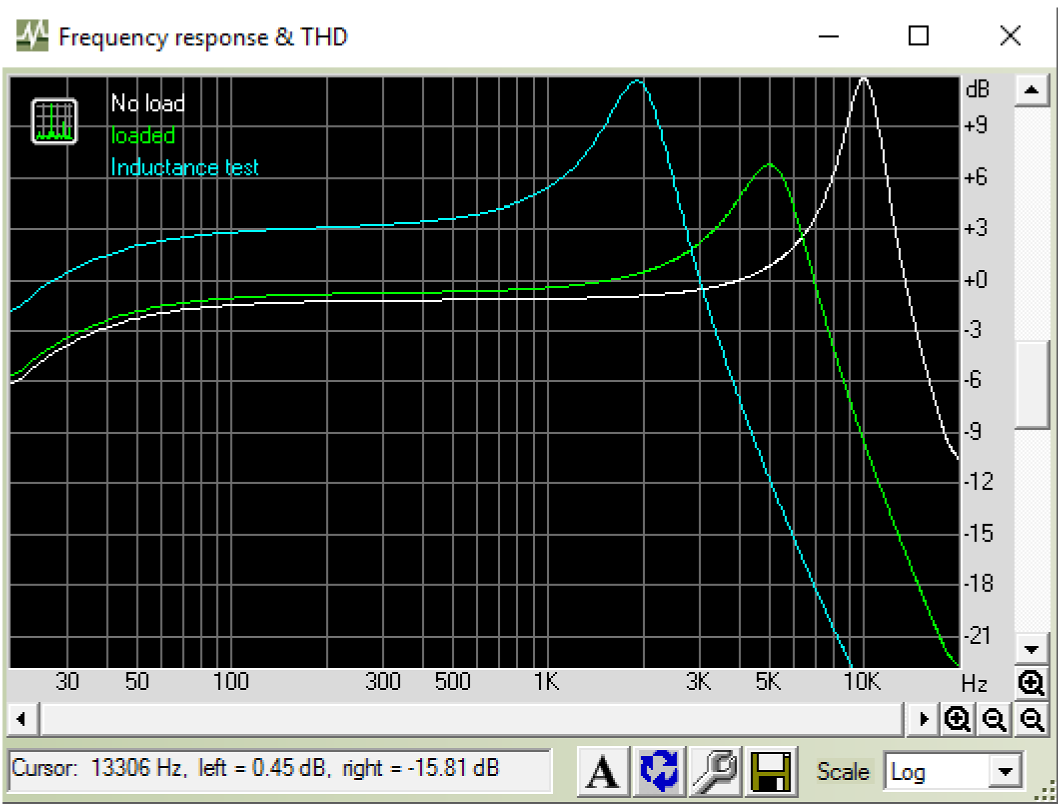


Illustration 7: Raw Plot

Notice that the plots are not centered on 0dB. Pickups actually have a uniform response at low frequencies, so we choose an arbitrary frequency of 220 Hz, and use the tool at the bottom that looks like a wrench, to align them. It is easier to do this by making the plot full screen, before restoring it to a convenient size.

By examining the values at 200 Hz, we can figure out an offset to add using the "wrench" tool. Here I found that the first graph needed 1.2 dB and the second graph needed 0.8 dB to place them on the 0 dB line. The inductance test does not need adjustment because the level is not important:

This is the result:

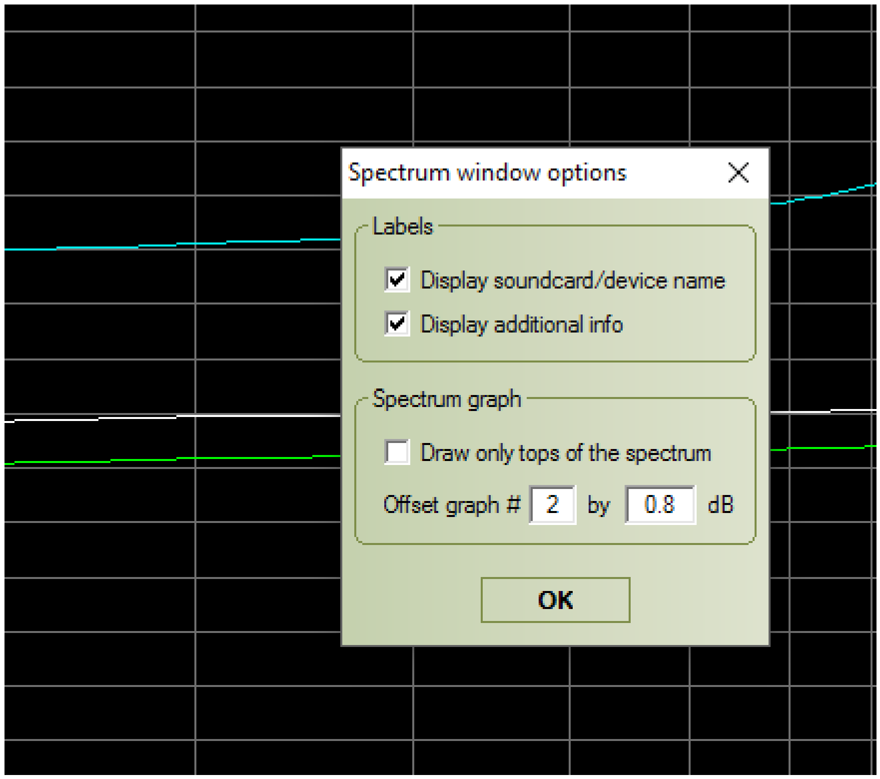


Illustration 8: Adjusting level

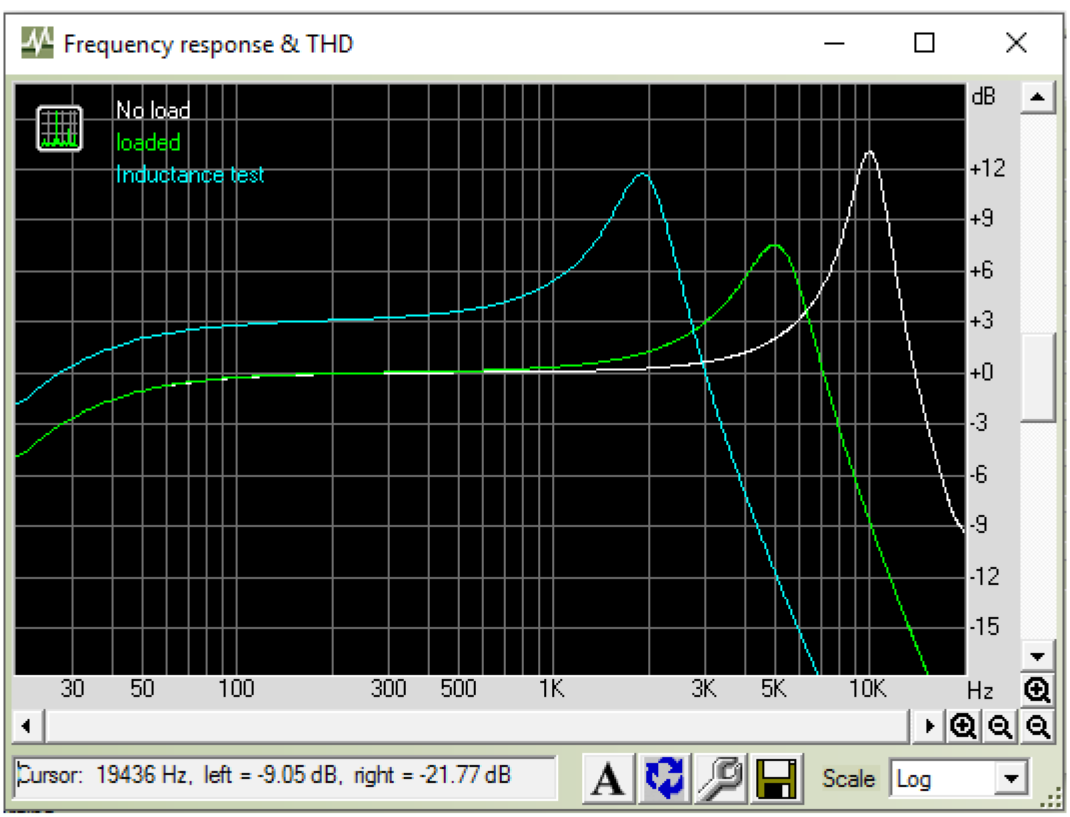


Illustration 9: Corrected levels

Now that the levels are corrected, we can use the zoom tools in Rightmark to collect data. Here we place the cursor on the peak of the unloaded measurement, and the frequency is displayed in a text box at the lower left, as well as it being possible to read with reference to the marking grid.

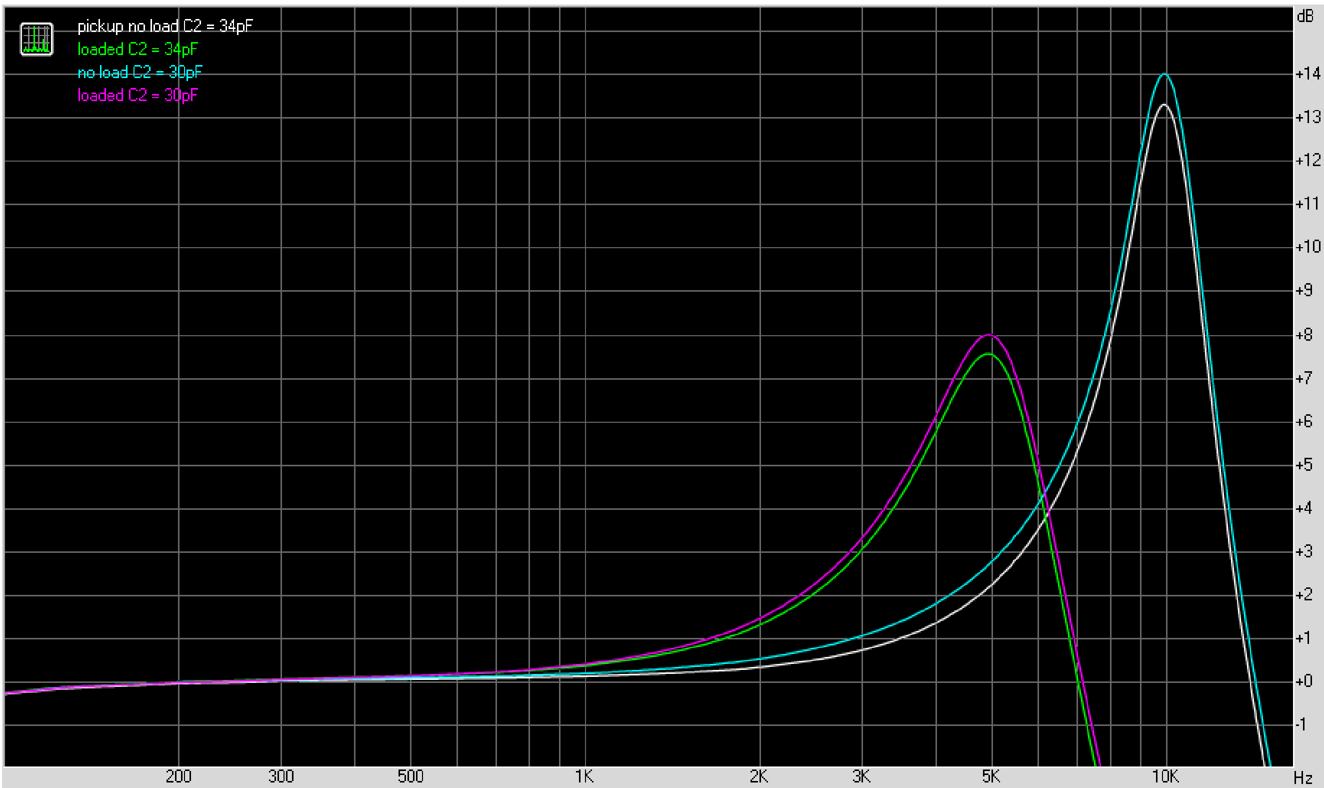
Illustration 10: Capturing measurement data

After the peak amplitude and frequency of the loaded and unloaded plots, and the frequency of the inductance test are recorded, the plots can be selected and scaled in various ways to highlight different aspects or display a useful overall graph. With eight slots available, more than one pickup can be compared with another, or changes in the pickup can be documented. I have found that it is useful to have a spreadsheet that can be used to enter the data that is produced by the plots, and automatically calculates key values, such as the inductance.

Input Frequency Response Calibration

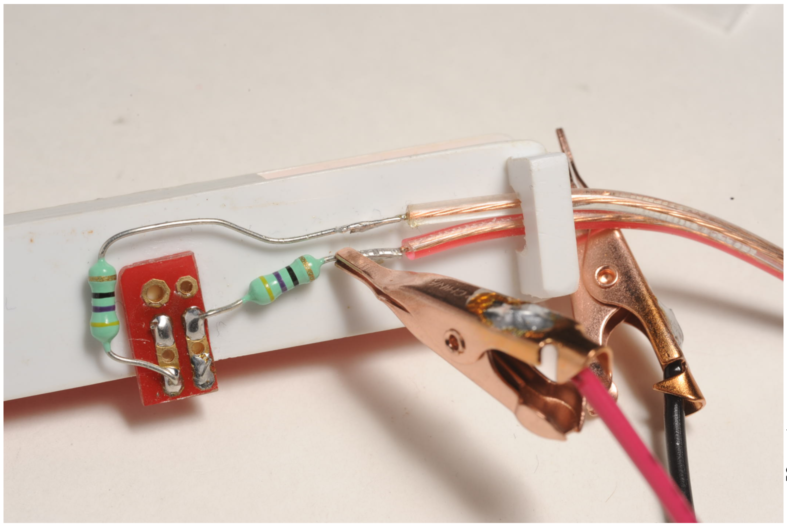
The input circuit consists of an RC voltage divider, as is used in most oscilliscope probes. Just as with the probes, stray capacitances in the circuit require that the capacitor values be adjusted to achieve a flat frequency response. Probes have an adjustable capacitor to allow user adjustment, and this feature is also built into the V5.8 PCB. Consequently, it is good to adjust variable capacitor C2 after constructing a new integrator. This should also be done if the op amp is replaced.

The values of C1 and C2 are chosen somewhat empirically to match the present layout and input capacitance of the LT1058 op amp, which influences the circuit. The 4pF/30pF (V5.6), 4pF/40pF (V5.7) 4pF/25-45pF (V5.8) combination comes quite close, but it isn't perfect. The difference shows up as an inaccuracy in amplitude values as measured here with an arbitrary pickup:



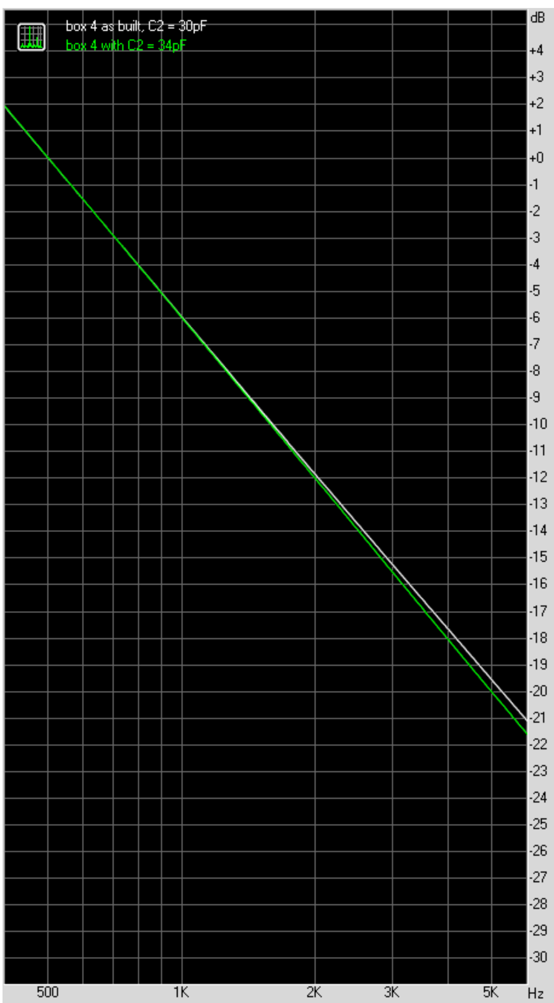
On an oscilloscope, the frequency response can be monitored by looking at the "squareness" of a test signal while adjusting the probe capacitor. Consequently, this method can also be used when the integrator is used with a software oscilliscope. I found another method so that the calibration can be performed without a scope, using only the integrator circuitry. The key is that the -20dB/decade slope of the integrator is combined with the input circuit slope. So, if the circuit is not balanced, a slighly different slope will be observed.

By appying the sweep test generator output directly to the input, it is possible to measure and graph the integrator slope, and adjust the capacitor values until it is closer to the desired -20dB response.



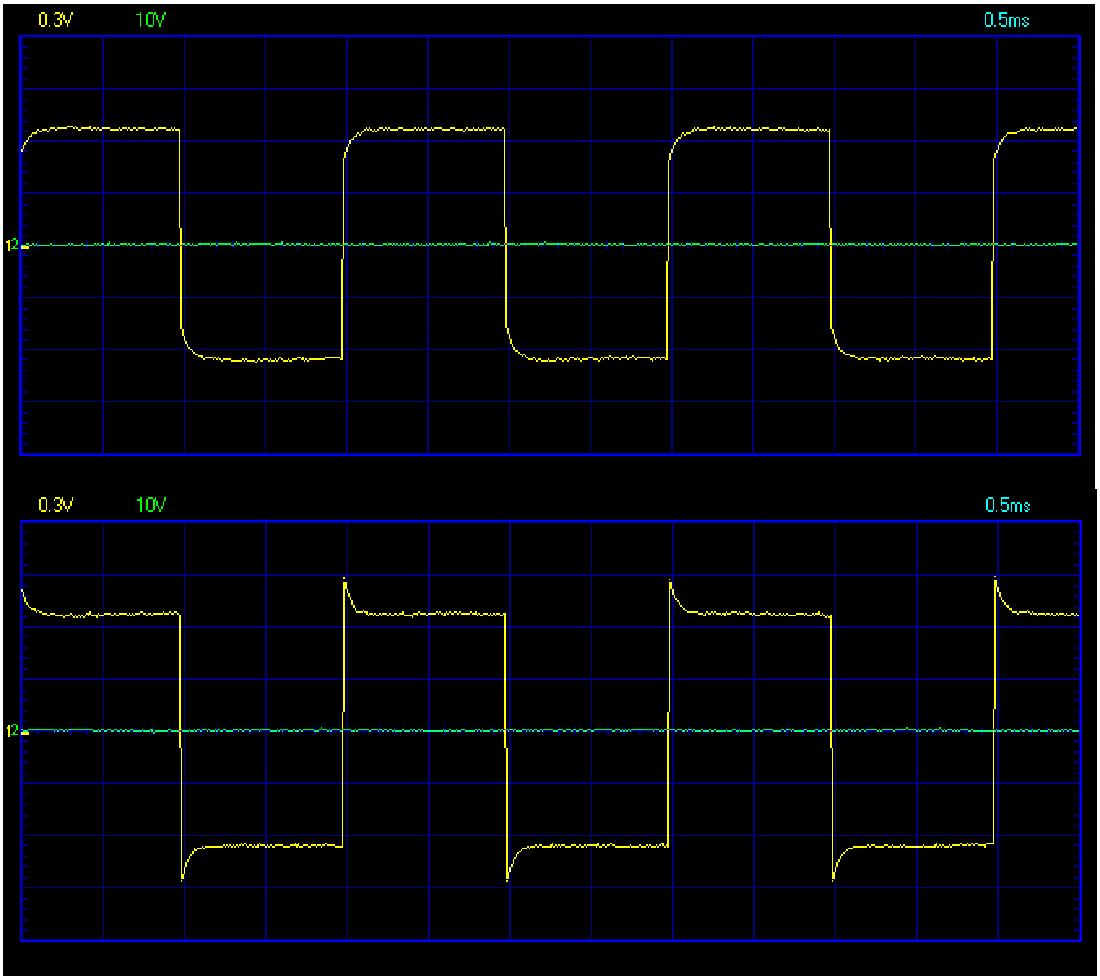
Since the grounds are usually common on the computer DAC interface, I found that I could just connect the input to the DAC output where it appears on the test coil (before the 100 ohm resistor!).

Running some test sweeps produces a plot that has useful slopes above 200 Hz or so. Below that, the huge gain distorts the curve but we can ignore that. By choosing two values that are a decade apart, the plot should show a -20dB difference. Choose 500 Hz as a low frequency, normalize it to 0dB and then examine the response at 5000 Hz. Adjusting variable capacitor C2 will alter the slope. Thus when the normalized response is exactly -20dB at 5000 Hz, calibration is complete.

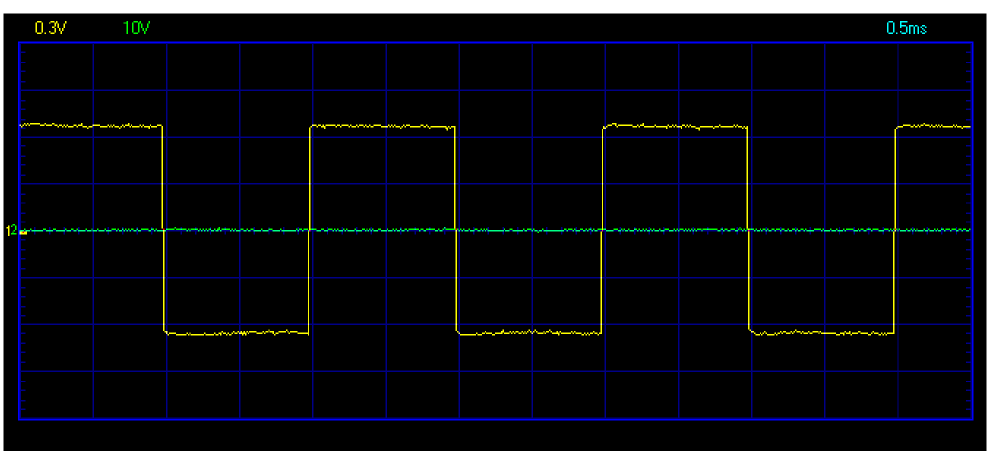


If an oscilloscope is available, it is much easier to adjust C2 using the traditional squarewave method. Apply an approximately 500Hz square wave from a signal generator, or from the calibration lug of the scope, if it has one, to the input of the integrator. Set the integrator to the "no load" position, Gain switch to +20dB, integration switch to "off". Connect the integrator output to a scope input.

You should see the square wave on the scope display. The leading edge will either overshoot or undershoot, as here:

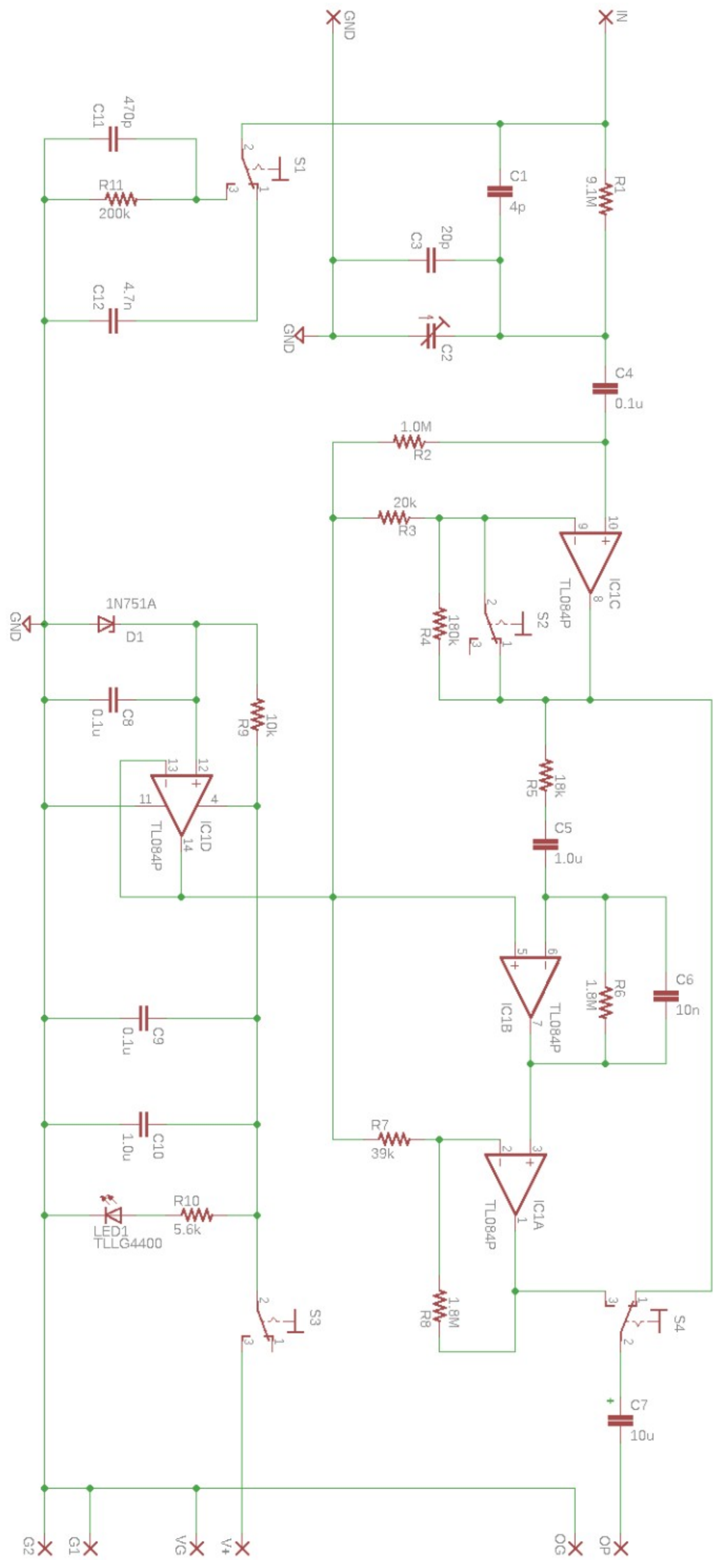


Simply adjust C2 until there is minimal undershoot/overshoot as below, and calibration is complete:



Appendix

V5.8 Integrator Schematic:



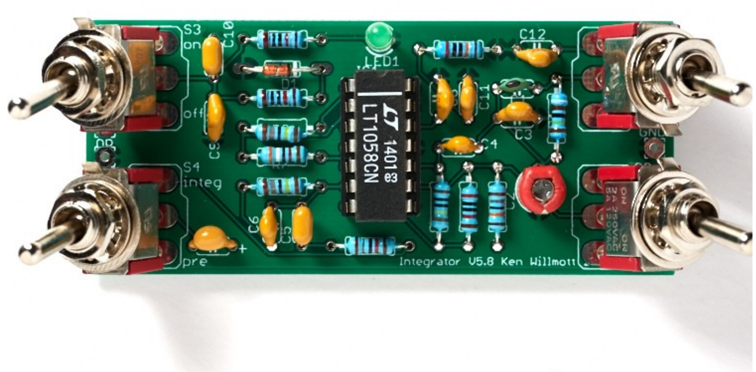
Note:

The schematic shows IC1 as a TL084P. This part will work, but the preferred part is the Linear Technologies LT1058ACN. The LT part has better GBP, which results in more accurate integrator response at higher frequencies.

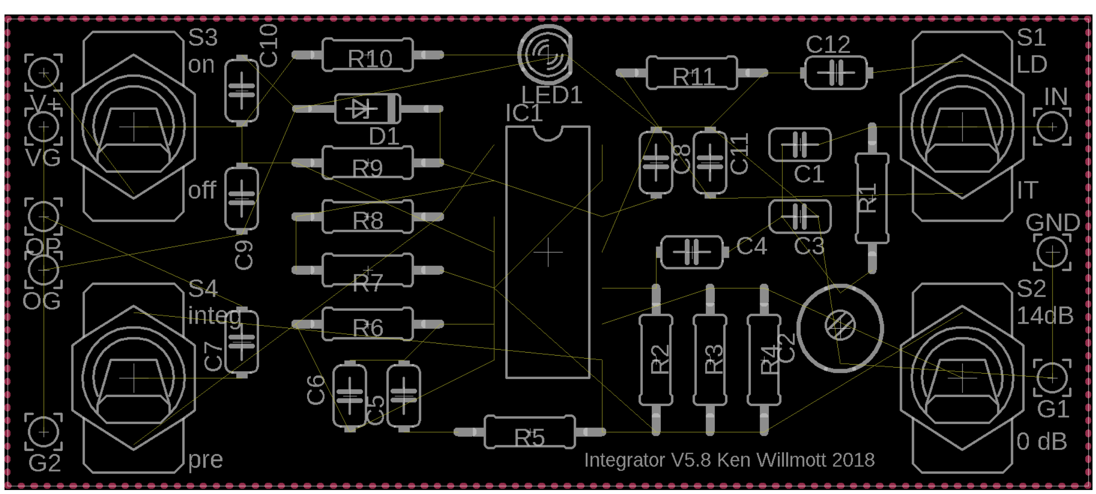
The input circuit is sensitive, so the test leads as well as the switch connections LD/COM/IT should be as short as possible. The circuit should be in a shielded enclosure, and the test surface must be grounded. It can be conveniently connected to one of the auxiliary ground points G1/G2 by running an additional wire and clip lead for that purpose, to a banana jack on the enclosure.

Because of the sensitivity of the circuit to small capacitances, the final device calibration should be performed with the entire device fully assembled, in its case. For this reason, I recommend placing C2 on the solder side of the PCB so that it is accessible to a screwdriver with the unit assembled and the enclosure cover removed. However, I have found that the input network is mostly affected by the input components including the op amp, and does not vary significantly enough to worry about, if for some reason this is not possible.

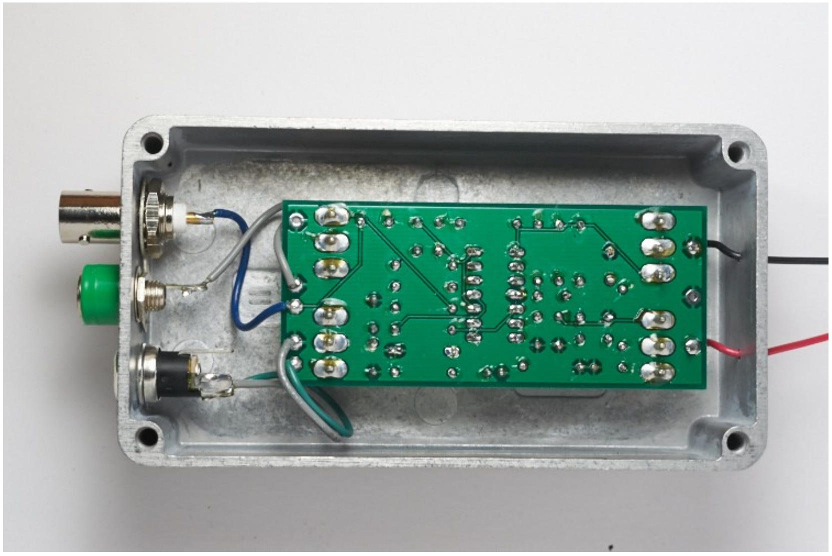
The V5.7 circuit has been upgraded to V5.8. Here is a view of an assembled V5.8 board:



V5.8 Integrator PCB Parts Layout:



Here is a recommended enclosure installation:



Notes:

1. The housing is grounded via the ground connection of the output jack. This can be a BNC or 1/4" phone jack, or any other audio plug. If the jack has no ground connection to the housing, then a separate ground connection must be made to the housing, or the auxiliary ground banana jack may be used for this purpose instead.
2. The auxiliary ground connection does not normally need a wire, because it can be mounted in such a way that the sleeve contacts the housing directly, providing a ground. If needed, it can be wired to G2 on the PCB.

In order to facilitate the alignment of switch mounting holes, it is preferable to assemble the switches into the housing prior to soldering them to the PCB.

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