ZRLC Electronic Interface

Three hardware implementations for impedance measurements with Visual Analyser

By Massimo Marucchi · English translation of the historical technical document (original: 75 pages)

About this edition

This volume brings together the four translated parts of the original Italian work on electronic interface circuits for ZRLC impedance measurement. The original author's first-person descriptions, experimental observations, technical values, circuit diagrams and photographs have been retained wherever possible. Figure and software-interface labels may remain in their original language.

Historical context: the software screenshots, operating-system instructions, component availability and equipment descriptions reflect Visual Analyser and PC hardware at the time the original document was written (around 2010). They are not instructions for the current version of Visual Analyser. Readers should verify any hardware construction and electrical-safety details independently before attempting a build.

In memory of Massimo Marucchi, whose practical experimentation and careful documentation contributed to the ZRLC project. This English edition preserves his technical account, observations, and personal voice.

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- Part IV — Third version: power output stage and additional circuits (original pp. 62–75)

Each part begins on a new page. Original page numbers are retained in the translated text where present.

Part I

Introduction and the first interface

This document is an English translation of a historical 75-page technical work by Massimo Marucchi, describing electronic interface circuits for ZRLC impedance measurements with Visual Analyser. It reflects the hardware and software available at the time of writing.

Part I corresponds to original pages 1–12. The complete English edition also includes Parts II, III and IV, covering all 75 pages of the original work. The author's first-person voice has been preserved.

1. Introduction

What I have built—hereafter referred to as "ZRLC"—relates to Alfredo Accattatis's work entitled "An Impedance Meter with Automatic Compensation of Systematic Errors", presented on the corresponding page at http://www.sillanumsoft.org/Italiano/zrlc.htm (click the red link to download it). My circuit provides the necessary complement to that work.

ZRLC is a practical, effective instrument for measuring impedance (Z), resistance (R), inductance (L) and capacitance (C), offering very good accuracy over an exceptionally wide range. In addition to measuring resistances from a few ohms to several megohms, its five ranges cover the following values:

Range	Resistance	Capacitance	Inductance
1	0.1 Ω – 1 kΩ	100 nF – 1000 µF	10 µH – 10 mH
2	1 Ω – 10 kΩ	10 nF – 100 µF	100 µH – 100 mH
3	10 Ω – 100 kΩ	1 nF – 10 µF	1 mH – 1000 mH
4	100 Ω – 1 MΩ	100 pF – 1 µF	10 mH – 10 H
5	1 kΩ – 10 MΩ	10 pF – 100 nF	100 mH – 100 H

Three versions are presented. The first, and simplest, uses the sound card built into virtually every PC. The second, called "All In One", incorporates its own sound interface and operates through a USB connection alone. The third, originally developed by the magazine Nuova Elettronica, improves measurement of resistances of only a few ohms and makes it possible to measure loudspeaker impedance.

2. Preface

ZRLC is a new specialized function of Visual Analyser (VA), which at the time of writing had reached version 2010 NE-XT – V.3 BETA. Its author, Alfredo Accattatis, had worked for many years as a software engineer in a variety of roles. He had written software for embedded systems (DSPs and microcontrollers), personal computers, avionics computers and even IBM mainframes (Z900), using C, C++, Pascal (Delphi / RAD Studio 2007), Ada, REXX and a variety of assembly languages.

What is VA? I quote its author:

"In the diverse world of Windows (9x, ME, 2000, NT, XP and Vista), there are already quite a few programs that turn a personal computer into an oscilloscope and/or spectrum analyser. Visual Analyser, however, offers some distinctive capabilities. It was originally created for enthusiasts of audio electronics—Class A and Class B amplifiers, oscillators and the like—but quickly developed into a set of general-purpose measuring instruments. Dedicated oscilloscopes and spectrum analysers can be prohibitively expensive for purely amateur use, even though they would make an experimenter's work much easier.

“Paradoxically, a PC-based package can be more flexible than a dedicated professional instrument: the sound card can be replaced, the computer upgraded with a faster processor or more RAM, or the program simply updated to a newer version. Printers, storage devices and other software remain available at the same time.

“The central idea is that most modern PCs already have a sound card, which in many cases is of good quality and can in any event be obtained very cheaply. Furthermore, the computing power of an ordinary PC is now sufficient to execute real-time routines that until only a few years ago were the exclusive province of digital signal processors.

“In practice, the program uses the PC sound card as an analogue-to-digital converter, with its left and right channels serving as inputs for a useful dual-trace oscilloscope. The main limitations are the bandwidth imposed by the audio hardware—approximately 10 Hz to 20 kHz—and the absence of direct-current inputs. The program handles everything else.”

The original site contained pages in Italian (http://www.sillanumsoft.org/Italiano/index.htm) and English (http://www.sillanumsoft.org/index.htm).

Visual Analyser features at the time of writing

1. Dual-trace oscilloscope, with time-base settings, X–Y display, triggering, cursor-based frequency and amplitude measurement, and a real-time values window.
2. Dual-channel spectrum analyser displaying amplitude and phase; linear and logarithmic scales, line and bar plots, and fractional-octave analysis (1/3, 1/6, 1/9, 1/12 and 1/24 octave).
3. Function generator designed to avoid aliasing: triangle, square, sine and pulse signals; a custom function built from a Fourier series using a graphical Visual Tool; Gaussian and uniform white noise, pink noise and DC generation with DC-coupled cards.
4. Frequency meter and counter in the time and frequency domains.
5. AC voltmeter (true RMS, peak-to-peak, mean, dB and DC measurements).
6. Digital filters: low-pass, high-pass, band-pass, band-stop, notch, “rectifier”, inverse notch and DC removal.
7. THD and THD+noise distortion measurement, with automatic frequency sweeps and graphs that can be stored in various formats, displayed separately and copied or saved.
8. X–Y inputs.
9. Complete D/A conversion in the oscilloscope.
10. Frequency compensation: editing or importing an arbitrary frequency-response curve to overlay on measurements, together with standard A, B and C weighting curves.
11. Storage of time- and frequency-domain samples, spectral analysis of stored samples, printing and export to .tee, .txt, .wmf and clipboard.
12. Internal viewer for .tee and .txt formats, independent of the acquisition windows.
13. Operating-system recognition including Vista and Windows 7.
14. Use of 80-bit internal floating-point variables to minimize rounding error.
15. Cepstrum.
16. Cross-correlation.
17. Extended THD measurement.
18. Real-time calculated parameters: peak-to-peak, peak, crest factor, form factor, true RMS, mean, frequency by zero-crossing and associated uncertainty.
19. Compatibility with Vista and Windows 7.

The historical development-news page was www.sillanumsoft.org/Italiano/news.htm. The then-current 2010 NE-XT – V.3 BETA release incorporated fixes and improvements through 22 March 2010 and was still under development, although already capable of controlling the interface and obtaining consistent results.

Release	Version
VISUAL ANALYSER 2010 0 - beta	12.0.0.1120
VISUAL ANALYSER 2010 3 - beta	12.0.0.1942
VISUAL ANALYSER 2010 4 - beta	12.0.0.1998
VISUAL ANALYSER 2010 5 - beta	12.0.0.2077
VISUAL ANALYSER 2010 NE-XT	12.0.0.2188
VISUAL ANALYSER 2010 NE-XT - V.1	12.0.0.2297
VISUAL ANALYSER 2010 NE-XT - V.2.1	12.2.0.2300
VISUAL ANALYSER 2010 NE-XT - V.2.2	12.2.0.2302
VISUAL ANALYSER 2010 NE-XT - V.2.3	12.2.0.2304
VISUAL ANALYSER 2010 NE-XT - V.2.4	12.2.4.2305
VISUAL ANALYSER 2010 NE-XT - V.3 BETA	12.3.0.2306

The original software-download page was http://www.sillanumsoft.org/Italiano/scarica_programma.htm; the beta release was also distributed at an address on casa.accattatis.org and within the Files.zip package associated with the source document. These are historical references, not verified current download locations.

3. The ZRLC Analyser

I again quote the author:

“A short preamble: to obtain more than merely amateur-level performance from ZRLC, a very simple additional hardware circuit must be built. Initially, this amounts to a pair of operational amplifiers connected as impedance buffers, intended to make the input impedance of the instrument as high as possible. The reason is straightforward: a low input impedance, typical of sound cards, appreciably disturbs the impedance under test and therefore reduces measurement accuracy.”

As the author himself notes, this long-running project was inspired by earlier work, including that of Dr George Steber and an article by Martin Klaper and Heinz Mathis in Elektor. The source document refers to two papers, “Steber_An_LMS_Impedance_Bridge.pdf” and “RLC_Meter_EN_01.pdf”. Those works explain the underlying theory in detail.

Earlier applications using the same ZRLC circuit relied on software that was rather cumbersome and far from intuitive; calibration had to be carried out manually and the instructions were not particularly clear. Their main virtue was a thorough explanation of the operating principle. The ZRLC page mentioned above gives the essential explanation in English. I shall summarize it here, beginning with the general principle.

The voltage-divider principle

Imagine a voltage divider consisting of two resistors, Rm and Rs, with a known voltage Vr across the series combination. The voltage Vx across Rs is:

$Vx = Vr \times Rs / (Rm + Rs)$

If Rm = Rs, then $Vx = Vr \times Rs / (2\ Rs) = Vr / 2$. Since Rm is known, Rs can be obtained by measuring Vr and Vx.

If we now replace the DC voltage with a sinusoidal AC voltage of known frequency, the basic principle remains the same. The resistor Rs can then be replaced with a capacitor or inductor: Vx depends on its capacitance or inductance and on the frequency. Instead of resistance, however, we must work with the component’s impedance Z.

Impedance can be expressed in rectangular form, $Z = R + jX$, where R is its real (resistive) part and jX is its imaginary (reactive) part. It can also be expressed in polar form, $Z = |Z|\angle\theta$, where θ is the impedance phase angle.

In practice, a more sophisticated version of the simple voltage divider is needed. The input impedance of both line-input channels of the sound card—used to acquire Vr and Vx—must first be raised as much as possible by two operational amplifiers. Visual Analyser generates Vr at the right-hand line output, measures Vr and Vx on the two line inputs, and performs the required calculations.

VA was designed around an important principle: avoid overwhelming the user with settings and technical details, particularly on the first run. This is a considerable improvement over the earlier software. Nevertheless, two or three essential settings—one in the sound-card volume controls and others in VA—can completely prevent the instrument from working if overlooked. I confess that discovering these details took considerable effort, not least because the author had never found time to prepare a user manual. Once this hurdle is overcome, operation really does become a matter of clicking a button and connecting the unknown component.

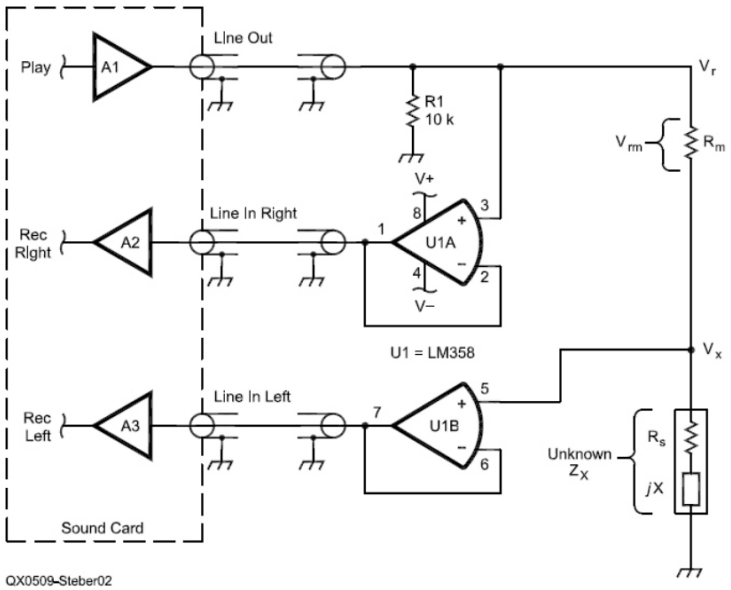
4. First version: basic ZRLC

4.1 The measurement circuit

The original circuit uses the sound card's right line output ("Play") to drive the measurement network and its right and left line inputs ("Rec") to acquire two voltages. The outputs of operational amplifiers U1A and U1B feed the right and left inputs, respectively. R1 provides a ground reference for the sound card. The unknown impedance Zx comprises a real part Rs and an imaginary part jX. The fully developed, working schematic is shown below.

Il circuito elettronico di misura

Nella versione originale, lo schema del circuito è questo:



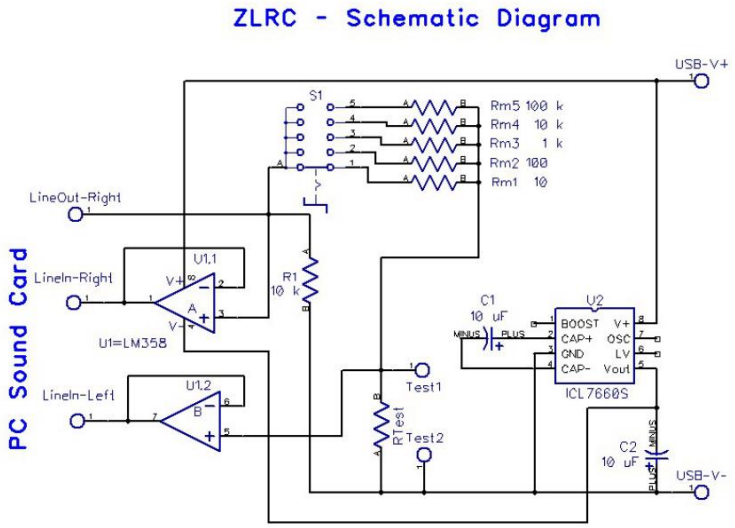
Con "Play" si intende "Line Out" o "Uscita Linea"; con "Rec" si intende "Line In" o "Entrata Linea". Il canale usato per "Line Out" è il **Destro** (Right); le uscite degli

Original circuit concept, reproduced from page 9 of the Italian document. Symbols and electrical connections are unchanged.

4.2 Left-hand section: operational amplifiers

As in the original design, the two operational amplifiers are the halves of an LM358. The principal change is a five-position rotary switch selecting one of the five values suggested by the author: 10 Ω, 100 Ω, 1000 Ω, 10 kΩ and 100 kΩ. The corresponding measurement ranges are listed in the table at the beginning of this document and in the list box to the right of “Reference” in the VA ZRLC window.

Most illustrations in the original document, with some exceptions, refer to an older release (2010 4 – beta), preceding the 2010 NE-XT series. The switch position and the selected software range must match. Otherwise, the indicated value can be wrong by a factor of ten or more: a 100.54 nF capacitor, for instance, might be displayed as 10.054 nF or 1005.4 nF. VA also provides a suggestion to move up or down a range using the symbols “(u)” for up and “(d)” for down.



Vediamone i dettagli.

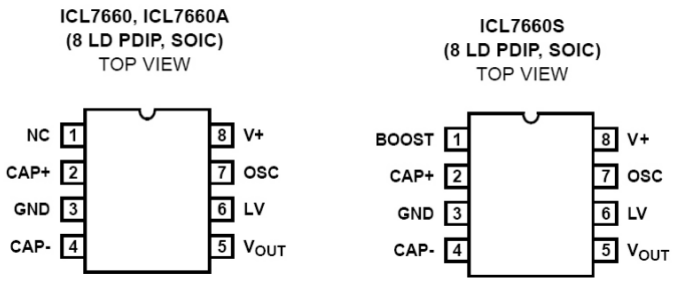
Working schematic from the original document (page 10).

4.3 Right-hand section: negative-voltage generator

This section uses an Intersil ICL7660S (or ICL7660). What is its purpose? The two operational amplifiers use the conventional bipolar supply, V+ and V−. In principle this could be achieved with four AAA cells and a central ground tap, providing approximately +3 V and −3 V. It is preferable to keep supply voltages low to protect the sound card in the event of a fault. But since the circuit is attached to a computer, can its power supply be used instead, avoiding batteries and all the problems associated with them? Certainly.

Every PC provides USB connectors with +5 V and ground. Only −5 V is missing. A voltage converter such as the ICL7660 solves the problem. With just two small electrolytic capacitors—one for the charge pump and one for energy storage—it converts a positive supply within its specified range of approximately +1.5 to +10 V into a corresponding negative voltage. Positive supply is applied between pins 8 (V+) and 3 (GND); the negative supply appears between pins 5 (V−) and 3.

Ogni PC dispone di una serie di connettori USB, completi di due collegamenti a +5V e massa. Mancherebbe solo il -5V. Niente paura. Basta un "Voltage converter", come appunto l'**ICL7660**. Con solo due condensatori elettrolitici di bassa capacità (per la pompa di carica e l'immagazzinamento) realizza la completa conversione di tensione di alimentazione da positivo a negativo per qualsiasi tensione tra + 1.5V e + 10V, fornendo la tensione complementare (uguale in valore assoluto) di -1.5V a -10V. La tensione positiva viene applicata tra i piedini 8 (V+) e 3 (Gnd); la corrispondente tensione negativa si ritrova tra i piedini 5 (V-) e 3.



Historical ICL7660 / ICL7660S pinouts reproduced from page 11. Always consult the appropriate component datasheet before construction.

4.4 Grounding, connections and calibration resistors

One detail not apparent from the schematic is the need for a physical ground connection between the USB ground line (USB −V) and the ground terminals of the panel-mounted stereo jack sockets. Initially I assumed that the corresponding connections inside the PC would be at the same ground potential. Without a direct connection, however, the interface did not work: oscilloscope measurements showed nonsensical waveforms going toward the line input.

Because the two jack sockets are mechanically fixed to the same metal front panel, their ground contacts are electrically continuous. It is therefore sufficient to connect the ground terminal of one socket to the panel terminal marked "Test2", which in turn is wired to the corresponding interface-board connection.

Before soldering, use a multimeter to establish the correspondence between the terminals of the panel sockets and the plugs on the two male-to-male stereo cables used to connect the interface to the PC sound card. Insert a plug into its socket and test the right, left and ground connections at the free plug against the socket terminals.

Reading the original papers suggests that precision measuring resistors Rm should be used and their exact values known. In actual operation, I found that this is not strictly necessary, as discussed later in the calibration chapter. Obtain two sets of five resistors: one set is installed on switch S1 and the other set is retained as carefully measured test standards for calibration.

USB Type-A connections

For completeness, the standard Type-A connector pin assignments used in the original design are given below. The 500 mA maximum shown is the historical USB 2.0 supply-current context described by the author, not a universal rule for all modern USB ports.

Pin	Name	Function	Wire colour
1	Vcc	+5 V supply	Red
2	D−	USB data −	White
3	D+	USB data +	Green

4	GND	Ground	Black

The document next illustrates the standard stereo-jack connections used on PC audio peripherals. R is the right channel, L the left channel, and the third contact is ground. The following chapters in the original document describe construction, operating settings and calibration.

Continuation and source note

Translation coverage: original pages 1–12 of 75. Chapters on construction, detailed settings, zeroing, calibration, PCB fabrication, the “All In One” version, alternative measurement methods and the Nuova Elettronica version have yet to be translated. No technical content from those chapters is claimed to be included in this Part I.

Part II

First version: construction, setup and calibration

Construction

Original document: page 13 / 75

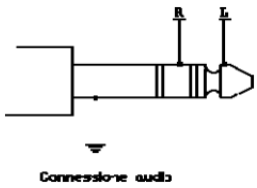
These are the connections of the stereo jack plugs commonly used with PCs and audio peripherals, together with the location of the audio-card connectors on a PC. R means Right, L means Left, and the third contact is ground.

It is now time to show the working prototype of the measuring interface. I should explain that a very long time passed between my student days, when I was enthusiastic about electronics, and the present, when I have taken up my old passion again. For the moment I have not thought it worthwhile to equip myself to make printed circuit boards, as I used to do. Instead, I built the circuit on a stripboard with 2.54 mm (more precisely, one-tenth of an inch) spacing and parallel copper tracks.

Here is the board layout. On the left is the component side, with the track pattern shown through it; on the right is the copper side. The board measures approximately 30 × 50 mm.



Original illustration · source p. 13 · 1



Original illustration · source p. 13 · 3



Original illustration · source p. 13 · 4



Original illustration · source p. 13 · 5

Building the stripboard

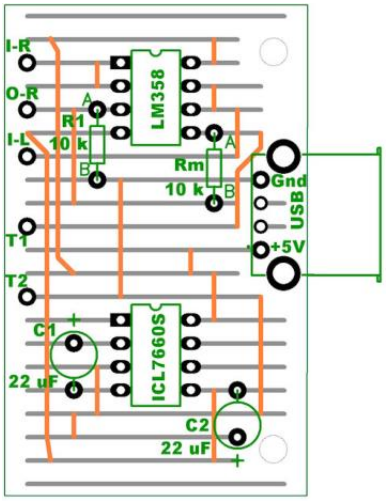
Original document: page 14 / 75

The orange connections are wire links. As you can see, I used a PCB-mounted USB socket, which is convenient to use and gives the assembly good mechanical and electrical robustness. Resistor Rm is not actually installed on the board because, as mentioned above, it is replaced by the external range selector.

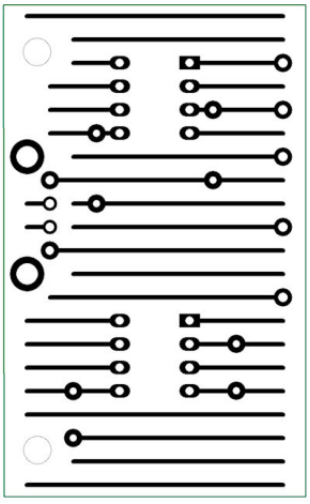
Some copper tracks are shortened or interrupted where required by the circuit. I used a small 1 mm steel milling bit fitted to a Dremel to remove the copper at the appropriate points.

Here is the actual board, copper side, with the USB connector visible at the top.

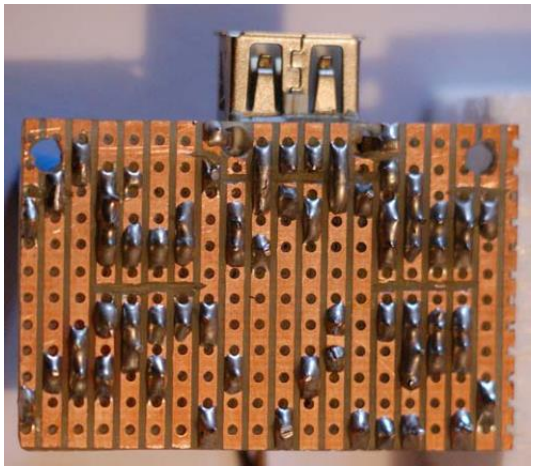
And here is the same board viewed from the component side.



Original illustration · source p. 14 · 1



Original illustration · source p. 14 · 2



Original illustration · source p. 14 · 3

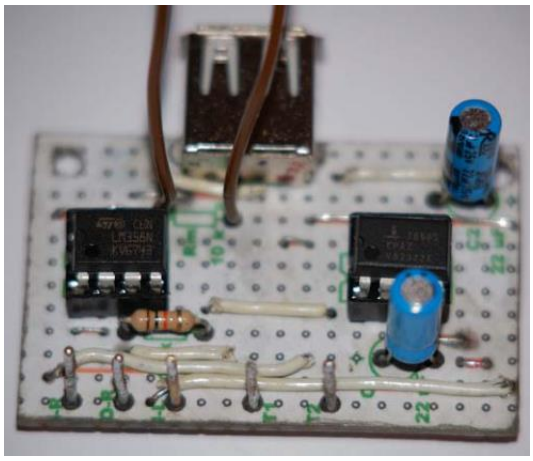
Components and range selector

Original document: page 15 / 75

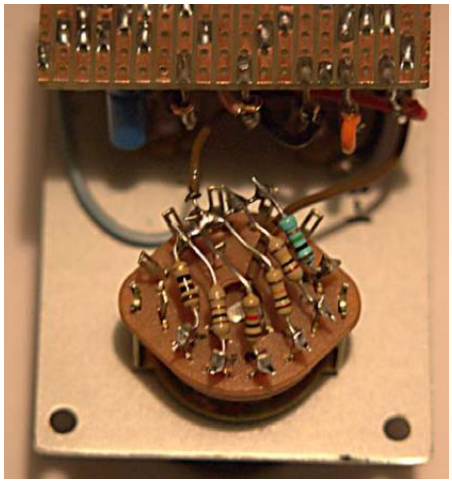
As you can see, there are more wire links than components! The LM358 is on the left and the ICL7660S on the right. In order, the terminals are “LineIn-Right”, “LineOut-Right”, “LineIn-Left”, “Test1” and “Test2”. The resistor is R1.

The two brown wires leaving the points labelled “Rm 10 K” lead to the rotary switch illustrated below. Attentive readers will notice a sixth 1 MΩ resistor, added for possible experiments because the switch has six positions. In practice, however, I did not use it.

Here is the switch mounted on the panel, alongside the jack sockets and the terminals for the component under test. The board is temporarily held by the seven wires that connect it to the panel-mounted parts. It will then be secured to the bottom of the enclosure with two screws and nuts. I have already made the necessary mounting holes and the slot for the USB socket.



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Original illustration · source p. 15 · 2

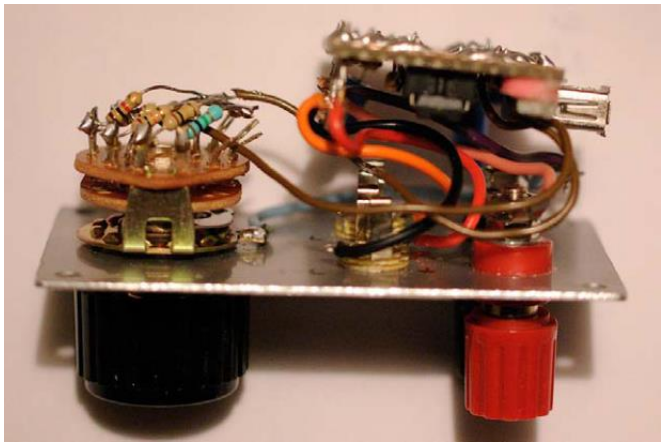
Enclosure construction

Original document: page 16 / 75

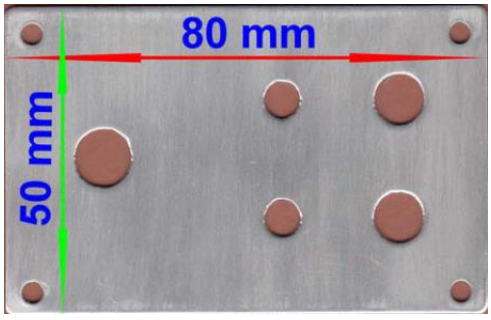
This is the aluminium front panel.

And here is the bottom of the enclosure, with the slot and two spacers for the board. Unfortunately, this was not an easy photograph to take...

With the board installed inside the enclosure, the USB socket is visible through the side opening.



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Original illustration · source p. 16 · 2



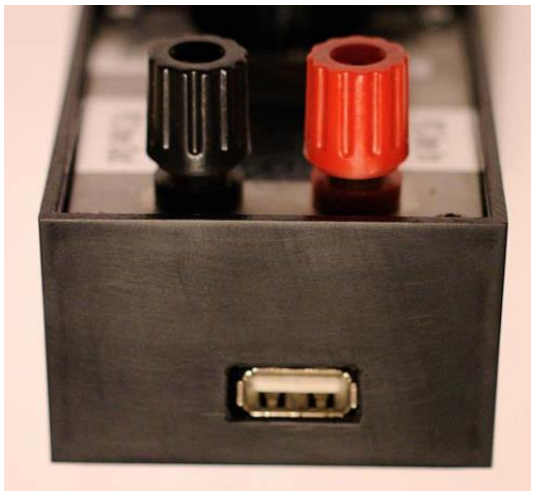
Original illustration · source p. 16 · 3

The completed prototype

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Here is the finished enclosure. I labelled the front panel using a Dymo “LabelPoint 150” label maker.

I completed the instrument with two test leads for connecting the components to be measured, each fitted with a banana plug at one end and a crocodile clip at the other.



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Original illustration · source p. 17 · 2

Settings and use

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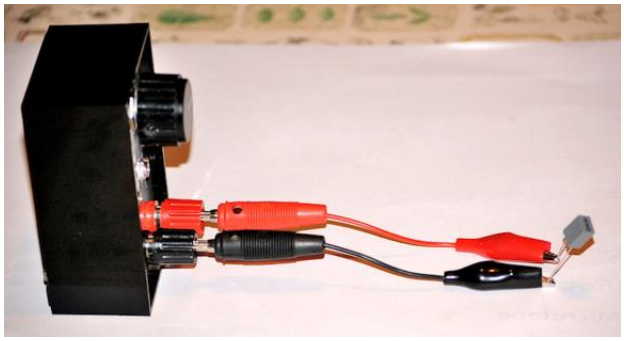
Assuming that the whole assembly is complete, the wiring has been checked, and the positive and negative 5 V supplies have been verified at pins 8 and 4 of the LM358, and so on, connect the interface USB socket to a USB socket on the PC using a type-A-to-type-A cable. Then use two male-to-male 3.5 mm stereo jack cables to connect the interface's “PC line In” socket to the blue Line Input socket of the sound card, and its “PC line Out” socket to the green Line Output socket. Naturally, the PC must be switched on.

Now start VA (VA.exe).

The analyser power button appears on the left. Leave it as it is for now. From the list box in the centre, select “Line Input”. Click “Input Gain”, which opens the Windows Recording Control panel, and “Output Gain”, which opens Master Volume. In Recording Control, “Line Input” should be selected, with a check mark in the “Select” box. Make sure the volume slider is at the top and that Balance is centred.

If you never change Balance, it will normally be set to 50% Left and 50% Right. If you move it, however, it is almost impossible to tell the actual percentages from the Windows control panel. If it is changed between uses of the analyser, the relative sensitivities of the two inputs will change and the instrument will give incorrect results.

Fortunately, in my case the integrated motherboard sound card (a “SoundMAX®”) has its own control panel, which supplements the Windows controls and displays numerical settings when the sliders are moved. This avoids unpleasant surprises. Perhaps your sound card has a similar panel.



Original illustration · source p. 18 · 1



Original illustration · source p. 18 · 2

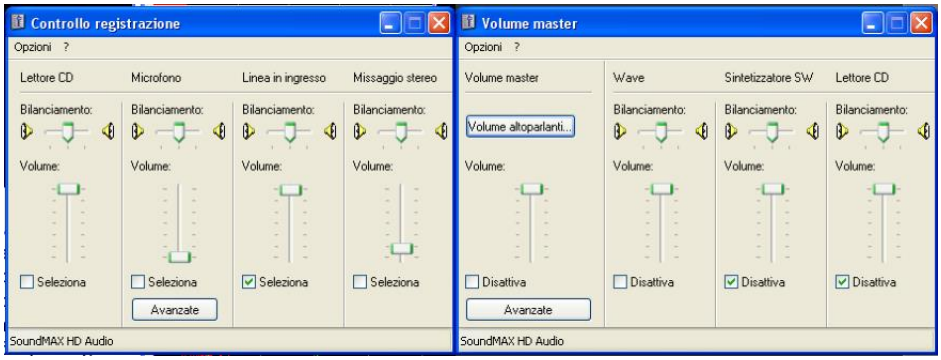
Windows audio controls

Original document: page 19 / 75

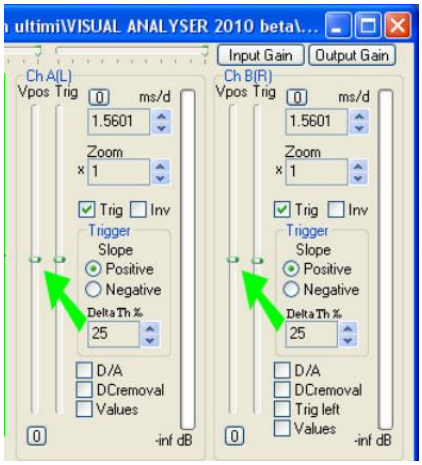
Note that “Line Input” is not normally selected when Windows starts. Unless it is selected, VA cannot operate because it does not receive the two voltages from the divider. Master Volume is usually already correctly set; at most, you may need to disable “SW Synthesizer” and “CD Player”. See the illustration below.

Now several VA parameters must be set. Check the two “Trig” boxes and move the four vertical “Vpos” and “Trig” sliders, for both channels, to the midpoint of their travel.

At the lower right, make sure “A and B” is selected in the “Channel(s)” list box. Check “X - Axis - Log” and uncheck “Y - Axis - Log”.



Original illustration · source p. 19 · 1



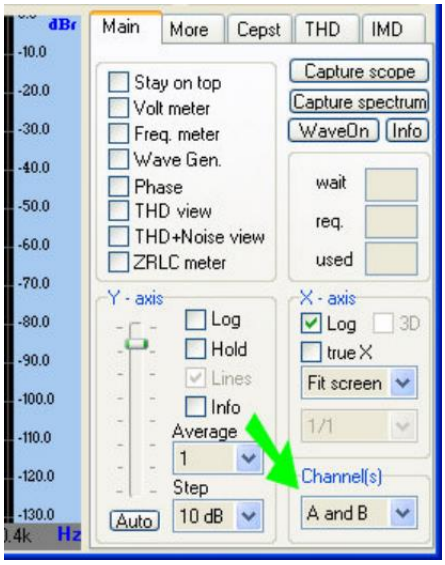
Original illustration · source p. 19 · 2

VA configuration

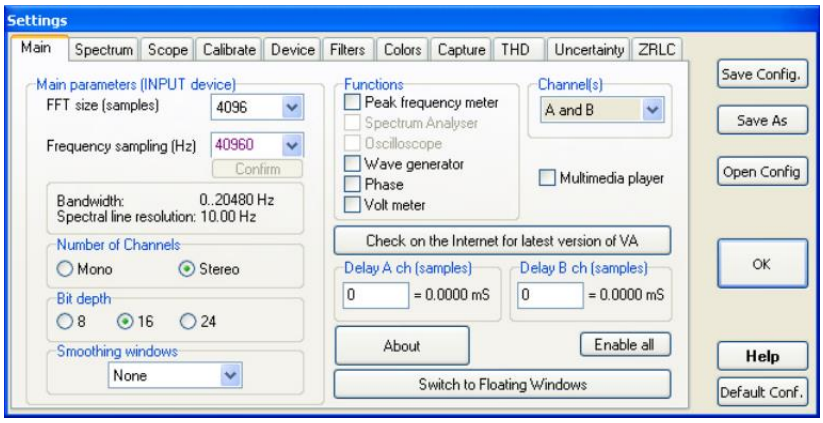
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Click “Settings” at the upper left, immediately to the right of the power button. In the window that opens, select the “Main” tab and check that “A and B” is selected in the “Channel(s)” list box. Refer to the illustration.

Select the “ZRLC” tab and check “Auto Bias”. This is absolutely essential.



Original illustration · source p. 20 · 1



Original illustration · source p. 20 · 2

Preparing a measurement

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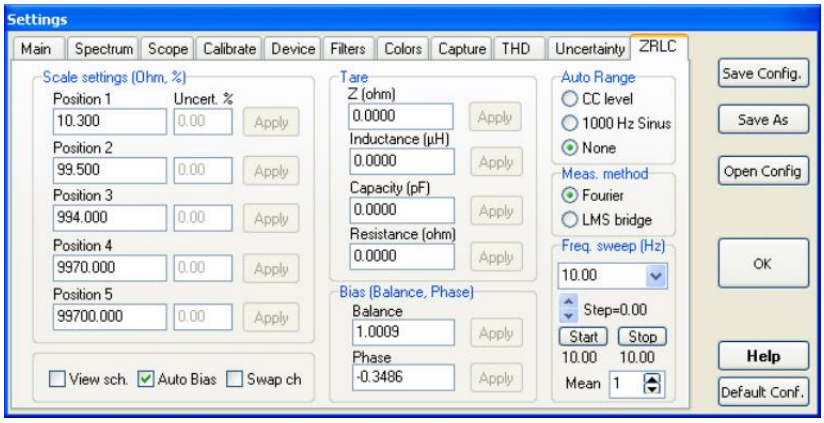
In the five fields of the “Scale settings (Ohm, %)” area, positions 1 to 5 initially contain the standard values 10, 100, 1000, 10000 and 100000. The values shown in the illustration, obtained by calibrating my own instrument, will be determined during the calibration procedure described later.

We are ready to begin. Check the “ZRLC meter” box on the right-hand side of the lower half of the main VA window, beside the spectrum display. The “ZRLC meter FOURIER” window opens. Leave the frequency at 1000.00 Hz, as displayed at the top. The power button, previously marked On, will now show Off, meaning that it can be used to turn the instrument off—not to exit the program.

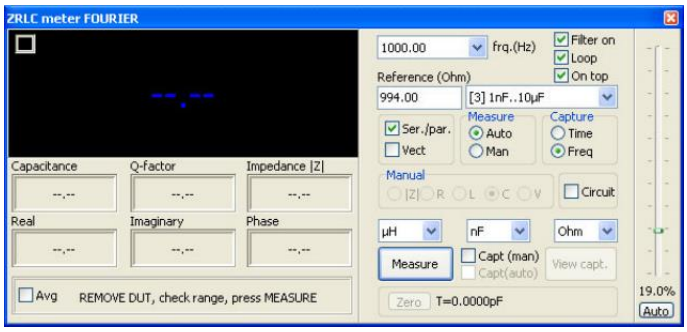
Move this window so that the main VA window remains visible as a check on correct operation. You can now take a measurement.

1. At this stage do not connect anything to the “Test” terminals.

2. Set the rotary switch to position “3” and select “[3]” from the list box under “Reference (Ohm)”. (You can choose any position, provided the hardware and software settings match.)



Original illustration · source p. 21 · 1



Original illustration · source p. 21 · 2

Taking the first measurement

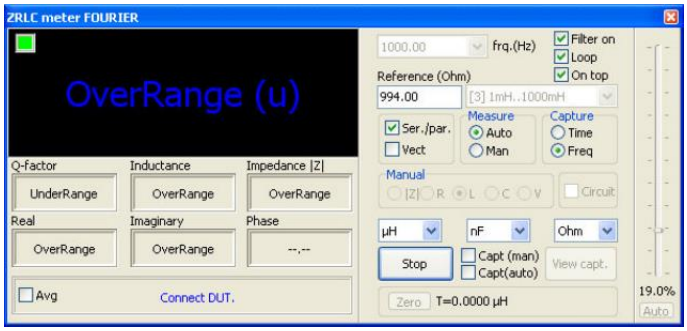
Original document: page 22 / 75

3. Click “Measure”. The analyser performs an initial calibration, which may take several tens of seconds, after which “Connect DUT” appears (DUT = Device Under Test).

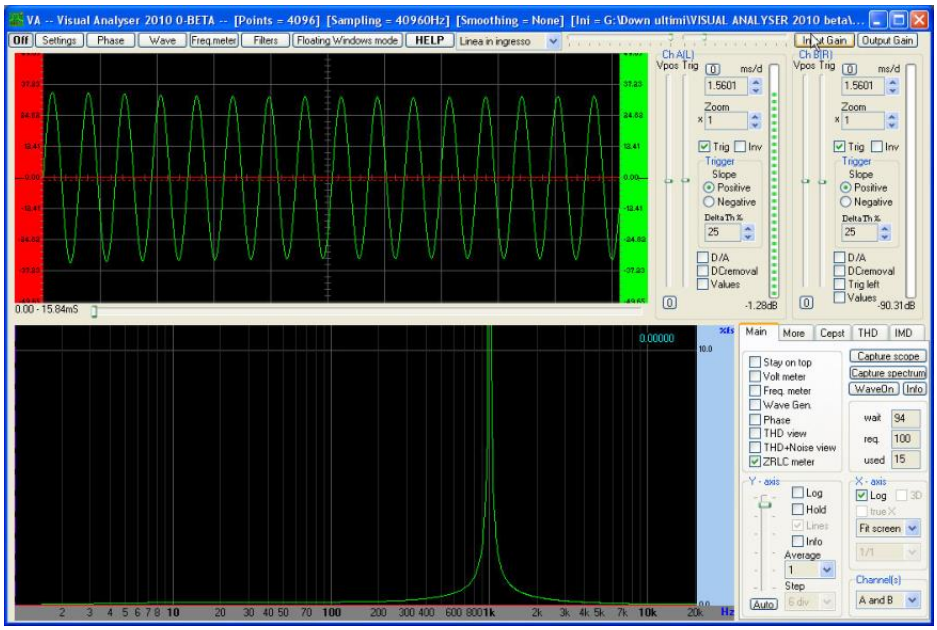
If you look at the main window, the oscilloscope in the upper graph shows the 1000 Hz sine wave applied to the divider; the spectrum display shows a peak at 1 kHz.

Warning! If these traces do not appear, something is wrong. Check your settings and connections again.

4. Now connect the component to be measured (hereafter the “DUT”). The example shows the result obtained with a 56 nF capacitor.



Original illustration · source p. 22 · 1



Original illustration · source p. 22 · 2

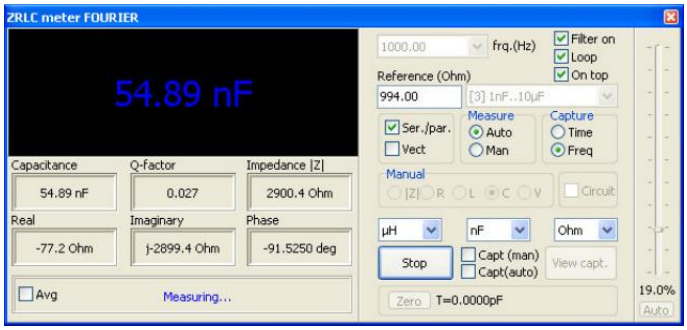
Reading the results

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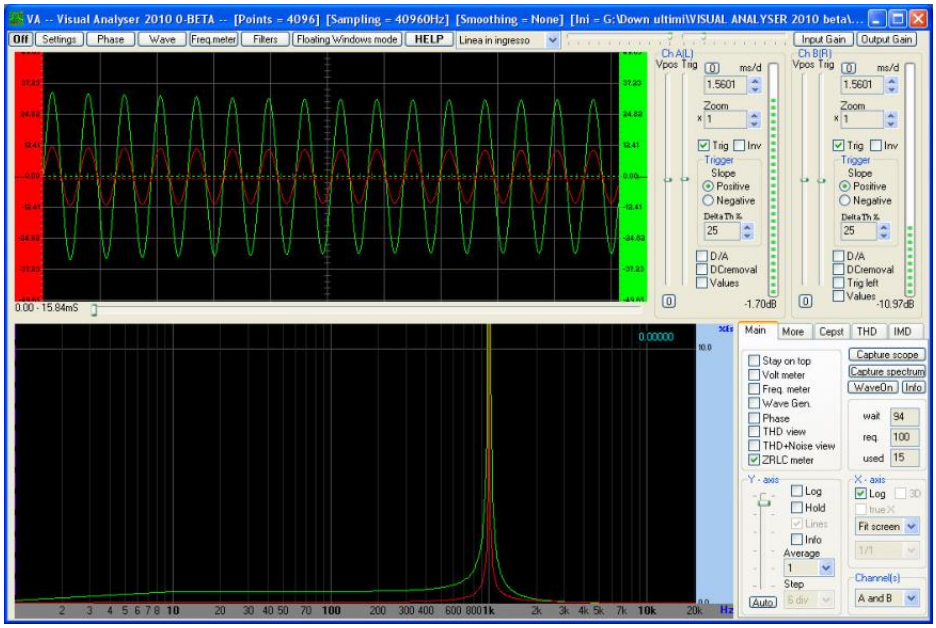
If you look at the main window again, a second (red) sine wave has appeared. This represents the alternating voltage across the component under test. Likewise, a second peak appears in the spectrum display, centred at the same frequency as the first.

You may see “(u)” or “(d)” to the right of the measured value, meaning “Up” or “Down”. These indications mean that the selected range is unsuitable. Press “Stop”, disconnect the DUT, change to a higher or lower range as indicated, and start again from step 1.

If everything is satisfactory, you can disconnect the DUT and substitute another similar component—for example, when selecting two or more components with the closest possible values.



Original illustration · source p. 23 · 1



Original illustration · source p. 23 · 2

Measurement interpretation and the need for calibration

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Some readers may wonder how the program identifies the correct electrical quantity for the component being tested: in this case capacitance, displayed in pF, nF or µF. Remember the voltage divider discussed at the beginning? When a capacitor or inductor is inserted in the divider, its reactive component produces a phase shift θ (theta) between the alternating voltage across the divider and the voltage across the component. Together with the sound card's analogue-to-digital converter, the program detects this shift (leading or lagging as appropriate) and responds accordingly. The choice of unit depends on the measured value and range.

This happens when “Auto” is selected in the “Measure” section. If you select “Man”, the five buttons in the “Manual” area below become active, allowing you to choose which quantity to display. If you choose “R” or “L” with a capacitor connected, no reading appears.

Before making other measurements, however, it is advisable to calibrate the analyser.

This subject was not covered in Accattatis's article. From reading it and examining the software, one might think it sufficient to measure accurately the five reference resistors installed on the switch and enter their actual values under “ZRLC” in “Settings”. But this is not so!

In my first tests I measured a nominal 10000 Ω resistor whose actual value, according to my digital meter, was 9920 Ω. ZRLC displayed 9950 Ω, even though I had entered the measured actual values of the five reference resistors, using the same meter. It was not an intolerable error, but could accuracy be improved?

To investigate, I connected an oscilloscope to the voltage across the divider and to the output voltages. I noticed that they changed with the position of the switch. The output impedance of my sound card may be too high for this particular application. Another op-amp could be inserted between the audio output and the divider as a buffer, but who can establish the true cause? Fortunately, there is an easier way, described next.

Calibration: principle and zeroing resistance

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Here is the procedure I devised to calibrate the instrument as accurately as possible... at least, I hope so! Suppose that the reference resistor Rm and the resistor under test Rs have the same value. The voltage Vz across Rs should be half of the reference voltage Vr. In theory, the program solves the voltage-divider equation and assigns Rs the same value as Rm, namely the value entered under “Scale settings” in the “ZRLC” window. If the result differs, there must be factors other than the divider itself affecting the final reading. Other instrumental parameters, besides the real values of the reference resistors, must therefore be taken into account; in my opinion, it does not matter if they are not known exactly.

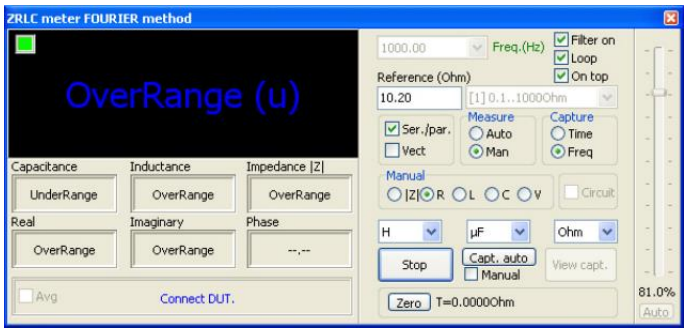
To make the instrument display the true test resistance, it is not enough to enter the actual reference-resistor value in Settings. Instead, enter an adjusted value which causes the program's calculation to produce the real result. This value can be found quite easily by comparing, once and manually, the true resistance under test with the value displayed before correction.

To calibrate the analyser, proceed as follows. Earlier I suggested preparing a set of five test resistors with the same nominal values as those fitted to the selector. Their precise values are not particularly important, provided they are within their manufacturing tolerances.

Before starting, zero the instrument. Zeroing is especially important for resistance measurements, because the leads always have a residual resistance, ranging from a few tenths of an ohm to approximately 1 Ω. It is also important for small capacitances.

The Zero function is enabled only while a measurement is running and only on the lowest ranges: position 5 for capacitance and position 1 for the other measurements. Set the rotary switch to position 1 and choose “[1]” under “Reference (Ohm)”. Select “Measure - Man - R” and click “Measure”. After the automatic initial calibration, “Connect DUT” appears. The “Zero” button is enabled, with “T=0.0000 Ohm” beside it.

Short the ends of the test leads together. Their resistance will be displayed (1.032 Ohm in this example).



Original illustration · source p. 25

Zeroing resistance and capacitance

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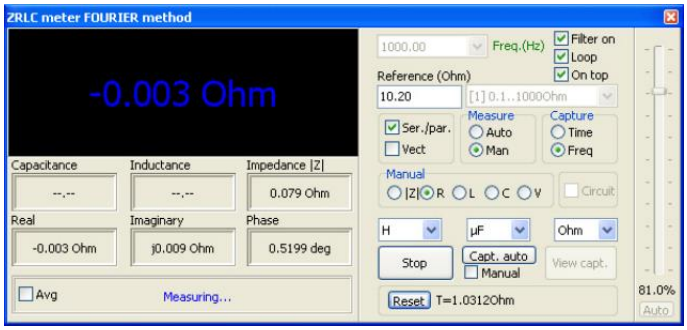
Click “Zero”. The button changes to “Reset”, and “T=1.0312 Ohm” appears beside it. The displayed lead resistance is now approximately zero. Slight fluctuations in the readings during these operations are normal.

For capacitance, proceed similarly, but set the rotary switch to position 5 and select “[5]” under “Reference (Ohm)”. Choose “Measure - Man - C”. Leave the leads disconnected from each other and from every component, then click “Measure”.

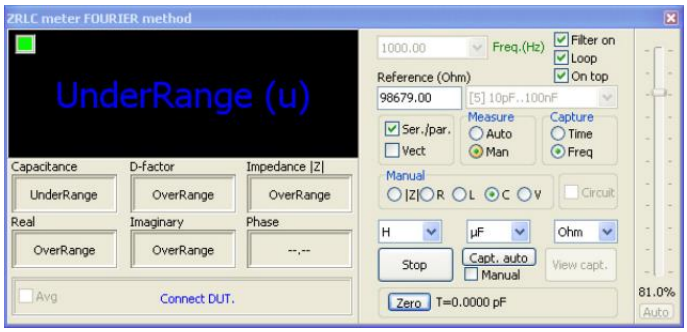
After automatic calibration, when “Connect DUT” appears, the “Zero” button is enabled and “T=0.0000 pF” is shown beside it.



Original illustration · source p. 26 · 1



Original illustration · source p. 26 · 2



Original illustration · source p. 26 · 3

Calibration using reference resistors

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Click “Zero”. It changes to “Reset” and the indication becomes, in this example, “T=3.2773 pF”, representing the total residual capacitance.

We can now carry out the actual calibration.

a. Use your meter to measure the five test resistors that you intend to keep for this purpose, and record their values. Remember that the analyser's accuracy will be limited by the accuracy of the meter you use.

b. Open “Settings”, select the “ZRLC” tab and leave this window visible.

c. Start the measurement as described from step 1 under “Settings and use”, setting both the switch and the software to position [1].

d. At step 4, connect the 10 Ω test resistor and record the reading.

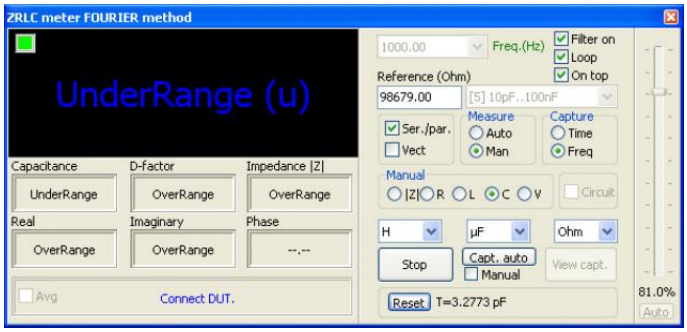
e. Suppose the test resistor's actual value is 10.40 Ω (Rp), while the displayed reading is 10.10 Ω (Rv). Calculate the factor:

$$F = Rp / Rv$$

In this example, F = 10.40 / 10.10 = 1.0297.

f. Without pressing “Stop”, click the field for “Position 1” under “Scale settings” and replace 10 with 10 × 1.0297, that is, 10.30 (there is no need to be too fussy...). You will notice that “Apply” for this position, previously unavailable, becomes enabled. Click it to apply the change. The correct value should appear immediately, apart from small, unimportant fluctuations.

g. Repeat for the other four positions, using the corresponding test resistors and restarting each time from step c.



Original illustration · source p. 27

Saving calibration and checking capacitors

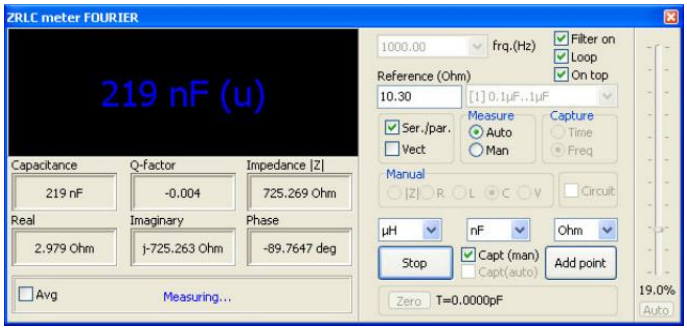
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h. At the end, it is worth preserving these settings so that the calibration does not have to be repeated every time. There are two ways to save the configuration. The Settings window contains “Save Config.”, “Save As” and “Open Config”. Even without using these buttons, when the program closes it saves the operating parameters to “VA.ini” in the same folder as VA. They are automatically reloaded whenever the program starts. After finishing all setup and calibration operations, I recommend closing the program and keeping a backup copy of VA.ini for use if necessary.

We have calibrated the analyser for resistance; what about other components?

I have a meter with capacitance ranges of 2 nF, 20 nF, 200 nF, 2 µF and 20 µF. I first used it to measure two nominal 220 nF polyester capacitors (like the one photographed with the crocodile-clip leads). Their readings were 211 and 217 nF respectively. Measuring them with ZRLC in position [1], I obtained 215 and 219 nF respectively. The following illustration shows the result for the second capacitor. One thing I have not mentioned yet is that readings are generally not completely fixed, but fluctuate slightly between two limits; in this case, between 219 and 221 nF.

If we press “Stop”, disconnect the capacitor, change both the analyser and ZRLC to position [2], and start again, the following result is obtained.



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Original illustration · source p. 28 · 2

Inductors and the vectorscope

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Not bad, is it?

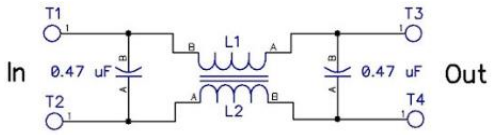
As for inductors, I had nothing useful with a known value at hand. But I found an old homemade interference-suppression filter, consisting of two interleaved coils wound on a length of ferrite of the type used in medium-wave portable radios, together with two 0.47 µF, 630 V capacitors. Here is its circuit.

Connecting terminals T1 and T3 to the Test terminals (T2 and T4 would be equivalent), I obtained the measurement shown below.

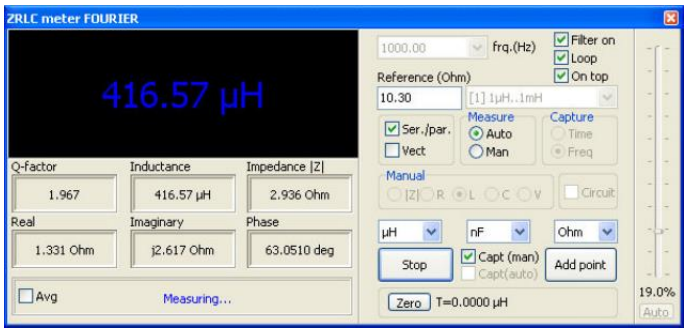
Notice the low “Real” resistance of 1.331 Ω, as is usual for inductors. After all, we are dealing with two lengths of enamelled copper wire...

Since we have said nothing about the “Vectorscope”, here it is in operation. It is enabled by checking “Vect” in the ZRLC window, to the left of the “Measure” section.

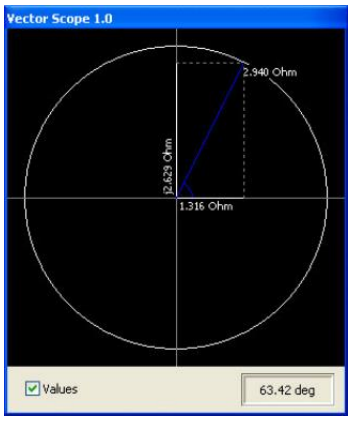
The filter's parameters (here viewed, I repeat, as an inductance) are displayed graphically as a vector in two dimensions. Small differences between corresponding values in the two displays are normal, due to the slight fluctuations mentioned earlier.



Original illustration · source p. 29 · 1



Original illustration · source p. 29 · 2



Original illustration · source p. 29 · 3

A variable air capacitor

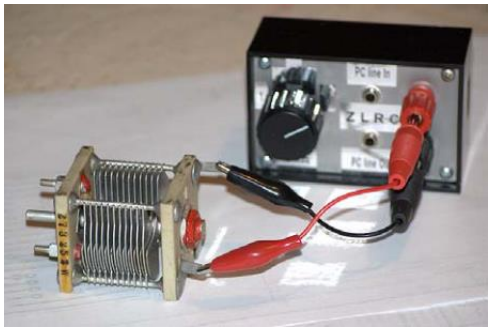
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To view the filter as a capacitor, I would have had to connect it between T1 and T2 or between T3 and T4.

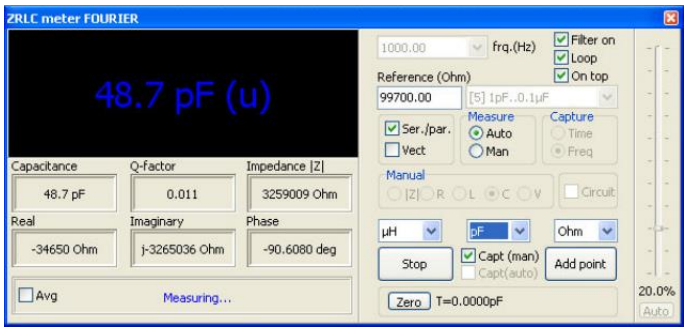
One last test: an air-variable capacitor on a ceramic support, a survivor of my very earliest radio-frequency experiments! I do not know how to determine its capacitance from the codes printed on it: GH-1072-12-3 and 273252W. I photographed it connected to the analyser, although not beside the PC because there was not enough space. Here it is.

I wondered: will the analyser be able to measure it?

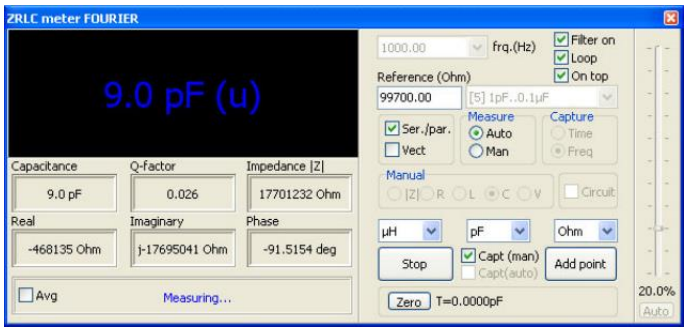
The answer appears in the following readings, taken with the plates fully meshed and almost fully unmeshed, respectively. If I opened it completely, the analyser could no longer provide a measurement.



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Original illustration · source p. 30 · 2



Original illustration · source p. 30 · 3

Concluding remarks on the first version

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As I expected, especially in the open position, moving my hand closer to or farther from the capacitor caused the reading to change...

Better than nothing, wouldn't you say?

I really think I am finished. I have “completed” a good program by providing the necessary hardware, and I believe I have demonstrated in practice the soundness of the project, its usefulness and its convenience.

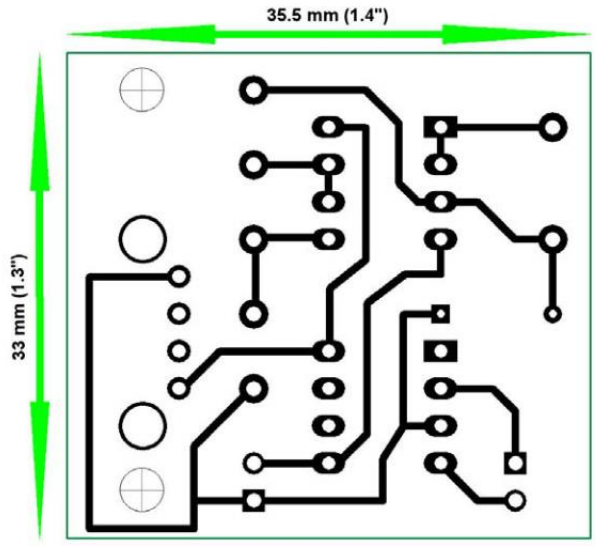
Appendix — printed circuit board

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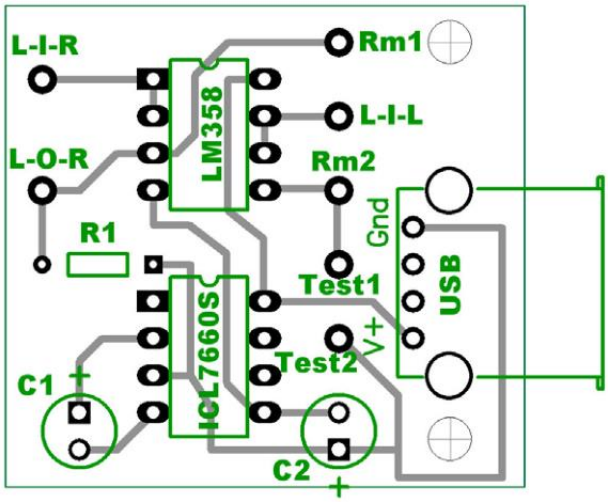
For readers who prefer to make a printed circuit board, I have prepared a PCB layout for the interface. Here it is, viewed from the copper side.

And here is the component placement.

A few clarifications follow.



Original illustration · source p. 32 · 1



Original illustration · source p. 32 · 2

PCB connection labels

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1. L-O-R = Line Out Right (right-channel line output).

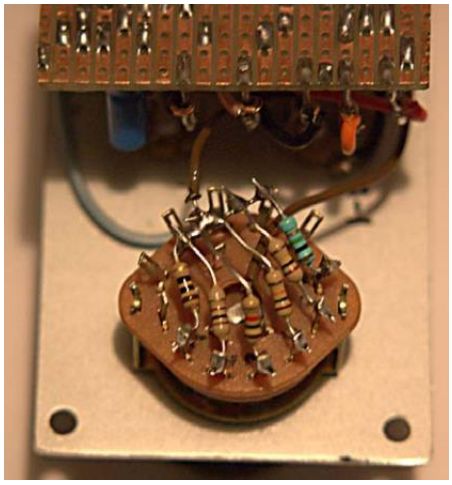
2. L-I-R = Line In Right (right-channel line input).

3. L-I-L = Line In Left (left-channel line input).

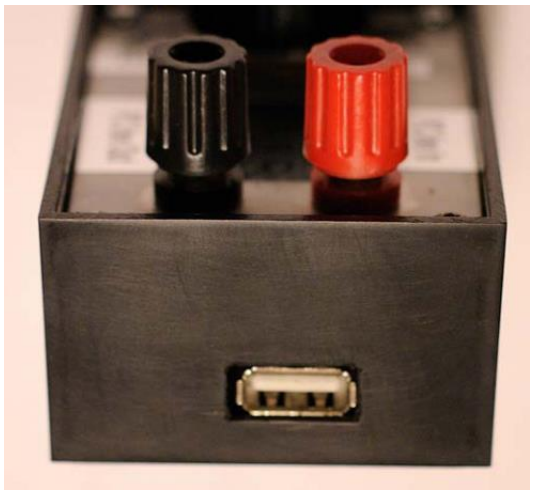
4. Rm1 and Rm2 = connections to the range selector containing the reference resistors (corresponding to the two brown wires).

5. Test1 and Test2 = connections to the red and black terminals for the component under test.

6. USB = PCB-mounted type-A USB connector.



Original illustration · source p. 33 · 1



Original illustration · source p. 33 · 2

Notes for builders and available files

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The PCB exists only “on paper”, so I do not currently have a ZRLC interface built using it. It has therefore not been tested in practice. I have, however, checked the track pattern for formal correctness as follows.

• The initial routing was generated by converting the original DipTrace schematic “ZRLC4.dch” into a PCB. The resulting file is “ZRLC7_USB_PCB3.dip”. I am making both files available, together with JPG files corresponding to the illustrations above and a PDF containing the copper-track layout alone at 1:1 scale.

• I carefully checked the tracks visually, comparing every connection in the schematic with the PCB one by one. This was not difficult, given the simplicity of the circuit. Nevertheless, I suggest that anyone making the PCB perform the following checks in addition to their usual precautions.

a) After making the board, solder the IC sockets and USB connector.

b) Connect the USB socket to one on the PC with a type-A male-to-male USB cable. Use a meter to verify approximately +5 V (the exact value will, of course, depend on the PC power supply) between pins 8 and 3 of the ICL7660S socket, and between pin 8 of the LM358 socket and Test2 (which corresponds to USB ground).

c) If the results are correct, unplug the cable and insert the ICL7660S in its socket.

d) Reconnect the cable and verify approximately +10 V between pins 8 and 4 of the LM358 socket—or, more precisely, twice the magnitude measured at step b, allowing for small deviations—and approximately −5 V between pin 4 of the LM358 socket and Test2, close in magnitude to the value found at step b.

e) Disconnect the USB cable and continue assembling the board.

Available files (click the filenames in the original online document to download):

• Copper-track PDF at 1:1 scale: ZRLC_x_PCB2.pdf
• Enlarged JPG of the same tracks: ZRLC_x_PCB2.jpg
• Component placement, at the same scale, JPG: ZRLC_x_PCB_Top.jpg
• DipTrace PCBLayout file, zipped: ZRLC7_USB_PCB3.zip
• DipTrace schematic file, zipped: ZRLC4.zip

Part III

Second version: ZRLC All In One

Why was ZRLC A.I.O. created? How does it differ from the previous version, and what advantages does it offer?

To understand this, we need to go back a little and remember that the previous ZRLC is a simple electronic circuit (essentially a voltage divider and two operational amplifiers) which, thanks to a Windows program and low-frequency connections to the Line In and Line Out sockets of any PC sound card, can measure impedance, resistance, inductance and capacitance. As a reminder, the original idea is attributable to Dr George Steber and to an article published in Elektor by Martin Klaper and Heinz Mathis. Links can be found in the preceding article mentioned above.

The main characteristic of this interface is its remarkable simplicity, which also makes it inexpensive. It is no coincidence that the Elektor article was entitled “2-Pound RLC Meter”. But simplicity has a downside. Almost every PC nowadays has a reasonably good sound card, but only one, with at most two inputs (microphone and line) and one output. Many PC users permanently connect their sound card to a hi-fi system or multimedia equipment, or use it for hands-free communication with other users on the Internet. I myself use my PC's sound card to listen to my favourite music.

Having to disconnect and reconnect the stereo cables to replace them with ZRLC's cables can therefore become a nuisance. And the ZRLC “umbilical cord”—two audio cables plus the USB cable used for power—takes up quite a bit of desk space.

Of course, one could dispense with a cable and power ZRLC from batteries alone. But batteries run down, and it may be precisely when the instrument is needed that they are exhausted, with no spares at home.

Inspired also by Nuova Elettronica magazine—which had on several occasions presented circuits equipped with a USB Audio Codec, including a PC oscilloscope and spectrum-analyser kit based on the same Visual Analyser program I used to operate ZRLC—I decided to build a new version in which the USB cable would carry not only power but also the audio signals in both directions. For this I needed a USB analogue-to-digital/digital-to-analogue audio converter.

I therefore purchased a couple of assembled “LX.1667” kits from Nuova Elettronica's online shop.

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The kits were listed at http://www.nuovaelettronica.it/it/kit/index.cfm?fb=scheda_kit&ww_articoli_id=17577 and cost €18.00 each. Was that a lot or a little? I will not judge, but because the board uses SMD components, including the converter, and I was not equipped to assemble such parts, it was certainly the simplest solution. The board itself is designated KM1667.

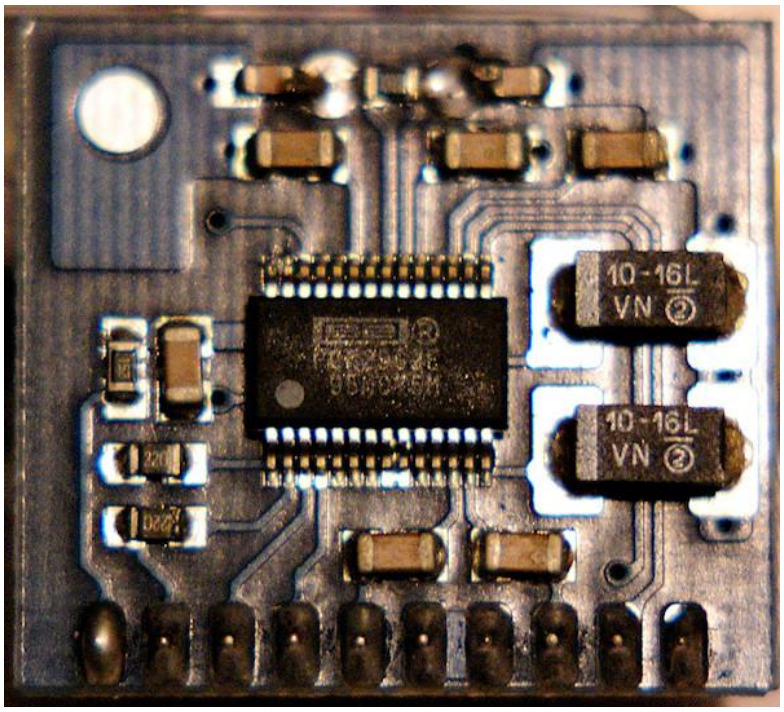
I set to work and, after several attempts, eventually arrived at the device I am presenting here. So, let us start by taking a look at it.

Description and circuit diagram

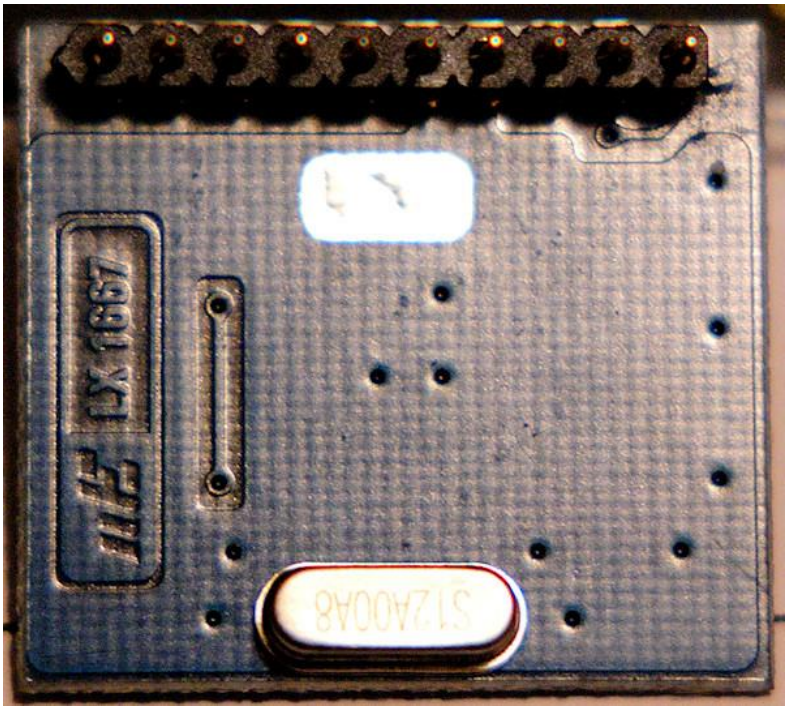
Since this article revolves around the KM1667 board, I shall begin with that. Here are its photographs and its diagram.



Original illustration · source p. 36 · 1



Original illustration · source p. 36 · 2

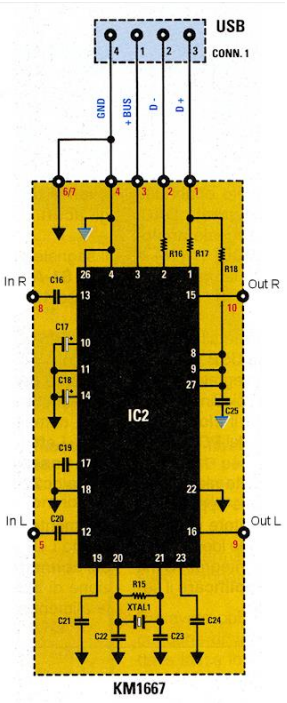


Original illustration · source p. 36 · 3

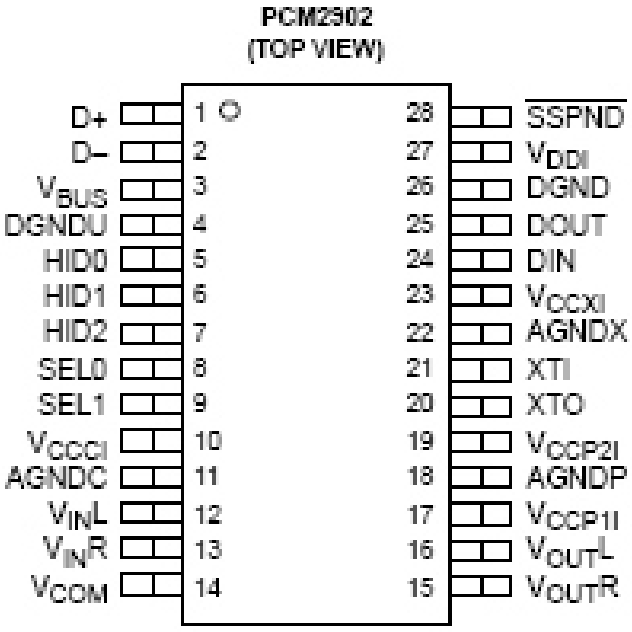
Original document: page 36 / 75

Here is the pinout of the PCM2902, the heart of the board.

How should it be incorporated into the original circuit, reproduced below?



Original illustration · source p. 37 · 1

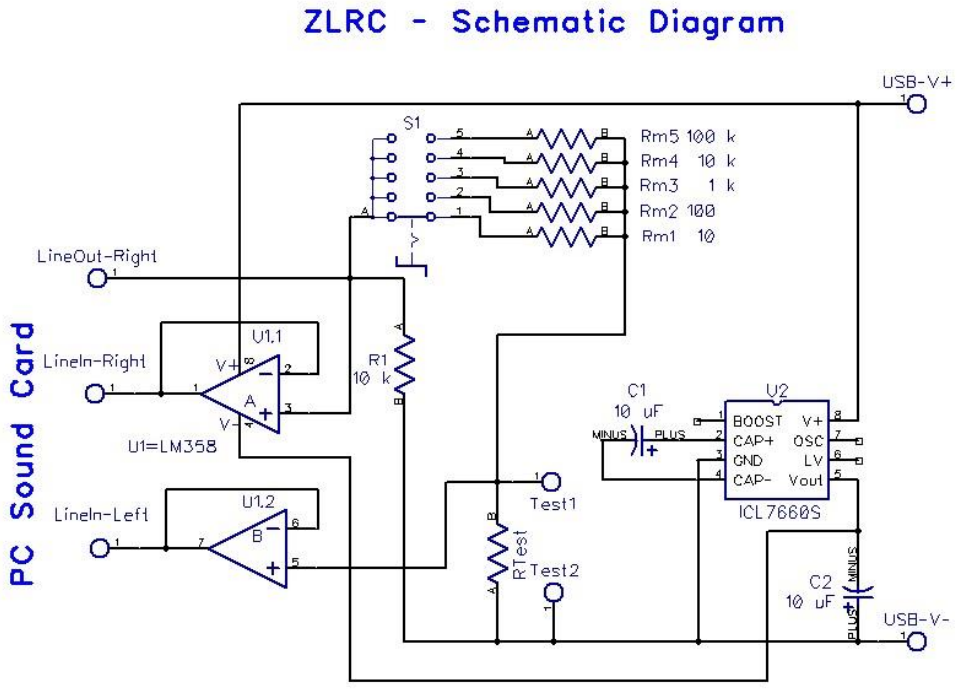


Original illustration · source p. 37 · 2

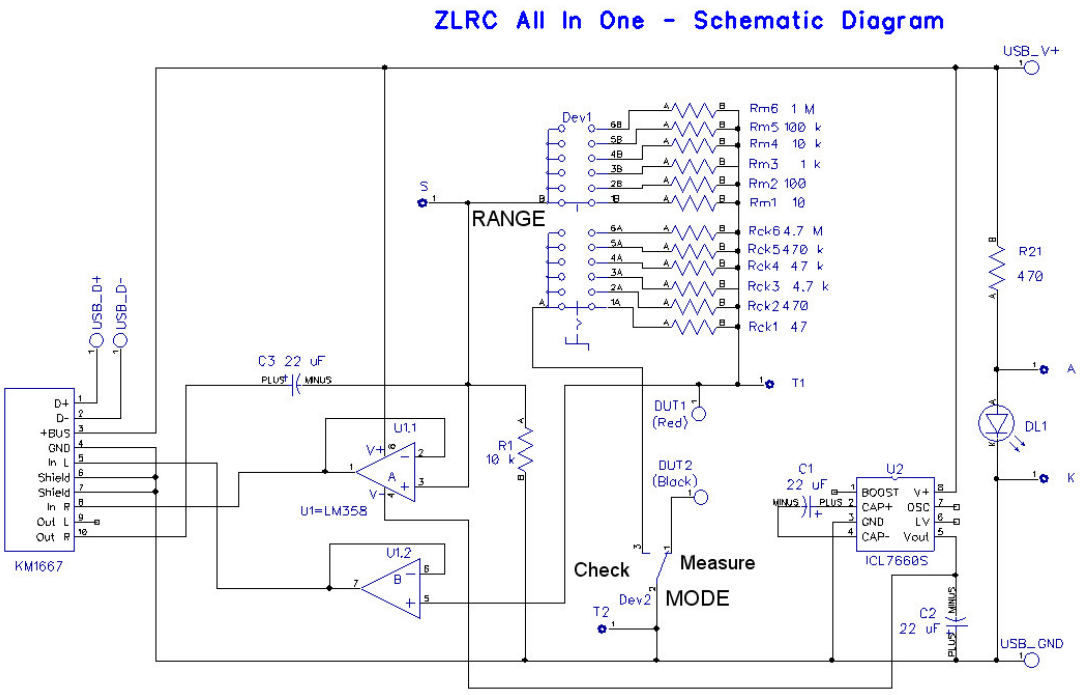
Original document: page 37 / 75

At first sight, it seems sufficient to connect pins 1, 2, 3 and 4 to the USB socket, and to connect “Out R”, “In R” and “In L”, respectively, to the “LineOut-Right”, “LineIn-Right” and “LineIn-Left” terminals in the original circuit.

In broad terms this is correct, but there is one detail to consider. It explains why a 22 µF capacitor, C3, appears after “Out R” in the final schematic. First, here is the ZRLC A.I.O. schematic.



Original illustration · source p. 38 · 1



Original illustration · source p. 38 · 2

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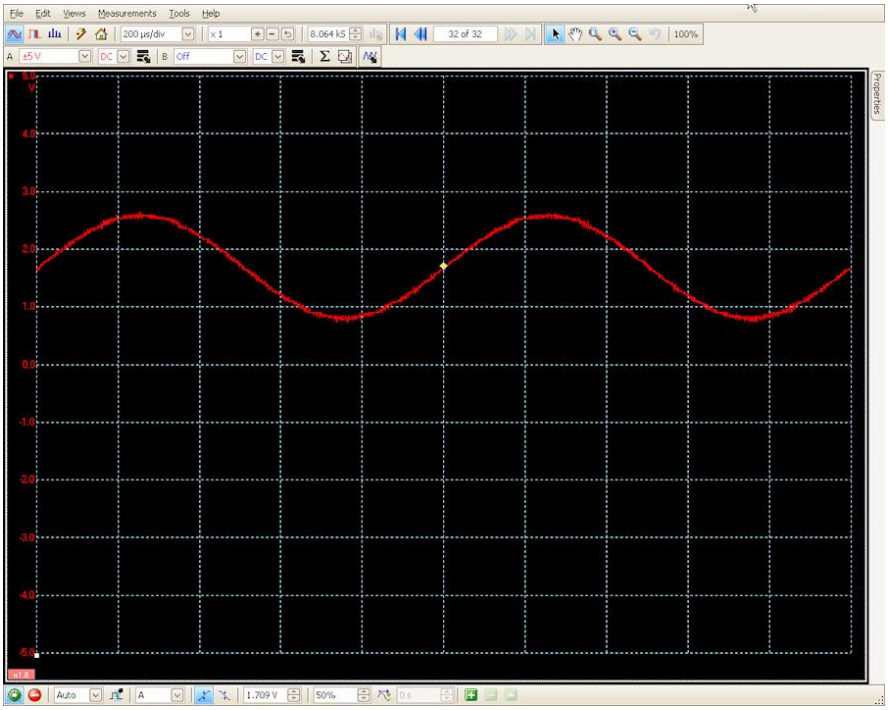
Initially C3 was not present, and ZRLC did not work—or worked poorly. I therefore connected a DC-coupled oscilloscope between GND and Out R. The result is shown below.

The 1,000 Hz signal amplitude was correctly 1.6 V peak-to-peak, but there was a 1.6 V DC offset: the negative peak had shifted from −0.8 V to +0.8 V, and the positive peak from +0.8 V to +2.4 V. Adding the capacitor removed the DC component, and everything worked correctly.

The new schematic also has another switch—or, more precisely, a second section coaxial with the first, which selects the Rm resistors needed for the different ranges. In short, it is a conventional two-pole, six-position rotary switch.

On the second bank I fitted another series of resistors, with nominal values approximately five times those of the corresponding resistors on the first bank. More precisely, 10 Ω on the first bank corresponds to 47 Ω on the second, 100 Ω to 470 Ω, and so on. Why? With the MODE toggle switch I can connect either an external component to be measured (as in the earlier version) or an internal resistor as the DUT (Device Under Test), namely the matching resistor in the second bank. I chose the roughly 5:1 ratio to obtain a larger signal that ZRLC can use more effectively.

As we shall see in “Settings and operation”, this makes it easy to enter values in “Scale settings (Ohm)” so that the ZRLC window displays the correct value. The advantage is that the calibration resistors are always available and are electrically connected automatically, rather than having to be found and attached and detached manually each time.



Original illustration · source p. 39 · 1

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You will also notice that, although ZRLC has five measurement ranges, the All In One schematic includes a sixth position. Here is a brief explanation, which will become clearer after reading “Settings and operation”.

Since the switch has six positions, I decided to add a sixth Rm resistor of 1 MΩ. This is used with position “5” in ZRLC, remembering to multiply the displayed value by 10 for resistance or inductance, and to divide it by 10 for capacitance.

It works reasonably well. For example, I can even read the minimum value of the air-variable capacitor with ceramic support described in the previous article. Accuracy may suffer a little, but so be it.

With the capacitor fully closed, the normal setting gives 48 pF; however, I can open it only to about halfway before ZRLC can no longer measure its capacitance and displays “Underrange”.

In position 6, I read 488 pF when it is closed and 18 pF just a few degrees before fully open. At 100% open I again get Underrange, which is understandable.

Dividing these readings by 10 gives roughly 49 pF closed and 2 pF open. Those measurements seem plausible to me.

Incidentally, under these conditions the capacitive effect of the hand turning the capacitor is noticeable: the indicated capacitance increases, so the hand must be moved away before taking the reading.

To use this mode, however, it is necessary to select the “Man” radio button in “Measure”, then choose R, L or C according to the quantity being measured, before starting. Again, see “Settings and operation” below.

Also note the terminals marked S, T1, T2, A and K. These might appear to duplicate connections already present, but the RANGE rotary switch (Dev1), the MODE toggle switch (Dev2), the DUT1 and DUT2 terminals, and the power-indicator LED DL1 are mounted on the upper panel rather than on the board. They connect to the board

through these five terminals. A close-up photograph of the switch appears later and shows that all twelve resistors are soldered directly to its contacts, producing a very compact assembly.

Practical construction

As I mentioned in my earlier articles, I had not yet decided to equip myself to manufacture printed circuit boards. At the same time, I did not want to build this circuit on the usual 0.1-inch-pitch perforated board with parallel copper strips.

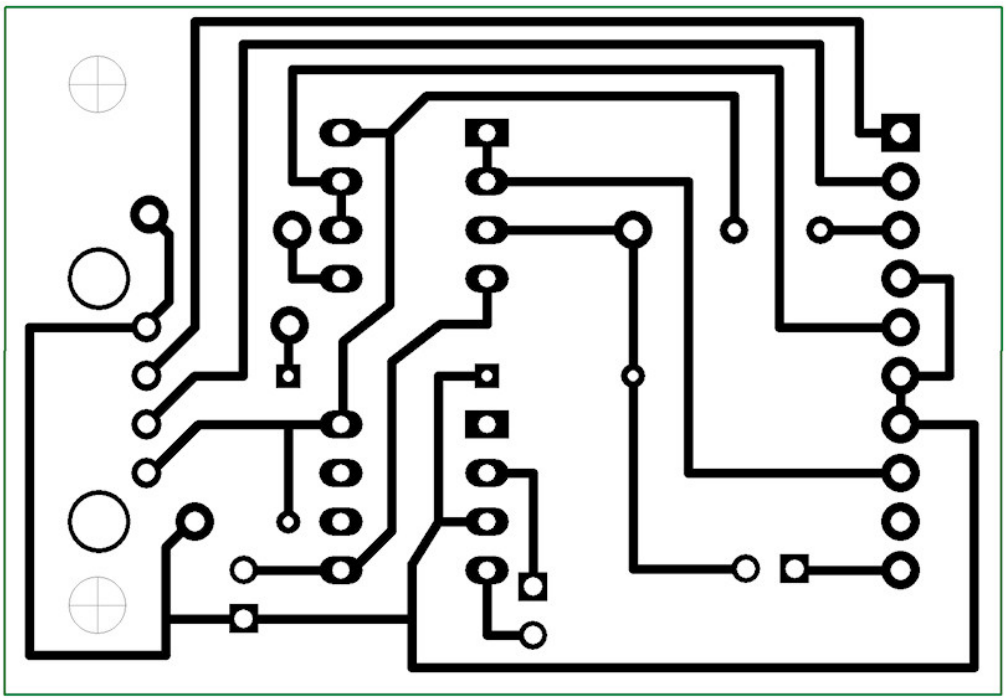
Original document: page 40 / 75

Nevertheless, I prepared a PCB layout to make life easier for anyone choosing that solution. The board measures 52 × 36 mm. The layout is quite clean, as can be seen below, and requires only one jumper (J1). The outline of the KM1667 module is shown in brown.

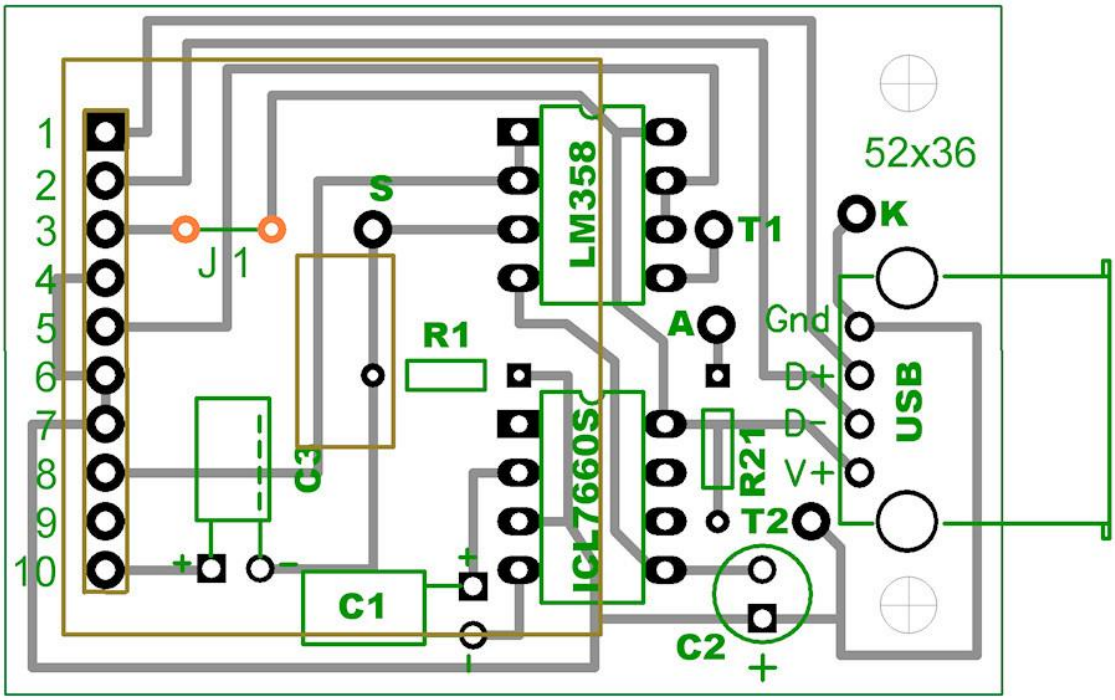
Here are enlarged views of the copper side and component-side silkscreen. Remember that the little KM1667 board, plugged into a 10-pin single-in-line connector, sits above the PCB without touching the components beneath it. In the silkscreen drawing, the module is brown and the other components are green.

A ZIP file can also be downloaded containing the 1:1 PDF drawing, two enlarged images, the DipTrace schematic file (ZRLC_AIO_4.dch) and PCB file (ZRLC_AIO_PCB5.dip), the PCM2902 datasheet, and a newer—though still beta—version of Visual Analyser (VA.exe).

But how did I actually make the prototype? By a solution which will strike many people as odd and probably uneconomical: I used the PCB from another kit conceptually similar to this instrument, designed for four operational amplifiers and a KM1667 board, with a Type-B USB socket and sockets for the eight-pin DIP and ten-pin SIP devices.



Original illustration · source p. 41 · 1



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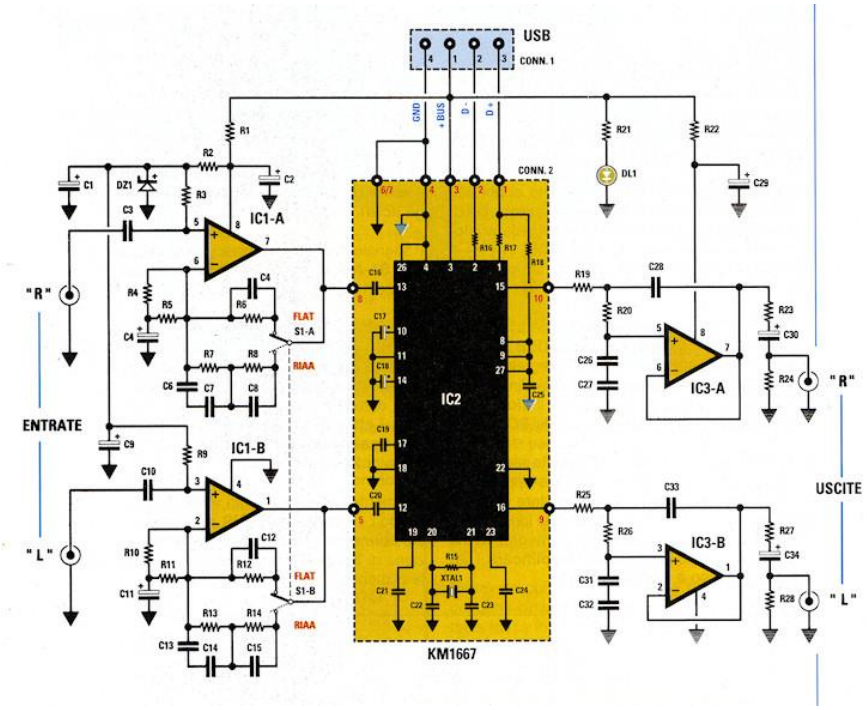
Those sockets could be reused, although a fair number of components were left over.

The kit is “LX.1666 — Transfer VINYL to COMPUTER”, which also uses the PCM2902 USB converter. For details, component values and so forth, the original reference is issue 231 of Nuova Elettronica, June–July 2007, then priced at €5.00.

The PCB is very well made: a double-sided board whose two copper layers are linked through plated-through holes (I believe with silvered rivets).

However, comparing the pinouts of IC1 and IC3 with the intended schematic reveals that some modifications are required. For IC1, pin 4 must be isolated from ground because it will receive −5 V; a hole is also needed in a short piece of copper deliberately left in place after removing the coating (see arrows “f” and “d” below). This is complicated by the ground connection existing on both sides of the board.

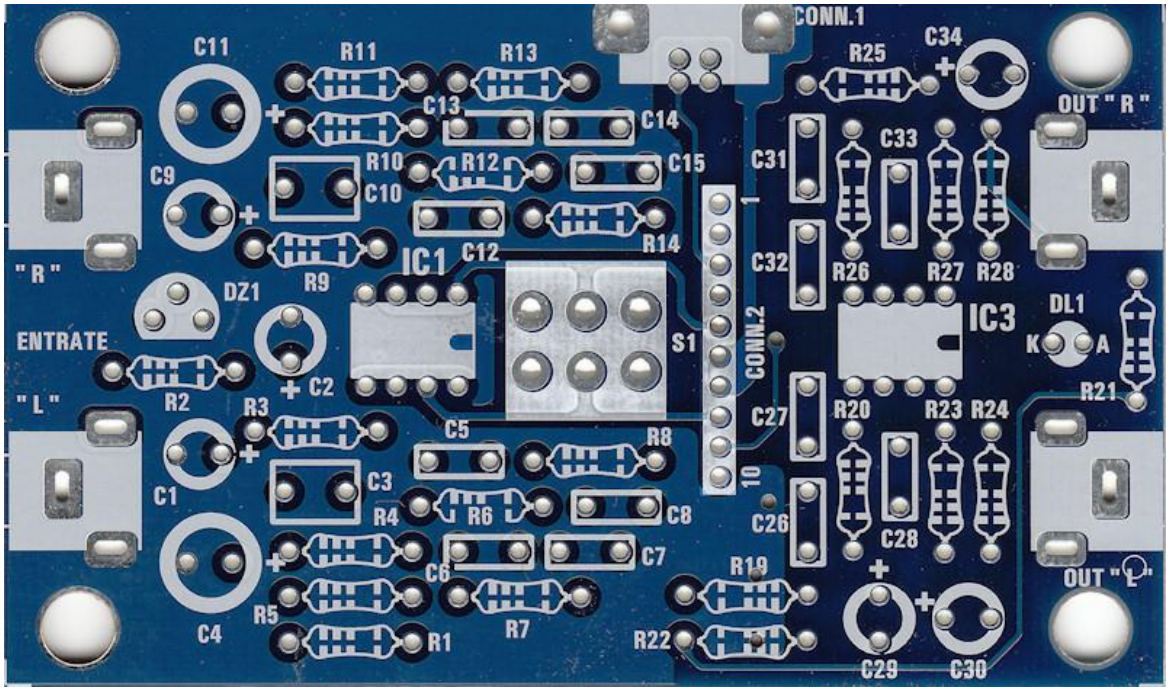
For IC3—the operational amplifier will be replaced by the ICL7660S voltage converter—pins 1 and 2 must be separated, as must pins 6 and 7, while retaining one pad for each. Below is a scan of the unmodified board, followed by views of both sides before and after modification. The cuts are clearly visible; the necessary wire links are marked in red.



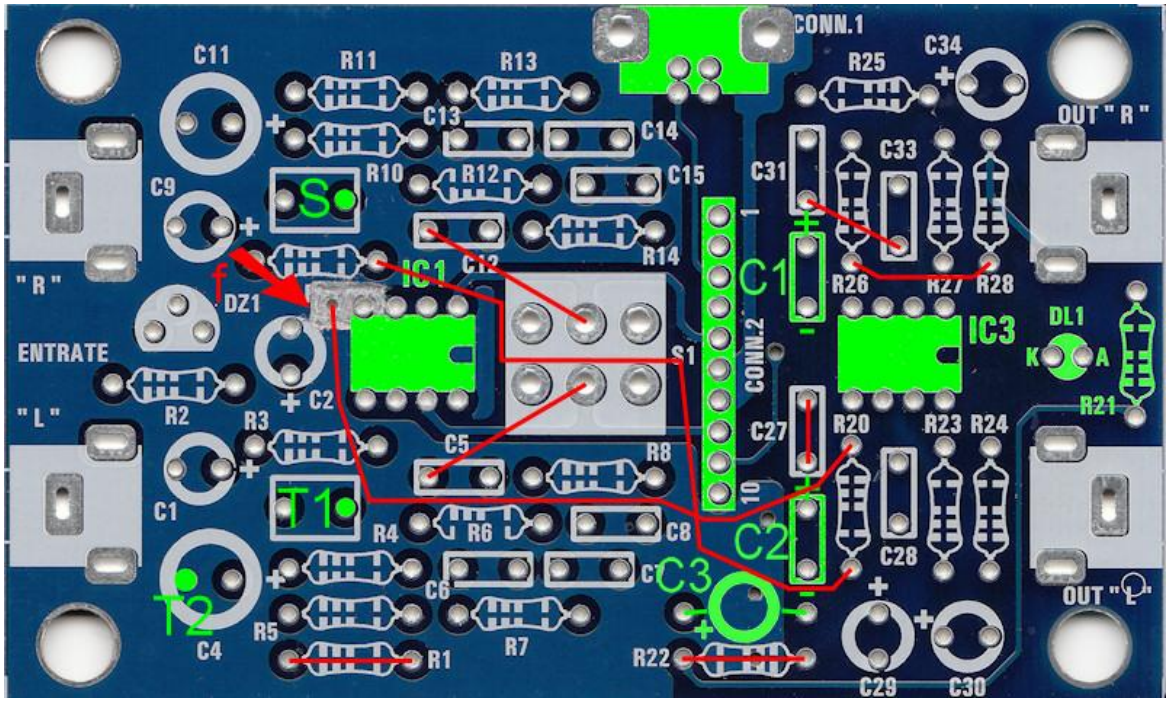
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The illustration also shows how resistor R1 is mounted on the underside. It is soldered directly to the copper after scraping away a small patch of coating near arrow “e”.



Original illustration · source p. 43 · 1



Original illustration · source p. 43 · 2

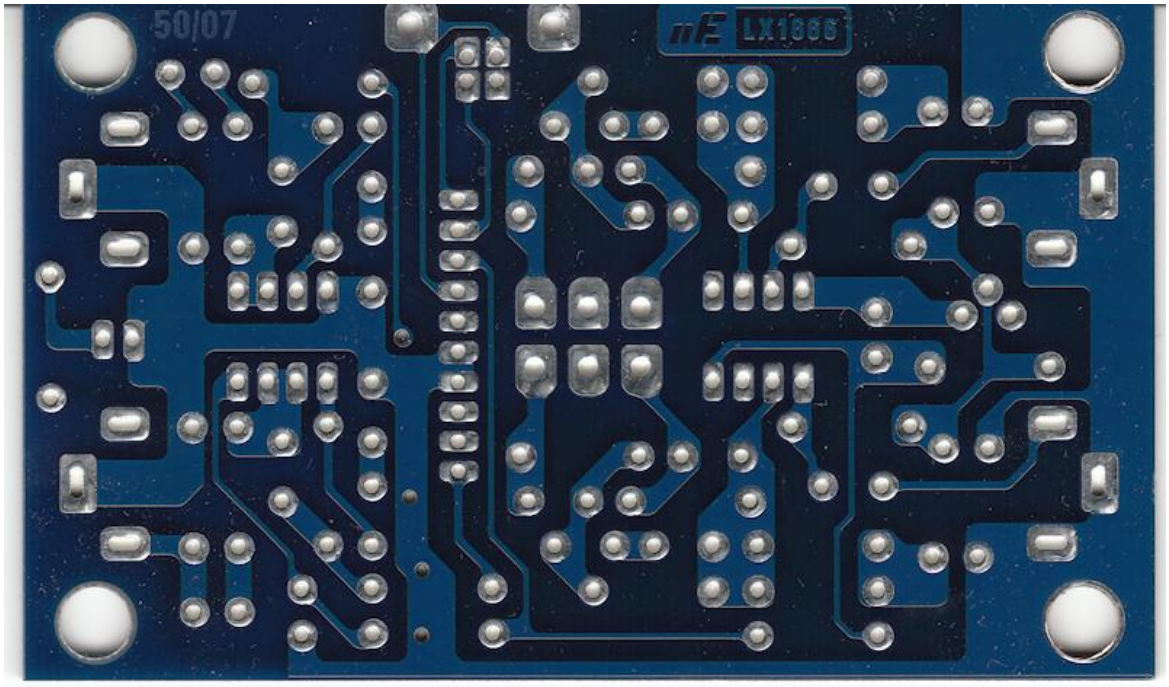
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What can I say about this operation? First, it is by no means essential: you can always make a dedicated PCB or use a perforated board. Above all, though, it requires considerable manual skill and a sharp eye, such as those developed by someone like me who comes from the world of model railways.

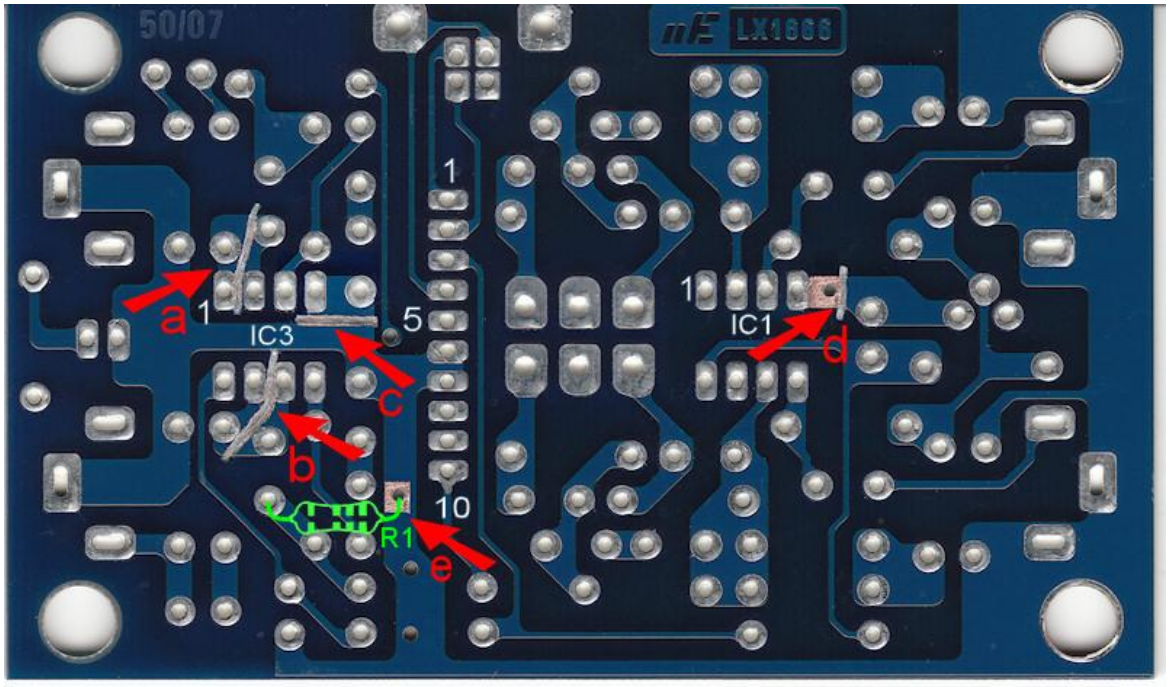
Using the appropriate cutting tools, this is delicate work: there is a simultaneous risk of permanently damaging the board and injuring an operator who lacks the necessary skills. Nevertheless, it is possible, as my results demonstrate.

Why describe it in such detail, then? Because I know that anyone reading an electronic construction article quite reasonably likes to see photographs of a real example of the proposed project. This modified PCB is the basis of my instrument, which is real rather than theoretical and works perfectly well.

Here are some photographs of the device.



Original illustration · source p. 44 · 1

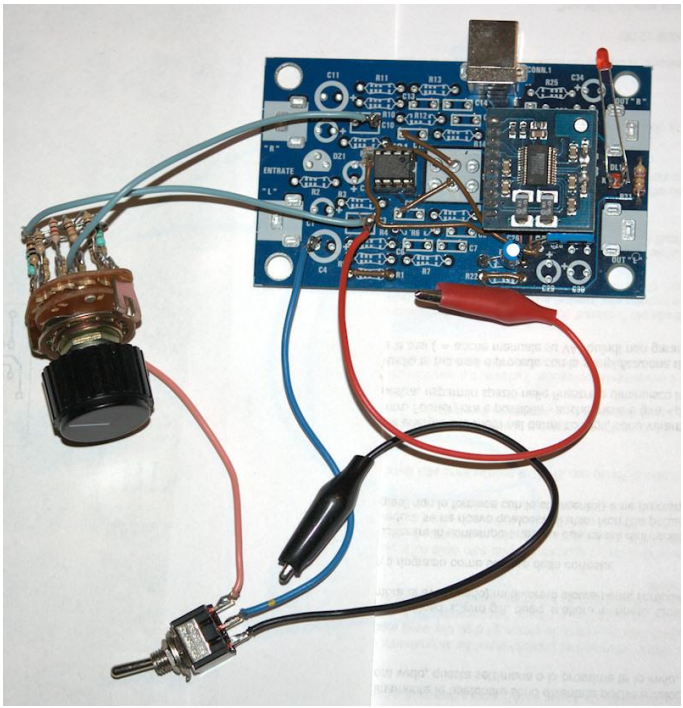


Original illustration · source p. 44 · 2

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The board under test, before being fitted into its enclosure.

The instrument in perspective; the USB Type-B connector is visible on one side.



Original illustration · source p. 45 · 1

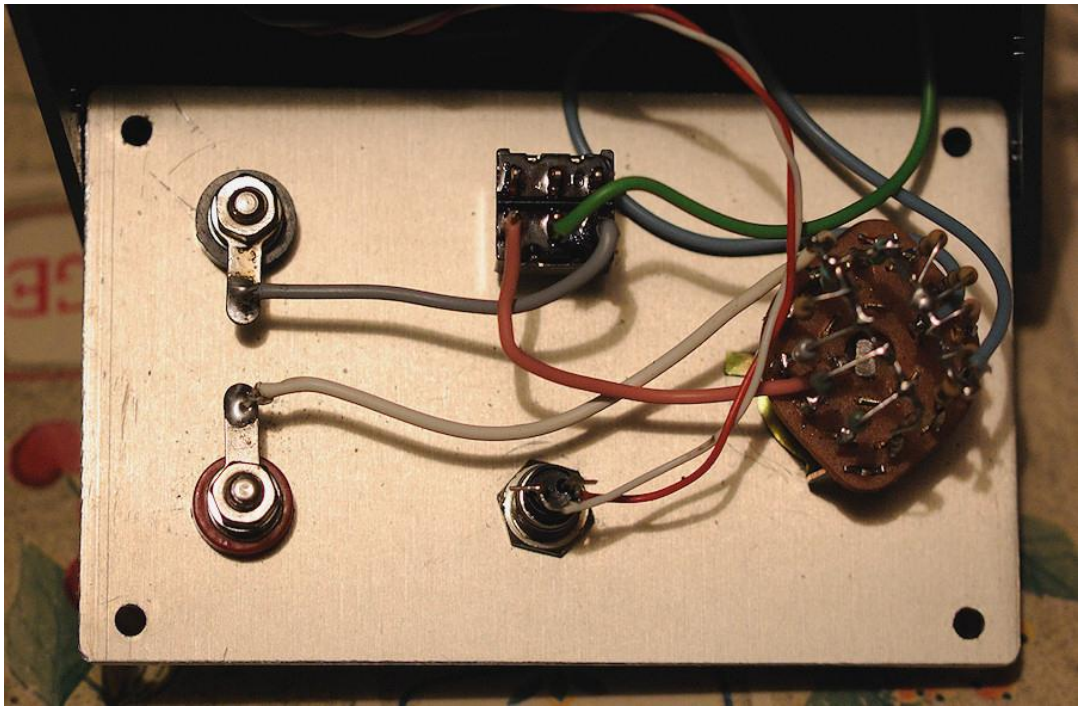


Original illustration · source p. 45 · 2

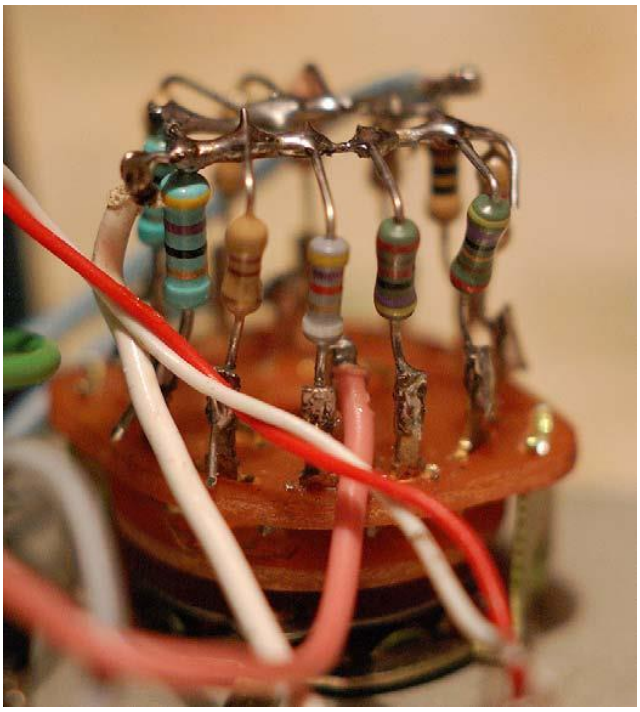
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The rear of the top panel, clearly showing the MODE toggle switch and the RANGE selector.

A detail of the RANGE selector: as already mentioned, all twelve resistors are soldered directly to the switch terminals.



Original illustration · source p. 46 · 1



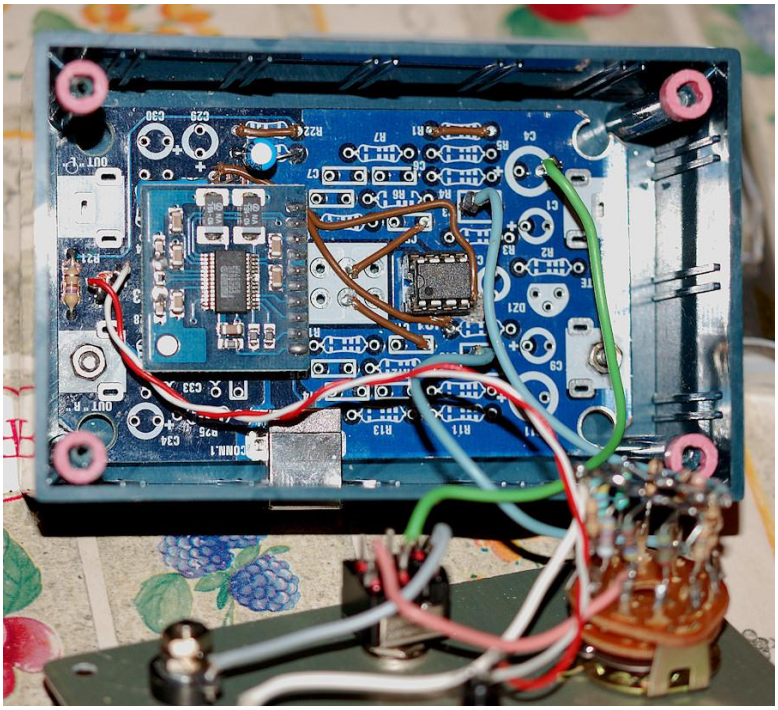
Original illustration · source p. 46 · 2

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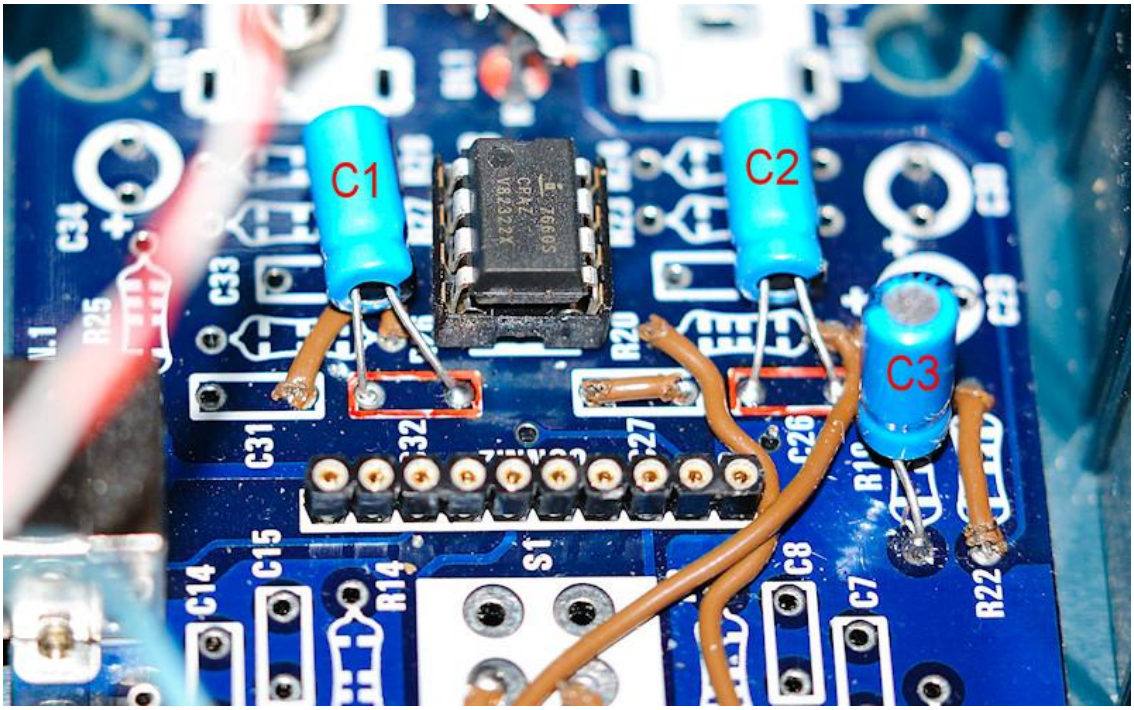
Now for the interior. On the left is the small KM1667 module; beneath it is the ICL7660S voltage converter. Above is capacitor C3; on the right is the LM358 operational amplifier, and below is the USB connector.

Removing the KM1667 module exposes the ICL7660 and, especially, capacitors C1 and C2, mounted horizontally so that they do not obstruct the module.

It is time to switch on ZRLC A.I.O. and get it ready to do its job.



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Settings and operation

Much of what follows was covered in the preceding article. However, the PCM2902 Audio Codec has a few peculiarities, which I shall describe, and these lead to some differences—and some extra explanations. The instructions below refer to a PC running Windows XP SP2.

Before using ZRLC A.I.O., it is advisable to perform the following assembly checks.

(a) After making the board, solder the two IC sockets, the socket for the KM1667 module, and the USB socket.

(b) Connect the USB socket to a port on the PC using a suitable USB cable. With a tester, check for approximately +5 V (the exact value obviously depends on the PC power supply) between the following points:

• pins 8 and 3 of the ICL7660S socket;

• pin 8 of the LM358 socket and terminal T2 (corresponding to the USB socket's GND);

• pins 1 and 4, and likewise pins 1 and 6+7, of the KM1667 socket.

(c) If everything is correct, disconnect the cable and insert the ICL7660S in its socket.

(d) Reconnect the cable. Measure approximately +10 V between pins 8 and 4 of the LM358 socket—or, more precisely, about twice the absolute value measured in step (b), allowing for small differences. Also check for about −5 V between pin 4 of that socket and T2, again approximately matching the magnitude measured in (b).

(e) Disconnect the USB cable and continue the assembly.

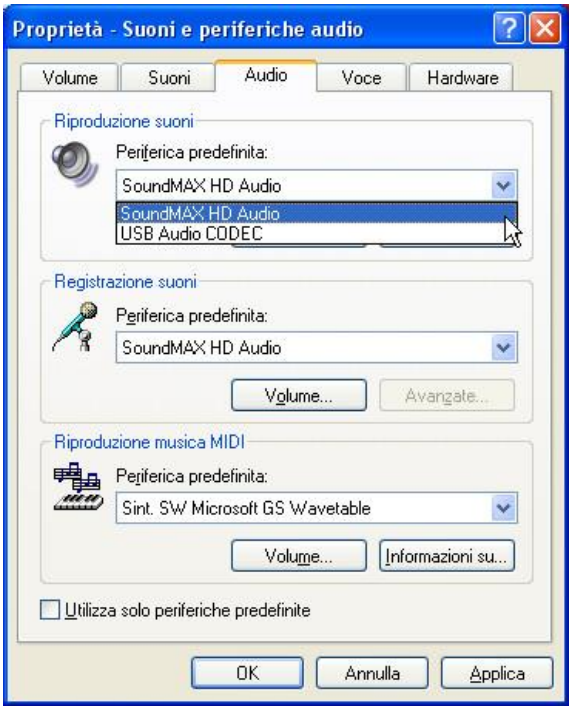
(f) Before wiring the RANGE switch with its twelve resistors—or, if the wiring has already been completed, with MODE in “Measure” to isolate the Check section—carefully measure, with a digital multimeter, the six resistance values between the common end of all twelve resistors and terminal A of the switch. Terminal A must connect to contact 3 (“Check”) of the MODE switch. Select ranges 1 through 6 in turn. Record all six values carefully and keep them, perhaps in a file.

Once the PCB has been completed and the instrument assembled, check everything again, as you normally would. Connect ZRLC A.I.O. with a USB cable. Windows will display its usual sequence of notifications that new hardware has been found, ending with the message that the new hardware is installed and ready for use.

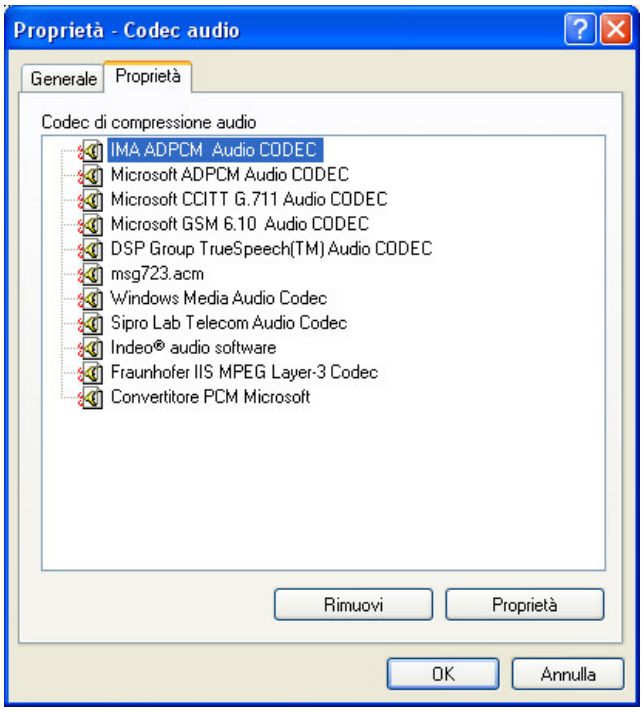
In the Windows Control Panel, open “Sounds and Audio Devices” and select the “Audio” (or “Voice”) tab. In the default-device lists for sound playback and sound recording, you should find “USB Audio CODEC” in addition to the previously installed device or devices.

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Under the “Hardware” tab, the entry “Audio Codecs” should also be present. Select it, click “Properties”, and then the “Properties” tab again: something similar to the illustrations below should appear.



Original illustration · source p. 49 · 1



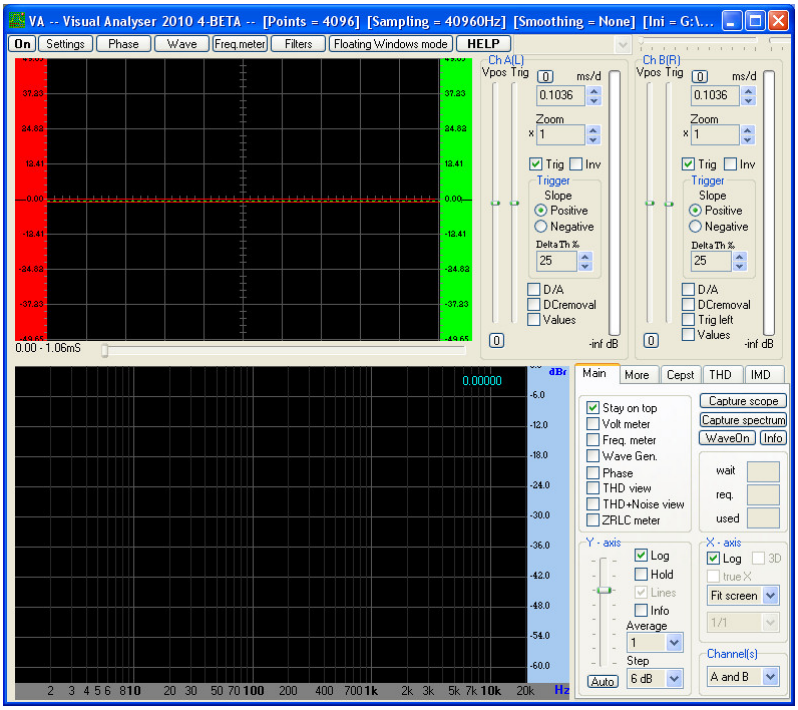
Original illustration · source p. 49 · 2

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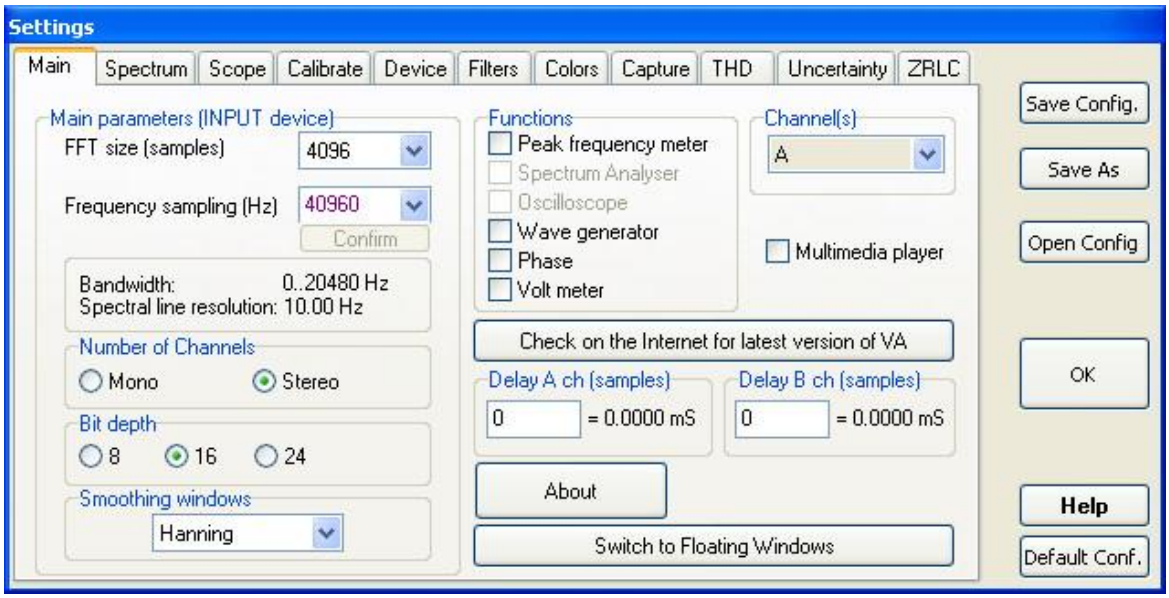
Assuming you have downloaded Files.zip, unpack VA.exe into a folder of your choice.

Run VA.exe. The following screen appears.

Click the “Settings” button. The “Main” settings window appears.



Original illustration · source p. 50 · 1



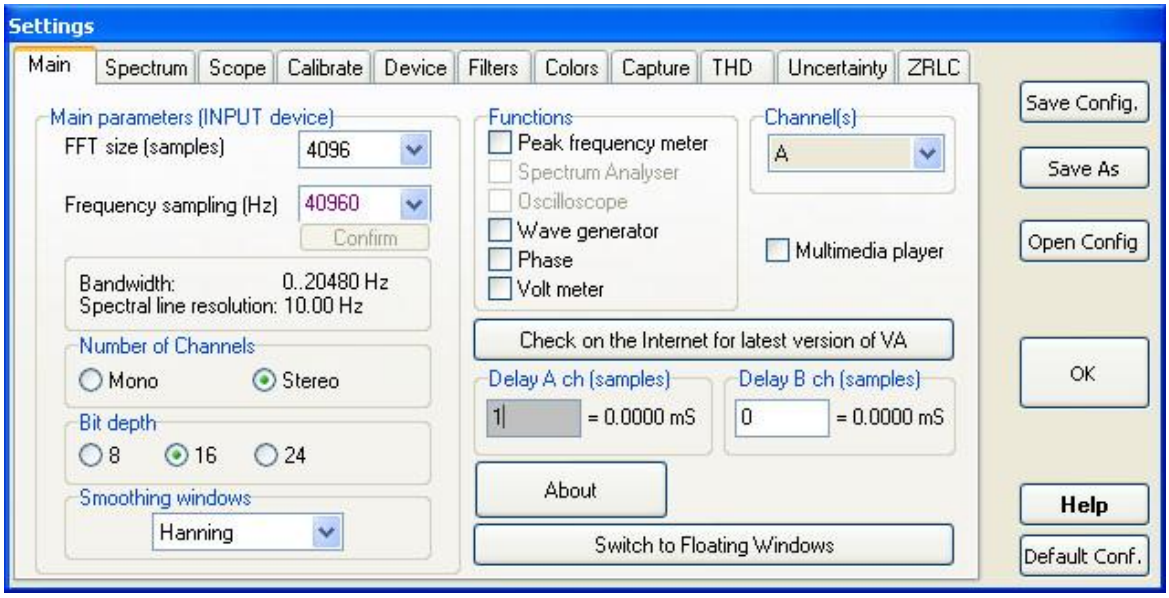
Original illustration · source p. 50 · 2

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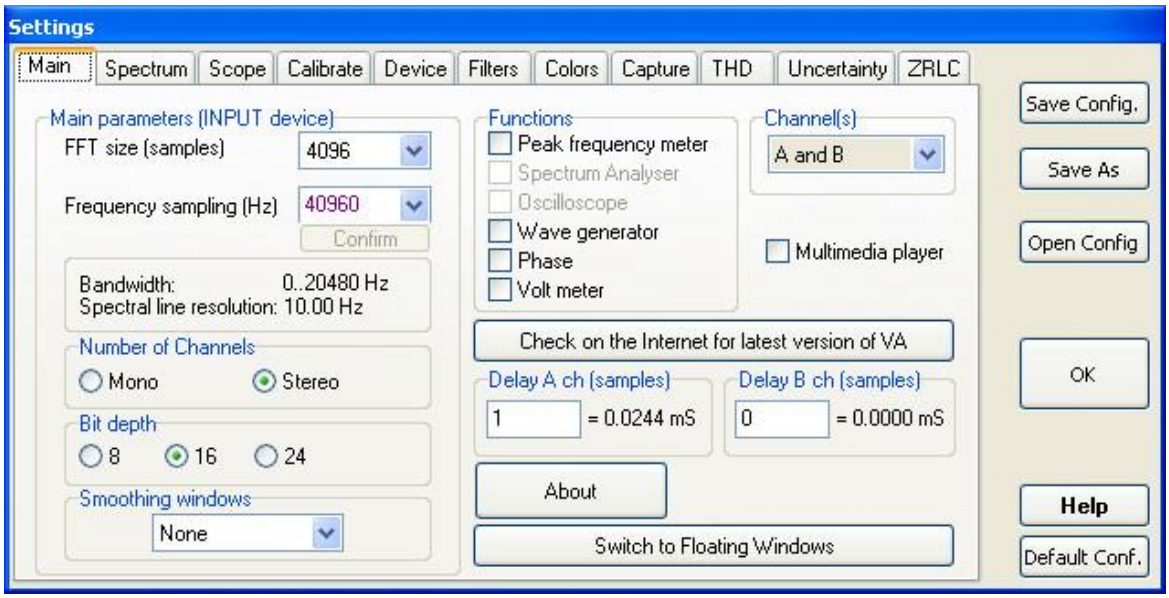
A special setting must now be entered for certain sound cards, including those using the PCM2902, which have a single ADC (analogue-to-digital converter) shared by the two channels. More precisely, channel A must be delayed by one sample. Click inside the “Delay A ch (samples)” edit field and enter 1. When a value is entered, the field turns grey, indicating that “Enter” must be pressed to accept it. The displayed time changes from 0.0000 ms to 0.0244 ms.

Next, choose “A and B” from the “Channel(s)” list.

Now select the “Device” tab. This is where you choose the sound card used by ZRLC A.I.O. Select “USB Audio CODEC” in both the “Input device” and “Output device” lists.



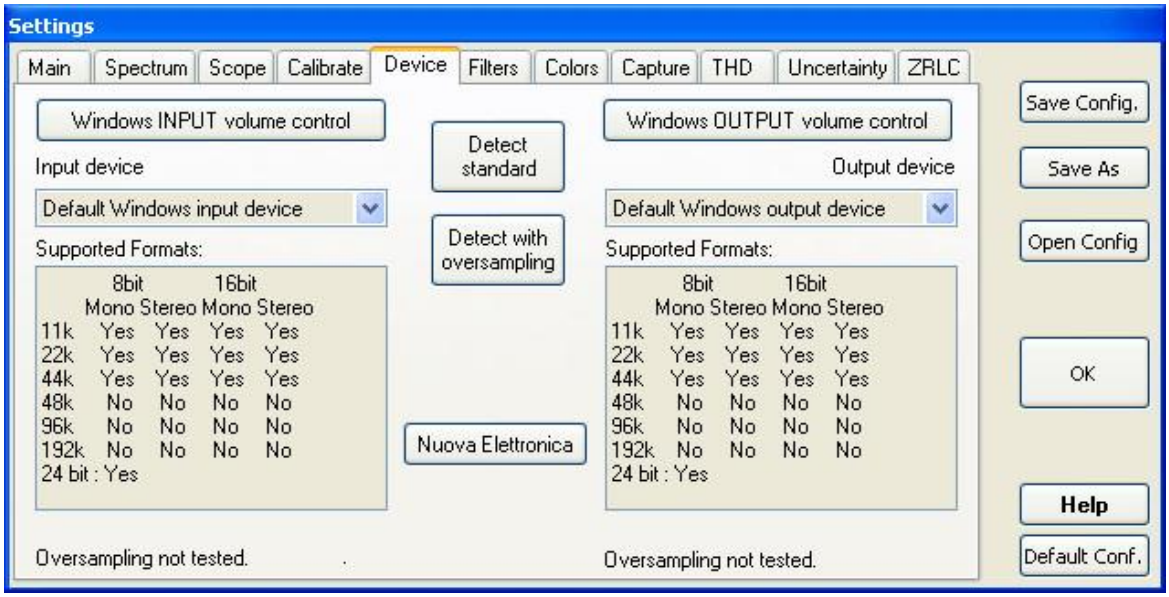
Original illustration · source p. 51 · 1



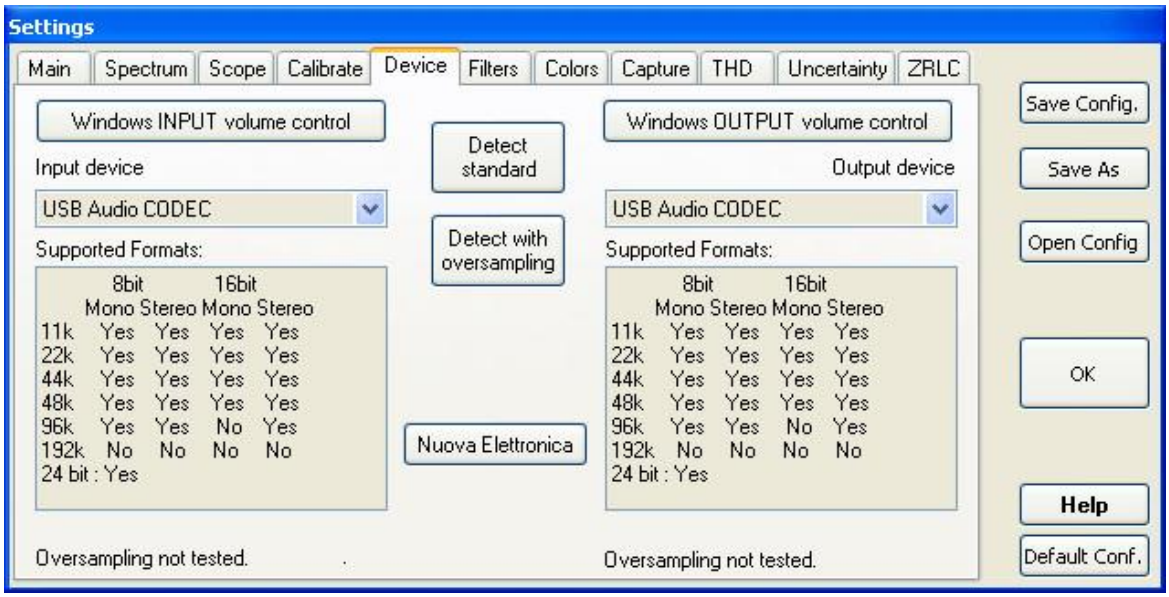
Original illustration · source p. 51 · 2

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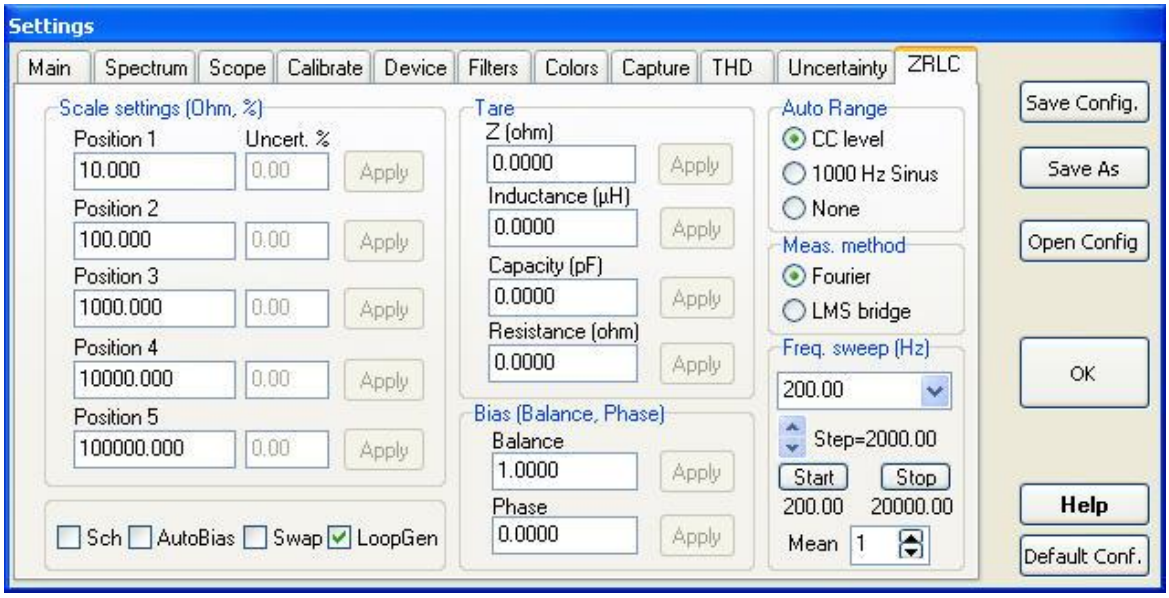
Finally, select the “ZRLC” tab. At the lower left, tick both “Auto Bias” and “Swap”.



Original illustration · source p. 52 · 1



Original illustration · source p. 52 · 2



Original illustration · source p. 52 · 3

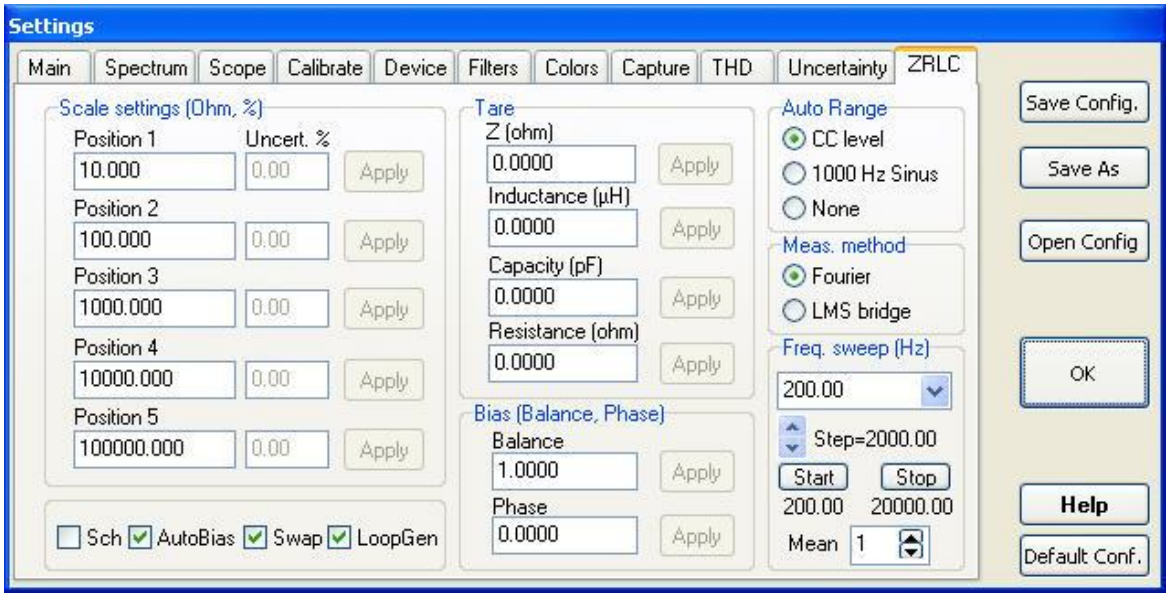
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Let me point out another characteristic—or, rather, limitation—of the PCM2902. If you widen the main Visual Analyser window, the “Input Gain” and “Output Gain” buttons appear.

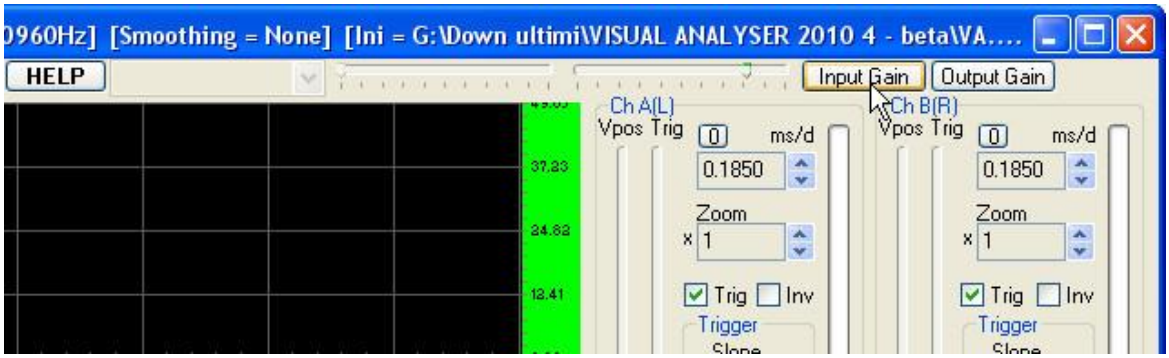
Try clicking them. “Output Gain” opens the control labelled “Speakers”, essentially the standard Windows control usually called “Master Volume”. But clicking “Input Gain” produces a Windows “Volume Control” error message. This happens because the PCM2902 has no input mixer, which is normal for this device. The error message is therefore appropriate. The mixer is usually (though not always) a hardware feature accessed by Windows and Visual Analyser. If it has not been implemented in the chip, no program can make it appear.

It is now time to test the meter and calibrate it. The Fourier measurement method is selected automatically when the program opens.

In the main Visual Analyser window, to the lower right of the spectrum display, tick “ZRLC”.



Original illustration · source p. 53 · 1



Original illustration · source p. 53 · 2

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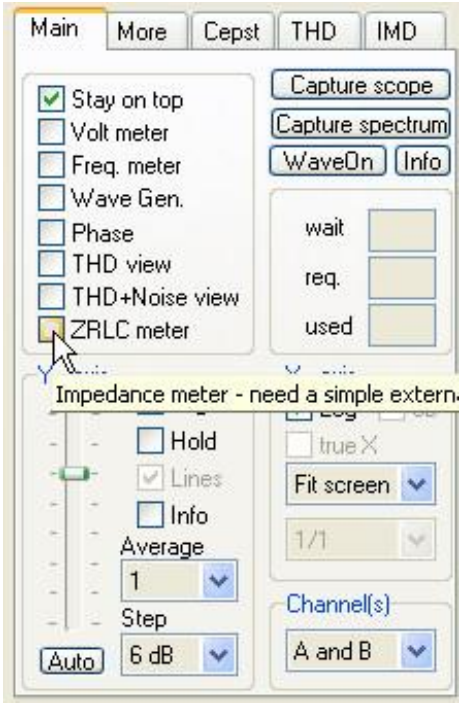
The ZRLC window opens.

On the interface, set RANGE to 1 and MODE to “Measure”. Also select position [1] in the list below “Reference (Ohm)”, to the right of the Rm reference value taken from “Scale settings (Ohm, %)” for that range.

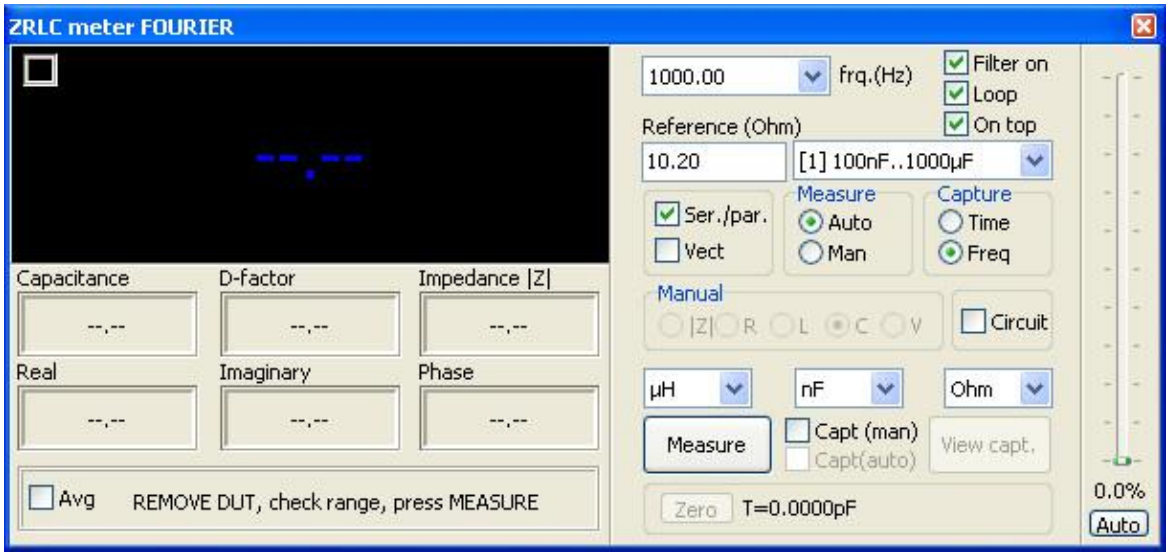
Notice the vertical slider on the right, which controls input level. To make the self-calibration performed before the measurement more visible, move the slider to its minimum (0%) if it is not there already.

Click “Measure”. You will see the slider rise and, if necessary, fall again until it reaches a suitable level. During this stage, before the DUT is connected, ZRLC starts a process that attempts to do several things, including making the two channels (connected, as we have seen, to S and T1) identical in phase and amplitude. These are not merely multiplication factors, as in the original Steber and Klaper programs, which were rather cumbersome and not yet automated.

A recording of the calibration process made with “NE-XT - V.3 BETA” was available under the red link in the original document. Notice the slider on the right side of the window.



Original illustration · source p. 54 · 1



Original illustration · source p. 54 · 2

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Video filename: Calibr_FourierNEXT_n2.wmv

When ZRLC decides it is ready to measure, the message “Connect DUT” appears. Move MODE to “Check”: the first internal resistor will immediately be measured, at about 48 Ω.

Now this range must be calibrated. The method is the same as the one described under “Calibration” in the preceding article, to which I refer for more detail. For example, suppose the first Check resistor has an actual value Rp = 47.5 Ω and the displayed reading is Rv = 48.1 Ω. Calculate the factor:

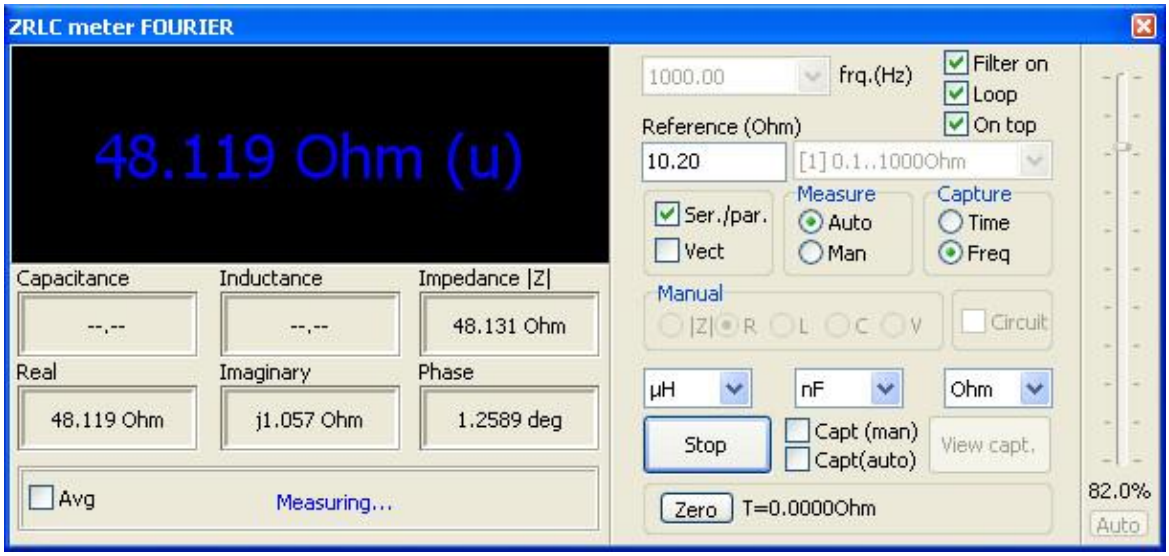
F = Rp / Rv

In this case F = 47.5 / 48.1 = 0.987.

Without pressing “Stop”, click the field for position [1] under “Scale settings (Ohm, %)”, and replace 10 with 10 × 0.987, or 9.87 (there is no need to be excessively fussy). You will notice that the “Apply” button for that position, previously disabled, becomes active. Click it to apply the change. The correct value should immediately appear, apart from small, unimportant fluctuations.

Return MODE to “Measure”, set RANGE to 2, select [2] under “Reference (Ohm)”, and repeat the procedure. Correct the corresponding value for position 2 in “Scale settings (Ohm, %)” using the same formula. Repeat for positions [3], [4] and [5].

A clarification is needed here. Unfortunately, I found that the previously described method of saving calibration values in the ZRLC settings does not always work. I had said that clicking “Save Config.” among the “Save Config.”, “Save As” and “Open Config.” buttons would cause all current parameters to be reloaded automatically every time the program was started.



Original illustration · source p. 55 · 1

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Fortunately, simply closing Visual Analyser is sufficient: at that point the program writes the complete configuration to VA.ini. It is worth making a backup in case something gets messed up.

Original document: page 56 / 75

Other measurement methods

1. Frequency sweep

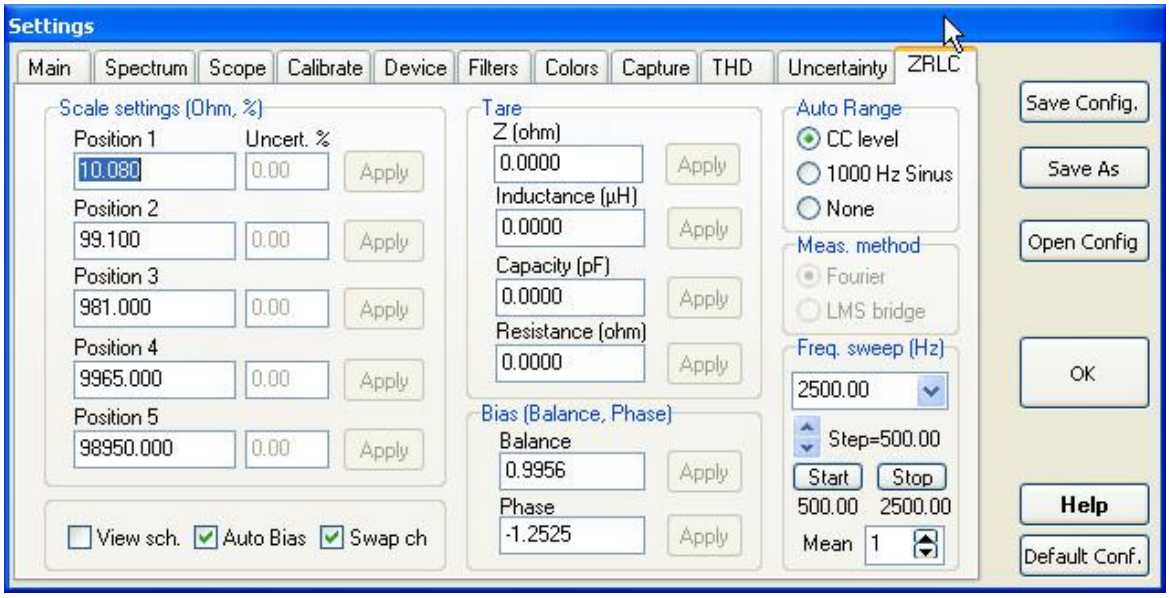
You may have noticed the “frq.Hz” list at the top of the ZRLC window, where you select the measurement frequency. It is normally set to 1,000 Hz. However, any frequency from 10 Hz to more than 20,000 Hz can be selected in 10 Hz increments. At the time of writing, changing the analysis frequency is an experimental feature.

Capacitance and inductance are fundamentally physical properties of the component being measured and, in an ideal component, are independent of frequency. What does depend on frequency is its impedance (in broad terms, opposition to current flow). In real components, however, the effective capacitance or inductance may change slightly with measurement frequency. We should also remember the stray capacitances and inductances of the measurement circuit: although generally negligible at audio frequencies, they can affect the final reading.

It is therefore interesting to measure a component at different frequencies. The software author provided an automatic “Sweep” facility allowing the start and stop frequencies and the step—the difference between successive frequencies—to be set.

For this purpose, the ZRLC page in “Settings” includes a “Freq. sweep (Hz)” section, with a list for choosing the frequency limits and a step selector. Select the initial frequency and click “Start”; the selected frequency appears below it. Select the final frequency and click “Stop”. Then use the arrow buttons to set “Step”; holding them down changes the value faster. You may also specify how many repeated measurements are performed at each frequency using the buttons beside “Mean”, or by entering a number. ZRLC calculates the mean of each group of readings.

For example, see the settings shown below.



Original illustration · source p. 57 · 1

Original document: page 57 / 75

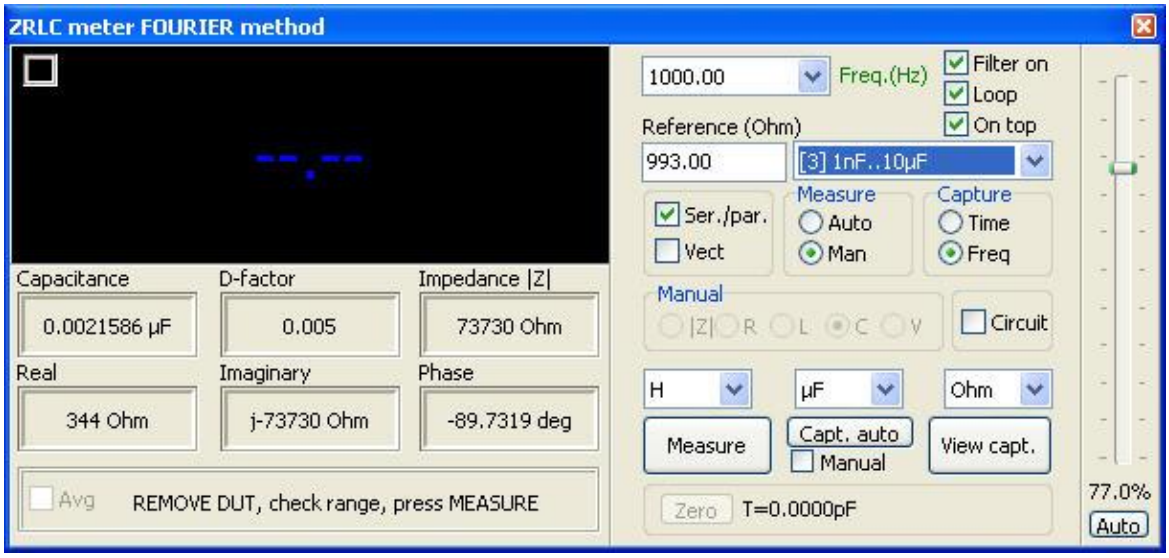
Now set “Measure” to “Man” and “Capture” to “Freq” in the ZRLC window. In the “Manual” section select the button for the quantity to be measured, as illustrated; for a capacitor, choose “C”.

Click “Capt. auto”. ZRLC performs an initial basic calibration; when the message “Remove DUT...” appears, make sure nothing is connected and press “OK” to start the sweep calibration sequence, which runs at every selected frequency.

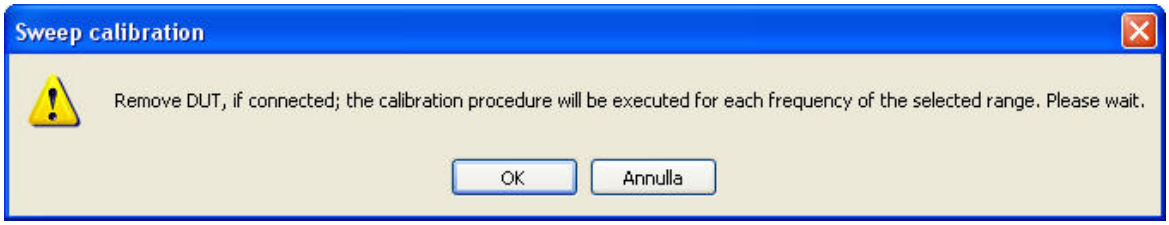
The original document linked to an animation, recorded using “NE-XT - V.3 BETA”, in which the frequency values and the sequential measurement number appear at the top: Calibr_SweepNEXT_n.2.wmv.wmv.

At the end, a message instructs you to connect the DUT and press OK.

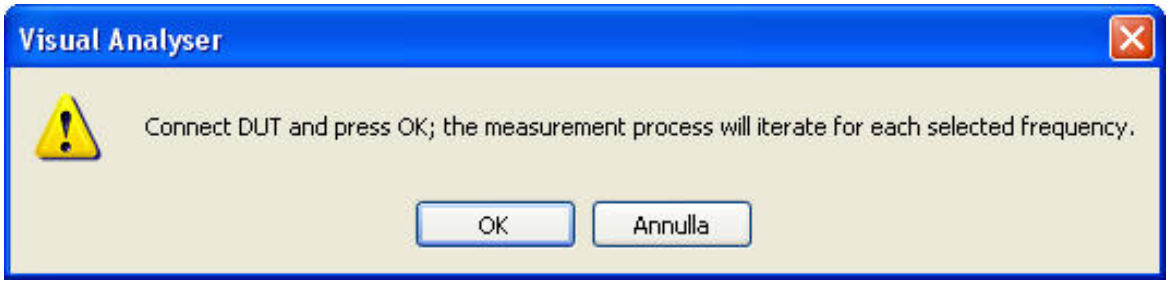
Connect a capacitor, for example, and press OK. The measurement sequence starts. In a second animation linked by the original document, the frequency and measurement number appear in succession, together with the repetition number if applicable.



Original illustration · source p. 58 · 1



Original illustration · source p. 58 · 2



Original illustration · source p. 58 · 3

Original document: page 58 / 75

Video filename: Measure_SweepNEXT_n.2.wmv

When “Capture ENDED” appears, click “View capt.” to display the results.

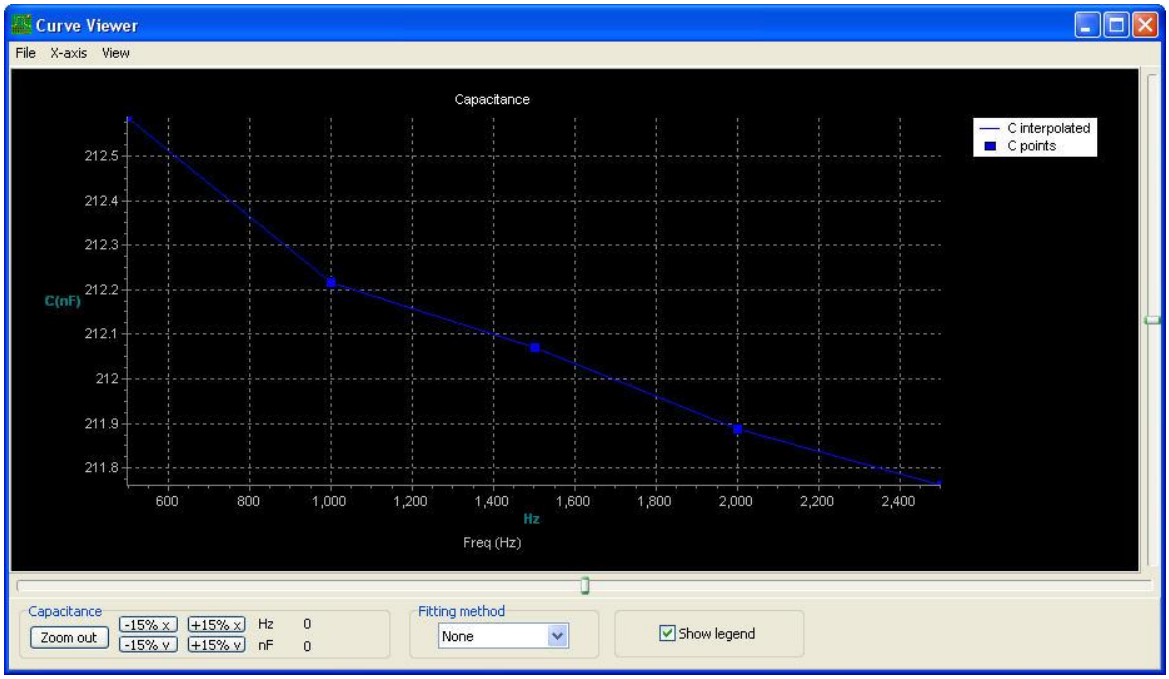
This display can be saved as an image or as data using the “File” menu.

2. LMS Bridge

The author of Visual Analyser initially drew inspiration from Steber's and Klaper's work, creating a routine based on the LMS algorithm (Least Mean Squares), resulting in an instrument that operated like the earlier “LMS bridges”. That routine is still included in the program and is the one considered here.

Subsequently, the author developed a routine making use of resources already included in Visual Analyser, producing a new and highly customised ZRLC meter. In addition to a proprietary algorithm, the routine uses the Fast Fourier Transform (FFT), an efficient algorithm for calculating the Discrete Fourier Transform (DFT), which is based on summing a series of complex numbers.

The FFT is important in a wide range of applications, from differential equations and partial derivatives to algorithms for multiplying very large integers and digital signal processing, as in the present case. The advantage is that, with a large number n of sampled values (and bearing in mind that impedances are complex quantities), directly computing the transform requires $O(n^2)$ arithmetic operations.



Original illustration · source p. 59 · 1

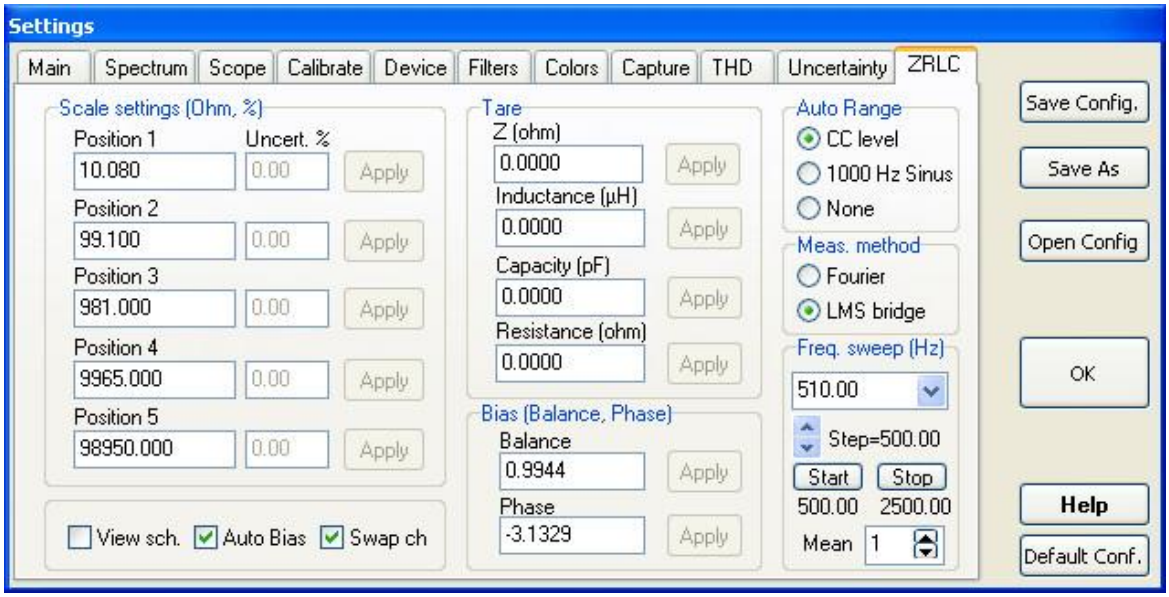
Original document: page 59 / 75

An FFT algorithm obtains the same result in O(n log n) operations.

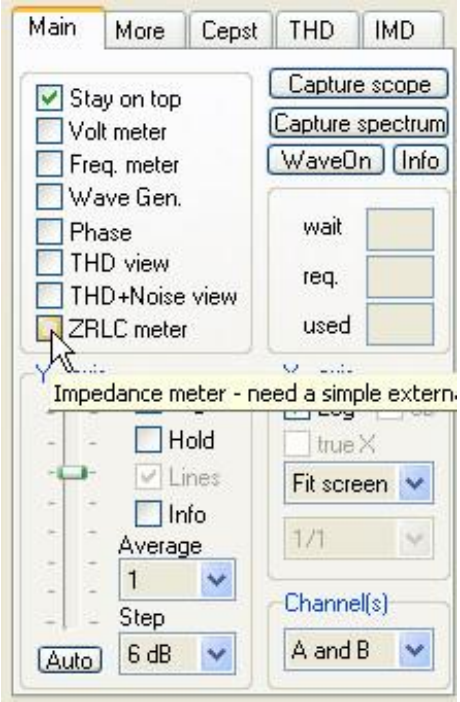
The Fourier method is now the principal method and is selected automatically when Visual Analyser opens. Nevertheless, the ZRLC interface can still be used as an “LMS bridge”. Here is how.

First close the ZRLC window if it is open. Then, under the “ZRLC” section in “Settings”, select “LMS bridge” in the “Meas. method” group.

In the main Visual Analyser window, tick “ZRLC” to the lower right of the spectrum display. The ZRLC LMS bridge window opens. With older software versions it differs slightly from the FFT window; in the 2010 NE-XT - V.3 BETA version the windows are the same.



Original illustration · source p. 60 · 1



Original illustration · source p. 60 · 2

Original document: page 60 / 75

All that remains is to select the desired range in the ZRLC window and set the interface RANGE switch to the corresponding position.

Connect the DUT and click “Measure”.

Now experiment for yourself!

Required files

A ZIP archive was originally provided with all necessary files. It also contained the newest VA version at the time (3.beta), with all corrections and improvements up to 22 March 2010. The original document instructed readers to click “Files.zip” to download it.

Archive contents:

• PCB bottom 1-1.pdf — 24 KB

• PCB bottom 250x100.bmp — 7.1 MB

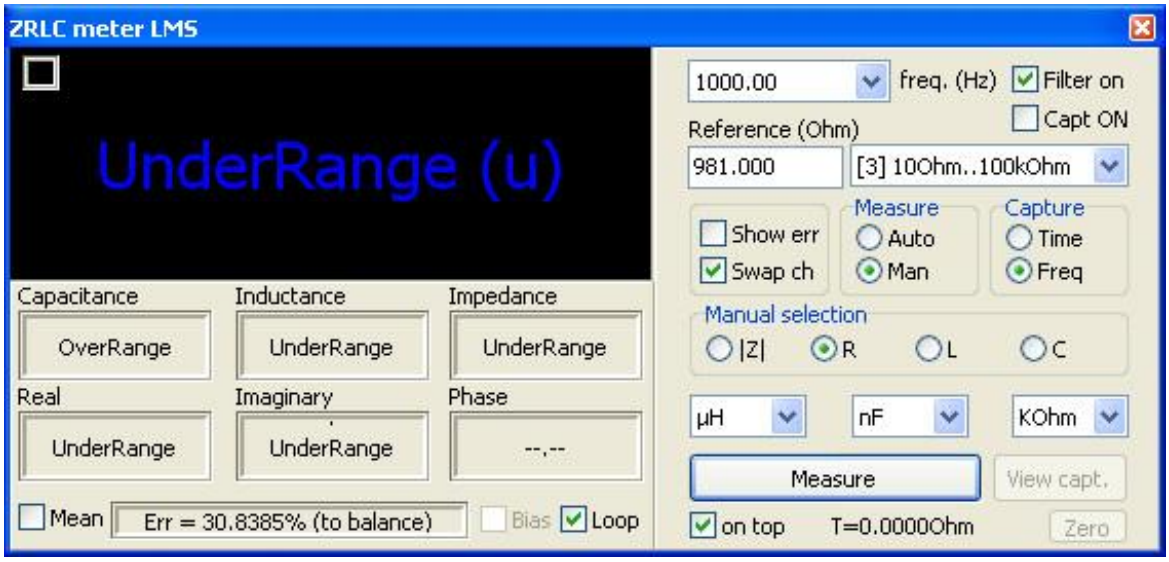
• PCB serigrafia 250x100.bmp — 7.1 MB

• pcm2902.pdf — 279 KB

• VA.exe — 4.6 MB

• ZRLC_AIO_4.dch — 54 KB

• ZRLC_AIO_PCB5.dip — 22 KB



Original illustration · source p. 61 · 1

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Part IV

Third version: power output stage

Third version — ZRLC with a power output stage

As already mentioned, this version improves the ability to measure resistances of only a few ohms and makes it possible to measure loudspeaker impedance. The idea came to me both from various discussions with A. Accattatis and from reading the article “USB Impedance Meter for Personal Computers” in issue 242 (November–December 2009) of Nuova Elettronica.

In fact, I had already realized that the “All In One” version could not measure loudspeaker impedance. When I connected a 4 Ω loudspeaker to the ZRLC All In One, no measurement was made: VA stubbornly displayed “Connect DUT”. Similarly, whereas a 10 Ω resistor could be measured, albeit with some uncertainty, a 5 Ω resistor behaved like the loudspeaker.

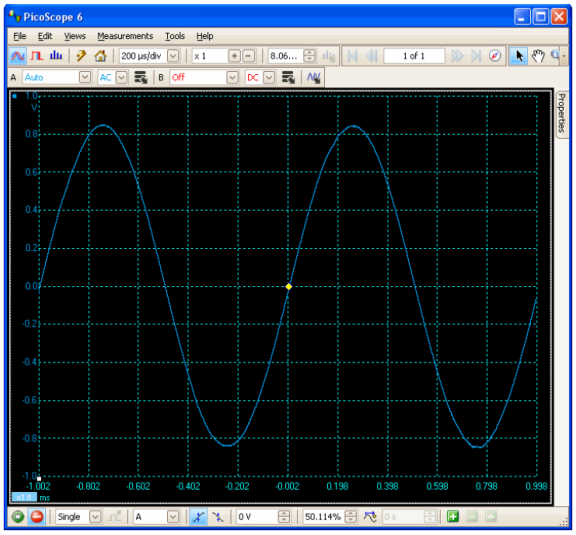
But why? One may suppose that in the ZRLC All In One, which supplies the measurement divider directly from the PCM2902 output stage, that output impedance is not low enough; in other words, it may not be able to deliver enough current to drive a load below a certain value.

The loudspeaker probably presents an additional complication. In the presence of alternating current, the voice coil produces a varying magnetic field. Its interaction with the fixed field of the magnet causes the coil, and therefore the cone, to oscillate in synchronism with the current. There is more: by Faraday’s law, the movement of the coil through the fixed magnetic field also produces an induced counter-electromotive force (back EMF) opposing the applied alternating current.

When a loudspeaker is connected to a correctly dimensioned audio power amplifier, the back EMF is certainly negligible in this context. Evidently, however, when the same loudspeaker is connected to the output of the PCM2902 — moreover through the 10 Ω reference resistor — the available voltage is insufficient to counteract it.

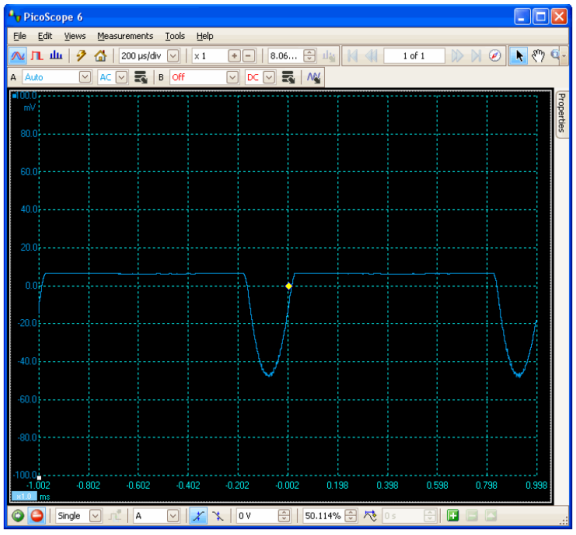
An analogy is the audio output found on many PCs: headphones or earphones can normally be connected, as they generally have a higher impedance and resistance than a loudspeaker; a loudspeaker, however, cannot normally be connected directly.

All this can be observed by displaying the AC voltage at the ZRLC All In One output terminals on an oscilloscope. With the circuit open, the voltage is a correctly shaped sine wave with an amplitude of about 1.7 Vpp.



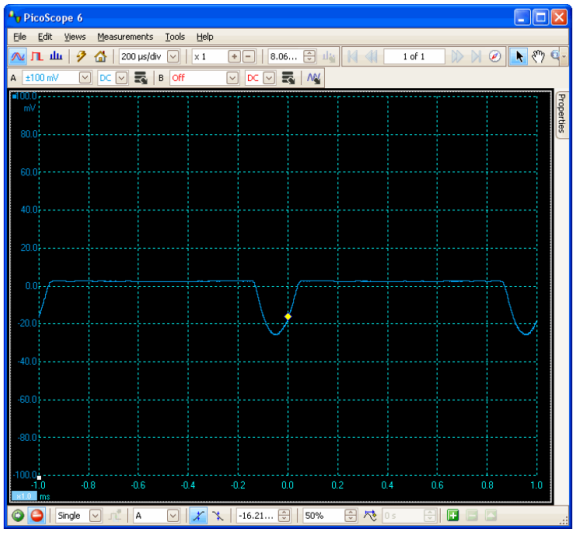
Open-circuit output waveform: approximately 1.7 Vpp (original p. 63).

Now, with a 10 Ω resistor connected on range 1, the first problems appear. As can be seen, the sine wave — reduced in amplitude out of proportion — is clipped on one half-cycle.



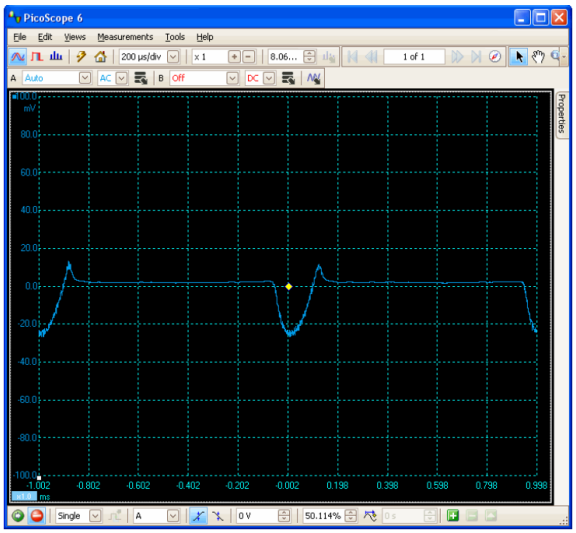
Output waveform with a 10 Ω resistor (original p. 63).

With a 5 Ω resistor, which the instrument can no longer measure, the situation becomes worse:



Output waveform with a 5 Ω resistor (original p. 64).

And here is the loudspeaker. The particular asymmetry of the voltage waveform is probably due to the back EMF:



Output waveform with a loudspeaker (original p. 64).

The Nuova Elettronica impedance meter

Having established this, and driven by curiosity — particularly after reading the article mentioned above — I purchased the “USB Impedance Meter for PC” kit (LX.1746 KIT). After assembling it, I was able to verify that it really works well.

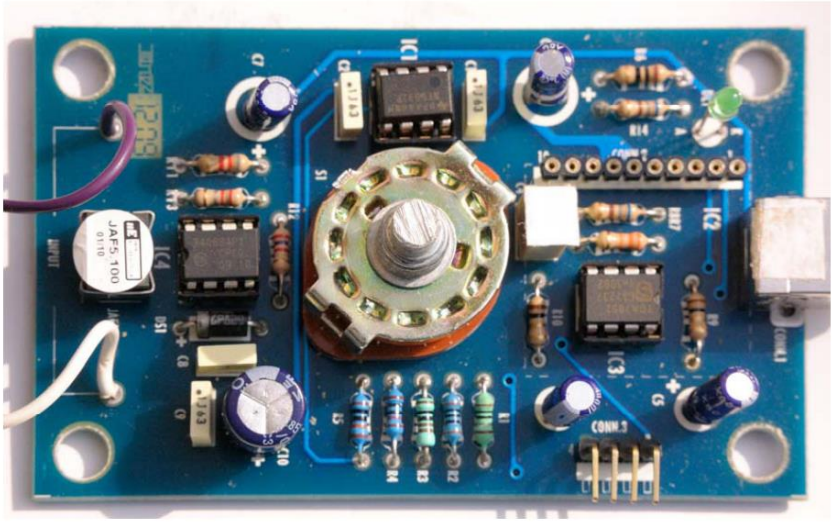
As the article shows, its circuit is essentially similar to that of the ZRLC AIO, but it has several significant differences, which I shall examine in detail.

Here is the impedance meter, fully assembled and housed in its enclosure:



The assembled Nuova Elettronica LX.1746 impedance meter (original p. 65).

Below we can see the completed PCB, both without and with the KM1667 board installed. On the left is the MC34063A voltage converter, in the centre the NE5532 dual operational amplifier, and on the right the TDA7052 audio power stage. Above the latter is the KM1667 board with its PCM2902 codec.

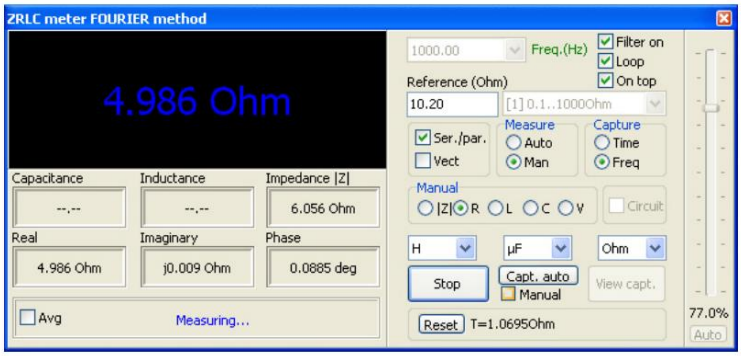


Board view before installation of the KM1667 module (original p. 66).



Board view with the KM1667 module installed (original p. 66).

This impedance meter measures low resistances correctly:



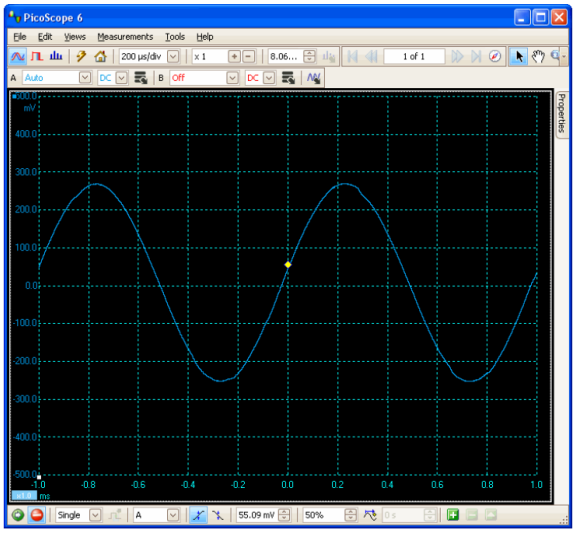
Low-resistance measurement (original p. 67).

It also measures loudspeaker impedance:



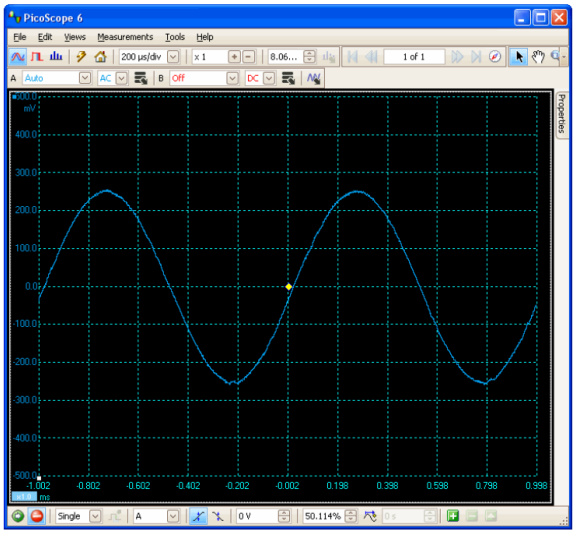
Loudspeaker impedance measurement (original p. 67).

And here are the oscillograms. First, with a 5 Ω resistor:



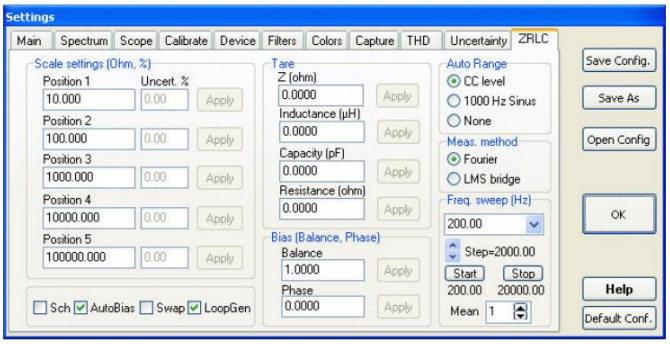
Waveform with a 5 Ω resistor and the amplified interface (original p. 68).

Then with a 4 Ω loudspeaker:



Waveform with a 4 Ω loudspeaker and the amplified interface (original p. 68).

One detail: with the Nuova Elettronica version I had to clear the “Swap” checkbox in “Settings – ZRLC”.



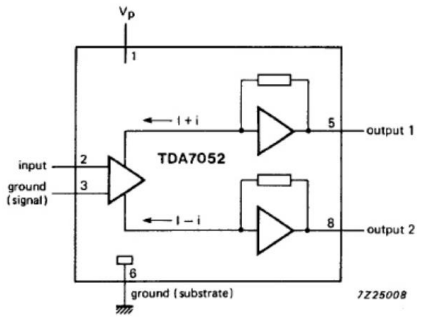
The “Swap” setting in the historical VA configuration window (original p. 69).

It is also worth noting that with this version the loudspeaker produces a strong 1,000 Hz acoustic signal, whereas with ZRLC without a power stage it emits only a faint sound!

So where does the difference lie? The novelty of the Nuova Elettronica version is a “miniature 1-watt power output stage”, built around the Philips TDA7052 integrated circuit. It is inserted between the audio output of the PCM2902 codec and the S1-B/S1-A range selector, which corresponds to switch S1 in the first schematic on page 36 and to switch Dev1 in the second schematic.

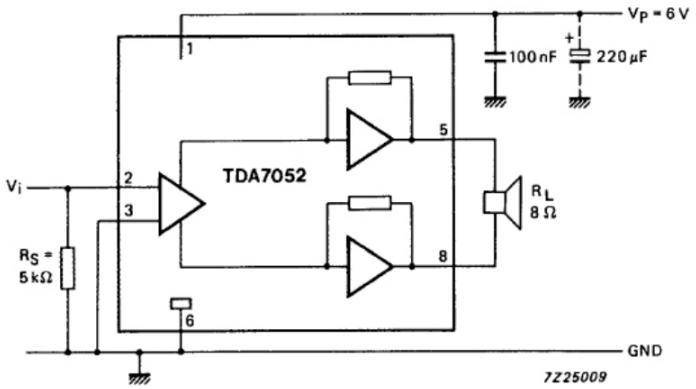
Strangely enough, the article does not explain why this output stage was included. However, tests performed on an assembled Nuova Elettronica kit showed that the problems encountered with the ZRLC All In One when measuring low-value resistors and loudspeakers were completely eliminated by using this stage. The observations therefore strongly support the explanations proposed above.

How is this stage implemented? Let us first look at Nuova Elettronica’s solution, referring to the cited article for the full circuit schematic. This is the IC block diagram:



TDA7052 internal block diagram from the original documentation (original p. 69).

And this is its application circuit:

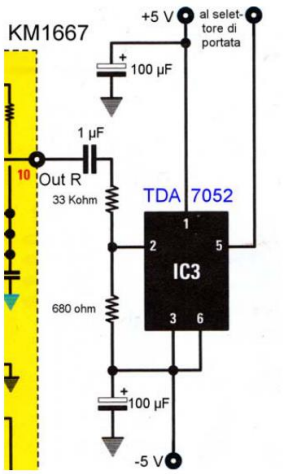


TDA7052 typical application circuit (original p. 70).

I am left wondering why the TDA7052, with its two “floating” loudspeaker outputs, was chosen as the final stage. I believe the answer lies in this integrated circuit’s ability to deliver relatively high power at low supply voltages. This is precisely due to the bridge configuration (BTL, Bridge-Tied Load), which uses two independent output terminals rather than a single output referred to ground.

Philips adopted this design to compensate for the reduction in output power caused by the low supply voltages in portable radios and recorders, which use fewer batteries to save space. According to the “Functional Description” in the datasheet, the IC can supply 1.2 W (THD = 10%) into an 8 Ω load with a 6 V supply.

This is the circuit used in practice: the amplifier stage is inserted “in series” between the PCM2902 right-hand output channel (“Out R”) and the range selector.



Practical insertion of the TDA7052 stage into the measurement circuit (original p. 71).

To maintain the correct input audio signal level for the bridge stage, the TDA7052 gain of 40 dB is compensated by a voltage divider formed by R7 and R8, 33 kΩ and 680 Ω respectively.

Compensated… almost. Philips states that the voltage gain is internally fixed at 40 dB. By the definition of decibels, 40 dB corresponds to a voltage ratio of 10^(40/20) = 100 between output and input. On the other hand, the R7–R8 divider introduces an attenuation of 680/33,680 ≈ 0.020, or a factor of about 50.

Thus, theoretically, the signal at the output of this arrangement is twice the signal at the PCM2902 output. In practice, however, this does not appear to cause problems.

Anyone interested in the entire circuit can find it, as already mentioned, in issue 242 (November–December 2009) of Nuova Elettronica.

Negative-voltage generator

The Nuova Elettronica impedance meter also uses a negative-voltage generator, but one different from that used in my own design: an MC34063A rather than the perhaps more familiar ICL7660. The TDA7052 is probably the reason for using the MC34063A.

The MC34063A is a switching “DC-to-DC Converter Control Circuit” capable of providing output currents of up to 1.5 A.

Switching DC–DC converters are used to change one DC voltage level into another. Typically, these circuits carry out the conversion by applying DC voltage to an inductor during one part of the operating cycle (usually at frequencies in the range 100 kHz to 5 MHz), allowing current to flow and magnetic energy to be stored. During the next part of the cycle, the voltage is removed and the stored energy is transferred in a controlled way to the converter output. This method of conversion is very efficient (approximately 80–95%).

The ICL7660 is a “switched-capacitor voltage converter”, commonly used as a negative-voltage converter operating as a charge pump. Although there is also a switch that operates cyclically, the operating principle differs from that of an inductor-based converter.

During the first half of the operating cycle, generally at 10 kHz, a capacitor (C1) is charged to the positive supply voltage V+ with respect to ground by MOS switches integrated into the IC. During the second half-cycle, the MOS switches disconnect C1 from the supply and connect it with a second capacitor C2 in such a way that one terminal is held at ground and a negative voltage appears at the other terminal.

The difficulty is that the switches have non-zero series resistance, giving the converter a typical overall impedance of 50 Ω. This means low output current (0.1 A at 5 V, as reported in the original document) and a tendency for output voltage to fall as the load current increases.

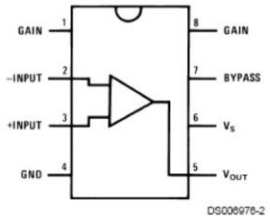
This limited current is probably inadequate for the Nuova Elettronica impedance meter, but more than sufficient for the ZRLC AIO.

This explains the choice of the MC34063A rather than an ICL7660, even though the former requires more components — three resistors, three capacitors, a diode and an inductor — compared with the two capacitors required by the latter.

Other possible audio output stages

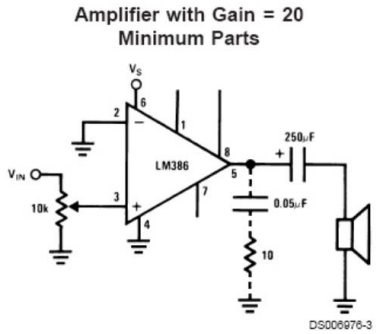
The TDA7052 is, after all, just one of many low-power audio amplifier ICs. A theoretical alternative could be National Semiconductor's LM386, described as a "Low Voltage Audio Power Amplifier". Its gain is internally set to 26 dB, but can be increased from 26 to 46 dB by adding a resistor and a capacitor between pins 1 and 8.

Here is the IC's block diagram:



LM386 block diagram (original p. 72).

And this is a typical circuit with the minimum number of components. It provides a gain of 20 dB, that is, 10^(20/20) = 10 times:

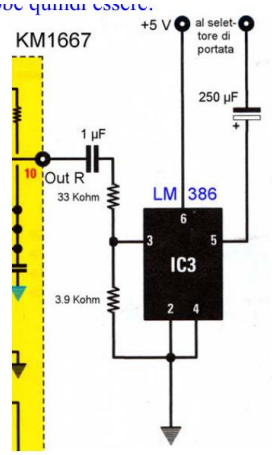


Typical LM386 application, minimum component count (original p. 73).

Since, according to the original discussion, the gain has changed from 100 to 20 — a fivefold reduction — the divider attenuation must also fall by a factor of five, becoming 50 / 5 = 10.

A practical circuit might therefore look like this:

Un circuito pratico potrebbe quindi essere:



Proposed LM386-based measurement interface (original p. 73).

There could, however, be a drawback. The LM386 datasheet gives the following output power values:

Device	Conditions	Min (mW)	Typ (mW)
LM386N-1, LM386M-1, LM386MM-1	Vs = 6 V, RL = 8 Ω, THD = 10%	250	325
LM386N-3	Vs = 9 V, RL = 8 Ω, THD = 10%	500	700
LM386N-4	Vs = 16 V, RL = 32 Ω, THD = 10%	700	1000

We can see that at 6 V, instead of the 1,200 mW provided by the TDA7052, only 325 mW are available. This could lead to a substantial reduction in performance.

An external audio power stage could also be used. Here is what Accattatis himself told me:

"As for Nuova Elettronica's idea: in the very early stages of the project I myself had suggested to NE that they use a proper power output stage. In fact, during some tests I used a small Kenwood power amplifier rated at 70 watts RMS (!!) as the output stage, and this enabled me to use reference resistors of only a few ohms, or even fractions of an ohm."

In any event, anyone who wishes to can try!

Datasheets

The following links to datasheets for the integrated circuits used or described were included in the original publication. They are retained for historical reference; availability of these links has not been verified.

LM358 — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/LM158.pdf

ICL7660 — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/ICL7660.pdf

ICL7660S — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/ICL7660S.pdf

Principles and Applications of the ICL7660 and ICL7660A CMOS Voltage Converter —
http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/Principles_Applications_ICL7660.pdf

PCM2902 — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/pcm2902.pdf

MC34063A — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/MC34063Amotorola.pdf

NE5532 — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/NE_SE5532_A_SA5532_3.pdf

TDA7052 — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/TDA7052.pdf

LM386 — http://www.marucchi.it/ZRLC_AIO_WEB/ZRLC_AIO_file/lm386.pdf

Editorial note

This is a faithful English adaptation of the historical document rather than a present-day circuit validation. In the original LM386 discussion, a gain of 20 dB (10×) is followed by a comparison using a gain value of 20×; the inconsistency is retained in the narrative rather than silently reconciled. Similarly, the author's technical hypotheses are reported as his interpretations, not as independently verified claims.