System theremino

Theremino MCA

Pmt Adapter V3.3
Audio Adapter
Pmt tube connections

First things first

IMPORTANT: If you do not have the new "Audio Adapters V2", with limitation of current, then: **Before connect the audio card to the USB port** the PmtAdapter must be connected well. Double check that the jacks are way down. If Jack is not well placed, can make a **short circuit on the power**.

Short circuit of short duration, less than a second, do not create problems for which you can also remove and insert the Jack under tension (with the audio card connected to the USB port) but **you should be careful to place them right**, fully and quickly, **check each time.**

If the jack is inserted wrong (and it takes a little bad luck because they have to be entered exactly in the right place), you can create a short circuit between the 5Vdc supply and ground.

In any case, do not cause damage to your PC or PmtAdapter but a short circuit may continue to heat the filter inductance, the audio card, to bake the enamel of his thin copper wire.

An inductance deteriorated (with the coils shorted to each other) would not remove more noise the USB and should be replaced, it costs a fraction of the euro, but it is not easy to replace, because there is little space in the audio card.

So be very careful to plug well the Jacks and maybe, to make no mistakes, do it with USB disconnected.

With the new "Audio Adapters V2" forget this ... have a current limiter and you can do short as you like.

IMPORTANT - Before disconnect the audio card from the USB port, check that its LED is lit. If the LED is blinking it means that some program is reading. Close the DAA, the Theremino MCA and any other programs that read the audio until the LED stops blinking.

If you disconnect the audio card during operation, applications can give errors or remain invisibly in memory and you will have to remove them with the TaskManager.

IMPORTANT - If you open the PmtAdapter container you should be careful. **The two high voltage filter capacitors can give a fair shake, not dangerous, but very unpleasant!** If shorted together can make a blast strong enough. If you make a short circuit between the high voltage capacitors and other components, these will "fry" and instantly you will have to change them.

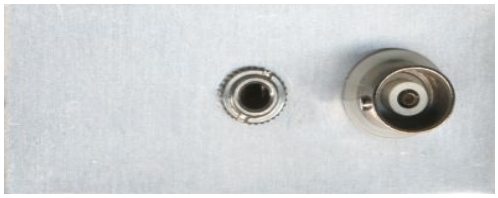
When the PmtAdapter is locked in his metal box the high voltage coming out of the BNC is not dangerous, can not hear anything or could, at best, give a little discomfort.

Arrangement of components

Some would put the audio card in the container PmtAdapter, it would not fit well, it would be very difficult to fit them together without interfering with each other.

Someone, even sadistically, think to put it all in aluminum tube that shields the photomultiplier, this is the most "impossible" of all, do not do it.

The PMT, wrapped in PVC foam, slips into an aluminum tube from 35 .. 40mm, fully closed. Even the slightest crack can create problems, then using black ribbon, to seal any possible route of entry of light. From the PMT to PmtAdapter using a shielded cable, no longer than one meter, ending with two BNC.

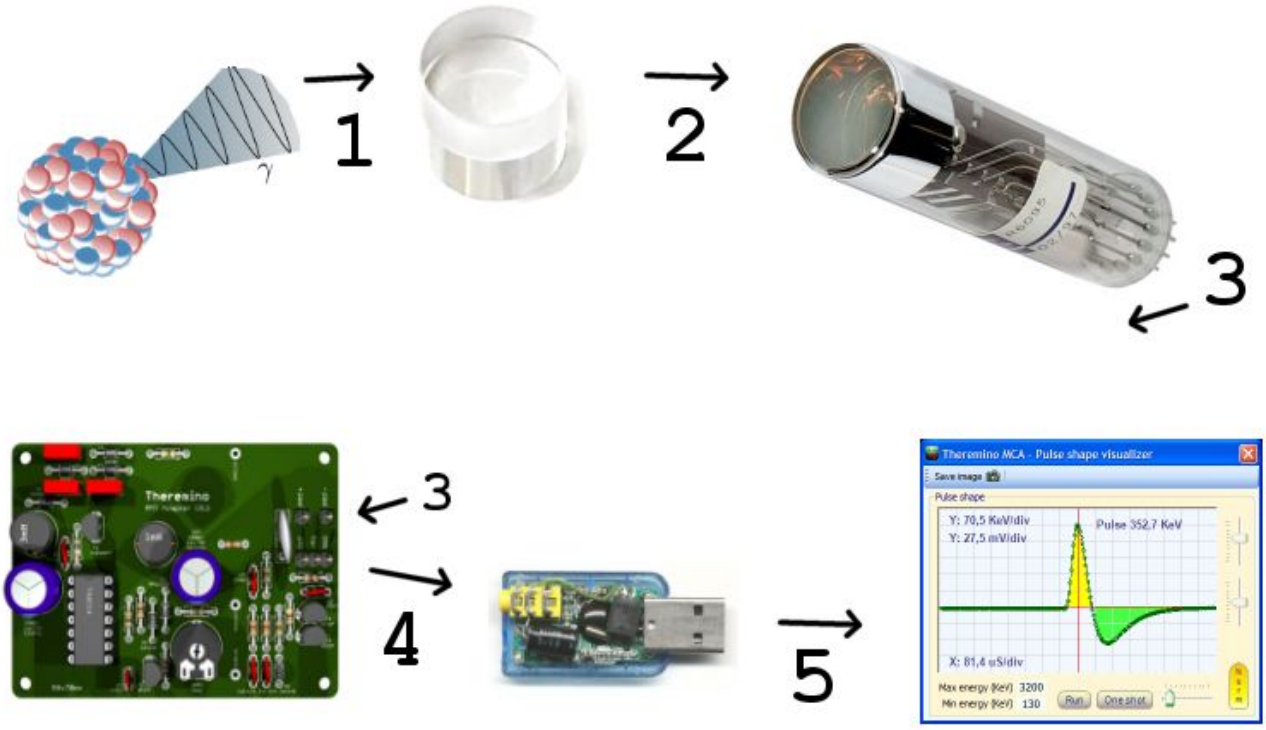


For the PmtAdapter use a container of thin aluminium 100mm x 60mm x 30mm, with short side rising from below. On one of the short side are mounted BNC and the stereo jack female 3.5mm.

A stereo audio cable, soft, good quality, shielded (read the section which explains how to recognize fake shielded cables) allows for the components to any distance. You can go a lot of meters from the PC.

The audio card should be in its natural place, connected to a USB port, In this way eliminates the USB extension that would be rigid, uncomfortable and expensive.

The signal path



(1) A gamma photon is emitted by a radioactive isotope. His energy is invariable, can do little or a long way, can pass through aluminum, plastic and other materials, and even if it comes from another galaxy, its energy will be exactly the same as when he started.

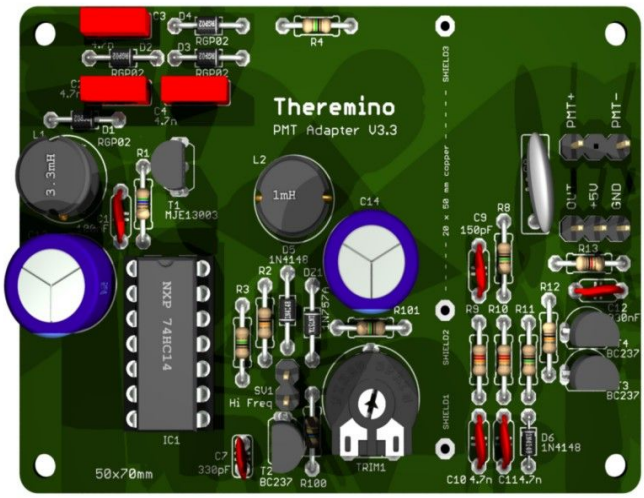
(2) The crystal scintillator converts the single photon in brief flash of visible light, composed of thousands of photons, many of them, but not all, are able to get to the photo-cathode of the photomultiplier tube. Depending on the material of the crystal, its purity and to what is transparent and easy the road, the number of photons that reach the photo-cathode changes, also between one pulse and the other. The number of photons variable produces an uncertainty in the measure that enlarges the isotope lines.

(3) The photomultiplier tube multiplies the electrons and produces a current pulse. Depending on the photon energy range, the load resistance and load capacity of the current produced by the tube, ranges from a few uA to a few hundred uA and the pulse width, from a few hundred nano seconds a few micro seconds. A pulse originating from a gamma photon from about 600 KeV, has an amplitude of about 10 volts and a width of 3 uS at the entrance of the PmtAdapter.

(4) The PmtAdapter signal conditioning circuit broadens the 3uS pulse over 100us and produces a pulse with zero-pole compensation, which goes back to zero "without undershoot"

(5) The audio card contains a high-pass filter to about 3KHz that produces a perfect "Bipolar" pulse, with a "undershoot" having exactly the same area of the positive part of the pulse. A well balanced bipolar pulse returns exactly zero in a short time, without producing undershoot or uppershoot tails.

The "PMT Adapter" - Features



Supply Current (with BSP300)
from 5mA to 70mA

Supply voltage (with BSP300)
from 4.5 to 6 Volt

Supply voltage (with MJ13003)
from 3.5 to 6 Volt

Output Voltage (R101 = 1Mega and R100 = 560k)
from 550 to 1000 volts

Output Voltage (with R101 = 680k and R100 = 560k)
from 700 to 1500 Volt

Stability of the output voltage

The output voltage is stable within 1% and does not cause appreciable displacement of the rows of the isotopes, with normal variations in ambient temperature of a laboratory (Note 1)

Output current R4 = R5 = R6 = R7 = 1Mega (normal operation with a ripple of less than 70uV eff)

from 0 to 25 uA - up to 1500 Volt (total PMT resistance > 25 Mega)

from 0 to 50 uA - up to 1000 Volt (total PMT resistance > 20 Mega)

from 0 to 100 uA - up to 500 Volt (total PMT resistance > 5 Mega)

Output current R4 = R5 = R6 = R7 = 100k (With high current ripple of about 1 mV rms)

0 to 100uA - up to 1000 V (total PMT resistance > 10 Mega)

0 to 250uA - up to 500 Volt (total PMT resistance > 2 Mega)

Total output noise (under "normal" operation - Note 2)

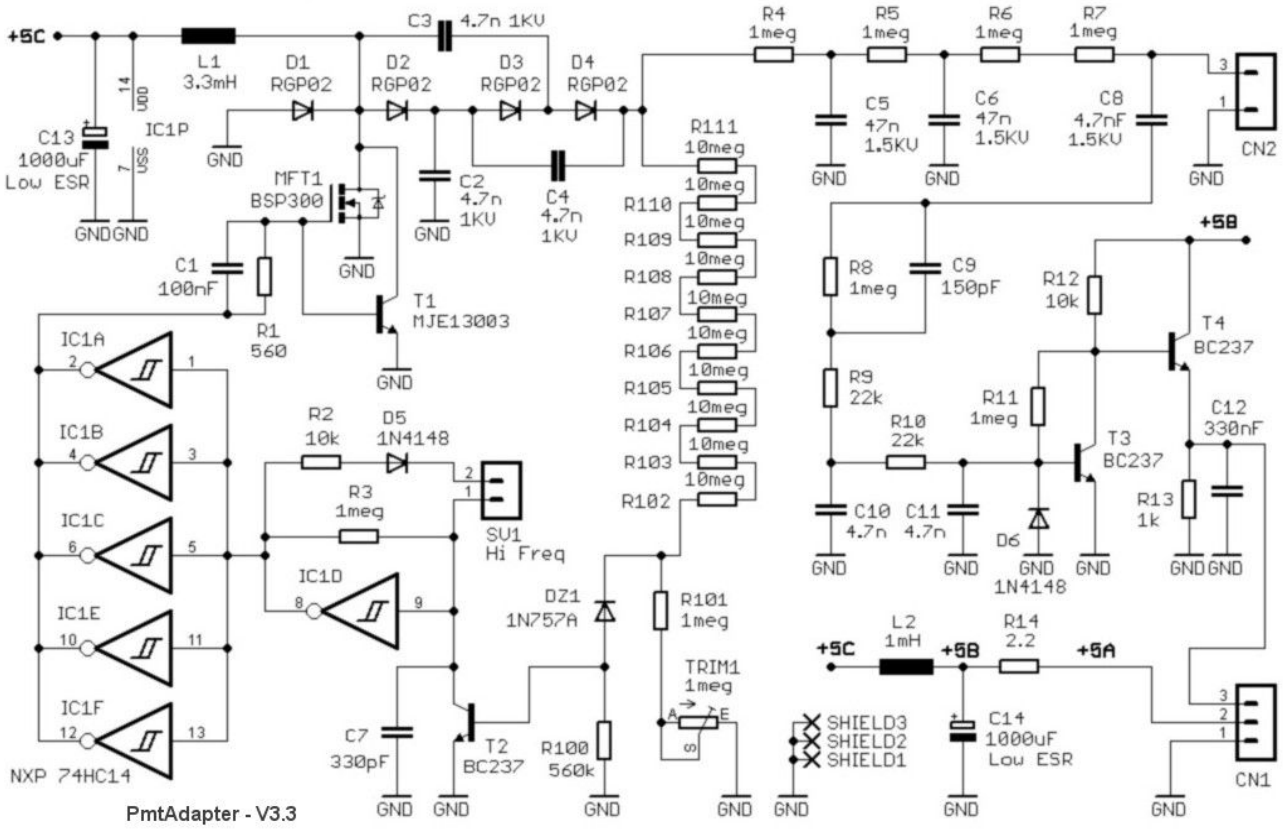
about 70 uV effective (Note 3)

(Note 1) *The stability depends on many factors including, the voltage calibration, the resistance and thus the tube current PMT, the characteristics of the Zener DZ1 and the value of the resistor R100. Even the container is important, must slow down variations and ensure the uniformity of the temperature on the PCB, otherwise the sudden changes in temperature may cause temporary changes in voltage. The PmtAdapter is designed for laboratory use. Outdoor, damp and extreme weather conditions (-30 degrees to +60 degrees) will need to re-calibrate frequently the energies in the MCA software.*

(Note 2) *The "normal" cobditions are: a PMT of 120 Mega ohms with 800 Volts and resistors R4 = R5 = R6 = R7 = 1Mega. The noise includes the power supply ripple and noise generated by the audio card and is measured by the the audio card ADC, modified with the high-pass filter, with all components in perfect condition.*

(Note 3) *A 70 uV rms noise corresponds to 200uV pep ie 0.2 mV pep, when measured by the DAA, increase the typical audio card noise of 0.3 mV pep to a maximum of 0.4 or 0.5 mV pep)*

The "PMT Adapter" - Changes and advices



To minimize the dependence of the voltage from the temperature *the zener DZ1 should be from about 9 or 10 Volt and with low leakage current. Depending on the zener model, you may need to change R100. If the voltage rises when the temperature rises then you must lower R100 to 560k or less, but if it reduces, you must increase R100 to 820k or more. The value of 560k is normally the best, with every type of zener, at medium working voltages. If you always work towards one end (500 Volt or 1500 Volt), it might be a good idea to change the value of R100 to obtain the maximum of stability.*

It is recommended to minimize the consumption *removing the jumper SV1, but if you want the maximum frequency of oscillation, connect the jumper. A high frequency minimizes the ripple, but the consumption increases and the mosfet heats more reducing stability. The heating of the mosfet is negligible up to about 30mA power, beyond 80mA causes visible peak shifts.*

High current PMT *- At the expense of increased output ripple and a lower current limit you could lower R4, R5, R6 and R7 to 100k. With high current (more than 100uA) 1600 volts can not be reached.*

L1 must have a low series resistance *(A few ohms, maximum 5, absolute maximum 15), impedance 3.0 to 3.3 mH, low parallel capacitance and low loss in the nucleus, its parameters are important for maximum efficiency and maximum temperature stability. Great inductors have lower resistance and lower losses. When connecting the wire to the capacitor C13 of the external loops of the coils and the internal MOSFET provides a small improvement in efficiency and minimizes radiated noise.*

C13 and C14 should be LOW-ESR *with a maximum series resistance of 0.05 ohms*

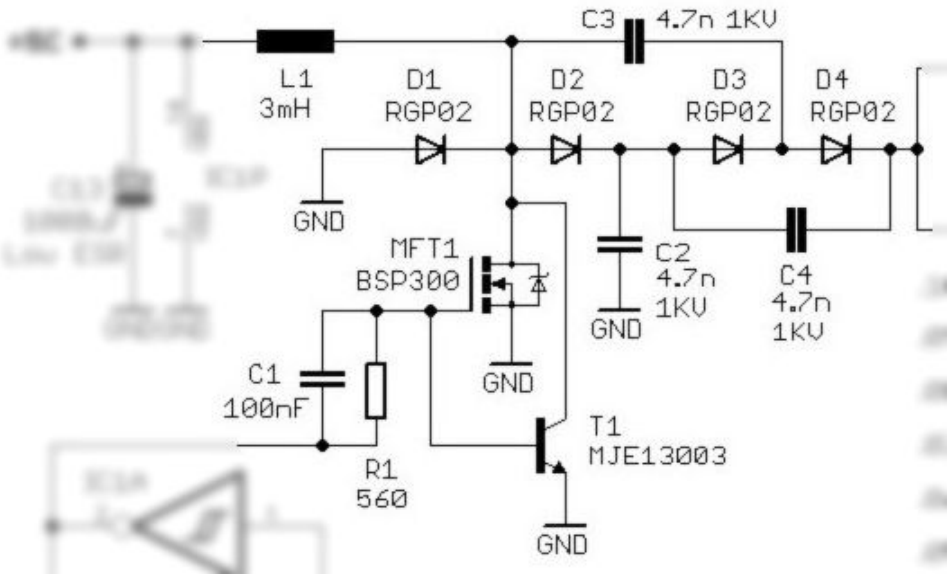
L2 must have a series resistance of less than 3 ohms, *if you really need can be reduced to 470uH.*

The transistors BC237 *can also be BC548 or equivalent.*

R101 sets the "range" of voltages obtained *- With a 1 Meg adjusts from 500 to 1000 volts (approx) With 680k adjusts from 700 to 1500 volts (approximately). Raising it you can even drop below 500 volts, and lowering it to go beyond 1500. It is recommended not to go over the 1600 - 1700 Volt for not straining the mosfet and the coil L1*

The "PMT Adapter" - Operation

The high voltage generator is a "flyback" circuit followed by a voltage doubler. The doubler allows to obtain output voltages up to 1600 volts, while maintaining all the components of this section, C2, C3 and C4 including, less than 800 volts.



When the MOSFET MFT1 (or transistor T1) goes into conduction, the current on the inductor L1 increases up to approximately 120 mA, past a time of about 100 uS the mosfet suddenly opens and the current flowing in the inductance L1, not knowing where to go, produces a high-voltage pulse lasting about 2 uS.

The high-voltage pulse, duplicated from D1, D2, D3 and D4, charges the capacitors C2 and C4 at a voltage from 50 to 1600 volts depending on the timing of ON and OFF with which the mosfet is driven.

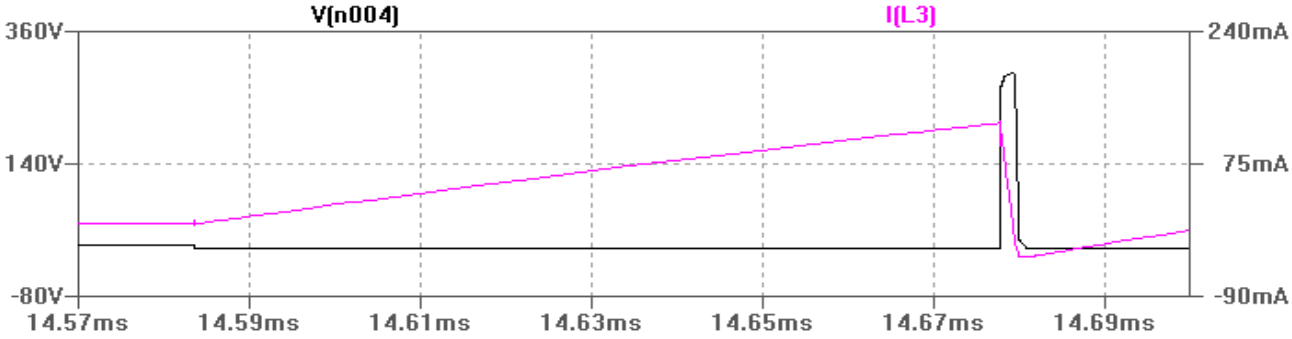
The maximum output voltage, limited by the MOSFET should be about 1600 volts, but we tried for a long time to 2000 volts and nothing happened. In a prototype of the L1 was very small and has begun to download internally, the voltage dropped to tearing of hundreds of volts. If it happens you do not like us we have replaced the capacitors, diodes and mosfets first to understand, immediately changed the coil, which is the only one that can download and place one bigger. Surely our coil had suffered because it was welded and welded many times and power to warm the enamel insulation was cooked.

The mosfet must be a BSP300, no other high voltage mosfet can work with a few volts of gate, do not try equivalents, would work with difficulty and only with voltages > 5 Volt.

Those who could not find the BSP300 could replace it with a transistor MJ13003 derived from fluorescent lamps burned low. If you use a transistor base is controlled by R1 and C1 instead with the Mosfet R1 and C1 is not needed and can be replaced with a bridge (or you can leave if you mount the mosfet)

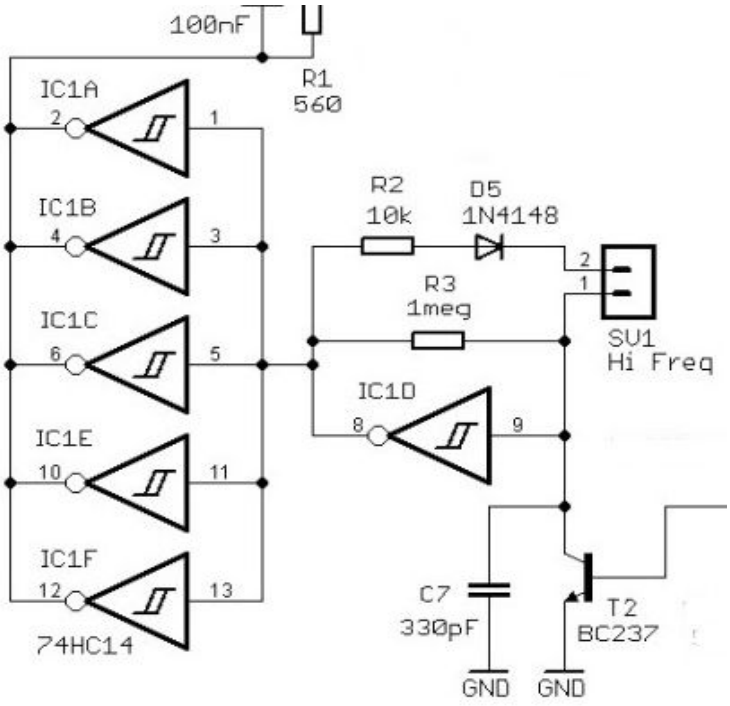
With the transistor consumption increases by a dozen mA for which it is preferable to use the MOSFET. The transistor has the only advantage of being able to work (with higher consumption) up to 3 volts. Instead, the mosfet can not go below 4.5 volts.

The inductor current grows up to 120mA and suddenly stops producing a high voltage "flyback" pulse.



It is very important for the efficiency to switch the MOSFET from conduction to interdiction in the shortest possible time, the 5 sections IC1A, IC1B, IC1C, IC1E and IC1F produce an instantaneous current of more than 200mA, be able to discharge the input MOSFET capacity in less than 200 nS

A high efficiency minimizes the consumption, reduces the heating of the mosfet and allows to obtain the maximum stability.



We recommend that you do not install the jumper SV1 in order to reduce the switching frequency and reduce consumption. With SV1 the OFF time becomes constant (about 2 uS) and the switching frequency rises towards the 20KHz. A high frequency minimizes ripple, but increases the current consumption, resulting in a greater heating of the mosfet and a lower voltage stability.

The transistor T2 inverts the signal and amplifies the current of at least 100 times, so it do not loads the delicate high voltage divider.

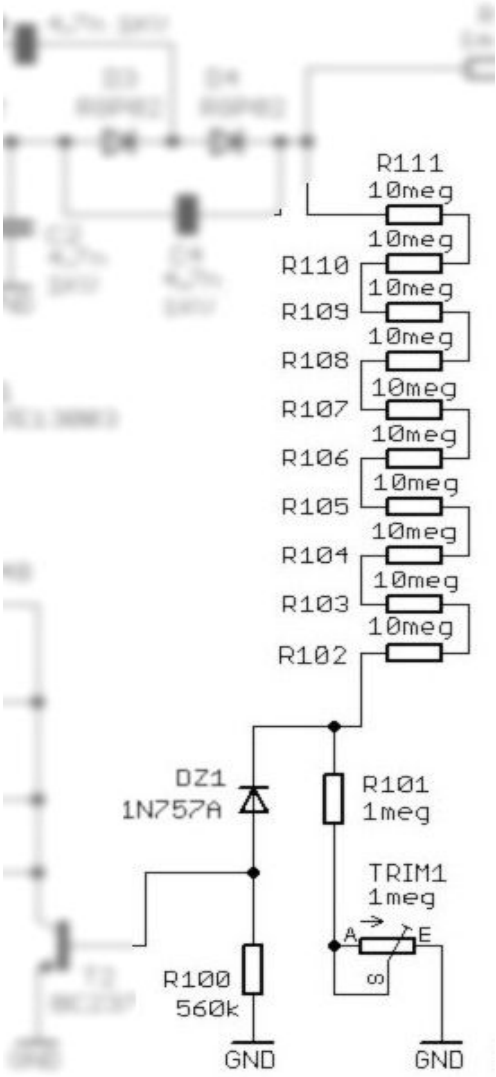
The oscillator section, composed of IC1D and C7, produces variable OFF and ON times, to maintain a constant voltage at the output of the doubler.

The times, depending on the voltage (from 500 to 1500 volts) and the output current (from 5uA to 200uA) are approximately the following:

Without R2 D5 and the OFF time varies from 5mS to 125uS and the ON time of 100us to 160uS

With R2 D5 and the OFF time is fixed at about 2US and the ON time varies from 50uS to 150us

The high voltage measuring circuit is composed of ten 10 Mega Ohm resistors forming a low cost, 100 Mega ohms resistor.



This solution is very reliable, thanks to its physical length eliminates problems caused by moisture even with artisan PCBs.

We use a very high resistance to lower the current measuring just 5 uA and not degrade too much the efficiency.

The divider composed of resistors R102 to R111, the resistor R101 and the Trim1, divides the output voltage and produces about 10 volts.

With R101 you set the maximum voltage.

- R101 = 1 Mega for 500 to about 1000 volts
- R101 = 560k for 700 to about 1500 volts

It could decrease the value of R101 and Trim1, bring the voltage directly at 0.6 Volts and apply it directly to the base of the transistor T2 but, given that the voltage base-emitter of the transistor changes with temperature, the dependence of the output voltage from the temperature would have been intolerable.

To which were added DZ1 and R100, which compensate almost perfectly, the variations of temperature.

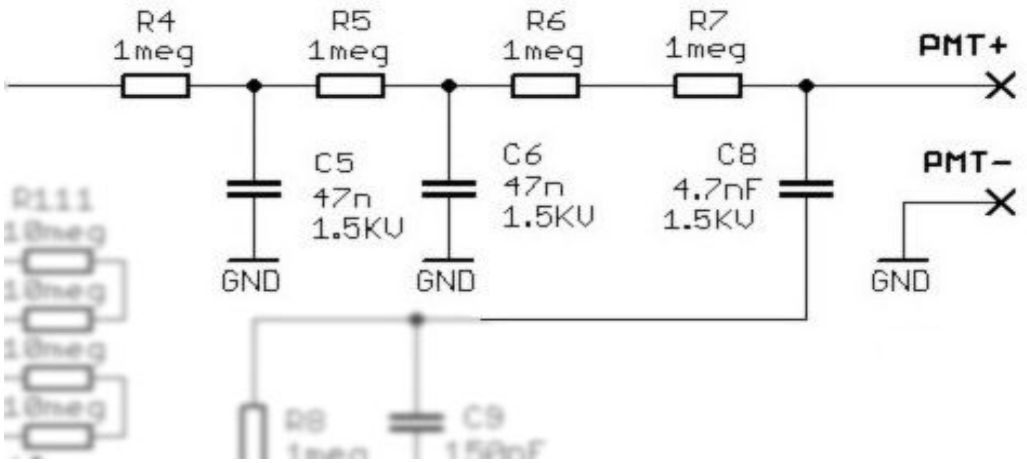
To minimize the dependence of the voltage from the temperature *the zener DZ1 should be from about 9 or 10 Volt, with very low leakage current. Depending on the model zener, you may need to change R100. If the voltage rises when the temperature rises then you must lower R100 to 470k or less, but if it comes down must get up to 680k or more. The value of 560k normally goes well, with every type of zener, at medium working voltages. If you normally work towards the extremes of 500 Volt or 1500 Volt, might be a good idea to test and modify the value of R100 to obtain the maximum of stability. Having decided on the working voltage, heat with a hair dryer to the outside of the container about twenty degrees, if the voltage rises lower R100.*

The latest tests (with zener 1N757A) suggest that the average working voltages (700 .. 900 V), we obtain the maximum stability with R100 = 560k.

The high voltage filter composed by R4, C5, R5 and C6 eliminates any trace of ripple from the supply of the PMT tube. Via resistors 1 Meg and expensive high-voltage capacitors from 47 nF, a very effective filter is obtained.

This filter has a very low (5 Hz) cutoff frequency, at 50 Hz attenuates already more than 20 dB and in the area of the power supply ripple (from 3 KHz to 25 KHz) attenuates from 60 to 80 dB (from 1000 to 10000 times)

Other two resistors 1 MegaOhm isolate the PMT by capacitors and limit the output current in case of errors, making this power supply completely safe, for us and for the PMT.



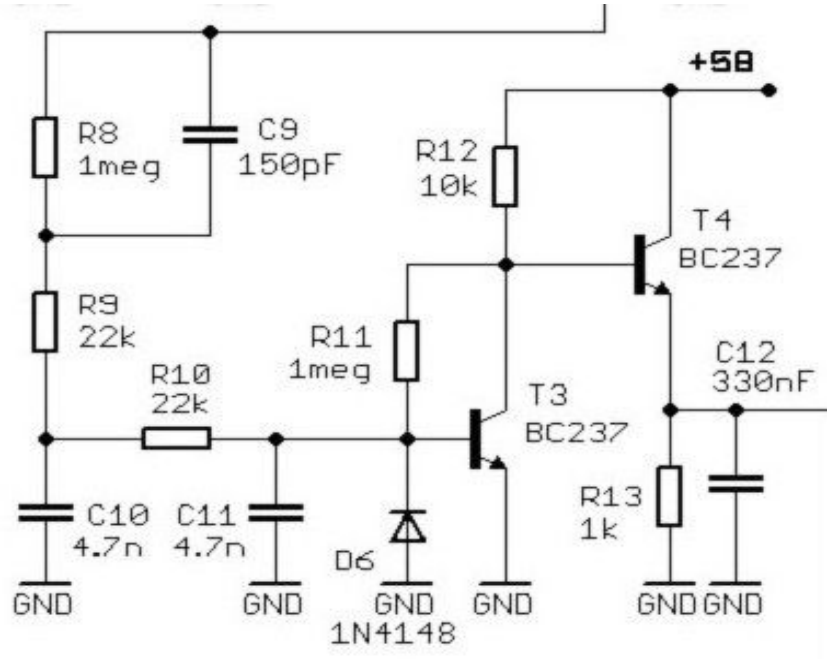
The four 1 Meg Ohm resistors in series provoke a fall of the output voltage of 2.5% (about 20 volts under normal conditions and with PMT of 120 Mega Ohm) but, since this is a constant, can be compensated by raising the voltage slightly.

Some think they have to use power supplies with a very low output impedance (and thus with high ripple, high maximum current and very dangerous) to not influence the PMT linearity, but this makes sense only for other types of signals, not for the gamma spectrometry.

The pulses produced by a PMT tube coupled to a scintillator crystal are so narrow that, even using 10 Mega resistors, the average voltage on the dynodes does not falls measurably, measure it to believe it. For which the linearity is not affected.

The capacitor C8 extracts the pulses blocking the high voltage. It must be high enough (at least 4.7nF) to not affect the shape of the pulses and not to ruin the delicate balance of conditioning circuit of the signal.

The signal conditioning circuit, composed of R8/C9, R9/C10 and R10/C11, is followed by an amplifier. Finally, the signal is lowered impedance to limit the noise on the cable.



The transistor T3 amplifies the signal attenuated a lot in the filter.

The transistor T4 and the capacitor 330nF lower the output impedance, minimizing the noise that the signal wire can collect for coupling with the power supply wire and with external disturbances.

C12 and R13 are also a third low-pass cell that enlarges the pulse and paves its tip.

The pulse of this output (DC coupled and without undershoot) is also perfect for the costly MCA hardware equipment, of ancient design.

R9, R10, C10 and C11 form the "Pulse shaper" that broadens the pulse to over 100 uS to increase the resolution of rows and slows its rising edge to minimize noise due to the "ringing"

R8 and C9 form the "Pole-Zero Cancellation", well described in the literature, which eliminates the "Undershoot" and produces a pulse that goes to zero in the shortest possible time.

The diode D6 prevents that the voltage goes negative and protects the base of the transistor. To positive voltage limit is accomplished by the transistor base-emitter junction.

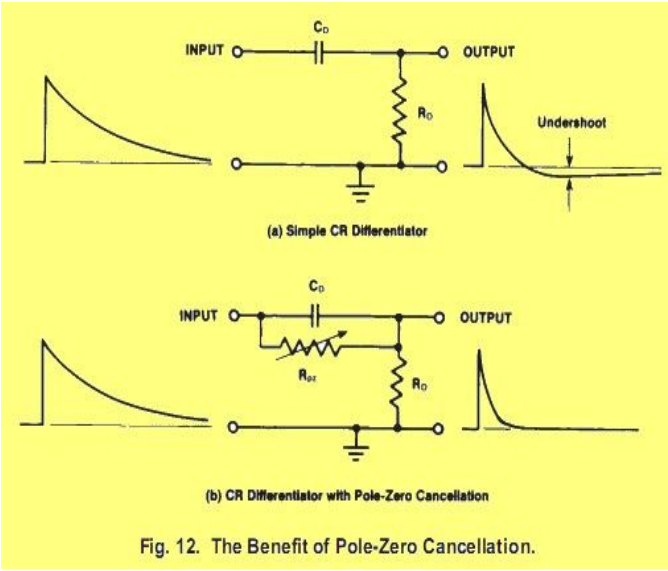


Fig. 12. The Benefit of Pole-Zero Cancellation.

In addition the resistors R8, R9 and R10 limit the current to levels absolutely safe, even if C8 go shorted by sending all the high voltage to the transistor, this would not break anyway.

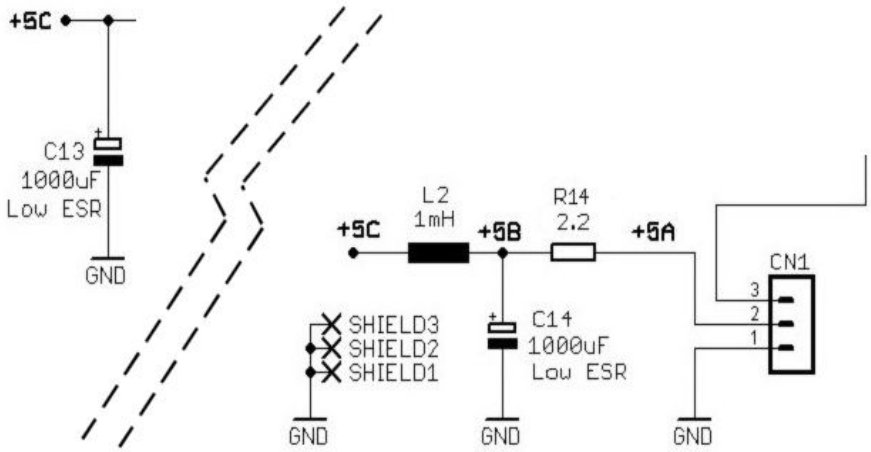
Someone is scared by the presence of high voltages close to a audio card, we can reassure and to guarantee 100% that with this circuit, nothing can go to his PC to do damage. We have over 40 years of experience in electronic design and know exactly what we are doing.

The components of the 5 Volt filter, L2, R14, C13 and C14 prevent the electrical noise generated by the switchings, propagates towards the signal conditioning circuit and the power supply line.

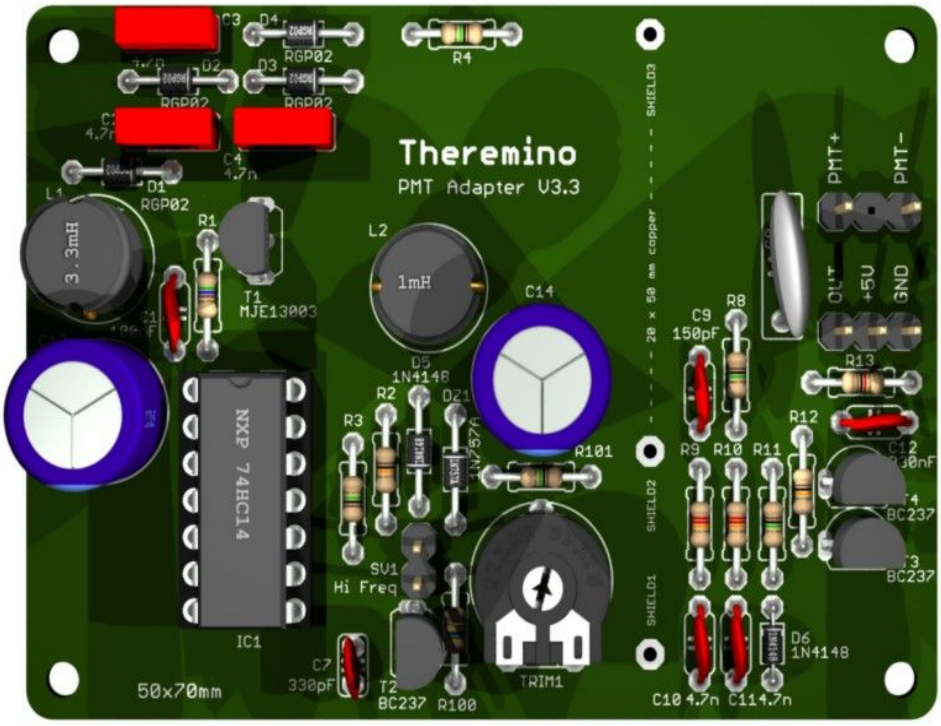
Electrolytic capacitors C13 and C14 **must be LOW-ESR.** It is possible to recover them from the old mother-board PC and Pentium2 Pentium3, usually around the processor they were mounted a number.

The inductor L2 should have a series resistance not greater than 2 or 3 ohms.

The screen divides the left side of the PCB, which causes switching interference, from the right side that contains the sensitive parts where the signal passes. The screen is composed of a thin copper foil, 45mm x 20mm, supported by three wires soldered on the plots "Shield1/2/3"



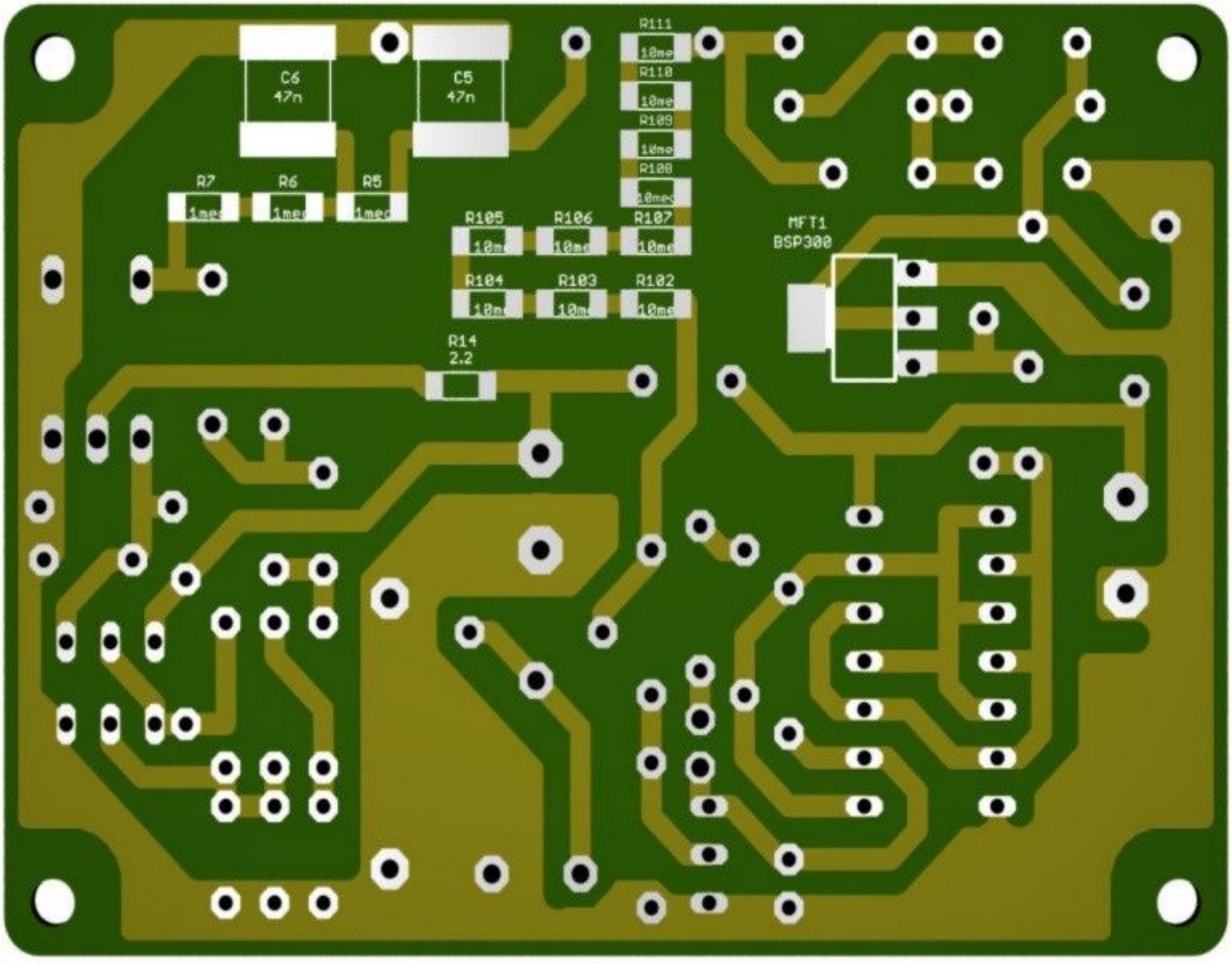
The coil, which in some old patterns was marked L3, is now replaced with a resistor of 2.2 or 3.3 ohm 1/8 watt, this substitution does not worsen the performance, indeed improves them because it facilitates the fitting of a screen of copper with a simpler and more efficient shape. In the latest versions R14 is mounted on the underside.



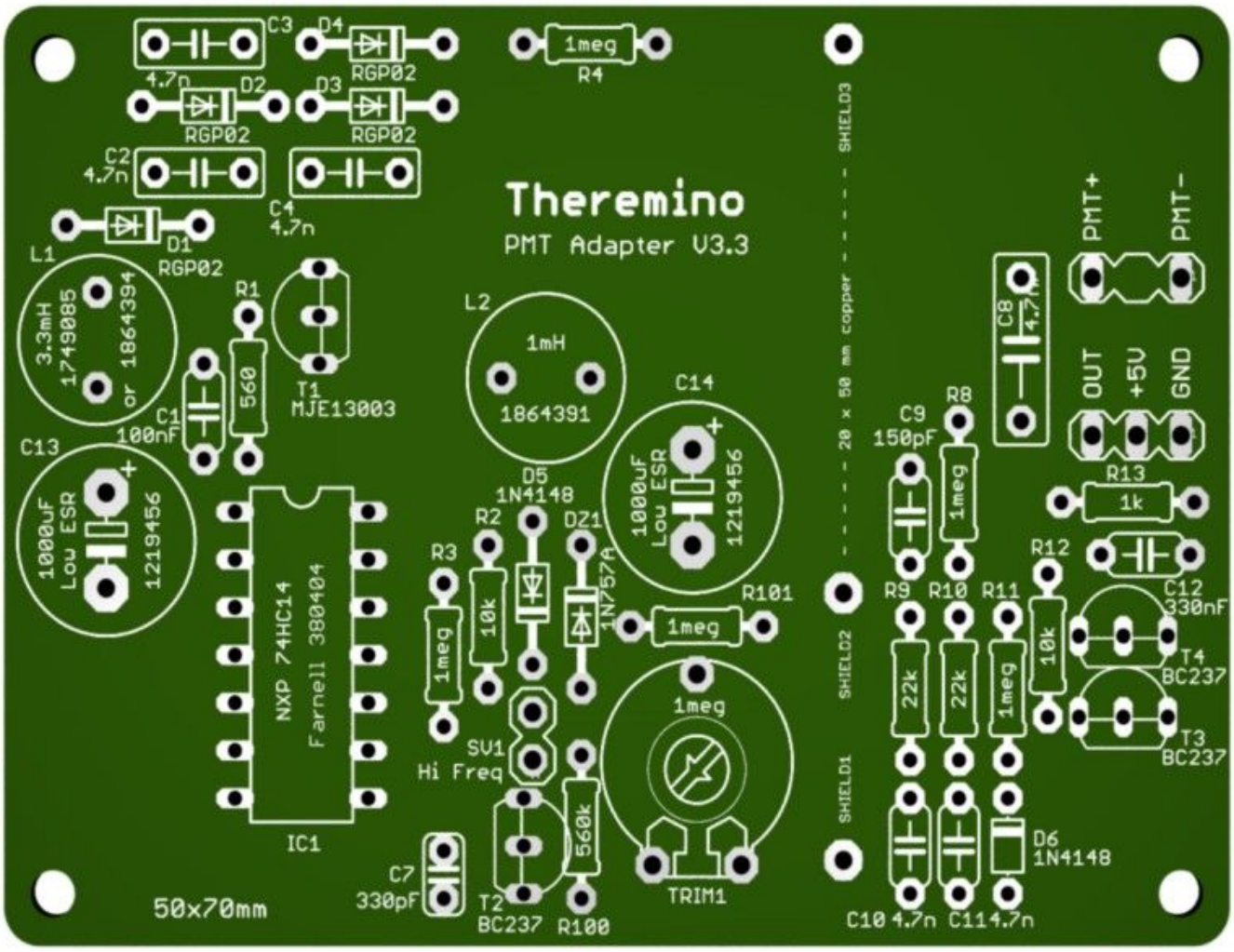
The "PMT Adapter" - Building

In the "Docs" folder you will find the PmtAdapter project, with Eagle PCB, LTSpice simulations and 3D images.

The following images facilitate the mounting of components on the PCB, you should begin to assemble all the components of the solder side.



The PCB seen from solder side



The PCB seen from the component side

It is recommended to start with the lowest components and solder only at the end the chip IC1, the trimmer, the transistors, the coils and the electrolytic capacitors.

The T1 normally will not mount because its function is performed by the mosfet. If not mount T1 then not even need C1 and R1, and replaced with a jumper wire soldered in place of R1.

In versions prior to V3.2 PCB jumper SV1 is not present, so to not go as HiFreq (constant off-time) you do not mount R2 and D5.

Normally once set the "Trim1" not moving more so it is not necessary to use a potentiometer accessible from the outside. Who wants to have this adjustment outside to make a hole in the container and connect a potentiometer 1 Mega Ohm linear instead of Trim1.

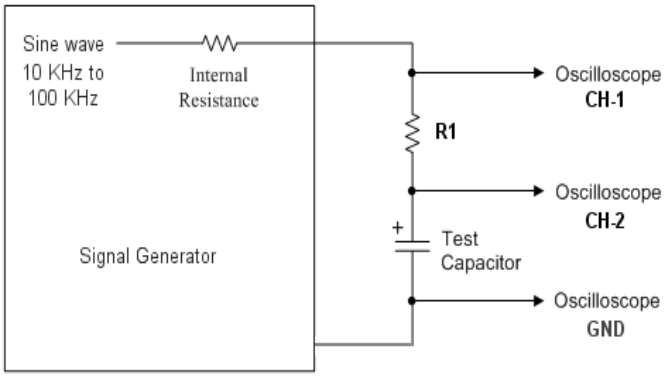
At the beginning, it is recommended to mount R101 of 1 Meg Ohm to have a more easily adjust if 1000 volts are enough. Then, if a increase maximum voltage is needed, you replace R101 with 820k or 680k

Test Low ESR electrolytic capacitors

The capacitors C13 and C14, and the 220uF or 470uF capacitor into the audio card, must have a "series resistance" less than 0.05 ohms. The normal capacitors have a resistance 50 times greater and do not fit.

Equipment necessary to control:

- Signal Generator
- Oscilloscope



This is a "four-wire" measure so you must have the connections exactly as shown in the figure. In other words, the generator current must not pass in the "measuring" connections of the oscilloscope. Not even an inch of wire, and even less crocodiles or terminals, must be shared between the generator circuit and the "measuring" circuit.

In place of the signal generator you could use a audio card output to the speakers (at least a few watts). In this case, as a signal generator and oscilloscope you could use the DAA that you download from here:
www.theremino.com/downloads/uncategorized

The signal generator should be adjusted to a sine wave voltage with from 1 to 10 Volts, if the capacitor is 1000uF up may suffice 10 KHz otherwise (from 100uF to 500uF) is better to use 100 KHz

If the signal generator also has a continuous adjustment of the add a few volts positive to maintain the electrolytic polarized in the right direction (but of short duration tests for this is not important)

Measure the peak to peak voltage on channel 1 and channel 2 of the oscilloscope. If the voltage on the channel 2 is very low and difficult to measure, try to lower R1 and give more signal with the generator.

For R1 to use a 100 ohm or 10 ohm resistor to facilitate the calculations. Finally we have three values R1, V1 and V2 (the two values measured peak-to-peak on channels 1 and 2 of the oscilloscope)

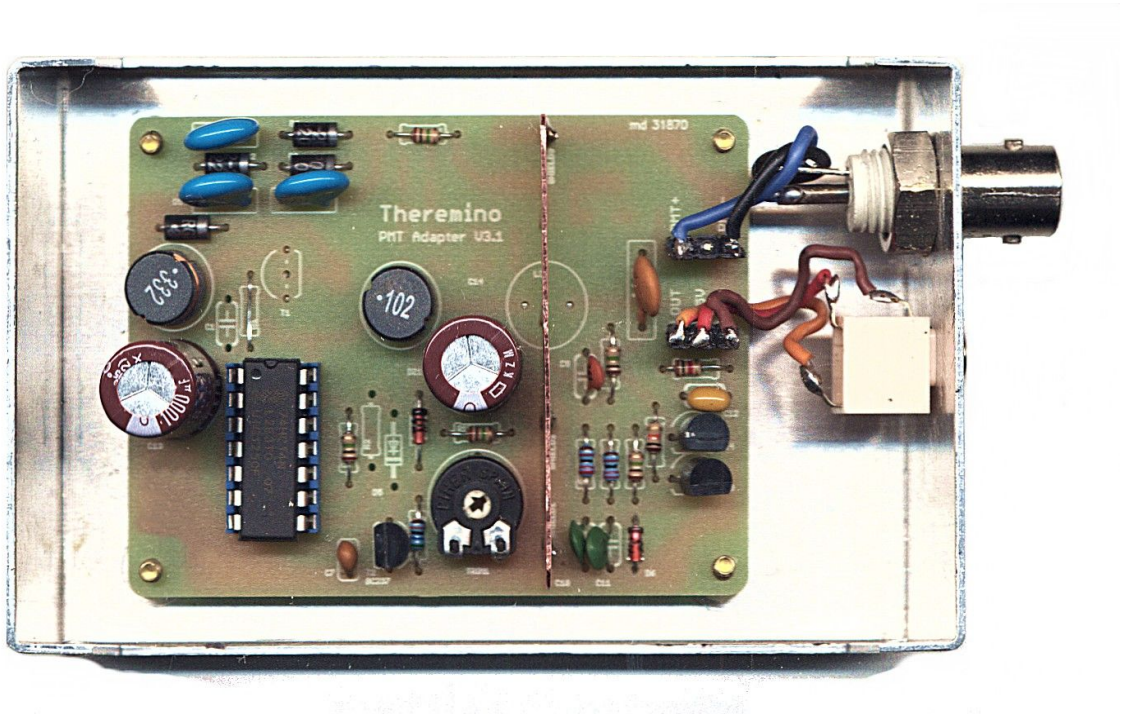
ESR = R1 * V2 / (V1 + V2)

but, as they are usually V2 is very small compared to V1, you can use the following simplified formula

ESR = R1 * V2 / V1

In practice: if you measure a V2 around 100mV ESR of the capacitor is some ohms and it is not LOW-ESR. If instead V2 is very low, a few millivolts, difficult to measure, then the capacitor is really a LOW-ESR and its series resistance is around 0.05 ohm or less.

A container for the PmtAdapter



The PmtAdapter **must be mounted in a metal container** as in this example, and **must have one little shield of copper 20x50mm,** that divides the left side (power supply) from the right side (signal). If you do not comply with **all the specifications of this entire document** the noise will exceed 70uV eff declared.

The container must have the narrow walls on the right and left that rise from below so as to be able to mount the connectors in the proper position to **make very short wire connections.**

The connections to the BNC jack to the female should be short, folded and gathered at the bottom, not to pick up interference from the switching power supply (the left half of the PCB) to keep them short, you must use soft wire (insulated with silicone) small and of good quality (with many wires inside)

It is good that the PCB wires terminate on a 2.54 mm spaced strip, so you can quickly connect and disconnect to remove the PCB, for tests and modifications.

Pay close attention to the connectors, the male strips are all okay but the female strips **must have the round holes** and **must be of high quality**, otherwise produce false contacts also from new and many problems later.

Only the female strips "Distrelec 120591" are fine, we have not found any others. Distrelec 120,591 (socket, straight, No. 1x3-pin) www.distrelec.it/prese-femmine-di-2-54-mm/preci-dip/prese-femmine-diritte-spinotto-% C3% B8-0-6-mm

Which audio card

Theoretically the Aux inputs or line a good audio card (perhaps a Creative) should be fine. In practice, however, problems arise that can not be resolved to prevent reduce noise over-100dB that it would take to exploit the full ADC dynamics

The problems which prevent to obtain a low noise are the following:

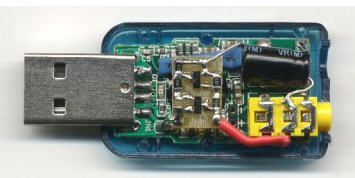
1) The audio card in a PC are in a very noisy electrical environment, the connectors themselves are very close to digital signals that create strong interference.

2) No one likes to modify an expensive audio card, or even worse, modify the audio card is on the mother-board PC.

3) Not being able to modify the audio card, to add a high-pass filter as close as possible to the ADC, you should add it in PmtAdapter, but in doing so the filter would lose much of its effectiveness, and not eliminate low-frequency noise collected by the cable.

4) Not being able to bring a 5Vdc to power connector that goes to the PmtAdapter you should feed PmtAdapter in another way, with an external power supply or a USB port. In both cases, it would inevitably create a ground loop causing noise on high frequencies (from 2 KHz to 20 KHz), and very often a loud hum at 50 or 60 Hz (mains frequency)

In addition, those who have tried it know, share the audio card with the operating system and perhaps also with Skype is very uncomfortable. In conclusion, without an additional audio card becomes very difficult to use Theremino_MCA.



Fortunately, there are small cards to be connected to the USB audio that give many benefits, cost very little, go up to 192KHz and are easy to modify.

The audio adapter (USB audio card)

On eBay you can buy for a few bucks. Do not be groped by different models or expensive, no better and are more difficult to modify, take exactly these (marked "Kunig" or "3D Sound") if you have any questions please send an image of the PCB to the seller and ask if it matches.

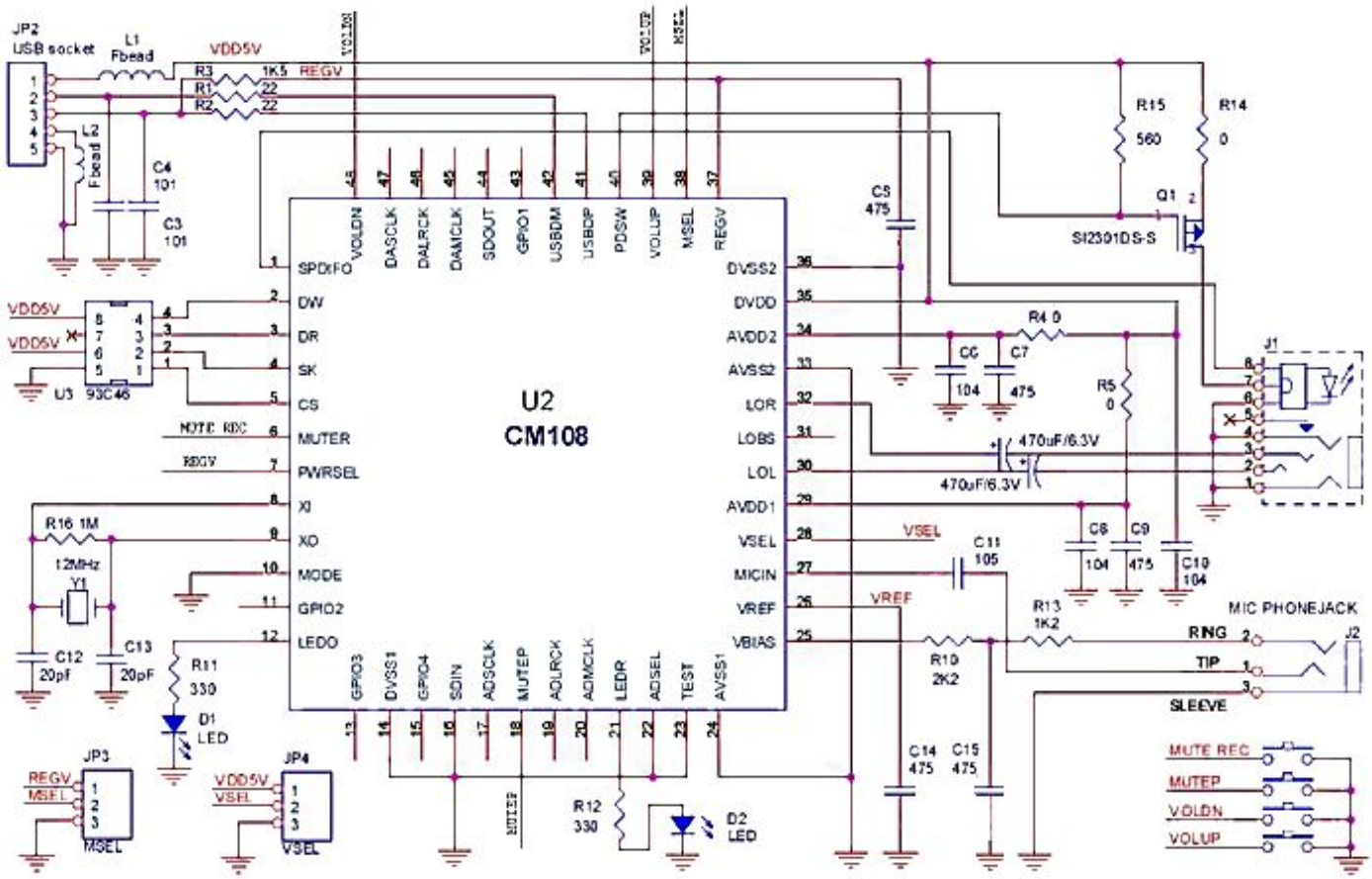
We will only use the mic input (yellow) that must be modifyed by adding a high-pass filter (a capacitor)

In order to eliminate low-frequency noise picked up by the cable, the filter should be placed inside the audio card, not in PmtAdapter.

Also in the audio card you have to make a change to bring the 5 Volt power for the PmtAdapter to the central connection of the yellow Jack.

The 5 volts coming from USB in some PCs and laptops is very noisy and must be filtered in the audio card, with an inductor and a low series resistance (low-ESR) capacitor.

USB audio devices schematics



This is the application of a chip CM108, one of the most used in the USB audio cards.

In this scheme the 1.2K resistor R13 is connected to the center pole of the jack and is then connected to the signal from the microphone but is most often connected directly on the PCB.

The buttons you see are only in some versions with adjustable volume, the MOSFET Q1 only in versions with the SPDIF output.

The two capacitors from 470uF, which go to the headphone jack, since they are the most expensive components (and which are welded manually) are often "forgotten". To us this does not matter, so we should take them off to make room for our 1 mH inductor and electrolytic filter.

We only need the input marked "MIC Phonejack" with C11 to 1uF that carries the signal to the ADC, R13 from 1.2K that would bring the power to the microphone and C15 from 4.7uF R13 that connects to ground.

Then we need an LED, quartz and its three components, some power supply capacitor and components that go into the USB connector. Everything else may not work or not be there.

Changes to the audio card (realization)

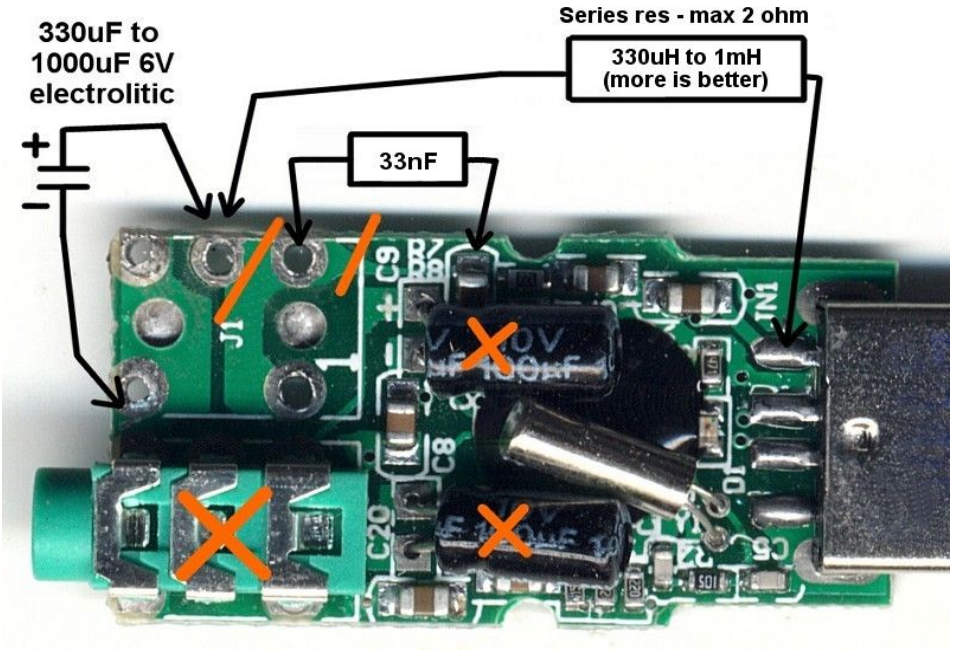
In this image the input jack (yellow) has been removed to show how the tracks on the PCB, but it really should be left in place.

The central link of yellow jacks, which carries the 5Volt for the PmtAdapter is isolated and connected to +5 volts of the USB socket through a small inductor and connected to ground with the electrolytic capacitor.

The green connector (output for headphones) must be removed to make space for the capacitor.

The two capacitors (marked with a cross), which serve for the headphone, must be removed.

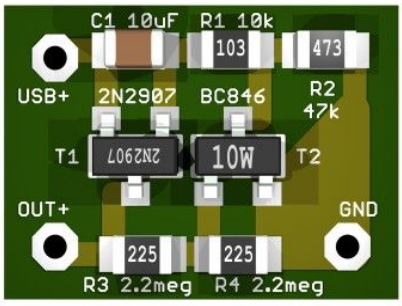
The 33nF capacitor connections must be very short so as not to pick up disturbances.



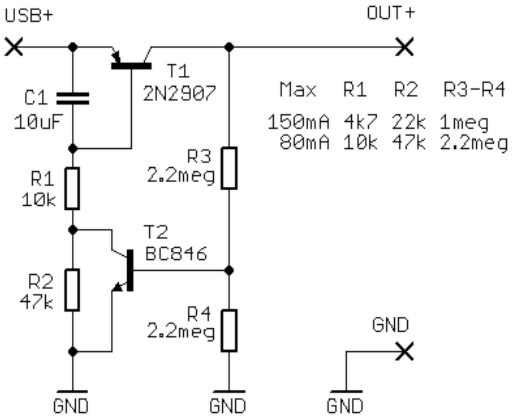
Inductor and electrolytic attenuate noise from the +5 V on the PC which is often very noisy. But it is *difficult to find a small enough inductor with low series resistance (<3 ohms) and proper impedance (at least 330 uH)*
A second problem of the inductor is that, with prolonged short-circuits, it can be heated and damaged.

Optional circuit for the current limitation

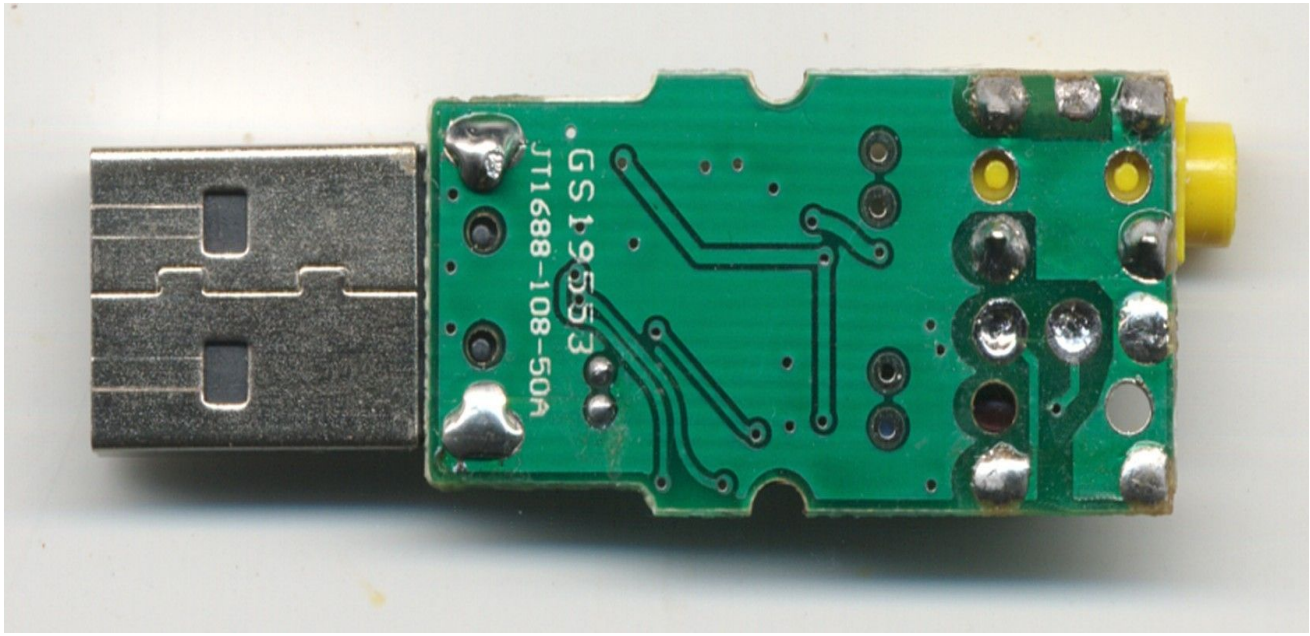
This is an alternative to the inductor, less expensive but more complex, allows to eliminate the overheating of the inductor in case of short.



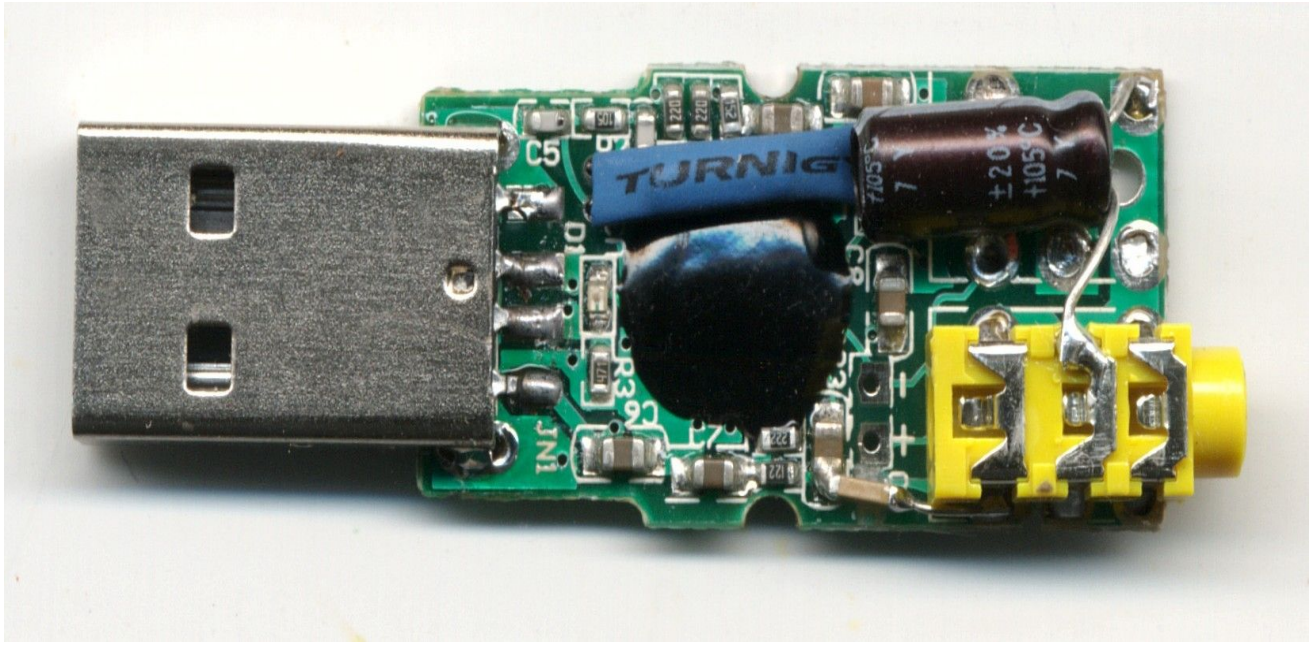
With this circuit you can plug incorrectly the jack and short the +5 Volt, for as long as you want.



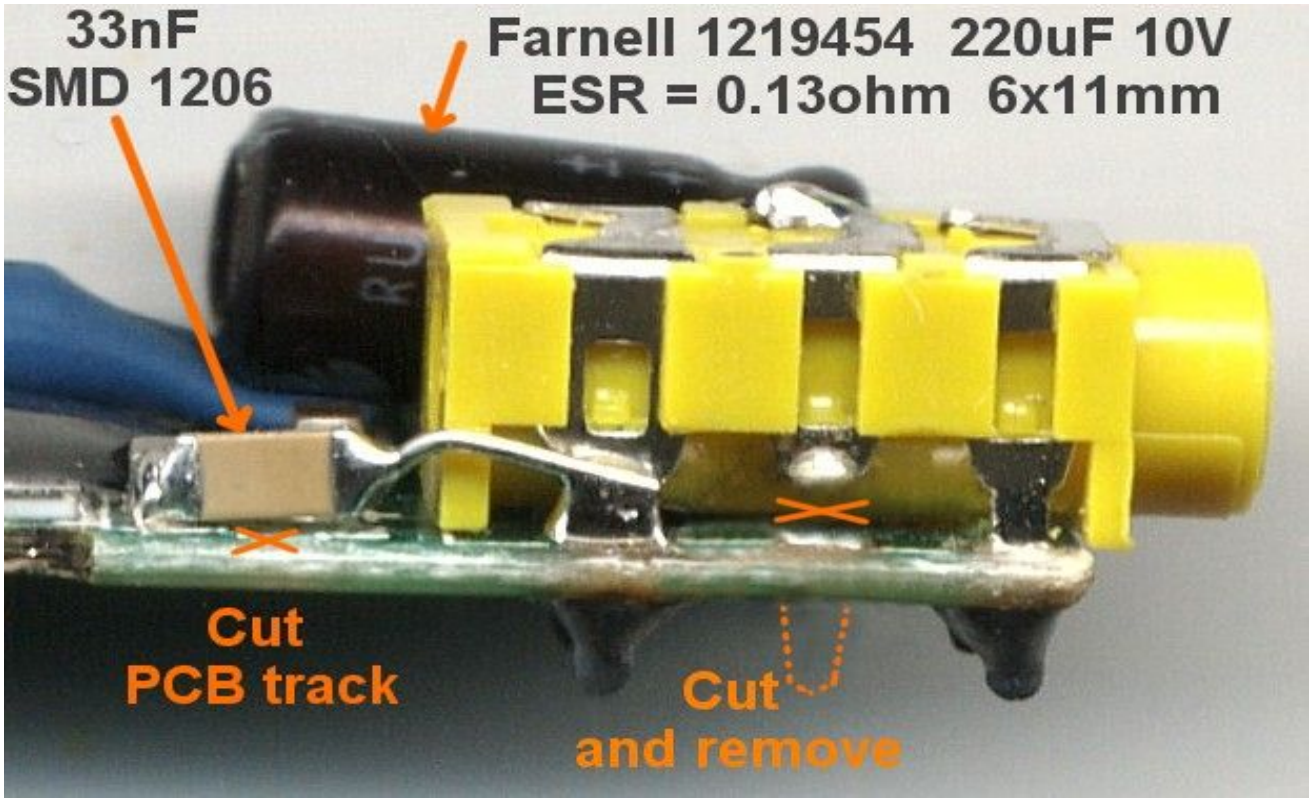
Changes to the audio card (realization)



First of all you remove the green connector and weld well the USB connector.



Cover the crystal with a piece of heat shrink tubing and weld the electrolytic capacitor. Must be LOW-ESR, we recommend Farnell 1219454.



Cut the track of the signal, weld a 33nF capacitor and connect it with a thin piece of bare wire.

Cut the Jack central pin and remove the part remaining in the PCB.

The finished audio card - Version with inductor

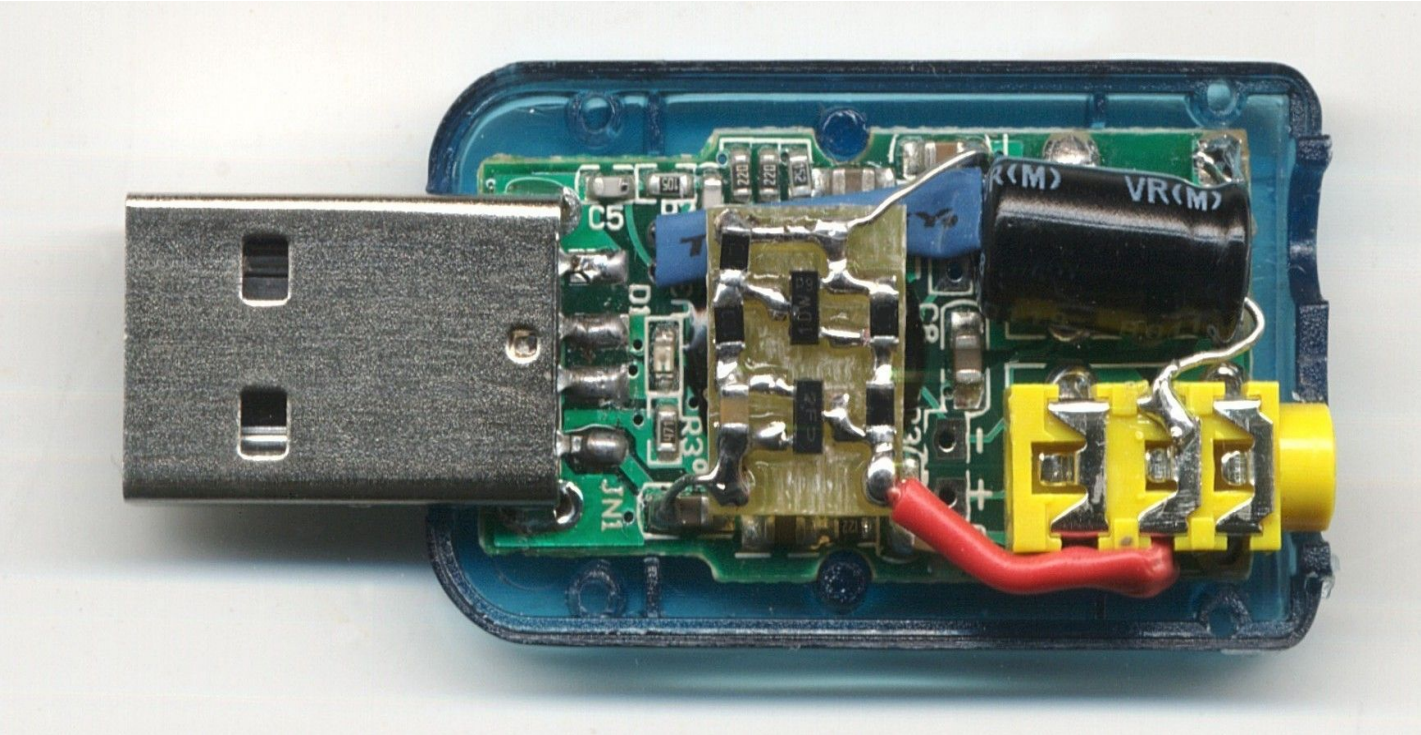
The version with inductor is simple and works well, but has some flaws.

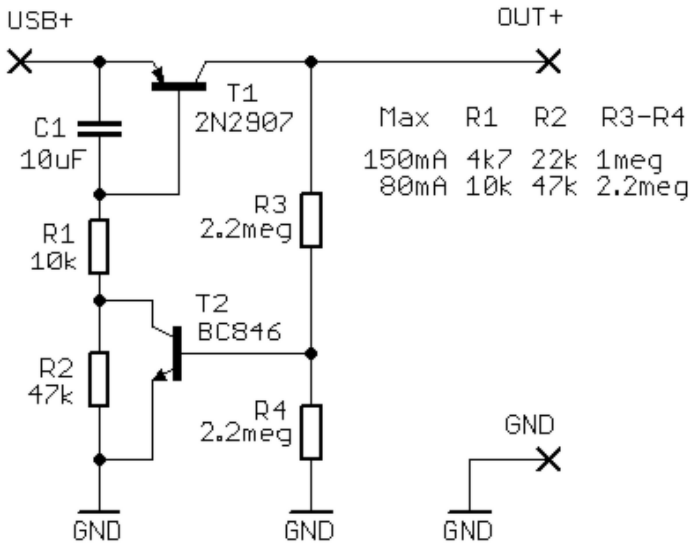
1) It is hard to find a small inductor, with high impedance and low enough resistance.

2) An inductor with good characteristics can be quite expensive.

3) If you put the jack in the middle and keep it plugged in at the right point for a long time, the coil gets hot and may be damaged.

The finished audio card - Version with limiter





The current is limited to 80mA and further lowered to less than 10mA in case of short (this behavior is called foldback)

As soon as you remove the short circuit the limiter restarts automatically.

The current limit is given by R1, the time constant R1/C1 and the current gain (hfe) of the transistor T1, produce an effect of filtering that, on the low frequencies, is better than any inducer of reasonable size.

If, as recommended, after this circuit there is a LOW-ESR electrolytic capacitor, then the disturbances from the USB, are reset to the point of no longer measurable.

In the "Docs" folder you will find the project for this limiter, with Eagle PCB, LTSpice simulations and 3D images.

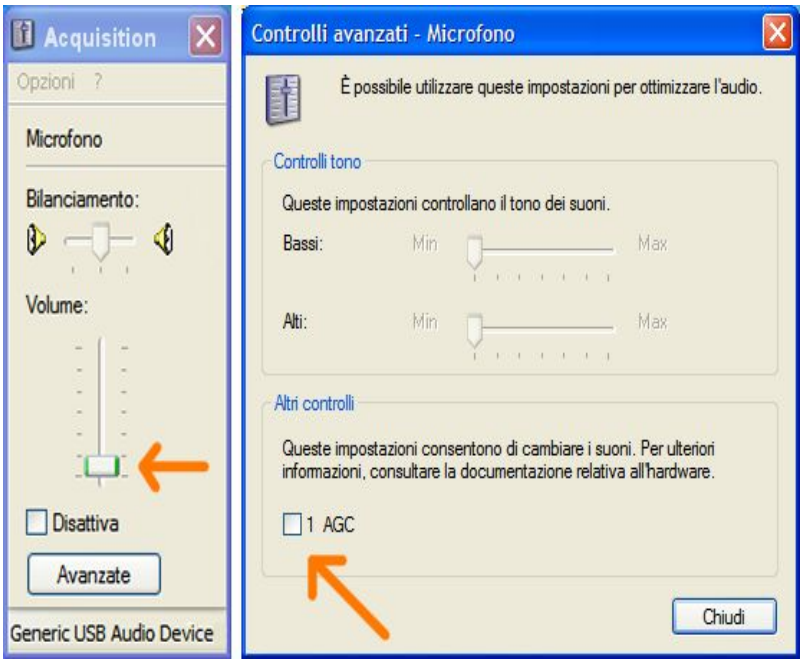
Adjusting the the USB audio card input cursor with Windows XP

Achieve this mixer from any open mixer with "Options" and then choosing the line of USB audio card - INPUT.

Adjust the slider to the minimum **using the arrows on your keyboard**. Get off until the input shuts off and **back, one click at a time,** until it finds the first working position.

Do not use the wheel mouse otherwise you can not select the first position.

It 'important to use this position because it is the only one that can be restored in a repeatable way if you lose the regulation or change computer.



By adjusting this slider, the zero voltage level shifts, when the "BaseLine test" is enabled the ThereminoMCA is independent of the voltage of zero, but when it is disabled, for example to measure the noise, it will be necessary to correct the value "Audio zero trim"(you can automatically do this with: Menu / Tools / NoiseTest)

Also check in the panel "Advanced", that "AGC" is disabled.

Make sure that if you disconnect and reconnect the audio card, both the volume control "AGC" may lose control, if you change the USB port lose for sure.

Please note that the AGC is always disabled, is reborn alone worse than zombies, and it's easy to miss!

Restore the original audio card

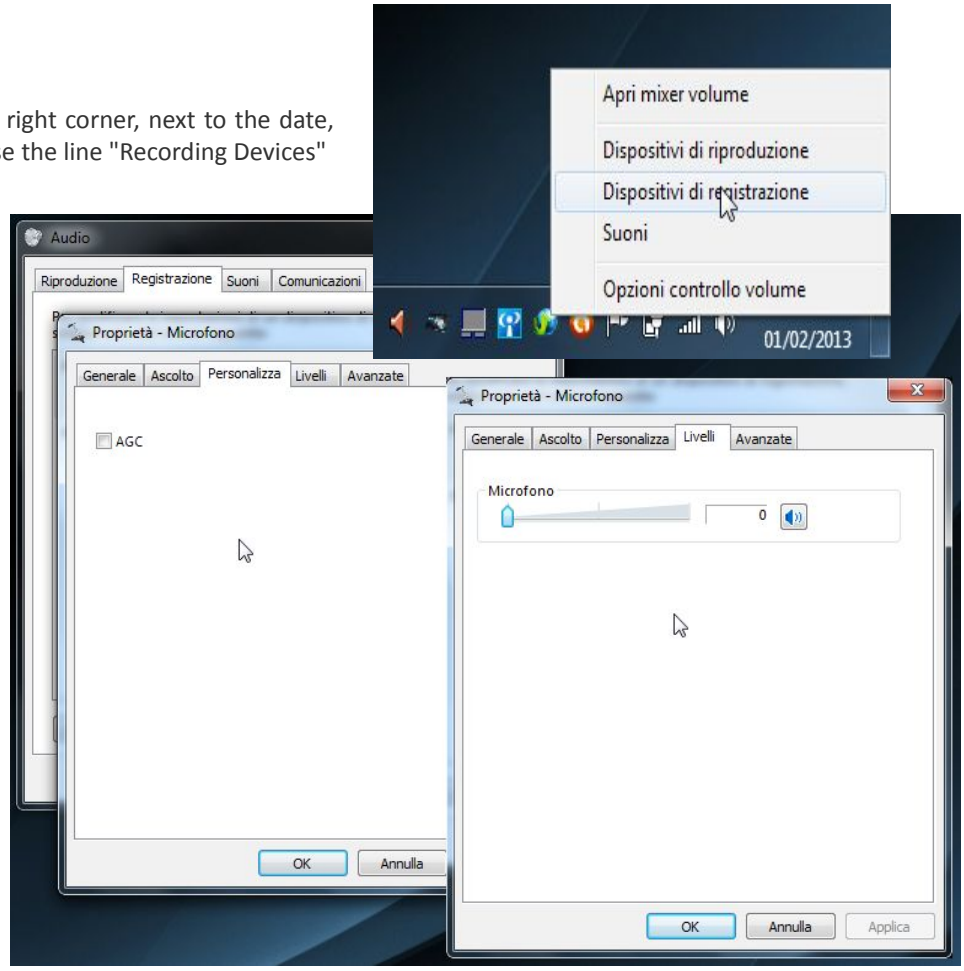
When you connect it to the USB, the AudioAdapter becomes the "default" audio input and output.

The audio reproduction will go to the additional audio card and you will not hear more sounds of Windows and Skype. In addition, Skype will use the wrong microphone.

Skype is set to take the input from the original card. Instead of Windows you have to click with the right mouse button on the speaker. Select "Adjust Audio Properties" and then, in the panel "Audio", set in "Sound playback" as "Default device" the not USB card.

Adjusting the the USB audio card input cursor with WindowsVista

Click on the speaker icon in the lower right corner, next to the date, with the right mouse button and choose the line "Recording Devices"



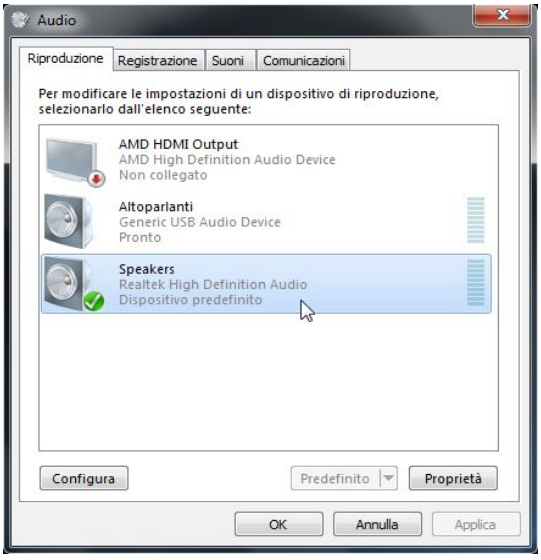
In the "Customize" disable 'AGC and the panel "Layers" turn down the microphone slider to the minimum position in WindowsVista, unlike XP, the microphone does not completely shut off.

It 'important to use the minimum level position because it is the only location that can be restored in a repeatable manner, in case you lose the adjustment, or is changed computer.

By adjusting this slider, the zero voltage level shifts, when the "BaseLine test" is enabled the ThereminoMCA is independent of the voltage of zero, but when it is disabled, for example to measure the noise, it will be necessary to correct the value "Audio zero trim" (you can automatically do with Menu / Tools / NoiseTest)

Make sure that if you disconnect and reconnect the audio card, both the volume control "AGC" may lose control, if you change the USB port lose for sure.

Please note that the AGC is always disabled, is reborn alone worse than zombies, and it's easy to miss!



Restore the original audio card

When you connect it to the USB, the AudioAdapter takes hold of the input and output of audio "Default"

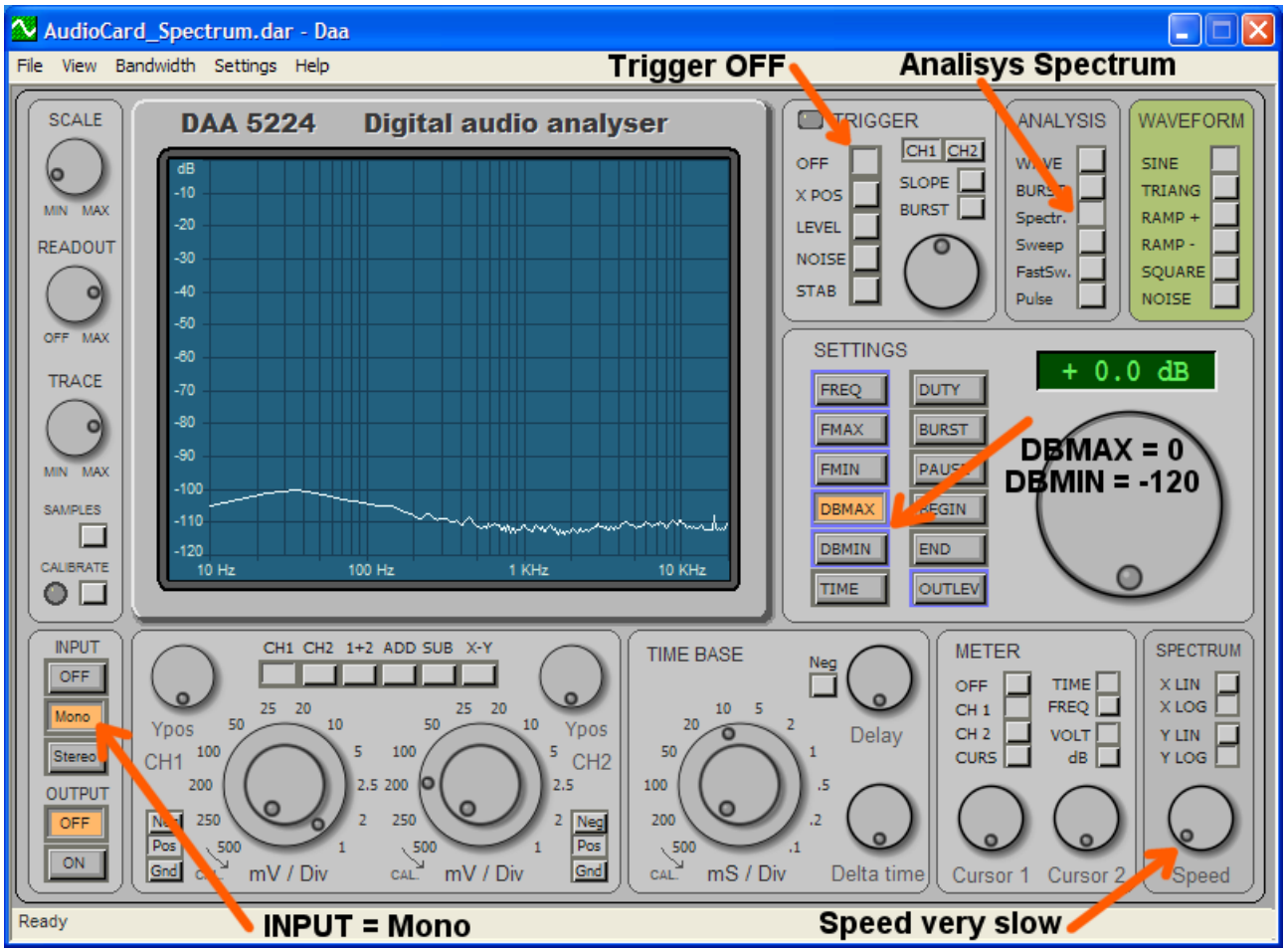
The audio reproduction will go towards the additional audio card and you will not hear more sounds of Windows and Skype. In addition, Skype will use the wrong microphone.

Skype is set to take the input from the original card. Instead of Windows you have to open up the "Playback" and set "Default Device" tab for "Speakers" (the not USB card)

What do you have to get the audio card (spectrum)

This is the minimum noise produced by a audio card with volume "mic" to a minimum and with the AGC disabled. 16-bit audio card (if everything works) have more or less than this level of background noise (-100 to -110dB)

This is because 16-bit ADC (each bit is 6dB and then 16 bits = 96dB... practically 100dB plus something as a gift) Below the -110dB we can never arrive, but we should not rise above the -100dB, if you connect the PmtAdapter to the audio card the noise should not increase (of course you have to measure the noise with the BNC PMT disconnected otherwise pulses coming from the PMT will cover all)



To adjust the DAA for spectrum analysis download it from here: www.theremino.com/downloads/uncategorized and set it as shown in the picture.

If there is offset *in the signal, the spectrum from 10Hz to 50Hz could rise much - spend a moment in "Analysis = Wave" and reset the offset as explained on the next page.*

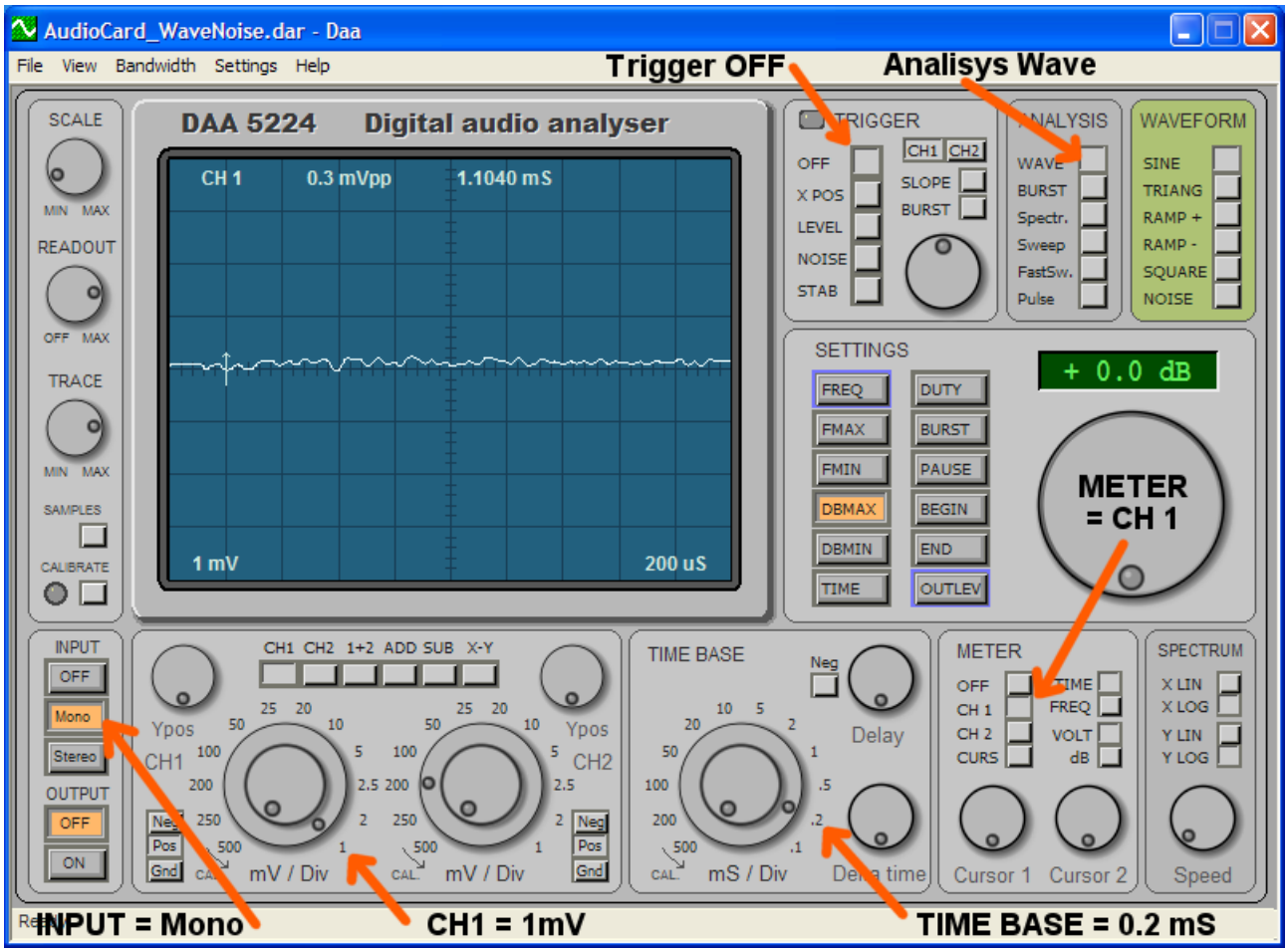
After carefully set, it might be a good idea to save this configuration as "AudioCard_Spectrum.dar", to be able to recover it quickly. This and other control files can be downloaded from here: DAA_Settings.zip

Just double click on a file "DAR" (digital audio regulations) to open the DAA and configure it, if the DAA files are not associated with the program, and you can not associate them with it, read the instructions in the documentation of the DAA

What do you have to get the audio card (wave)

This is the minimum noise produced by a audio card with volume to minimum and with the AGC disabled.

Note the indication 0.3mV pep, if you connect to the audio card PmtAdapter noise should not increase (of course you have to measure the noise with the BNC of the PMT disconnected otherwise pulses coming from the tube will cover all)



To adjust the DAA to measure noise download it here: www.theremino.com / downloads / uncategorized and set it as shown in this picture.

If there is offset *the trace may be very low, or high, and may even disappear off the screen. To correct the offset, make sure that the analysis is "Wave", as in this picture, disconnect any signal from your audio card and* ***press the "CALIBRATE"*** *- This should be* ***redone if the mixer recording level is changed*** *mixer and* ***should always be done before moving in "Spectrum"***

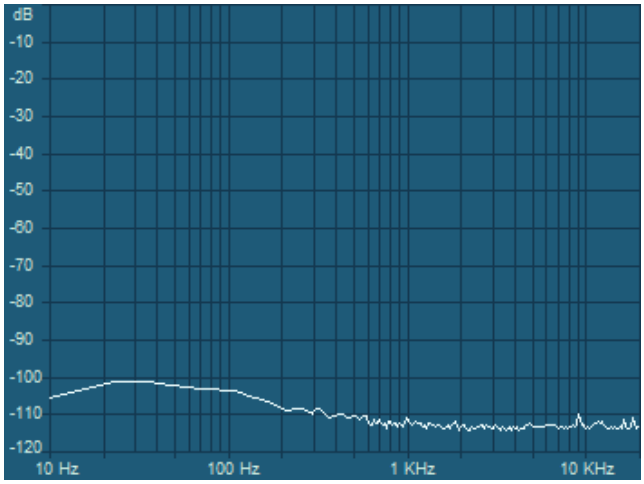
After carefully set, it might be a good idea to save this configuration as "AudioCard_WaveNoise.dar", so it can be restored quickly. This and other control files can be downloaded from here: DAA_Settings.zip

Just double click on a file "DAR" (digital audio regulations) to open the DAA and configure it, if the DAA files are not associated with the program, and you can not associate them with it, read the instructions in the documentation of the DAA

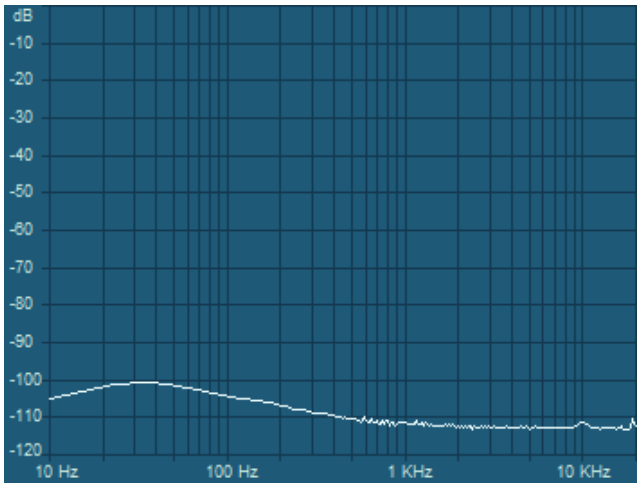
Reduce the noise down to zero

Unless you get to prepare and test the system by an expert (Alessio), it is difficult to be able to eliminate all sources of electrical noise.

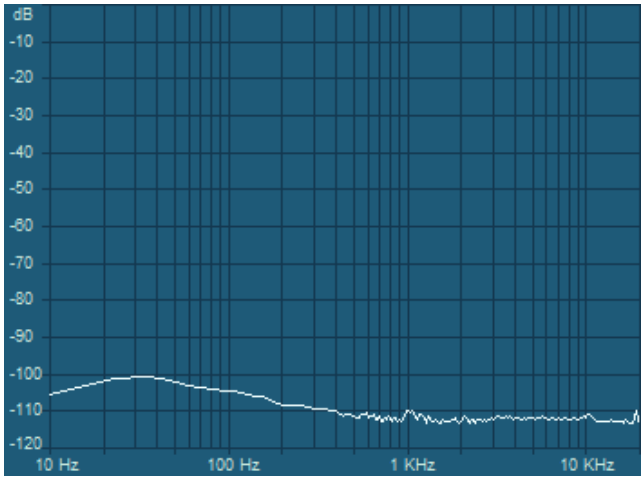
The possible "errors" are many, a tube PMT wired for other uses, an amplifier unsuitable, a cable with a fake screen, power supply noise and a audio card not proven, the wires connecting the BNC to the PCB a bit long, the screen of copper that touches the container of aluminum, etc ...



The audio card alone



Audio Card + shielded cable with open end



Audio Card + shielded cable + adapter

If everything is OK the PmtAdapter does not add almost anything to the noise of the audio card.

If something is wrong, to locate the problem should proceed step by step.

1) The only audio card (weldings / AGC / mixer to the minimum position)

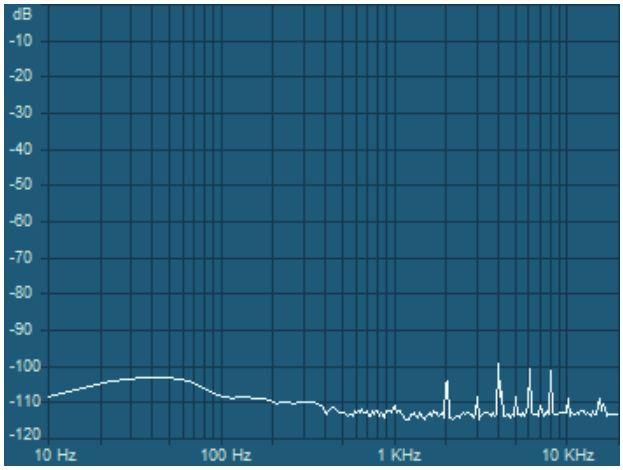
2) Audio Card + shielded cable with open end (cable shielding test)

3) Audio Card + shielded cable + adapter (power supply noise test)

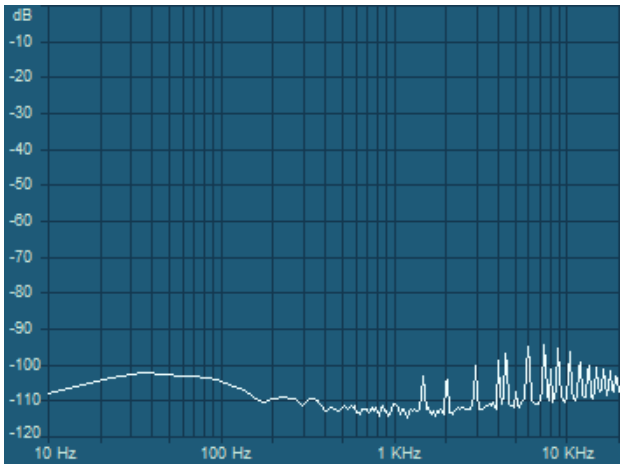
4) Only at the end will connect audio card + cable + adapter + PMT tube

If one of the steps increases the noise up than -110 dB (measured by the DAA in Spectrum) or over the 0.4mV pep (measured by the DAA in Wave) stop and fix it.

Possible defects causing noise



Example of audio card noise



Example of noise caused by PmtAdapter

Audio card defects

1) Read completely this document. The recommendations also apply to similar audio cards.

2) Check the audio card PCB weldings on the side of the USB connector (if missing then do them now)

3) Make sure that the in audio card is present the 33 nF capacitor (and have very short wires)

4) Make sure that in the audio card is present the inductor and electrolytic capacitor

5) Visually inspect the audio card with a lens (missing components or poorly-managed welds)

Try changing the audio card, between 8 cards only 7 were working and only 6 have passed all the tests and have a very low noise. Just buy were all a mess, missing welds on the connector and had a huge noise and an offset was enough to touch and bend them slightly to make jumps of 10 mV to the signal. Also try to change the USB port.

System defects

1) Check that the AGC is **disabled**

2) Check that the record level **is set to the minimum,** with the arrow keys "down" and "up"

3) Check that the jack cable is shielded. Read the section "The fake audio cables"

PmtAdapter defects

1) Make sure the wires between the PCB and jacks and BNC **are very short.**

3) Check that the PCB is in aluminum box and that the mounting screws do not touch the PCB ground.

4) Check that the copper shield isolate well the right side and does not touch the upper box aluminum.

5) Check that the container is connected to the mass of PCB only through the jack panel and the BNC .

6) Check the capacitors C13 and C14 are truly LOW ESR resistance less than 0.05 ohm.

7) Check the value of the coils and of all other components.

The "fake" audio cables

From the audio card to PmtAdapter you must use a shielded cable for audio connections with male 3.5mm jack, stereo.

Please note that many cables, although gold, soft and beautiful to look at, **are a scam**. Vendors defend themselves by saying that they did not write "shielded" and therefore it is not a "AUX or Microphone" cable but a "Speaker" cable, and we all fall regularly.

In the usual connection between iPad and PC buzz you hear almost normally and no one complains. Only we spettro-maniacs are so picky to claim a noise that is measured in microvolts.

So it's not just the words "audio cable" **must be written explicitly "Shielded Audio Cable"**. When it comes to earning the sellers are smart, if it is shielded write it. If they write "audio cable" you can be sure that it is not shielded.

To check if a cable is shielded:

1) Connect the cable to the audio card leaving open the other end

2) Check that the noise is all under the 100dB (With DAA in Spectrum - read how to adjust the DAA)

3) Touch the tip of the jack at the open end with your fingers (the noise must rise by 10 to 20 dB)

4) Wrap the cord and place the palm of your hand on the roll (**the noise should NOT increase**)

Characteristics of audio cards

To the audio spectrometry it is important to minimize the noise and it must **eliminate the low frequencies** with a high pass filter (which also has the effect of making "bipolar" signal)

In case of too high signal, it should also reduce the sensitivity with a resistor.

The following characteristics apply to the typical USB audio device, such as, for example, the "Kunig", almost all audio cards (well-functioning) have very similar characteristics.

Suppose you enter a hall "Mic" and that the AGC is never enabled otherwise would increase the gain by 20dB when the signal is low.

Inputs "Mic", without modification, saturate with pep 250mV when the volume control is at maximum and about 3.4 volts pep when the volume control is turned down.

Any additional resistor form a voltage divider with the internal resistor from 1.2K to mitigate of 6, 12 or 24dB. The mixer slider can provide further attenuation of 22.5dB (fifteen 1.5dB steps)

Summarizing with a table:

Mic Volume Control.	Saturation without resistor	Saturation with 1.2K resistor (- 6dB)	Saturation with 3.6K resistor (-12dB)	Saturation with 18k resistor (-24dB)
Maximum	250 mV pep	500 mV pep	1 Volt pep	4 Volt pep
To 50% (-6dB)	500 mV pep	1 Volt pep	2 Volt pep	8 Volt pep
To a minimum but not to zero (-22.5dB)	3.4 Volt pep	6.8 Volt pep	13.6 Volt pep	54.4 Volt pep

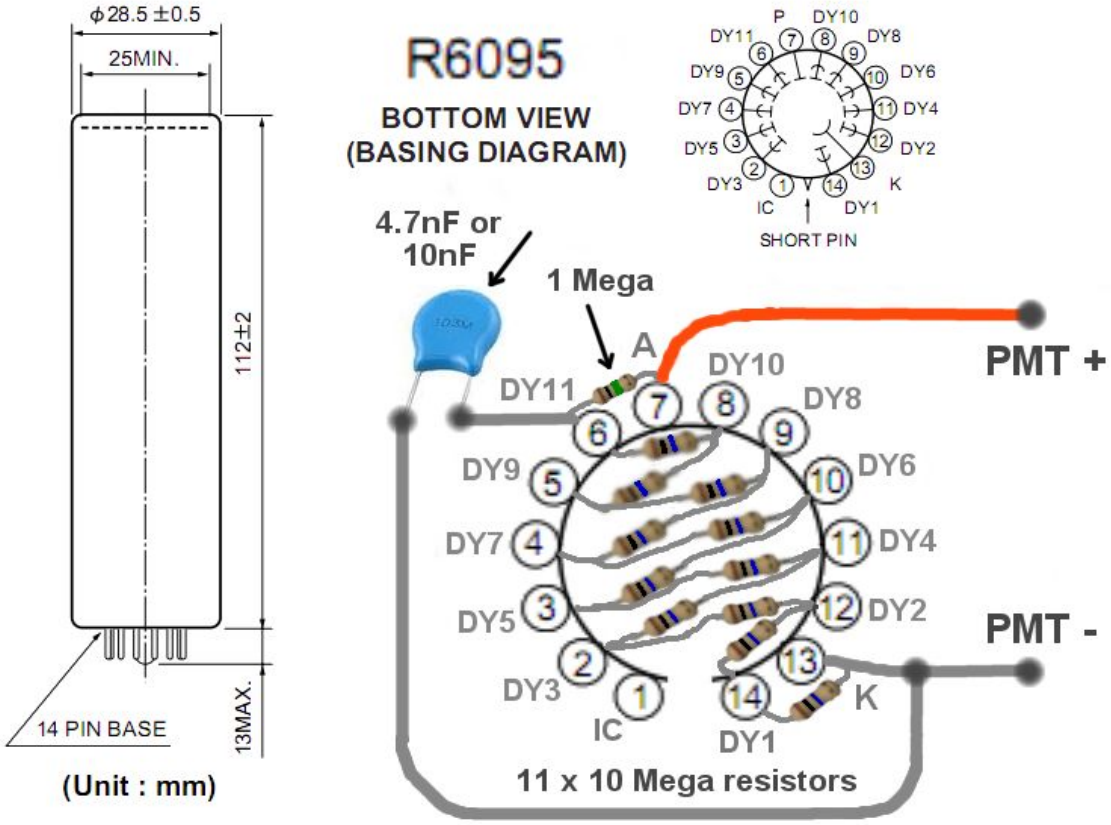
The capacitor in series with the signal attenuates low frequencies and makes the signal "bipolar" if you use an additional resistor capacitor must be recalculated according to this table:

Cutting point at-3dB	Without resistor	Resistor 1.2K (- 6dB) (div. 2)	Resistor 3.6K (- 12dB) (div. 4)	Resistor 18K (- 24dB) (div. 16)
3000 Hz	33 nF	18 nF	10 nF	2.2 nF
1500 Hz	68 nF	33 nF	18 nF	4.7 nF

Our latest test suggest *not to use additional resistors, but only a 33nF capacitor in series with the signal. This capacitor, with the impedance from 1.2K input, form a high-pass 3 KHz, which* ***makes the bipolar signal and eliminates low frequency noise****. (so there must be the 1.2K resistor of the microphone power supply -* ***you can not use AUX or LINE-IN*** *- or you should add a 1.2K resistor, after the 33nF, to GND)*

Connect the PMT tube

After trying various solutions, we have come to this simple solution, which produces excellent linearity and low noise.



This scheme is valid for a tube Hamamatsu R6095 but can be adapted to each photomultiplier tube. Just pay attention that the socket may have a different arrangement of the connections.

1) Connect with eleven 10 Mega resistors the cathode and all the dynodes.

2) Connect the last dynode to the anode, with a 1 Mega resistor.

3) Connect the last dynode to the cathode, with a 4.7 nF (or 10 nF) 2000 Volt capacitor.

4) Connect the anode (A), with a small insulated wire (preferably red) to the center of the BNC.

5) Connect the cathode (K), with a small insulated wire (black), the outside of the BNC.

6) Make sure the outside of the BNC makes good contact with the aluminum tube.

Everything has to be in the aluminum tube, well shielded and absolutely impervious to light. Just a minimum gap, from which nobody would think light can enter, to impede the smooth operation. The front of the crystal, it must also be made of aluminum - not plastic. You could make aluminum foil, or other metal, but it is better if conducts electricity, and connect it to the ground with a good electrical contact.

Experimenting with separate power supply

Some users have asked if configurations are possible with separate feeding tube PMT. We strongly advise against these solutions, all our evidence to that effect, gave worse performance than the simple one, with a single BNC-BNC cable, we are proposing.

This is a beautiful Hi Voltage Supply (1 mA at 10 KV). Making the counts it is 10 Watts - great for capital punishment - a little less for a tube PMT - every mistake means "kaputt". According to the manufacturer's specifications, models 10 Watt like this, they ***a ripple of "0.01% of full scale"*** *then: 10KV / 100 * 0.01 =* ***1 Volt pep*** *(****a ripple ten thousand times greater than our PmtAdapter****) In addition, since it is powered from the mains, will cause inevitable disturbances at 50Hz, on the delicate GND connection, which goes to the audio card.*

But everyone is free to try, with an additional filter to remove the power supply ripple, good shielded cables, good connectors, proper GND "star" connections and paired wires all the way, the increase in the uptake of noise and hum could be tolerated and could get almost the same performance of our simple version with single cable.

To use dual cable PMT, or external power supply, you must make the following changes to PmtAdapter:

1) Remove the capacitor C8.

2) Use the connections PMT- and PMT+ to provide the high voltage to the tube on separate cable.

3) Pull back the signal from the PMT on the joining of C8 / C9 and C8 and GND

4) Check, if there is a decoupling capacitor, which is at least 4.7 nF (note 1)

5) Send us the final scheme of the PMT to control.

(Note 1) If the decoupling capacitor is low, for example 100pF, the pulses of the output of PmtAdapter contain '"Undershoot" and finally, after the high pass filter would no longer be fully bipolar (positive and negative different areas)

You could also use an external power supply (even negative) and use our PmtAdapter only for signal conditioning. In this case it would be best to remove L2 to "turn off" the oscillator, reduce consumption and avoid unnecessary noise.

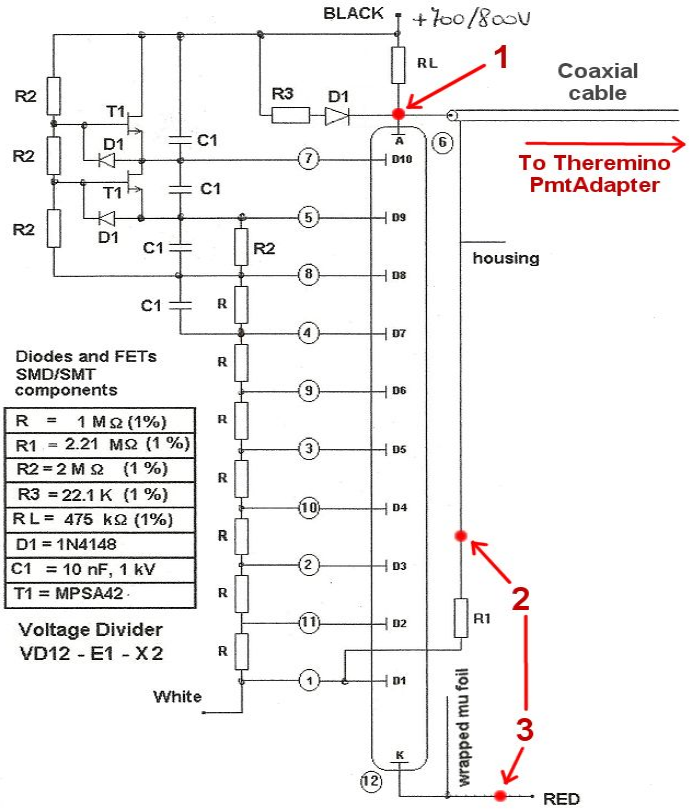
WARNING: with these changes and power supplies not current limited*, could suffice for a small slit of light on the tube, to degrade it instantly. If you exceed the current of a few hundred uA the photocathode degrades quickly and will never be silent and sensitive as new.*

Our power supply limits the output current and isolates the filter capacitors from the tube PMT with two resistors in series, avoiding risks of taking shock hazard. And limiting the possible degrade of the PMT tube.

The tube disconnected from (BNC cable disconnected for safety), can take light without breakthrough, but it must be the same ***use the minimum light necessary for the operation****. Each time the PMT takes light, becomes noisy and employs many days to return to normal.*

Experience with "strange" wired PMT tubes

With corrections in red, also this strange PMT can be connected to PmtAdapter. We can assure you that with these changes do not break anything. Everything remains polarized in the right way, but its performance will be lower than that of simple wiring we proposed.



Connect the D1 to the central shielded cable and RL, as shown by arrow "1"

Connect the cathode (K) with the mass of the shielded cable as indicated by arrows "2" and "3"

All connections must be inside the tube, going out with a single BNC connector and go to PmtAdapter with a single shielded cable without a separate power supply.

Be careful not to open the way for the light in any way, even a small hole or a crack can do enormous damage. Also, be careful to maintain the electrical continuity of the shield, no part made of plastic.

Given that the current required by this PMT is very high will be necessary to take account of the fall on the five resistors 1 Meg of filter and protection of PmtAdapter and raise the voltage regulation, or lower resistors at 100k (enduring a ripple 10 times greater)

Why a so complex circuit?
And why does not work better than our simple solution?

The photomultiplier tubes are not born for the gamma spectrometry *and even less to be connected to the audio card of a PC. In the past decades have accumulated many application diagrams, suitable for the conditions for which they were designed (astronomy), but* ***should not be transplanted spectrometry audio without changes****. The spectrometry pulses are particularly narrow and the audio card operation pretends signal to noise ratio as high as possible.*

The two transistors which stabilize the voltage on the dynodes and the resistors of low value (only 1 MegaOhm against the 10 that are normally used) would aim to minimize the non-linearity due to the lowering of voltage on the dynodes with pulse wide and strong currents. But with narrow pulses and low currents spectrometry these measures are useless and even negative, because they increase the current more than 10 times and therefore increase by 10 times the power supply ripple (all other conditions being equal - same components filter)

The separation of the power from the signal allows the use of very noisy commercial power supplies (ripple greater than 5 or 10 mV pep) but it forces to take power with a second wire and create a loop of the masses. The double cable favors the uptake of disturbances at the mains frequency and also the transfer of the impulsive noise feeder, through the current mass, on the delicate connections of the audio signal.

Much better to keep low the current in the tube and use a very low power, low noise single supply like ours. It thus becomes possible to obtain a ripple less than 50 times and minimize the induced disturbances and the current ripple on the power supply wires. The low current power supplies have also the advantage of being less hazardous to us and to the PMT (the low current limits the damage in case of light)