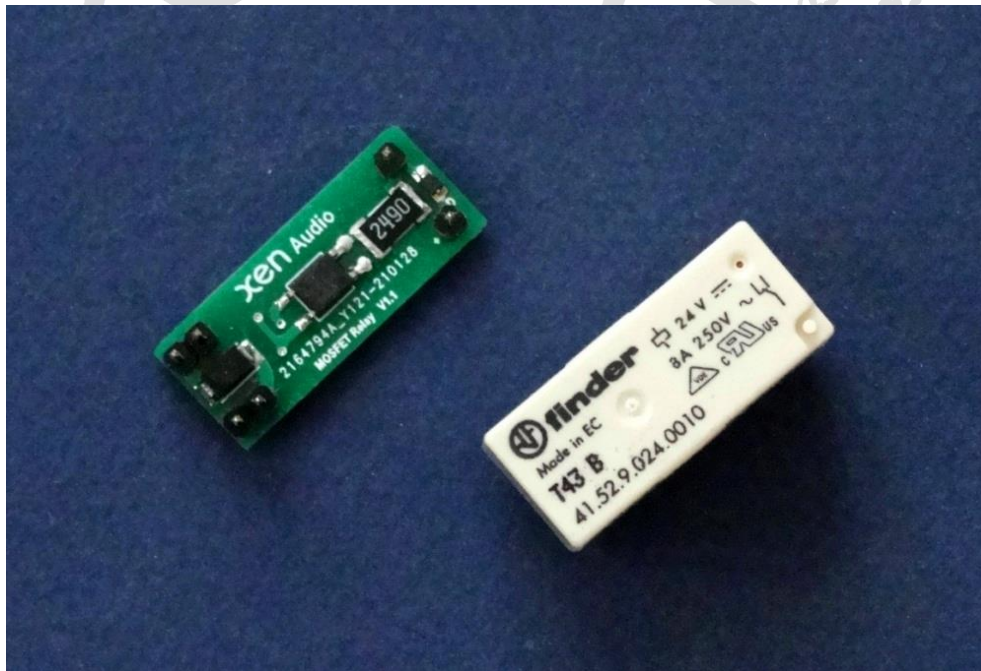


Distortion Measurement of a MOSFET Relay for Loudspeaker Protection

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April 2021



The Measurement Task

A good audio amplifier is probably not much better than -120dB at 1W 1kHz into 8 Ω . That would be 0.35Arms in terms of current. The relay does not want to be contributing anything more than -150dB of the total load (including the speaker). Since the relay resistance is about 1.3m Ω , the relay on its own should have a THD better than -75dB. If we can measure anything down to -80dB across the relay alone, the relay itself is in spec.

At 0.35Arms, the voltage across the relay is only 0.45mVrms. For even the best distortion analyser (AP2722) to give reliable results, we need to amplify by $\sim 100\times$. But -80dB at 0.45mVrms is 50nV. So any pre-amplifier for that task need to have an input noise level below 50nV, and distortion better than -80dB. The AD797 will just meet the requirements.

The first task is to provide an amplifier which can provide the $\pm 500\text{mA}$ with low distortion. We need a low distortion current buffer capable of $\pm 0.7\text{A}$ minimum, driven by a low distortion opamp in close loop. This current should have a THD of -100dB at the output. That would be 20dB better than what we try to measure on the relay itself.

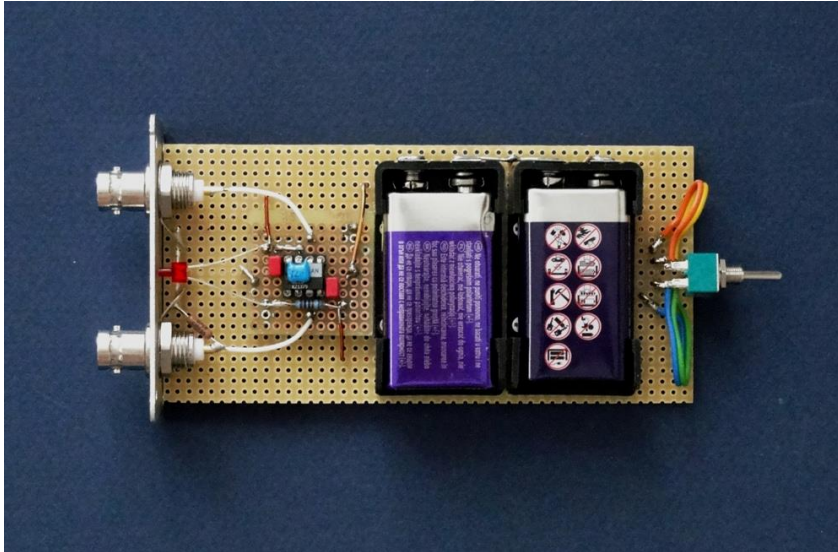
For this to function properly, we also need to have some additional resistive load with very low distortion, say 3R. This RL is placed in series with the relay, and has also to be itself linear to better than 120dB. This is provided by 3x Isabellehütte PBV 1R 0.1% on heatsinks. These are rated at 10W, 30ppm/K, and -120dB linearity. The 3R resistor is 2300 \times that of the relay resistance. So the contribution of the relay non-linearity, when in series with the 3R, is suppressed by another 67dB. We shall set the power amp to output $\pm 1.5\text{V}$ 1kHz, which will give us the required current.

The power amp for this purpose only needs to be low distortion. It does not need to "sound good". So we choose the XELF buffer at 500mA bias with ADA4627. Currently the XELF PCB is set to a closed-loop gain of 11. We can change it to unity gain if necessary. A low-distortion 1kHz functionals

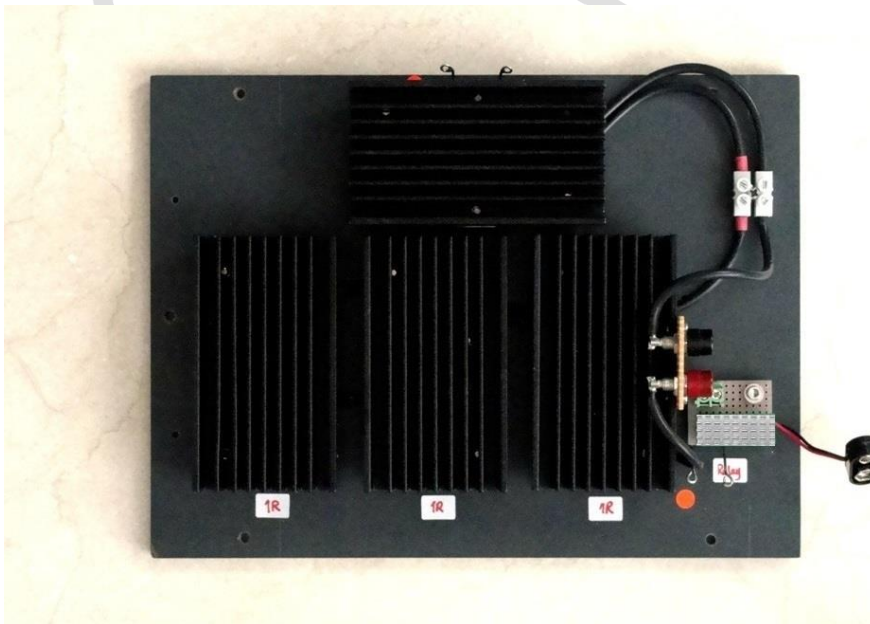
generator acts as an ideal signal source. In spice simulation, the XELF / AD4627 combination delivers 0.5A into 3R with a distortion of -115dB with 11x gain.

Verification of the Measurement Chain

With a functionals generator and a potential divider, a low distortion 1kHz sine of 0.5mVrms can be created to feed the AD797 preamp input. The distortion of the output can then be measured with the AP. We can then verify the performance of the preamp itself. The preamp is powered by 2x 9V dry batteries inside.



A 3R ballast load for the XELF is already connected in series to a dummy relay load (which is a Isabellehütte PBV of 0.5mOhm with Kelvin connection, the closest value I have on hand).



The distortion across these two combined at +/-1.5V 1kHz will be a measure of the distortion of the current delivered by the XELF. If the AD797 is then connected across the Kelvin connections of the 0.5mOhm dummy, we can measure the distortion of the total setup from functionals generator to the AP. This will give an idea of whether we are capable of measuring down to -80dB across the relay.

The assumption is of course that every element in this chain (Functionals generator, XELF, 3R series load, 0.5mOhm dummy load, AD797, AP2722) has distortion levels well below the desired -80dB.

Once we have verified the measurement chain, we can disconnect the 0.5mOhm dummy, and connect the two wires from the white terminal block to the green terminal block of the MOSFET relay (bottom right corner of the photo above). A 9V battery will switch the relay on, and the relay contacts are also wired with Kelvin connections. We can now repeat the measurement across the relay contact. This should give us the required result.

Of course, once set up, we can also measure distortions at other frequencies. That depends on what function generator you have. 😊

Measurement of the Test Setup

First of all, most sincere thanks to Jan Didden of Linear Audio who carried out all the measurements on our behalf.

The first thing to measure is the noise baseline of the AD797 100x preamp. With the input shorted to Gnd by a 50R resistor, the noise level was measured to be -130dBV at the preamp output. This corresponds to 32nV, within the specification of the AD797.

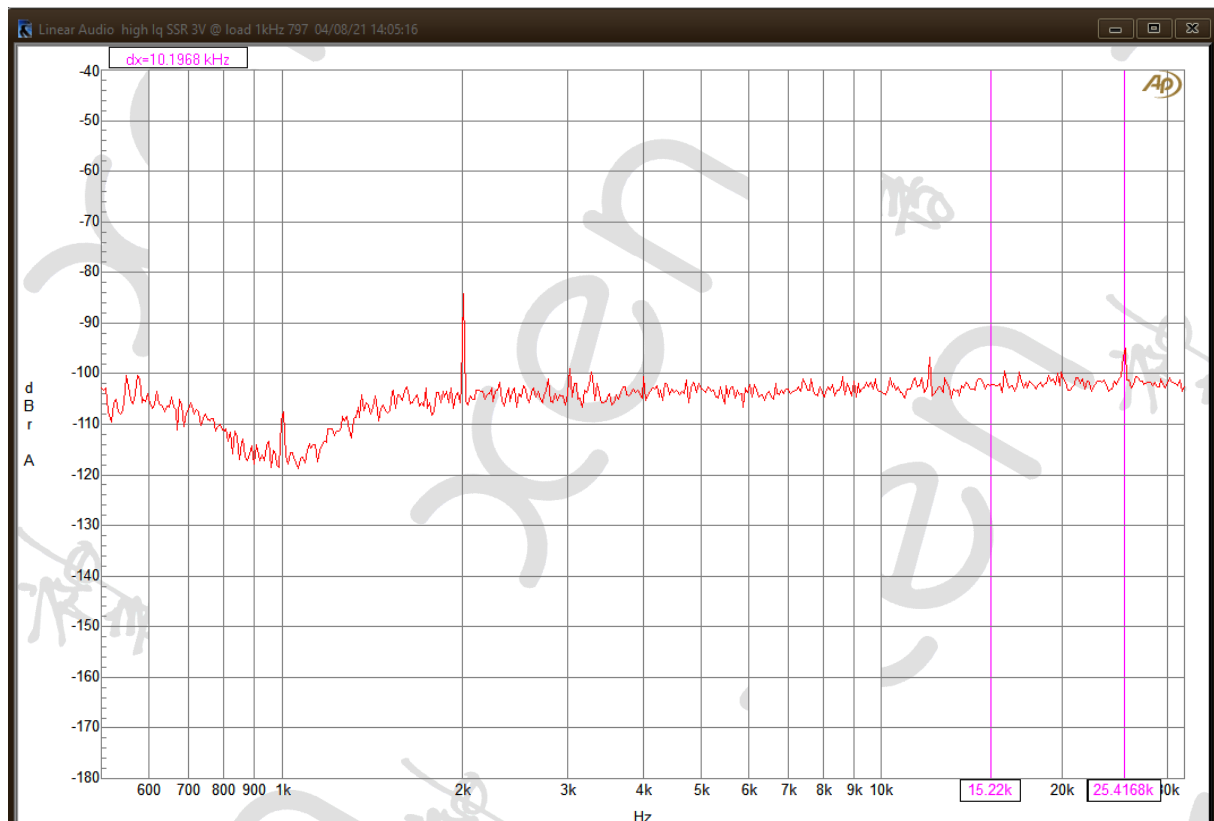
The next is to calibrate the entire measurement chain using the 0.5mR Isabellehütte reference resistor. This was measured with 1kHz and 5kHz sine waves corresponding to current levels of 0.33A, 0.67A, 1A and 1.5A rms. The result can be seen below (all values normalised to the fundamental) :

1kHz

RMS Current	Baseline	H2	H3	H4	H5
0.33		< -94dB	< -94dB	< -94dB	< -94dB
0.67		-85dB	< -98dB	< -98dB	< -98dB
1.00		-84dB	-98dB	< -100dB	< -100dB
1.50		-94dB	-92dB	< -105dB	< -105dB

5kHz

RMS Current	Baseline	H2	H3	H4	H5
0.33		-86dB	< -90dB	< -90dB	-84dB
0.67		-88dB	< -94dB	< -96dB	-92dB
1.00		-86dB	-83dB	-97dB	-95dB
1.50		-72dB	-77dB	-93dB	-96dB



Measurement Chain baseline Calibration at 1kHz 1Arms.

As can be seen, even at current level of 1Arms (or 8Wrms into 8Ohm), the distortion of the measurement chain is well below 80dB. The measurement chain as a whole meets our expectations.

The measurements with the same current levels were repeated for the MOSFET relay. The internal resistance of the relay, measured at the PCB output pins with Kelvin connections, turned out to be about 5 mOhm, including all the PCB traces, solder joints, etc. This is also noticeable as the noise level drops by 20dB compared to the baseline measurements.

The results are as follows :

1kHz

RMS Current

	H2	H3	H4	H5
0.33	-94dB	< -110dB	< -110dB	< -92dB
0.67	-87dB	-106dB	< -115dB	-102dB
1.00	-82dB	-102dB	< -115dB	-100dB
1.50	-77dB	-95dB	-113dB	-104dB

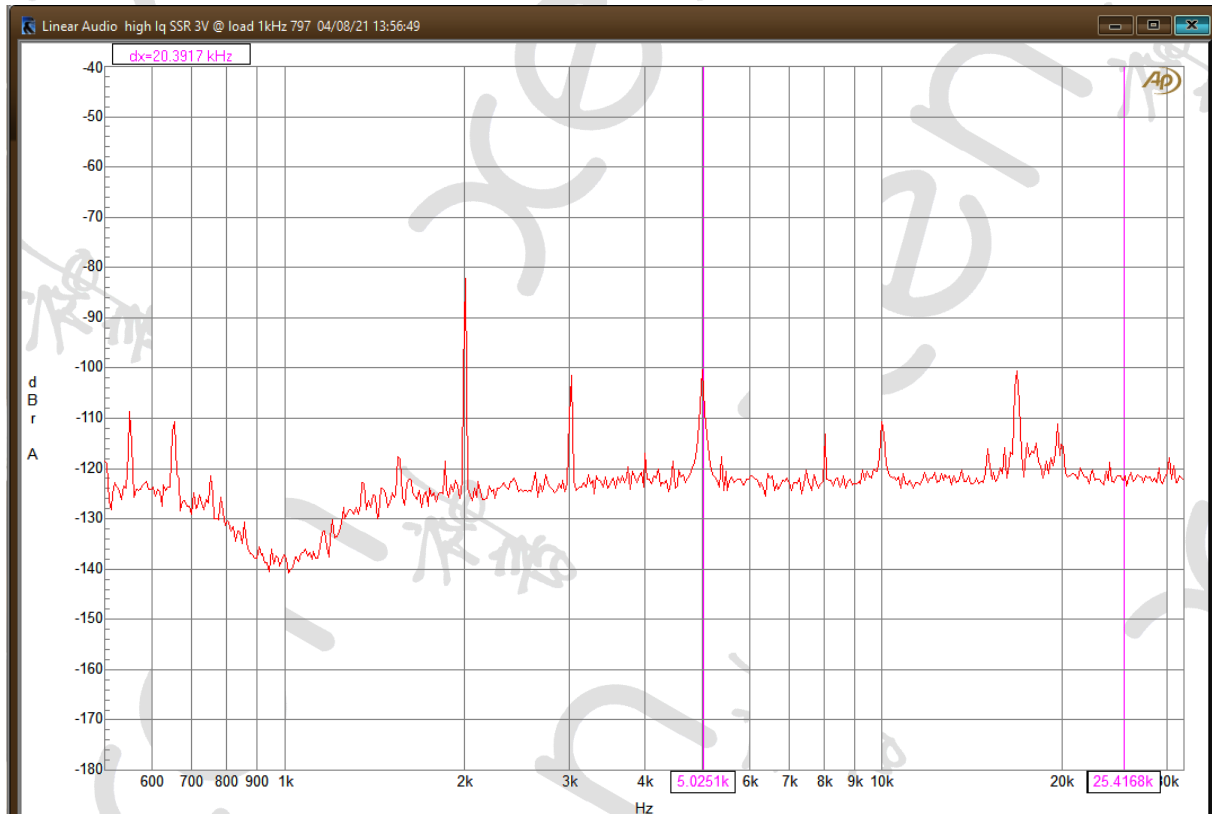
5kHz

RMS Current

	H2	H3	H4	H5
0.33	-103dB	-102dB	-102dB	-97dB
0.67	-104dB	-93dB	-106dB	-102dB

1.00	-104dB	-84dB	-110dB	-106dB
1.50	-86dB	-75dB	-104dB	-93dB

Those values in grey are results that are below or at the same level as the baseline. Nevertheless they are included here for reference.



MOSFET Relay Distortion at 1kHz 1Arms.

It can be noticed that while the distortion at 1kHz is mostly second harmonics, those at 5kHz are third. In any case, distortion contribution of the relay, when used with a 8-Ohm load, is below -140dB even at 18Wrms at the speaker.

It should be noted that the device under test is of our own design with extra measures to render it insensitive to relay power supply and to load-induced temperature fluctuations.

[illegible]