RESISTOR TEST PROJECT: SUMMARY

Developed with support from:

Audio Builders Workshop

https://www.audiobuildersworkshop.com/

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Rev 3.0

VERSION HISTORY

REV 1

- 4-Jan-18. Initial release or parts 1, 2, and 3 for review.

REV 2

- Incorporate feedback on Rev 1 release
  - Added list of abbreviations
  - Added reference to paper on battery noise
  - Possibly fixed figures that appear correct in the Word document but don't display correctly in the pdf
- added measurements and plots with ASD and smoothing for FFTs
  - Rev 1 data was retained to show the general consistency between the two sets of tests.
  - The 1K non-inductive wirewound resistors could not be retested as more parts need to be ordered
- Add additional verification and test results
  - Yagoe thick film resistors added to test results.
  - A lot more parts still to mount up and test…
- General cleanup of descriptions as needed

REV 3

- Test additional components
- Compare AP555 and AP515 noise characteristics
- Update "Future investigation" to match latest work
- Posted an example of the recorded noise, see http://clk.works/?p=210
- Prepare a presentation for a local Boston AES meeting (to be posted)
  - Includes a number of audio files of noise examples as well as files to evaluate the audibility of noise and noise with 1/f noise

ABBREVIATIONS

- AC. Alternating current.
- ADC. Analog to Digital Converter.
- ADI. Analog Devices (semiconductor manufacturer). http://www.analog.com/en/index.html
- AES. Audio Engineering Society. http://www.aes.org/
- AP. Audio Precision. A well known manufacturer for audio testing products. https://www.ap.com/
- AP515, AP555. Models of test equipment manufactured by Audio Precision.
- ASD. Amplitude spectral density. Units of amplitude per root-Hz.
- BNC. Bayonet Neill–Concelman connector. A standard connector system in electronics.

- BW. Bandwidth. Generally this would be taken to mean the – 3dB point, though when calculating RMS signal level from noise spectral density it's $f_2 – f_1$. In this system f_2 is 45 kHz and f_1 is 5 Hz, then $f_2 >> f_1$ and BW is taken to mean f_2 here.
- DAC. Digital to Analog Converter.
- dB. Decibel. Throughout this paper voltage, not power, levels are used so dB = 20 log (X/Y).
- DC. Direct current.
- DUT. Device Under Test.
- EMI. Electro Magnetic Interference.
- EQ. Equalization.
- f. Frequency. Used in the expression *1/f noise* in this writeup.
- FFT Fast Fourier Transform. A mathematical function for converting discrete time domain samples to the frequency domain.
- Hz. Hertz.
- I/O. Input/Output.
- kHz. KiloHertz (1000 Hertz)
- NI Noise Index. A dimensionless value in dB that provides the excess noise of a component. 1uV/V RMS is 0 dB.
- Op-amp. Operational Amplifier. An ideal 3 terminal device that obeys the relationship $Vout = A(Vin_p – Vin_n)$ where A is a very large number, usually at least 1 million.
- PSD. Power Spectral Density. Units of amplitude per Hz.
- RREF. A project specific term for Resistor Reference. The reference Wheatstone bridge used to provide a known curve with each excess noise measurement to ensure the test jig and AP are being operated correctly.
- SPICE. Simulation Program with Integrated Circuit Emphasis. A standard software for circuit simulation. The specific version used here called TINA-TI.
- THD. Total Harmonic Distortion. Expressed as a percent or a dB value. As a dB value it would be negative, but many times the minus sign is dropped as it's understood that the value can't be bigger than 0 dB which represents 100% distortion.
- THD+N. Total Harmonic Distortion plus Noise.
- TI. Texas Instruments (semiconductor manufacturer). http://www.ti.com/
- USB. Universal Serial Bus.
- XLR. Originally called Cannon XL connectors. A 3 pin style is used for balanced audio.

OVERVIEW

The project report has been split in to multiple parts. At present the parts are:

1. Test Design. Describes the design of the system
2. Test jig verification results. Tests the jig to validate that it is working as planned and serve as initial trial at measurements
3. Results using AP515.
4. Create a final summary report/paper, post results

This summary covers parts 1, 2, and 3 listed above.

Each of the documents recorded the details of each step and are therefore quite long, though much of that length comes from data plots.

This document does not repeat content from the other documents; the final report would be the place that things are distilled down. This document is intended to:

- serve as a guide to the three current parts of the report[1]
- summarize work done
- outline issues to resolve

Originally it was planned to examine both resistor noise and resistor distortion. However the data and analysis of just the noise aspect has already grown to a large size (60 pages plus) so distortion will be saved for a separate effort.

During the course of the noise testing it was observed that the better parts have 1/f noise below the AP515 measurement limit. To determine the differences between the parts will require a special low noise instrumentation amplifier (LNA) which is a project of its own.

The importance or lack thereof of 1/f noise in an audio system needs to be considered along with the results obtained here. One part being better than another does not mean that the system is magically better. With the better parts 1/f noise levels are only higher than Johnson noise in the bottom few octaves. Audibility of broadband noise in that range is limited.

1/f noise is a factor in many instrumentation applications as there the signals of interest are right in the range of the noise, i.e. less than one kHz or so. In cases of animal physiological or seismic geological data signals in the few to dozens of Hz range overlap the excess noise.

A presentation was developed that includes example of noise at differing levels. Even in a crude listening test under uncontrolled conditions it is relatively easy to make an informed guess about the audibility of both the Johnson noise and 1/f noise in real world playback systems.

A more rigorous investigation of this topic should be performed as at the moment an initial research in to 1/f noise audibility didn’t turn up substantiative answers.

PART 1

This document provides background on resistor noise measurement as implemented for this set of experiments. At a minimum the *Seifert* paper should be reviewed to understand the use of the Wheatstone bridge. The design of the test fixture is presented, along with results of modeling it in SPICE to include the effects of 1/f noise.

[1] The documents were done in Word, and cross referencing between docs looks very broken (at least to someone who’s used that in Frame for the past 10+ years). So the references will only be textual descriptions, not links…it’s like it’s 1990 or something.

Issues about the effects of excess noise in the op-amp circuit are raised. More research and testing with AC stimulus is needed to determine how excess noise might affect the results.

ANALYSIS

The section **Items for improvement** in the Part 1 document outlines questions raised across all three parts of work. Decisions about these issues are key to any future effort.

PART 2

This document more or less follows the bring up of the test fixture to validate the results obtained are representative of the underlying devices.

A small component fixture that connects directly to a BNC jack was created to allow testing of single components with minimal intervening circuits/connectors/wire.

The AP allows a DC offset; an investigation in to component response with a DC shift in the small fixture should be performed to compare the results against the bridge configuration.

The residual noise of the test setup as well as Johnson and excess noise measurements of a few representative resistors were all consistent and generally agreed with the theoretical values; agree in this context is +/- 10%.

The big surprise was that the non-inductive wirewound resistors that were chosen for the reference bridge actually had high excess noise relative to other values measured in Part 3. It was also observed in Part 3 that the AP's two channels seem to have some variability in the 1/f noise measurements at low frequencies. Some sort of calibration is called for to ensure consistency.

Under the bridge conditions used, the AP515 has an equivalent noise index (NI) of -48 dB.[2] The expected NI for the thin film parts is around -40 dB, so the AP515 will be a consideration for the lowest noise parts. It was noted that the Johnson noise floor of the AP515 is of the same order of magnitude as the 1/f noise in the frequency range of interest. The AP555 has a higher NI equivalent; a low noise pre-amp(s) would be needed for parts with exceptionally low NI (see *Seifert* for further discussion).

The op-amp circuit showed higher (by about 40%) noise than calculated with SPICE.[3] This needs further investigation to determine the source. Initial testing uncovered cable grounding issues and this might not be solved yet. Knowing how the resistors perform, the overall usefulness of the op-amp circuit to evaluate real world component use is still debatable.

There's some validity to moving the op-amp test to its own enclosure as the final design didn't share much circuitry with the reference bridge.

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[2] It is not really valid to assign a NI to a piece of test equipment as you don't apply a DC voltage to the equipment. We only do it here as an analogy to a perfect measurement system plus a resistor with excess noise and a DC voltage applied.

[3] The actual SPICE program is TINA-TI, the free version of TINA available from Texas Instruments.

Another open question is the use of an AC signal for bridge and what that implies about excess noise when the part has an AC signal. If the same theory that favors use of excitation in a bridge configuration applies to single resistors passing an AC signal then the impact of 1/f noise in most circuits becomes even less of an issue.

ANALYSIS

The setup and AP515 can achieve the measurement goals for all but the lowest noise (metal film) parts. Validation of the setup raised as many (currently unanswered) questions and/or alternate tasks as it was supposed to answer.

PART 3

Some different representative parts were looked at using the bridge configuration. As time allows more parts will be tested but the work to date is sufficient to validate the test set up and identify issues before using the AP555.

For the parts measured the results for the noise index is provided below. Several of the parts have noise spectra that were marginally above the AP's floor; the small observed difference in the plot could be attributed to the Johnson noise of the part. These are labeled with the AP's noise floor derived value and flagged with a * in the list below.

Given the number of factors that affect excess noise, and that the combined test fixture and instrument limitations come in to play on several parts, no conclusions should be drawn yet from this preliminary data.

Op-amp boards built up from different resistors were not created as the test for that was originally thought to have been with AC stimulus; the null result from AC testing of the bridge and the realization that the amplifier topologies don't normally have DC voltages across the resistors requires further work before any testing can be done.

All parts were retested for rev 2. There was no meaningful change in any of the NI numbers from rev 1 to rev 2. Additional parts were tested for rev 3.

There is a general observation that the NI numbers are better than expected for what should have been bad parts (carbon based).

A summary of results follows.

WIREWOUND

All are Ohmite WN series.

- 1K -43 dB
- 2.5K -36 dB (in DUT position). -34 dB for RREF (no obvious explanation yet as to why the two numbers do not match, nor why the 2.5K value is so bad).
- 5K and 10K limited by AP noise. Approx -48 dB*

CARBON

These parts were pulled from the spare parts bins so no details on manufacturer are known.

- 2.2K Carbon film –40 dB. This value seems too good for the technology so a retest is called for as the parts could not be confirmed to be carbon film.
- 22K Carbon comp -18 dB.

FILM

- Panasonic thin film 0603 2K 1/10W limited by AP noise. Approx -48 dB*
    - 10K part is similar but the higher Johnson noise makes it difficult to interpret the measurement
- Susumu thin film 0805
    - RS series 2.2K limited by AP noise. Approx -48 dB*
    - RG series 1K and 10K limited by AP noise. Approx -45 to -48 dB*
    - RR series 10K. -40 dB
- Stackpole 2K axial 1/4W metal film. -44 dB
    - 10K part the higher Johnson noise makes it difficult to determine if the excess noise is the AP's noise or from the part.
- Yagoe 2K thick film 0603. -17 dB