Linear Audio AutoRanger ARII Version 3

Technical Data and some design background

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In this document I will discuss some important technical performance data and design choices for the Linear Audio AutoRanger ARII V3 (AR). The AR is an unusual piece of equipment and for the best appreciation of the following information you should also read the User Guide at https://linearaudio.nl/la-autoranger.The AR is available as a partial kit and all information including an Assembly Guide can be found at the same link.

Chapter 1: Self Noise, Signal to Noise Ratio and Dynamic Range

While listing the above Tech Specs is usually trivial for an analog I/O device, the versatility and operation of the AutoRanger makes it near impossible to show the performance of the device by a small set of numbers. Already in manual mode the opamp stage has a multi-stage attenuator in front, where impedance changes the effective noise floor. Not to mention that thanks to being a DIY project the AutoRanger's input impedance can be whatever one picks for the attenuator's resistor values. Two typical values suggest themselves: 20 kΩ for general applications, and 10 kΩ* for typical modern solid-state applications (lower noise floor). But as the name suggests there is even more: in Auto mode the AutoRanger automatically steers gain and attenuation so that the output signal falls into a user-set range. Choices are 0.5 V, 1 V, 2 V, 3 V and 4 V RMS measured. Range, because the output level is not exactly X Volt, as both gain and attenuation are performed in steps of 6 dB. So obviously using a lower auto reference value the SNR will be limited by not using the maximum level that the used opamp could handle.

That said here are measurements taken on a version with 10 kΩ input impedance (* modified with 100 V 33 µF input capacitors. I do not measure signals with higher voltages than that – not even close, but the higher cap values improve CMRR in the lower frequency range significantly). Used opamps are OPA1612 for BAL and SE (the third, signal level measuring opamp is not part of the analog I/O path and not critical), and alternatively the recommended OPA1656. Other well working opamps are OPA1692, OPA2209 and many more. A powerbank was used to galvanically isolate the AR. I also scrubbed off the paint around the XLR ground screw, the BNC socket, and on the rear studs where the PCB is fixed by two screws. This ensured the best measurement results at my workplace.

Measurements were done with an APx555B and a self-built, super low noise 34 dB gain preamp, to be able to measure lower than the -118 dBu self-noise (1 µV) of the AP.

All values are RMS with 10 Hz high pass and 20 kHz low pass (AES 17). Noise floor is smooth and flat, there is no excessive high frequency noise nor hum, so adding 2.5 dB will give dBA weighted results.

This table shows the noise in all configurations and gain steps, measured with 400 Ω shorted input.

Gain dB	SE In BAL Out	BAL I/O	SE I/O	BAL In SE Out	BAL I/O 1656	BAL - SE 1656
-42	-116.6	-116.6	-112.3	-112.2	-115.6	-111.8
-36	-116.6	-116.6	-112.3	-112.2	-115.6	-111.8
-30	-116.5	-116.6	-112.3	-112.2	-115.6	-111.8
-24	-116.7	-116.7	-112.3	-112.2	-115.6	-111.8
-18	-111.2	-111.2	-109.5	-109.4	-113.3	-110.8
-12	-111.7	-111.8	-109.8	-109.8	-113.5	-110.9
-6	-109.7	-109.8	-108.4	-108.4	-112.7	-110.5
0	-117.4	-118.5	-112.5	-112.7	-116.9	-112.3
6	-111.9	-112.9	-110.6	-110.2	-111.4	-109.6
12	-107.1	-108	-107.1	-107.1	-106.0	-105.4
18	-101.4	-102.6	-101.9	-101.9	-100	-99.8

The first columns were taken with 2 x OPA1612. At 0 dB gain the noise is partly below the measurement limit of the APx555B (-118.5 dBu), but also slightly higher values like -115.6 dBu would still be measured wrongly when not using my measurement preamp.

The table puts some light on several things:

- Higher attenuation values always show the same noise floor. Logical, as the opamp's input is near shorted by low resistor values anyway.
- Higher gain raises the noise - no surprise. But the numbers show that the rise in noise largely matches the additional gain, so the circuit works ok.
- -6 dB gain shows the worst noise values.

The latter is easy to explain. Attenuation steps are performed by changing series and shunt resistors. At 0 dB gain the active gain stage opamp is directly connected to the input socket – hence lowest noise floor with the input shorted. At -6 dB a series resistor and a shunt resistor to ground are added, and because it is -6 dB, they have identical values. The opamp now sees an input impedance of half the values used for the resistor network – on my unit 10k : 2 = 5 kΩ per leg, so the opamp effectively sees 10 kΩ balanced input impedance (the source sees the expected 20 kΩ).

With higher attenuation the resistor to ground gets smaller, so noise goes down.

So, what is the Signal to Noise Ratio and Dynamic Range? Both are identical here as there is no noise modulation at higher levels (too simple circuit for such side effects, so to say). The effective Signal to Noise depends on the reference or maximum level that you typically measure at. The AR II can spit out +22 dBu undistorted at the unbalanced output, and +27.5 dBu at the balanced output (with proper rail to rail opamps and disabled input protection, else +26.5 dBu).

As an example: with an ADI-2 Pro I usually choose +19 dBu as ref level and use manual gain setting on the AR. In balanced operation this results in an SNR of:

Higher attenuation: 116.6 +19 = 135.6 dB (138.1 dBA)

-6 dB: 109.8 + 19 = 128.8 dB (131.3 dBA)

0 dB: 118.5 + 19 = 137.5 dB (140 dBA)

+18 dB: 102.6 +19 = 121.6 dB (124.1 dBA)

You read that right – a SNR of one hundred thirty-seven point five, rms unweighted – the AR can do!

Now put this into some real-world perspective. In the above table you just wanted to complain about the drop in performance at -6 dB, right? Do you really have a DUT where this would matter at all?

Ok, DIYers usually don't have an ADI-2 Pro at hand, so either must use a lower ref level or use the AutoRange feature of the AR. Let's have a quick comparison by listing the respective dBu values for the available AutoRange voltage settings:

0.5 V: -3.8 dBu

1 V: +2.2 dBu

2 V: +8.2 dBu

3 V: +11.8 dBu

4 V: +14.3 dBu

The AutoRanger can only follow the input signal in 6 dB steps, but it also has to apply a hysteresis to avoid switching wildly up and down when the signal level is near the switching threshold. The next pic shows two level sweeps and the result at the AR II output when set to 4 V. One sweep is upwards, one downwards. Hysteresis turns out to be exactly 1 dB, and the maximum output level is +16 dBu or 4.89 V, while minimum level is +10 dBu or 2.45 V, over a range of 36 dB. Recalculating the available SNR for the worst case (+10 dBu @ -6 dB gain) is still 119.8 dB.

Chapter 2: THD and THD+N

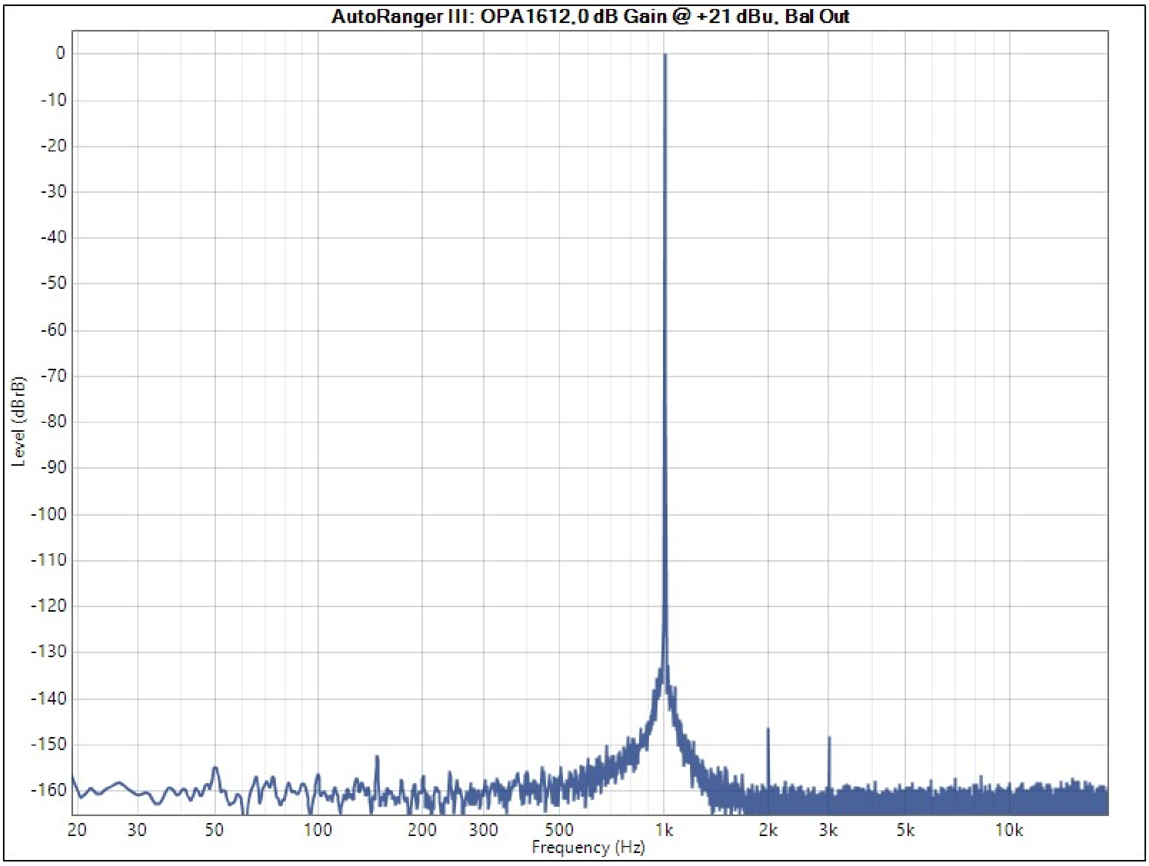
I smell a rat! This guy is talking about noise all the time – what's up with distortion?

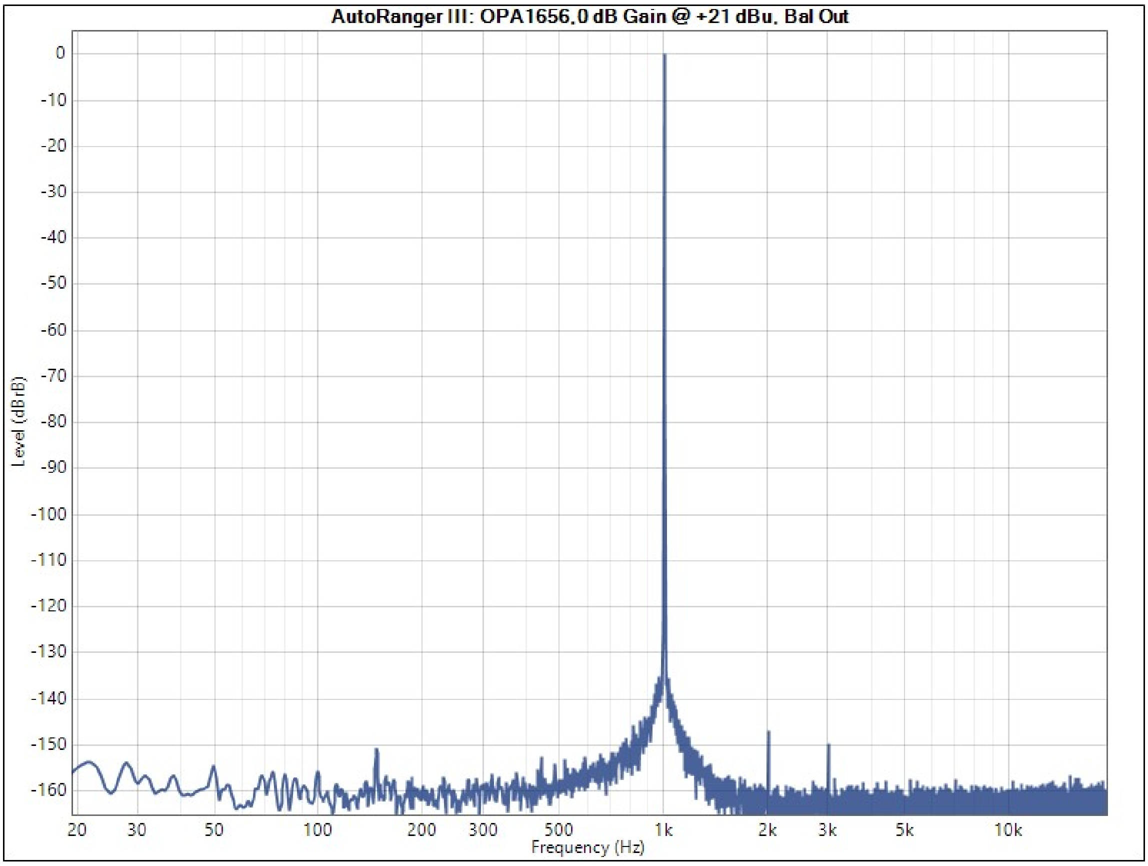
Well, believe it or not - there is none. At least if you define 'none' with harmonics lower than -150 dB. Or stuff one can't measure reliably if at all.

The reason for this is simple: the AR is just a basic double opamp stage, built with high quality resistors and relays (and some caps). No dynamic processing of levels, no intentional altering the signal. The only distortion one should be able to measure is the one that the chosen opamp introduces.

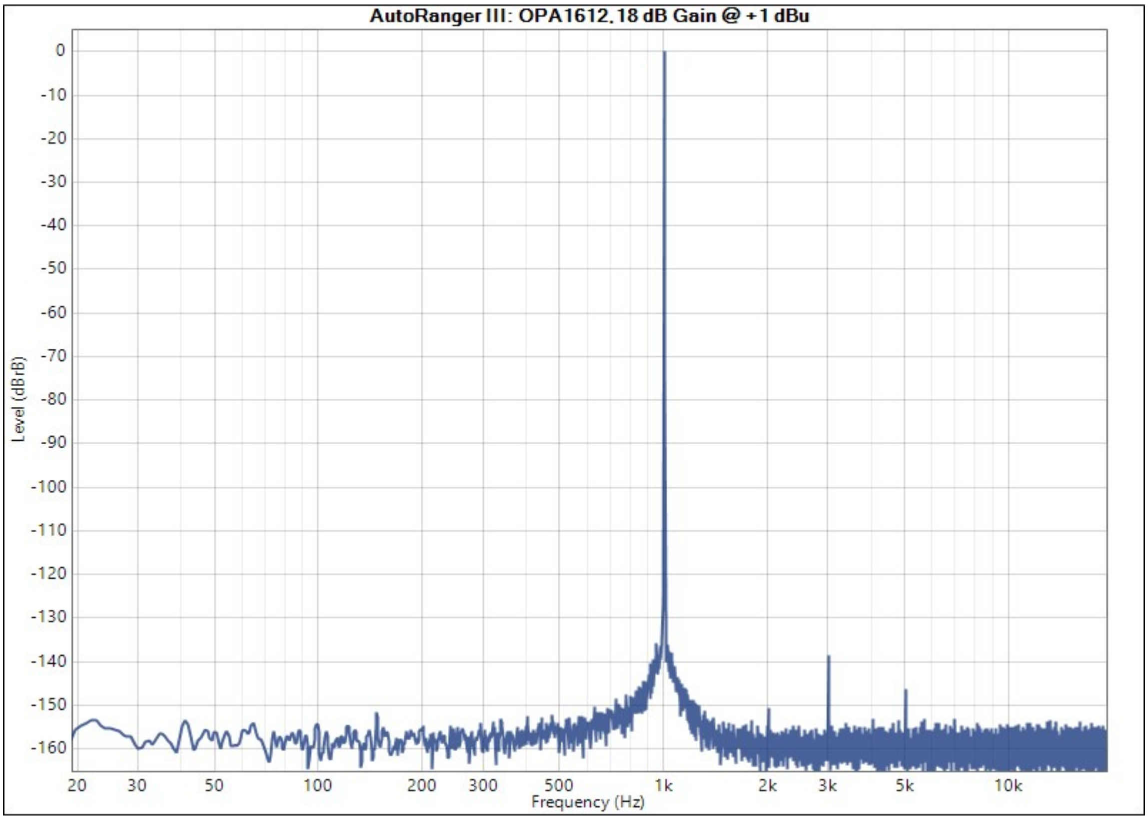
To demonstrate that here is one of my favourite AR applications: using it as opamp test circuit. I soldered all opamps on 8 pin DIP adapters and therefore can easily change them. I feed the AR with the balanced super-low THD signal of the APx555B, set the AR II gain manually to fixed 0 dB and 18 dB, load AR's output with a few hundred Ohms, and crank up the level. At 0 dB gain most of today's opamps are literally free of distortion, or it's so low that one can't be bothered. At 18 dB gain the differences become more noticeable.

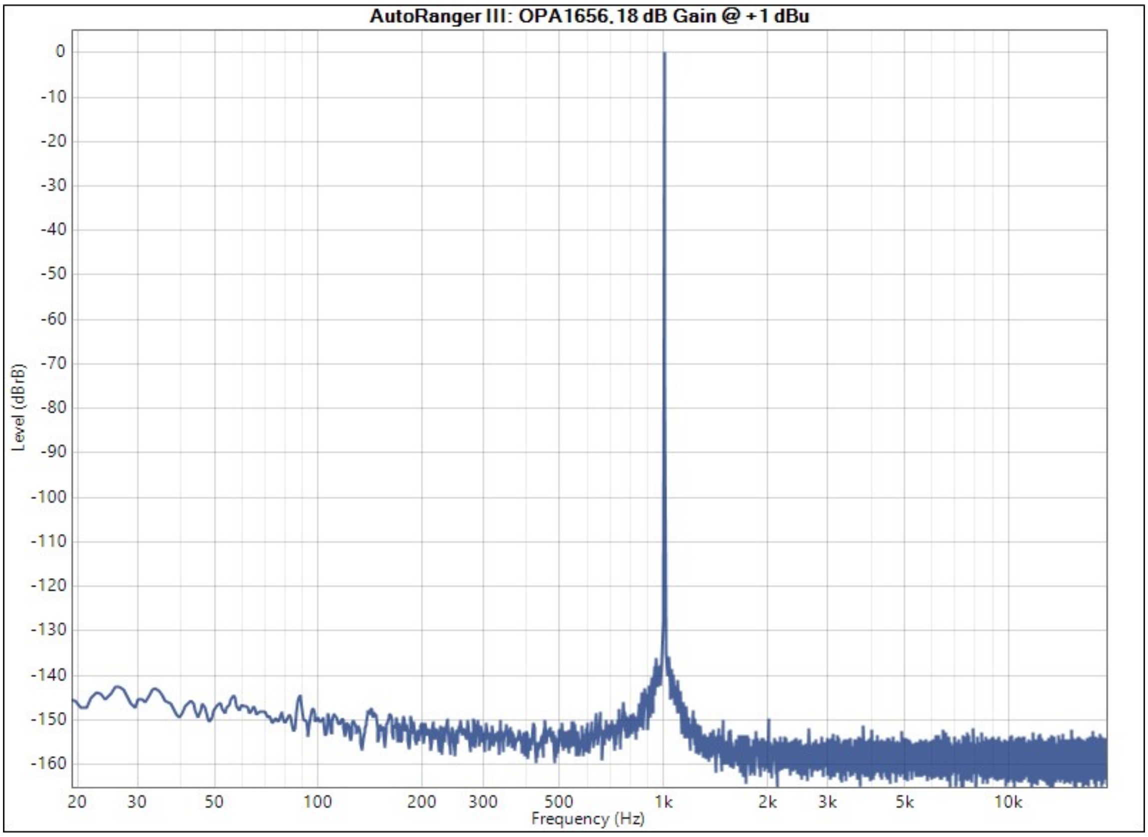
Here are two examples. The first pic shows the OPA1612. Input signal is 1 kHz sine at +21 dBu, AR set to 0 dB gain, BAL I/O. The two harmonics down at around -150 dB are indeed from the APx generator, and the next pic shows basically the exact same state using an OPA1656.


AutoRanger III: OPA1612, 0 dB Gain @ +21 dBu, Bal Out
Level (dBrB)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
20
30
50
100
200
300
500
1k
2k
3k
5k
10k
Frequency (Hz)

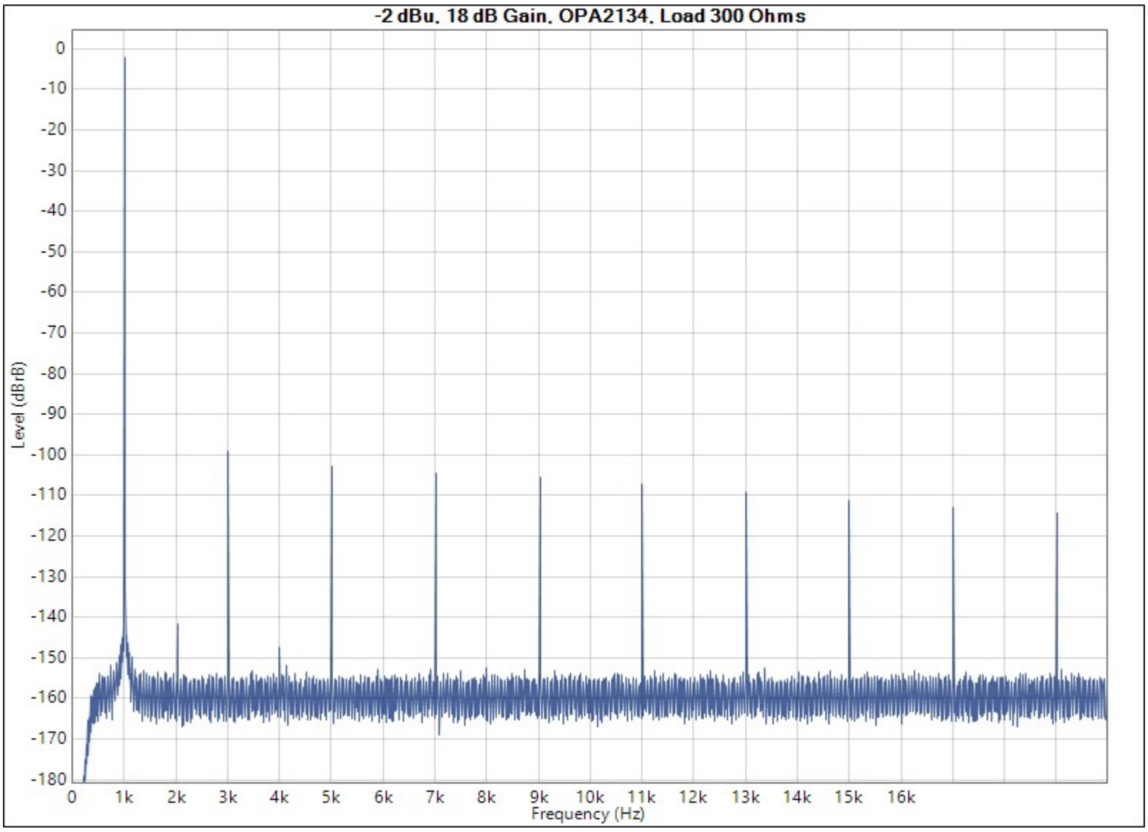

AutoRanger III: OPA1656, 0 dB Gain @ +21 dBu, Bal Out
Level (dBrB)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
20
30
50
100
200
300
500
1k
2k
3k
5k
10k
Frequency (Hz)

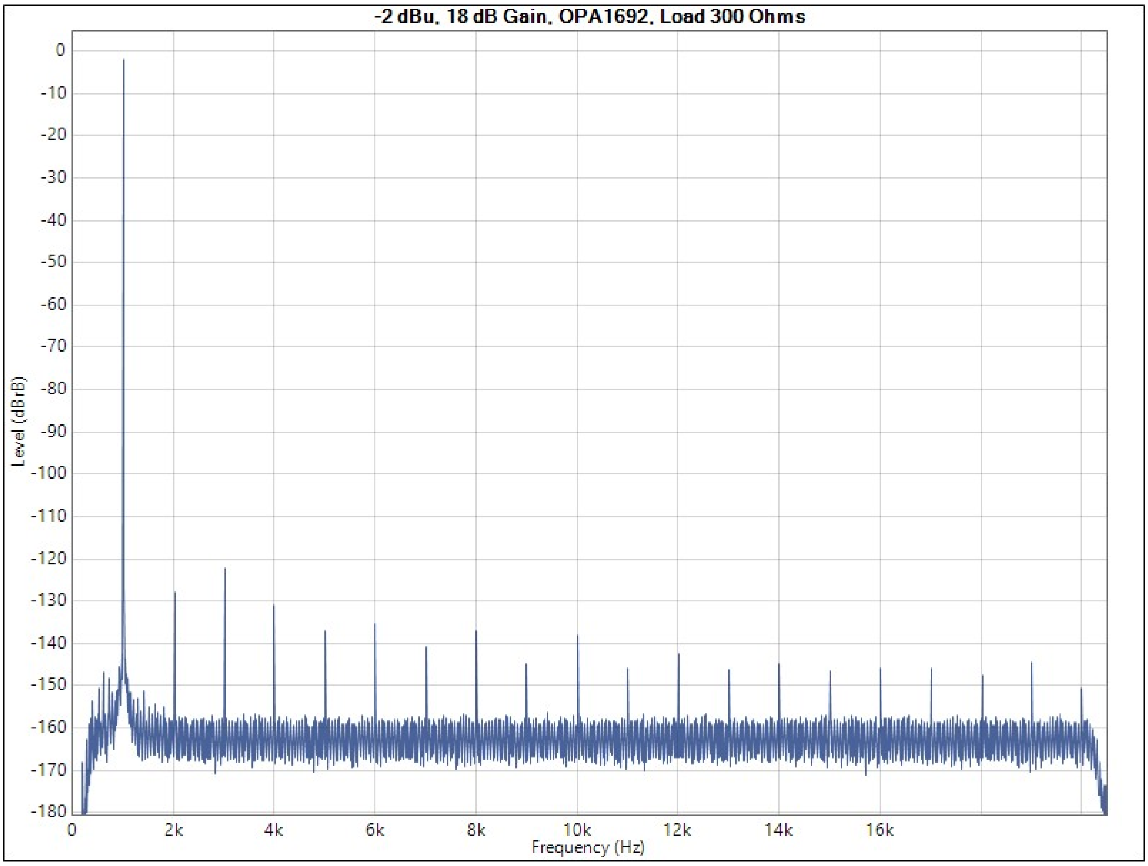
That changes significantly when using 18 dB gain. The OPA1612 now shows K3 at -138 dB while the OPA1656 has all harmonics still down at -150 dB. The different noise performance between both chips also becomes visible: OPA1612 is still low, while OPA1656 shows higher noise, especially in the lower frequency range – as expected and documented, caused by its FET input stage.





Setting the AP to 300 Ω input impedance puts a hefty load on the opamp in the AR. Differences here are quite big. Two examples of +16 dBu balanced output level, so every opamp stage processes +10 dBu only.





Please note that due to internal serial resistors in the AR, the real output load was a total of 700 Ω for this measurement. First pic details an OPA2134, second pic an OPA1692. Unfair comparison, yes, but it just shows how easy it becomes to verify manufacturer specs, and to see the real-world performance with the levels/impedances that one needs in a design. Just plug it into the AR!

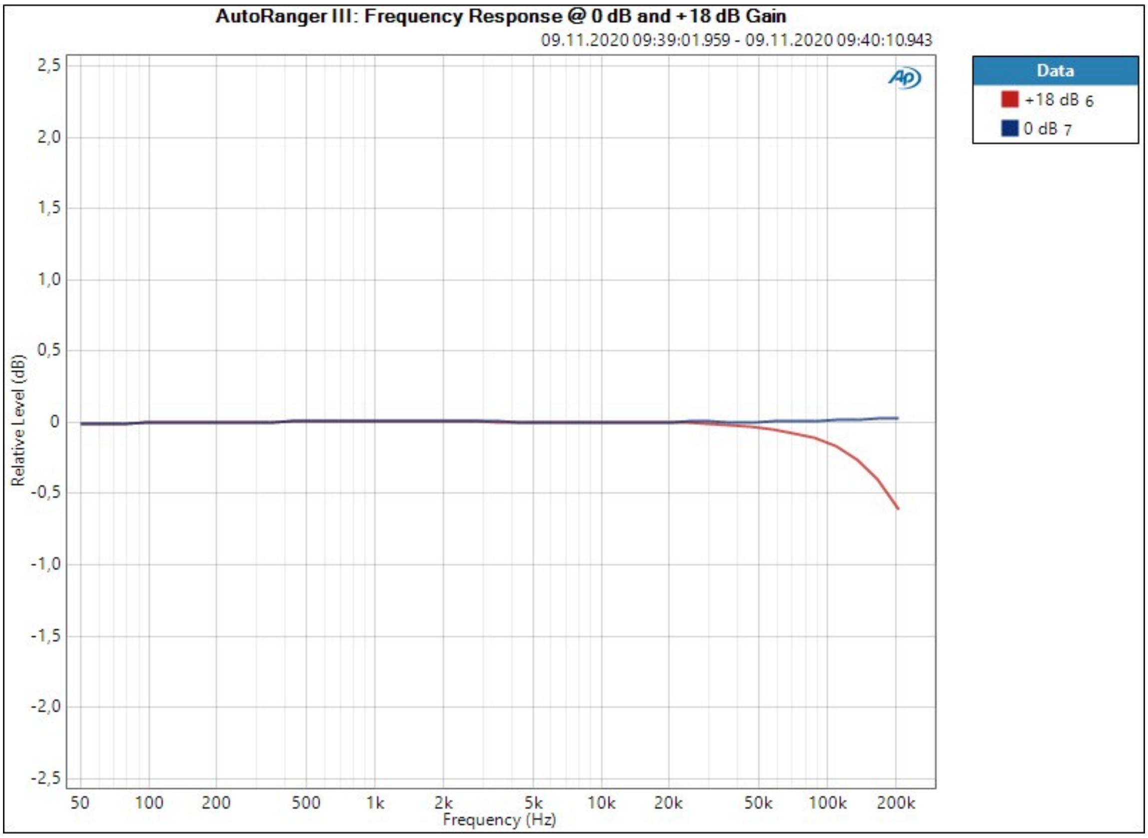
Chapter 3: The Single Ended Output

In the AR II, the single ended (SE) output has been improved significantly. The output limiter is now optional via jumpers, so if you want to measure at higher levels for highest SNR just don't place them. The circuit is a super-balanced design, which puts identical loads on both outputs of the first, balanced opamp stage, and output level is identical to balanced. The biggest change to earlier versions is that using the BAL output will automatically cut off the SE circuit, preventing distortion to couple back into the balanced input stage when using levels above +22 dBu.

But no matter what circuit you use, the transition from balanced to unbalanced always removes a few dB of SNR. The noise floor of the circuit steals near 6 dB at some gains, and nearly none at others. THD is as exemplary as with the balanced input stage, though, and as it can be driven up to +22 dBu, measurements using the SE out are still top – expect your DUT to be the limiting factor.

Chapter 4: Frequency Response

As shown by above measurements, the balanced I/O stage (that includes the SE input) has been designed for full transparency. But for a stable operation with as many different opamps as possible, it turned out to be necessary to add both series resistors as well as small feedback caps. The frequency response at 0 dB gain down to highest attenuation is therefore linear far over 200 kHz but gets limited with higher gain. Worst case is +18 dB gain, where 80 kHz is down 0.1 dB; the -3dB point is still far above 200kHz. You certainly can live with that. The SE output has the same frequency response.



Chapter 5: CMRR

Doing balanced I/O measurements with a stage that should be most transparent would mean that the CMRR would be equal to bypassing the AR II. To come closer to this goal the AR II has been further optimized. A changed circuit plus 10 times bigger input caps improve CMRR in the lower frequency range a lot (1 kHz around -90 dB, 50 Hz around -70 dB). For the SE output CMRR is also good, but not record breaking, as there is (intentionally) no adjustment of the resistor deviations available. It reaches 60 dB from 20 Hz to 20 kHz.

Chapter 6: The Power Supply

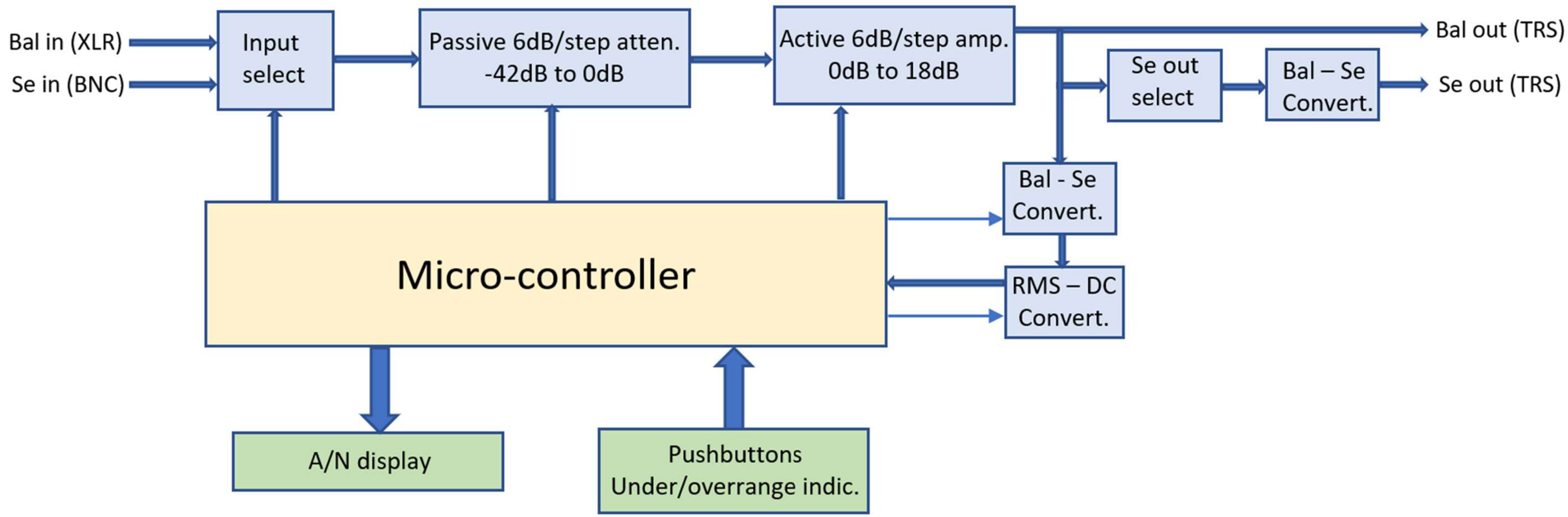
The exemplary noise performance and FFTs free of spurious tones prove that the power supply of the AR is outstanding as well. It contributes a lot to the very good performance. Or rather, it does not contribute anything except extremely clean +/-15 V rails. It also supplies the control and display circuitry from its auxiliary 5V output.

The AR has been equipped with Linear Audio's *SilentSwitcher*, a prime example of how modern switching supplies can be efficient and super-clean as well. Additional filtering includes a pair of ultra-low-noise linear regulators with CMRR of better than 70 dB up to 1 MHz. It can run from any 5 V source via its USB socket.

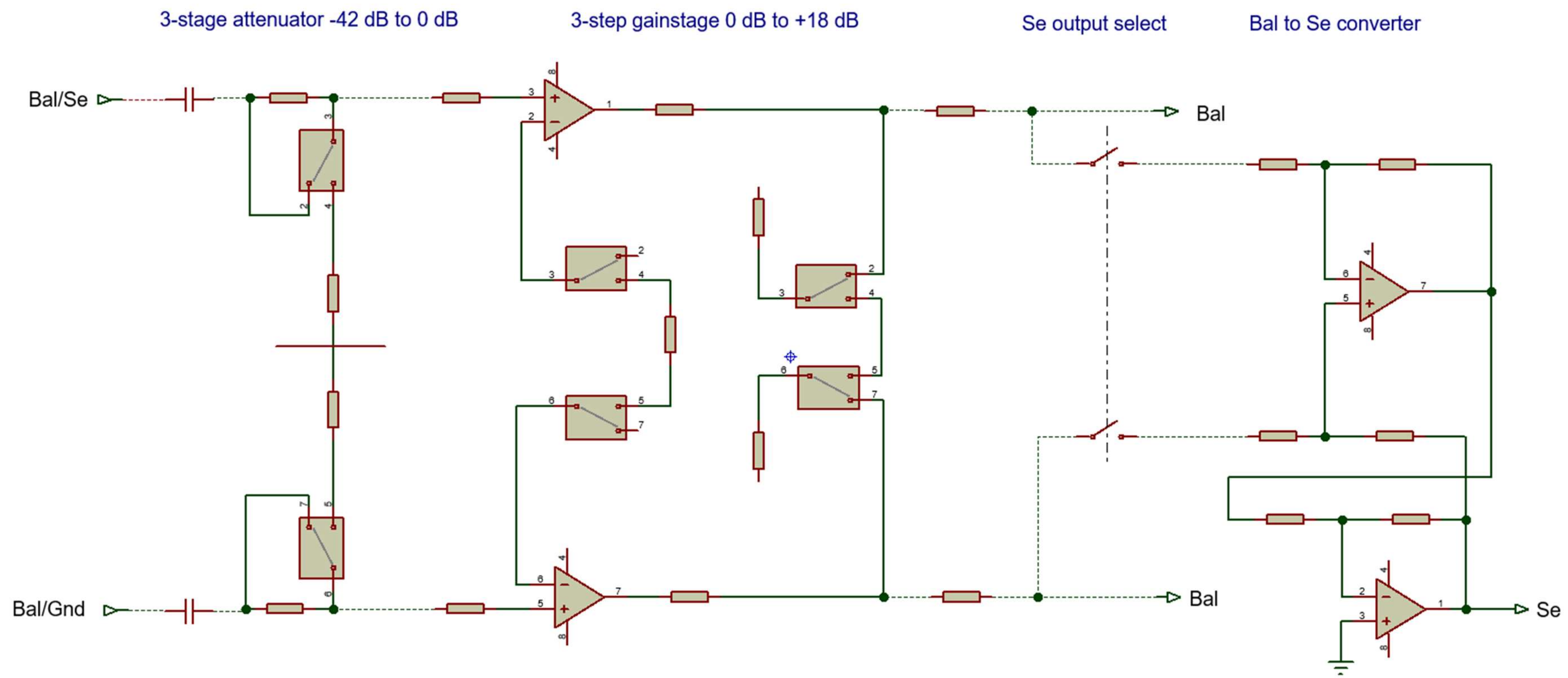
Note that the SilentSwitcher does not include galvanic isolation. While in most cases any USB port or Smartphone charger will work, doing measurements at extreme resolution might add mains spurs in a FFT due to ground coupling. In that case simply use a typical Smartphone Powerbank (as was done here). These are cheap and let the AR run for hours – with full galvanic isolation.

Chapter 7: Some Useful Stuff

- The series input resistor for the active gain stage is 220 Ω per opamp input. If you measure SNR with a shorted input, the source resistance that the opamp sees is 440 Ω balanced. The difference to a perfectly shorted input is about 1 dB only. Do not bridge these two resistors, they are there for protection and stability.
- The balanced amplifier has 47 Ω as output impedance on each leg. This gives a total of 94 Ω output impedance at the balanced output, and this must be accounted for when doing measurements with a test load, as these resistors cause a voltage drop under load test conditions.
- The balanced amplifier has 47 Ω within the feedback loop on each leg. While the opamp compensates the voltage drop over this resistor under load test conditions, the total load value includes these two resistors as well. Example: when loading the ARII V3 with 470 Ω at the BAL output, the real load for the BAL opamp is 470 plus 188 = 658 Ω.
- Warning for all these 47 Ω resistors: Stay away from removing them as they are necessary for stable operation.
- Input impedance is 'per leg'. The specified input impedance describes the single ended input. Balanced the value doubles (20 kΩ turns into 40 kΩ). So, the lower impedance version (10kΩ) is still 20 kΩ on the balanced input.
- Good grounding helps. While the ARII V3 PCB now has ground pads at the rear of the PCB, these need to make contact. The housing is completely coated, so scratch off the coating at those mounting studs, and around the BNC input socket at the front.
- The AR is as flexible as your imagination. For example, measuring SE in to SE out you could also grab the output signal at the tip of the BAL output, not using the additional super-balanced circuit in the balanced to single-ended converter, and its added noise. Then it is just a single opamp stage in the path, as transparent as the measurements with BAL I/O.



AutoRanger ARII-V3 block diagram



Autoranger ARII V3 signal path concept

Epilog: Even simple things can be fun

I would like to thank Jan for starting this really useful, easy to build and use DIY project. And for listening to my comments and ideas on how to further improve it. It was fun to bring the AutoRanger to where it is now. And that’s what this hobby should be all about – learning, trying, testing, enjoying what you achieve in the end after the soldering iron’s smell filled the air. Hope you have fun too!

Matthias Carstens