TECHNOTE 009

AK4490 DAC AND A²B I²S CLOCK JITTER

Rev 2

14-Oct-20

Clockworks
Signal Processing

http://clk.works/

1. TABLE OF CONTENTS

1 Introduction 3

1.1 System performance impact 5

1.2 A^2B Spread Spectrum modes 5

2 test configuration 6

2.1 Test measurement limits 7

2.1.1 Local measurement Limits 8

3 AK4490 performance 11

4 Measurements 13

4.1 THD+N 13

4.2 DR 14

4.3 SNR 15

4.4 Spectrum 15

4.4.1 The test conclusion 22

5 What to do? 24

6 Summary 25

Clockworks' TechNote008 investigated the jitter properties of the I²S clock output of the AD2428 A²B transceiver part. From that analysis we saw that designers of mid range and above consumer audio, and pro audio applications, as well as related industrial, scientific, and sensing applications that need highly accurate ADC and DAC performance must evaluate the planned hardware platforms to ensure performance is not unexpectedly degraded.

The AD242x A²B transceiver device's output clocks have high jitter in comparison to I²S clocks derived from crystal oscillators that are typical in ADC/DAC systems. The performance effects of the A²B transceiver clock output jitter might not be of concern if the chosen ADC and/or DAC had documented jitter reduction performance and it was possible to pick parts based on those datasheet numbers. Real life is much crueler, with nothing more than a passing marketing reference to "great jitter tolerance" but no published data to define what that means for parts examined to date[1].

This TechNote looks at the AKM AK4490 Stereo DAC, which is a high performance part that finds use in many audio applications. While always dangerous to draw conclusions from a sample size of one, it at least shows one possibility.

Mostly though this TechNote should serve as a blueprint for your own tests.

If you want to skip the background and jump to the results, see **Chapter 4 Measurements**.

1 INTRODUCTION

A test environment based around AKM's AKD4490 EVM platform was used with Clockwork's standard A²B hardware products. ADI's SigmaStudio tool was used to configure the three different test configurations.

Figure 1 shows the SigmaStudio schematic for the full 10 node configuration. The root (A²B master) node is ADI's WDZ eval board; it includes ToSlink input and output so is convenient for providing digital audio from the audio analyzer.

[1] If you find a part that's documented please do let us know!

Two Clockworks AB0109 Quad module carrier boards provide a compact way to increase node count. The last node is Clockworks AB0106L which provides I^{2}S input and output that can be connected to the AKM EVM.

To further emulate a typical system a combination of six 4m cables and the 1m cables were used between nodes to provide a total cable length of 27m.

When testing with less nodes one or both quad carrier boards are removed from the daisy chain. The AKM EVM was located at the first location (client node 0 in A^{2}B numbering convention), the 5th location (node 4), and the 9th location (node 8).

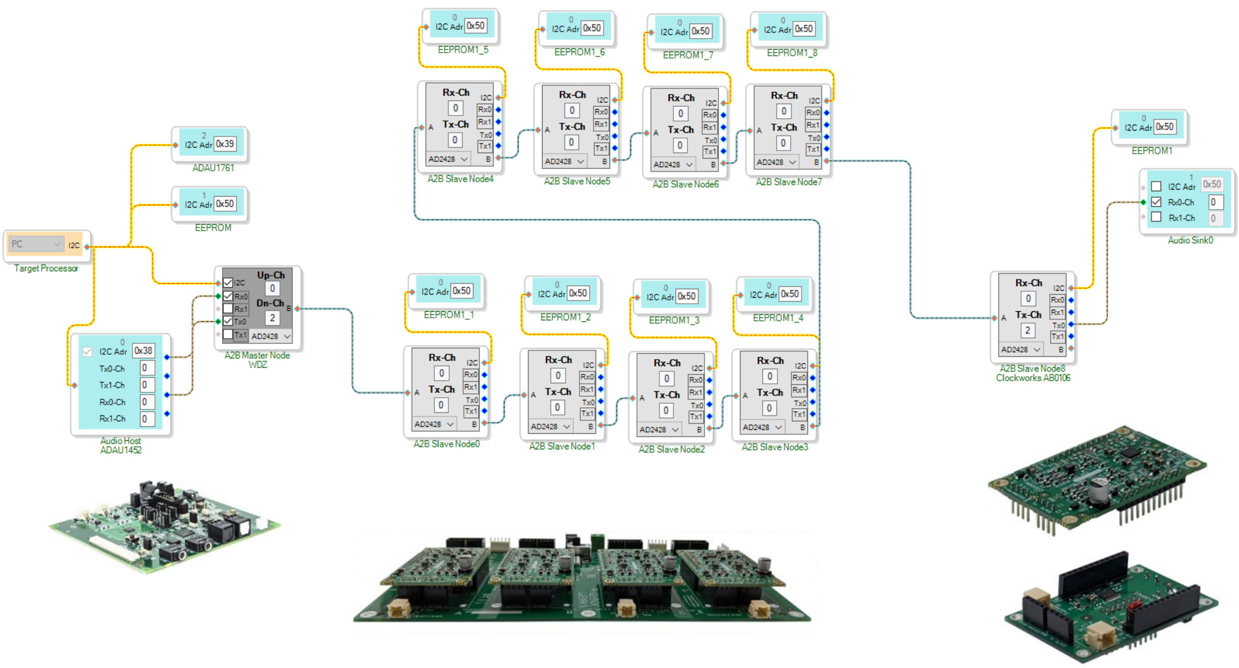

Figure 1 10 node configuration used for test (other configurations are subsets of this)

Clock jitter specifications for the AD2428 A^{2}B transceiver had been of concern on the Clockworks hardware because of this table in the datasheet:

Table 10. SYNC Output RMS TIE Jitter at Each Slave

Slave Node	Typ	Max	Unit
1	1.57		ns
2	1.79		ns
3	1.91		ns
4	2.04		ns
5	2.15		ns
6	2.27		ns
7	2.44		ns
8	2.47		ns
9	2.58		ns
10	2.70	5.50	ns

Figure 2 RMS TIE table from AD242x datasheet

tSOJ from the parameters in Table 7 of the AD2428 datasheet specify 2.2 nsec typical and is assumed to be an average derived from the above. Regardless, this is an unusually high number for audio designers.

Clockworks performed jitter measurements on the A^2B hardware and published them in TechNote008 A^2B I^2S Clock Jitter. For those not familiar with the topic of jitter and audio please see Clockworks Appnote001 – Jitter Spectrum measurement with a DSO.

1.1 SYSTEM PERFORMANCE IMPACT

Complicating matters is that ADCs and DACs all respond to clock jitter differently, and theoretical analysis is difficult. With pro audio aiming for Dynamic Range (DR) > 120 dB (AES-17 measurement) and high performance consumer systems having DR > 110 dB, system hardware measurement and test is the only definitive way to evaluate the impact of the A^2B jitter.

1.2 A^2B SPREAD SPECTRUM MODES

To pass EMI tests most modern system include a spread spectrum mode that intentionally jitters a clock to cause the emissions to be spread across a wider bandwidth,[2] and A^2B is no exception. Both the A^2B bus and the I^2S ports can be jittered under software control.

[2] As opposed to reducing the cause of the emissions. Spreading EMI creates problems for most modern wireless systems which use "wide" channels. Though if the noise modulated down in to

The tests here are all performed without the spread spectrum modes disabled as they theoretically only make matters worse, though a test done as part of this investigation suggests that it doesn't further degrade performance of the AK4490.

In a real system it is possible the degradation is small and passing EMI certification will be easier. If you're making a high performance audio systems the approach should always be too fix the EMI problem first.

2 TEST CONFIGURATION

- Root (A^2B Master) node: Analog Devices EVAL-AD2428WD1BZ (controlled via USBi from PC with SigmaStudio)
- Intermediate client (A^2B slave) nodes: Clockworks AB0001 modules in AB0109 carrier.
- Last node: : Clockworks AB0003 module with AB0106L I/O expander.
- AKM AVD4490 EVM
- AverMetrics AverLAB Audio Measurement Platform

audio frequencies things that raise the noise floor are less objectionable than little whistling birdies.

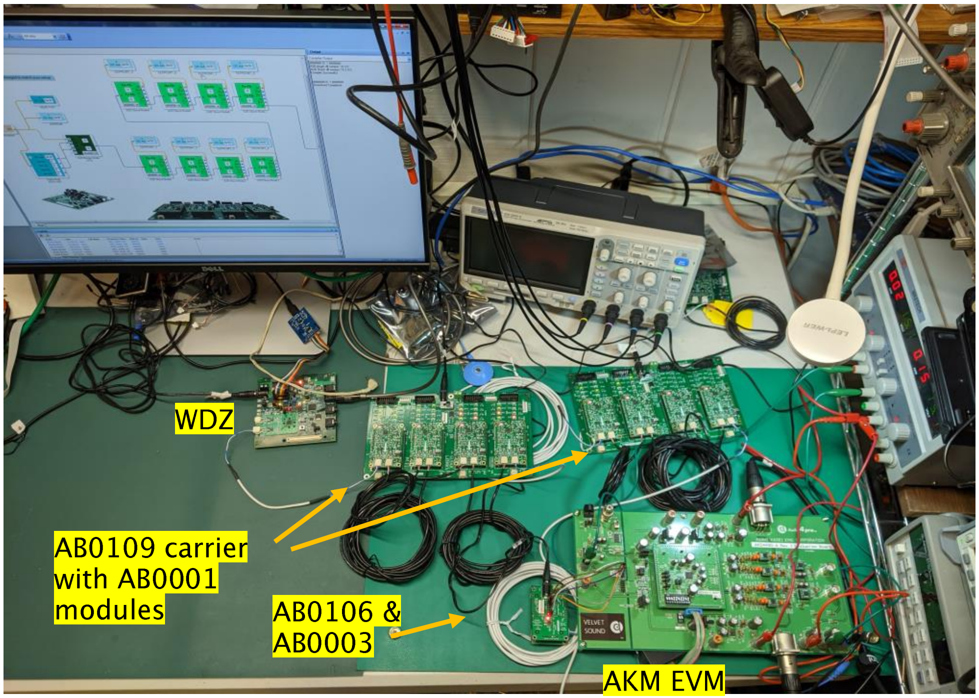

Figure 3 Test hardware setup[3]

2.1 TEST MEASUREMENT LIMITS

Modern audio equipment can achieve "straight wire with gain" status in terms of reducing audible artifacts multiple orders of magnitude below even the most optimistic hearing thresholds. With the ability of wide dynamic range and low distortion has come the need for even more capable test equipment. With such sensitive equipment minor outside perturbations can dominate the measurements.

Before performing measurements a check of the test equipment is done to ensure the validity of the measurements.

The AverLAB system numbers that are relevant to the analog measurement here are:

[3] If replicating this the default data format for the AKM EVM with SPDIF is MSB first; with the AB0106 the format needs to be changed to I^2S, along with moving the 4 jumpers to select port 2.

- THD+N −110 dB (for signal levels > −12 dBV[4], note there is autoranging up to +10 dBV input so the THD+N is not constant)
- Residual input noise < 0.8 uV (−121 dBV)

2.1.1 LOCAL MEASUREMENT LIMITS

Lots of things can conspire to reduce theoretical performance. Using the AverLab's output in a loopback test:

1. At 0 dBV level measured THD+N is −106 dB. The generator is spec'd at −108 dB, so this would indicate the actual measurement performance is close to the −110 dB measurement limit of the analyzer from the datasheet.
2. At −60 dBV the measured loopback THD+N is −66 dB.[5] This could be interpreted as 126 dB DR, though the autoranging of the AverLab unit makes that not be a good way to think about it.
3. With cabled input but no signal the measured noise floor is −126.5 dBV[6]

Figure 4 is the FFT plot (32 K points , 16 averages) of a 1 kHz loopback. While this doesn't tell us if the harmonics are from the generator, analyzer, or some TBD combination, it does set an upper bound. The second harmonic is around 108 dB down from the fundamental.

[4] dBV will be the preferred measurement unit as the author find dBU about as convenient as providing measurements in *furlongs per fortnight*.
For those that can't deal, 0 dBu = −2.218487…blah blah dBV.

[5] In the "good" A channel. The Averlab unit, at lower levels (below −30 dBV), performs 3.4 dB better in channel A than channel B. This is a known operational characteristic of the AverLAB. Therefor for this Technote will always use Channel A measurement though the plots will display both DAC output channels.

[6] The input is not shorted and the source impedance is around 50 ohms. −126.5 dBV is about 0.5 uV RMS. Like THD+N, channel A is about 4 dB better performance and will be used for calculating performance even though the plots will show both channels. The RMS thermal noise for 50 ohms is 0.14 uV RMS.

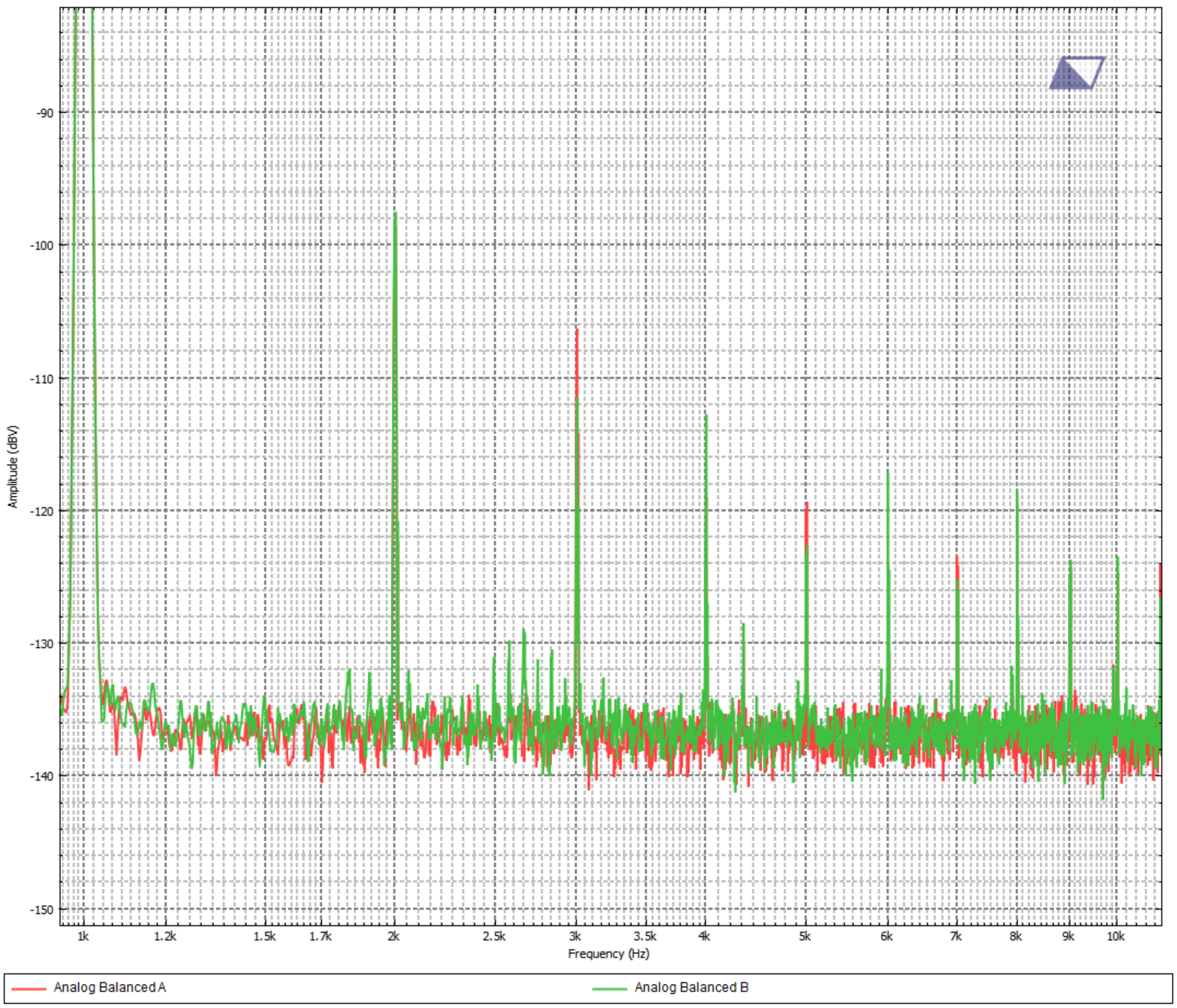

Figure 4 AverLAB loopback of 10 dBV (-1 dBFS if DAC was used) 1 kHz. 16K pt FFT

The same loopback check is also repeated for an 11 kHz signal in Figure 5. 11 kHz is better at exposing clock jitter that a 1 kHz waveform. With the 22 kHz measurement bandwidth (48 kHz sample rate) the higher harmonics fold back in to the measurement window. The 2nd harmonic dominates at -107 dB down from the peak. As with Figure 4, this test does not identify the source of the harmonic components (generator vs. analyzer). All other harmonics are > 120 dB down so we would be safe to consider that inconsequential.

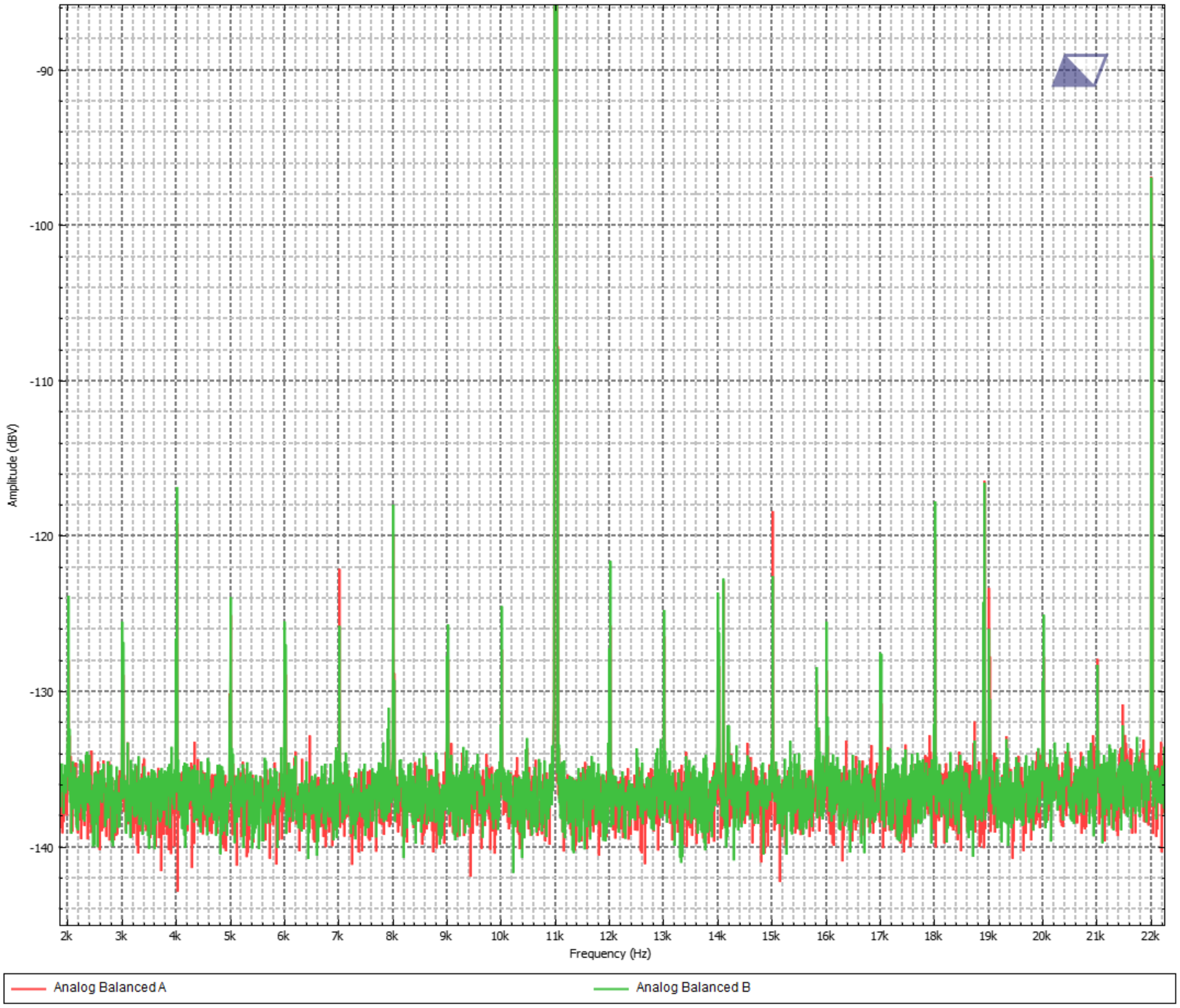

Figure 5 AverLAB loopback of 10 dBV (-1 dBFS if DAC was used) 11 kHz. 32K pt FFT (linear frequency scale)

Later testing will look at a wider 88 kHz bandwidth so the loopback over the wider bandwidth is included in Figure 6. The generator[7] does put out rising energy over 30 kHz which is not uncommon with sigma delta DACs.

---

[7] The analyzer has flat frequency response.

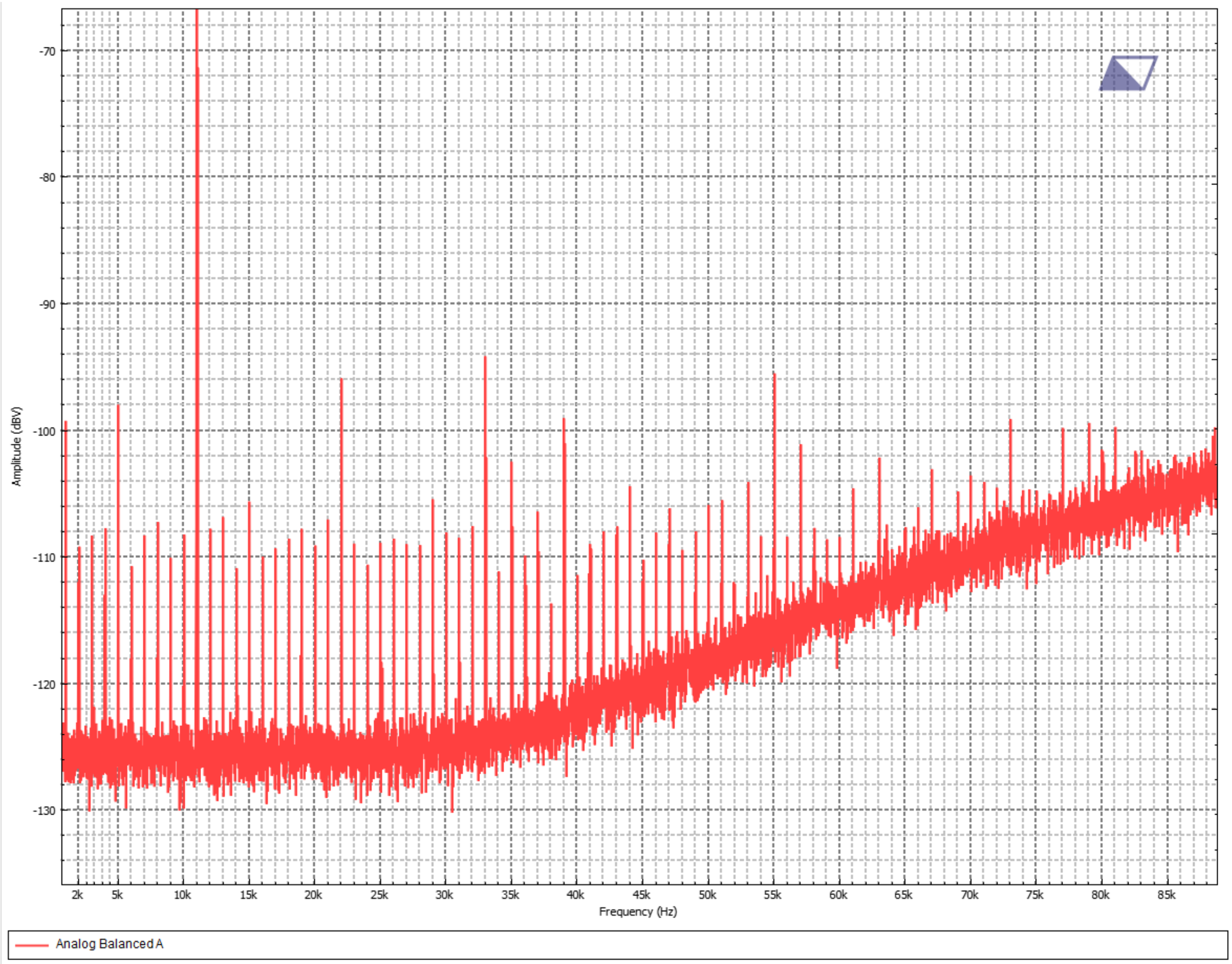

Figure 6 88 kHz BW AverLAB loopback of 10 dBV (-1 dBFS if DAC was used) 11 kHz. 32K pt FFT (linear frequency scale)

3 AK4490 PERFORMANCE

The datasheet for the AK4490 specifies typical values (worst case are spec'd about 5 dB below the typicals) of:

- -112 dB THD+N
- 120 dB DR & SNR (0 dBFS = 0dBV RMS output from the DAC) A weighted, no unweighted numbers provided.

The EVM board will degrade those numbers a little, though it also provides gain as 0 dBFS on the EVM DAC corresponds to 11 dBV (3.5 VRMS). In the EVM the DAC clock is coming from a SPDIF receiver, and SPDIF is well known for causing clock jitter unless the SPDIF Rx implements a decent clock/PLL management scheme.

In some ways using the EVM with SPDIF input is a more *apples-to-apples* comparison with A^2B than comparing with the DAC clocked from an oscillator.

The EVM board came with a test result sheet:

- −109 dB THD+N (0 dBFS)
- −120 dB SNR (which translates to a floor of −109 dBV) (A weighting implied)
- −60 dB THD+N at −60 dBFS (A weighting implied)

The AKM provided results were measured with an Audio Precision (model not specified) which should have better performance than the AverLAB used here.

Measured values with the AverLAB from the EVM:

- −105.6 dB THD+N (11 dBV output, 0 dBFS).
  - Lowest THD+N is −107 dB at −4 dBFS
  - We would expect to measure −106.5 dB with a source of −109 dB and a measurement contribution of −110 dB.[8]
- −58 dB THD+N at −60 dBFS (unweighted)
  - This is reasonable for weighted versus unweighted measurements.
- −106 dBV noise floor (117 dB SNR) unweighted
  - Typical difference between unweighted and weighted measurements for flat noise is 3 dB so we are OK here.

The output spectrum was captured (Figure 7) and shows the individual harmonic components are at least 110 dB down. Second harmonic level of −110 dB(r) would be our expected analyzer limit, so we can ignore the even harmonics as a measurement artifact (see Figure 4).

[8] At < 100 dB getting repeatability to 1 dB is reasonable given the unknowns related to cabling, power supplies, etc. Also, for this TechNote the absolute values are not important, it will be the change in measurement in each configuration.

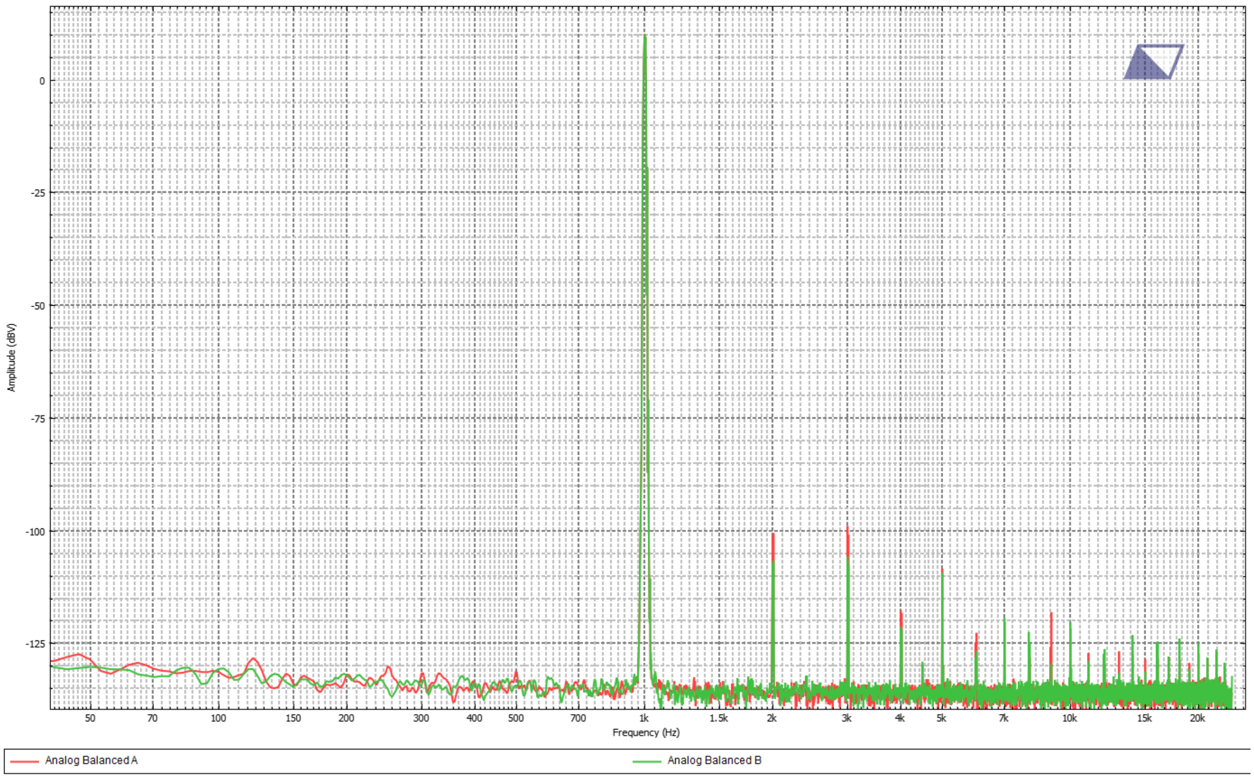

Figure 7 AK4490 EVM 1 kHz −1 dBFS spectrum (32K pt)

4 MEASUREMENTS

Measurement bandwidth is 22 kHz. Sample rate is 48 kHz. Both unweighted and A weighted measurement are made for noise. FFT size is 16 K points for 1 kHz signals and 32 K points for 11 kHz signals. FFT bandwidth is 22 kHz (48 kHz sample rate) unless noted otherwise.

4.1 THD+N

The Clockworks measurements are presented in the next table, Figure 8. The second column is advance data provided by ADI on a DAC that has lower specified performance than the AK4490. The 3rd column is the TIE (Time Interval Error) from the AD2428 datasheet.

The 4th column is the measured value, which includes the THD+N of the measurement instrument (−110 dB). We can subtract that number to get a reasonable approximation of the THD+N due to the AK4490, which is the 5th column.

Node	ADI DAC test (to be published)	ADI AD2428 TIE RMS	AKM AK4490 EVM measurement	Derived AK4490 THD+N value
Direct (no A2B)	-98 dB	-	-106 dB	-109 dB
1st	-98.5	1.57 nsec	-100	-100.5
5th	-97.5	1.79	-98.5	-99
9th	-96.5 (extrapolated)	1.91	-96.5	-96

Figure 8 THD+N for ADI DAC and AKM DAC. 1 kHz −1 dBFS (unweighted)

From the table we see that the AK4490 is susceptible to the relatively large jitter amounts, with an over 8 dB loss in performance at the first node in an A^2B network to a 13 dB loss in performance as the 9th node.

4.2 DR

As measured with −60 dBFS 1 kHz input. Unweighted measurement.[9] The analyzer floor is low enough that it makes only about 0.5 dB difference and so has been ignored.

Node	ADI AD2428 TIE RMS	AKM AK4490 EVM measurement	
Direct (no A2B)	-	-118.5 dB	
1st	1.57 nsec	-118	
5th	1.79	-117.5	
9th	1.91	-117.9	

Figure 9 DR for AKM DAC.

The difference in measurements at the different nodes could be attributed to random measurement uncertainty from a single measurement. If there is degradation with jitter it is very minor.

[9] Many datasheets only provide an A weighted measurement since it's usually about 3 dB better and numbers sell. For very low levels of signal weighting for audibility is not unreasonable, but that requires assumptions about the THD and noise spectra that unweighted measurements don't need.

4.3 SNR

Node	AKM AK4490 EVM (SPDIF in) A weighted	ADI AD2428 TIE RMS	AKM AK4490 EVM measurement	
Direct (no A2B)	-121 dB	-	-117 dB	
1st		1.57 nsec		(test data lost)
5th	-120.4	1.79	-116.8	
9th	-120.4	1.91	-116.9	

Figure 10 SNR for AKM DAC.

SNR seems largely unaffected by the increased jitter, which could be considered an unexpected result as some DAC architectures result in higher in-band noise when the clock it modulated.

For the AK4490 this is good news that the system noise floor won't suffer.

4.4 SPECTRUM

DR, SNR, and THD+N numbers provide a general sense of where issues may be occurring. As a single number they don't provide insight in to the details. For a better understanding the spectrum of the AK4490 EVM output was captured.

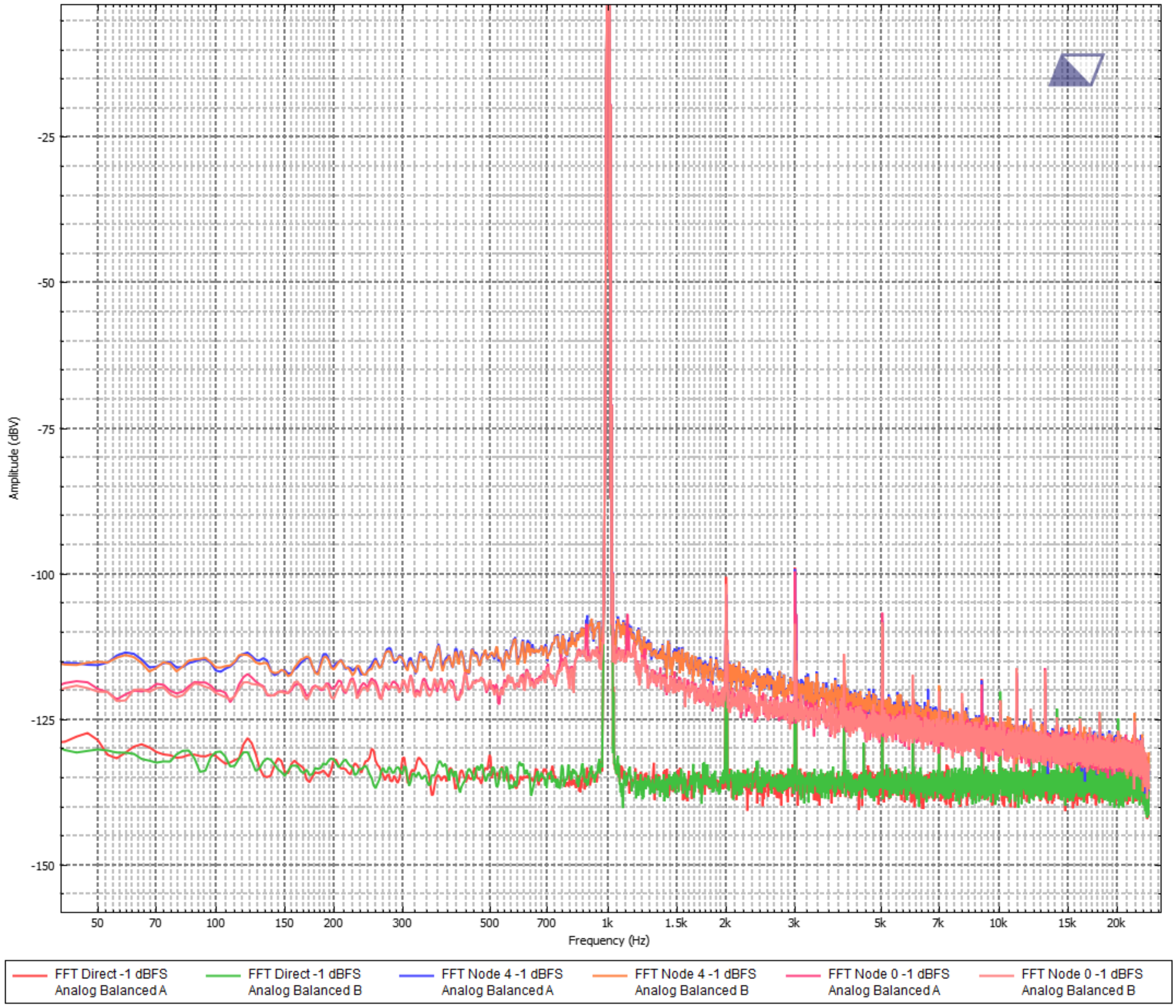

Figure 11 EVM input from SPDIF vs. A^{2}B 1st and 5th node location1 kHz -1 dBFS (32 K pt FFT, 16 avg) (instrument 2nd harmonic is -107 dB)

Figure 11 makes it readily apparent why the AK4490's THD+N suffers in an A^{2}B application. The increase in noise floor is obvious, and we can also note that the additional degradation between the 1st (node 0) and 5th (node 4) locations is not as large as the direct SPDIF input to A^{2}B spectrum(s) comparison.

Figure 12 looks in detail at the 2nd harmonic and we can see that the level of the harmonics appear higher, about 5 dB worse. Though we can't actually tell if that's actually just broadband noise raising them (rising tide lifts all ships type thing) or the spectral components have been modified in a way that the general noise floor hasn't.

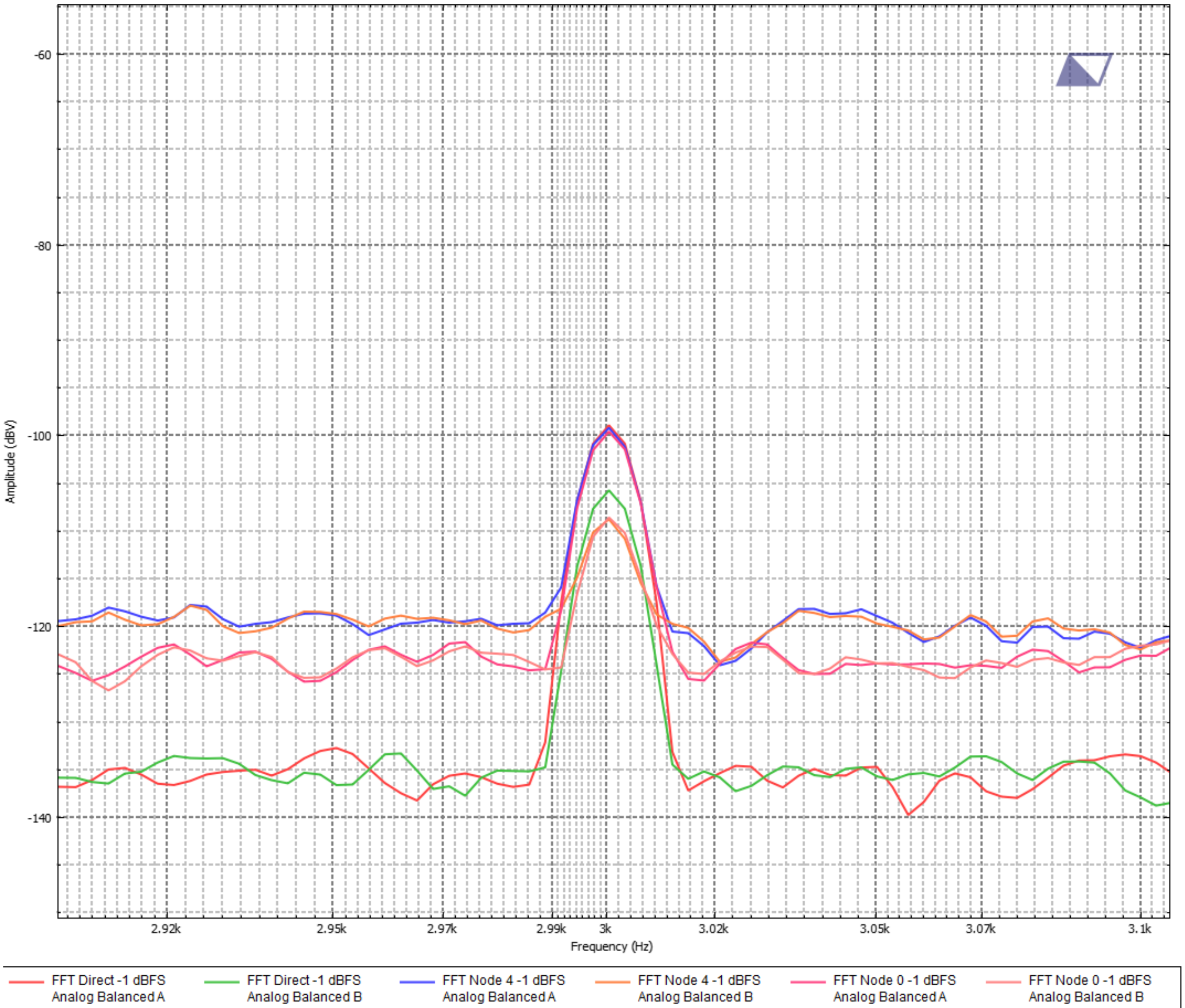

Figure 12 Detail of 3rd harmonic levels (-1 dBFS input).

Regardless we do have a clear indication as to what's causing the degradation in THD+N measurement.

Looking at -60 dBFS (the level used for DR determination) Figure 13 shows the baseline EVM performance from its SPDIF input.

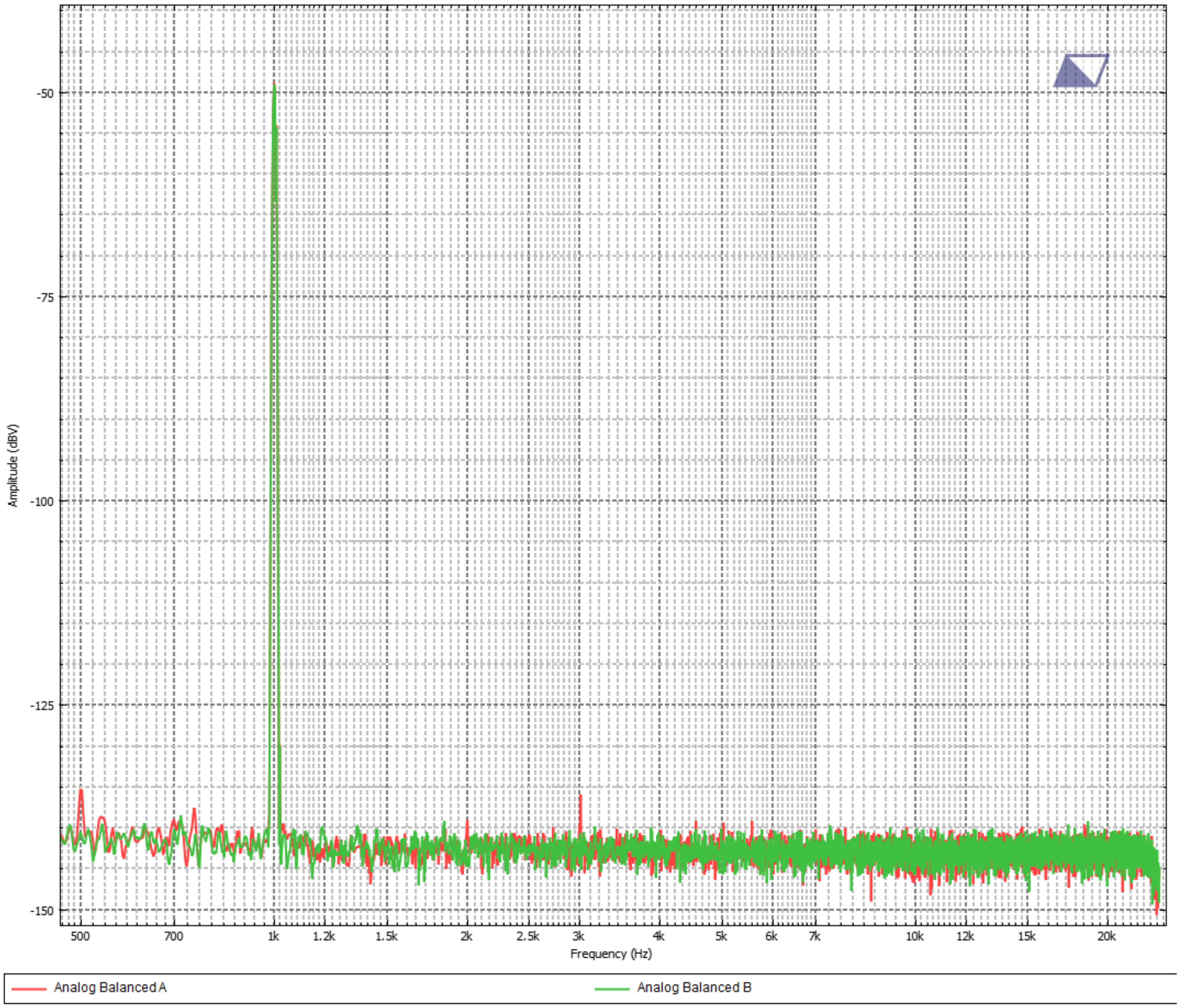

Figure 13 Direct SPDIF input to EVM -60 dBFS shows just a minor 3rd harmonic spike

In Figure 14 there are a number of odd harmonic peaks present. More interesting are the ones that aren't harmonics, which would assumed to be caused by spectral components in the clock jitter. We see the noise floor doesn't change.

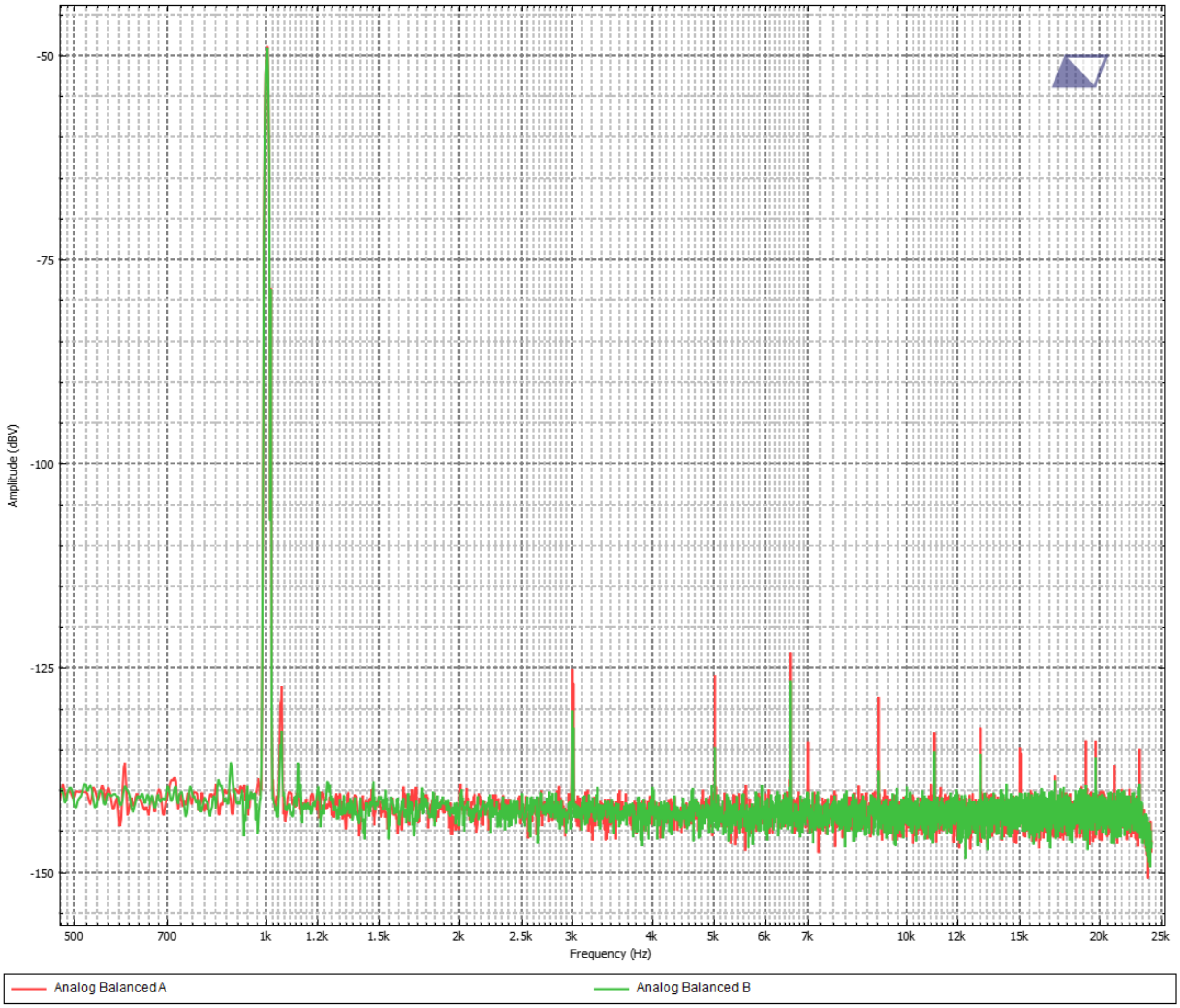

Figure 14 A2B node 4 DAC output with -60 dBFS input

There's a close in component at 1051 Hz, but if that was from jitter modulation at 51 Hz we would expect a mirror of that component on the other side of 1 kHz but one is not present. Instead it must be much higher modulation artifact folded down.

Similar non harmonic tones are at 6560 Hz and 19680 Hz, all of the other peaks are odd order harmonics. Allowing for the frequency mirroring that would occur if the modulation was > 24 kHz doesn't help to establish if the three non-harmonic components are related to a fundamental in the jitter spectrum. For the three components in question a frequency difference of 4320, 17440, and 22950 Hz can be computed, and no obvious common relationship could be found.

A higher frequency signal will more readily expose imperfections, in Figure 15 a 11 kHz test signal was used.

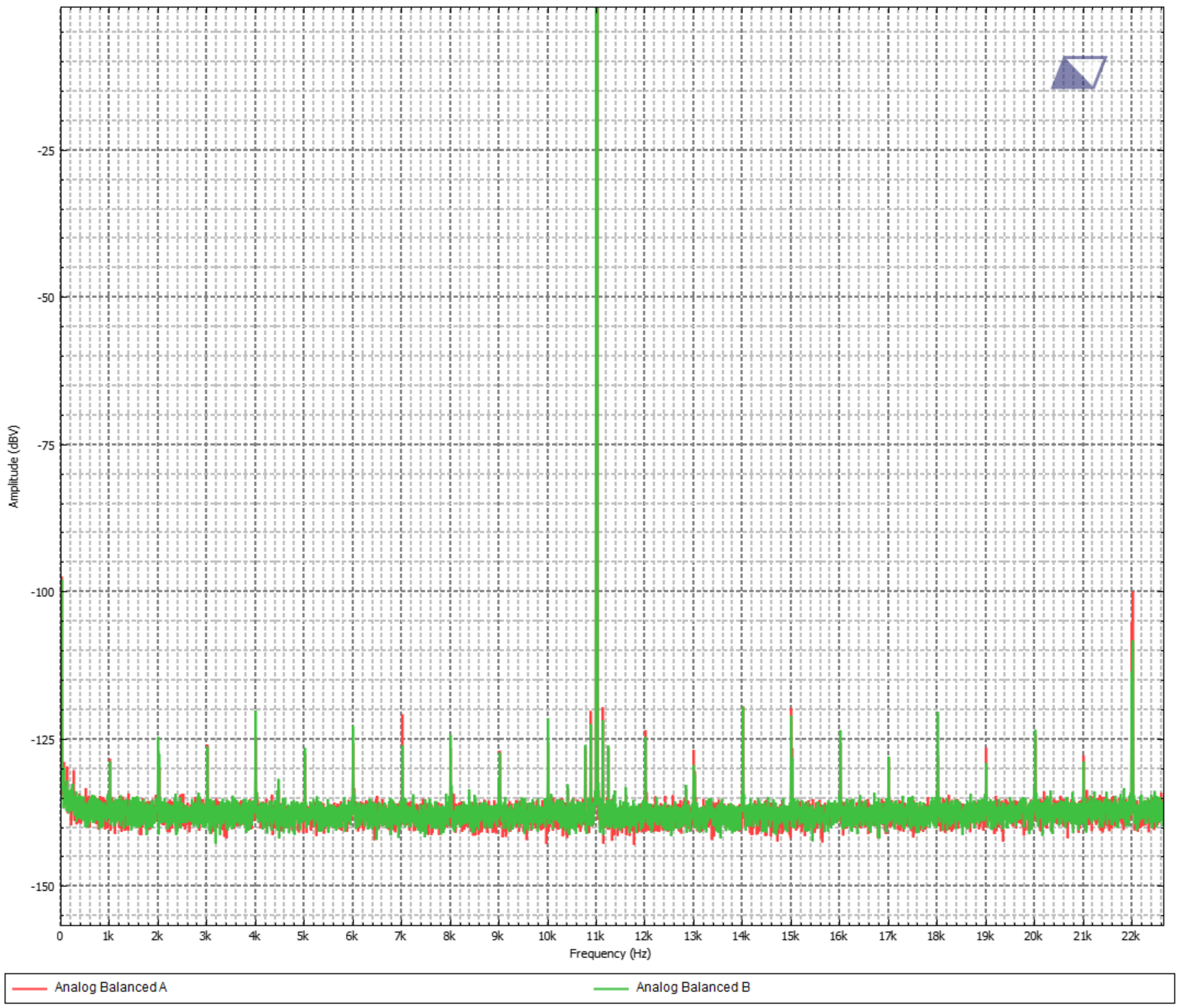

Figure 15 SPDIF input to DAC with -1 dBFS 11 kHz input. Linear frequency axis.

There are a couple things happening in the FFT, though before getting too worried about the small spike compare Figure 15 with Figure 5 and Figure 6 (loop back test) to see that the 1 kHz picket fence is measurement system related. Given the spikes are down around 130 dB or more from the fundamental we can ignore them. The second harmonic is 110 dB down.

What is of interest are the spikes close in to the fundamental in Figure 16.

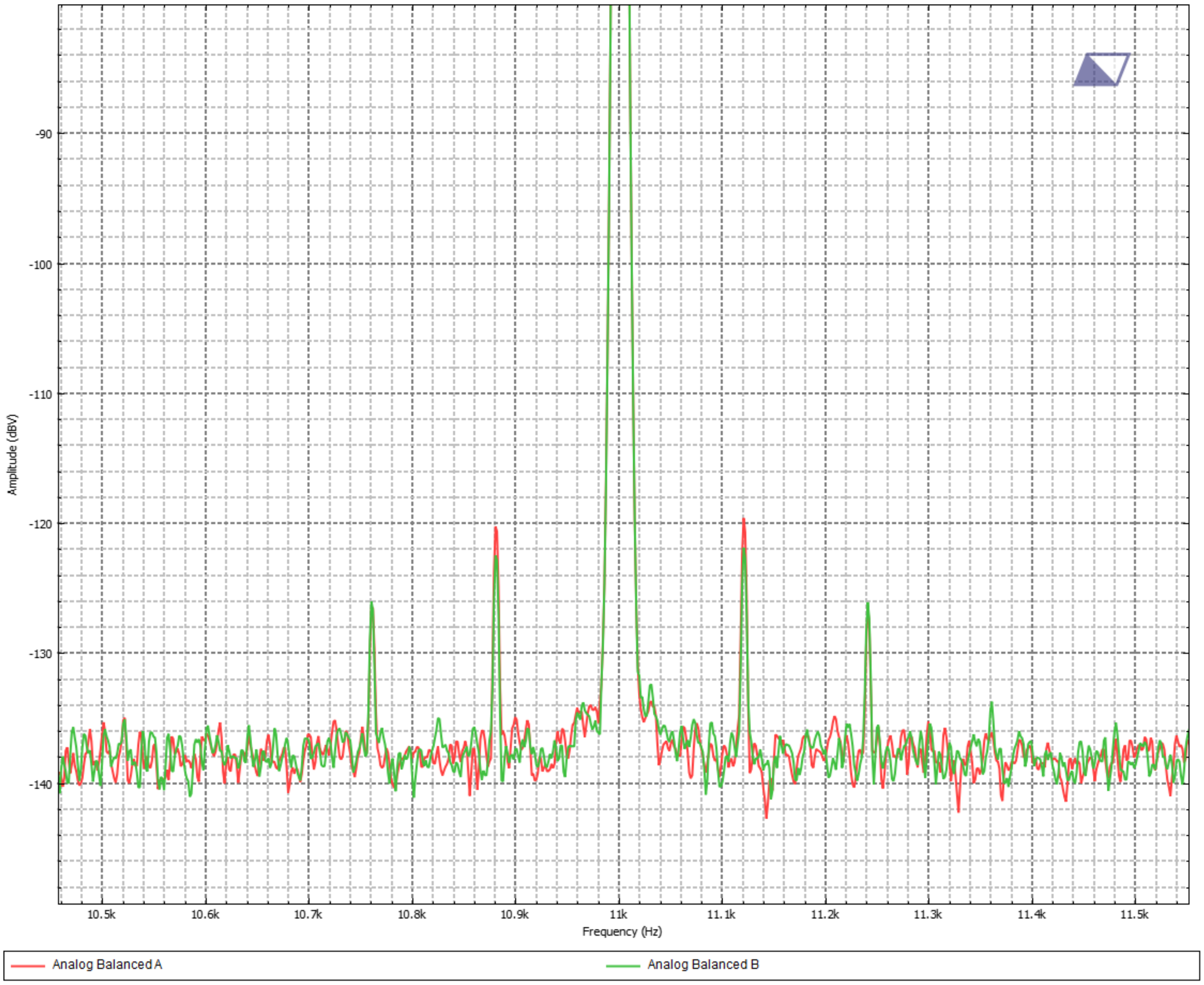

Figure 16 DAC SPDIF input 11 kHz -1 dBFS (10 dBV out) close in (32K pt FFT)

The spikes are +/- 120 Hz and +/- 240 Hz from the fundamental. That would not appear to be an obvious SPDIF related jitter frequency so for now it will be attributed to 60 Hz related noise from the test set up.[10] There are many other things it could be as well. Figure 16 is provided as a representation of what we expect might be the best case DAC performance in this set up (which may be worse than the DAC's actual best case performance). As with the other tones present, they are 130 dB or more down from the fundamental and not of concern.

[10] During some of the tests some low level 120 Hz components was noted in the analog signals based on cable positions.

4.4.1 THE TEST CONCLUSION

Using the higher 11 kHz test tone will more readily expose jitter related problems (see the referenced TechNote008 and AppNote001 documents for more info on why). Figure 11 provided the indication that the AD2428 I²S jitter would create an increased noise floor, and the THD+N tests also showed that too.

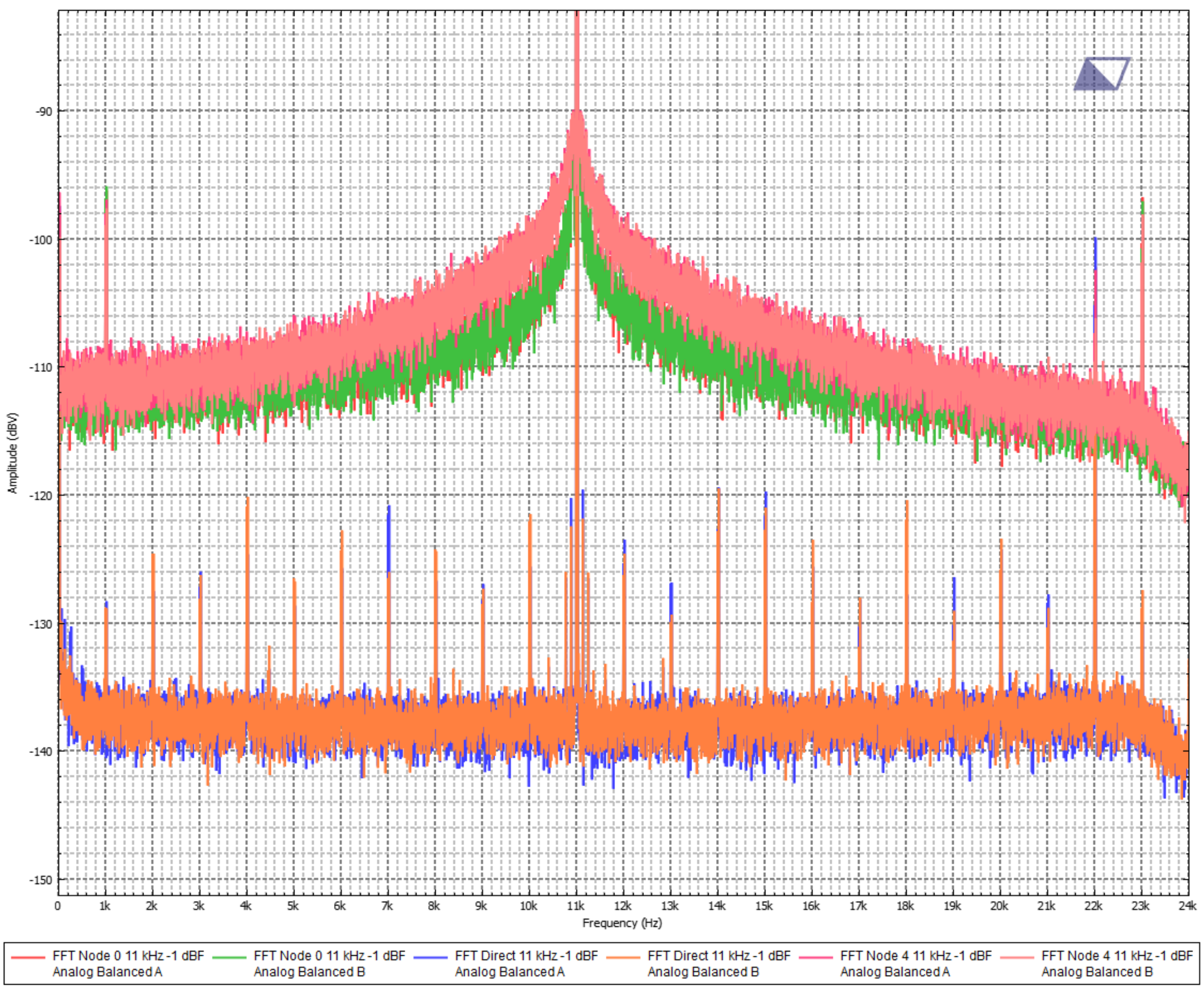

Figure 17 SPDIF, Node 0, and Node 4 spectrum for 11 kHz -1 dBFS (10 dBV out) (32K pt FFT)

Figure 17 shows the degradation in performance by comparing SPDIF, Node 0, and Node 4 DAC output. The spikes at 23 kHz and 1 kHz could be from a strong jitter component or other related multiple(s) of the sample rate and test frequency.

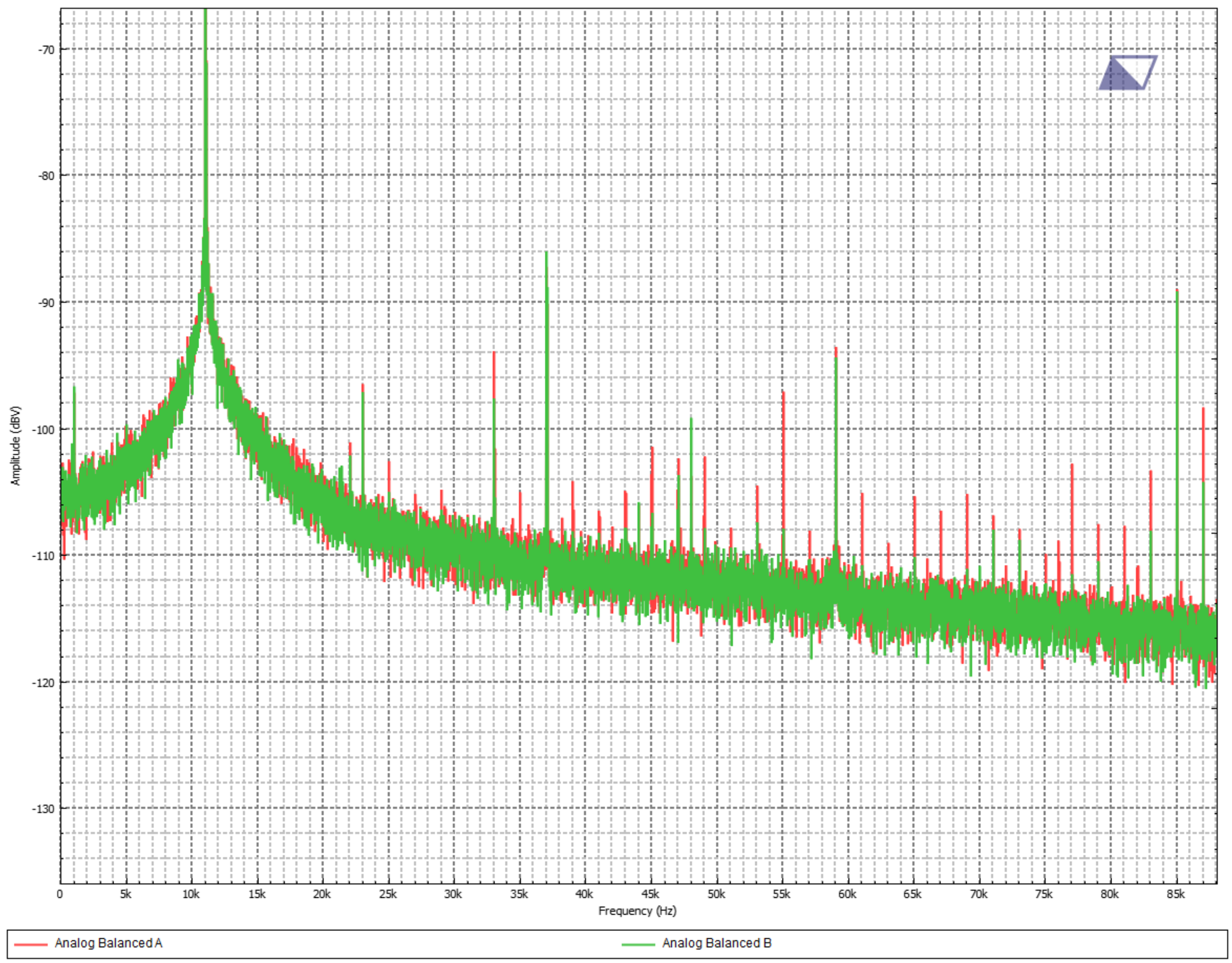

Figure 18 Node 4 11 kHz –1 dBFS output – wide band view (32K pt FFT)

A look at a wider bandwidth in Figure 18 shows a number of higher frequency tones outside of the audio band. A comparison with the SPDIF mode of Figure 19 shows 1 kHz spaced components are at low levels and present in the 11 kHz loopback of Figure 6.

A run was also performed with the AD2428 spread spectrum features turned on but the results of Figure 18 do not noticeably change. Without further analysis it appears the I^2S jitter already exceeds an intentional jittering for EMI reduction.

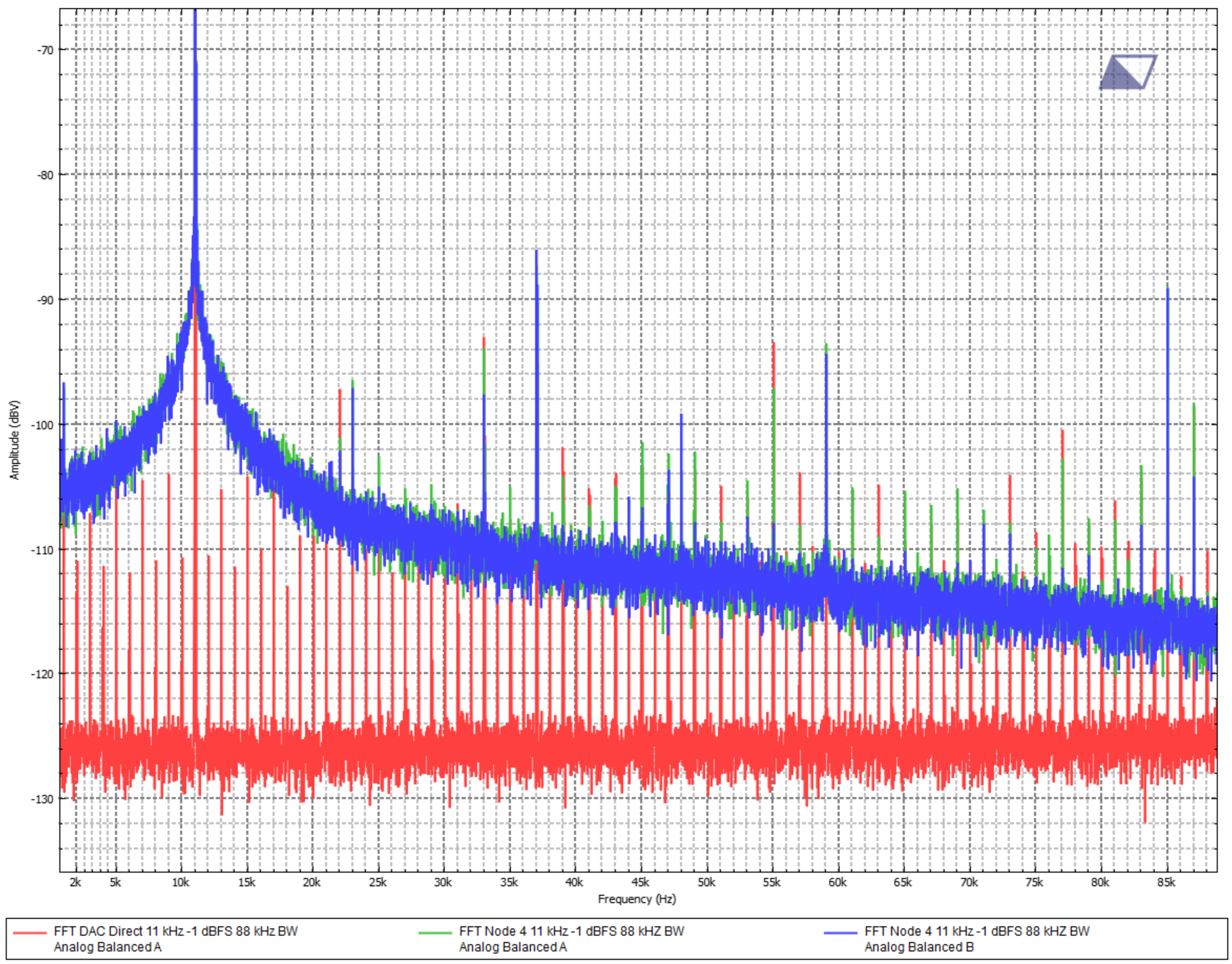

Figure 19 Node 4 results (blue/green) compared to SPDIF results (red, just L channel used for this plot)

In summary we could interpret these results to mean that there's only a small level of tonal jitter and it's mostly random jitter creating the problems.

5 WHAT TO DO?

There are three choices in A^2B system design if the desired DAC (or ADC) performance degradation from the AD2428's I^2S jitter is problematic:

- Add a clock cleanup chip

- Add an ASRC
- Pick a different DAC or ADC

There are pros and cons with all three of these possible solutions and are outside the scope of this TechNote, which is just intended to provide data to design engineers to aid them in system design.

6 SUMMARY

The I^2S outputs of the AD2428 were previously shown to have high jitter relative to typical audio applications. The testing here demonstrates an AKD4490 EVM measured THD+N of -109 dB is reduce to -100 dB to -96 dB when used in an A^2B network application. The cause is seen as an increased noise level and additional testing with a 11 kHz test signal confirms that.

The A^2B jitter does not degrade SNR and DR of the AK4490 which from a practical aspect may be more important than THD+N.

If the application is inside of a product that won't have THD+N directly measured (for example a powered speaker) then the THD+N degradation would be inconsequential. In a piece of audio electronics that may be reviewed with high performance test equipment (e.g. same or better than used here) then the THD+N and FFT spectral analysis degradation may be of concern.