Audio Opamps, fact, no myths and THD measurement results

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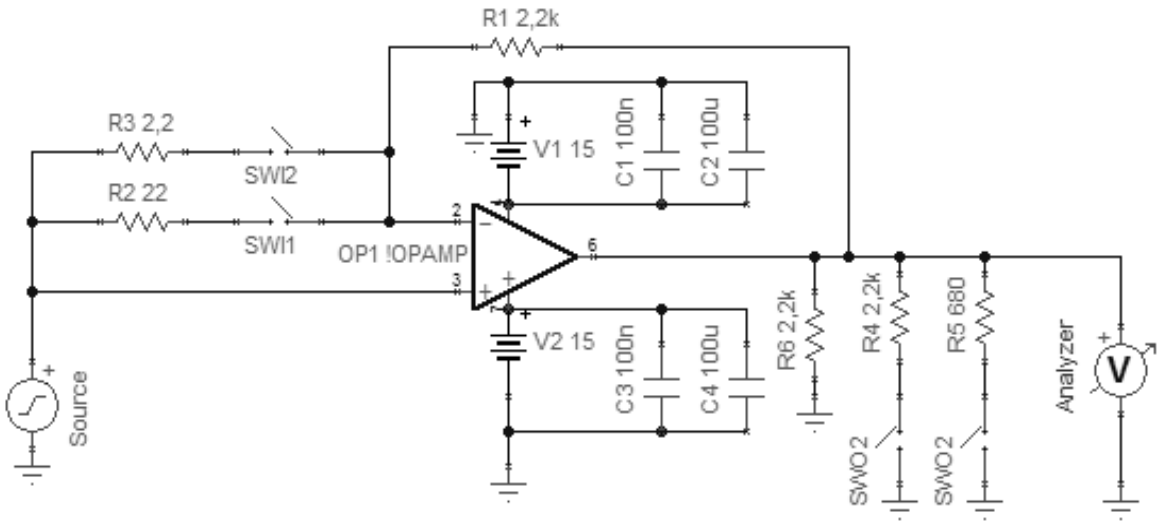
About Audio Opamps, many myths exist about "special" parts. Let's see if the choosen opamp is bargain or fool.....

Test Setup

As it is not easy, if not impossible, to find a measurement system capable of measuring THD well below the -100dB, it must be done in other ways....
National Semi (now TI) and BurrBrown (now TI) mentioned the test setup inside their datasheets to be able to test their own devices. The idea is to only amplify the THD and not the signal itself or better: Steal awy some amount of open loop gain.
In that way, it's possible to use ordinary soundcards to measure THD on the workbench.
The gain used in the datasheets was 101 (= ~ 40dB) and this was not enough when the soundcard itself is not capable of generating and measuring below -70dB THD. So a gain of 1001 (~ 60dB) was choosen and realized with Rf=2k2 and Rg=2R2. The measurements showed, that it was not practical to use no load resistance. Therefore, a minimum load of 2k2 was added.

Please be aware of the problems arising with measurements taken with remaining Open Loop Gain below 0 ! This paper should not replace the manufacturers datasheet nor should it give absolute answers. It's intended to show dependencies not available in the datasheet and measurements hard to find. The reader itself is responsible for his choice and should read a datasheet carefully.

Schematic



For practical reasons and limiting the number of measurements, I decided to only use 3 output voltage levels (1Vrms / 3Vrms / 5Vrms) and 2/3 load resistances (2k2, 1k1=2k2//2k2 and 520R=2k2//680R). Also only different frequencies were used: 1kHz, 2kHz, 5kHz, 6kHz, 10kHz, 15khz and 18kHz. Because of the limited bandwith of 48kHz (96k/2), only the following harmonics could be measured:
5kHz/6kHz: 2nd, 3rd, 4th, 5th, 6th, 7th, (8th)
10kHz: 2nd, 3rd, 4th
15kHz: 2nd, 3rd
18kHz: 2nd

So the 15kHz and 18kHz measurements seem to be worthless, but even with the 2nd harmonic only you can see wether it is a good part or a bad one.....

Tested parts

NE5532A, MC33078, OPA2134/134, OPA2604/604, NJM2068, NJM4580, NJM4558

This parts are of high interest, but unfortunately, no usable THD figure is given from the manufacturers, so this was catched up here.

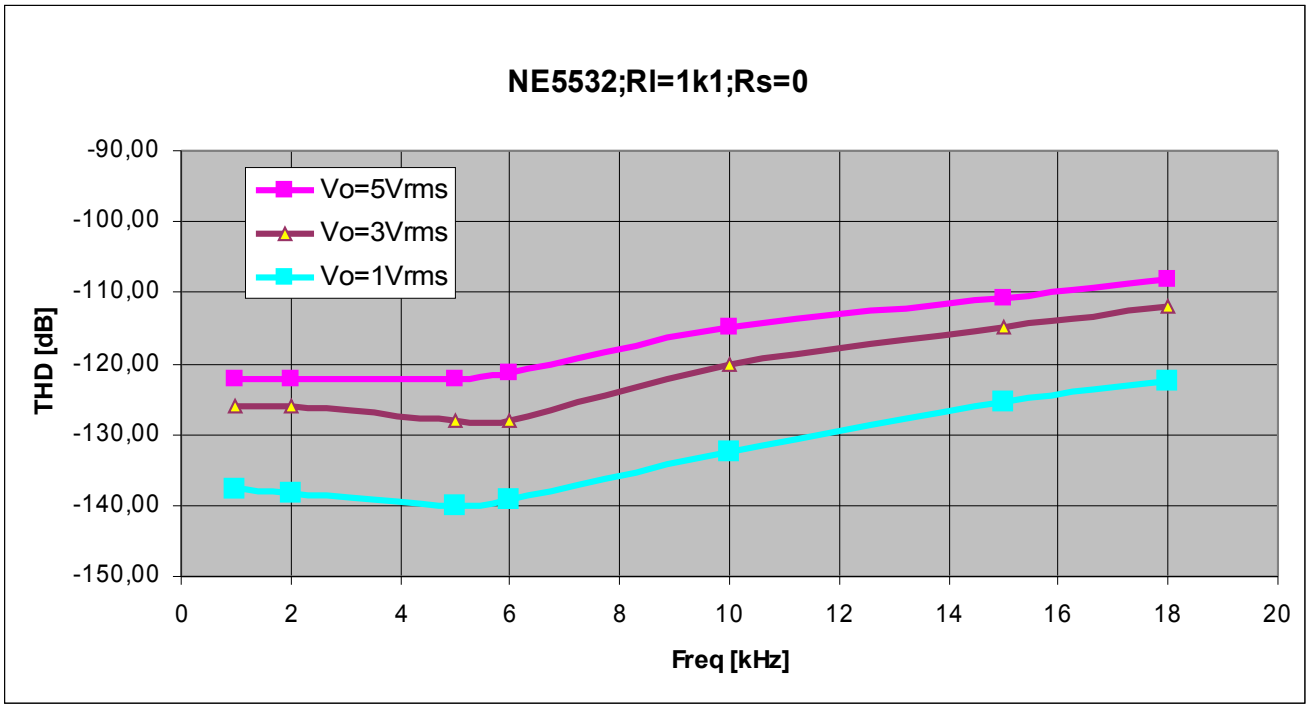
The TL07x, the uA741, and other designs aren't worth spending time into their THD measurements.

Additionally, there are more opamps, esp. from TI/BB/NS, AD, That, OnSemi and others, but for the newest designs, mostly after 2004, THD figures are given in the datasheet, and if not, there's something wrong.

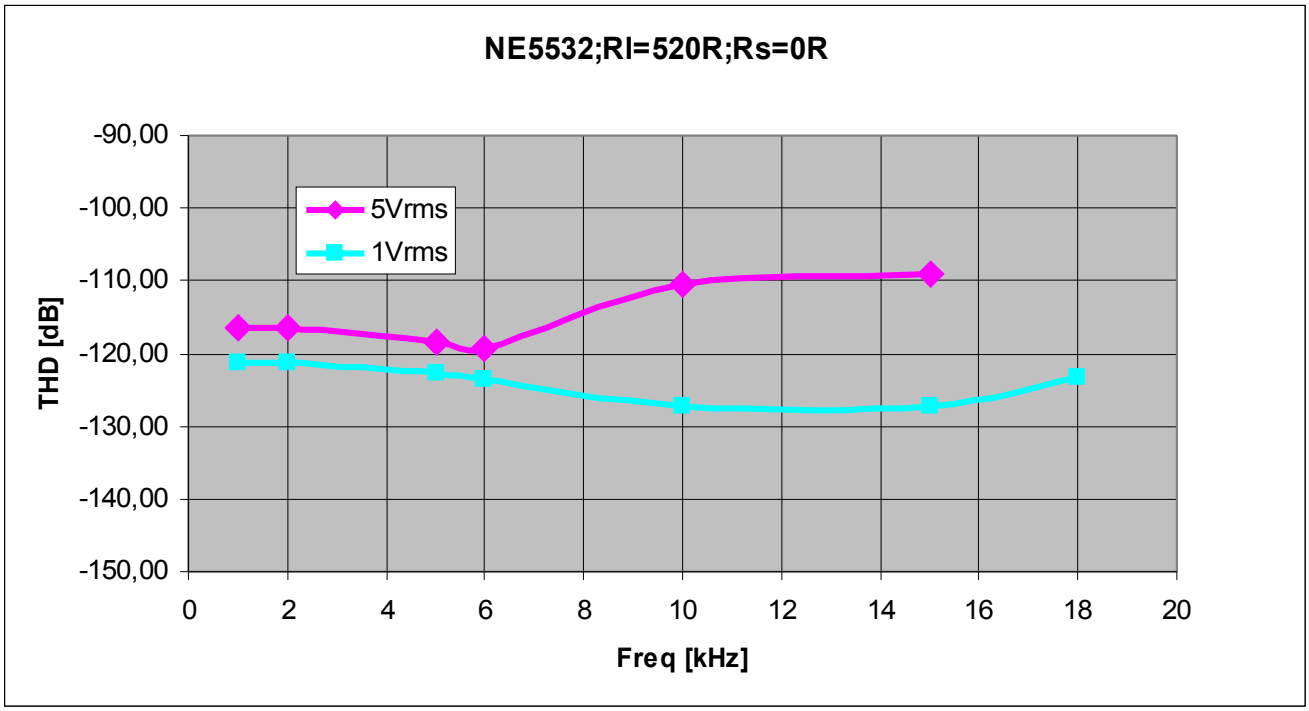
The NE5532A part was in PDIP and manufactured by TI and it seems to be dated back into 2011.

Results

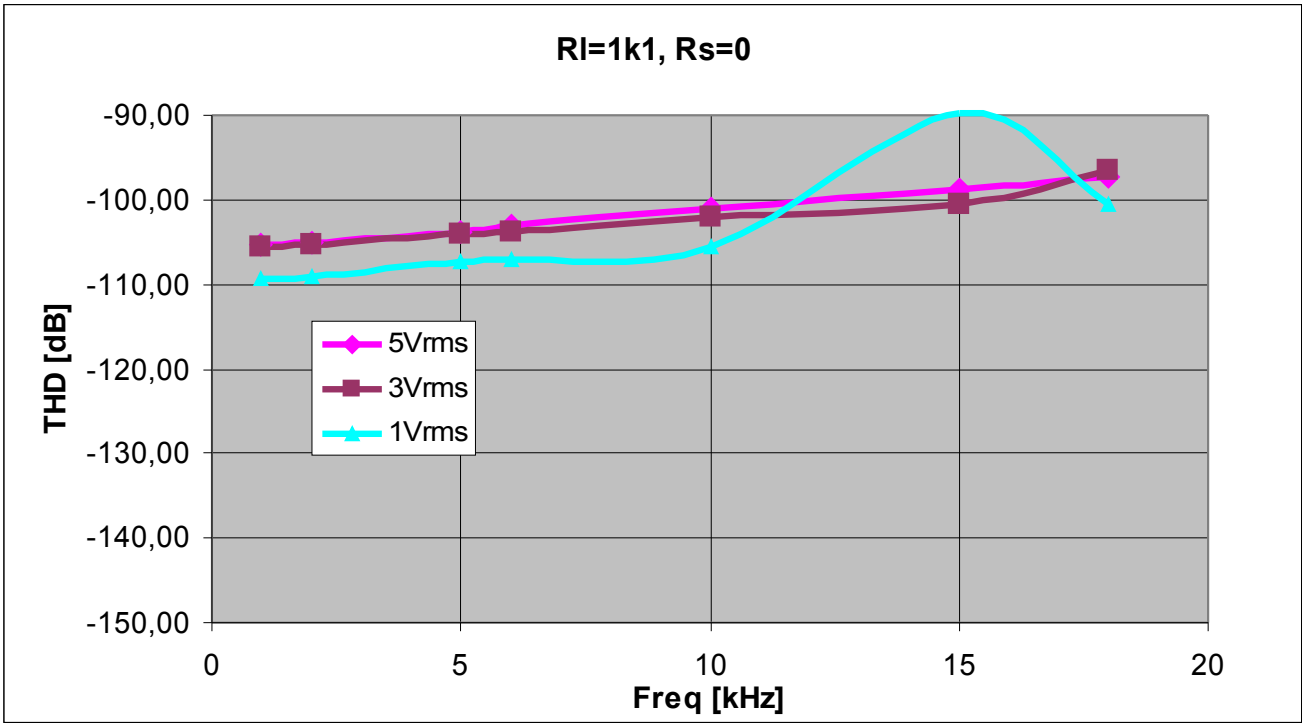
NE5532 with Rl=1k1 and different output levels vs frequency



NE5532 with Rl=520R and different output levels vs frequency

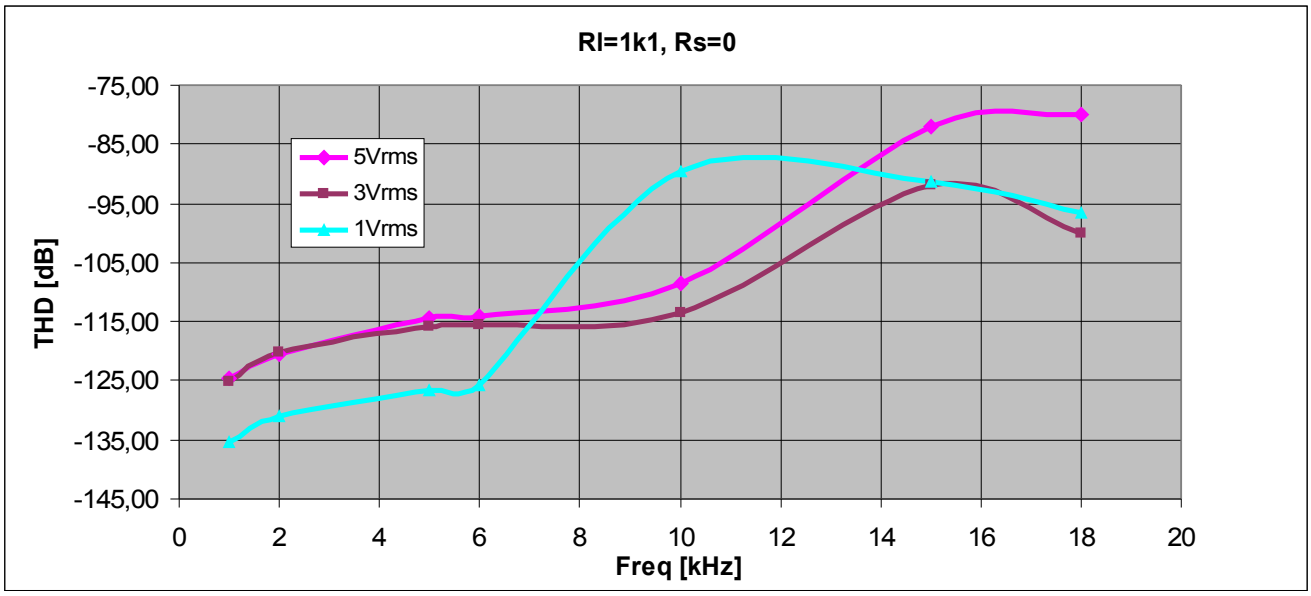


MC33078 with Rl=1k1 and different output levels vs frequency



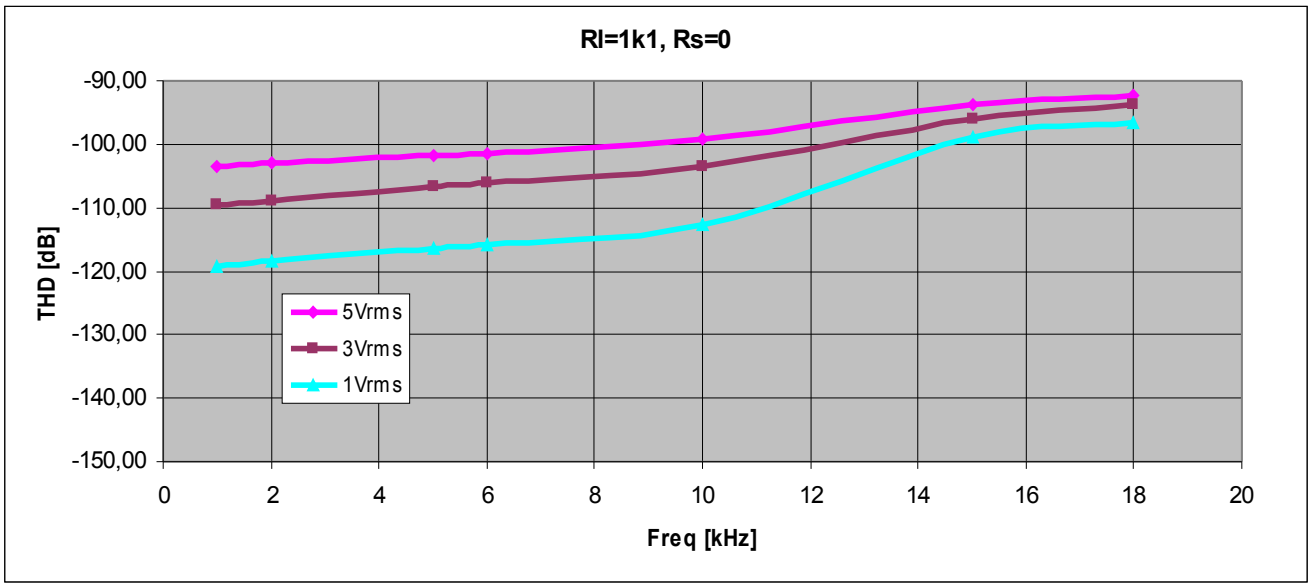
The bad 1V result is related to the fact, that the internal gain is below 0, so there is no more feedback to control the different stages. With higher output current possible internal oscillations would be damped ?

OPA2134 with Rl=1k1 and different output levels vs frequency

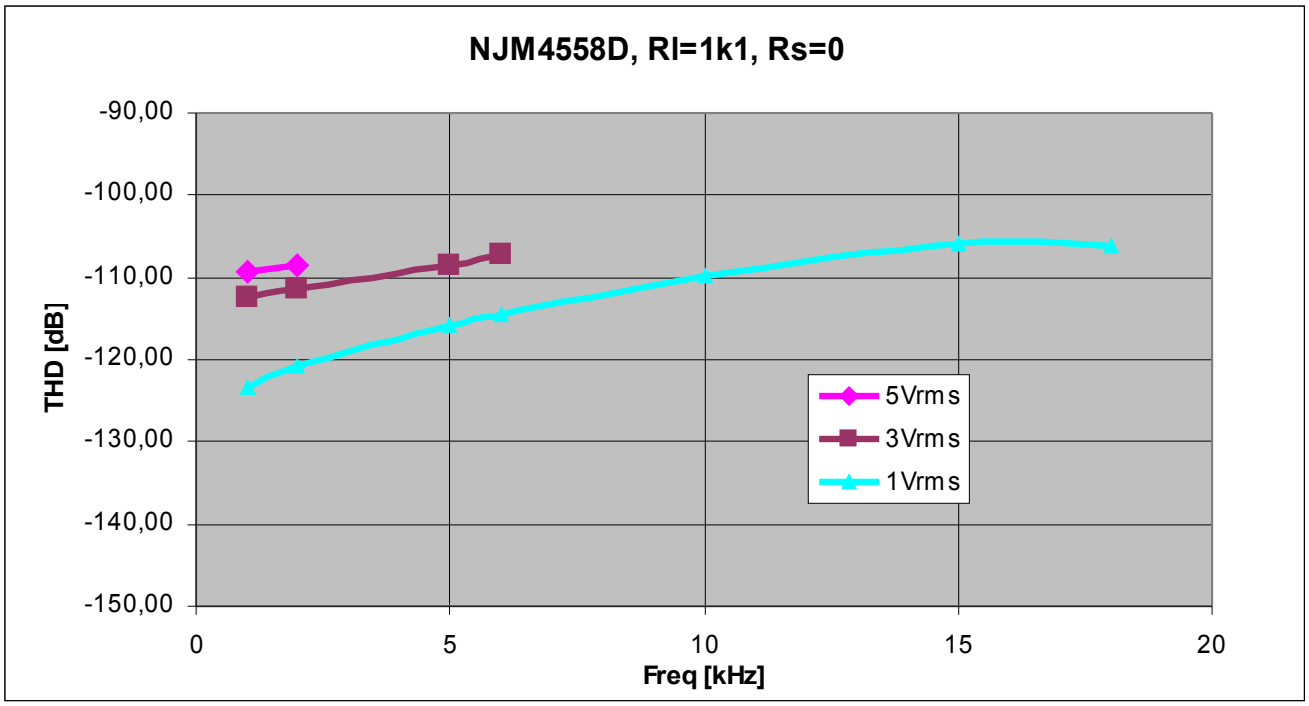


The bad 1V result is related to the fact, that the internal gain is below 0, so there is no more feedback to control the different stages. With higher output current possible internal oscillations would be damped ?

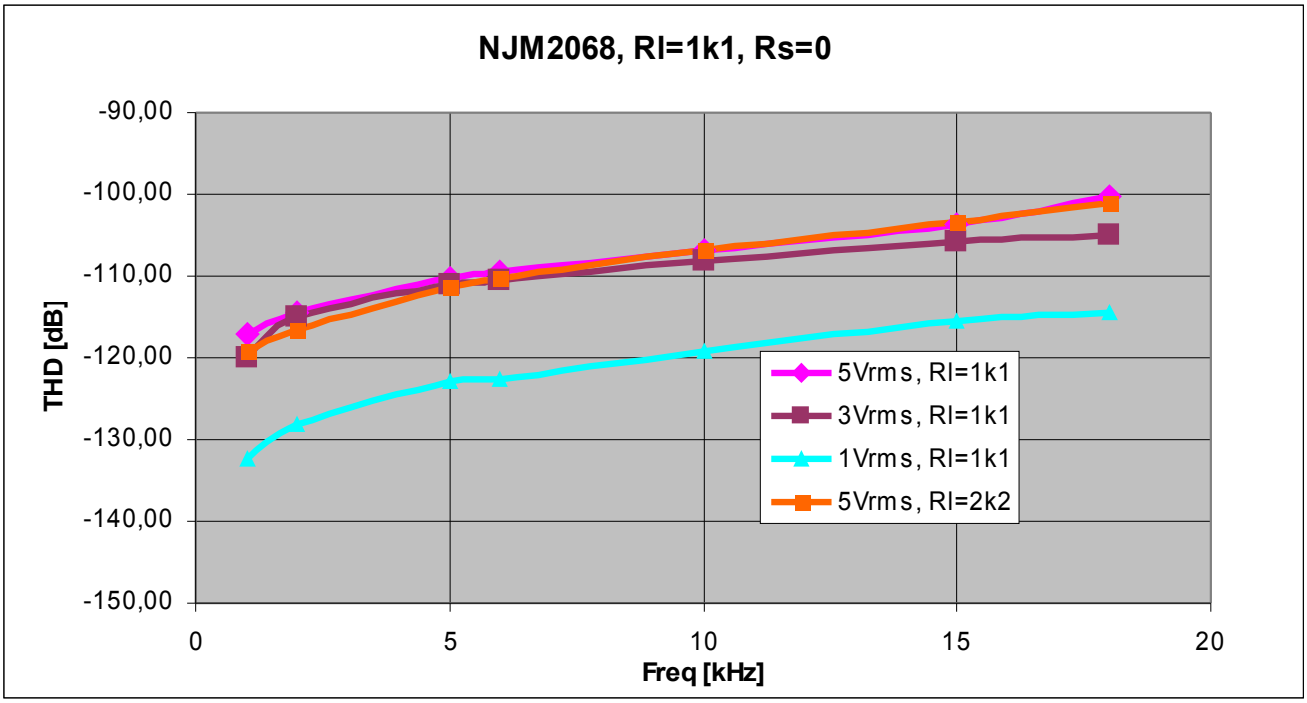
OPA2604 with Rl=1k1 and different output levels vs frequency



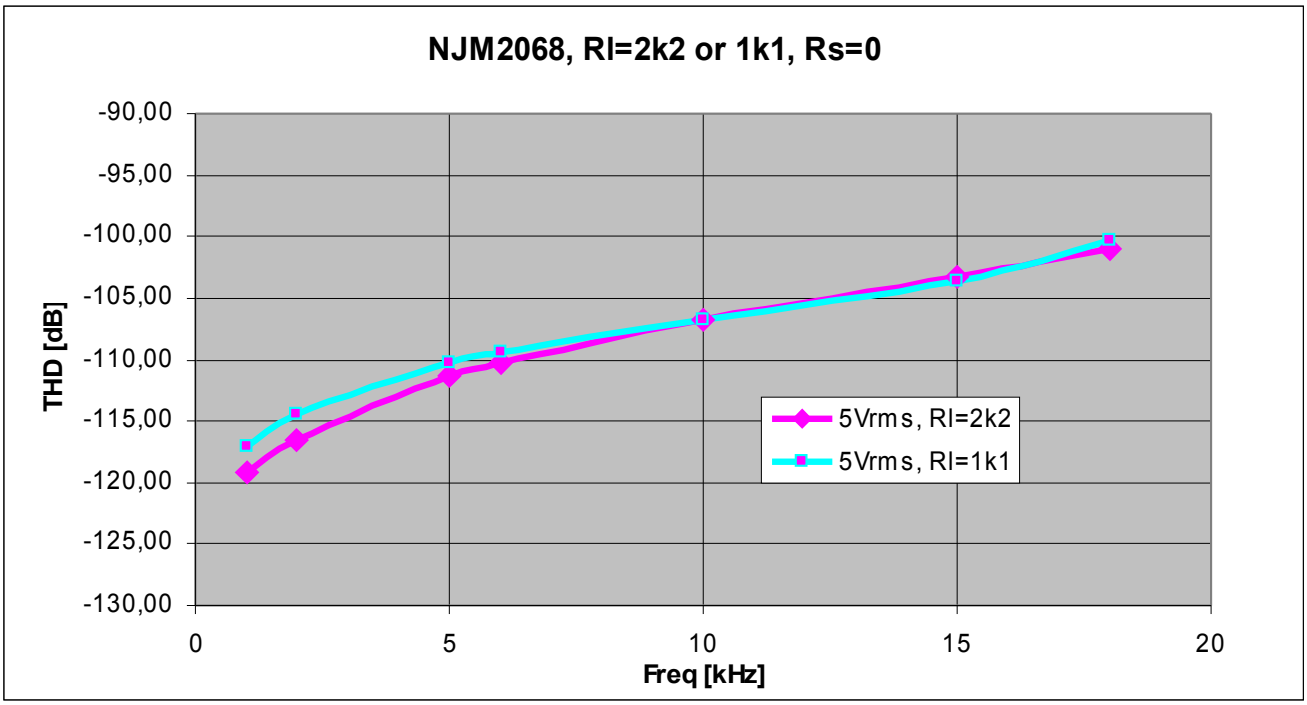
NJM4558 with Rl=1k1 and different output levels vs frequency



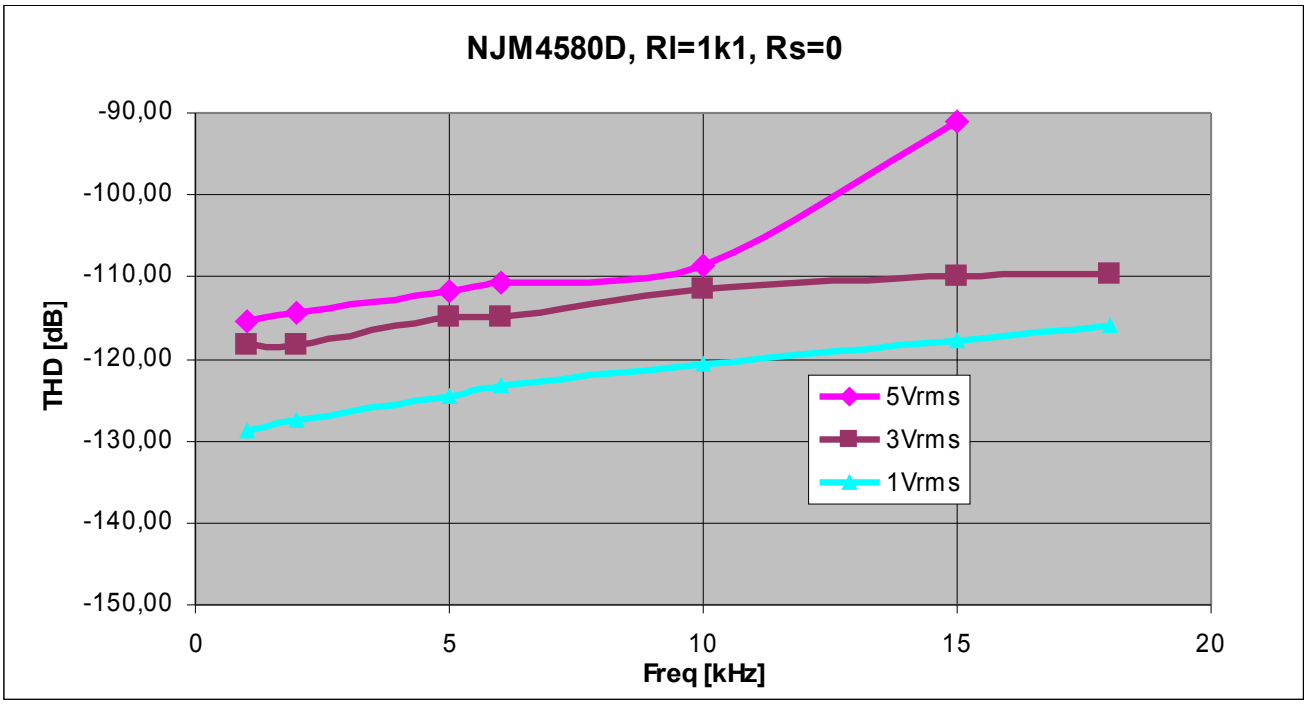
NJM2068 with Rl=1k1 and different output levels vs frequency



NJM2068 with Rl=1k1 and Rl=2k2 at 5Vrms vs frequency

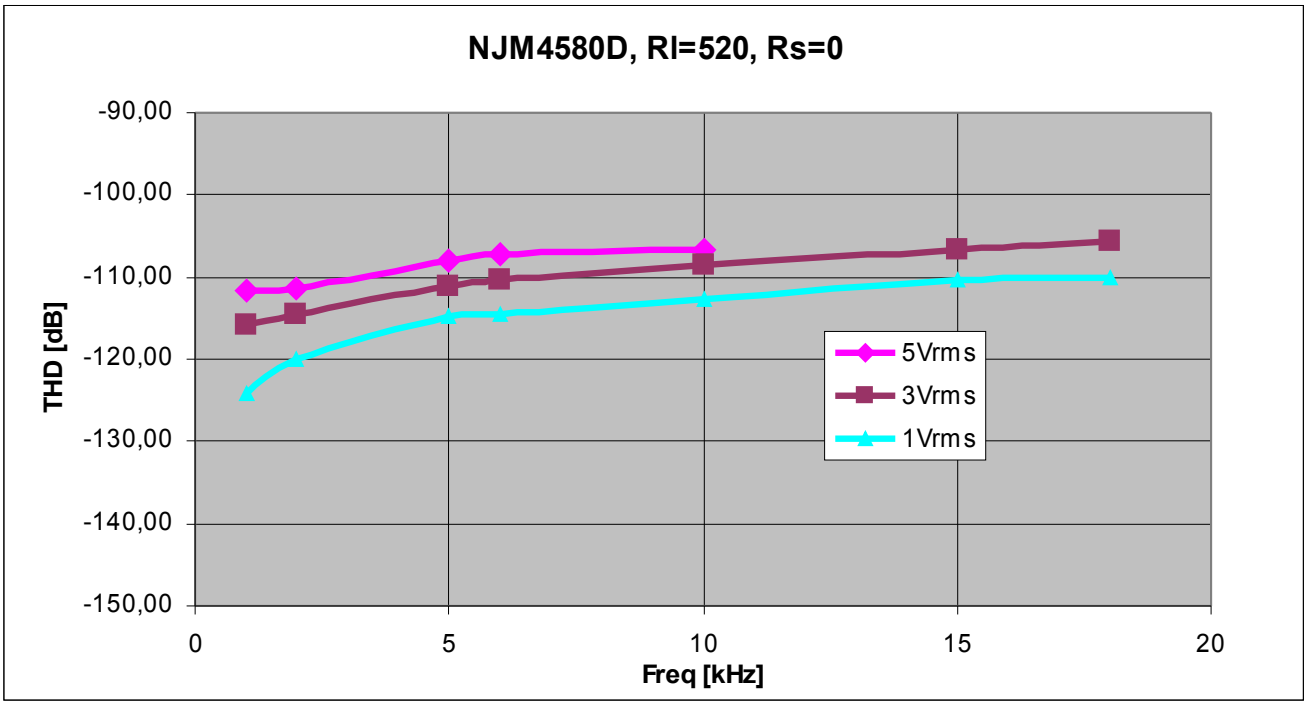


NJM4580D with Rl=1k1 and different output levels vs frequency

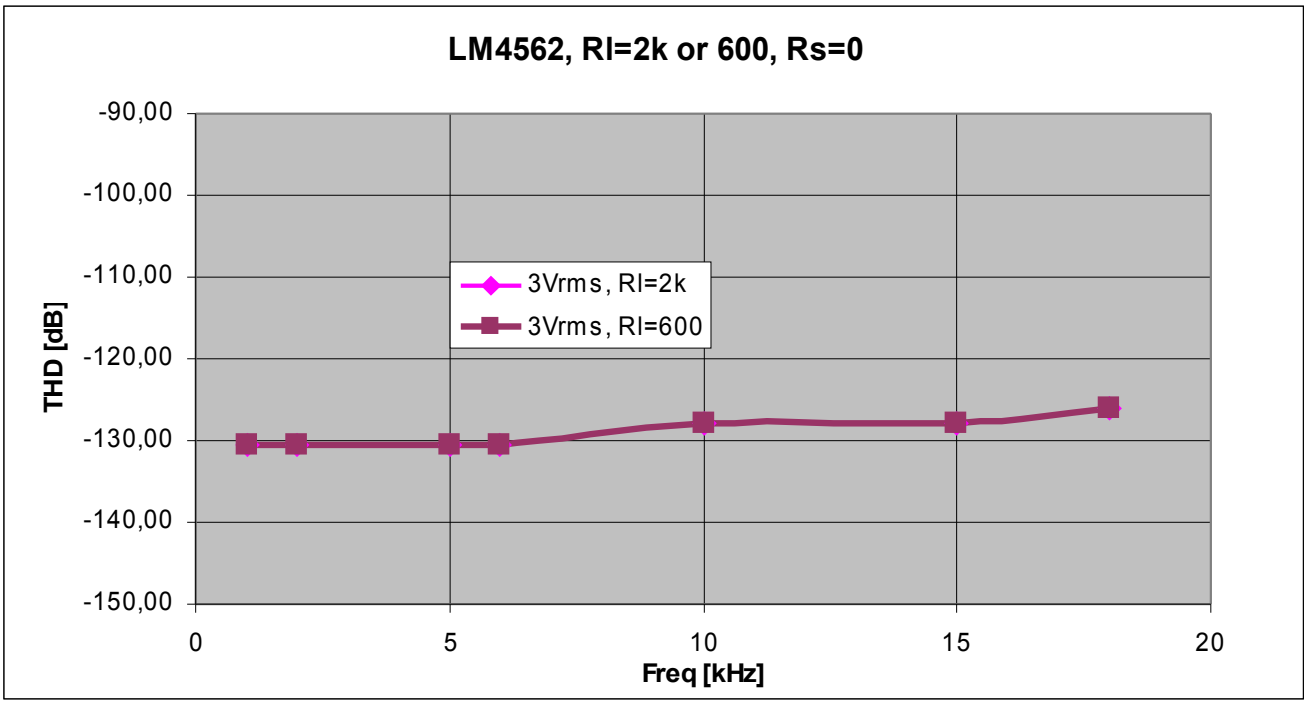


The bad 5V result is related to the fact, that the internal gain is below 0, so there is no more feedback to control the different stages.

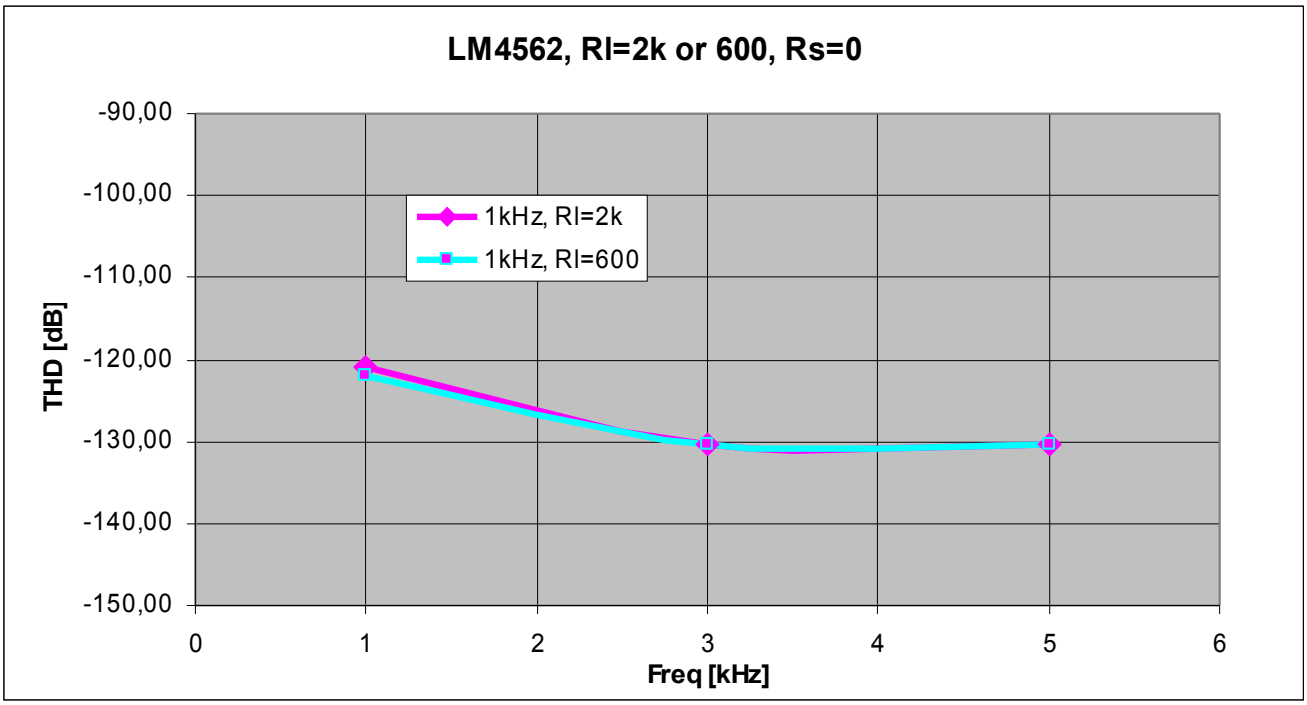
NJM4580D with Rl=520 and different output levels vs frequency



LM4562 with Rl=2k or 600 vs frequency (Datasheet)

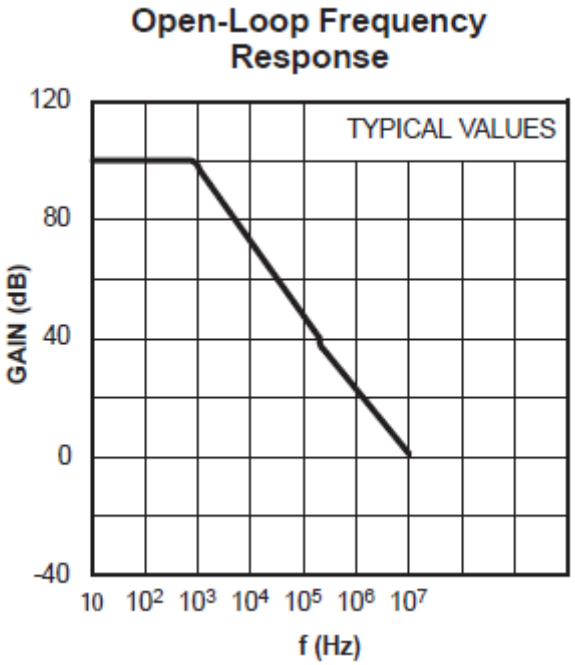


LM4562 with Rl=2k or 600 vs level (Datasheet)



Open Loop Gains

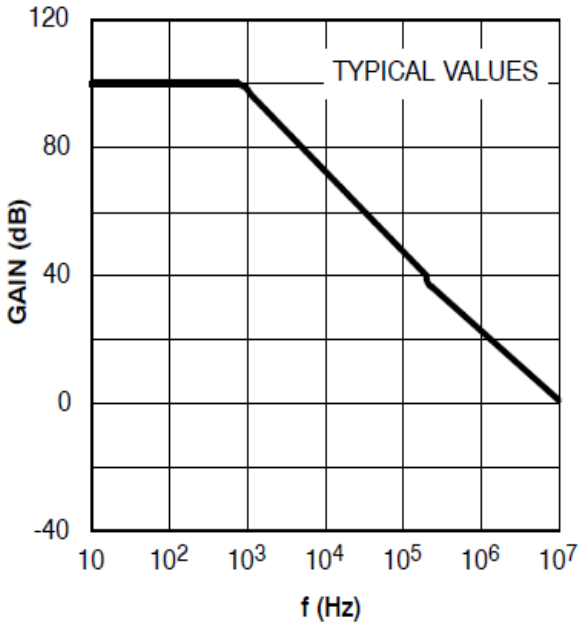
NE5532 datasheet Signetics/Philips Open Loop Gain



max. 100 dB until 1kHz
~ 75dB @ 20kHz

Subtracting 60dB from measurement:
~ 15dB remaining at 20kHz
~ 60dB reamining at 1kHz

NE5532 datasheet OnSemi Open Loop Gain



max. 100 dB until 1kHz
~ 75dB @ 20kHz

Subtracting 60dB from measurement:
~ 15dB remaining at 20kHz
~ 60dB reamining at 1kHz

MC33078 datasheet OnSemi Open Loop Gain

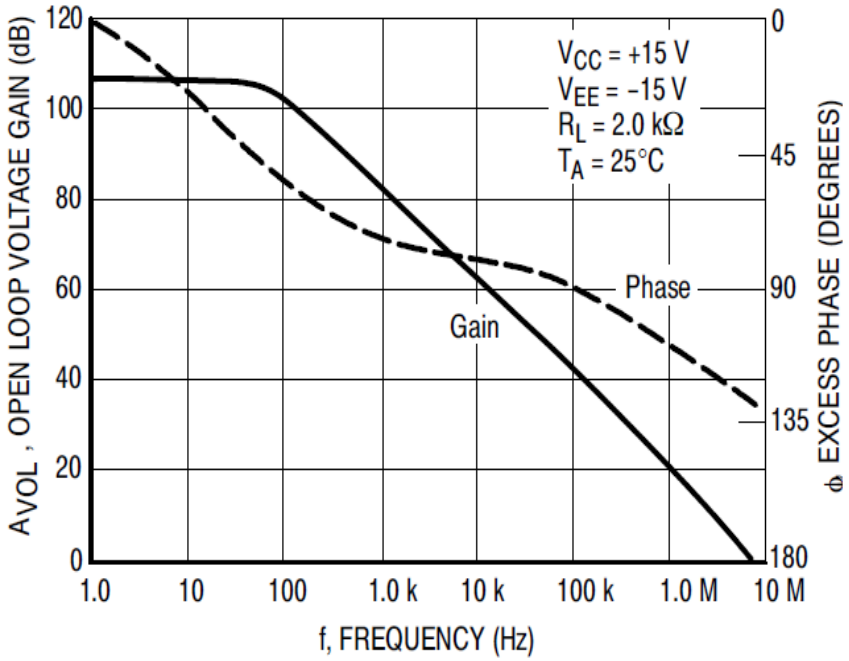
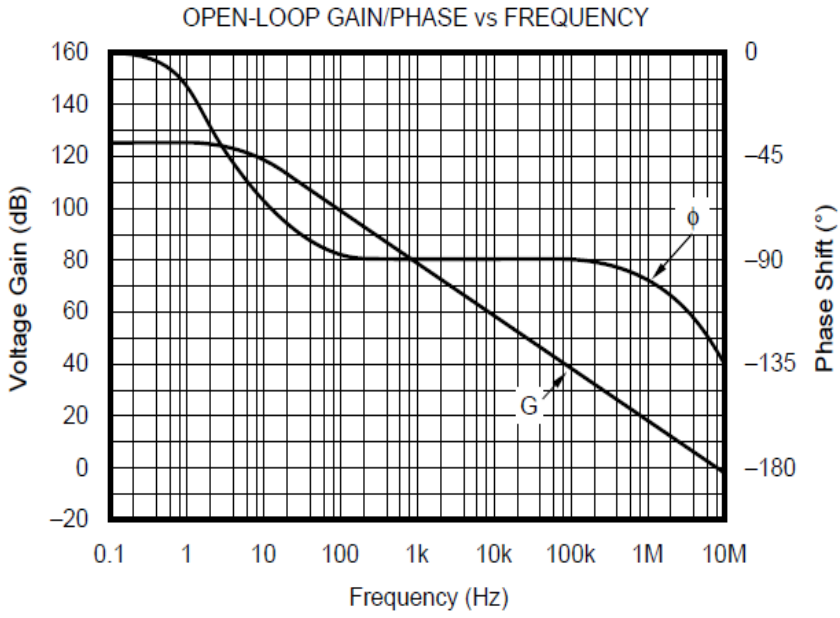


Figure 25. Voltage Gain and Phase versus Frequency

max. 105 dB until 100Hz
~ 55dB @ 20kHz

Subtracting 60dB from measurement:
~ 0 dB remaining at 20kHz
~ 20dB reamining at 1kHz

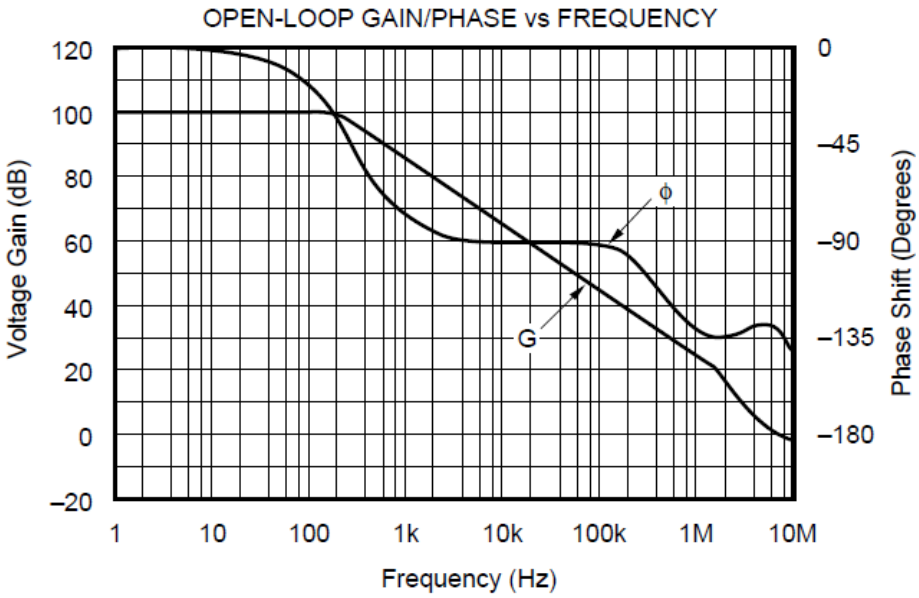
OPA134/2134 datasheet BB/Ti Open Loop Gain



max. 125 dB until 10Hz
~ 50dB @ 20kHz

Subtracting 60dB from measurement:
~ 0dB remaining at 20kHz
~ 20dB reamining at 1kHz

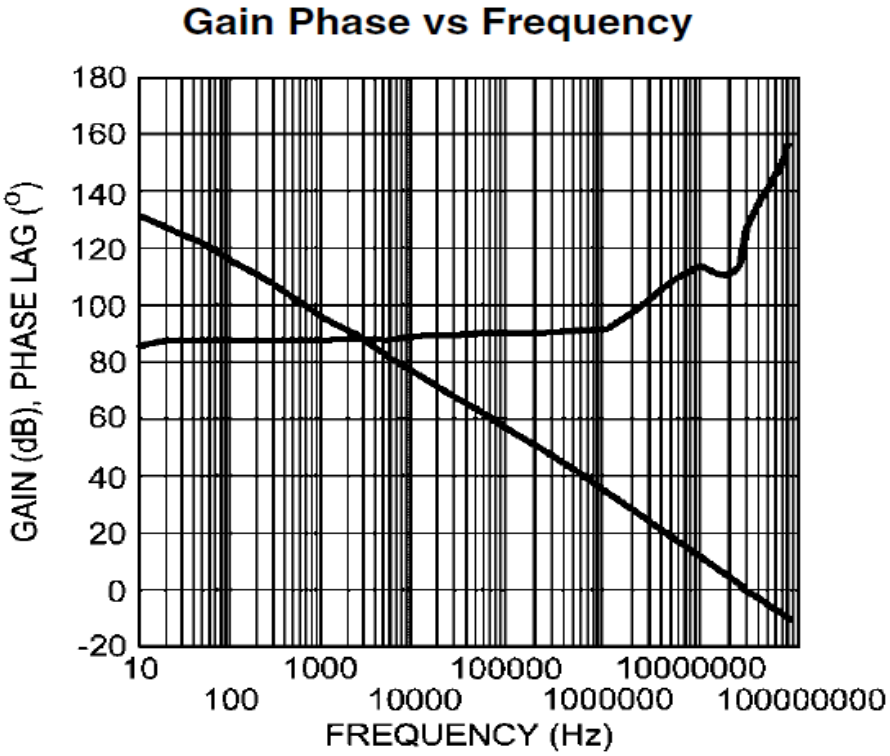
OPA604 datasheet BB/Ti Open Loop Gain



max. 100 dB until 100Hz
~ 60dB @ 20kHz

Subtracting 60dB from measurement:
~ 0 dB remaining at 20kHz
~ 30dB reamining at 1kHz

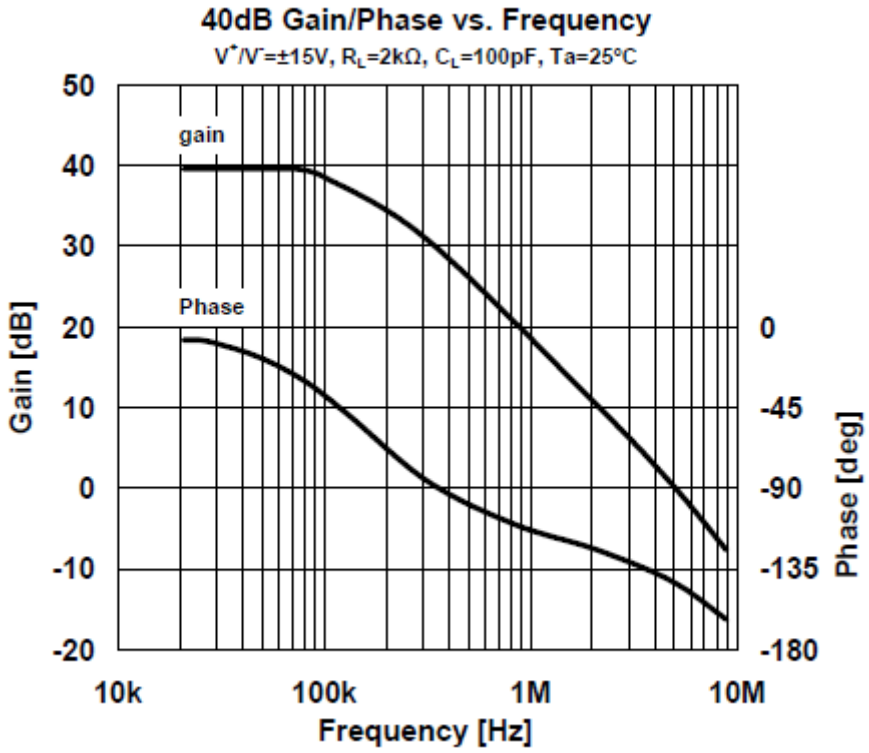
LM4562 datasheet NSC/Ti Open Loop Gain



max. 140 dB until 1Hz
~ 90dB @ 20kHz

Subtracting 60dB from measurement:
~ 30 dB remaining at 20kHz
~ 35 dB reamining at 1kHz

NJM2068 datasheet NJR Open Loop Gain

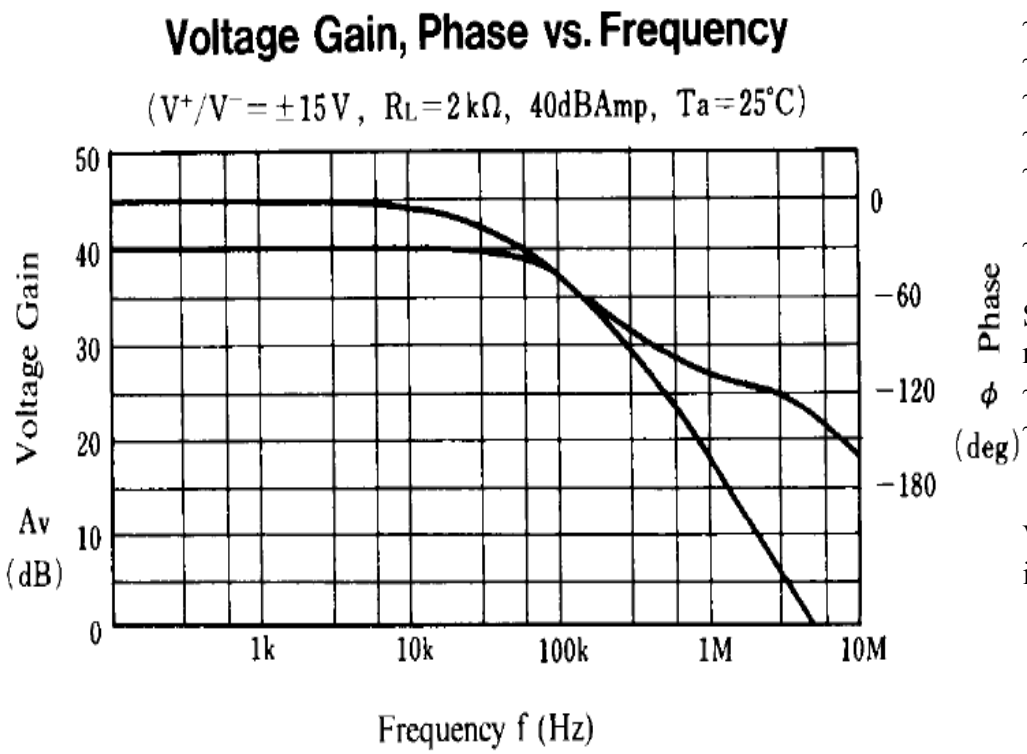


~ 20dB @ 1Mhz
~ 40dB @ 100kHz
~ 60dB @ 10kHz
~ 80dB @ 1kHz
~ 100dB @ 100Hz
~ 120dB @ 10Hz

Subtracting 60dB from measurement:
~ 0 dB remaining at 20kHz
~ 20 dB reamining at 1kHz

Values below 1MHz interpolated !

NJM4580 datasheet NJR Open Loop Gain



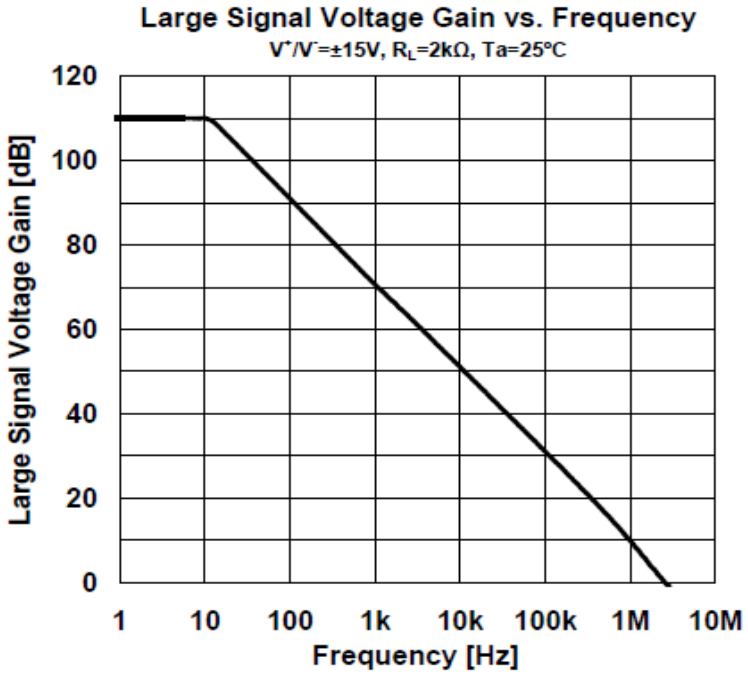
~ 40dB at 100kHz
~ 60dB at 10kHz
~ 80dB at 1kHz
~ 100dB at 100 Hz
~ 110dB at 30 Hz

~ 54dB @ 20kHz

Subtracting 60dB from measurement:
~ 0 dB remaining at 20k
~ 20 dB reamining at 1k

Values below 100kHz interpolated !

NJM4558 datasheet NJR Open Loop Gain



max. 110 dB until 10Hz
~ 50dB @ 20kHz

Subtracting 60dB from measurement:
?
?

Results in contrast to open loop gain

Open Loop gains: (values given readout from diagram !)

Name	OLGain @ 1 Hz	OLGain @ -3dB	OLGain @ 10kHz	OLGain @ 5kHz	OLGain = 0dB	Slope 1	Slope 2
NE5532	100 dB	1 kHz	70 dB	80 dB	10 MHz	24 dB / decade until 100kHz	26 dB/ decade until 10MHz
MC33078	105 dB	100 Hz	60 dB	70 dB	8 MHz	20 dB / decade until 1 MHz	24 dB / decade until 8MHz
OPA2134	125 dB	10 Hz	60 dB	65 dB	10 MHz	20 dB / decade until 10 MHz	na
OPA2604	100 dB	200 Hz	65 dB	72 dB	10 MHz	20 dB / decade until 2 MHz	28 dB / decade until 10 MHz
LM4562	140 dB	1 Hz	80 dB	82 dB	25 MHz	18 dB / decade until 25 MHz	na
NJM2068	120 dB	~ 30 Hz	60 dB	66 dB	5 MHz	18 dB / decade until 1 MHz	26 dB / decade until 5 MHz
NJM4580	110 dB	~ 30 Hz	60 dB	66 dB	15 Mhz	18 dB / decade until 4 MHz	???
NJM4558	110 dB	50 Hz	50 dB	55 dB	4 MHz		

Test Results at 10kHz with moderate load and Vo=5Vrms

Name	Load [Ohms]	Ftest [kHz]	THD [dB]	OLGain at Ftest	Open Loop THD	Pricing
LM4562	2k (3V)	10k	127	~ 80 dB	~ 47 dB (3V)	1,20 € @ 1000
NE5532	1k1	10k	115	~ 70 dB	~ 45 dB	0,35 € @ 1k (A-grade)
NJM4558	1k1 (1V)	10k	110	~ 50 dB	~ 60dB (1V)	0,35 € @ 1000
NJM4580	1k1	10k	109	~ 60 dB	~ 49dB	0,30 € @ 1000
NJM2068	1k1	10k	107	~ 60dB	~ 47dB	0,27 € @ 1000
OPA2134	1k1	10k	107	~ 60dB	~ 47dB	1,50 € @ 1000
MC33078	1k1	10k	102	~ 60dB	~ 42 dB	0,20 € @ 1000
OPA2604	1k1	10k	99	~ 65dB	~ 34dB	2,40 € @ 1000

Test Results at 10kHz with high load and Vo=5Vrms

Name	Load [Ohms]	Ftest [kHz]	THD [dB]	Open Loop Gain at Ftest	Open Loop THD
LM4562	600	10k	127	~ 80 dB	~ 47 dB (3V)
NE5532	520	10k	110	~ 70dB	~ 40 dB
NJM4580	520	10k	108	~ 60dB	~ 48 dB

Test Results at 5kHz with moderate load and Vo=3Vrms

Name	Load [Ohms]	Ftest [kHz]	THD [dB]	OLGain at Ftest	Open Loop THD	Pricing
LM4562	2k	5k	130	~ 82 dB	~ 48 dB	1,20 € @ 1000
NE5532	1k1	5k	127	~ 70 dB	~ 57 dB	0,35 € @ 1k (A-grade)
NJM4558	1k1	5k	108	~ 55 dB	~ 53 dB	0,35 € @ 1000
NJM4580	1k1	5k	115	~ 66 dB	~ 49 dB	0,30 € @ 1000
NJM2068	1k1	5k	110	~ 66dB	~ 44 dB	0,27 € @ 1000
OPA2134	1k1	5k	115	~ 65dB	~ 50 dB	1,50 € @ 1000
MC33078	1k1	5k	104	~ 60dB	~ 44 dB	0,20 € @ 1000
OPA2604	1k1	5k	106	~ 72dB	~ 34 dB	2,40 € @ 1000

Test Results at 5kHz with high load and Vo=3Vrms

Name	Load [Ohms]	Ftest [kHz]	THD [dB]	Open Loop Gain at Ftest	Open Loop THD
LM4562	600	5k	130	~ 82 dB	~ 48 dB
NE5532	520	5k	120	~ 70 dB	~ 50 dB
NJM4580	520	5k	111	~ 66 dB	~ 45 dB

The distortions in closed loop applications are a combination of the open loop distortions divided by the remaining internal gain at a given frequency and the external gain.

As a conclusion, it can be seen, that the top opamps have a good internal design especially with high loads and high frequency wich is additional supported by huge amounts of open loop gain.

THD estimations

It is possible to predict THD for given gains wich will roughly fit in general.

THDest(f)	estimated THD at frequency f and gain g
OL-THD(f)	open loop THD at frequency f and gain g (see above, also includes load)
OL-Gain(f)	open loop gain at frequency f and gain g (see above/datasheet)
g(f)	gain for the circuit at frequency f (can never be < 1 !)

THDest(f) = OL-THD(f) + OL-Gain(f) – g(f)

Conclusions

NE5532A

This opamp is worth using it, because it outstands all other parts in respect to THD (excl. LM4562). Also the noise spec is better (OPA2134) or equal (MC33078) to the others.
The only thing to be mentioned here is, that there is no valid THD curve given in the datasheet (except NJR), so behaviour could change in future. Therefore, the THD parameter should be checked from time to time.

Noise:	~ 4.5nV/sqrt(Hz)	@ 1kHz
Quiscent current:	~ 16mA	
Manufacturers:	Ti, OnSemi, [NJR] (NJM5532), [Rohm](BA15332)	
Pricing:	0,30 € @ 1000 (non-A) , 0,35 € @ 1k (A-grade)	

MC33078

This opamp can be used if you want to save money, need 3 direct replacement manufacturers, want to use a quad version (MC33079), quiscent current is a concern or must use the TSSOP8 package.

Noise:	~ 4.5nV/sqrt(Hz)	@ 1kHz
Quiscent current:	~ 5mA	
Manufacturers:	Ti, OnSemi, ST	
Pricing:	0,20 € @ 1000	

OPA2134/134

This opamp should only be used if a "brand" name is important, you don't know better or the input currents are very important. Be aware of it's noise !

Noise:	~ 8 nV/sqrt(Hz)	@ 1kHz	(this is a FET opamp !)
Manufacturers:	Ti		
Pricing:	1,50 € @ 1000		

OPA2604/604

This opamp should be avoided as audio amplifier device. There could be places where it's usefull, but not in audio amplification. Be aware of it's noise !

Noise:	~ 10 nV/sqrt(Hz)	@ 1kHz	(this is a FET opamp !)
Manufacturers:	Ti		
Pricing:	2,40 € @ 1000		

NJM2068

This opamp can be used, if load resistance is above 2.5kohms and pricing and/or quiscent current matters.

Additionally, this opamp should'nt be overlooked if gains > 10 are required (high open loop gain)

Quiscent current: ~ 8mA
Manufacturers: NJR
Pricing: 0,27 € @ 1000

NJM4580

This opamp can be used, even with load resistances down to 100 ohms and pricing and/or quiscent current matters.

Additionally, this opamp should'nt be overlooked if gains > 10 are required (high open loop gain)

Quiscent current: ~ 9mA
Manufacturers: NJR
Pricing: 0,30 € @ 1000

This device can put out significantly more current than standard. Loads down to 100 ohms are possible, but THD will increase and output voltage is limited, interstingly it's more powerfull by sinking current than sourcing it.

NE/NJM4558

This opamp should be avoided as audio amplifier device. Better devices are available
Quiscent current: ~ 6mA
Manufacturers: NJR
Pricing: 0,35 € @ 1000

LM4562

The king of the test but for "high" cost. Usable if lowest THD at higher gains is necessary or high output voltages into high loads must be driven.

Noise: ~ 2.7 nV/sqrt(Hz) @ 1kHz (max = 4.7 nV)
Quiscent current: ~ 12mA
Manufacturers: Ti
Pricing: 1,20 € @ 1000

It seems, that this is NOT a NE5532 based design with new processes and higher open loop gain.

If the price tag falls, it could replace the NE5532 in near future.

Summary

The NE5532 is doing a good job, even with high loads (600R),high frequencies and high output voltages.
If the last db's THD must be squeezed out, the LM4562 should be the choice.

Also the NJM4580 could be a choice, even for high loads and high frequencies, have a look into it's datasheet for peak output current.

The NJM2068 is worth having a look on it, if looking on the price tag and or quiscent current is a concern. If the price must be even lower, the MC33078 is a good advice.

All other opamps tested here shouldn't be used as audio amplifier.

Revisions:

2016-07-11	initial Release
2016-07-13	Open Loop Gain correction of NJM4580 and NJM2068 "Open Loop THD" correction of NJM4580 and NJM2068