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Analysis of Digital audio D-class Power Amplifiers Characteristics

V. Puidokas, A. J. Marcinkevičius
Vilnius Gediminas Technical University, Computer Engineering Department, Naugarduko str. 41, LT–03227 Vilnius, Lithuania, tel.: +370 67590792, e-mail: Vytenis.Puidokas@el.vgtu.lt, Albinas.Marcinkevicius@el.vgtu.lt

Introduction

There is presented a structure analysis and performance simulation of modified digital interpolation Sigma-Delta digital-to-analog (DAC) Class D amplifier in the [1]. The characteristics family and parameters of experimental analysis of two amplifiers of this class is presented in the work. It is shown that applying created the experiment plan and measurement algorithms can analyze a wide range of such amplifiers characteristics.

Hardware and software

When discussing a measurement, the equipment to be measured refers as the Equipment Under Test (EUT). EUT1: Panasonic AV control receiver SA-XR55. It is 7 channel a Home Theater Receiver with Digital Amplifier [2]. The front channels will be tested. EUT2: Texas Instruments (TI) customer evaluation amplifier module TAS5518-5261K2EVM. It is one of the best from TI PurePath Digital™ family amplifiers [3,4].

EUT1 is driven from optical digital audio input (S/PDIF) 96 kHz 24-bit and loaded FRONT A speakers output. VOL −20 dB (experimentally defined that this is approximately 0 dBFS); SPKR SET: SUBW NO, L_R _ __; FRONT SPEAKERS: LARGE; other is factory default settings.

EUT2 is driven from optical digital audio input (S/PDIF) 96 kHz 24-bit on TI Input-USB board. Output stage supply voltage: 49,8 V; System supply voltage: 15 V. Modulation index limit register (0x16): 0x04 (set to 96,1%); Master volume register (0xD9): 00 00 00 48 (set to 0 dB).

These above settings are used for all tests, unless otherwise specified.

Two analyzers were used: Cleverscope Oscilloscope CS328A-XSE (further it will refer as AN-1) and Analog Device EVAL-AD7760EB (AN-2). Latter consist of ADC AD7760 evaluation board and Blackfin board ADDS-BF537 EZ-KIT Lite with USB mezzanine board.

VOLT/mA Calibrator Mastech MS7221, LCR meters Escort ELC-3133A and Mastech MS5300, True-RMS multimeters Mastech MS8218 and MS8226T, multimeter ELV Elektronik VC88C, analog multimeter Protek 7004, function generator GW Instek SFG-2110, several dummy loads and series of filters. There were same problems with filters made from cheap components from Lemona and Evita stores. For example, Twin-T 997 Hz notch filter has only a 32 dB rejection (capacitors Q≈60). However it was not the worst: maximum rejection frequency highly depended on temperature (in direct ratio) and signal level (in inverse ratio). The signal level depended lesser on high temperatures, for ex., 997 ± 100 Hz@0,1÷10V_{P-P}@75°C. The use of high quality of metal film resistors and silvered mice capacitors (Q≈360), the stable frequency (<±0,1 Hz) notch filter with >50 dB rejection was obtained. However, the filter price increased by eight times.

Bench top linear power supplies: HQ-Power PS3020, Matrix MPS-3005L-3, Mastech HY3005-2 and Mastech HY1803D. The power supplies of analyzers were changed to analog ones with good galvanic isolation from mains, which minimize possibility of ground loops formation, and cause lesser high frequency noise. The improvement especially was noticed in AN-2.

Not including analyzers own software, the NI LabView was intensively used. It was written three VI's: first, – signal generation VI, with level and frequency sweep and possibility add dither to signal; second, – signal analysis VI, with noise and distortion analysis; third, – conversion VI, which helps convert results from binary format to MS Excel spreadsheet with possibility reduce amount of data. OriginLab Origin was used to plot the data. Spectrum Software MicroCap was used for filters simulation.

Original 1 kHz vs 997 Hz

If frequencies are used which are submultiples of the sample rate, the waveform will exercise only a few codes of the digital word. For example, generating 1 kHz in a 192 kHz sample rate system will require only 192 different data values. This may leave large portions of a converter untested. If frequencies are used which are prime to the sample rate then eventually every code in the data word will be used. Using 997 Hz instead of 1 kHz will result in all codes of a digital system being exercised.

Output amplitude & Gain

The maximum undistorted output amplitude of the EUT1 (according AES17 [4]) is obtained at 997 Hz before introducing 1% THD+N (because it is earlier than 0,3 dB compression), when input signal in digital domain is at full scale: 0 dBFS = 28,3 dBV = 26 V. This notwithstanding can not be reached by the volume control, because the volume control in this case should be −19,9 dB. The volume control step is 1 dB nevertheless. The real level is –0,1 dBFS at VOL = –20 dB, but it will be accepted as 0 dBFS.

The gain normally quoted as the analog output level resulting from a digital input level of 0 dB FS. Thus, Gain = 28,3 dB(V/FS) @ VOL = −20 dB (equal for both channels). However volume control could be could be variable from −79 dB to 0 dB in approximately 1 dB step. Consequently, Gain = −30,7 ÷48,3 dB(V/FS).

EUT2: 0 dBFS = 30,1 dBV = 32 V, therefore Gain = 30,1 dB(V/FS) @ MasterVolume = 0 dB. Volume control could be could be variable from −127 dB to 18 dB in approximately 0,25 dB step. Consequently, Gain = −96,9 ÷48,1 dB(V/FS).

Output-level stability

The gain of a converter may drift due to instability in the reference voltage or the value of other components. This variation can be monitored over time to determine the gain stability. The output level stability test defined in AES17 is a measurement of the variation in the DAC output level with a –6 dBFS input, over a period of at least an hour, in the first given a brief warm-up.

Since EUT1 have not reached equilibrium during one hour, the measurements were prolonged till 6 hours (Fig. 1). It reach balanced state after 3 hours. This phenomena is not in EUT2, but unlike EUT1, the EUT2 operating in open-air conditions (without chassis). Moreover, in case of EUT1 testing, it is actually class D amplifier plus its power supply testing. The better channel matching is in EUT2.

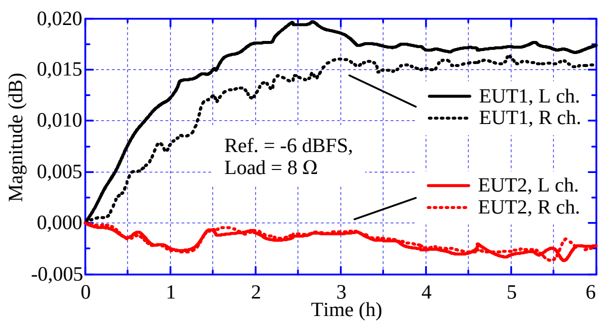

Fig. 1. Output level stability of EUT1 and EUT2

Most level of instability of EUT2 is due to bench top power supply instability. This unfortunately is malady of all Class D amplifiers without negative feedback.

The behavior of EUT's is contrary: the level of EUT1 is tend to rise, when the level of EUT2 is tend to drop. However, deviations output level of both EUT's from the starting point are negligible. The parameter is mentioned neither [2] nor [3].

Level-dependent logarithmic gain

It is a change in logarithmic gain of the EUT with signal level, frequently called deviation from (perfect) level linearity. The method is very useful for examining the steady-state (static) characteristics of converter. If a straight line is fitted to a presumed-linear section of the data and then every data point of the complete set is subtracted from this straight line, the result will be a graph of deviation from perfect linearity. There could be seen small deviations from linearity in excellent detail.

Level dependent logarithmic gain of EUT1 and EUT2 (in the same scale) is shown in Fig. 2. The gain of EUT1 is more or less linear (±0,5 dB) down to −95 dBFS, while gain of EUT2 is linear only down to −70 dBFS. However there is perfect channels matching in EUT2.

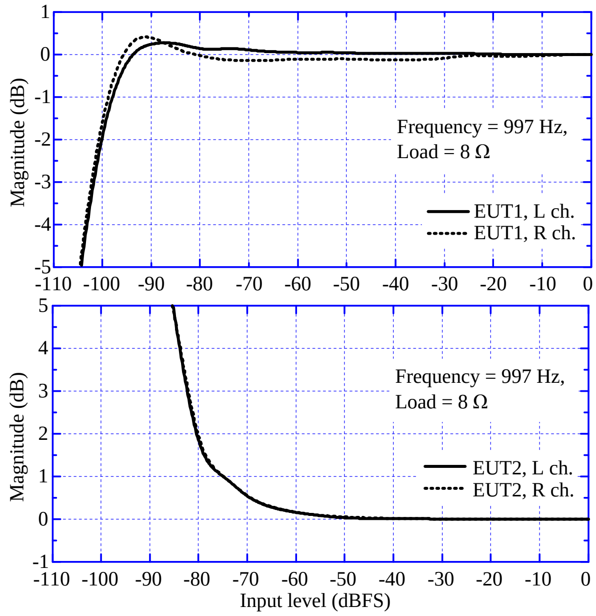

Fig. 2. Level dependent logarithmic gain of EUT1 and EUT2

There is also need to note, what is not obvious from graphs, the EUT1 have residual level of −(70÷71) dBV, from −100 dBFS an below. The behavior of EUT2 is contrary: there is no output signal below −90 dBFS.

Frequency response

According AES17, frequency response shall be measured at −20 dBFS. The response should be expressed as a graph in decibels relative to the amplitude at 997 Hz. If a graph is not provided, the specification shall indicate the worst-case variation in amplitude over a specified frequency range. Rough frequency response of EUT1 at 6 Ω load (specifications in [2] are written at this load and power near clipping point) is shown in Fig. 3. The specifications are satisfied (nevertheless line "Power bandwidth −3 dB, in specifications should be ±3 dB, however in another graph it is written correctly: ±3 dB). The situation is worse for the most popular, 8 Ω load. However it is unlikely, that one would use high level signals at frequency above 20 kHz.

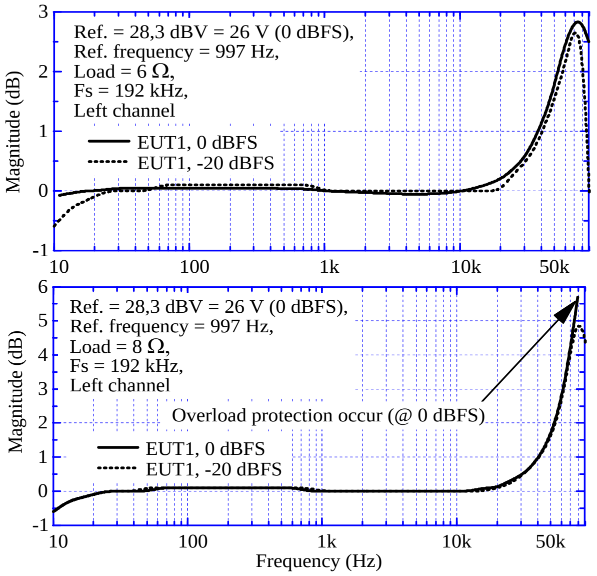

Fig. 3. Rough frequency response of EUT1 at 8 Ω load

Precise frequency response (in 20 Hz ÷ 20 kHz range) of EUT's (in the same scale) are shown in Fig. 4. If one compare it with Fig. 10 from [3], it is difficult to say, how close the characteristics is, since the later figure is not correctly scaled. Nevertheless, it satisfy specification, written in Table 4 from [3]: +1/−0,5 dB at 125 W / 8 Ω, unclipped (0 dBFS). For Truth, it is marginally better.

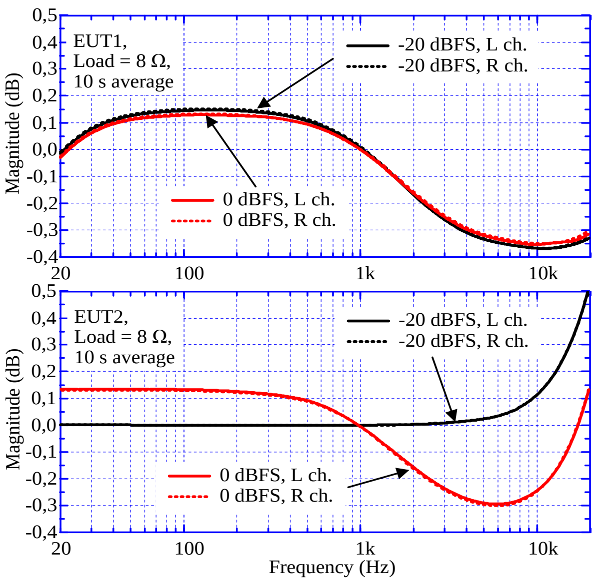

Fig. 4. Precise frequency response of EUT1 and EUT2

Interchannel separation

It is the linear leakage of information from one channel of a multichannel EUT into another channel. According AES17, it should be measured at input level −20 dBFS. However some manufacturers measure it at 0 dBFS. In [3] it is measured at 0 dBFS as well.. Slightly better results of EUT1 is obtained at 0 dBFS (Fig. 5).

If one assumes measurement bandwidth up to 20 kHz, than both EUT's satisfy specifications (62 against 55 dB and 77 against 75 dB). Separation of EUT2 is a little better than in [3] (Fig. 6) and at the high frequency is much better EUT1.

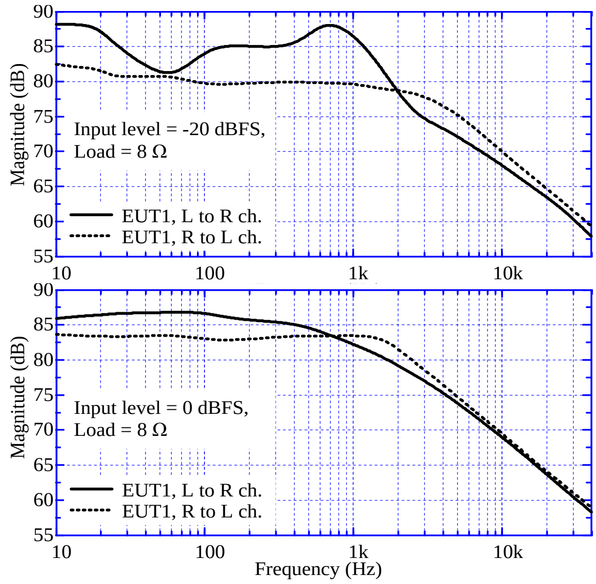

Fig. 5. Interchannel separation of EUT1

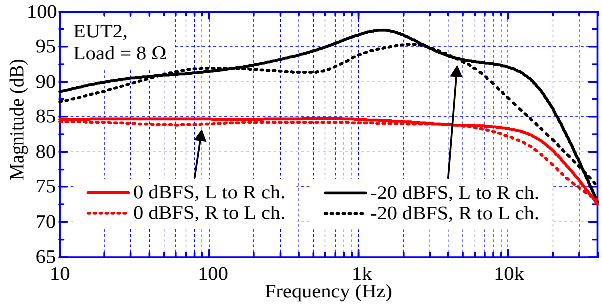

Fig. 6. Interchannel separation of EUT2

A quite big (12 dB) difference of EUT1, could be explained easily: the results is always worse in tests with 7 channels mode then in 2 (stereo).

Efficiency

Power efficiency is the essential advantage against still popular AB-class power amplifiers (with its theoretical efficiency limit ≈ 78,5%). The power efficiency curves of EUT's are shown in Fig. 7. The fairly broad range of relatively high efficiency near full output power – is characteristic of switch-mode amplifiers.

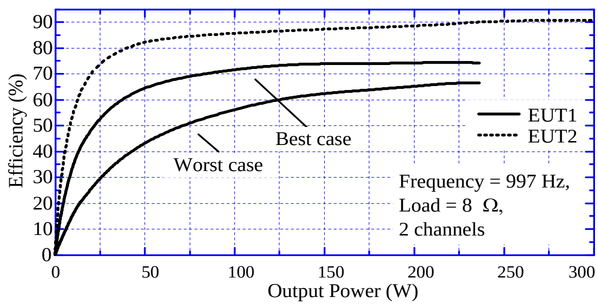

Fig. 7. Power efficiency of EUT1 and EUT2

In case of EUT1, it is actually class D amplifier plus its power supply efficiency, therefore it is normal, that efficiency is much lower, including the fact that EUT1 is designed to work in multichannel mode, when here it is worked in stereo mode only (2 channels). "Best case" – curve with compensation of other circuit power consumption (neither power stage nor supply), which reach nearly 75%. The parameter is not mentioned in [2,5].

The obtained efficiency of EUT2 curve is worse than in Fig. 13 from [3]. However, the figure caption is "Output Stage Efficiency", not overall. Nevertheless, it satisfies specifications, written in Table 3 from [3]: 90% at 2×125 W, 8 Ω. On lower load efficiency usually depredates.

Future work

The first part of intended measurement is presented here. There are much more measurements which reveal quality of DAC, as Maximum signal level versus frequency, Out-of-band spurious components, Suppression of imaging components, Signal-to-noise measurements, Total harmonic distortion and noise (THD + N) measurements, Intermodulation measurements and etc. All these are in plans.

Conclusions

The research on digital Sigma-Delta DAC Class D amplifiers characteristics have been fulfilled by applying created experiment analysis approach and measurement algorithms.

The family of amplifiers characteristics is presented which could be identify its qualitative and quantitative parameters.

It has been Found that such structure of amplifier efficiency is higher than the AB-class and reach up to 90%

It has been found that frequency response of such amplifiers is closely coincided (Fig. 2, 4 and 6).

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The characteristics family and its analysis of experimental research of two digital Sigma-Delta digital-to-analog converter D-Class audio amplifiers (Panasonic SA-XR55 and Texas Instrument TAS5518-5261K2EVM) is presented. The presented characteristics could help to identify amplifiers qualitative and quantitative parameters. Tested: Output-level stability, Level-dependent logarithmic gain (deviation from perfect level linearity), Frequency response, Interchannel separation and Power efficiency. Measurements are made on the basis, but not limited to AES17 standard. Characteristic is compared not only among themselves but also with the manufacturer's documentation. Research results closely coincide with its. The significant characteristics of amplifiers, which is not disclosed in manufacturers datasheets, is established as well. Ill. 7, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

В. Пуйдокас, А. Й. Марцинкявичюс. Исследование характеристик цифровых Д класса аудиоусилителей // Электроника и электротехника. – Каунас: Технология, 2010. – № 2(98) . – С. 41–44.

С помощью разработанных алгоритмов, проведено экспериментальное исследование цифровых D класса ΣΔ аудио усилителей мощности, построенных на базе Panasonic SA-XR55 и Texas Instrument TAS5518-5261K2EVM. Представлены основные зависимости параметров и определены количественные их значения. Тестированы следующие параметры: стабильность входного уровня, логаритмическая зависимость коэффициента передачи от входного уровня, отклонение входного уровня от идеального, амплитудно-частотная характеристика, межканальное отделение коэффициентов полезности. Измерения проведены в рамках стандарта AES17 и не только. Выполнен сравнительный анализ полученных характеристик с характеристиками в сопроводительной документации. Результаты экспериментального исследования близко совпадают с оригиналом. Ил. 7, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Puidokas, A. J. Marcinkevičius. Skaitmeninių D klasės garso galios stiprintuvų charakteristikų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 2(98). – P. 41–44.

Pateiktos dviejų skaitmeninių Sigma-Delta SAK D klasės garso galios stiprintuvų „Panasonic SA-XR55" ir „Texas Instrument TAS5518-5261K2EVM" eksperimentinio tyrimo charakteristikų šeimos, iš kurių galima nustatyti stiprintuvų kokybinius bei kiekybinius parametrus, ir parametrų analizė. Testuoti parametrai: išėjimo lygio stabilumas, logaritminio perdavimo koeficiento priklausomybė nuo įėjimo lygio (išėjimo lygio nuokrypis nuo idealaus tiesiškumo), dažninė amplitudės charakteristika, tarpkanalis atskyrimas bei naudingumo koeficientas. Matavimai atlikti remiantis, bet neapsiribojant AES17 standartu. Ištirtos charakteristikos lyginamos ne tik tarpusavyje, bet ir su gamintojo pateikta dokumentacija. Tyrimų rezultatai gana gerai su ja sutampa. Taip pat nustatyta ir reikšmingų charakteristikų, nepateiktų stiprintuvų techninėje dokumentacijoje. Il. 7, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).