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Filter for Intermodulation Distortion Measurement of Audio Power Amplifiers

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Introduction

Two main tests for the high level non-linear behavior of an audio power amplifier or digital to analog converter are harmonic distortion (THD, THD+N or SINAD) and intermodulation distortion (IMD) tests.

THD+N is well known and popular criteria of audio equipment rating. However, for digital audio systems which are band-limited, this test is not capable of revealing the highest harmonic distortion products. It can be a problem if ones wish to measure non-linearity due to slew-rate limiting. For example, in 20 kHz band-limited system the information of 3rd harmonics above 6,7 kHz and 2nd harmonics above 10 kHz is lost. This can be seen in Fig. 1 for signal level of -1 dBFS (EUT2 from [1]).

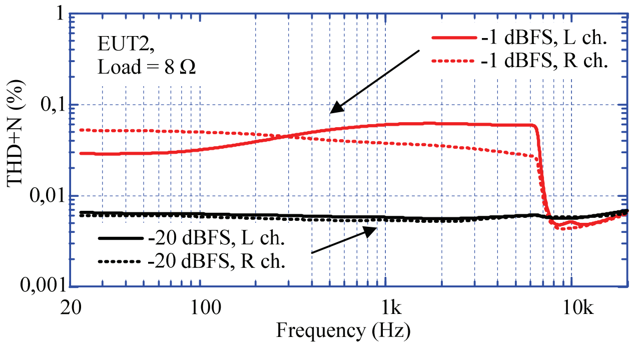

Fig. 1. THD+N versus frequency

Dynamic range of D class amplifier and IMD

For the measurement of the high quality sound devices parameters are required high quality measurement devices, e.g., the price of the Audio Precision APx525 series basic model starts from 20,000 USD. Even without „High-End“ power DAC (D class power amplifier) required dynamic range of the measurement devices can be estimated: e.g., Texas Instrument TAS5518-5261K2EVM [2] intermodulation distortion decline for 5th harmonics even -90 dB for output level of 300÷500 mW (Fig. 2). Levels of the individual IMD are yet less.

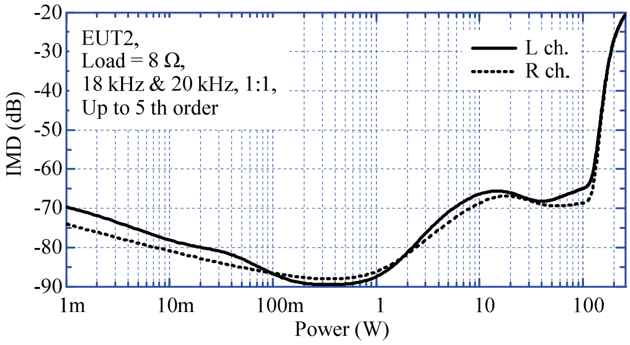

Fig. 2. IMD versus level

The principle of the method, which is applied in the THD (or THD+N) versus signal output level (power) measurement technique, may be used when dynamic range of the analyzer is insufficient [3]. The idea of the method that is based on the usage of the notch filter for the main frequency suppression is given in Fig. 3.

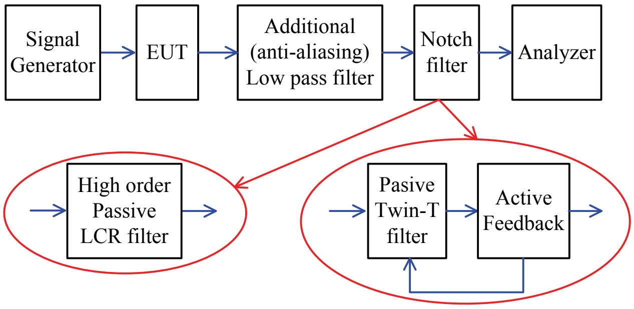

Fig. 3. THD+N versus level measurement

Main difference of the above mentioned IMD measurement is the requirement to suppress two strong tones (18 kHz and 20 kHz main pair accordingly to AES17; 41 Hz and 8 kHz additional pair accordingly to AES17 [4]; 60 Hz and 7 kHz accordingly to SMPTE

PR120-183; 250 Hz and 8 kHz accordingly to DIN45403). In such case a simple consecutive connection of the filters is not possible, because first stage will suppress only one tone, and second stage will overload operational amplifiers of the same stage, when the dynamic range of the operational amplifiers is not exceptionally high. High order LCR filters are complicated and expensive. Here the temperature stability will be achieved more complicated; size is considerable, no flexibility in relation to input impedance, etc.

On purpose of simplicity in Fig. 3 are presented only two possible versions of the notch filter. There are various filters, e.g., Wien Bridge (HP 330–334 family THD analyzer), Bridged-T (HP 339, 433A), State-variable (HP 8903, Sound Technology 1700 family, Tektronix devices) [5], and others.

Twin-T filter circuit design

One of possible circuits diagram of the prototype is given in Fig. 4. If required, input impedance of the filter may be lowered using resistor R1. Resistors R2–R7 and capacitors C3, C6–C8 is a passive 20 kHz part of the Twin-T filter. Resistors R8–R15 and capacitors C11, C14–C16 is a passive 18 kHz part. Capacitor C17 and resistors R16–R20 is a phase correction circuit. Feedback coupling is realized using DA2A–DA2C with resistors R21–R24. Filter output buffer and level-correction are realized using operational amplifier DA2D and resistors R25, R26. Two-pole supply is ensured by DA1, which creates a virtual ground.

With the adjustable resistors R3, R4, R6 will be corrected higher suppressed frequency and ratio (both these parameters are interrelated), and with R10, R11 and R13 – lower suppressed frequency. The quality of each part can be adjusted accordingly with resistors R23 and R21. R25 can be used for the correction of total output level of the filter.

The configuration of the first 20 kHz part and subsequently 18 kHz part has two advantages. First of all total impedance of the filter is higher, because the resistance of the first part resistors is higher. Second advantage: filter slope at 18 kHz frequency can be potentially higher, because the impedance of the subsequent circuit is substantially higher.

An elimination of the DC voltage blocking capacitors requires two-pole supply voltage. Such requirement is inconvenient for the user because special power supply units must be used. Therefore, the stable virtual ground was created by Texas Instruments TLE2426. When the filter will be integrated in another system with available two-pole supply, the components DA1 and C1, C2, C4, C5 can be eliminated.

A priori in place of the operational amplifiers DA2A–DA2C can be used every high speed operational amplifier. Here are none special requirements to the operational amplifier DA2D. TI OPA4134 was used for several reasons. First of all, 4 operational amplifiers suited in one case. Second, case type and size are not substantially inconvenient for the manual assembling. Third, manufacturer supplies SPICE macro-model. Fourth, acquisition was not expensive. The main electrical parameters of OpAmps are as follow: broad range of supply voltage (from ±2,5 V till ±18 V), stable operation by unity gain; slew rate: 20 V/μs; bandwidth: 8 MHz.

In the prototype were used Vishay MMU 0102 series precise (1%), thermostable (±50 ppm/K) resistors and Cornell Dubilier CD15FD series silver mica capacitors with +70 ppm/K temperature coefficient and Q>360 quality. Mostly used ceramic capacitors (dielectric NP0, X7R, X5R or Y5V) are of low quality – capacity inaccuracy from 5÷20% till +80% –20%; temperature coefficient usually ±750÷10000 ppm/K, energy dissipation from 0,1% (NP0) till 9% (Y5V); quality Q at 10 kHz rarely exceeds 60÷90, and capacity deviation by voltage variation from 0 till 50 V can achieve –15% (X7R) or even –95% (Y5V). Thus, such capacitors are nonlinear and are a source of additional harmonics during measurements, so measurement results may be unreliable.

Filter was build on the FR-4 (woven glass and epoxy)

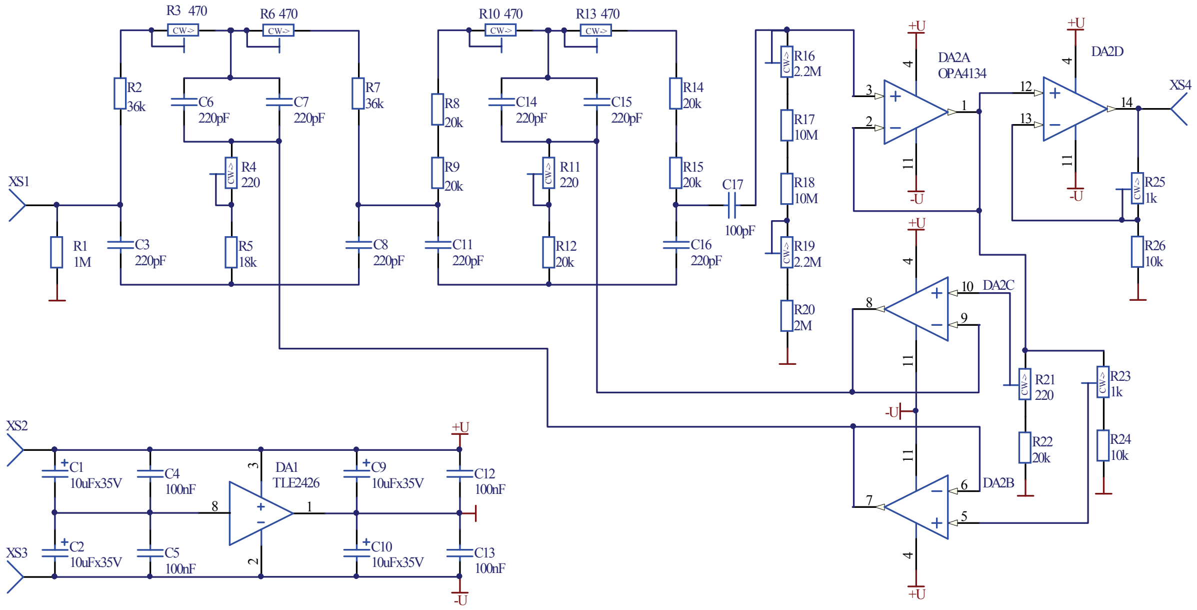

Fig. 4. Schematic circuit of the prototype

plate and suites in the screened case with BNC connectors for protection from undesirable noise disturbances and interferences. Size including connectors and switch is (W×L×H): 95×160×40 mm, weight – 430 g. Filter's photo in the scale M 1:2 is presented in Fig. 5. Power supply requirements: 6÷36 V stabilized, 40 mA, linear with good galvanic separation from industrial power net.

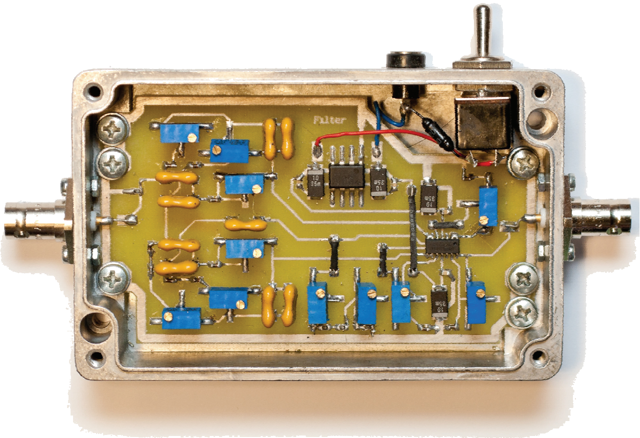

Fig. 5. The prototype (M 1:2)

Simulation and experimental study of the filter performance

Most informative and underlying feature of the performance – frequency response – is presented in the Fig. 6. Simulation results obviously justify the strategy of active-passive parts separation. Unfortunately, experimental results are in not good agreement with the simulation results. Filter quality is obviously to low: –3 dB crossing points are at frequencies of 14,2 kHz and 38 kHz, and the suppression at dominant third intermodulation harmonics (16 kHz and 22 kHz), accordingly, are 16 dB and 19 dB. Yet the gain exceeds 30 dB, because the pair of the test tones is suppressed near 50 dB.

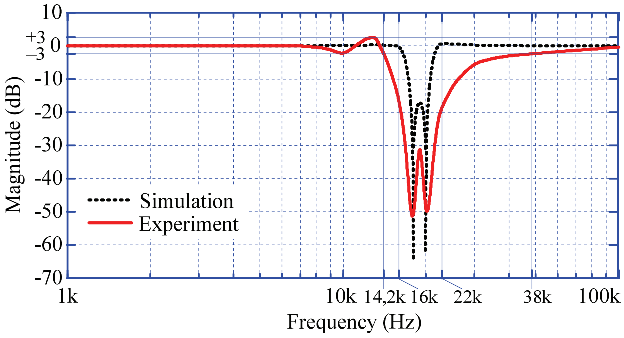

Fig. 6. Frequency response with OPA4134

Similar situation the author has with a notch filter of 997 Hz [1]. The Texas Instrument operational amplifier OPA2227 (8 MHz; 2,3 V/μs) for the filter was used. The situation was improved with another operational amplifier OPA2134 (8 MHz; 20 V/μs) of the same manufacturer. It is characterized by better operational speed (for strong signals) and has the same passband.

When the study of the filter with OPA4134 was completed, a usage of other operational amplifiers was investigated because of too low quality of the filter Q (see Fig. 6) Good simulation results were achieved with Elantec EL2424, EL2444, EL2445; Texas Instruments THS4032, THS4061, THS4062; and family of Linear Technology LT1357–LT1365 etc. Considering the compatibility of the cases and pins of the operational amplifier OPA4134 (decision was taken to revise existing prototype) and availability, LT1365 was chosen for the experimental study. It is characterized by high speed and low input offset voltage, witch is important for operational amplifiers [6 - 8]. Main changes of the frequency response (Fig. 7) were achieved at the passband slopes, i.e., filter quality was increased. Now all lower band of the required frequencies (till 16 kHz) is in the range of ±3 dB (previously only till 14,2 kHz). The situation was improved for the higher frequencies too – at 22 kHz the suppression was lowered to 9 dB (previously 19 dB), intersection point of –3 dB was shifted from 38 kHz to 27 kHz. Experimental curve was drawn near to the simulation curve. The suppression of the tone pair has undergone no changes.

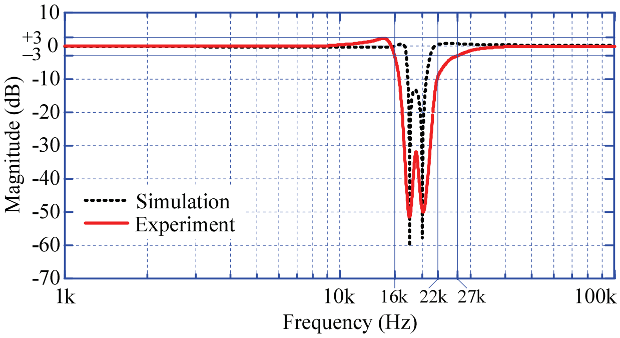

Fig. 7. Frequency response with LT1365

The aim of the second supplementary study – filter circuits simplification. Now the circuit has only two operational amplifiers (Fig. 8) and without level regulation and no need for buffering, only one operational amplifier is sufficient.

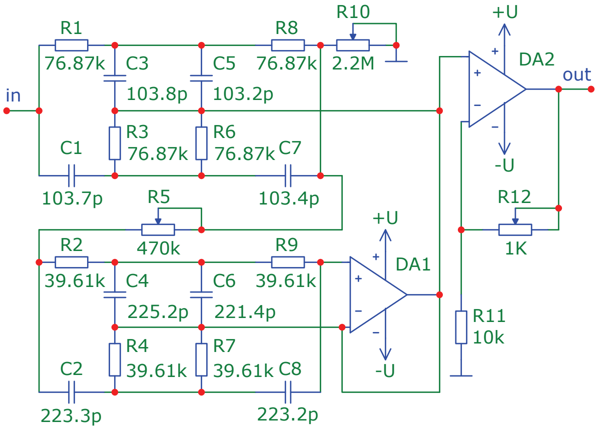

Fig. 8. Simplified circuit diagram with two OpAmps

Notwithstanding simplified circuit, the frequency response in the lower frequency band (till 16 kHz) has undergone almost none changes (Fig. 9) – all response curve is lying in the range of ±3 dB.

Unfortunately, the slope in the higher frequencies range is more low-pitched: at 22 kHz the suppression is 14 dB in place of previously value of 9 dB, still it is for 5 dB better in comparison with the original prototype, operational amplifier OPA4134. Intersection point of –3 dB has been shifted form previously 27 kHz to 28 kHz. However at 35 kHz the curve intersects +3 dB line and goes out from ±3 dB area till +5 dB, such feature was absent in previous versions.

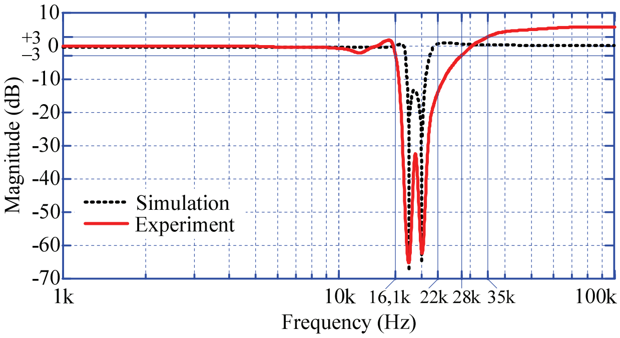

Fig. 9. Frequency response, when two OpAmps are used

The experimental results of tone pair suppression rebate in relation to the simulation results only for 2 dB and at frequencies of 18 kHz and 20 kHz achieve accordingly 64 dB and 62 dB, i.e., yet 12 dB better as previous versions. Therefore, such features allow to use even 8 bit cheap analyzers, i.e., Pico Technology PicoScope series, Hantek DSO family, BitScope analyzers, MicroTec TiePieSCOPE family, Cleverscope, LeCroy, Tektronix, and many others.

Conclusions

The filter has following advantages (prototype parameters in parentheses): Compact – small size (W×L×H: 95×160×40 mm, without power supply), lightweight (430 g, without power supply); Achieved impedance exceeds 20 kΩ; Temperature stability (<±0,1 Hz @ 10÷75 °C, with silver mica capacitors); Stable operation by strong tested tone pair signals (18 kHz and 20 kHz, >50 V); Sufficient suppression (especially of the 2 operational amplifiers version) for the usage of 8÷12 analyzers; None inductive components; High dynamic range operational amplifiers are unnecessary; Inexpensive (<60 Euros, without prototype remaking).

In spite of many advantages, some disadvantages are present. Main of them are: Power supply is required; Frequency response is not ideal, especially in the higher frequency band. The last one disadvantage can be compensated by digital processing in the same analyzer (digital filter calibration).

In spite of above mentioned drawbacks, the study results confirm that the separation of passive and active parts of the filter give expected results, and this was the main aim of the experiment.

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The proposed technique enables measurement of the intermodulation distortions with cheap lower dynamic range (10÷14 or even 8 bit) analyzers using modified Twin-T filter. The idea of the modification is based on the separation of the active and passive filter parts, with location firstly of the passive parts with subsequent active parts. The prototype of the filter was developed for experimental investigation. The both simulation and experimental results confirm that the separation of passive and active parts of the filter give expected results. Ill. 9, bibl. 8 (in English; abstracts in English and Lithuanian).

V. Puidokas, A. J. Marcinkevičius. Filtras garso galios stiprintuvų tarpmoduliaciniams iškraipymams matuoti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 8(114). – P. 47–50.

Pateikta metodika, naudojanti modifikuotą Twin-T filtrą, įgalina matuoti tarpmoduliacinių iškraipymų vertes pigiais mažesnio dinaminio diapazono (10÷14 ar net 8 bitų) analizatoriais. Modifikacijos esmė – atskirti pasyviąsias bei aktyviąsias filtrų dalis, signaliniame trakte išdėstant pirmiausia pasyviąsias, o tik vėliau aktyviąsias. Eksperimentiniam tyrimui buvo sukurtas filtro maketas. Modeliavimo bei eksperimento rezultatais buvo įrodyta, kad, atskyrus pasyviąsias ir aktyviąsias filtro dalis, gaunami planuoti rezultatai. Il. 9, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).