Pragmatical Approach To Speaker Industrial Testing

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***Abstract*— The aim of the project is to develop a sine wave generator and a measuring system suitable for testing speakers made in an acoustic factory. The compactness of the device is characterized by the fact that it can be easily calibrated in a few steps and used in the production area or in laboratories with the right instrument frame. The device is based on an RPI 4B single-card computer running self-developed software that makes working with the system enjoyable and easy with a graphical interface. This article presents the necessity and structure of the system itself, a description of its functions, a measurement system analysis (MSA), and finally the results of a distortion measurement.**

I. Introduction

As a result of the development of the automotive industry and the growing market demands in the field of speaker manufacturing, it has become necessary to use a tool that can be used to test every single built-in speaker. Most signal generators on the market today can perform a number of functions, all of which are paid for by the customer. The purchased device should know a sine wave generator and a function that implements the impedance measurement of the speaker. The problem is that simpler signal generators alone are unable to deliver the power needed to test a speaker and at the same time determine the impedance curve of the speaker. It would be an easy solution to get, more tools to do the testing, but it would be a huge investment, as the company currently needs about 15 such test systems. So on the current market, there is no “turnkey” tool that would meet the criteria we have set up. thus, a self-developed tool is required to perform the tests. The in-house system had to be designed in such a way that it could later be universally [1] developed to perform new tasks, be easily reproduced / serviced, and be low-budget with ease of use.

II. Structure of the System

The measuring system “Figure 1”, “Figure 2” is based on a Raspberry PI 4 B + microcomputer [2], [3]. Because PI alone is not capable of processing analog signals, an ADC + DAC manufactured by Hifiberry [4] was necessarily used. The ADC / DAC is capable of producing and processing a maximum signal level of 2.1Vrms, which in some cases is not sufficient to meet the specifications specified in the speaker specification test stimulus. Thus, the signal from the DAC must be amplified by an amplifier to which the JBL CSA 2120 [5] class-D amplifier [6] has been dedicated. To determine the speaker impedance curve, it must be measured at a shunt resistor connected in series with the speaker for maximum load on the ADC. For use in industry, the components of the measuring system are housed in a plastic instrument frame with the appropriate connection points. The user can interact with the software running on the PI using a touch screen [7].

III. Programming Challenges

The software is written in python 3 [8], [9] and, in addition to the kivy [10], [11] module, provides a clean and easy-to-use interface for the user. The program was written following object-oriented paradigms and can be divided into four main functions: sinusoidal signal generator function, where 20-20kHz sinusoidal signal generation can be implemented; sweep function, impedance measurement function, and calibration. The program communicates with the HifiBerry card via the pyaudio [12] module.

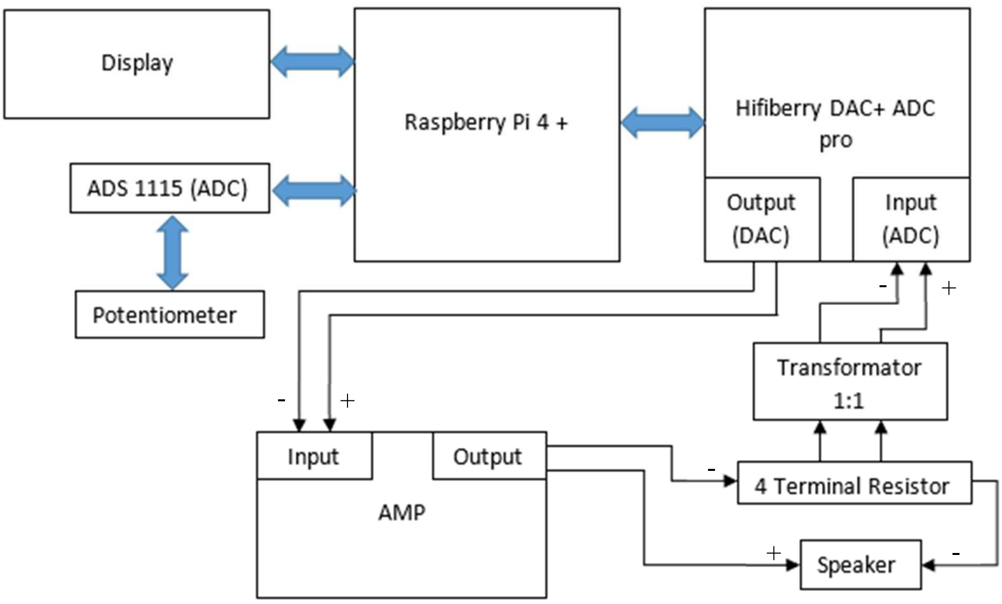

Fig. 1 Measurement system block diagram

A. *Signal generator function*

In the sine signal generator function, the user has the option to adjust the signal level and frequency of the sine signal displayed at the output of the measuring system, either by moving virtual sliders or by entering a precise value through a pop-up window. A button can be used to start or stop signal generation. In addition, it is possible for the user to adjust the frequency using an external potentiometer [13], or rather perform a manual sweep. You can switch to manual sweeping with a switch on the display. As the testing of the speakers falls in the lower frequency range, the characteristic describing the movement of the potentiometer increases exponentially. An algorithm that describes the process of signal generation occupies an array of hexadecimal values representing the sine signal on which the DAC is iterated to display the sine signal at the output. This array contains the components of the sine signals in a way where each wave begins and ends at phase 0.

Fig. 2 Measurement system

B. *Sweep signal generator function*

The speakers are tested at the end of production. One test method is when the operator listens to each speaker one by one, looking for possible sound defects. This test is not performed at a single frequency but by a logarithmic sweep [14] (1)

$$\int_0^t 2\pi f(t)\, df(t) \tag{1}$$

The function f (t) is explained for the software as follows (2)

$$f(t)=\cos\left(2\pi\cdot\frac{t_1}{\log\left(f_1\cdot f_0^{-1}\right)}\cdot f_0\cdot\left(\frac{f_1}{f_0}^{(t\cdot t_1^{-1})}-1\right)+\varphi\right)\cdot A \tag{2}$$

where t – times at which to evaluate the waveform; f_0 – frequency at time t=0; t_1 – time at which `$f_1$` is specified; f_1 – frequency of the waveform at time `$t_1$`

The sweep function is suitable for this. Here the user can set the start and end frequency of the sweep stimulus, the signal level and how many seconds a stimulus lasts.

For testing, it is advisable to use a backward sweep signal and allow this until the user interrupts or changes any of the stimulus parameters. Since the array containing the points representing the stimulus lasts for a certain time, ie it consists of a given element, care must be taken to ensure that the generated stimulus ends at phase 0 and that the next signal is in sync with it. If this problem is not eliminated, the following waveform occurs at the intersection of the rising and falling sweep signal "Figure 3".

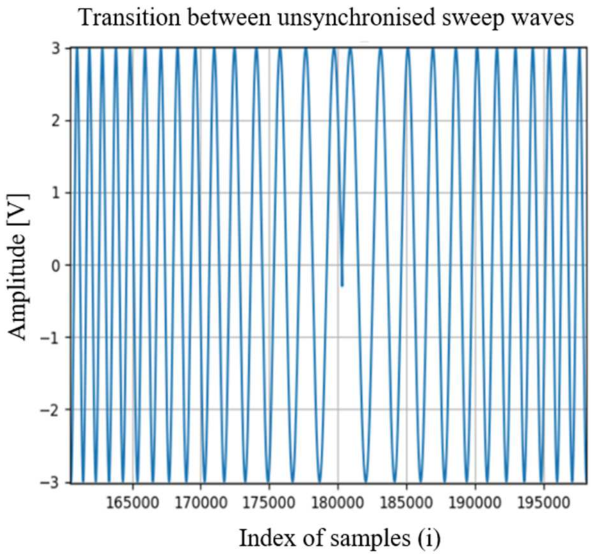

Fig. 3 Encounter of unsynchronized sweep signals

Looking at the spectrum of this waveform in "Figure 4", it can be seen that a number of harmonics appear, which are audible on the speaker as a "Tick" sound. Because point these sound errors are searched for by the operator, so this phenomenon can mislead the user.

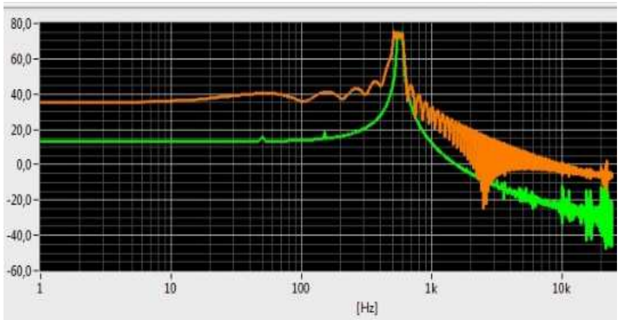

Fig. 4 Spectrum of the encounter of unsynchronized sweep signals

In the figure, the orange curve represents the spectrum of the encounter of non-synchronous sweep signals. The green curve is the synchronized signals.

C. *Speaker impedance measurement function*

One of the significant characteristics of speakers is the impedance response. The developed measuring system, unlike other measuring systems, measures impedance in a non-complex way. Or rather, it measures the resistance of the speaker measurable at a given frequency "Figure 5.". The measurement stimulus is a stepped sine signal whose discrete measurement points are determined by the ISO stepped sine frequencies. Due to the Hifiberry ADC's 2.1V maximum input load, a 100mΩ shunt resistor is required. To achieve more accurate measurements and to meet automotive standards, a 4-terminal resistor was connected.

The user sets the parameters of the measurement stimulus (signal level, frequency range) and then starts the measurement process. At the beginning of the measurement cycle, the DAC generates the first discrete frequency signal that reaches the speaker through the amplifier. And the ADC will measure the voltage at the shunt [15], [16], [17] resistor True-RMS [18] with some delay. The measured value is saved and then measured at the next frequency. If the program has scanned the user-set frequency range, the program converts the saved RMS values to resistance values. It displays the highest value, Zmax and the corresponding frequency (resonant frequency) to the user [19], [20]. The first minimum value following the highest value will be the minimum resistance of the speaker, which will also be shown on the display.

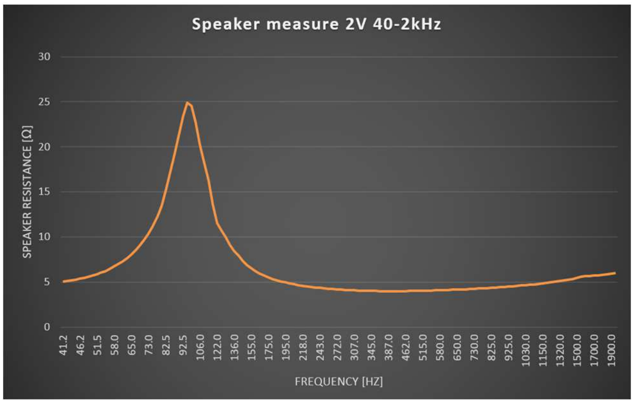

Fig. 5 Speaker resistance curve

It is important to note that the sine signal for a given frequency of the stimulus will be generated by the DAC from a predetermined number of conversion values. The number of these conversion values in the lower frequency range is determined so that at least 5 complete periods of the sine signal are displayed on the speaker. Above the 100Hz cut-off frequency, all sine signals are generated for 50ms. The generated signal will also appear on the shunt resistor, which will be sampled by the ADC at 96 kHz, from which the voltage at the resistor for that frequency will later determine the True-RMS value. Before that, however, the sampled signal sequence may contain transient signals at the beginning of the measurement „Figure 6." or incomplete whole periods due to fixed signal generation. Transients occurring at the beginning of the signal sequence shall be cut out of the sampled signal or the sampled signal sequence shall be reduced to such that they contain only complete periods "Figure 7".

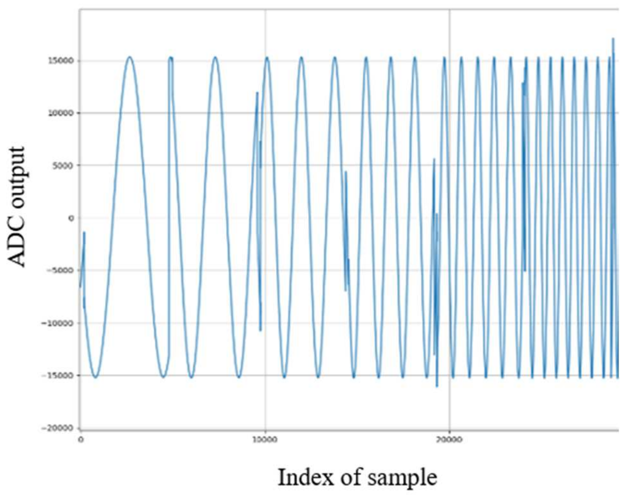

Fig. 6 Sampled signal

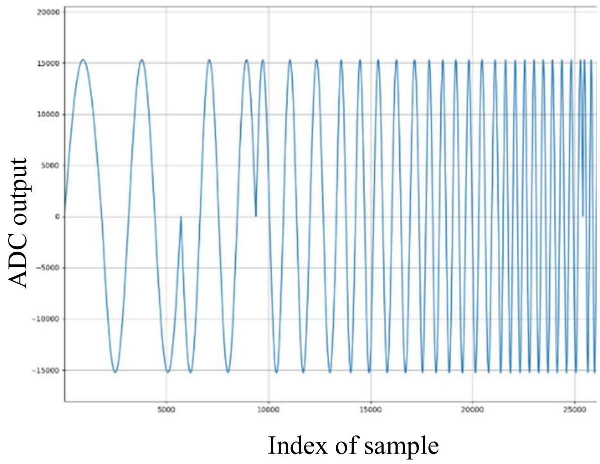

Fig. 7 Filtered signal

IV. Calibration

In order for the device to be used in production or in laboratories, the device must be calibrated. Moreover the measurement system has to be amplifier-independent. To help with this, a calibration menu has been created where a wizard guides the user through the calibration. Login is required for calibration so that only the right people can change the calibration of the device. The first step is to calibrate the DAC. The calibration signal level and frequency must be set before calibration. During calibration, the device performs a sine wave generator function. The frequency of the generated signal will be the specified calibration frequency, but the amplitude of the signal must be calculated by the following formula (3)

$$A = \frac{U_{pref}}{U_{max}} \cdot DAC_{res} \tag{3}$$

Where A – the conversion value of the amplitude of the sine signal; U_{pref} – calibration signal level; U_{max} – maximum p-p voltage of the DAC; DAC_{res} – bit resolution of the DAC.

The user starts the signal generation, measures the voltage at the output of the DAC with a calibrated multimeter, and enters the measured value into the software. In this case, the quotient of the measured value and the calculated value will be the calibration factor of the system output. Further, it is necessary to correct the array representing the signal sequence arriving at the DAC converter with this calibration factor.

The next step is to calibrate the amplifier. The user also uses the signal generator function of the system. The already calibrated sine signal must be applied to the input of the amplifier. Being a class-D amplifier, the terminal voltage at the output of the amplifier must be measured and the measured value has to be entered into the software by the user. The program calculates the gain value of the amplifier from the measured value and the calibration signal level.

Calibration of the amplifier is followed by calibration of the 4-wire resistor, where the user measures the resistance with a four-wire resistance meter and enters the measured value into the software.

The calibration process is completed by the ADC calibration. Here, the user re-generates a signal using the signal generator, only now measuring the voltage across the shunt resistor. Enters the measured value into the software and clicks the "Finish Calibration" button. The system then uses the ADC to measure the voltage across the shunt resistor. From the value measured by the ADC and the value specified by the user, the program calculates the calibration factor of the ADC according to the following formula (4)

$$ADC_{cf} = \frac{U_{pref} \cdot DAC_{cf} \cdot AMP_{Gain} \cdot R_s \cdot (R_s + R_l)^{-1}}{U_m} \quad (4)$$

Where R_s – value of serial resistor; R_l – value of load resistor; U_m – value of measure voltage.

At the end of the calibration, the system saves the calibration values in a .txt file and the details of the calibrator and the time of the calibration for traceability.

Users have the opportunity to test the current calibration in a separate menu item. Here, three types of tests can be performed. There is a generator function that allows you to adjust the signal level and frequency displayed directly on the DAC output. (In the normal generator function, the voltage at the output of the amplifier can be adjusted.) The adequacy of the DAC calibration can be determined by measuring the generated signal with an external, certified multimeter. There is an ADC calibration check function where it is possible to connect an external certified function generator to the ADC input. During the test, the measuring system displays the RMS value of the voltage measured by the ADC. Alternatively, there is a combined test function where the system simultaneously operates as a generator function and also measures the voltage at the input to the ADC input.

V. Measurement system analysis (MSA)

Like any measurement system that is used directly in production or in laboratories, the current automotive standard requires the analysis of all measurement systems. In the present case, two types of MSA [21] are made on the already calibrated measuring system.

A. *Type1*

The first test is to examine the repeatability of the measurement system (Type 1 Gage Study) [22]. During the test, the impedance characteristics of a sample speaker were measured on a higher level measuring system (high-resolution anechoic room), which serves as a reference for the MSA. In the study, this speaker was measured 50 consecutive times on an RPI-based basis on a measuring system. The results of the MSA can be read from the following table.

TABLE I. MSA Type1

MSA Type1 results	Zmin[a]	Zmax[b]	fs[c]
Reference	4,81	53,68	61,45
Tolerance (Tol)	1,4	40	30
Mean	5,0090	57,4736	63,0476
Bias	0,1990	3,7936	1,5976
Cg	2,59	1,58	3,24
Cgk	-1,09	0,08	1,51
%Var Repeatability	7,74%	12,62%	6,17%
%Var Repeatability and bias	-18,34 %	244,52%	13,20%

[a] minimum impedance of reference speaker
[b] maximum impedance of reference speaker
[c] resonance-frequency of reference speaker

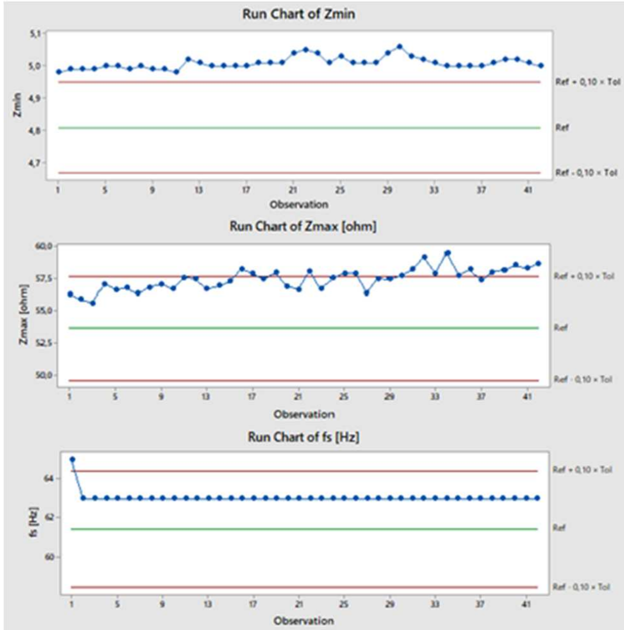

Fig. 8 MSA Type1

Analyzing the table "Table 1"shows that the system has a good repeatability with respect to Zmin and fs (resonant frequency). Furthermore, it can be seen that for Zmin, the measured values are above the upper limit. From this, it can be concluded that the system has a permanent fault resulting from the cabling within the system. Further investigations are needed to prove this and to compensate for the permanent error later on. This permanent error also causes a negative value for cgk. Analyzing the Zmax value, it can be seen that Cg is greater than 1.33 is therefore reasonably acceptable. The value of% Var Repeatability and bias is very high due to several factors (bias value is only 0.2Ω). First and foremost, there is also a permanent fault in the system, which can result from the internal physical cabling of the system. The second factor is that when the measurements were made, the speaker was measured in hand and not in a fixed clamp. The third factor from the graph for Zmax can be read from "Figure 8". It can be seen that the measured values follow an increasing trend, which more or less results in an increase in the spring slackness of the speaker pillar. The value of fs stagnates when looking at the chart. The first couple measurement, the system measured a resonant frequency of 65Hz, hereinafter referred to as 63Hz. This is due to the fact that the parameters related to the oscillation system of the measured loudspeaker (mainly the spring slackness of the pill) change during the measurements, and the system measures with a resolution of approximately 2Hz around the resonant frequency. In the case where the resonant frequency is known, the device can determine more accurate values by measuring at a higher resolution in a given range. Overall, the Type1 analysis performed on the measurement system is encouraging, and after further testing, the system can be further developed. In particular, by compensating for the permanent error of the measuring system, by increasing the number of measuring points in the resonant frequency environment, and by making a speaker clamp and working instructions to perform the measurements, the Type1 results can be substantially improved.

B. *Type3*

The second analysis required the measurement of 15 sample speakers with the same part number. Each speaker was measured once during one series of measurements and three series of measurements were made. The results of the measurements are reported in the tables below.

TABLE II. MSA TYPE3 - TOTAL GAGE R&R

Total Gage R&R	Zmin	fs
Tolerance (Tol)	1,4	30
% Study Var (%SV)	41,96	6,41
% Tolerance (SV/Toler)	15,15	11,35
Number of Distinct Categories	3	21

TABLE III. MSA TYPE3 - TOTAL VARIATION

Total variation	Zmin	fs
% Study Var (%SV)	100,00	100,00
% Tolerance (SV/Toler)	36,09	177,06

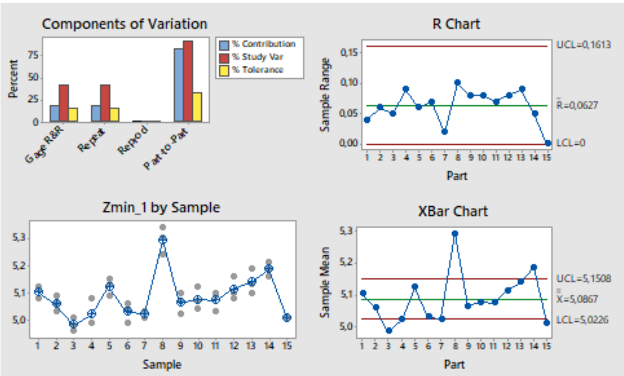

Fig. 9 MSA Type3 - Zmin

By analyzing the Zmin values, "Figure 9" it can be seen that the value of Total Gage R&R [23] "% Study Var (% SV)" is "Table 2." 41.96%, which means that the standard deviation of the products is quite low for the 15 samples, so the standard deviation of the system is slightly comparable to with specimens. Respectively, the system can distinguish 3 different categories.

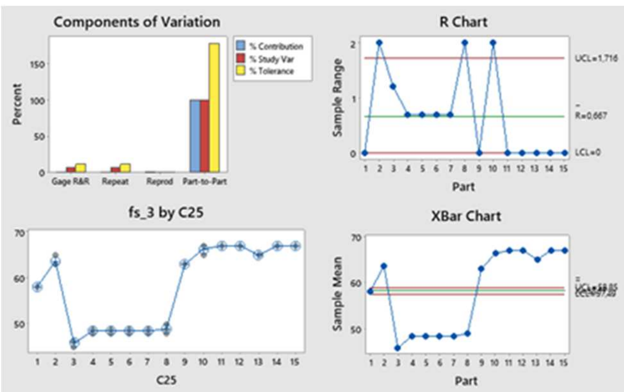

Fig. 10 MSA Type3 - fs

Analyzing the values of fs "Figure 10", it can be seen that the value of Total variation% "Tolerance (SV / Toler)" is "Table 3 "is quite high (177.06%), which is due to the fact that the speakers that form the samples of the analysis, although belonging to the same article number, are from different production batches. The difference between the two production batches is the difference between the spring tolerances of the pillar which is responsible for centering the swing system. The value of Total Gage R&R "% Tolerance (SV / Toler)" (11.35%) is "Table 2" is acceptable and the system can distinguish 21 different groups.

VI. THD MEASUREMENTS

After examining the MSA of the system, another important question is how faithfully the generated signal appears on the output. This is especially important in cases where an operator is looking for sound defects by listening to the speaker. The distortion of the RPI-based system was analyzed using another measurement system (SoundCheck_v17). In the first step, the distortion [24] of the DAC is "Figure 11". The result of which is shown in the figure below.

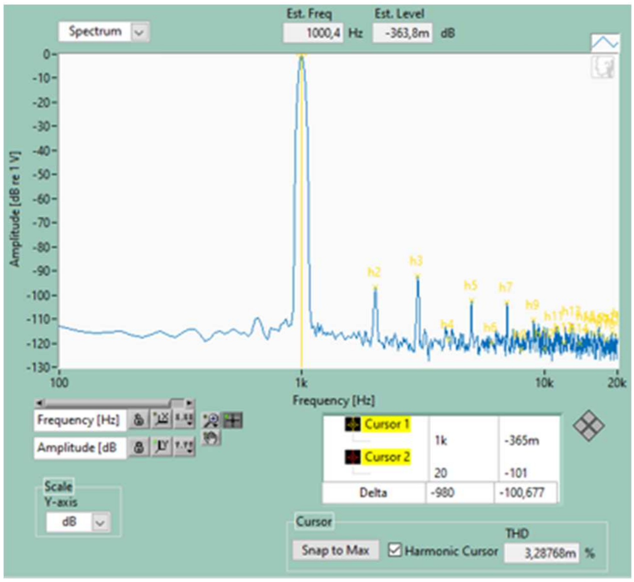

Fig. 11 DAC THD 1V_1kHz

In the following figure, the spectrum of the sine signal at the output of the amplifier is "Figure 12" can be seen, where the dominance of the odd number of harmonics can be better perceived. This dominance is due to the terminating member of the class-D amplifier [25], [26], [27] (4 Ohm resistor). It can be seen that the distortion of the output of the measuring system is close to 1% during the measurement. This is in contrast to the value described in the amplifier specification. It is possible that the signal at the output of the amplifier will interfere with the spectrum analysis system. In the future, this analysis would be done using a tool to facilitate the measurement of class-D amplifiers supplemented with appropriate filter circuits [28].

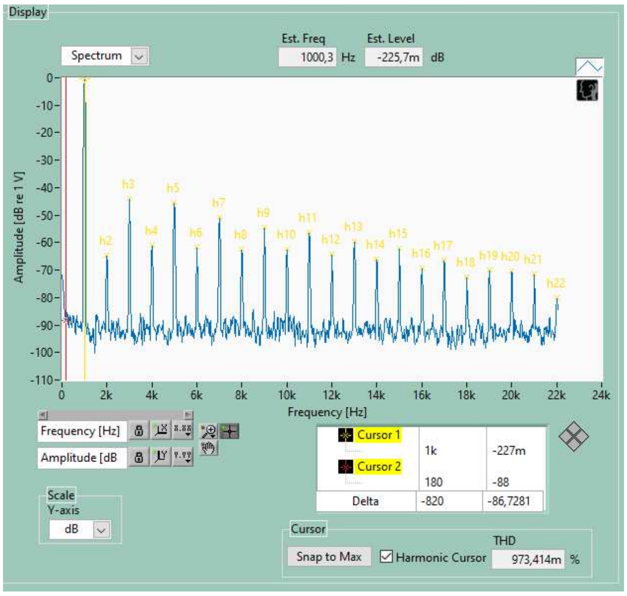

Fig. 12 Amplifier THD 1V_1kHz

VII. Summary

The aim of the project was to design and build a compact target device. The design meets the things specified in the functional specification, the completed system partly meets and partly needs to be improved. The sine signal generator of the device works properly. The sweep function fully covers the functions of the current generators used in production. Impedance measurement is currently under development. The system can be easily calibrated for various amplifiers in a user-friendly way, and then the completed calibration can be tested and validated. During the development of the measuring system, the permanent error of the system must be determined and the measured value has to be compensated, the user must be given the opportunity to adjust the measurement resolution, a clamp suitable for fixing the speakers in place for the duration of the measurement procedure. Once these have been established, another MSA test should be performed on the system and, if the analysis provides adequate output, the device can be used in both production and laboratory tests.

Acknowledgment

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References

[1] Michalak, S. (2014). *Raspberry Pi as a measurement system control unit.* 2014 International Conference on Signals and Electronic Systems (ICSES).

[2] Baklanov, A., Baklanova, O., Grigoryeva, S., ...Vais, Y., Györök, G., *The development of hybrid IP architecture for solving the problems of heating networks (Using pipeline-parallel data processing technology)* Acta Polytechnica Hungarica, 2020, 17(1), pp. 123–140

[3] The hardware in the Raspberry Pi [Online]. Available: https://www.raspberrypi.org/documentation/hardware/raspberrypi/README.md

[4] Datasheet DAC+ ADC PRO [Online]. Available: https://www.hifiberry.com/docs/data-sheets/datasheet-dac-adc-pro/

[5] JBL CSA-2120 amplifier specification [Online]. Available: https://jblcommercialproducts.com/en/products/csa-2120

[6] Berkhout, M., Dooper, L., Krabbenborg, B., & Somberg, J. (2013). *A 4Ω 2.3W class-D audio amplifier with embedded DC-DC boost converter, current-sensing ADC and DSP for adaptive speaker protection.* 2013 IEEE International Solid-State Circuits Conference Digest of Technical Papers.

[7] Raspberry Pi Touch Display specification [Online]. Available: https://www.raspberrypi.org/products/raspberry-pi-touch-display/?resellerType=home

[8] Python3 documentation/tutorials [Online]. Available: https://docs.python.org/3/tutorial/index.html

[9] Mark Summerfield, *Programming in Python 3: a complete introduction to the Python language.* Pearson Education, Inc. (2010)

[10] Kivy [Online]. Available: https://kivy.org/doc/stable/#

[11] Dusty Phillips, *Creating Apps in Kivy.* O'Reilly Media, Inc. Gravenstein Highway North, Sebastopol, CA (2014)

[12] PyAudio 0.2.11 Documentation [Online]. Available: https://people.csail.mit.edu/hubert/pyaudio/docs/

[13] Adafruit Python ADS1x15 python library [Online]. Available: https://github.com/adafruit/Adafruit_Python_ADS1x15

[14] Scipy_signal (python3 sweep waveforms) [Online]. Available: https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.chirp.html

[15] Gyorok, G., *Interactive Monitoring of Serial Electronic Circuit with Embedded Microcontroller*, INES 2019 - IEEE 23rd International Conference on Intelligent Engineering Systems, Proceedings, 2019, pp. 71–74, 9109501

[16] Beszédes, B., Széll, K., Györök, G., A highly reliable, modular, redundant and self-monitoring psu architecture, Acta Polytechnica Hungarica, 2020, 17(7), pp. 233–249

[17] PA2OHH, Rms meter with soundcard and software written in python (2011-2018) [Online]. Available: https://www.qsl.net/pa2ohh/index.html

[18] Dr. Bölöni Péter, Gellérthegyi József, Dr. Horváth Elek, Major László, Dr. Mersich Ivánné, Molnár János, Dr. Nagy Józsefné, Nemeskéri Istvánné: *Méréstechnika*. ÓE KVK 1161. Budapest, (2010)

[19] Jürg Jecklin, *Lautsprecherbuch franckh'sche verlagshandlung, kosmos-verlag*, Stuttgart (1967)

[20] Dr. Wersényi György, *Műszaki akusztika jegyzet*. (2010)

[21] Mark Allen Durivage, *Practical Attribute And Variable Measurement Systems Analysis (MSA) A Guide for Conducting Gage R&R Studies and Test Method Validations*, ASQ (2016)

[22] Burdick, R. K., Borror, C. M., & Montgomery, D. C. (2003). *A Review of Methods for Measurement Systems Capability Analysis.* Journal of Quality Technology, 35(4), pp. 342–354.

[23] Hoong, E. C. M. (2008). *Shortest Travel Distance For Full Reads On Least RFID Friendly Carton Stacking Configuration Using Advance DOE Techniques and Gage Reproducibility and Repeatability.* 2008 IEEE International Conference on RFID.

[24] Shabra, A., Cooney, P., Cantoni, A., Bamford, J., Ho, S., & Ashburn, M. (2019). *A 20 kHz Bandwidth Resistive DAC with 135 dBA Dynamic Range and 125 dB THD.* 2019 IEEE Custom Integrated Circuits Conference (CICC).

[25] Margaliot, M., & Weiss, G. (2010). *The Low-Frequency Distortion in D-Class Amplifiers.* IEEE Transactions on Circuits and Systems II: Express Briefs, 57(10), pp. 772–776

[26] Siniscalchi, P., & Hester, R. K. (2009). *A 20 W/Channel Class-D Amplifier With Near-Zero Common-Mode Radiated Emissions.* IEEE Journal of Solid-State Circuits, 44(12), pp. 3264–3271.

[27] Gyorok, G., Beszedes, B.,*Concept of a Reliable Redundant Off-grid Power Supply Chain*, SACI 2019 - IEEE 13th International Symposium on Applied Computational Intelligence and Informatics, Proceedings, 2019, pp. 205–210, 9111605

[28] Chen, K.-H., & Hsu, Y.-S. (2012). *A High-PSRR Reconfigurable Class-AB/D Audio Amplifier Driving a Hands-Free/Receiver 2-in-1 Loudspeaker.* IEEE Journal of Solid-State Circuits, 47(11), pp. 2586–2603