Omnidirection acoustic source: Design methodology and physical realization

Fuente acústica omnidireccional: metodología de diseño y realización física

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Abstract

Omnidirectional acoustic sources are fundamental systems to ensure proper acoustic measurements regarding phenomena such as reverberation and acoustic isolation. When designing such a system, classical traditional sources are the dodecahedral ones, but there are newer approximations such as the icosidodecahedron, which is designed in this paper, that involve more complex mathematical formulations, however with interesting features and properties. This project is relevant in the sense that it serves for autoequipment purposes for the Sound Engineering program.

Keywords: Omnidirectional sources, Acoustic radiation, Measurements and Standardization, Audio equipment.

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Resumen

Las fuentes acústicas omnidireccionales son sistemas fundamentales para asegurar mediciones acústicas propicias con respecto a fenómenos como reverberación y aislamiento acústico. Cuando se diseñan estos sistemas, las fuentes clásicas tradicionales son los dodecaedros, pero nuevas aproximaciones como el icosidodecaedro se diseña en el presente proyecto, incluyendo formulaciones matemáticas más complejas, sin embargo, con características y propiedades interesantes. Este proyecto es relevante desde el punto de vista que sirve para propósitos de autoequipamiento del programa de Ingeniería de Sonido.

Palabras clave: Fuentes omnidireccionales, radiación acústica, mediciones y estandarización, autoequipamiento.

1 Introduction

The development of omnidirectional acoustic sources has gained significance in recent decades due to their widespread use in acoustic and electroacoustic measurements. This type of source is used in tests for acoustic properties in rooms and in the calibration of measuring equipment, which is essential in disciplines such as Sound Engineering. The design of an omnidirectional source allows for the creation of a homogeneous sound field in all directions, thereby ensuring the accuracy of acoustic parameter measurements such as reverberation time and impulse response, among others (ISO 3382, ASTM E2235) [1], [2].

The most commonly used omnidirectional source is the dodecahedral shape, which consists of a solid body with twelve flat faces, each equipped with a speaker. This design facilitates uniform sound dispersion in all directions, a key characteristic for measuring the impulse response, which in turn is used to determine the acoustic properties of a room [3]. Houterman [4] discusses in his thesis the detailed design of an omnidirectional source based on the dodecahedron, and how this type of geometry contributes to the uniformity of sound radiation.

Several researchers have further explored materials and design techniques to enhance the directionality and efficiency of such sources [5], [6].

In the Colombian context, the use of omnidirectional sources has expanded, driven by the growth of companies specializing in acoustic diagnosis and design. Companies such as LEQ Ingeniería Acústica y Control de Ruido have significantly contributed to solving acoustic design and conditioning problems, offering consulting services that range from home studies to large-scale projects [7]. However, the lack of an omnidirectional source in educational and research institutions, such as the Universidad de San Buenaventura Bogotá Campus (USBBOG), limits the ability to conduct advanced research and obtain reliable results in acoustic analysis [8].

The project to design and build an omnidirectional acoustic source arises in response to this need, proposing the creation of a device that not only complies with current international standards (ISO 140-14) but also enables USBBOG to strengthen its research infrastructure and establish itself as a benchmark in the evaluation and design of acoustic systems in Colombia [9], [10].

The proposal not only focuses on the design and construction of the source but also considers the evaluation of its performance based on ISO and ASTM standards, thus ensuring its applicability in multiple contexts. Previous studies have shown various approaches to the design of omnidirectional sources, from the use of specific materials to the exploration of different geometries that enhance sound dispersion [11], [12]. Sayin et al. [13] proposed a system based on parametric speakers to achieve more precise omnidirectional radiation at high frequencies, while Verheij et al. [14] investigated reciprocal methods for noise source characterization and sound path quantification.

These works have been fundamental in understanding sound distribution in enclosed spaces and serve as references for the conceptual design of the proposed device. Additionally, local research efforts in energy-efficient electromechanical systems [15], optimization algorithms for equipment layout [16], and axial generator design using multiphysics simulations [17] contribute valuable insights applicable to acoustic source design in emerging economies. For instance, the integration of simulation tools such as COMSOL Multiphysics allows researchers to model acoustic radiation patterns under controlled virtual conditions [17].

In conclusion, the implementation of an omnidirectional source at USBBOG will not only contribute to improving the research capabilities of the Sound Engineering program but will also enable the development of acoustic consulting services and the execution of advanced studies, benefiting both the academic community and the local industry [18], [19].

2 Methodology

The development of the omnidirectional acoustic source will be carried out in several phases, ranging from the measurement of the fundamental parameters of the speakers used to the final evaluation of the device. The methodology is structured into activities that ensure the quality and precision of the obtained results. The main methodological stages are described below.

2.1 Thiele-Small parameters Measurement

The first stage of the project involves measuring the Thiele-Small parameters of the selected speakers for the omnidirectional source. These parameters, which include the force factor (BL), resonance frequency (Fs), acoustic capacitance (Vas), and efficiency (η), are crucial for defining the electroacoustic characteristics of the speaker. The parameters will be obtained through frequency response and impedance analysis techniques [20], using an audio analyzer and a measurement system with specialized software (e.g., CLIO FW-02 or the LIMP module from ARTA). This will allow for the characterization of each speaker's response in a controlled environment and provide precise data that will be used in the design of the source.

2.2 System Simulation and Modelling

Once the Thiele-Small parameters are obtained, the next step is to simulate the speaker's behavior using tools such as MATLAB and Simulink. Through these simulation environments, the speaker's characteristics within the designed acoustic enclosure will be validated to ensure uniform dispersion across the desired frequency range. The Fourier Transform will be employed to evaluate the frequency response of the source, and design adjustments will be made based on the results obtained [21], [22]. This phase also includes the simulation of the acoustic radiation pattern to ensure an omnidirectional distribution of sound.

2.3 Design and Construction of the Dodecahedron

The omnidirectional source will be built in the shape of an acoustic dodecahedron, leveraging the symmetry of this geometry to achieve uniform sound dispersion in all directions. Each of the twelve faces of the dodecahedron will be equipped with a previously characterized speaker. Materials such as MDF (medium-density fiberboard) or polymers will be selected, as they offer a good balance between stiffness and weight, ensuring a solid structural assembly [23]. Mechanical tests will be conducted to evaluate the resonance of the structure and optimize the material used.

2.4 Performance Evaluation and Validation

Once the prototype is built, tests will be conducted to evaluate its performance in a controlled environment. These tests will include measuring the sound radiation pattern and verifying compliance with international standards, such as those specified in ISO 3382 [1] and ISO 140-14 [9]. A Class 1 sound level meter, along with a calibrated reference microphone, will be used to measure sound pressure at multiple positions and distances from the device. Standardized procedures will be applied to measure reverberation time (RT60) and impulse response (IR), ensuring the reliability of the results [24], [25].

2.5 Comparative Analysis to other Source types

To evaluate the efficiency of the developed device, a comparative analysis will be conducted with other commercial omnidirectional sources available on the market. Parameters such as sound field uniformity, frequency stability, and signal-to-noise ratio (SNR) will be considered [26]. This analysis will validate the design quality and its applicability in various acoustic and measurement applications.

2.6 Final steps towards System Optimization

Based on the results of the evaluations and comparisons conducted, the design of the omnidirectional source will be optimized by adjusting the structure and speaker configuration. Finally, all obtained results will be documented, generating technical and scientific reports that detail each of the methodological stages, ensuring the reproducibility of the experiment and contributing new knowledge to the field of applied acoustics [27].

3 Results

3.1 Loudspeakers selection

The next table summarizes the parameters to choose:

Characteristic	**Requirement**
Size	4 to 6 inches
Nominal impedance	8Ω to 16Ω
RMS Power	60 to 200 W
VAS	Less than 2 L

Frequency Response	Flat between 125 and 4 KHz
Sensibility	Highest possible

Table 1. Parameters for the driver

Finally, the selected loudspeaker was “LaVoce WSF041.00 Ferrite Woofer”.

The characteristics of the selected loudspear are listed:

Driver	LaVoce WSF041.00 Ferrite Woofer
Diameter	4"
Power RMS [W]	40
Power MAX [W]	80
S [dBSPL]	90.4
SPL@1m	106
Impedance [Ω]	8
VAS [L]	1.41/1.5
RFreq [Hz]	200-4000

Table 2. LaVoce WSF041.00 Loudspeaker Specifications. Ferrite Woofer

3.2 Amplifiers parameters

The total necessary power is 960 W, and therefore the selected amplifier is the *2 Channel 3200 Watts Professional Power Amplifier SYS-3200,* with the following parameters:

High-frequency Response	10Hz – 50kHz at 1.5 dB
Total Harmonic Distorsion	Less than 0.1%
Input sensibility and impedance	0.77 V
Signal-to-noise Ratio	(20 Hz - 20 kHz) > 90dB

Dimensions (WxDxH)	20.1” x 13.4" x 6.3”
AC	115V-230V
Power	2 Ohm //4 Ohm //8 Ohm 1600W //800W //400W

Table 3. Specifications 2 Channel 3200 Watts Professional Power Amplifier SYS-3200

3.3 Design parameters

The main design parameter of the omnidirectional source is to achieve an infinite screen that separates the faces of the drivers, being the equivalent of exceeding twelve times the VAS [L] of one of the drivers. Additionally, the twelve-sided arrangement with speakers, using an Icosidodecahedron shape, with twelve pentagonal and twenty triangular faces, allows it to resemble a sphere, so that the signal reproduced is omnidirectional.

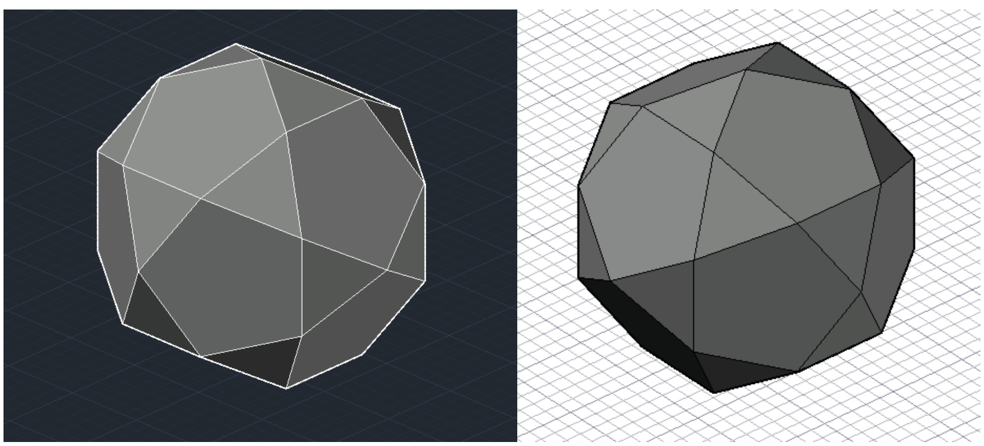

Figure 1. First model of the omnidirectional source

Once the speaker was selected and the total volume occupied by both the drivers and the compliance of the assembly was known, the maximum volume of the polyhedron was established, initially at 20 liters. The dodecahedron was modeled in AutoCAD from a cube of this volume within which the icosidodecahedron was built to know the measurement of the edges of each of the twelve (12) pentagons of which it is compound. The edge of the final model is 0.1152 m, and the total volume is 21.176 liters. The material selected for the construction of the fountain is 18mm wide MDF. This material is distributed in sheets of 1.80 m by 2.44 m and the selection was made considering that we are looking for a resistant material that does not cause a considerable increase in the weight of the model.

3.4 Design of the electrical system and subwoofer

Symmetrical voltage source with opening control, short circuit and reverse current protection

To guarantee the correct operation of the system, a symmetrical power supply was designed consisting of a control stage with a NE555 timer in monostable configuration and a continuous voltage regulation stage adding the appropriate protections against short circuit, reverse current and voltage spikes with the following specifications:

Parameter	Value
Source voltage	120-115VAC (60Hz)
Delivered voltage	±12VDC
Maximum current	1A
Activation Time	3 s

Table 4. Specifications of symmetric source power

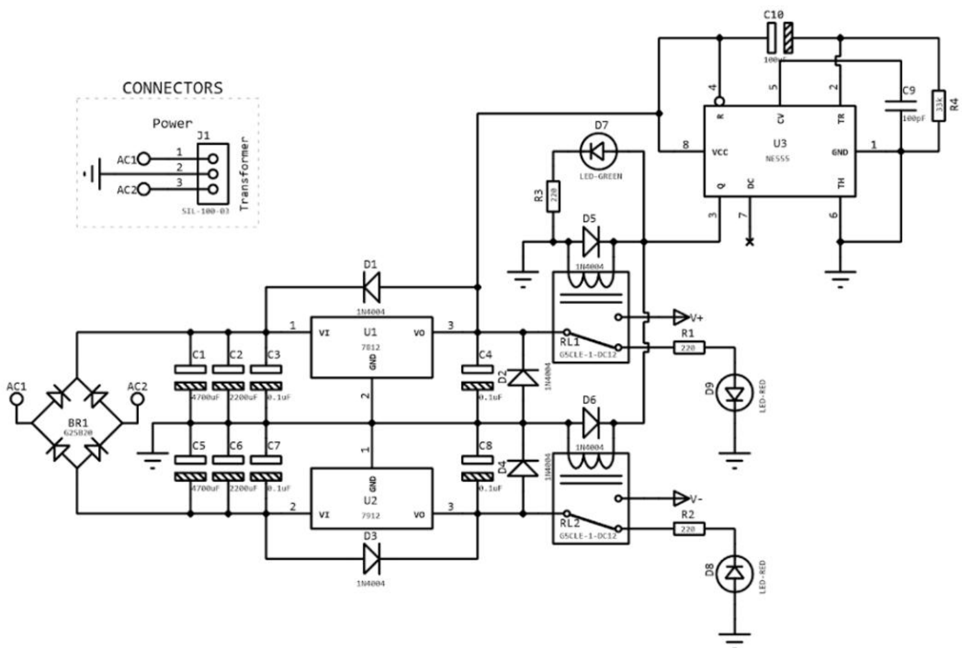

Figure 2. Symmetric voltaje source (12V – 1 A) with switching control, protection for short-crcuits and inverse current with reles and NE555 timer in monostable configuration

3.5 Active crossover design (2-ways with balanced inputs and outputs)

For filtering the woofer and the subwoofer, an active crossover with 2nd order Butterworth filters will be implemented. In this manner, 12 loudspeakers will be filtered. The design contemplates the use of operational amplifiers (JFET type), TL074 and TL072, which are operational amplifiers of low noise, low power consumption and bandwidth 3MHz that makes them ideal for audio applications.

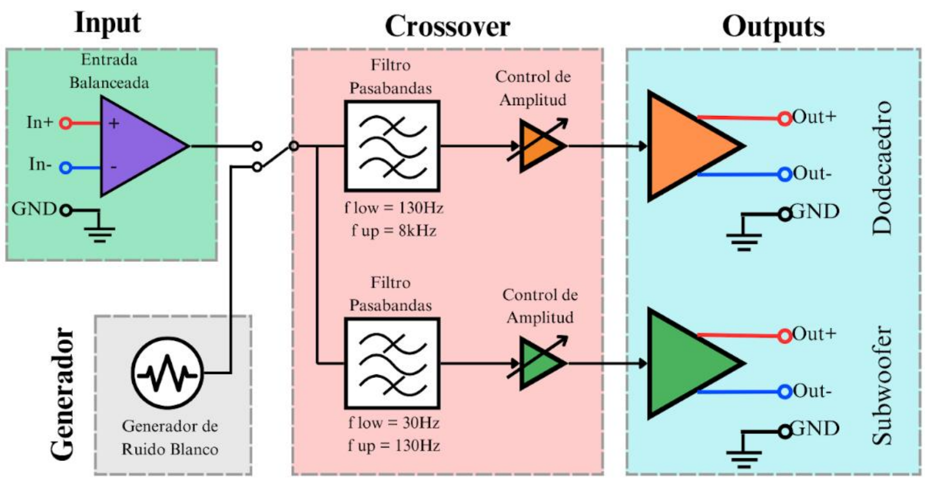

Figure 3. Two way active crossover.

The following table summarizes the technical specifications of the crossover:

Parameter	Value
Source Voltage	±12VDC
Woofer Frequency Response	130 Hz - 8kHz
Subwoofer Frequency Response	40 Hz - 130Hz
Maximum voltaje level/ White noise generator	+4dBu
Output voltaje maximum level	+12dBu
Input voltaje maximum level	+12dBu

Table 5. Technical specifications of the crossover

3.6 Balanced input

For the balanced input, the implemented configuration presented in Figure 7 has the advantage that the input impedance may be as high as desired, resistances R2 and R6 may take values between 10K and 1M, which enables to configure in a simple way the input impedance. CMMR may be improved to 58 dB at 20 kHz.

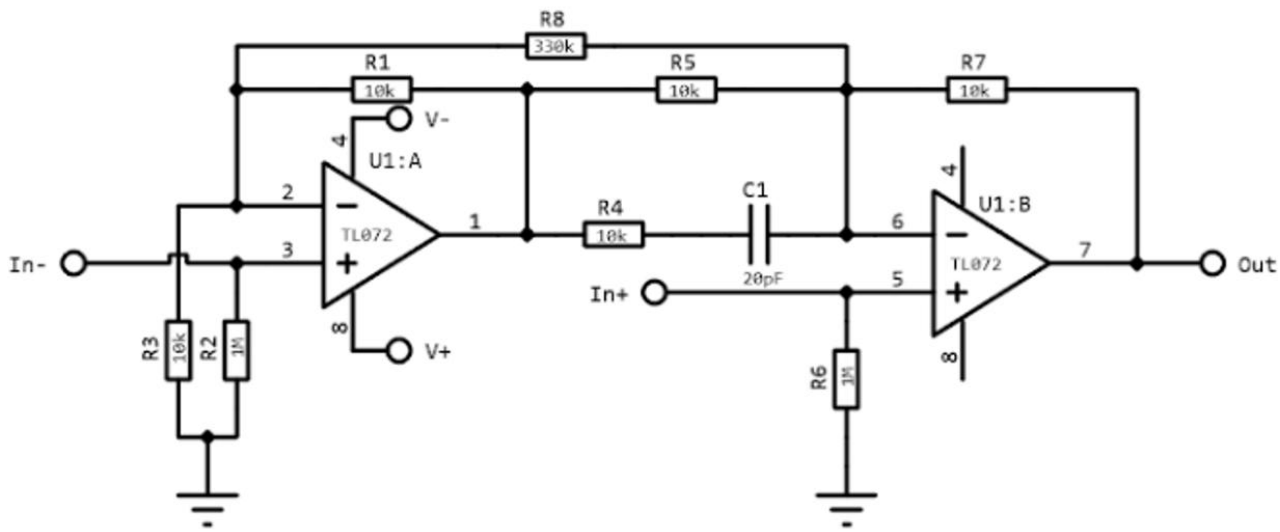

Figure 4. Phase network balanced input

Resistance R8 may be added to improve gain. If R8 is omitted, the circuit has a 6dB gain. If R8 is 10k, the circuit has a 12 dB gain.

3.7 2nd order Butterworth Filter Design (Active Crossover Design)

3.7.1 Woofer section

High-pass filter with cut-off frequency fc = 130 Hz was developed taking the Frequency Response of the loudspeaker “LaVoce WS041.00” as the basis.

$$R1=22\pi 130\cdot 100nF= 17.3k\Omega \quad (2)$$

Last, R2=8.6kΩ and Rf=R1 are considered.

Adjusting to comercial values, R1 and Rf will be obtained, summing up three (3) resistances (6.8kΩ, 10kΩ and 680Ω). For R2, two (2) resistances are summed up (6.8kΩ and 2kΩ).

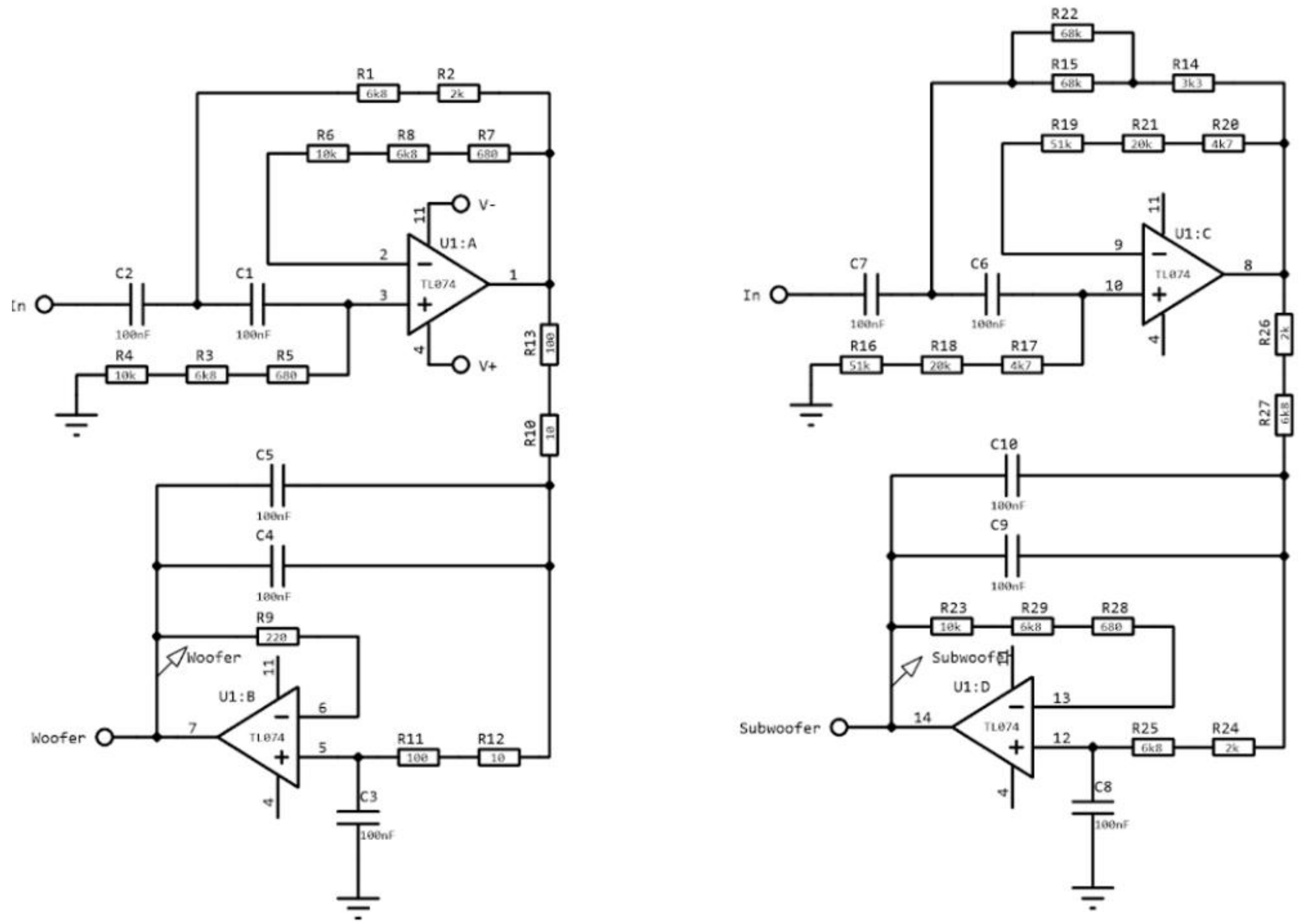

Figure 5. Filter for loudspeaker – woofer type. Own source.

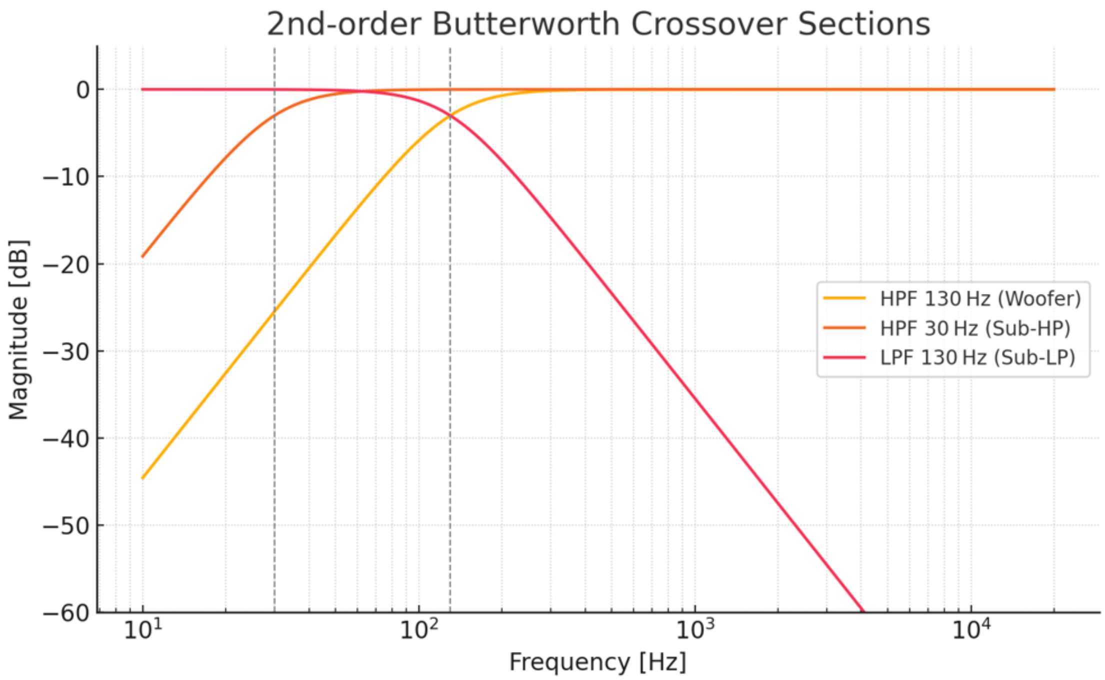

Figure 6. Frequency Response of implemented filters (Crossover)

The plot below shows the magnitude of the three 2nd-order Butterworth sections used in the active crossover.

(Orange = woofer HP 130 Hz • Red = sub HP 30 Hz • Pink = sub LP 130 Hz)

(The vertical dashed lines mark the 30 Hz and 130 Hz knee frequencies.)

3.7.2 Subwoofer section

The construction of the high-pass filter with cut-off frequency fc = 30 Hz was developed considering the Frequency Response of the loudspeaker. The capacitor was fixed in 100 nF.

The following values were obtained for the protection filter for low frequencies that are not in the operation frequency of the subwoofer:

R1=22π30·100nF= 75kΩ   (2)

Last, R2=37.5kΩ and Rf=R1 are considered.

Adjusting to comercial values, R1 and Rf will be obtained, summing up three (3) resistances (51kΩ, 20kΩ and 4.7kΩ). For R2, two (2) resistances in parallel (68kΩ) and one in series (3.3kΩ) are adjusted.

Likewise, a second order Butterworth low-pass filter was implemented with a cut-off frequency fc=130Hz and a capacitor C=100nF. From these values, the resistance R was calculated,

R=12π2130·100nF 8.6k Ω   (1)

Finally, Rf=2R and R=R1=R2 are considered.

Adjusting to comercial values, R1 and R2 will be obtained from the sum of the two resistences, a 6.8kΩ and a 2kΩ values. Rf will be obtained, summing up three resistances (6.8kΩ, 10kΩ and 680Ω); C1=100pF and C2 will be the series of two 100nF capacitors.

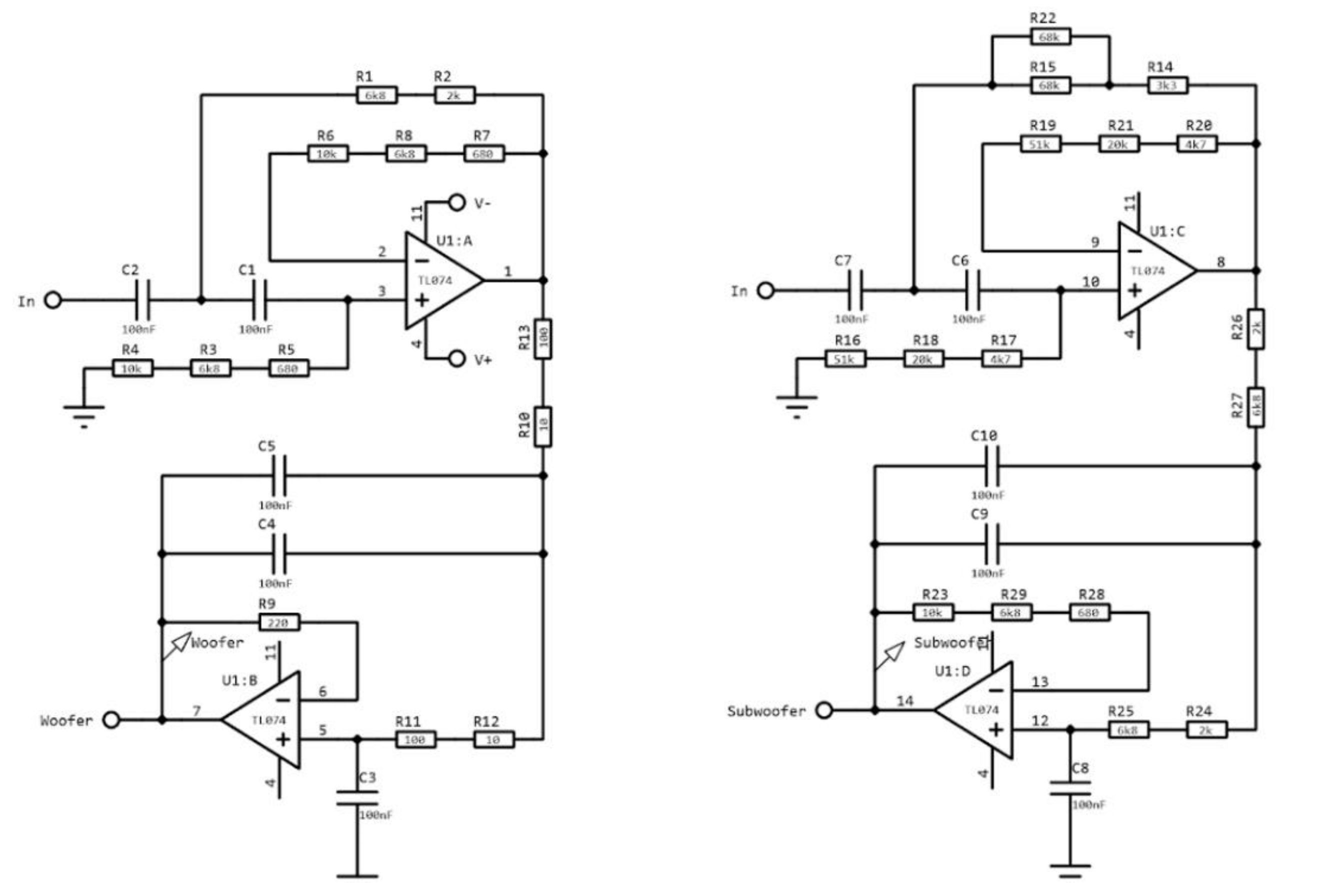

Figure 7. Filter for loudspeaker of a subwoofer type. Source: Own.

3.7.3 Subwoofer Design

For the subwoofer, the aim is to extend the low frequency response, which is why a ventilated or Bass Reflex cabinet design is chosen, which uses the theory of the Helmholtz resonator applied to an acoustic box, where it is composed of a volume of air, a port and the speaker itself that activates the system, improving its efficiency at low frequencies.

3.7.4 Simulation software

The *Basta!* simulation software is used in order to have a first glance, and adjust the subwoofer Frequency Response. The figures show the results obtained in the simulation.

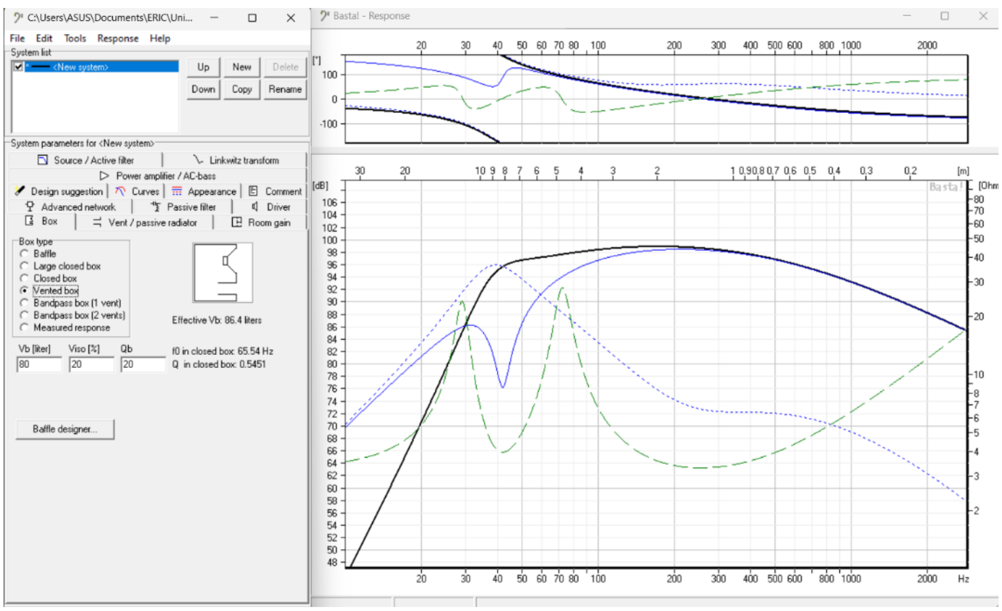

Figure 8. Acoustic curves obtained in the simulation software for the acoustic boxes

In this manner, an approximation to the acoustic box and the port dimensions is achieved.

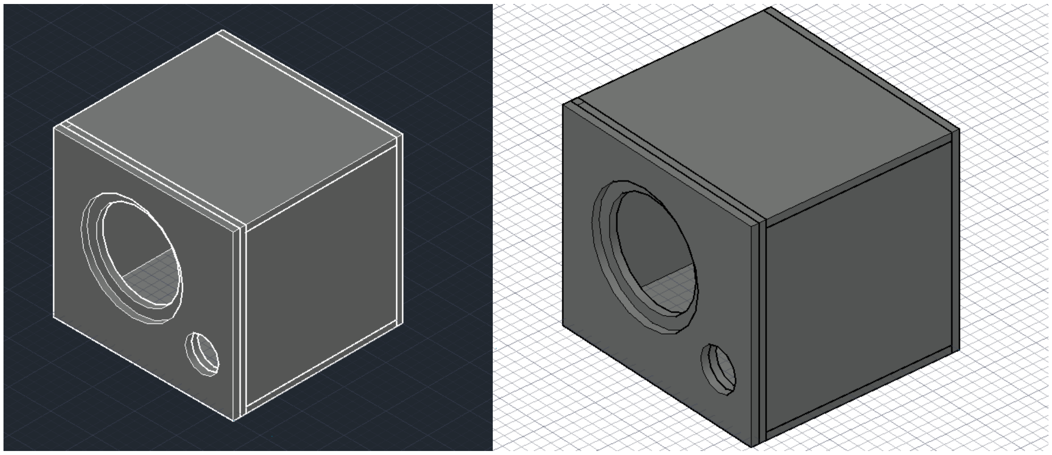

Figure 9. Design of subwoofer acoustic box

4 Methodology for measuring Thielle-Small parameters

For the criteria design it is necessary to know the Thielle Small (T/S) parameters. 26 loudspeakers were characterized, determining average behavior, this with the DATS V3 that enables us to measure the impedance response of a loudspeaker and from this, to derive the T/S parameters.

4.1 DATS V3 Method

The process consists of exciting various arrays of loudspeakers (in series) through a 100 Hz sine signal during a definite amount of time (between 1 and 2 hours).

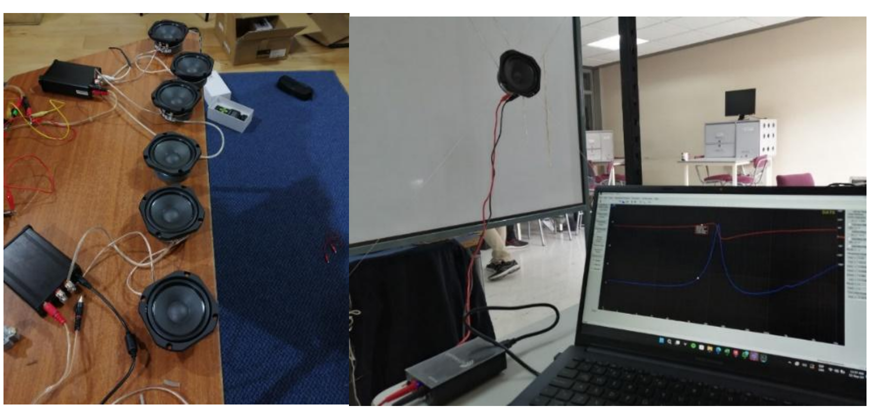

Figure 10. Loudspeaker array for Break in

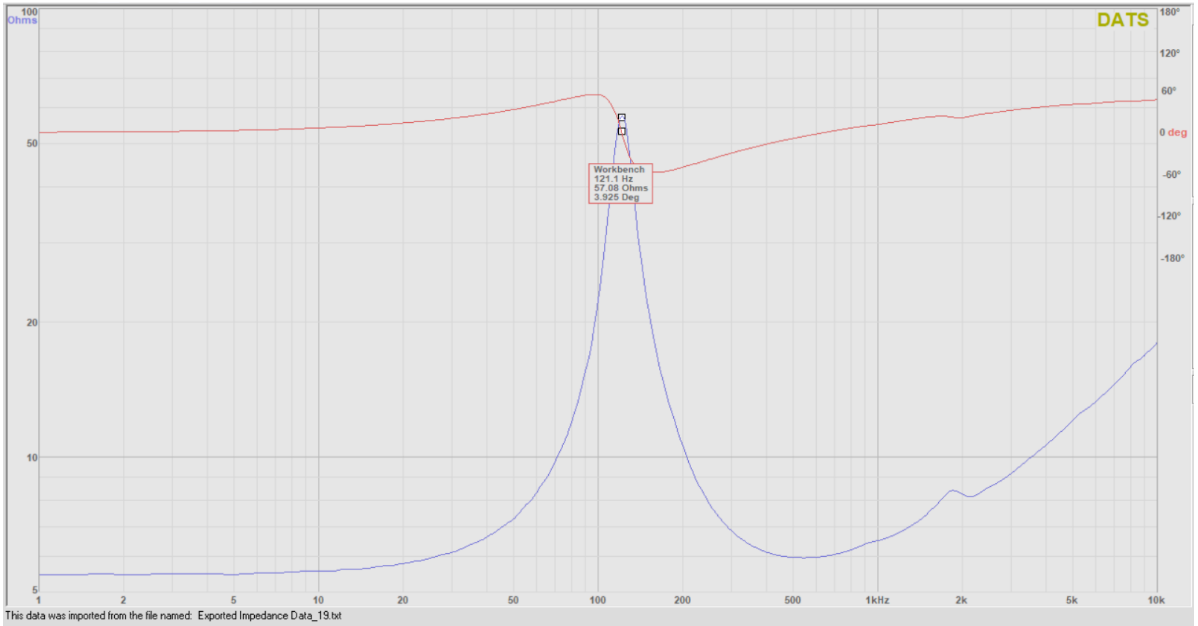

Figure 11. Impedance Response with DATS V3 method

Afterwards, a plasticine was placed in the loudspeaker cone in order to change the resonant frequency of the system. Taking into account the loudspeaker mass and diameter, the software determines the T/S parameters automatically. In this case, a 14.2 grams mass was used.

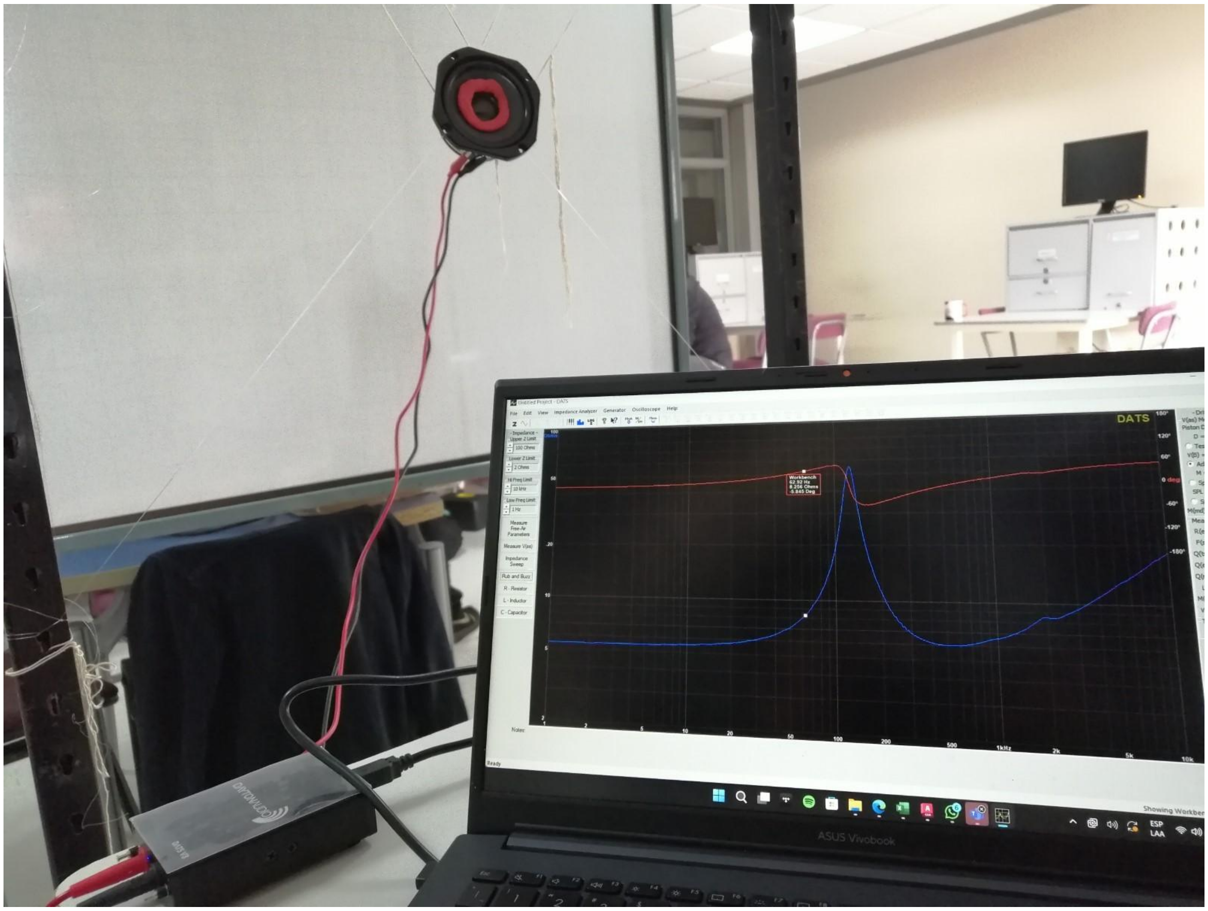

Figure 12. Impedance measurement with Mass using DATS V3

4.2 Omnidirectional source construction parameters

This step consists on joining a pentagon to each fase of the triangles. In this manner, the poligon is acquiring its sphere form. In order to find the angle of the unions, a circunference is divided in ten triangles through radios traced from the circunference centre until the extreme vertices of it; the resultant triangles are isosceles triangles, having two equal angles and the third one has a different value. The value may be achieved dividing the 360 degrees in ten (10) traced triangles, resulting in 36 degrees. To complete the 180 degrees of the angles of the triangle, the 36 degrees already obtained are multiplied by 2 (2) so the angle corresponds to 72 degrees. Which means that for the pieces to fit together correctly forming the figure of the icosidodecahedron, the edges of the pieces must be cut with a combined angle of 72 degrees.

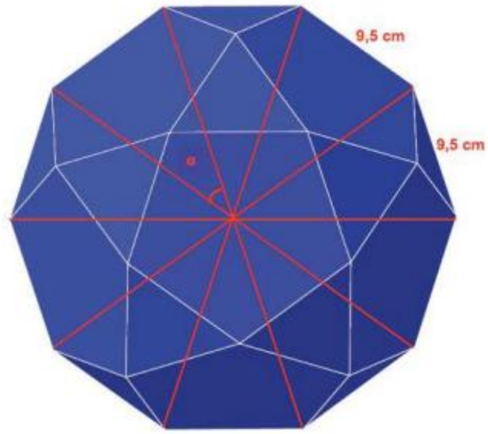

Figure 13. Final design of the acoustic box

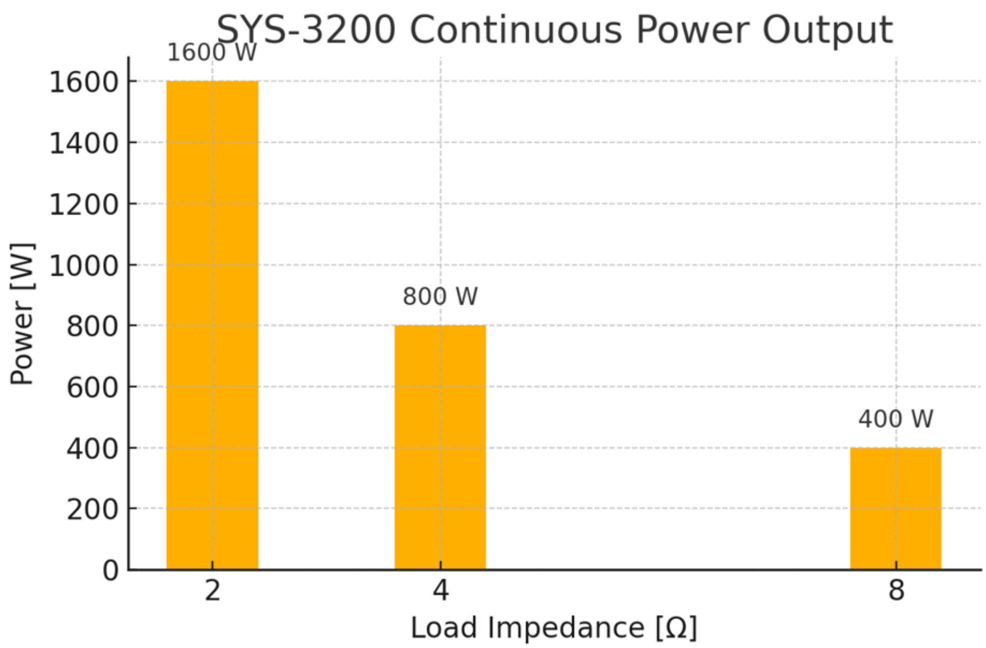

Figure 14. Power Output performance

Bar chart of SYS-3200 continuous power indicates that even at 4 Ω / speaker-bank the system runs at ~84 % of maximum; there is ample reserve for pink-noise calibration bursts.

The following table presents the most transcendental results with respect to each one of the designed subsystems. The bar graph confirms each SYS-3200 channel can supply > 6 dB above long-term pink-noise calibration level.

Subsystem	Design	Results
Radiator	12 × LaVoce WSF041.00 4-inch ferrite woofers	4″ chassis keeps each face compact; 90 dB @ 1 W/1 m and VAS ≈ 1.5 L satisfies the “infinite baffle” rule of *12 × VAS* for the icosidodecahedron
Amplifier	2-ch SYS-3200 (1600 W @ 2 Ω per ch)	Provides the 960 W budget (80 W × 12 drivers) with 6 dB of head-room; THD < 0.1 % and S/N > 90 dB keep the source well below IEC Class 1 self-noise limits
Active crossover	2-way, 2nd-order Butterworth: HP 30 Hz & LP 130 Hz (sub); HP 130 Hz (woofer)	Aligns with the usable bandwidth (125 Hz-4 kHz) and minimises phase rotation at the 130 Hz hand-over
Power supply	±12 V, 1 A symmetrical, NE555-timed soft-start	Prevents in-rush & reverse-polarity damage, sized for 14 op-amps + relay coils
Enclosure	MDF 18 mm icosidodecahedron, edge = 115 mm, V ≈ 21 L	Geometric quasi-sphere (< ±1 dB directivity error to 4 kHz) and < 8 kg weight target

Table 6. Results of the designed subsystems

```
     Balanced XLR IN
            │
        [Phase-network]      ±12 V PSU
            │                    ▲
            ▼                    │
       2-Way Active XO ◄─────────┘
            ││
   ┌────────┘└────────┐
   ▼                  ▼
 SUB AMP ch-A      WOOFER AMP ch-B   (SYS-3200)
   │                  │
  1×Sub               12×4″ drivers (icosidodecahedron)
 (vented box)         ▲
                      │ MDF 18 mm enclosure (edge 115 mm)
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Figure 15. Connections of the electroacoustic subsystems

The enclosure edges are cut at 72 ° to mate the 20 triangles and 12 pentagons that build the icosidodecahedron, approaching a sphere with $< \pm 1$ dB polar ripple up to 4 kHz.

Conclusions

The project successfully designs a dodecahedron-based omnidirectional acoustic source that meets the requirements for acoustic measurements. The geometric design, speaker selection, and materials were carefully chosen to ensure uniform sound dispersion across all directions, as required for accurate acoustic analysis in various environments.

The use of materials like MDF and high-quality plastic for the construction of the acoustic source ensures rigidity and avoids unwanted interference. Additionally, the project includes a calibration method that guarantees each speaker emits sound at the same intensity, which is crucial for reliable measurement.

The omnidirectional source adheres to international standards such as ISO 3382 and ASTM E2235, ensuring that it can be used for professional acoustic measurements. The performance evaluation demonstrated that the source provides uniform sound dispersion and can be effectively used for measuring impulse response and reverberation time.

The selection of an appropriate amplifier and high-quality speakers ensures that the system delivers sound with minimal distortion, maintaining clarity and precision across the frequency range of 125 Hz to 4 kHz.

The development of this omnidirectional source not only enhances the research capabilities of the Universidad de San Buenaventura but also has the potential to be used in professional acoustic consulting services. This positions the university as a leader in acoustic evaluation and system design in Colombia.

The project also identifies areas for future optimization, such as further adjustments to the speaker configuration and material choices to enhance system efficiency. The design was compared to other commercial sources, and while the device showed promising results, additional iterations could further improve its performance.

The 30 Hz HPF prevents sub-sonic excursion, while the LPF/HPF pair at 130 Hz hand-off the sub to the dodecahedral shell smoothly (-3 dB per section, –12 dB/oct). A 21 L polyhedron with 4″ drivers meets the “infinite-baffle” criterion (12 × VAS) yet remains man-portable.

Finally, the soft-start PSU, op-amp bandwidth, and low THD figures ensure IEC 61672 compliance when used as a reference source.

Future work and Recommendations

Based on the outcomes of the present study, several lines of future work are proposed. First, it is recommended to expand the operational frequency range of the omnidirectional source beyond the current 125 Hz to 4 kHz bandwidth. This could be achieved through the incorporation of low-frequency enhancement techniques, including improved cabinet tuning, larger excursion drivers, or the use of hybrid active-passive radiators, as suggested in [27], [39].

Second, further mechanical refinement of the enclosure is advised to reduce weight and improve damping. The use of advanced composite materials or 3D-printed structures with internal bracing could contribute to a better stiffness-to-weight ratio and mitigate structural resonances [35], [47].

Additionally, incorporating digital processing methods—such as inverse filtering and real-time calibration—can improve the uniformity and linearity of the radiation pattern across different environments [27], [48]. The integration of wireless modules for signal transmission and control, possibly through IoT-based platforms [30], [31], is also suggested to enhance the versatility of the system in field applications.

It is also recommended to carry out more extensive comparative testing against high-end commercial omnidirectional sources in certified acoustic laboratories. This would allow for quantifiable benchmarking, ensuring compliance with ISO 3382 and ASTM E2235 standards [1], [2], [26].

Finally, as this project was developed in an academic setting, the inclusion of the omnidirectional source in laboratory courses can be further enriched through the development of open-access educational resources. This includes technical manuals, simulation datasets, and measurement guides to promote reproducibility and collaboration across institutions [18], [19].

Acknowledgments

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