

Computers in Acoustical Engineering Education: Loudspeaker System Simulation Program.

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Abstract: In the last years loudspeaker simulation software has been a great development in order to study and design radiator systems. Specially, in acoustical engineering teaching it has been an important tool to help student in loudspeaker systems comprehension. Commercial software has its particular characteristics and it is not adequate its use always. Our department has developed different packages programmed in Matlab in order to provide a simple use and understanding of loudspeaker behaviour. Matlab has been selected for its numerical and graphical capabilities and let the user not to have great skills in programming and focusing his attention in loudspeaker understanding. The software we will describe allows the study and analysis of direct radiation loudspeaker systems of one or multiple ways and with different configurations in the woofer one, by means of computer simulation, based on electro-acoustical analogous circuits. This program allows simulating the electrodynamic loudspeaker behaviour from the electrical, mechanical and acoustical point of view, and could get information about different variables frequency response (like pressure, volume velocity, displacement, acceleration, etc.). Also, we could get information about the system temporal response. The user could design the electromechanical and constructive system parameters and could change them in any moment during the simulation. Other software feature is focused in the design of two or three ways passive crossover networks, based upon standard configuration (like Butterworth, Linkwitz-Riley, etc.) or in user defined ones. In the same way, we have able an option to import experimental data from laboratory measurements with different equipment (FFT spectrum analysers, RTA spectrum analysers and MLS analysers), that allows students verifying the models used in simulation. The program has all the graphical facilities from Matlab. This kind of programs is being used for our students with interesting results in the last two years.

Keywords: loudspeaker, simulation, modeling, equivalent circuits.

1. Introduction

Loudspeaker simulation software is an important tool in the design process for manufacturers and in the last years has been a great implantation in universities and research centres. The software we describe in this paper is the last two years work in Audiovisual Engineering Department of Universidad Politecnica de Madrid.

The software is based in the use and analysis of lumped element electrical equivalent circuits of electrodynamic transducers, normally used like radiators in loudspeaker systems. This kind of circuits are very useful in the study of the low frequency margin but it is not capable to model the high frequency margin because not take into account the transversal diaphragm vibrations.

The most general equivalent circuit used in the simulation is shown in figure 1. This equivalent circuit represents the acoustical part of a one way transducer and there we could see a loudspeaker system composed by an active driver - represented by an acoustic impedance Z_{as} (frequency dependent)-, an acoustic enclosure -represented by an acoustic impedance Z_{ab} (frequency dependent)- and a lot of different radiation devices grouped in a parallel branch - represented by an acoustic impedance Z_{aa} (frequency dependent). The analysis of the different volume velocities for each branch allows getting the response function $G(s)$ for this generic system [1], according to equation (1) and once we have the response function $G(s)$, it is possible to evaluate the pressure response $p(s)$ as equation (2).

In the same way, we could analyse the electric equivalent circuit to evaluate the input impedance $Z_{ee}(s)$, as in figure 2.

$$G(s) = s \cdot M_{as} \cdot \frac{-U_b(s)}{p_g(s)} = \frac{-s \cdot M_{as}}{Z_{as}(s) + Z_{ab}(s) + \frac{Z_{as}(s) \cdot Z_{ab}(s)}{Z_{aa}(s)}} \quad (1)$$

$$p(s) = G(s) \cdot e_g(s) \quad (2)$$

In this equivalent circuit, Z_e represents the electrical voice-coil impedance and Z_{es} , Z_{eb} and Z_{ea} represent the electrical transformation of Z_{as} , Z_{ab} and Z_{aa} of figure 1, respectively (all of them are frequency dependent).

$$Z_{ec}(s) = Z_e(s) + \left[Z_{es}^{-1}(s) + (Z_{eb}(s) + Z_{ea}(s))^{-1} \right]^{-1} \quad (3)$$

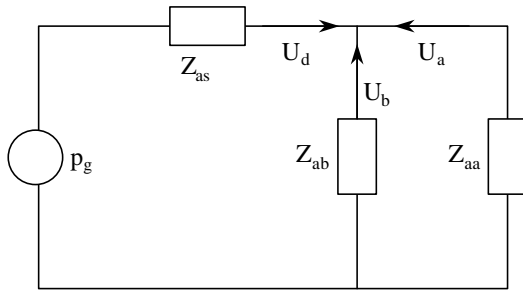


Fig. 1. Acoustical equivalent circuit for a generic one way loudspeaker system.

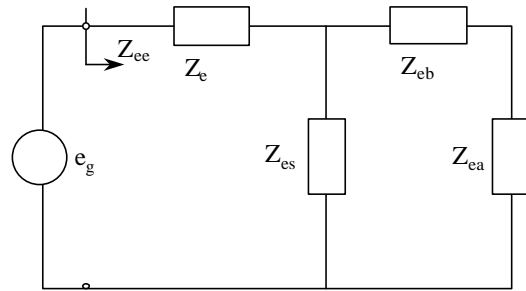


Fig. 2. Electrical equivalent circuit for a generic one way loudspeaker system shown in figure 1

Beginning with the volume velocity analysis of this generic system it is possible to simulate any kind of enclosure, except the case of band-pass system that requires other equivalent circuit to model the multiple chamber configurations.

2. Program description

The simulation software we have developed, called SSAVV [2], is based on the analysis describe before. The program has windows like view, with pop-up menus and dialog windows to select all the variables needed for the simulation.

The program is divided in two different type of systems: one way systems (which include infinite baffle, closed or sealed box [3], vented-box[4], passive-radiator box [5] and band-pass system [6]) and multiple way systems (which include passive filter design of two and three ways).

2.1. One way systems

In one way systems, first the program requires defining the enclosure parameters (internal enclosure volumes and absorption losses) and the Thiele-Small driver parameters. And other geometrical parameters like length and diameter of tuning tubes. Now we select the kind of system to simulate (one of described above). Next step, we could see the acoustical and electrical equivalent circuit corresponding to the selected system, as shown in figure 3.

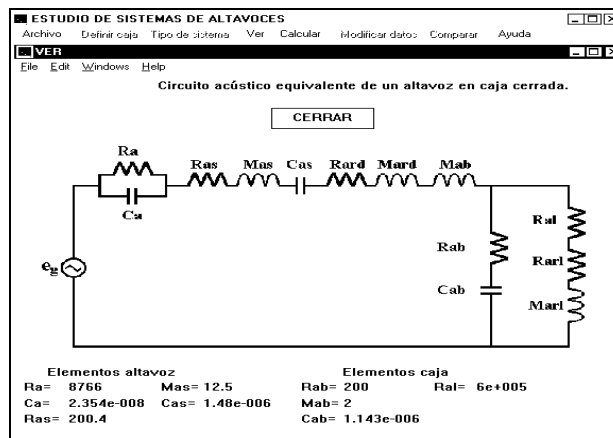


Fig. 3. Lumped element acoustical equivalent circuit for a closed box loudspeaker system.

Now we could select the result to analyse. The program calculates the pressure response versus frequency in condition of sensitivity measurement (free field, on axis, 1-meter distance, and 1-watt electrical power), as we could see in figure 4. From this results and using an inverse FFT algorithm calculates the system impulse response, see figure 5.

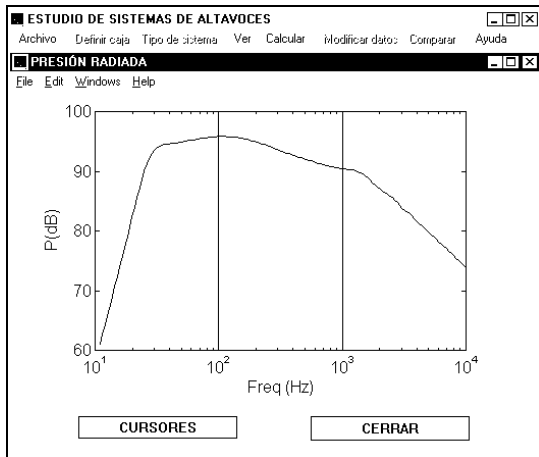


Fig. 4. Radiated sound pressure level for a vented-box system.

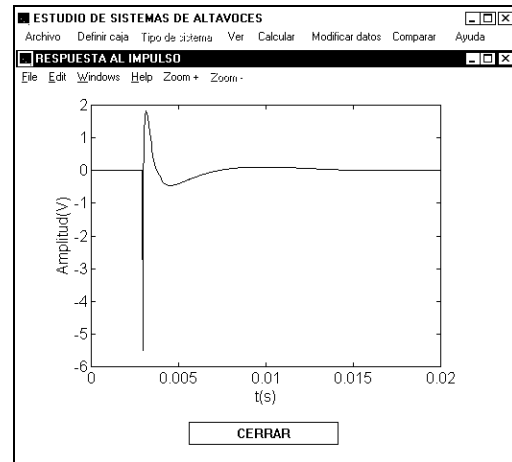


Fig. 5. Pressure impulse response corresponding to system described in figure 3.

In the same way, and analysing the electrical equivalent circuit, we could see the electrical input impedance like in figure 6.

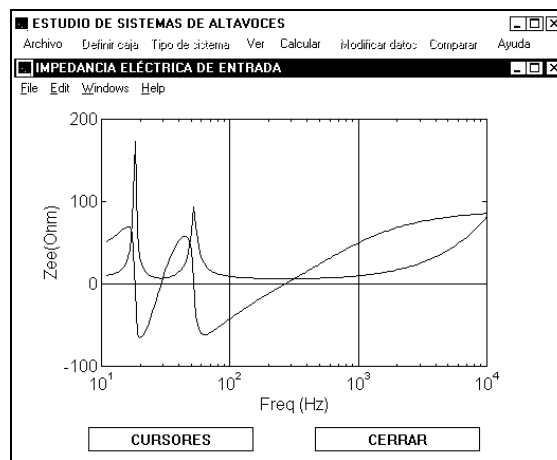


Fig. 6. Electrical input impedance of a passive-radiator system.

Also, the program calculates the volume velocity response versus frequency (see figure 7) and from this evaluates the movement parameter: displacement, velocity and acceleration (see figure 8). All the graphical windows have possibilities to activate cursors slide bars with indication of variable values, grids and zoom options.

The program could represent jointly or separately these responses and compare between different systems, using the capabilities of saving system data to disk and loading data from disk. All data are saved in Matlab as .mat files. After a system simulation, we could modify all parameter so for enclosures, tuning systems and drivers.

Other program capability is importing data files from measurement systems like CLIO and MLSSA, both in time and frequency domain and comparing with results obtained from simulation to validate them. At this moment, we are working with imported data from B&K spectrum analysers, both RTA and FFT, and from AudioPrecision System Two.

The program has an on-line help menu for every options.

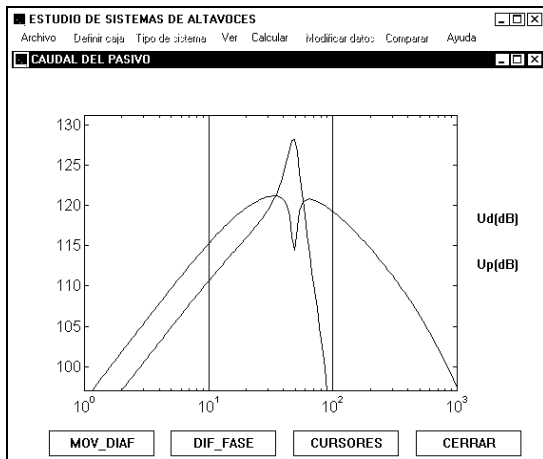


Fig. 8. Movement variables comparison for a closed-box system and a vented-box system.

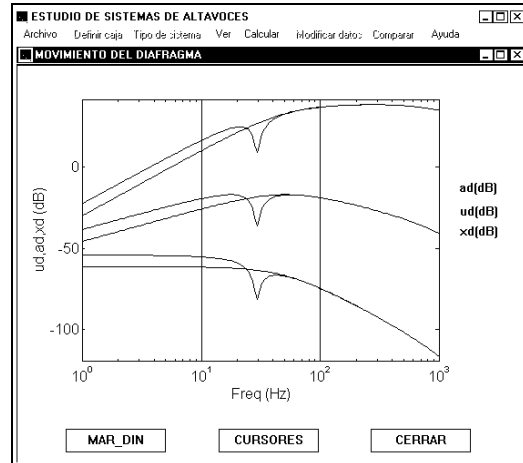


Fig. 7. Volume velocity in a passive-radiator system comparing active and passive driver.

2.2. Multiple way systems

In multiple way system, we could design two and three way passive crossover filter based on classical network or user defined ones [7].

In the case of two way systems, we could select between:

- Butterworth (1st, 2nd and 3rd order).
- Linkwitz-Riley (2nd, and 4th order).
- Constant voltage (symmetrical and asymmetrical 1st, 2nd, 3rd and 5th order).
- Delay-derived high slope (1st, 2nd, 3rd order).
- User defined (where we must type the polynomial coefficient of numerator and denominator for each way).

In the case of three way systems, we could select between:

- Butterworth (1st, 2nd and 3rd order).
- Linkwitz-Riley (2nd, and 4th order).
- Constant power (1st, 2nd, 3rd and 4th order)
- User defined.

In both cases we have to select the crossover frequencies and the program calculates the transfer function (modulus and phase) for each section and the total voltage response (figure 9). Also, calculates the power transfer function, as we see in figure 10.

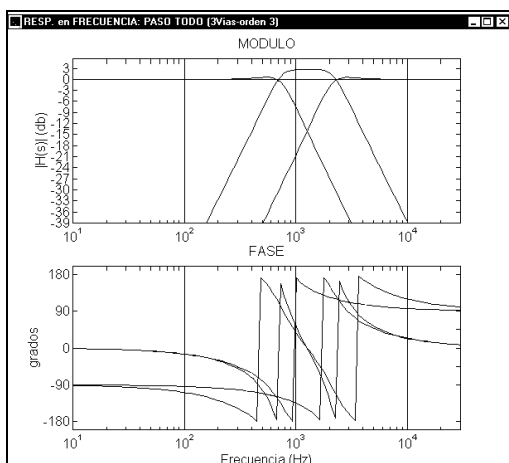


Fig. 9. Example of a 3rd order constant power three way crossover network response in modulus and phase.

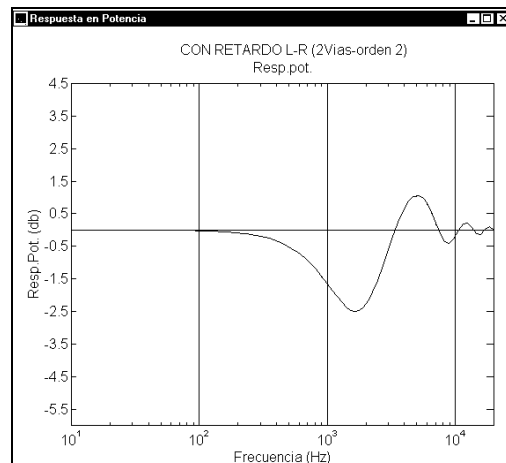


Fig. 10. Power response versus frequency for a 2nd order delay-derived two way crossover network.

In addition, we could simulate the real system response with loudspeakers like network load. The program offers the possibility of selecting for the bass section one of the system described in one way case and for the mid-range and high section simulates the response according to explained in before chapter. An example is shown in figure 11.

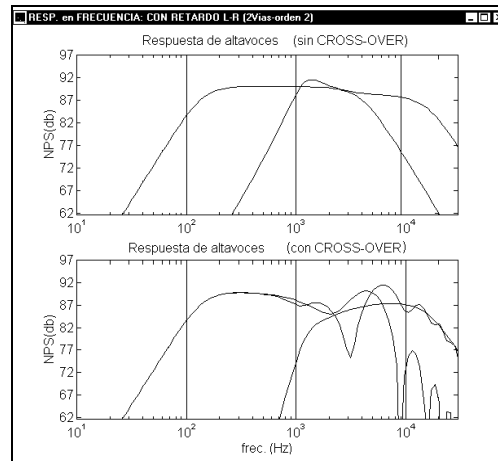


Fig. 11. Pressure response versus frequency for a 2nd order delay-derived two way crossover network with real loudspeaker simulated as in before section.

As a curiosity, it is possible to simulate the variation on tweeter position for acoustic centre alignment. Also, we could make zoom, activate cursors and equalize each loudspeaker frequency response for compensating different sensitivities.

3. Conclusions

The program described is the final result of three preliminary works developed during the last three year in our department [8]-[10].

SSAVV is a simulation software very useful in Electroacoustics teaching, both in theoretical and practical credits. In theoretical one, we use as help in student understanding and in practical one is very useful for comparing loudspeaker simulation with experimental measurement get with packages described before.

Future trends are the inclusion of horn systems and the implementation of finite element method to simulate the loudspeaker behaviour at high frequency.

4. References

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