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Bless the Room: an EQ that Fixes Room Mode Imbalance

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ABSTRACT

You may have experienced times when you are listening to audio and upon moving across the room, the mix of that audio sounds much different. The patterns that sound waves exhibit as they reflect around the room greatly influences the ways we hear audio at different positions in the room. To solve this issue, *Bless the Room* serves as a parametric EQ plugin that fixes the modal frequency imbalance at your exact listening position within your room. This paper details a brief background of the issues that producers and engineers in imperfect spaces face, as well as the processes of how *Bless the Room* fixes these issues.

1 Introduction

As audio engineers, we are faced with the constant challenge of acoustically optimizing our listening environments. When designing recording studios, concert halls, and other music settings, architects and designers must consider room size and shape, building materials, placement of structures within the room, and acoustic treatments—all factors that will influence the ways that sound waves behave in that room. When properly taken into account, these properties can minimize the negative effects of standing waves, sound diffusion, and modal frequency build-ups scattered around the room.

However, what if we aren't given the luxury of designing an optimized room from scratch, and have to transform an existing room into an acoustically acceptable space? This is the situation that a majority of at-home musicians and engineers finds themselves in. This demographic often cannot position themselves at an ideal listening position due to the confines of their room (e.g. a bed taking up significant space), and consequently must deal with the modal frequency build-ups in that particular spot. Whether it's a muddy resonance at low-frequencies, or a series of nulls at mid-frequencies, the phenomena of room mode build-ups tends to be largely overlooked by less experienced producers and engineers lacking the space or budget to improve their room acoustics.

The *Bless the Room* EQ plugin fixes this problem by analysing the user's room and generating EQ settings that balance the most troublesome modal frequencies that occur at the user's exact listening position within their room.

2 Theory and Design

There were many considerations to make when designing the *Bless the Room* EQ. The program not only had to locate each mode within a given room, but also identify which groups of modes were most troublesome, and then determine whether or not to boost or cut them out of the mix, and by how much. Different types of modes and their harmonics exhibit different behaviours when reflected off of surfaces, and with different intensities. These details had to be taken into account during the development process.

Bless the Room was developed using C++ programming in RackAFX, a plugin-designing software created by Will Pirkle.

2.1 Features

The GUI contains the following features:

- Cutoff Frequency knobs for Bands 1-6 (Hz)
- Q Factor knobs for Bands 1-6
- Gain knobs for Bands 1-6 (dB)
- Room Type: a drop-down menu listing several room presets that tell the plugin generally what type of room the user is in.
- Room Dimensions: a section of the GUI that contains knobs for room length, width, and height (ft).
- Listening Position: a section of the GUI that contains knobs for listener X, Y, and Z, indicating the user's distance from the left wall, distance from the rear wall, and distance off the floor.
- BLESS Button: The one-click solution that runs all of the acoustic calculations and adjusts the EQ bands accordingly.

2.2 Finding the Schroeder Frequency

The **Schroeder Frequency** defines the cutoff for "worrisome" (noticeable modes) vs. "worry-free" frequencies. Modes below the Schroeder Frequency are most troublesome to the listener, while modes above the Schroeder Frequency do not contain enough energy to disturb the listener's perception of sound. Equation 1 shows the formula used to calculate this value.

Finding the Schroeder Frequency is the first step of the programming process, as it determines which room modes to analyze and which modes can be ignored. As the equation states, we need to find the volume of our room, provided by our Room Dimensions, as well as the RT60, which is found



Figure 1: *Bless the Room* GUI.

using the room's total acoustic absorption (A). The EQ's Room Type feature contains several room presets that determine the total absorption based on structural materials that are typically found in that type of room.

```
//if (room_type == "Bedroom")
if (room_type == 0) //if(compareEnumToInt(roomTypeEnum::Bedroom, room_type))
{
    double walls1 = A_plaster * length * height * 2; //SA * a * 2 walls
    double walls2 = A_plaster * width * height * 2; //Other 2 walls
    double floor = A_carpet * length * width;
    double ceiling = A_plaster * length * width;
    A_total = walls1 + walls2 + floor + ceiling;
}
```

Figure 2: Snippet of code showing the total absorption (A) calculation of the Bedroom room type. This preset contains walls of plaster, carpeted flooring, and a plaster/popcorn ceiling.

2.3 Identifying the Room Modes

Now that the Schroeder Frequency has been identified, we can begin to look for the modes present in the room.

Room Modes are represented by (p, q, r), which refer to the integer harmonics of a mode. There are 3 types of room modes (Fig. 3):

- **Axial Modes** occur between two opposing walls and are represented by two zeros and one nonzero interval. For example, (2, 0, 0) is a second-harmonic axial mode occurring on the x-axis of the room. Axial modes are the strongest and most noticeable type of mode.

- **Tangential Modes** occur between four walls and are represented by one zero and two nonzero intervals, e.g. (0, 2, 1).

- **Oblique Modes** involve all six walls and are represented by three nonzero intervals, e.g. (2, 1, 3). These modes contain the least energy and are the least prominent in the room.

Note the formula for calculating room mode harmonics [Equation 2]. A triple for-loop is used to cycle through each mode up to third harmonics [from (0, 0, 0) to (3, 3, 3)]. These modal frequencies are stored in a <vector> and then sorted from lowest to highest frequency. If a mode frequency is greater than the Schroeder cutoff, it is disregarded and not added to the vector. Groups of modes that count as a "build-up" are identified later to set the cutoff frequencies and Q factors of the EQ bands.

2.4 Calculating Gain Values

Once a room mode is identified, we must also determine whether or not this frequency at the listening position is closer to a null/node or a peak/antinode (Fig. 4). For a given mode frequency, if the listener is located at a point where the sound wave has a positive amplitude, a *negative* **gain value** will be assigned to that mode and stored in a separate vector for mode gain values. By the same principle, if the listener is positioned on a negative amplitude value of the sound wave, a *positive* gain will be applied.

One thing to note is that the **gain range** for each mode depends on whether the mode is axial, tangential, or oblique. Because axial modes contain the most energy and are more significant to the listener, the gain range for each axial mode is set to [-3dB, +3dB] and is linearly scaled depending on the relationship between the listening position and the amplitude at that point on the sound wave. For example, if the user is positioned exactly on a peak, a value of -3dB will be assigned for that mode.

Tangential modes are scaled from [-2db, +2dB] because they have less energy than axial modes, and oblique modes are scaled from [-1dB, +1dB] because they contain the least energy and only need to be corrected slightly.

The challenge of calculating these gain values stems from the fact that each mode has different properties—meaning different mode types occurring on different axes. The mode (0, 0, 3), for instance, is an axial mode that occurs between the ceiling and the floor; the mode (2, 0, 1) is a tangential mode with 2nd harmonic behaviors on the X axis and 1st harmonic behaviors on the Z axis. Each of these specific modes must be calculated using their respective axes and harmonic patterns.

2.5 Determining Modal Buildups

Now that we have individual gain values strung to each mode, we can determine which clusters of modes are most problematic.

The plugin program proceeds to analyze each mode in the vector of modes that were made in section 2.3. For each mode, if the next highest mode is <=5.0Hz (a reasonable gap between frequencies that is small enough to contribute to a modal build-up), a flag is used to keep track of how many consecutive modes are "too close together" (+1 to the flag for every subsequent mode that is too close). This repeats until a subsequent mode is >5.0Hz away from its preceding mode, at which point the flag count is analyzed. If the flag has reached a count of at least 3 (signaling at least 4 modes that are clustered together), then the program confirms there is a modal buildup among those modal frequencies. The lowest and highest frequency of the build-up are noted by the program, as well as the total (summed) gain value of all the modes in the build-up. The flag is then reset to prepare to search for another build-up.

By the time the list of modes has been fully looked through, the plugin has taken note of the frequency range and total gain of each build-up. With this data, we can finally assign values to the EQ bands:

- Each Cutoff Frequency is assigned the center frequency value of each modal build-up
- Q factor is calculated to capture the full range of the build-up
- Gain knob receives total gain value of each mode in the build-up summed.

The "Bless" Button at the center of the GUI activates steps 2.2 through 2.5, and instantly assigns each buildup to an EQ band to fix the most troublesome modal imbalances present at the user's exact listening position within a room.

3 Figures

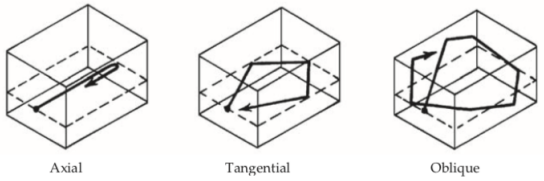


Figure 3: Visualizations of the three types of room modes. Axial Modes occur between two opposing surfaces, Tangential Modes occur between 4 walls, and Oblique Modes involve all 6 walls.

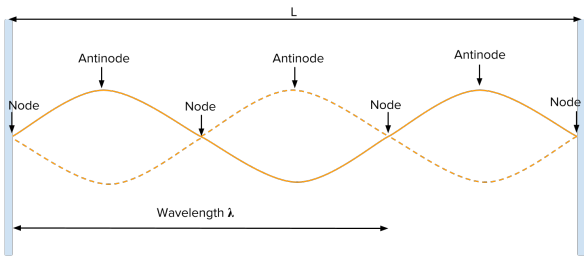


Figure 4: A standing wave with antinodes (peaks) and nodes (nulls) labeled.

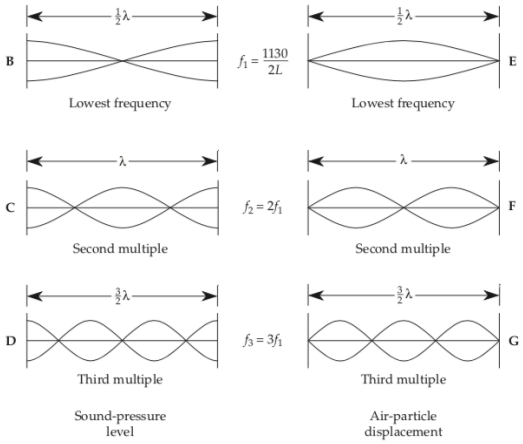


Figure 4: Sound wave multiples.



Figure 6: A screenshot of the plugin after setting the user specs and hitting the "Bless" button. With an example room size of 12.00 ft x 13.00 ft x 8.98 ft, and a listening position that is 6.00 ft from the left wall, 7.50 ft from the rear wall, and 4.80 ft off the ground, the EQ has detected three modal build-ups and has balanced them with bands 2-4.



Figure 7: A screenshot of the plugin performing a "corner test". Undoubtedly, corners are the most sonically unbalanced points in a room, as they are hotspots of clashing and interfering sound waves. To correct this, the plugin has balanced the three most troublesome build-ups at the rear left corner in the room (0, 0, 4.8).

4 Equations

Schroeder Frequency Equation

$$f_c = 11{,}885\sqrt{\frac{RT_{60}}{V}} \quad (1)$$

where RT_{60} is the reverberation time at 500Hz (s) and V is the volume of the room (cubic ft.).

Room Mode Equation

$$\text{Frequency} = \frac{c}{2}\sqrt{\frac{p^2}{L^2} + \frac{q^2}{W^2} + \frac{r^2}{H^2}} \quad (2)$$

where *c* is the speed of sound (1130 ft/s); L, W, H are the room length, width, and height, respectively; and *p, q,* and *r* are the integer multiples/harmonics of the modes.

5 Future Work

Bless the Room provides a unique solution to a common problem that home producers and engineers face, whether or not they even realize it. Nonetheless, there is always room for improvement and development:

1. Going forward, the algorithm of the plugin could improve to handle oddly shaped, non-rectangular rooms. In many cases, acoustical analyses of irregular rooms are significantly more complex and widely unresearched, but the plugin could start by focusing on analysing rooms with extra cavities.
2. A visualizer could be added in order for the user to see the physical modal layout of their room. A visualizer for the parametric EQ could also be added.
3. The plugin could include more Room Type presets that cater to the user's environment more specifically, factoring in beds, type of carpeting, surface material, amount of acoustic panelling, etc.

6 Conclusions

With the challenge of perfecting sonic spaces ever present, the need for audio software as an acoustic corrective tool continues to grow. The *Bless the Room* EQ plugin is an easily accessible, user-friendly way for producers and engineers with makeshift music setups to significantly improve their listening environment. *Bless the Room* simply takes the measurements of the user's room and listening position and adjusts its EQ parameters to level the modal imbalances at the point from which you are listening. This paper contains a detailed breakdown of what goes on behind the GUI, from acoustic theory considerations to implementation of original algorithms handling the EQ calculations.

References

[1] Admin. "Sound Absorption Coefficient Chart: JCW Acoustic Supplies." *Sound Absorption Coefficient Chart | JCW Acoustic Supplies*, JCW Acoustic Supplies, 24 Nov. 2020, www.acoustic-supplies.com/absorption-coefficient-chart/.

[2] Pirkle, William C. *Designing Audio Effect Plugins in C++: for AAX, AU, and VST3 with DSP Theory*. Routledge, Taylor Et Francis Group, 2019.

[3] "Sound - Room Absorption Coefficients." *Engineering ToolBox*, www.engineeringtoolbox.com/accoustic-sound-absorption-d_68.html.