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Design Considerations for a New Compact and Efficient Musical Instrument Amplifier

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ABSTRACT

This paper describes the design considerations for a high output, musical instrument amplifier in a small, portable enclosure. The unique goal of this design is to achieve excellent sound quality, with a continuous sound pressure level greater than 120 dB SPL, from the smallest possible package dimensions. In addition, the system must be highly reliable. The technical development of the preamp circuit, signal processor, power amplifier and loudspeaker driver are described below.

INTRODUCTION

Traditional musical instrument amplifier products capable of providing high output are large and not easy for a person to transport frequently. There are also small, portable amplifiers available on the market, but they are limited in their sound level capability and cannot be used for group playing or loud music styles. Both amateur and professional musicians require transportable equipment that will sound great at all levels, and which is very reliable. It is the goal of the amplifier described here to provide excellent tone and sufficient output for almost all playing situations and musical styles, while remaining very compact and easy to carry.

1.0 DESIGN GOALS

Modern music can sometimes place large demands on amplification systems, with high sound pressure levels and long periods of continuous maximum output. Sound level and frequency spectrum studies were made of musicians playing amplified guitar under many different conditions. It was determined from this research that an amplifier which can produce an continuous output greater than 120dB SPL@1M will meet the needs of players under most conditions. Even under these very loud levels, additional short-term power peaks should be available, to give the music a “dynamic” audible characteristic.

Reaching this output with a relatively small loudspeaker driver requires high electrical power and good loudspeaker efficiency. A very high performance 165mm driver was chosen as the best balance between efficiency and size. To keep the enclosure small, adaptive filtering of deep bass frequencies is performed, and good control of signal dynamic range is maintained.

The system block diagram is shown in Figure 1. This block diagram is generally similar to other musical instrument amplifiers, but additional filtering and equalization are provided at several points in the signal flow. This filtering is carefully adapted to the loudspeaker and enclosure, and is adapted to the output signal level. Included in the “Dynamics” section of the amp are proprietary algorithms which optimize signal mapping on to the acoustical and psychoacoustic characteristics of the loudspeaker and enclosure. Working together with the signal-adaptive filtering, a very high sound output is possible, while maintaining excellent subjective tonality.

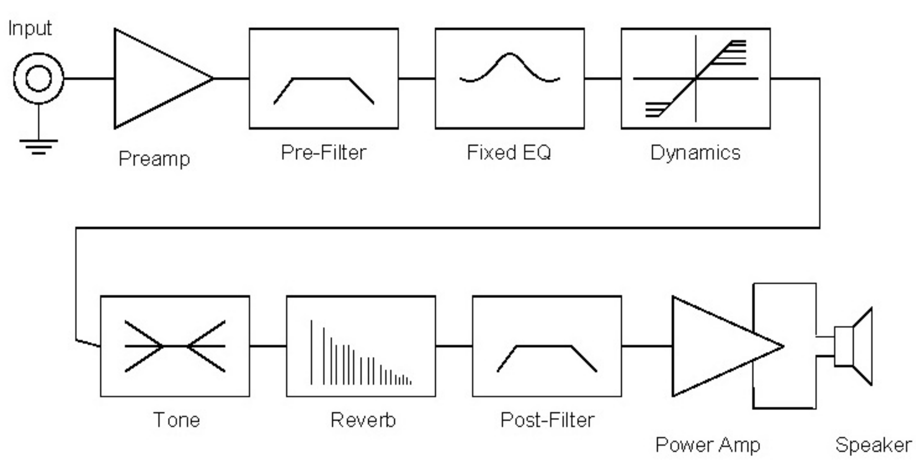

Figure 1: Block Diagram

2.0 ENCLOSURE

The system enclosure is a critical part of the sound quality in any musical instrument amplifier. To handle the high power dissipation and to achieve the most internal volume a composite MDF enclosure was chosen. The enclosure was developed to meet several key requirements:

1- High strength-to-weight ratio.

2- Impact and wear resistance.

3-.Minimum external dimensions.

4- Maximum internal volume.

5- Good heat dissipation.

6- Enough mass to avoid vibration when played loudly.

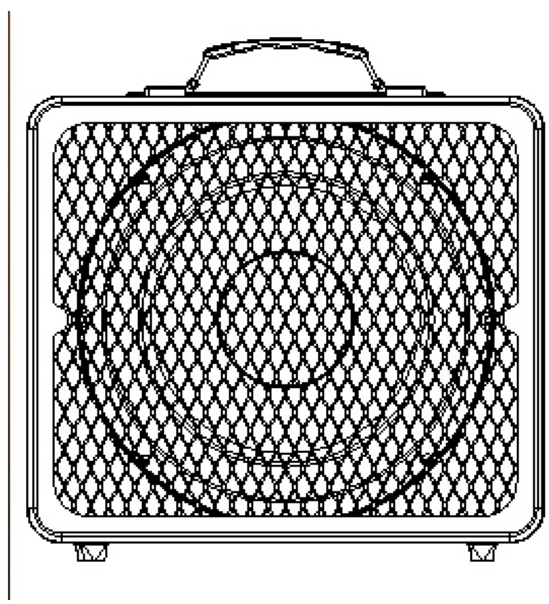

Figure 2: Mechanical Assembly

The assembly uses a heavy MDF material and a laminated finish to provide the proper cosmetic appearance and durability. Great care was taken to minimize structural resonance . The feel of the enclosure is very solid to the touch. The rear panel of the enclosure is bare aluminum and is the main point of heat dissipation in the system.

The loudspeaker driver is of a relatively small diameter, therefore a closed-box design was selected to maximize the low frequency output. This avoids the cancellation of long wavelengths from the rear of the driver and controls driver excursion below the Fc resonance point. Since there are fewer anti-phase reflections, a closed box also has the benefit of maintaining a more consistent response when placed close to the wall or stacked with other amplifiers.

3.0 INPUT STAGE

It is generally understood that a electric guitars sound the best when presented with a load impedance of at least 1 MΩ. The input stage configuration is shown in Figure 3. The circuit topology is selected to provide the proper loading and low noise, while also reducing the sensitivity of the input stage to possible RF interference.

Many amplifier designers assume that the maximum output of the electric guitar is only a few hundred mV. This is true under most conditions. However, when played very hard, some types of guitar pickups can put out instantaneous peak voltages of over 6Vpp into a high impedance. Design goals for the input stage are as follows:

1- Up to 6Vpp.

2- 0.5V average level.

3- High input impedance; 1 MOhm.

4- Immune to RF interference.

5- AC-coupled.

6- Low noise.

7- Protected against accidental overload.

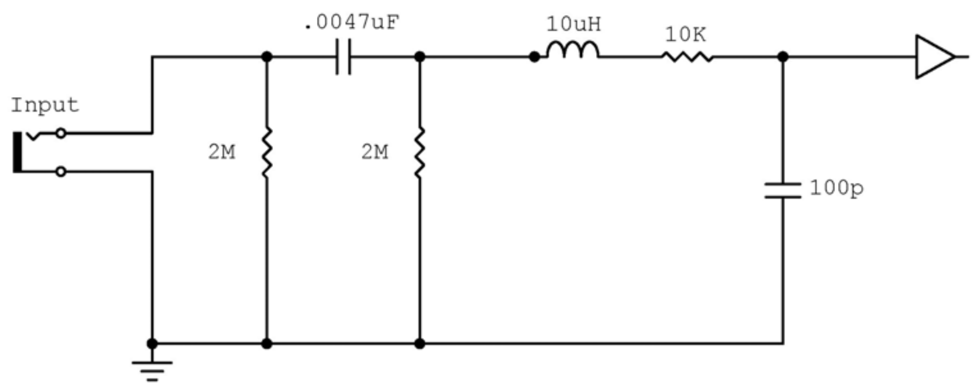

Figure 3: Equivalent Input Stage

3.0 SIGNAL PROCESSING

Once the guitar signal is handled by the preamplifier circuit, it operates at a more consistent level and lower impedance. At this point, signal processing functions may be applied to achieve the desired sound quality. Important features of the signal processing include:

1- Gain.

2- Controlled non-linear distortion.

3- Frequency response equalization.

4- User Tone Controls.

5- Reverberation.

6- Power protection of the loudspeaker driver.

7- Proprietary filtering and dynamic signal control algorithms.

4.0 AUDIO AMPLIFIER

During typical use, the power output stage of a musical instrument amplifier is often operated above the "clipping" point. This is normal and expected, and helps to generate the harmonic overtones that are part of the musical sound. How the amplifier circuit reacts to the voltage overload condition is an important part of its sound quality. At first, a Class D switching amplifier was considered, to try and maximize the efficiency of the system. However, it was difficult to obtain the kind of overload response that is desirable.

The AB design chosen exhibits exactly the desired output overload characteristics. Further., in real world musical instrument use, a Class AB output stage operates at nearly the same efficiency as a Class D, because of the very low crest factor and high average level of the signal. Thus, not much power is wasted during high volume use, the most important condition. The A/B design used is also very stable as the power supply varies, with excellent rejection ratio.

The amplifier output is a fully balanced, "bridged" design. This topology maximizes the instantaneous peak voltage available across the load. The output stage can easily deliver more than 40Vp across a nominal 8 Ohm loudspeaker. This is more than sufficient to meet the sound pressure level targets required.

5.0 POWER SUPPLY

The power supply arrangement is shown in Figure 5. This arrangement provides +/-24V to the power amplifiers with a virtual ground, thus eliminating the requirement for coupling capacitors. +/-12V rails are created to operate the general audio circuitry. In addition, there is a small, 3.3V sub-regulator to supply the digital circuitry used.

No regulation is used on the +/-24V rails, since the natural behavior of a linear supply is very well-suited to musical instrument use. The sag behavior introduced by the supply supports high short-term peaks, while limiting the output dissipation of the amplifier under continuous signal conditions.

The overall supply is fully transformer-isolated, with very low leakage current. This reduces system hum at high gains, and contributes to the very strict safety standards of the amplifier.

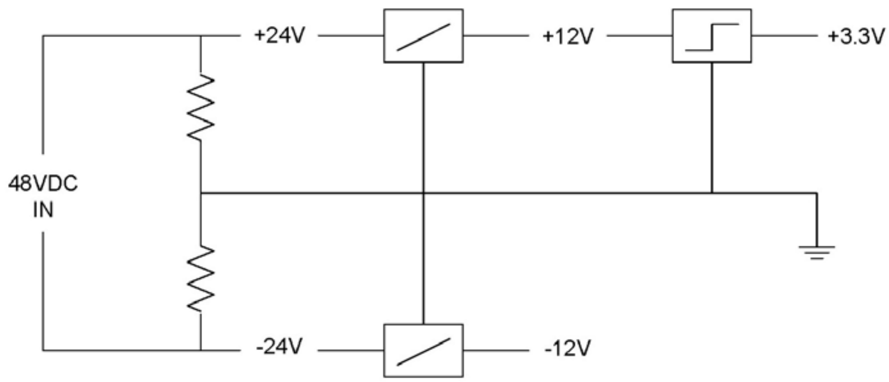

Figure 5: Power Supply Configuration

7.0 LOUDSPEAKER DRIVER

Proper selection of the loudspeaker driver is one of the critical elements in achieving the necessary sound and reliability from a musical instrument amplifier. This is especially true when the loudspeaker must be small, and will be pushed to near its operating limits. A driver diameter of 165mm was determined to be the minimum size for operation at the high SPL levels needed. Many engineering aspects of this driver are optimized to give the highest possible output level. For example, compared to typical high fidelity loudspeakers, this driver is not required to have very low distortion or good bass output. Thus, it may be constructed with a small Xmax, relatively high Fs, in favor of the highest possible efficiency.

Other features of the loudspeaker driver include very good power handling, and the ability to work well in a small, sealed enclosure. The overall near-field response of the amplifier system, including both the electronics and the acoustical elements, is shown in Figure 6. Two slightly different response curves are plotted. The red curve indicates the response with the tone control set to a “minimum,” while the blue curve is the opposite setting. This response may be compared to the electrical curve shown previously in Figure 4 in order to understand the transfer function of the loudspeaker driver.

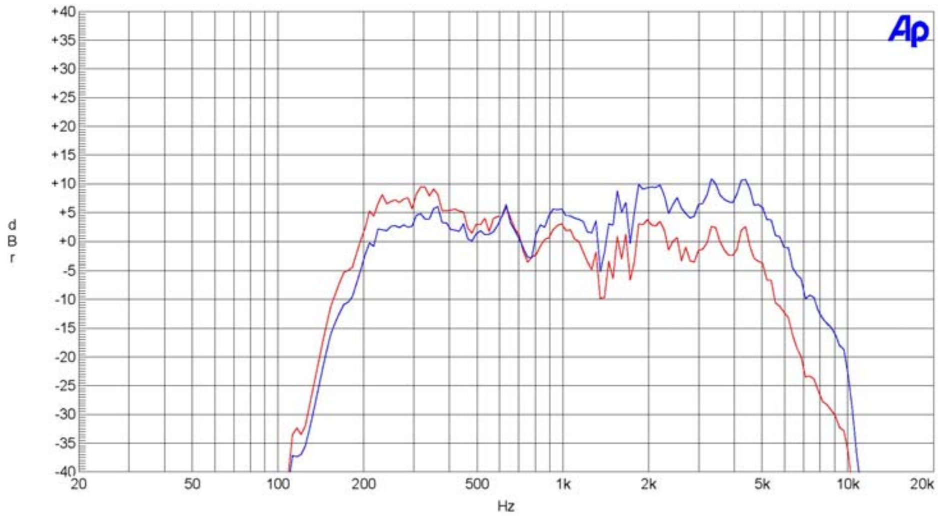

Figure 6: Acoustical Frequency Response and Tone Control Range

8.0 SUMMARY

The engineering design of a small guitar amplifier with high output has been discussed. Many aspects of the design have been optimized for improved sound pressure level and compact size. The system is capable of very loud output and excellent sound quality in a size that is easily portable.

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