EMI and Noise: Their Effects on Audio Amplifiers and Means to Counter Them

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***Abstract*—Audio amplifiers are subject to electromagnetic interference (EMI) and noise. EMI, a disturbance of an electrical circuit (in this case, an audio amplifier), can negatively impact the circuit's performance. When affected by EMI, noise can be introduced to the circuit manifesting itself as audible artifacts and distortion in the amplifier's output. There are numerous methods to mitigate, suppress or even eliminate the effects of EMI and noise. This paper will discuss the phenomena that are EMI and noise, their effects on audio amplifiers and several methods to suppress these effects.**

***Index Terms*—EMI; noise; audio amplifier; countermeasures; mitigate; suppress.**

I. Introduction

This paper is written as part of PRO-Q2, the last project in the 2nd year of the Electrical Engineering course at The Hague University of Applied Sciences. In order to prove our competence in performing research and practice with writing papers and studying literature, all students participating in PRO-Q2 are to write an English paper on a subject that is closely related to the project assignment (designing and realizing a speaker system). Not only will this help gaining experience on writing papers and doing research, but the knowledge gained from the research into the subject will also be of help during the designing and realization of the project's speaker system. For this paper, EMI and noise will be discussed. EMI and noise are known to have adverse effects on the performance of audio amplifiers. It is therefore very important to gain insight into the matter before the design of the audio amplifier begins. An introduction to these terms will be made, explaining what they are and what impact they may have on audio amplifiers. Then, several methods on mitigating/suppressing/eliminating the effects of EMI/noise will be explained in detail. Thus, the questions we intend to answer are as follows:

- What is EMI and noise and what effect(s) do they have on audio amplifiers?
- What methods can be used to mitigate/suppress/eliminate EMI and/or noise?

II. EMI/noise and their effect on audio amplifiers

A. EMI

EMI, short for electromagnetic interference, is the degradation of the effective performance of a system due to electromagnetic disturbances. It can occur anywhere in the electromagnetic spectrum, from 0 Hz up to 20 GHz. It is however most commonly encountered in the radio frequency (RF) range, in which case EMI is also often referred to as radio frequency interference (RFI). [1] EMI has become a significant and (in some cases) complex issue, as its presence does not only negatively impact the performance of devices, but may also impact the health of living organisms. Sources of EMI are as diverse as they are aplenty. There are natural sources such as cosmic radiation and discharges originating from the atmosphere (lightning being one of many examples), and there are sources created by man such power lines, radio transmitters, igniters, generators, etcetera. The consequences of EMI can range from mildly annoying (noise in AM radio receivers due to lightning, TV and radio signals being disturbed by operating vacuum cleaners) to even life-threatening and lethal situations (pacemakers failing prematurely, electrically powered wheelchairs being set in motion because of radio- and microwaves, military helicopters crashing) [2]. Audio amplifiers are also sensitive victims to EMI, since the audio signals they process should be as close to the original signal as possible, safe for the amplification applied. When not properly protected against EMI, noise may manifest into these signals, causing undesirable audible alterations to the final output (the sound that can be heard coming from the speakers). It is clear that, in case of audio amplifiers where sensitive audio signals are present, appropriate measures should be taken to mitigate the effects of EMI and achieve high-quality performance.

B. Noise

A possible result from EMI on electrical devices is the introduction of noise on signal paths. In electronics, noise is an unintended arbitrary change in the electric signal. In the case of audio amplifiers, there are certain types of noise that may affect the amplifier. A couple of these noise types will be explained in further detail, to give an idea of what kind of factors play a role in the creation of noise. Some examples of noise in audio amplifiers are:

- Thermal noise
- Shot noise
- Flicker noise

Thermal noise (also referred to as Johnson–Nyquist noise) originates from the random thermal movement of charge carriers, in almost all cases these carriers are electrons. This type of noise occurs in any kind of impedance, and its magnitude is independent from the voltage applied.

Shot noise is also caused by electrons. When electrons traverse barriers (such as a gap), the times at which they arrive on the other side of the barrier are discrete. The amount of discrete arrivals of these electrons are so numerous that they greatly resemble a continuous current. However, because this transfer of electrons is actually discrete rather than continuous, shot noise is generated [3].

Flicker noise (also commonly known as 1/f noise or pink noise) is caused by local variations of the emission rate of the cathode. As one of its names already suggests, flicker noise is dependent on frequency. In this case, the magnitude of the noise increases as the frequency lowers.

As already mentioned earlier, noise can be introduced through EMI. When noise is introduced to the audio signal in an audio amplifier, its output will be affected negatively, from buzzing to static noise and pops. Noise creates random changes on a signal, and this is something that should be avoided when it comes to audio signals in amplifiers.

III. Suppressing EMI

The goal of this section is to explain the measures that can be taken in order to mitigate/suppress/eliminate EMI and/or noise. The four types of possible measures against EMI and/or noise that will be discussed are shielding, filtering, use of a snubber circuit and the use of a differential amplifier.

A. *Shielding*

In order to reduce the electromagnetic field a conducting material is used to shield a component from electromagnetic radiation. This is usually applied to the casing of the devices that need to be isolated from the EMI. Cables can also be shielded to isolate the wires from the EMI. In order to protect a system, the shielding in its entirety must be capable of warding off guided as well as space waves. This will result in EMI sources outside of the shielding being unable to degenerate the performance of the protected system. If a perfectly conducting cylindrical hull that is closed at both ends is used, no EMI will affect the circuits inside the hull. Considering it is a closed hull, EMI wouldn't be able to penetrate and interfere with the internal conductors because there are no rifts or conductors in the hull. Due to the cylindrical hull being a perfect conductor, no fields radiate through the hull.

In practice, cable shields have rifts through which electromagnetic fields are able to infiltrate. These rifts are caused by the interlaced wires and tapes. The carriers within interlaced wire shields shuttle between the outer surface and the inner surface in the woven interlacing, allowing a current induced on the outer surface to be shipped to the inside of the shield where it will be able to interfere with the internal signals and circuits.

The effectiveness and frequency-dependence of the EMI shield is altered by the construction techniques and material characteristics used for the cable. For instance, with an interlaced shield the amount of leakage is dependent on the angle and optical coverage of the interlacing, while tape shields grant leakage at the tape overlaps. At very high frequencies, even foil shields with intertwined slots may exhibit leakage. Rifts also contribute as a factor in shielding effectiveness.

If shielding effectiveness is used to assess the performance, the current on a core conducter with the shield and without the shield needs to be measured on the same point so that both currents are affected by the same source from outside the shield. The shielding effectiveness is expressed as the ratio of the measured currents between the two measurements expressed in decibels [4].

B. *Filtering*

Theorically, an electrical filter network can be used to filter out lower and higher frequencies while letting exact bands of frequencies pass. The basic property of an EMI filter with a low pass design, is offering a considerably higher impedance to higher frequencies. This causes obstruction to the flow of high frequency signals. Thus, the strength of undesirable signals get diminished and attenuated by the EMI filter. This will result in laying the focus on thinking in terms of attenuation, insertion loss and filter impedance when designing a EMI filter, opposed to designing a regular filter where the emphasis will be laid on poles, zeros, group delay, pre-distortion, attenuation, and the order of the filter. While in both circumstances the approach is mathematically the same, EMI filtering is not a definite science like regular filtering.

For instance: if an anti-alias filter within a data-acquisition application is needed, an active low-pass filter might be used. This requires exact placement of the -3dB corner frequencies. The goal of EMI filters is to create maximum mismatch impedance at unwanted frequencies while causing no change to the desired frequencies due to arranging the maximum matching impedance [5], [6].

C. Snubber circuit

A simple RC snubber consists of a small resistor that is placed in series with a small capacitor. The snubber can be placed over a switch so it may be used to diminish the peak voltage at turn-off and to damp the ringing. Usually the proper values can easily be resolved by using a very simple design technique. In situations where a more optimized design is necessary, a considerably more complicated procedure is used. The downside of RC snubbers is that when the power level exceeds a few hundred watts, the loss in this type of snubber can be enormous in contrast to other types of snubbers. Within the high power applications the RC snubber can still be used as a secondary damping network to muzzle high frequency ringing which does not consist of high amounts of energy [7], [8], [9].

The RCD snubber has a few advantages over the RC snubber such as being able to limit the peak voltage, the total circuit can be reduced by the RCD snubber and the losses of given values of the capacitor will be decreased. However there is a downside to having a RCD snubber. On account of the diode across the resistor. When de capacitor is being charged, the effective value of the resistor is approximately zero. Due to this not being an optimal value for a given capacitor, the voltages will be surpassing those of an optimized RC snubber [9]. So if a proper snubber is used to suppress EMI, multiple of the intermediate frequencies are attenuated by a substantial amount. For that reason, it is clear EMI can be supressed by snubbers [10].

D. Differential amplifier

The differential amplifier consists of an operational amplifier. The operational amplifier is an active electronic voltage amplifier. These are generally used in integrated circuits that have a very high gain factor whereby the amplified input voltage will be offered at the output. The differential amplifier amplifies the discrepancy between two points with none of the points being a ground. The non-differential amplifier will amplify a proportion of a signal where the ground of the circuit is commonly used as reference signal. Differential amplifiers may be used to measure the difference between the input terminals. Now the common-mode interference that exists on the input terminals is effectively filtered out. In order to filter out noise on the input signal, the amplifier will use both a non-inverted input signal and an inverted input signal. This will cause the inverted signal to be subtracted from the non-inverted signal, subsequently filtering out the noise [11], [12], [13].

IV. Related works

- C. D. Motchenbacher, *Low-Noise Electronic System Design*, Wiley-Interscience, 1993.
- D. Foo Kune, J. Backesy, S. S. Clarkz, D. Kramer, M. Reynolds, K. Fu, Y. Kimk, and W. Xu, “Ghost Talk: Mitigating EMI Signal Injection Attacks against Analog Sensors,” in *2013 IEEE Symposium on Security and Privacy*, pp. 154-155, May. 2013.

V. Conclusion

EMI is the degradation of the effective performance of a system due to electromagnetic disturbances. EMI has become a significant and (in some cases) complex issue, as its presence does not only negatively impact the performance of devices, but may also impact the health of living organisms. Audio amplifiers are also sensitive victims to EMI, since the audio signals they process should be as close to the original signal as possible, safe for the amplification applied. When not properly protected against EMI, noise may manifest into these signals, causing undesirable audible alterations to the final output (the sound that can be heard coming from the speakers).

In electronics, noise is an unintended arbitrary change in the electric signal. In the case of audio amplifiers, there are certain types of noise that may affect the amplifier. When noise is introduced to the audio signal in an audio amplifier, its output will be affected negatively, from buzzing to static noise and pops.

Four possible methods to mitigate/suppress/eliminate EMI and/or noise are shielding, filtering, use of a snubber circuit and the use of a differential amplifier. Shielding is an effective way to eliminate EMI from an application. It can be accomplished by casing a circuit in a conducting material. If this casing is completely closed from the outside, the circuit inside the casing will be protected from EMI. However, if cables are connected to the circuit from outside, these will need to be shielded too. Filtering is used to diminish and attenuate the strength of undesirable signals. Thus, the goal of EMI filters is to create maximum mismatch impedance at unwanted frequencies while causing no change to the desired frequencies. The snubber circuit, if calculated properly, will substantially attenuate EMI by attenuating multiple intermediate frequencies. The differential amplifier will subsequently filter out the noise by subtracting an inverted input signal from a non-inverted input signal.

References

[1] Y. A. Adediran, D. A. Ogundele, E. C. A. Akoma Henry. (2010). *ELECTROMAGNETIC INTERFERENCE: CAUSES, EFFECTS AND MITIGATION* [online]. Available FTP: unilorin.edu.ng Directory: publications/adediranya File: ELECTROMAGNETIC INTERFERENCE CAUSES EFFECTS & MITIGATION.doc

[2] H. Li et al, "Suppressing electromagnetic interference in direct current converters," in *IEEE Circuits and Systems Magazine*, vol. 9, pp. 10-28, Dec. 2009.

[3] H. J. Woll, F. L. Putzrath, "A note on noise in audio amplifiers," in *Transactions of the IRE Professional Group on Audio*, vol. AU-2, pp. 39-42, Mar.-Apr. 1954.

[4] *IEEE Guide on Shielding Practice for Low Voltage Cables*, IEEE Std 1143, 1994.

[5] R. L. Ozenbaugh, T. M. Pullen, "Introduction," in *EMI Filter Design*, 3rd ed. Boca Raton, CRC Press, 2012, ch. 1, sec. 1, pp. 1-1.

[6] P. J. van Duijsen, "Magnetische componenten," in *Vermogenselektronica - Schakelende Voedingen*, 1st ed. Haagse Hogeschool, 2014, ch. 16, sec. 3-5, pp. 119-121.

[7] P. J. van Duijsen, "Flyback converter," in *Vermogenselektronica - Schakelende Voedingen*, 1st ed. Haagse Hogeschool, 2014, ch. 10, sec. 2, pp. 55-57.

[8] P. J. van Duijsen, "Snubbers," in *Vermogenselektronica - Schakelende Voedingen*, 1st ed. Haagse Hogeschool, 2014, ch. 22, p. 161.

[9] R. Severns, *Design of snubbers for power circuits*, International Rectifier Corporation, 2006

[10] S. Yuvarajan, R. Nelson, D. Quek, "A study of the effects of snubber on switching loss and EMI in an MCT converter," in *Industry Applications Society Ann. Meeting, 1994., Conf. Rec. of the 1994 IEEE*, Denver, CO, 1994, pp. 1344-1349.

[11] F. Fiori, "Design of an Operational Amplifier Input Stage Immune to EMI," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 49, pp. 834-839, Nov. 2007.

[12] M. G. Johnson, "Bias circuit and differential amplifier having stabilized output swing," U.S. Patent 5 451 898, Nov. 12, 1995.

[13] J. Lumsden, A. Flum, "Variable gain differential amplifier circuit," U.S. Patent 5 481 225, Jan. 2, 1996.