Envelope Identification Method for Guitar Amplifier Modelling with Wiener-Hammerstein Models

Tiago Fernandes, Nuno Paulino
NOVA School of Science and Technology
Center of Technology and Systems (UNINOVA-CTS)
Associated Laboratory of Intelligent Systems (LASI)
NOVA University Lisbon
2829-516 Lisbon, Portugal
tmr.fernandes@campus.fct.unl.pt, nunop@uninova.pt

***Abstract*—Vacuum tube guitar amplifiers are regarded as the best in terms of sound, and the clear choice for many professional musicians. Their warm sound is featured in countless records since the 1950s and has shaped music as we know it today. Amplifiers with other technologies have tried to reproduce or emulate this characteristic sound, with varying degrees of success. Nowadays, digital signal processing is becoming increasingly more powerful, and methods are being studied to digitally emulate this desired sound. This paper describes a modelling method using envelope identification to measure the frequency response, with the goal of adapting a Wiener-Hammerstein model to closely replicate the amplifiers' behavior. This model consists of two filters, with a non-linear block between them, the latter was optimized through a genetic algorithm. The resulting models for different presets of a BOSS Katana, were evaluated in the time and frequency domains, as well as through listening tests, demonstrating that the system was able to accurately model different types of amplifiers, with the whole modelling process taking approximately 5 minutes.**

***Keywords*—Wiener-Hammerstein model, digital signal processing**

SUMMARY

The Wiener-Hammerstein is composed by an input filter, generally limiting the input frequency, a non-linear block, where the distortion is introduced, and an output filter, responsible for shaping the distorted tone, Fig. 1.

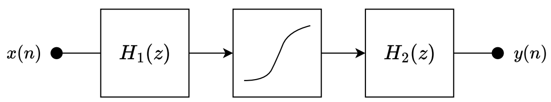

Fig. 1. Wiener-Hammerstein model block diagram.

Both filters are of the Finite Impulse Response (FIR) type, as to provide enough detail while being stable. The identification method for the non-linear block uses a logarithmic increasing amplitude sine wave. The amplifier response to this signal is recorded, and the genetic algorithm optimizes parameters to match the model's response to the amplifiers.

The envelope method determines $H_1(z)$ and $H_2(z)$ from the upper contour of the frequency response of the amplifier. Opposed to the swept sine method, this allows for the use of non-periodic, non-sinusoidal signals to excite the amplifier, such as noise. White, blue and pink noise signals. The envelope is computed by finding the local peaks of the magnitude of the FFT of the output signal, then interpolating between these values, and applying a Gaussian filter to smooth the curve. The swept sine signal was also tested with this method, obtaining the filter through the envelope instead of the first order response. The required measuring time is 30s both for swept sines and noise signals.

A system based on the Teensy 4.1 microcontroller was developed (Fig. 2), serving both as a channel between the computer and the amplifier, and as the guitar amplifier emulator, running the final model in real time.

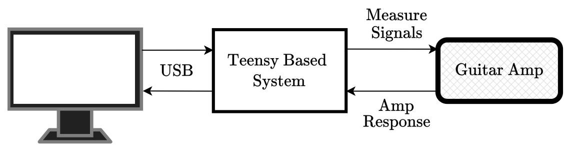

Fig. 2. Measurement Setup.

During testing, eight different amplifier presets were used, ranging from clean amplifiers to distorted ones with a booster at the beginning of the signal chain. These allowed testing the system with varying degrees of distortion and different frequency responses.

The measured Normalized Root Mean Square Error (NRMSE) for each identification method and amplifier preset is shown in Tab. I, where 'n/i' refers to the methods where the envelope was normalized. In the center Bass, Mids and Treble bands, the best method was proved to be the original swept sine, while in the Low Bass and High Treble bands, the swept sine envelope and normalized swept sine envelope, respectively, achieve the best results. The average score shows that the normalized swept sine envelope is the best method overall with the original swept sine coming in second place.

TABLE I
AVERAGE AMPLIFIER BAND RMSE FOR DIFFERENT TEST SIGNALS.

	LB	**B**	**M**	**T**	**HT**	**Avg**
SS 1st	6.965	**2.991**	**1.392**	**1.718**	13.820	5.377
SS	**6.313**	3.553	2.607	9.046	15.316	7.367
WN	9.143	3.540	2.166	5.300	8.442	5.718
PN	8.722	3.661	2.497	8.428	10.853	6.832
BN	9.291	3.458	2.129	5.308	7.921	5.621
SS n/i	6.753	3.476	1.783	2.344	**5.516**	**3.974**
WN n/i	9.257	3.544	2.189	5.413	8.557	5.792
PN n/i	8.030	5.206	2.829	4.956	8.200	5.844