Modeling of Yamaha TX81Z FM Synthesizer in Csound

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Abstract. The paper presents authors' original method of hardware synthesizers and sound processing devices modeling, focusing on the Yamaha TX81Z FM synthesizer as an example. The Csound 6 is used for the software simulation of original TX81Z, which is 4-operator FM synthesizer from 1987, well-known for its peculiar C15 preset called *Lately Bass*, and total amount of 8 waveforms. The paper gives a review of the most prominent FM synthesizers, considering both hardware and software implementations, brief description of Yamaha TX81Z features, the review of modeling method used by authors, and analysis of modeling results. During the modeling, we measured and modeled DAC unit of TX81Z to achieve the same waveforms. It was done using MATLAB *Filter Design Tool*, prior to code the corresponding pair of LP and HP filters in Csound. After that step, we modeled oscillators and envelopes. The given figures show the comparison between original TX81Z recorded sound samples and ours Csound-based model.

Keywords: sound synthesis systems, modeling, Csound, FM synthesis

1 Introduction

The advanced development of sound synthesis and processing software greatly contributed to the reduction of corresponding hardware. The noticeable progress in the field of computer sound has provided software implementations which surpass their hardware counterparts in both sound quality and functionality. At the same time, the field of electronic and computer music directly affects a number of creative and aesthetic factors. In the cultural plane, the timbre of the epoch of electronic music is essential. Thus, the preserving the corresponding electromusical instruments and / or their accurate modeling using computer-aided synthesis algorithms are both relevant and topical. The 80s and 90s of the 20th century were of rather important for the modern timbral landscape of electronic music. It was during these two decades that a significant number of synthesizers were released, and the sound of those synthesizers determined the timbral thesaurus of existing musical styles of electronic music. With detailed study of some (Yamaha DX7, Roland TB303), the modeling of many other synthesizers is still on its way to mature. In particular, among the hardware implementations of the frequency modulation synthesis (FM synthesis) that dominated in the 80s, in addition to the well-known Yamaha DX7, later models, such as the TX81Z and FS1R, to be outlined. The first had defined the bass sound for the *Eurodance* style popular in the mid-90s. The existing software models are not widely used and are being questioned by experts, and besides, the closeness of commercial software implementations excludes the study of algorithms by experts in the field of computer music and sound processing.

Thus, one of the topical issues of computer music is the exact (perceptual and algorithmically identical) modeling of various sound synthesis and processing devices. The article proposes a solution to this issue based on the method of software modeling of sound synthesis devices, which takes into account the hardware implementation features (the effect of the synthesizer DAC on the generated waveform) and examines the generated sound objects in different time-frequency sound space planes. The considered method can be applied to various devices, allowing the possibility of obtaining the frequency response and other characteristics of the DAC.

2 Prominant hardware and software implementations of FM synthesis

The digital FM synthesis was first proposed by John Chowning at Stanford University in 1967-68, licensed by the Japanese company Yamaha in 1973 [1, 2]. The most known hardware implementation of FM synthesis is the Yamaha DX7, released in 1983. Yamaha stopped production of hardware FM synthesizers in the early 90s with the transition to the production of multi-functional digital audio workstations. Currently, FM synthesis is mainly implemented in software synthesizers, such as Native Instruments FM7 / FM8, Image-Line Sytrus, etc. At the same time, almost any modern synthesizer features frequency modulation between (at least) a one pair of generators. Table 1 contains a summary of the main FM synthesizers in chronological order. Budget analogs of the DX7, i.e. DX9, DX21, DX27, DX100, FB-01, as well as the corresponding rack versions like TX7, TX802 were intentionally omitted.

The table shows that the most of FM implementations recreate the features of the original Yamaha DX7, which confirms the thesis about the relevance of developing models of other hardware. Much of the existing software models use closed code. Among the existing open-source DX7 software models, the most widely known is the Russell Pinkstone's model from Csound Book [3]. Along with good algorithmic accuracy, the model meanwhile does not take into account the DAC influence on signal. In addition, no correspondence was made between the parameters of the simulated Yamaha synthesizer (which are set in the range from 0 to 99) and real values of one or another quantity.

3 Description of Yamaha TX81Z

The Yamaha TX81Z synthesizer (1987) is a four-operator FM synthesizer in rack-mounted version. The main difference between TX81Z and others from DX-

Table 1. Basic hardware and software implementations of FM synthesis

Name (Year)	Form	OPs/ALGs	Waveforms	Compability
Yamaha DX7 (1983) Yamaha DX7-II (1987)	Hardware, 61 keys	6 OPs /32 ALGs	Sine	-
Yamaha TX81Z (1987)	Rack module, 1U	4 OPs /8 ALGs	8 waves	-
Yamaha FS1R (1998)	Rack module, 1U	8 OPs /88 ALGs	8 waves	-
NI FM8 (2006)	Software plugin	6 OPs /-	32 waves	DX7, DX11 TX81Z
Image-Line Sytrus (2008)	FL Studio plugin	6 OPs /-	Any	-
asb2m10 Dexed (2016)	Software plugin	6 OPs /32 ALGs	Sine	DX7
Hexter (2004)	Software plugin	6 OPs /32 ALGs	Sine	DX7
Arturia DX7 V	Software plugin	6 OPs /32 ALGs	25 waves	DX7
LoftSoft FMHeaven (2004)	Software plugin	6 OPs /-	16 waves	DX7, TX81Z
Oxe FM Synth (2004)	Software plugin	6 OPs /-	6 waves	-
DXi FM (2011)	iPad app	4 OPs / 8 ALGs	12 waves	-
KQ Dixie (2018)	iPad app	6 OPs / 32 ALGs	Sine	DX7
Primal Audio FM4 (2014)	iPad app	4 OPs / 8 ALGs	8 waves	-
Yamaha reface DX (2015)	Hardware, 37 keys	4 OPs / 12 ALGs	Sine	-
Korg Volca FM (2015)	Hardware, 15 keys	6 OPs / 32 ALGs	Sine	DX7

series is the ability to use various waveforms (8 waveforms are used). The most featured and well-known sound of this synthesizer is the C15 *Lately Bass* preset, which can be heard in many compositions of the dance scene of the early 90s. At the beginning it is necessary to recreate the TX81Z waveform array as accurately as possible. Figure 1 demonstrates the discrepancy between the ideal waveform 5 and its real form, recorded through a sound card with a sampling frequency of 96 kHz. This discrepancy is due to the non-linearity of the frequency response of the original synthesizer's DAC. This leads to modeling the DAC used in the TX81Z. The measurement of magnitude response was carried for the 1-OP sine wave mode (Fig. 2) and modeled using Matlab's Filter Design Tool as a system of two serially connected low-pass and high-pass filters.

Csound 6 was chosen as the software for real-time sound synthesis. Below we give an example of the implementation of the corresponding filters in the form of User-Defined Csound opcodes. The next step to building a model is to measure the parameters and characteristics of the synthesizer, for example, detune parameters. Most of the TX81Z parameters were manually measured using time, frequency and phase measuring tools in *Cockos Reaper*. For cases where it was possible, some parameter tables were approximated with corresponding math functions i.e. power of N, others are written directly in ftables as values.

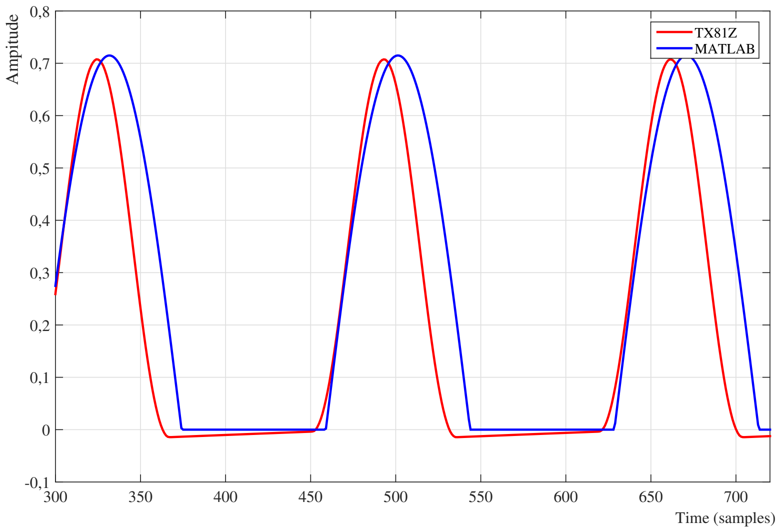

Fig. 1. Comparison of waveforms of type 3 (positive half-period of sine)

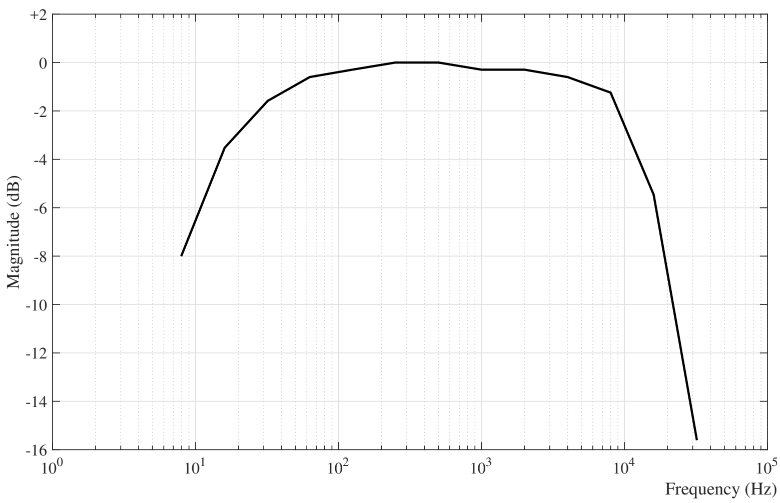

Fig. 2. Measured magnitude response of Yamaha TX81Z DAC

```
;LP filter
opcode TX_LP, a, a
setksmps 1
aL xin
aD0 init 0
aD1 init 0

iA1 = -0.5100490981424427
iB0 = 1
iB1 = 1

aD2=aD1
aD1=aD0
aD0=aL-aD1*iA1
aout=aD0*iB0+aD1*iB1
xout aout*0.24497545092877862
endop
```

```
; HP filter
opcode TX_HP, a, a
setksmps 1
aL xin
aD0 init 0
aD1 init 0

iA1 = -0.99869495948492626
iB0 = 1
iB1 = -1

aD2=aD1
aD1=aD0
aD0=aL-aD1*iA1
aout=aD0*iB0+aD1*iB1
xout aout*0.99934747974246307
endop
```

UDO opcodes for TX81Z DAC modeling filters.

At the present state, the model implements the generation of all 8 types of original waveforms as a table oscillators, envelope generators of AR-D1R-D1L-D2R-RR type and operator connection algorithms (overall to 8 algs). Figures 3 and 4 show the results of the comparison of the original waveforms in the frequency domain. Figures 3 gives the comparison for only first pair of operators (OP2 - OP1). Figures 4 gives the comparison for the complete C15 preset, using 4 operators with a feedback on a OP4. Obviously, the operator pair is easy to model, thus the Csound FM instrument spectrum looks close to the original. The C15 sound still needs some improvements though hearing tests give promising results. During the estimation of modeling results we try to compare signals both in time and frequency domains. Also hearing tests results are considered.

4 Conclusion

The resulting method can be applied to simulate various hardware devices for the synthesis and processing of sound. The lack of accurate software models of hardware synthesizers determines the feasibility of continuing such studies. The method can be especially popular for modeling digital synthesizers - both early samplers and FM synthesizers of the 80s, and virtual analog devices of the end of the 90s. At the next stage, we plan to implement the reading of the original TX81Z presets in MIDI SysEx-format to develop a user interface and conduct a subjective assessment of the accuracy of modeling. The resulting code will be compiled as a VSTi / AU plug-in using Csound Cabbage. The project link is `https://github.com/gleb812/cs81z`

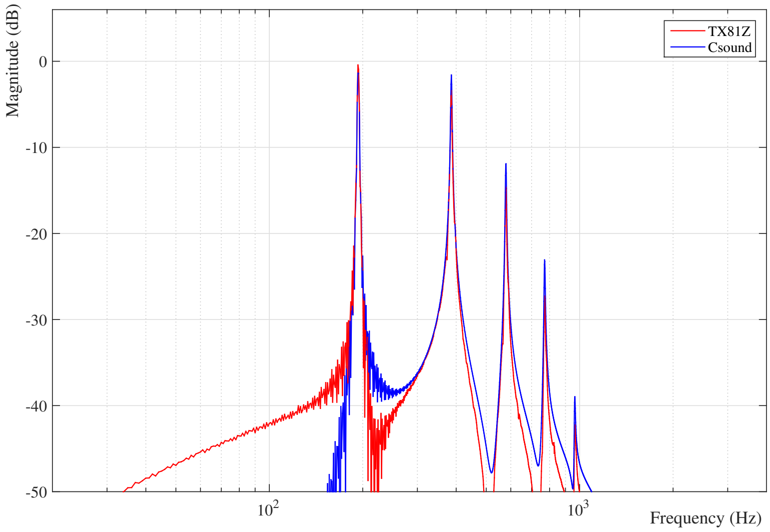

Fig. 3. Yamaha TX81Z vs Csound spectra for two operators only

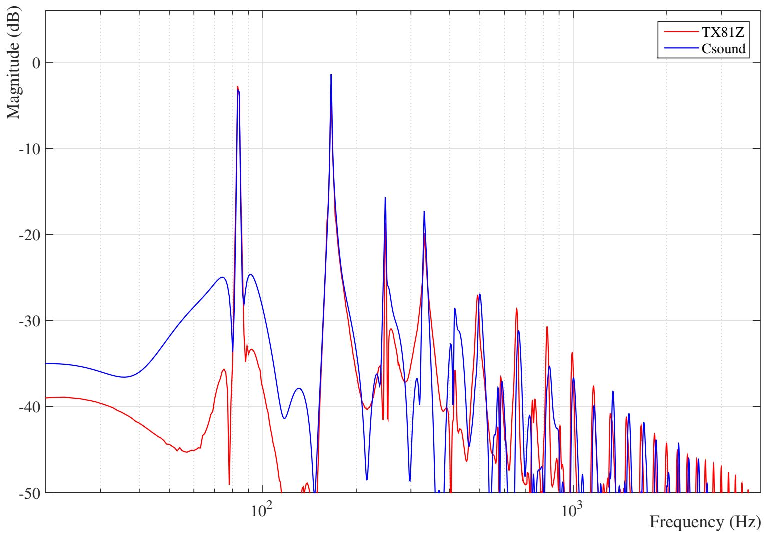

Fig. 4. Yamaha TX81Z vs Csound spectra for the C15 Lately Bass preset

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