Casio VZ Virtual Instrument:
A replica of the Casio VZ-1/VZ-10M music synthesizer

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See https://github.com/matthias-wolff/Casio-VZ-virtual-instrument/blob/master/Casio-VZ-virtual-instrument.pdf for the latest version of this document.

Abstract

[**TODO:** . . .].

Contents

1 Goals and Prerequisites

In this project I try to rebuild the vintage Casio VZ-1/VZ-10M music synthesizer in Reaktor 6 [3]. The primary goal is a fully functional player which is compatible with MIDI editor/librarian software like Midi Quest [4] or the like. My workplan is

1. make some debugging and development tools (waveform validator, envelope validator, etc.),
2. reproduce the 8 core waveforms of VZ-1/VZ-10M (1x sine, 5x sawtooth-like waveforms created by Casio's Phase Distortion Modulation, 1x white noise, 1x pitch-sensitive narrow-band noise),
3. implement the core sound engine (wavetable oscillators, phase and ring modulators, VCAs, oscillator circuits),
4. implement control signal generators (amplitude envelope, key following, layering, parametric sensitivity characterisitcs, etc.),
5. implement MIDI SysEx control capability, and
6. reproduce the factory voice and operation libraries.

I always strongly disliked the unpleasant—though most characteristic—aliasing and analog noise of the VZ-1. Hence, I will not attempt to reproduce this. Insofar, the remake is not intended to be perfect.

As a secondary goal I may want to reproduce the GUI of the original instrument. This would be a nice-to-have, however not necessarily of much practical use.

1.1 The VZ-1/VZ-10M Music Synthesizer

[**TODO:** . . .]

1.2 The Reaktor 6 Modular DSP Lab

[**TODO:** . . .] [3]

1.3 The Midi Quest 12 Editor/Librarian Software

[**TODO:** . . .] [4]

2 Development and Debugging Tools

2.1 Waveform Validator

[**TODO:** . . .]

2.2 Envelope Validator

[**TODO:** . . .]

3 Development and Debugging Tools

4 Core Sound Engine

VZ's sound engine is called "iPD (interactive phase distortion) modular sound engine" [2, p. 12]. According to Casio, this is an enhanced version of the phase distortion modulation introduced by the predecessor of the VZ-1 called CZ-1 [**TODO:** []]. Actually, the VZ synths series seem to feature wavetable oscillators—with waveforms partly generated by the original PD synthesis—together with ordinary phase modulation and ring modulation [**TODO:** []].

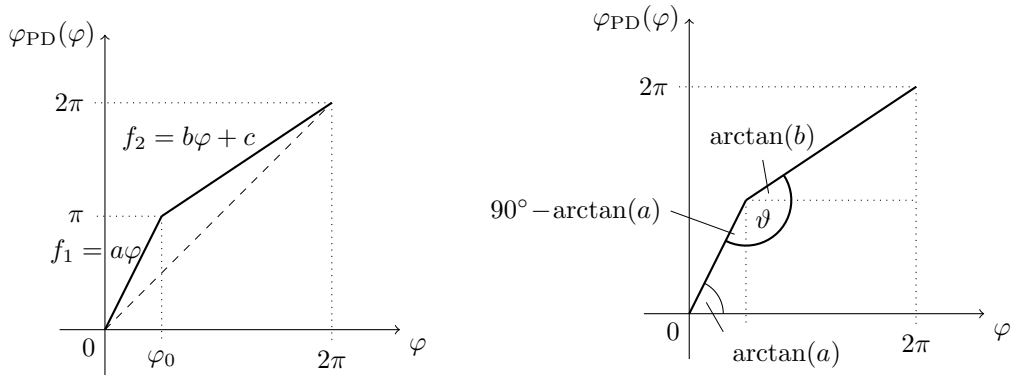
4.1 Theory

4.1.1 Tones, Frequency and Pitch

[**TODO:** . . .]

4.1.2 Phase Distortion Modulation

Casio's phase distortion modulation is based on the following characteristic curve [1, p. [**TODO:**]](Fig. 1a):



(a) Piecewise linear phase charateristics (b) Modulation parameter ϑ, $135° \leq \vartheta \leq 180°$

Figure 1: Characteristic curve of phase distortortion

We see that the curve consists of two straight sections

$$f_1(\varphi) = a\varphi, \qquad 0 \leq \varphi < \varphi_0, \qquad \text{connecting } (0,0) \text{ and } (\varphi_0, \pi), \tag{1}$$
$$f_2(\varphi) = b\varphi + c, \quad \varphi_0 \leq \varphi \leq 2\pi, \quad \text{connecting } (\varphi_0, \pi) \text{ and } (2\pi, 2\pi). \tag{2}$$

The slope a of the first section is variable and can take real values greater than one. The start end end points of the sections define the following constraints

$$f_1(\varphi_0) = a\varphi_0 = \pi \qquad \rightsquigarrow \varphi_0 = \frac{\pi}{a} \tag{3}$$
$$f_2(\varphi_0) = \frac{\pi}{a}b + c = \pi \tag{4}$$
$$f_2(2\pi) = 2\pi b + c = 2\pi \tag{5}$$

From Eqs. (3) to (5) follows

$$b = \frac{a}{2a-1} \quad \text{and} \quad c = \frac{2a-2}{2a-1}\pi, \tag{6}$$

and finally

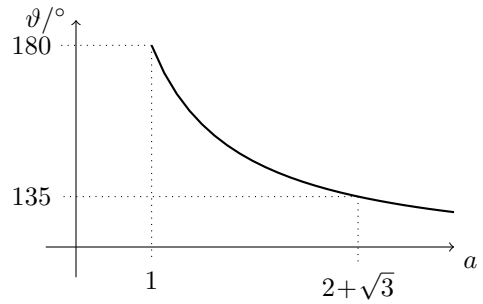
$$\varphi_{\mathrm{PD}}(\varphi) = \begin{cases} a\varphi & \text{for } 0 \leq \varphi < \frac{\pi}{a} \\ \dfrac{a\varphi + 2\pi(a-1)}{2a-1} & \text{for } \frac{\pi}{a} \leq \varphi \leq 2\pi. \end{cases} \tag{7}$$

Casio uses the angle between the straigt sections

$$\vartheta/° = 180 - \arctan(a) + \arctan(b) = 180 - \arctan(a) + \arctan\left(\frac{a}{2a-1}\right) \tag{8}$$

measured in degrees (see Fig. 1b) as modulation parameter. The permissible range is $135° \leq \vartheta \leq 180°$ [**TODO:** []]. As I did not manage to resolve Eq. (8) for a, I just plot the function and print a lookup table in Fig. 2.

Phase distortion modulation is applied in the Casio CZ synthesizer series as shown in Fig. 3. The VZ series uses wavetables basing on PDM.

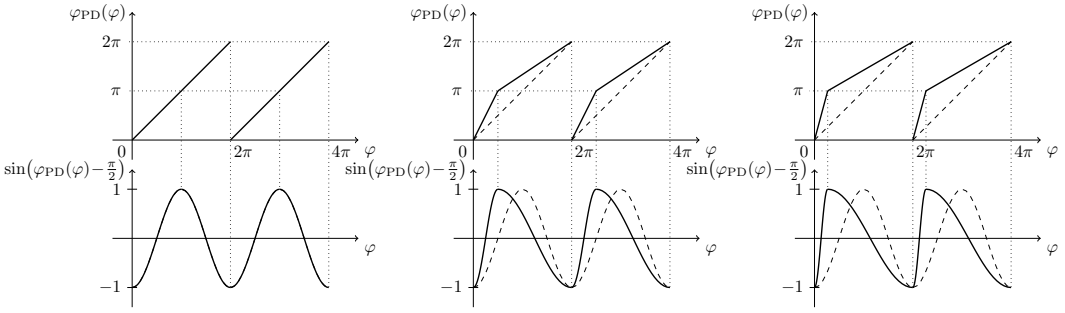


(a) Modulation parameter ϑ as a function of slope parameter a

$\vartheta/°$	a	$\vartheta/°$	a
135	$2+\sqrt{3} \approx 3.73$	160	1.52
140	2.92	165	1.35
145	2.39	170	1.21
150	2.02	175	1.10
155	1.74	180	1.00

(b) Lookup table

Figure 2: Relation between modulation parameter ϑ and slope parameter a, see Eq. (8)



(a) $\vartheta = 180°$ $(a = 1)$ no modulation

(b) $\vartheta = 150°$ $(a \approx 2)$

(c) $\vartheta = 135°$ $(a \approx 3.73)$ resembling a sawtooth signal

Figure 3: Example of phase distortion modulation of the function $\sin\left(\varphi - \frac{\pi}{2}\right)$ adapted from [1, p. [**TODO:** ...]]

Alternate phase distortion characteristics $f(x)$ with domain $0 \leq x \leq 1$ and value range $0 \leq f(x) \leq 1$ (may be needed for Reaktor implementation):

$$f(x) = \begin{cases} ax & 0 \leq x < \frac{1}{2a} \\ \dfrac{ax + a - 1}{2a - 1} & \frac{1}{2a} \leq x < 1 \end{cases} \tag{9}$$

where $a \geq 1$.

4.1.3 Wavetable Osciallators

The original VZ-1/VZ-10M is apparently based on wavetable oscillators [2, p. 34]. Such oscillators contain a set of digital waveforms, each comprising exactly one signal period. Depending on the pitch, these waveforms are played back at different rates. [**TODO: ??**] shows an example of a VZ waveform (`SAW4`).

Formally, a single waveform can be expressed by

$$w(\varphi) \quad \text{with } 0 \leq \varphi < 2\pi, \tag{10}$$

where the argument φ is a phase angle. A oscillator based on this waveform uses a time-varying phase angle $\varphi(t)$. Its output signal can be written as

$$x(t) = w\big(\varphi(t)\big) = w\big(2\pi(f_0 t \mod 1)\big) \quad \text{with } -1 \leq x(t) \leq 1 \tag{11}$$

where w denotes a waveform, $f_0 \in \mathbb{R}^{\geq 0}$ denotes the note frequency (aka. the pitch) in Hertz, and t denotes the time in seconds. Further, we denote by

$$x \mod 1 := x - \lfloor x \rfloor \quad \text{with } 0 \leq (x \mod 1) < 1 \tag{12}$$

the decimal fraction of the real valued quantity x. Hence, the argument $\varphi(t) = 2\pi(f_0 t \bmod 1)$ on the right side of Eq. (11) involves resetting the phase angle of the waveform to zero whenever the cycle length 2π is surpassed. [**TODO: ??**] shows an example.

Note: For simplicity I will assume continuous time signals $x(t)$ which take real values in $-1 \leq x(t) \leq 1$ throughout this report, even though we actually talk about digital signals of course. However, the simplification saves a lot of notational trouble with rounding and interpolation.

We will use the circuit symbol [**TODO:** ...] for a wavetable oscillator.

4.1.4 Phase Modulation

4.1.5 Ring Modulation

4.2 VZ Hardware

The VZ series features eight waveforms: sine (`SINE`), five sawtooth-shaped waveforms created by phase distortion modulation (`SAW1`–`SAW5`), white noise (`NOISE1`), and narrow-band noise (`NOISE2`).

4.3 Replica

4.3.1 Voltage-Controlled Oscillators (VCO)

4.3.2 Voltage-Controlled Amplifiers (VCA)

5 Control Signal Generators

6 MIDI SysEx Control

References

[1] Casio Computer Co., Ltd. Casio cz-xxx - user manual, [**TODO:**].

[2] Casio Computer Co., Ltd. Casio vz-1 digital synthesizer - user manual, [**TODO:**].

[3] Native Instruments GmbH. Reaktor 6 Modular DSP Lab. online: `https://www.native-instruments.com/en/products/komplete/synths/reaktor-6`. retrieved: Aug. 30, 2019.

[4] Sound Quest Inc. Midi Quest 12. online: `https://squest.com/Products/MidiQuest12/index.html`. retrieved: Aug. 30, 2019.