SPECIAL SECTION

The Blippoo Box: A Chaotic Electronic Music Instrument, Bent by Design

Rob Hordijk

ABSTRACT

This article addresses the design of the Blippoo Box, an audio sound generator that operates according to the principles of chaos theory. By designing the Blippoo Box, the artist attempts to bridge a crossover space between abstract (sonic) art, music and artistic craftsmanship. In the hands of performing musicians the Blippoo Box becomes an electronic music instrument that invites performers to improvise with the chaotic nature of the box. Despite this chaotic behavior, the produced sounds have particular characteristics that are roughly predictable and enable a performer to build a performance around a composed scheme.

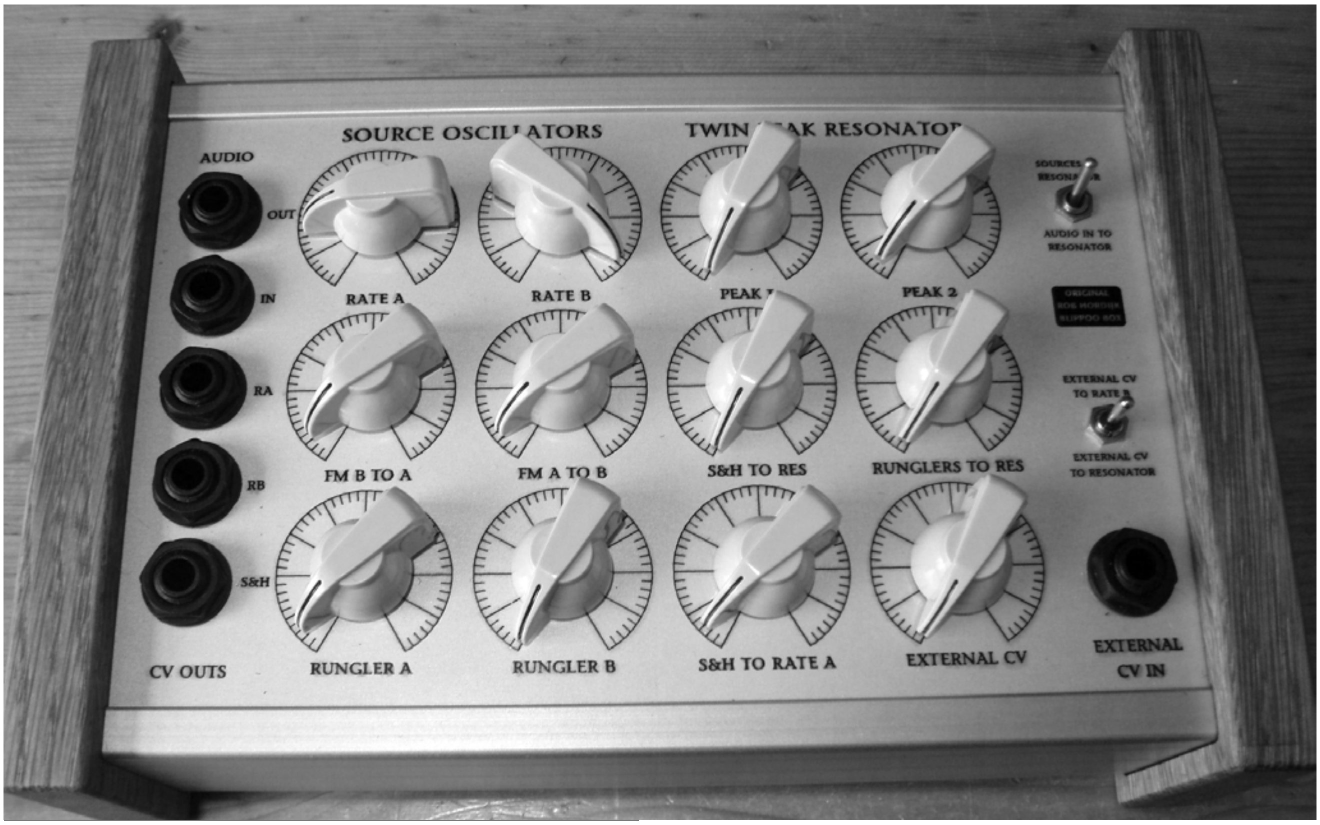
THE IDEA

Some years ago I became interested in designing an electronic sound generator based on the principles of chaos theory—a concept that has had my intellectual interest since the early 1980s. The decision to actually build a chaotic music box was made around the year 2003, when some of my colleagues began to practice the art of circuit bending [1]. By extrapolating from this concept I developed the idea of building a box that was already "bent by design." Of course this is something completely different from circuit bending, as it actually contradicts the definition of the latter. However, I found the idea of a box that is bent by design interesting enough to do the necessary labor to end up with a working product. This idea also coincided with another idea that I had about electronic objects that produce a huge range of sounds, each object with a distinct character to give it an objet d'art sort of individuality. Some 4 years of development resulted in a final design (Fig. 1) that I baptized the Blippoo Box (the double *O* in Dutch is pronounced "oh").

The design of the Blippoo Box is an attempt to bridge a crossover space between abstract art, music and artistic craftsmanship. As my background is in the visual arts and not particularly in music, I have always considered sound a "material" to sculpt; thus I consider the "art" aspect of the Blippoo Box to con-

Rob Hordijk (artist, designer), De Constant Rebecquestraat 76, 2518 RG Den Haag, The Netherlands. E-mail: <rhordijk@xs4all.nl>.

Fig. 1. The Blippoo Box.



sist of how it sculpts sound into abstract sonic soundscapes. This art is interactive, as the optional “playing” of the box can be a performing art, and hence the box becomes a musical instrument as well. To play a Blippoo Box means to anticipate what the box is doing and not vice versa, as the behavior can only be predicted in a broad sense. This forces the player to improvise. The boxes that I built so far very quickly found their way to performing artists; their recognition of the boxes as musical instruments makes the box in essence a musical instrument (Figs 2–4).

MORE ON CHAOS

To use a chaotic system for this bent-by-design box seemed an obvious choice to me. Chaos as defined by chaos theory [2] has some properties of musical interest, namely the fact that chaotic systems are able to create a wide range of relatively short repeating patterns, and when a pattern changes to another pattern, bifurcations or period doublings can occur. If the pattern is perceived as a pitched audio waveform, a bifurcation will cause the pitch to be lowered by one octave or an integer multiple of octaves. This means that a chaotic audio system should be able to produce a wide range of pitches covering the whole audio range.

Chaos theory assumes that nature is ruled by endless chains of causes and effects. These chains form a multidimensional matrix where all the chains are interconnected while combining to form more complex chains on larger scales. It interests me from an artistic point of view that many natural processes are balanced systems that appear to have many possible stable states, in which the chains of cause and effect repeat themselves. (Mathematical research over the last 50 years on exactly such systems, for instance the work done by Lorenz, has been a great resource for me.) A system in a stable state will repeat a specific pattern of a specific duration. It will stay in this pattern until some disturbance forces the process out of balance, after which it develops over time into another stable state. There is definitely a predetermined order in the system, but the order is too complicated for humans to comprehend or predict. It is hard to understand, for example, how the system develops between stable states, or even how to identify a disturbance. The word “chaos” refers to this inability of the human mind to grasp the overall order. Still, the stable states might be well recognized and perceived, in music, for example, as pitches with a particular timbre or as repeating drones.

Every nonlinear mathematical equation or physical nonlinear dynamic system is potentially chaotic. When the output value of a nonlinear mathematical equation is fed back as the input for a subsequent iteration, it will over time produce a series of values, creating a repeating pattern. The systems that are of musical interest are those capable of producing many different patterns of a limited length, the repetition rate producing either an audio waveform or a pattern that is perceived as a rhythm.

Each possible pattern or waveform is associated with what is called an “attractor.” The term can best be explained by

Fig. 2. Vocalist Amy X Neuburg performing an improvisation for voice and Blippoo Box at Temescal Arts Center on 13 February 2009. (Photo: Rob Thomas)

Fig. 3. Rehearsal session for the Blippoo 4tet, due to perform on 19 September 2009 in Cologne, Germany. Performing artists are Alberto de Campo, Hannes Hoetzl, hans koch and Joker Nies, all from Germany.

studying the behavior of a chaotic system. When the balance in the system is disturbed, the attractor will literally attract behavior toward one particular state out of the many possible balanced states. The system will always search for and eventually find a new balanced state. During the transition phase, behavior often appears to be random but in fact it is not. The new state can be calculated by knowing the mathematical description of the current state and bringing this state out of balance through a known high-resolution control parameter value and then reiterating until repetitions start to occur.

PROPERTIES OF A CHAOTIC OSCILLATION SYSTEM

A true chaotic audio oscillation system, or chaos oscillator, should exhibit many attractors that each reveal themselves as unique repetitive patterns or sequences of a certain length or duration. While the chaos oscillator is producing such a pattern it is in a stable state. A small variation in a controlling parameter should disturb the stable state, forcing the oscillator into a transition phase. During such a transition it will produce a series of apparently random values, until at a certain moment it becomes attracted and caught into another repeating pattern. On startup a chaos oscillator can be brought first into a specific state, with this state defining the possible attractors it can be attracted to. The chaos oscillator then can be disturbed by a control signal of a certain value or alternatively by a disturbance pulse, causing a change in the original state. Note that for a true chaotic system, the transition to a possible new state will depend on both the nature of the disturbance and the current attractor pattern.

PRACTICAL DESIGN CHOICES

The first design choice was which electronic technology to use; analog or a digital DSP-based design. For various reasons I chose to use analog electronics. One of the considerations was that analog circuitry gives some finality to a design, preventing the temptation to keep reprogramming code.

Another important requirement was that I should be able to produce small production runs all by myself without expensive tools, as I wanted to keep the production on a craftsmanship level similar to that of sculpting and jewelry design. The analog electronic techniques from the 1970s and 1980s allow for such craftsmanship (Fig. 5). Industry has abandoned these techniques in favor of large-scale miniaturized production techniques, using components that are too small to handle by hand. To my amazement, however, I found that the components used in the past are still widely available; apparently there is still a substantial market for them. This suggests to me that these older techniques have moved from the realm of industrial production into the realm of artistic craftsmanship.

Coincidentally, the sound of analog electronic instruments is once again highly in fashion. In comparison to digital sound systems, the analog systems are typified as having a “warm and spacious” sound. For the sonic character that I wanted to design into the chaos box, I found it interesting to refer to the soundtrack by Louis and Bebe Barron for the MGM movie *Forbidden Planet* released in 1956 [3]. To take this as a sonic reference was especially appealing as this soundtrack was made before the “invention” of the synthesizer as a musical instrument in the early 1960s, enabling me to argue that the sonic character of the chaos box is not “the sound of a synthe-

Fig. 4. Gino Robair performing on a Blippoo Box at 21 Grand in Oakland, 2 May 2009.

sizer" but truly has a generalized "electronic sound" character. Interestingly enough, I found that current analog electronic components are of very high quality, and the first prototypes had a very clean and undistorted sound, not at all like the reference sound I chose. However, this allowed me to design a degree of sonic distortion into the circuitry that shaped the overall timbre to closely resemble the reference sound.

Finally I had to decide upon the physical size and the amount of available controls. I decided that 12 controls in a 3 x 4 field should be the maximum, and that each control should in essence have its own distinct effect on the behavior of the box. The box should be easy to carry and should have a universal power supply to let it run on both 110 volt and 230 volt AC. Before the final design I built four different prototypes, the last prototype (Figs 6 and 7) being a much larger circuit so that I could decide which of all the many possible parameters formed the best combination given that only 12 parameter control knobs were to be used in a final design.

The Architecture of the Box

I decided to split the architecture into two parts (Fig. 8). The first part I baptized the "chaotic core," and the second part is basically a complex resonator that gets excited by pulses from the chaotic core, shaping the timbral aspects of the final sounds. The chaotic core also produces control signals that modulate the complex resonator. The built-in distortion in the resonator itself actually makes the resonator potentially chaotic. In the design I chose not to use the resonator in regions where bifurcations started to occur, but to ensure that when the resonator is driven by a high-level external input signal, it could hit these regions.

To design the chaotic core I began to do "proof of concept" experiments in the digital domain. By using a programmable DSP system, I was able to experiment with the diverse mathematical functions commonly used as examples in chaos theory. None of these functions behaved satisfactorily. I found that many had a chaotic region that was small in comparison to the regions where there was no chaotic behavior. The non-chaotic regions often failed to produce signals that could be used as audible waveforms or rhythmic patterns. Musically this sounds like the system simply stopping and sitting idle in silence.

It became obvious that for the most interesting results, a chaotic audio system had to be based on oscillators. I tested a single chaotic oscillator but found that I needed a wider palette of signals. Then I tested a dual oscillator system, and this was much more satisfying. Such a system has considerable advantages. One can use standard oscillators, and by applying cross-modulation the system immediately becomes chaotic. The transformation of the current output waveform value to the frequency parameter is the nonlinear aspect. As there are two oscillators cross-modulating each other, there are actually two nonlinear aspects in the system, greatly increasing the region where the system behaves chaotically. The two cross-modulation amounts are the two parameters that in essence define the behavior. But I was looking for more parameters that had some sort of sensible response, such as parameters that create pitch sweeps or a stepped pitch response or that modulate the time scale of rhythmic patterns. When arriving at this point in the design process one has to start anticipating the types of output signals that the chosen oscillator can produce. To create a sweep effect, one can use an oscillator that produces waveforms such as triangle, sine or sawtooth. Pulse waveforms cannot easily produce these sweeps. For the stepped response one needs waveforms that exhibit several fixed levels. These have to be constructed in some way. The type of oscillator that proved very useful is a common type that produces both a triangle and a square waveform. This square wave can be considered a one-bit signal; when this signal is on/high, the triangle wave slopes up, and when the bit signal is off/low, the triangle wave slopes down. With very little extra circuitry, it proved possible to produce three types of cross-modulation signals, causing a sweep, a step and a "time-warp" response.

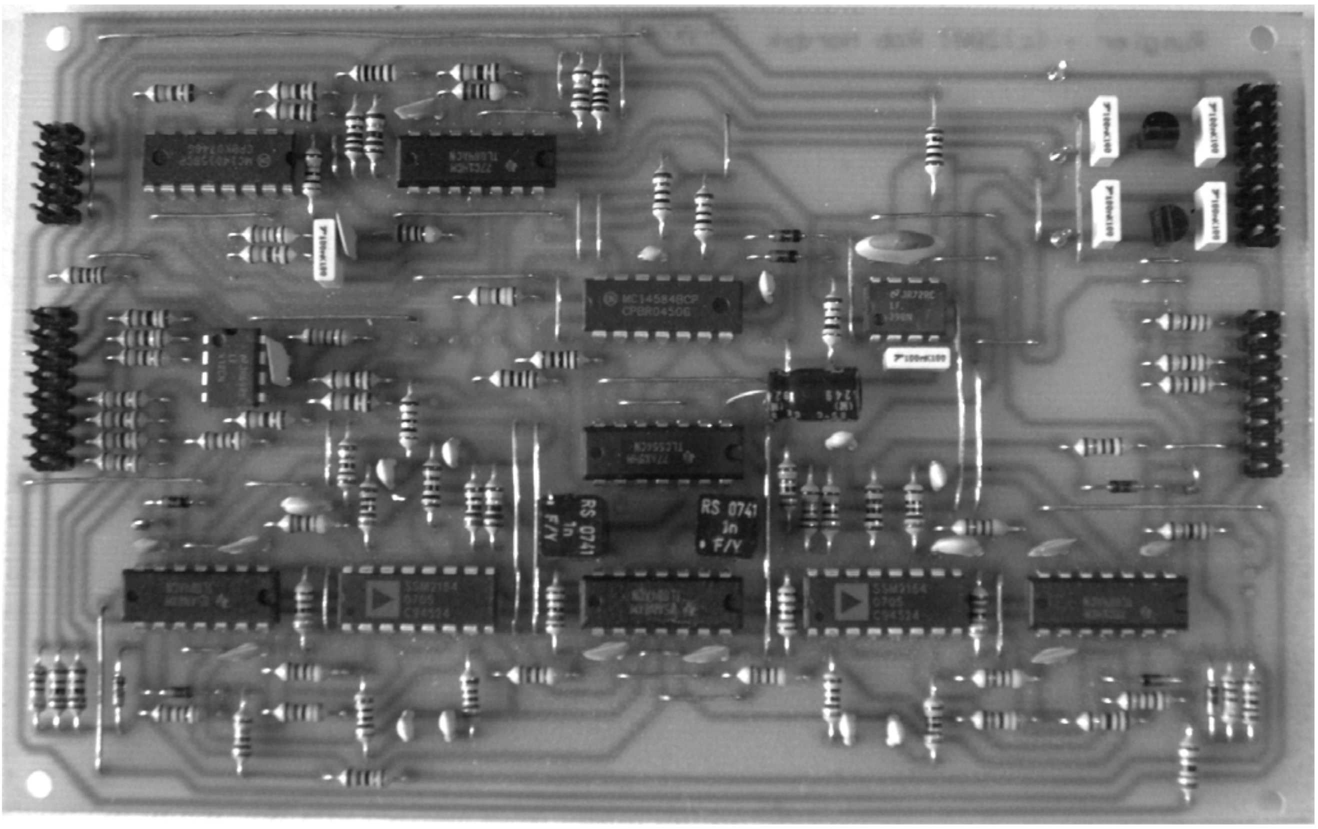
The stepped modulation signals are created by using two very short single-bit clocked delay lines. These delay lines have a data input and a clock input. For one delay line the data comes from the square wave of one oscillator and the clock input from the square wave of the other oscillator. For the second delay line the clock and data inputs are reversed. Then three consecutive bit outputs on each delay line are used to create two 3-bit digital signals that are converted to two analog signals, each with seven possible output levels and sort of a Gaussian statistical distribution. Such a circuit was never used in any electronic music device that I know of, and so I had to invent a name for it. I came up with the name "rungler," which is a fantasy word that I happen to like.

To create the "time warp" effect, I needed a parameter signal that was able to temporarily speed up or slow down both oscillators, and had to use signals already present in the two oscillators. The output signals of two oscillators can be combined in various ways into one single signal. This combination will be some sort of interference signal. I chose to compare the momentary values of the two triangle waves and to create a pulse whenever the values were equal. The moment the values are equal, a "sample and hold" circuit is triggered and samples the actual value of one of the triangle waves—it does not matter which, as at that moment they are of equal value. This sampled value can then be used to speed up or slow down one or both of the oscillators.

In total there are seven control knobs that control the chaotic core, two basic pitch knobs for the two oscillators, two "sweep" response cross-modulation controls, two "step" response cross-modulation controls (the runglers) and one sample-and-hold feedback control. The oscillators have a very wide frequency range, of about 20 octaves, set from a maximum frequency of about 12kHz to a minimum frequency at which the oscillator appears to have almost stopped. The left side of the oscillator frequency knob range lets the oscillators run as low-frequency oscillators, while the right side of the knob range lets them run in the audio range. No attempt was made to let the oscillators quantize to melodic pitch scales, as the purpose of the Blippoo Box is not to produce melodies. The oscillators do, however, have exponential control scales, just like the oscillators used in synthesizers designed to play melodies.

The resonator is a complex bandpass filter, with two strong resonances on the edges of the passband. Resonance is fixed at the point of near oscillation. Six filter poles are combined to produce this resonator. Basically the resonator is a combination of two parallel, highly resonant 3-pole low-pass filters. The output of the second filter is subtracted from the output of the first filter, thus removing the lowest band and producing a bandpass response. The advantage of this resona-

Fig. 5. Blippoo Box circuit board, etched and stuffed by hand in small series by the author himself.



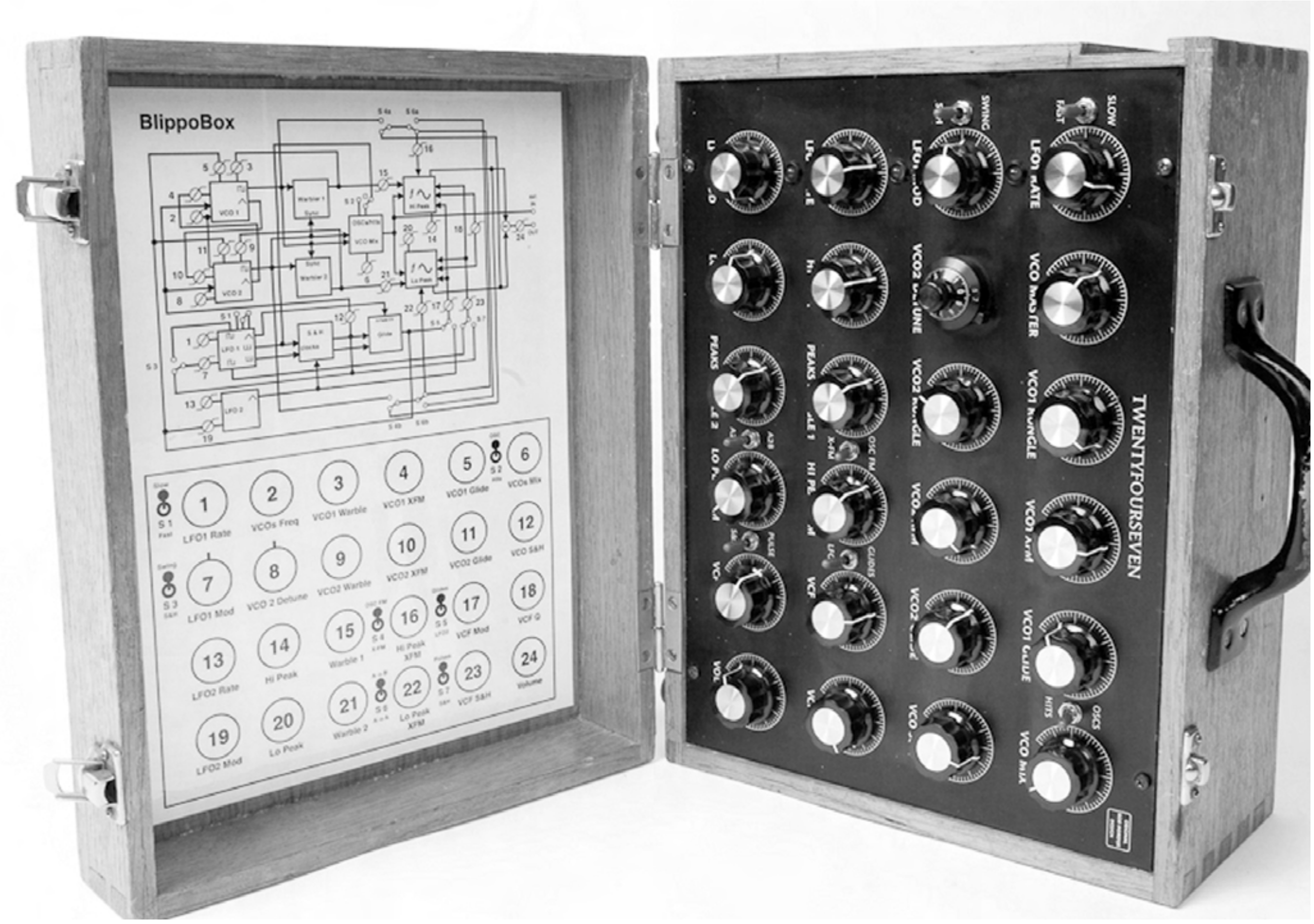


Fig. 6. A Blippoo Box prototype used to test the most interesting knob combinations.

tor topology is that it does not matter if one of the two low-pass filters is tuned lower or higher than the other; there will always be an audible passband. This is in contrast to a bandpass filter made of a low-pass and a high-pass filter in series, where the low-pass always needs to be tuned higher than the high-pass. The parallel low-pass filters form a bandpass filter under the condition that passband gain of both filters is equal, which is in general the case when the resonance settings are equal. Because there are two strong resonance peaks, I baptized the resonator the "twin peak resonator," with a wink of an eye to one of my favorite artists, David Lynch.

The advantage of the twin peak resonator is that it almost always passes a signal from input to output. Only when the two low-pass filters are tuned exactly equally does the passband become so narrow that it almost fully blocks the input signal.

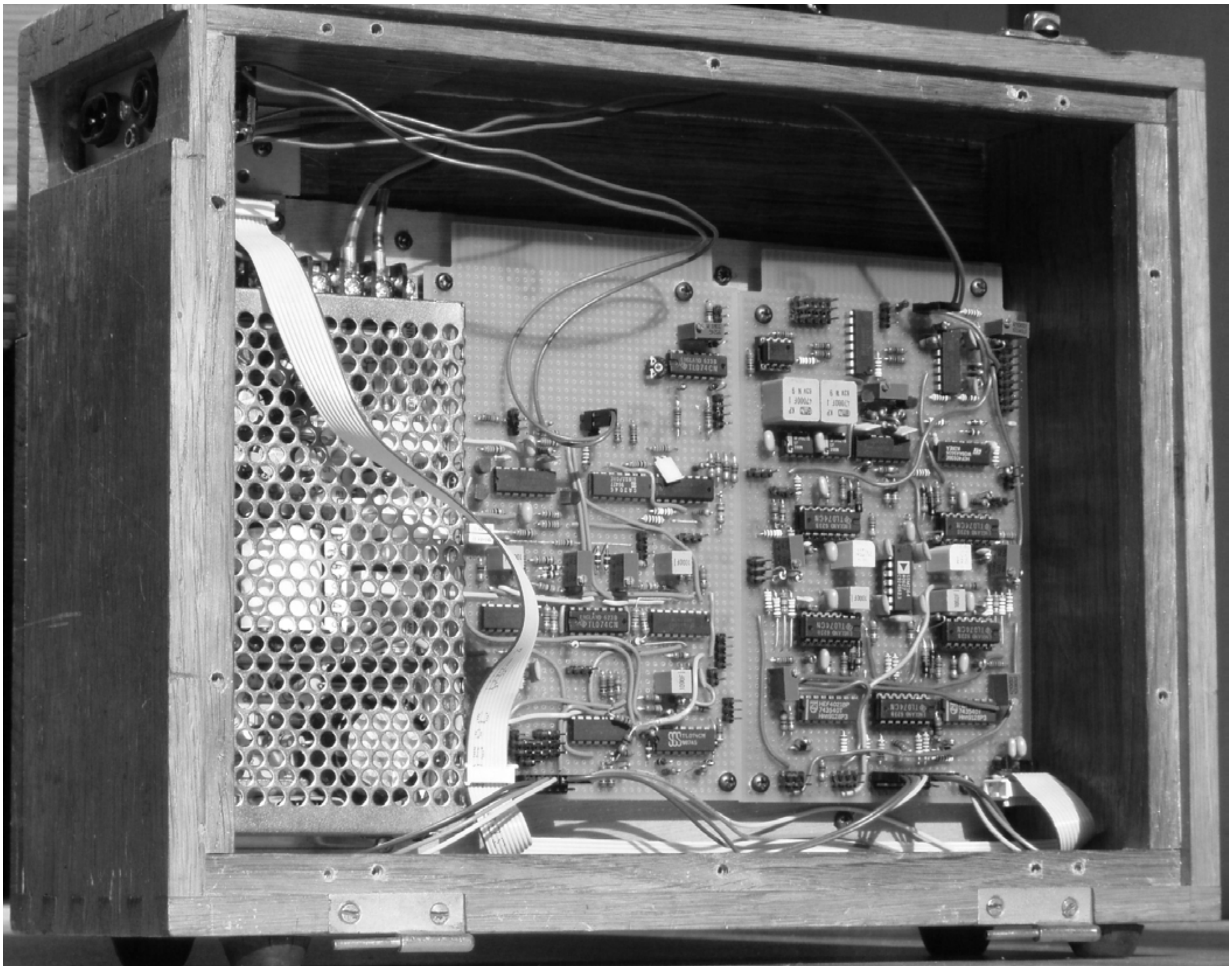
The input signal to the twin peak resonator is the same pulse train that is used to trigger the sample and hold circuitry to create the "time warp" effect in the chaotic core. Using pulses to excite the resonator has the advantage that when the oscillators are running at very low rates the pulses still strongly excite the resonator in the audio range and thus produce percussive sounds in the rhythm of the pulses. Without modification to the resonator, these percussive sounds are made up of two quite clean damped sine waves. To give the effect of the resonator on the final sound of the box a bit more character, I decided to build some inherent distortion into the resonator. There are two basic types of distortion, one that produces only odd harmonics and one that produces both odd and even harmonics. It is especially this latter type that was of sonic interest, as it most closely coincided with my sonic reference for the final sound of the box. It is also easier to produce than the odd harmonic distortion, but it is less obvious how and why it works. As defining the final sound of the box is an important part of the design process, I will roughly outline the method used to create the additional distortion in the resonator.

Odd harmonic distortion is produced by limiting the level or clipping the amplitude of the signal at the output of the resonator. Level limiting can also be applied at several points within the resonator itself. Usually some extra diode and resistor components are used to produce this level limiting.

To produce harmonic distortion (sometimes wrongly named "even harmonic distortion"), it is not the vertical amplitude axis that has to be deformed but the horizontal frequency/time axis. This implies that some form of frequency self-modulation must be applied. The most obvious way is to simply feed some of the resonator output signal back to the frequency parameter. However, this produces strong asymmetrical variations in amplitude as well, which easily creates unwanted clipping of the output signal, either in the box itself or in the sound or recording system used after the box. To avoid this practical issue a method must be used that does build a series of harmonics from an existing signal, without affecting the overall amplitude of the electrical signal in the resonator. A useful method makes use of the fact that a wave signal can be considered as a series of partials, where each partial is represented as both a sine and a cosine value at a certain amplitude. It is a common perception among musicians that sound is a two-dimensional phenomenon. Computer sound recording applications in particular have helped to create this perception. In such applications, the recordings are shown on the 2D computer screen, where the *x*-axis is time and the *y*-axis is amplitude. By putting the two axes together, a 2D graph of apparent waveforms is shown. When doing sound processing in the electronic domain, one does not necessarily have to think of the electronic signal as representing a sound wave in the way it travels through space or the 2D representation on the computer screen. For instance, a weight spinning around a pivot point can be used as a (simplified) model for a resonating filter (Fig. 9). In this model, one can imagine that the spinning weight causes a wavefront that over time travels as a corkscrew from the rotation plane at pivot point A to a plane at a point B, which is somewhere on a line perpendicular to the spinning motion. In this case it is possible to describe the traveling wavefront with two graphs, one being the *x*- and *y*-axes and one being the *x*- and *z*-axes. The *x*-axis is the straight line from point A to B. The *y*- and *z*-axes basically show when the wavefront is passing through the horizontal or vertical planes that are perpendicular to the *x*-axis. These are commonly named the *y*-plane and the *z*-plane. When the wave consists of only one partial, it will show up in one graph as a sine and in the other as a cosine. These two wave graphs are 90° out of phase. If the signal is not a sine/cosine wave but a complex wave, the partials in the *z*-plane will be 90° out of phase with the partials in the *z*-plane. If the resonator has a *z*-plane output and is used to feed back to the frequency parameter, the resonator will be able to produce all harmonics without affecting the overall amplitude levels. The more feedback, the more harmonics are produced. However, as this is a nonlinear form of feedback, the resonator will also start to behave chaotically when the feedback exceeds a certain level. This level is dependent on the input signal level, meaning that when the resonator is overdriven it will start to exhibit bifurcations, producing partials that are one or a multiple of an octave lower than the fundamental pitch in the input signal. These partials are sometimes called subharmonics.

The question, however, is where to get a feedback signal that has a *z*-plane relation to the signal output of the resonator, assuming that the resonator output is the *y*-plane. A formal way to do this would be to first transform the input signal into a *y*-plane and a *z*-plane by using a Hilbert transform and then use two identical filters to process the *y*-and *z*-planes individually and feed back the *z*-plane output to the *y*-plane frequency parameter and the *y*-plane output to the *z*-plane frequency parameter. A very accurate Hilbert transformer would require a lot of extra circuitry and double the amount of filters needed, which is in conflict with the initial design goals for the box. As the art of sound is eventually only a matter of the human perception of the sound, it is in my opinion acceptable for an artist to cheat a bit—to forgo mathematically exact results in favor of a result that exhibits to a large extent

Fig. 7. A look under the hood of the prototype in Fig. 6.



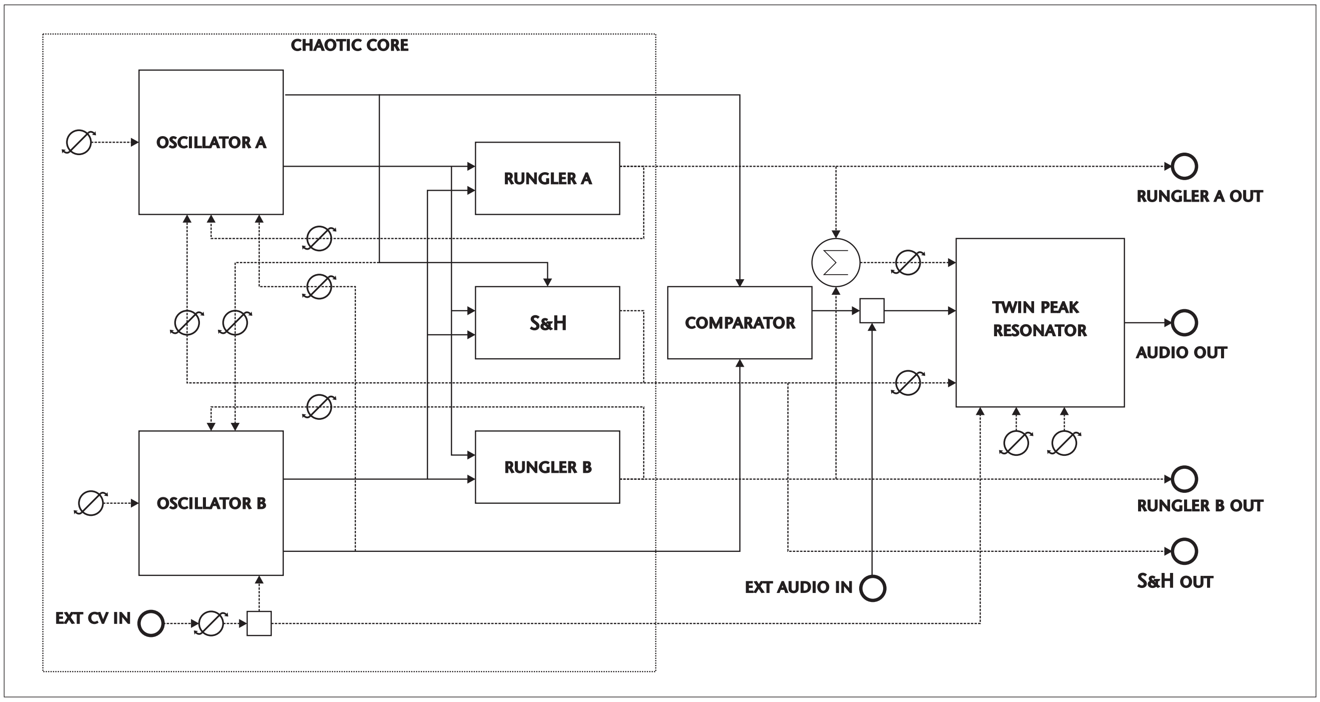
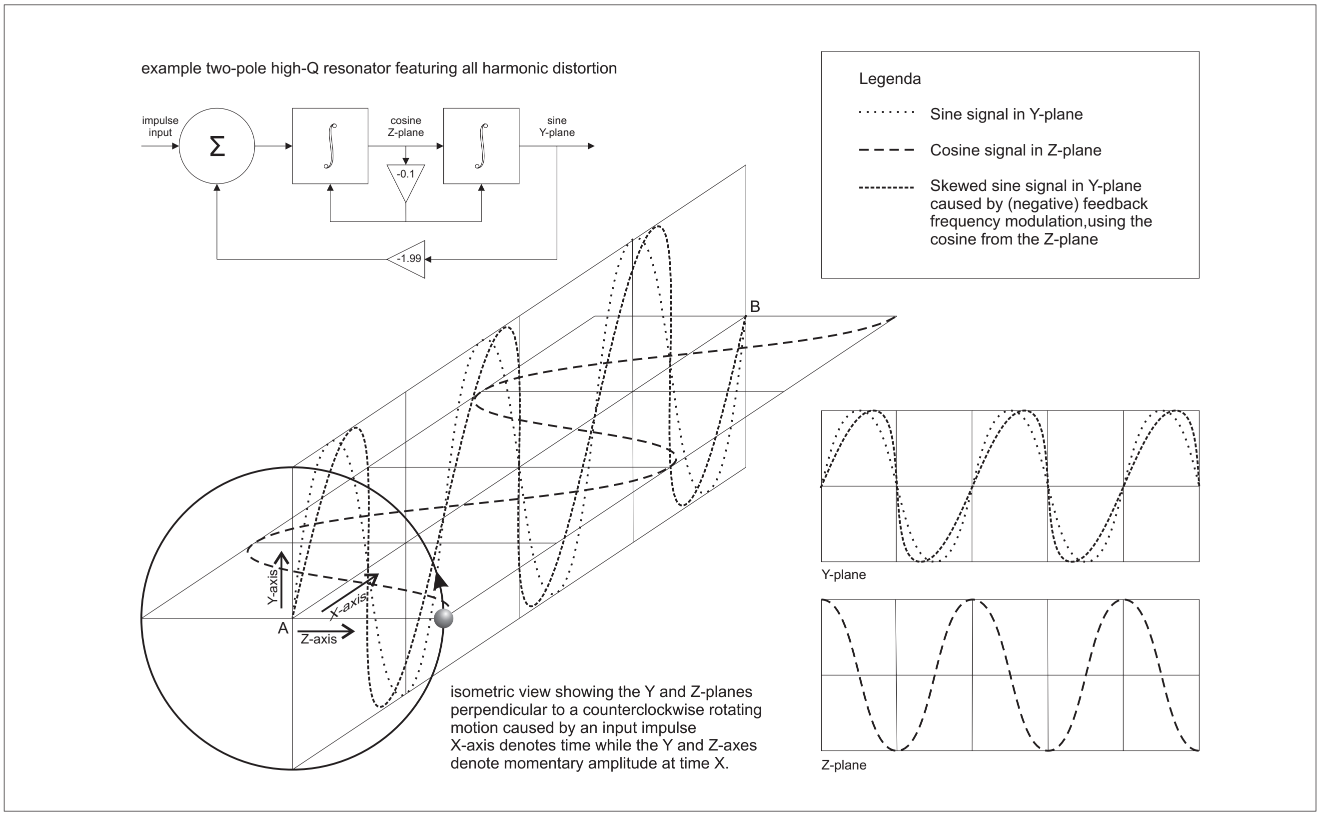


Fig. 8. Architecture of the Blippoo Box electronics.

the properties that one is after. In the case of a 4-pole resonant filter, it turns out that for the resonant frequency, the output of the second pole can mimic the *z*-plane with respect to the output of the fourth pole, this last pole being used in general as the signal output of the resonator. This is easy to understand when one knows that at the resonant frequency of a 4-pole filter each pole creates a phase shift of 45°. In the case of a 2-pole topology the output of the first pole can be used to mimic the *z*-plane. Because the twin peak resonator in the Blippoo Box is highly resonant, and the resonant peaks strongly dominate the overall sound, it is possible to use the output of another pole instead of the last pole to mimic *z*-plane behavior. The twin peak resonator lowpass filters are 3-pole filters, so there will be phase shifts of 60° after the first pole and 120° after the second pole. Using the output of the second pole actually works well enough in practice, though the harmonic series build-up is not as "linear" as that which a true *z*-plane would produce. In any case, it sounds very good to the

Fig. 9. The *x*-, *y*- and *z*-plane all harmonic distortion principle.



ear. Additionally, the effect on the amplitude is much weaker than when using the output of the last pole, and the resonator is just able to exhibit bifurcations when the input is overdriven. In essence it is only one single resistor that is needed to feed back some of the second pole output signal to the frequency control voltage input. The sonic effect of this type of distortion, as compared to odd harmonic distortion, is that it seems to emphasize the spaciousness in the sound and add a quality that Blippoo Box owners describe as "organic."

CONCLUSION

The chaotic behavior of the Blippoo Box reveals itself through the repetitive nature of the sound patterns it produces when in a stable state. When a control knob is changed to a new position, the box will soon go into an apparent random state and then find a new balance in a new stable state where it repeats another sound pattern. Tiny changes in a knob setting can sometimes produce dramatic differences in pitches and durations for new patterns. By careful tuning and changing the amount of modulation by the resonator, many timbral structures can be given to a pattern. Still, the particular design of the resonator and how it reacts when excited by the chaotic core of the Blippoo Box will impose a certain sonic character on the final sound, giving the instrument its own personality.

The box is now produced in small series of four boxes at a time, and my plan is to build no more than perhaps 20 a year.

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Discography

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Rob Hordijk (b. 1958) was trained as a sculptor and jewelry maker in the 1970s. In the late 1970s and early 1980s he became interested to see if sound could be sculpted in a way that is similar to how materials like metals are worked. Electronics seemed a good way to get control over "sculpting sound," and thus he invested a lot of time into becoming a master of electronics, with the purpose of being able to "sculpt sound." He has since been building high-end sound-synthesis electronics for his own artistic purposes, such as installations, and on request for other artists. Hordijk has been teaching for over 20 years at the art academy level, giving lectures and workshops on sound design and sound synthesis.