

Hardware vs. Software Instruments

Sequential Circuits Prophet-5 vs. Native Instruments Pro-53

Prepared by
Emre Yazgin, 11467
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Abstract

Musical instruments are constantly evolving. Each change brings new questions, and the question is “can software instruments compete with hardware instruments?”. This research project aims to shed light to the big question by trying to show the differences between two instruments: the hardware synthesiser Prophet 53 and the software emulation of the same hardware synthesiser made by another company.

Prophet 5 is a classic synthesiser made in 1981 by Sequential Circuits, which was founded by Dave Smith, creator of many other important musical instruments. Pro 53 is the software version of the Prophet 5.

Comparing two instruments similar in function but different in technology requires effort in establishing a careful methodology. Comparison of the features, quality of the sounds they can produce, accuracy of the instruments and real life performance are crucial aspects to be investigated. In order to carry the empirical research, careful and high quality recordings of the sounds the instruments, critical listening and visual analysis of the output should be employed.

Software platform has superiority over hardware in terms of the breadth of functions, convenience and cost effectiveness. In the framework of musical instruments, though, extra features do not always beat sonic qualities. Upon comparing the Prophet 5 and Pro 53, reasonable doubt still exists that, although software instruments are as nearly good as hardware instruments, they are still not perfect complements. This is partly due to the sonic characteristics of hardware instruments, but also it is a result of the better interaction of a hardware and its operator.

Introduction

Music is believed to have begun even before civilization¹. It is not unexpected that the history of musical instruments is closely related with the music history and also with the technological advancements the human race has been achieving. Technology and music styles have always been the driving force behind the evolution of musical instruments². The most likely candidate for being the first musical instrument is believed to be the human body itself used as a percussive and/or a vocal instrument. As the mankind have started to be proficient with the use of stone and wood, discovered bronze and iron, the musical instruments have also evolved into more complex mechanisms (see figure 1³).



Figure 1: Metal chimes with bronze legs¹

20th century has been an important milestone for the further evolution of the musical instruments⁴. Advancements in mechanics, electronics and the emerging of new possibilities in engineering helped the invention of new musical instruments like the electric guitar, electric piano, and eventually audio synthesisers, samplers and software musical instruments which are simply computer software capable of producing sounds when instructed to do so. Software based musical instruments are also called *virtual instruments* due to the fact that they are not tangible objects. Earliest software instruments, just like the first digital hardware musical instruments, were designed to emulate the sounds that earlier mechanical instruments were producing. However, the sounds they were producing were far from being convincing to human ear. Nonetheless, as the computing power of the personal computers grew, so did the quality of the software instruments. Today, software music technology is at such a level that, a significant amount of musicians, engineers and technology experts are arguing that software versions of some musical instruments sound at least as good as the hardware version of the same instrument and most of the time offer more functionality and features.

¹ Hamilton, C., (2003), pp.41-43

² Ibid., pp.3

³ *Zhonguo, F.*, (1990), pp.125

⁴ Cook, N., Pople, A., (2004), pp.18-21

Prophet 5

Prophet 5 (see figure 2) is an analogue-digital hybrid synthesiser, originally designed by Dave Smith and then manufactured by Sequential Circuits which has been an important milestone in the evolution of modern synthesisers⁵. According to Sequential Circuits, “instead of directly controlling the analogue synthesiser voices, the keyboard and most controls are actually devices which input “data” to a microcomputer system which in turn “programs” the voices.”⁶ Since the microcomputer’s output can be easily saved on to an erasable-programmable memory such as EPROM or a consumer cassette tape as square wave audio, this has enabled the functionality of full customisation and storage of presets of the synthesiser.



Figure 2: Prophet 5 revision 3.0

The Prophet has five (hence the model number) voices available at the same time and each of these individual voices are produced by two voltage controlled oscillators which are referred to as OSC A and OSC B on the signal flow chart of the synthesiser (see appendix a). A pink noise and a single low frequency oscillator (LFO) can also be mixed into OSC A and OSC b. These voices then pass through a low pass filter which has a dedicated attack, decay, sustain, release (ADSR) controls and then routed into the amplifier section which has a separate ADSR section. Pitch and the on/off status of the oscillators are controlled by the keyboard and also by means of an external control voltage (CV) feed into the CV input of the synthesiser. The keyboard also triggers the amplifier’s ADSR section for control of the dynamics of the sounds produced.

Prophet 5 offers two main modulation sources which can modulate the pitch, cutoff frequency of the filter, the VCO and the VCA. Modulation is an important aspect of any synthesiser as it is directly related to expressiveness and the range of

⁵ Vail, M., (2000), pp. 173-174

⁶ Jungleib, S., (1982), pp. 3

the sound palette of a synthesiser. These sources are the modulation wheel (MOD WHEEL) and the polyphonic modulation (POLY-MOD).

Being a true analogue synthesiser, prophet 5 also features external control of the oscillators, amplifier section and also the filter cutoff via voltage, trigger, gate and filter inputs housed at the back of the unit (see figure 3).



Figure 3: Gate, CV, Trigger and Filter Inputs at the back of the Prophet 5

Pro-53

Pro-53 is the software emulation of the Prophet 5 synthesiser (see figure 4). This software is made by the German company; Native Instruments. Pro-53 is the third and the latest generation of the series⁷. The first generation emulation was called Pro Five which was released in 2000, and Pro-52 was released with major improvements towards the end of the same year.

Native Instruments claims that “this virtual instrument, fashioned after the Sequential Circuits Prophet-5, provides the sonic properties of the unique originals while meeting the practical requirements of the present day”.⁸



Figure 4: Pro-53 User interface

⁷ http://www.nativeinstruments.de/index.php?pro53_us&ftu=c5ff2bc5316d1f7&flash=9

⁸ Ibid.

Pro-53 is available as stand-alone software and also as a plugin that can run on any computer that runs Microsoft Windows XP or Macintosh OS 10.4.x, and above. Plugin version of the software requires a host application that supports Audio Units, VST, RTAS or DirectX plugins. The biggest advantage of a software instrument plugin is that as long as the licence allows, technically the user can run multiple instances of the same plugin⁹. The only limitation is the computing power of the computer that runs the plugin. This is a huge opportunity compared to owning only one instance of a hardware instrument.

Prophet 5 vs. Pro 53

Signal Flow

The signal flow of the Prophet 5 is identical to the signal flow of the Pro 53 (see appendix b). There is only one difference between the two diagrams.

The difference is that, due to the fact that Pro 53 has a built-in delay effect, the dry signal that comes out of the ADSR amplifier section of the Pro-53 is routed into the “delay effect” section. This section has an “On” button to put the effect in between the ADSR amplifier and the master volume in series, and the amount of the effect is controlled by a wet/dry knob.



Figure 5: Delay Effect Section of Pro-53 to the right of the filter section

⁹ Grosse, D., Kurz, M., Wilhelmi, M., (2004), pp. 4

Tuning and Intonation

Tuning

Prophet 5 is a true analogue synthesiser. Due to the nature of the electrical components, any change in the environmental temperature or a change inside the unit's chassis due to the transformer's or the power transistors' heat, the oscillators might lose their stability, hence accuracy in producing the right pitch¹⁰. This will alter the tuning of the synthesiser. Therefore, Sequential Circuits implemented an auto-tune function. The user can automatically retune the oscillators by pressing the "Tune" button.



Figure 6: "Tune" button of the Prophet

This type of "problem", of course, is not an issue for the Pro 53 and not for any other software synthesiser either, simply because they do not rely on hardware oscillators. However, with Prophet 5, especially in the first 15-20 minutes, until the components reach at a stable temperature, frequent retuning is necessary.¹¹

Intonation

Majority of the keyboards including the piano, harpsichord, organs and similar instruments are tuned according to the equal temperament system¹². Most of the time, analogue synthesisers do not allow the user to change the intonation to other alternative systems.

¹⁰ Jungelib, S., (1982), pp. 1-4

¹¹ Ibid.

¹² Barbour, J.M. (2004), pp. 44

Both prophet 5 and pro 53 have a solution for this problem. The user of prophet 5 is able to change the intonation of the instrument by putting the synthesiser into a special mode called “Scale Mode” which converts the twelve knobs in the middle of the user panel to adjustment knobs for pitches of twelve individual keys (see figure 7). The user can then save these alternative temperaments as scale presets independent of the user presets for alternative sounds.



Figure 7: “Scale Mode” and pitch knobs in Prophet 5

The same task can be achieved with Pro 53 by using the function called “micro tuning”. The user can load or save alternative temperament settings from the main menu of the graphical user interface (GUI)¹³.

Oscillators

The 11 oscillators of the Prophet are powered by Curtis CEM 3340 voltage controlled oscillator (VCO) chips which can produce triangle, pulse and sawtooth waveforms and also combination of these waveforms (e.g. pulse + sawtooth = modulating pulse waveform into a sawtooth waveform) (see figure 8)¹⁴.

These are extremely precise voltage controlled self contained integrated circuits which have capabilities of syncing the frequencies to each other which

¹³ Grosse, D., Kurz, M., Wilhelmi, M., (2004), pp. 28

¹⁴ Jungelib, S., (1982), pp. 2-8

enables the Prophet 5 user to sync OSC A and OSC B together to overcome the *oscillator drift*¹⁵ phenomenon of analogue synthesisers.

On the other hand, Pro 53 oscillators are digital emulation algorithms based on the prophet's oscillators. Pro 53 can also produce all three waveforms and also all of the combination waveforms as well. It is possible to compare the pure waveforms visually by recording the output of the oscillators, bypassing the filter, ADSR and modulation settings by appropriate settings.



Figure 8: The voice board of the Prophet 5 with CEM chips
(Picture source: <http://users.telenet.be/prophet-5>)

Sawtooth

Visually, it is clear that the waveforms of the Prophet and the Pro 53 are identical (see figure 9) .However, upon a close look to the waveform it is visible that

¹⁵ Reid, G., (2005)

the Pro 53 is introducing some “harshness” to the sawtooth waveform with the formation of *aliasing*¹⁶ (see figure 9).

On the other hand, Prophet 5 is able to produce a smoother waveform which results in a slightly warmer and “analogue” sound (see figure 9). “Warmth” is a quality often associated to the analogue synthesiser sound and usually refers to a sound that does not sound “digital” and has the pleasant natural *analogue distortion*¹⁷¹⁸.

An audio comparison of a Prophet 5 sawtooth and Pro 53 sawtooth sound of the same pitch, filter, ADSR and modulation settings is a more realistic way of comparing the “warmth” quality than pure visual comparison of the waveforms (appendix C tracks 1 & 2).

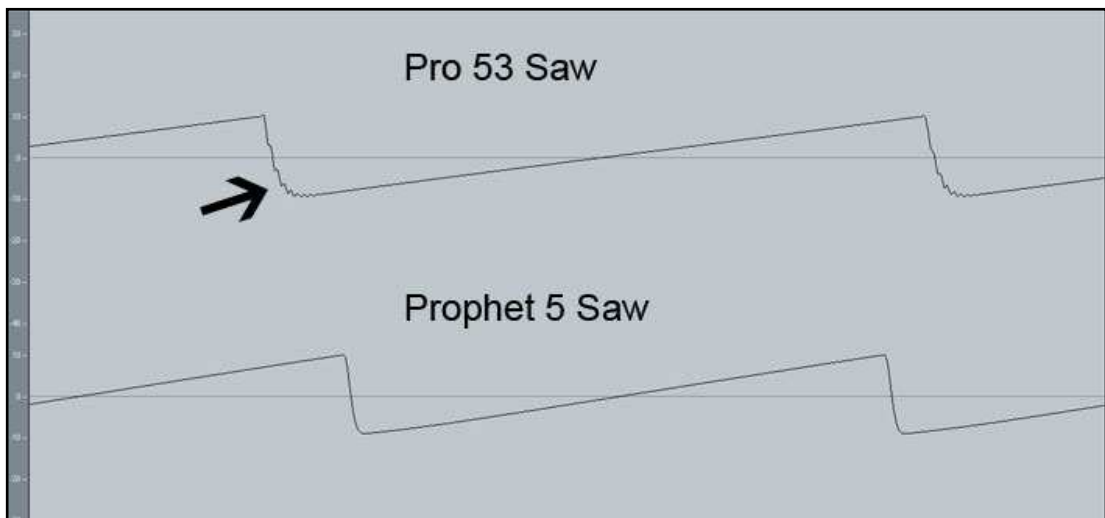


Figure 9: Prophet 5 vs. pro 53 sawtooth waveforms, “harshness” area shown with the arrow

¹⁶ Pohleman, K., (2005), pp. 28-30

¹⁷ Stewart, D., (2004), pp. 94

¹⁸ Katz, B., (2002), pp. 209

Pulse

Pulse wave is a variation of square wave, with more rounded edges¹⁹. This kind of waveform is easier for an analogue synthesiser to produce than a perfect square wave. This is due to the fact that the electronic components used in the synthesiser, especially the capacitors, need some time (even though it is a matter of nanoseconds) to charge and discharge which makes the waveform generated smoother. This phenomenon does not happen in the digital domain. This is where most of the software instruments' oscillator sections fail.

Upon comparing the prophet's pulse waveform with the Pro 53's waveform it is visible that, the same "harsh" edges are present (see figure 10). Once again, this is due to the inability of the Pro 53's digital oscillator to cope with digital aliasing. The audible effect of this is an unnatural and "digital sounding" generation of the pulse signal. In order to compare the prophet 5 and the pro 53 pulse signals please refer to appendix c, tracks 2 & 3.

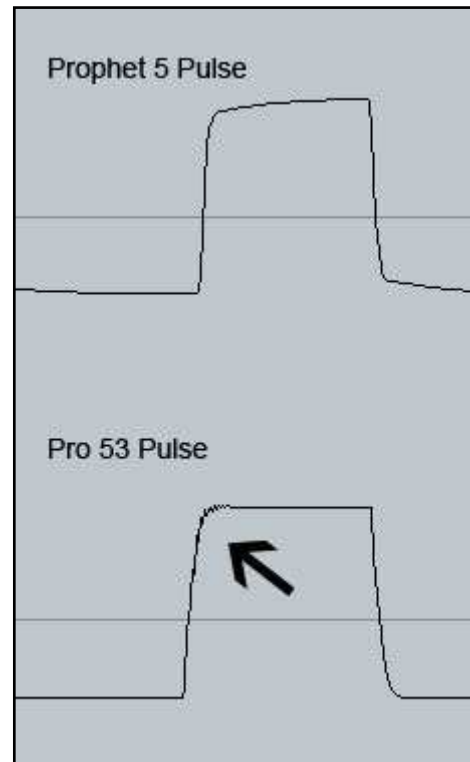


Figure 10: Prophet 5 vs. pro 53 pulse waveforms, "harshness" area shown with the arrow

¹⁹ Aikin, J., (2003), pp. 261-262

Triangle

On investigating the waveforms, it is seen that triangle is an area where pro 53 excel as much as the Prophet does. This is due to the nature of the waveform where there is not much of the possibility of distortion due to the gradual and linear increment and decrement of the waveform. Inspecting the triangle waveforms of the Prophet and Pro 53, it is clear that the waveforms are perfectly identical. The sound recordings of these two signals also suggest that Pro 53 oscillator does a good job in producing a triangle signal (appendix c, tracks 5 & 6).

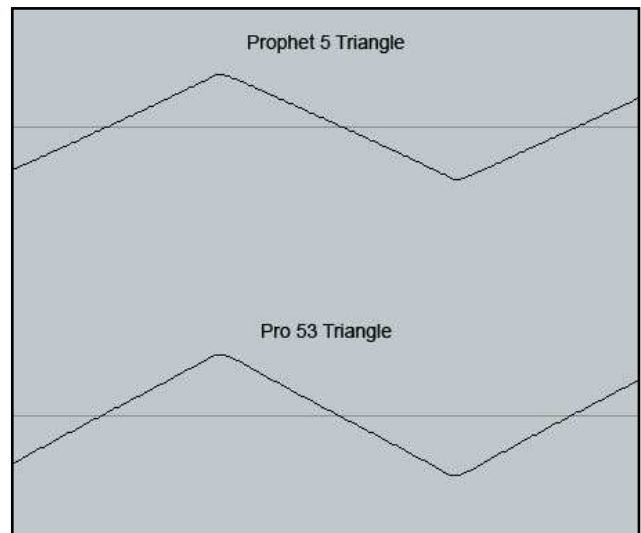


Figure 11: Prophet 5 vs. pro 53 triangle waveforms

Mixed waveform (Saw + Triangle + Pulse)

Both instruments offer the functionality of adding the waveforms together and having a more complex waveform, which is a combination of sawtooth, triangle and pulse waveforms. To get an even bigger sound, one could also use both of the oscillators at the same time. This results in the OSC A to produce a combination of Triangle + Pulse and OSC B to produce a combination of Saw + Triangle + Pulse. Both instruments give the option of syncing the oscillators together, so that each one of the oscillators (in this case OSC B) acts as a “slave” and syncs to the phase of the “master oscillator” (in this case OSC A).

When not synced it is normally expected to hear the oscillator drift phenomenon, which simply means minor frequency instabilities due to temperature or voltage differences that happen all the time within components²⁰. These kinds of glides have a great impact on the sound produced when both oscillators are active. Due to slightly different frequencies happening at the same time a chorusing will occur when the same note is produced by two oscillators at the same time. This is clearly audible with both the Prophet 5 and also with the Pro 53 (appendix c, tracks 7 & 8). The

notes played in the “piano roll” (see figure 12).

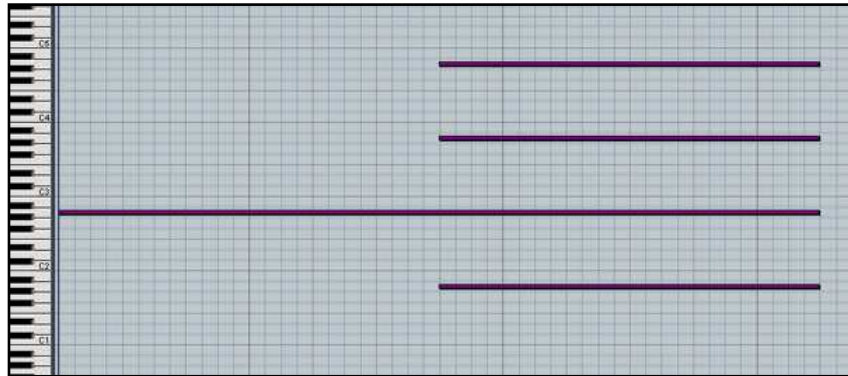


Figure 12: Piano roll for appendix c, tracks 7, 8, 9, 10

Although the Pro 53 is not an analogue instrument, the programmers have implemented a function, where the user is able to dial in an amount of “analogue instability” with a knob on the main graphical user interface. This function emulates the frequency drift that happens in the analogue oscillators. Mc Junkin of Mix Online Magazine admits, “The Pro-53 is a great example of pure emulation, warts and all. The original oscillators suffered some pitch drift, which lent to the warmth of the sound. NI allows for two operating modes: analogue warmth, which includes the inaccuracies of the original synth, or digital accuracy, which represents the synth with perfect circuits that never drift. The Pro-53 is so sophisticated that it allows variable control over the amount of analogue inaccuracies. This is a truly great virtual synth, and I use it in some way in almost every project.”²¹

When the two oscillators are synced together sonic differences between two instruments are substantial. With single oscillator and simple waveforms Pro 53 could cope with difficulties in emulating the prophet 5, however, the more complex the waveforms and the more interaction is introduced between oscillators, the more unconvincing starts the Pro 53 to become. Appendix C, tracks 9 & 10 exemplifies a

²⁰ Aikin, J., (2003), pp. 40

²¹ http://mixonline.com/products/buyersguides/audio_virtual_instruments_real

situation where both oscillators are active and the waveforms are Triangle + Pulse for OSC A and Saw + Triangle + Pulse for OSC B with SYNC active.

Filters

Emulating hardware filters in the digital domain is not always an easy task. Since, filter section is an important section in shaping the sound of the synthesiser, comparing the filters of two instruments can help understand the overall quality of a synthesiser.

Upon comparing a simple filter sweep with no resonance, it could be concluded that both filters have more or less same characteristics (Appendix c, tracks 11 & 12). However, one of the biggest challenges in the emulation of the filter section is that it is very difficult to emulate the behaviour of a filter that is about to resonate. This has been tested by playing a long note with both prophet and pro 53 and gradually turning up the resonance until the filter resonates. (Appendix c, tracks 13 & 14). When comparing the two audio files it is apparent that pro 53 has succeeded in emulating the character of the prophet's low pass filter at near resonance.

Another difficulty in emulating the filters is that, sometimes the user increases or decreases the amount of cutoff frequency or the resonance and the increment or the decrement steps might be perceptible. This is due to the nature of 128 step midi standard. However, some manufacturers use a technique of interpolation, so that the filter has smoother transition between values²². This is the case with the Pro 53. During the filter sweep, there is no audible "stepping" of the filter.

There are some features in the filter section of Pro 53 that does not exist in the Prophet. The most important one is that Pro 53 also has a high pass filter. In 80s, the most common type of filter for synthesisers was the low pass filter, however in the 21st century, as the genres demand more sophisticated sounds synthesiser, more filter options are needed. Another feature of Pro 53 filter section is that it has a

²² <http://www.fabfilter.com/products/one.php>

variable keyboard tracking knob for the filter section. This enables the user to select values between no-keyboard tracking and full keyboard tracking.

Modulation

Modulation, in Prophet 5 is handled in two ways, either with the modulation wheel or with the polyphonic modulation section²³. Pro 53 offers the exact same modulation options with some extra functions.

Because Pro-53 works with midi data, Native Instruments also included two extra functions to the software synthesiser which added one more connection to the signal flow (see appendix B). First one is the ability of the LFO to work in sync with midi clock data received and this could be enabled by clicking on the MIDI SYNC button. Second feature is that the LFO can retrigger any held notes.

In order to illustrate the use of the Polyphonic Modulation, the following patch has been prepared and applied to both Pro 53 and the Prophet 5 (See figure 13). The patch tries to emulate the typical sound of a rope swinging, first slowly then gradually faster.

Breakdown of the patch:

Oscillator section: Only a single oscillator is used for this patch and the waveform is a sawtooth.

Filter Section: Cutoff frequency is lower than middle so that the sound will start “closed” and with the appropriate filter ADSR settings, it will open up according to the “attack” time set, then decrease with “decay” and “sustain” for a very short time. This kind of setting will give a single swing sound of a rope.

Poly-Mod Section: In order to emulate the sound of a swinging rope, modulation of the oscillator’s frequency is needed. Here is the right place for the usage of the

²³ Jungleib,S., (1982), pp.2-9

POLY-MOD. FILTER ENVELOPE is turned up till halfway, so that the filter ADSR (envelope) will affect the POLY-MOD destination. On assigning the poly-mod destination as the FREQ-A (frequency of the oscillator A), and also FILT (cutoff frequency), the patch sound more convincing.

“No review of a Prophet clone would be complete without a mention of the brilliant 'Poly Mod' section. This is what separates the Prophet from virtually every other synth, and lies at the heart of its ability to make highly characterful sounds. By using Oscillator B and the filter envelope to modulate oscillator frequency, pulse width and filter cutoff, one can create all manner of outrageous distorted and clangy noises, as well as delicate and unusual sounds such as quasi-plucked string effects”²⁴

Amplifier ADSR: To finalise the patch settings, short attack, nearly halfway decay for the decrement of the initial attack and a very short release are chosen.



Figure 13: “Swinging Rope” patch settings on Pro 53

Same settings are made to the Prophet 5 for comparison (see appendix D for the patch setting images for Prophet 5). The resulting audio waves show that poly-mod function of the Prophet 5 and the Pro 53 are identical. (See appendix C, tracks 15 & 16).

²⁴ Stewart, D., (2004), pp.52

ADSR (Filter & Amplifier)

Both Prophet 5 and the Native Instruments Pro 53 has two ADSR (attack, decay, release and sustain) envelope functions. One of them is associated with the VCA (amplifier section), and the second one with the FILTER section. There are two differences among two instruments in terms of ADSR features. First, with Pro 53, the filter ADSR section can be inverted. According to Native Instruments, when the invert button is clicked, instead of the cutoff frequency to rise with attack, then fall with decay and release, the cutoff frequency drops during the attack period and rises with the decay and release periods²⁵.

Presets

Prophet 5 has a total of 40 presets, organized in 8 banks. Preset management in Prophet 5 is done in two ways. Either using an external cassette recorder to record digital data in the form of audio composed of a series of square waves or the presets are stored in the internal memory. It is possible to store all 40 presets on a cassette at once. This feature gives the user the opportunity of building a huge preset bank of theirs; the only limit is the length of the cassette tape. The audio information on the cassette looks like the following waveform (the waveform is actually recorded from the cassette output of the Prophet 5):

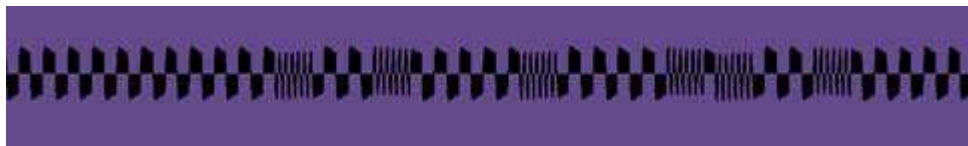


Figure 14: Cassette output data of Prophet 5

Pro 53, on the other hand, have space of 512 for presets. Another interesting feature of Pro 53 is that, if a prophet is equipped with a suitable midi interface, it could receive and understand SysEx data of the Prophet 5²⁶. This enables the importing of Prophet 5 patches into the Pro 53.

²⁵ Grosse, D., Kurz, M., Wilhelm, M. (2004).

²⁶ <http://www.nativeinstruments.de>

Comparison of features

	Prophet 5	Pro 53 ²⁷
Polyphony	5	<i>limitless</i>
Presets	40	512
Midi Response	No	Yes
Alt. Temperament	Yes	Yes
FX Section	No	Yes
Envelope Retrigger	No	Yes
LFO > midi clock	No	Yes
Velocity Sensitivity	No	Yes
Release Hold on/off	No	Yes
Variable Kyb. Tracking	No	Yes
HP Filter	No	Yes
Invertible ADSR	No	Yes
CV in	Yes	No
Cassette Interface	Yes	No
Midi control map	No	Yes

Musical comparison

In order to have a complete comparison of two instruments, aside of pure mathematical and visual comparisons, the instruments must also be assessed in terms of musicality. The Prophet 5 has been used by many important musicians since it has been introduced, and the sound of Prophet has been heard on many records, especially in 80s.²⁸ One of the most famous songs that the Prophet has been used is “In the air tonight”.²⁹ An attempt to play the introduction part of the song with Prophet 5 and also Pro 53 showed that it is possible to obtain a close version of any kind of synthesiser sound. The recording starts with the sound of Prophet 5 playing the chords, at 00:21 Pro 53 sound cross fades in and takes over and at 00:33 the original song fades in. (Appendix C, track 17).

²⁷ http://www.nativeinstruments.de/index.php?pro53_us&ftu=c5ff2bc5316d1f7&flash=9

²⁸ <http://users.telenet.be/prophet-5/main.htm>

²⁹ Collins, P., (1981)

Conclusion

Musical instruments of today are very different than they used to be decades ago. Modern musicians and composers no longer acquire the real instrument; instead they acquire a licence to use a software package that runs within the computer's operating system. This, as one would expect, brings up the question of *quality compared to the "real" instruments*. Could a software emulation of a classic synthesiser like the Prophet 5 convince the player? In most ways it could. Pro 53 offers the same design, user interface, functions and on top of that limitless polyphony, built in effects and full automation and control via midi. However, even though the Prophet 5 lacks the practicality of a software instrument, still, being a real instrument, made up of tangible components, physically producing sound with analogue circuitry adds the element of surprise, imperfection and more interaction to the equation of quality.

"The digital/software versions of real analog synths tend to be fairly close, especially if you've never played the real thing. So, it's a low cost way for more people to at least get to understand the instrument. But, when you compare them to a real instrument, the differences are more obvious. I see this often when people play one of the Evolver synths for the first time; they smile, and say "okay, now I get it!"³⁰

Dave Smith,
Designer of the Prophet 5

³⁰ From an email from Dave Smith himself

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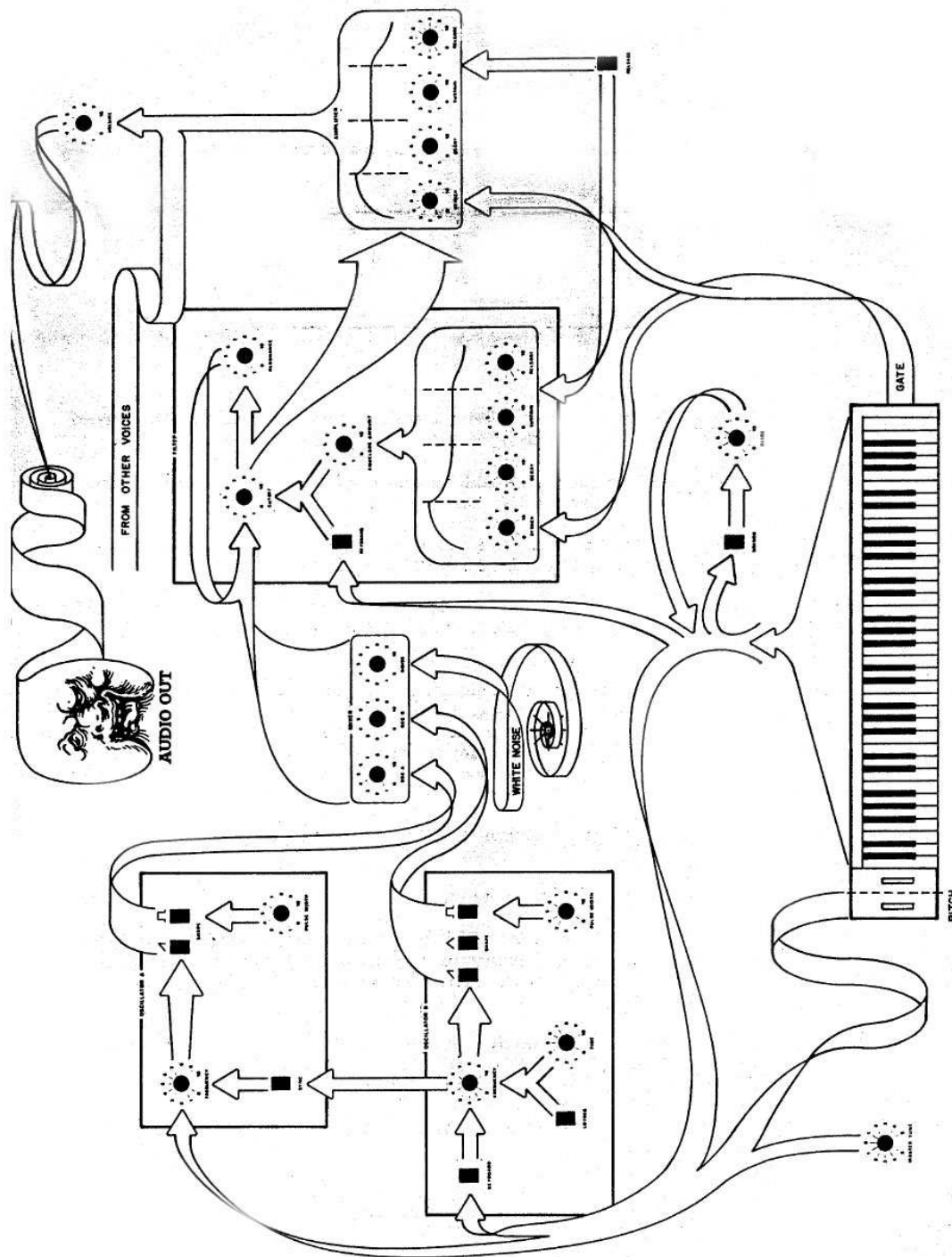
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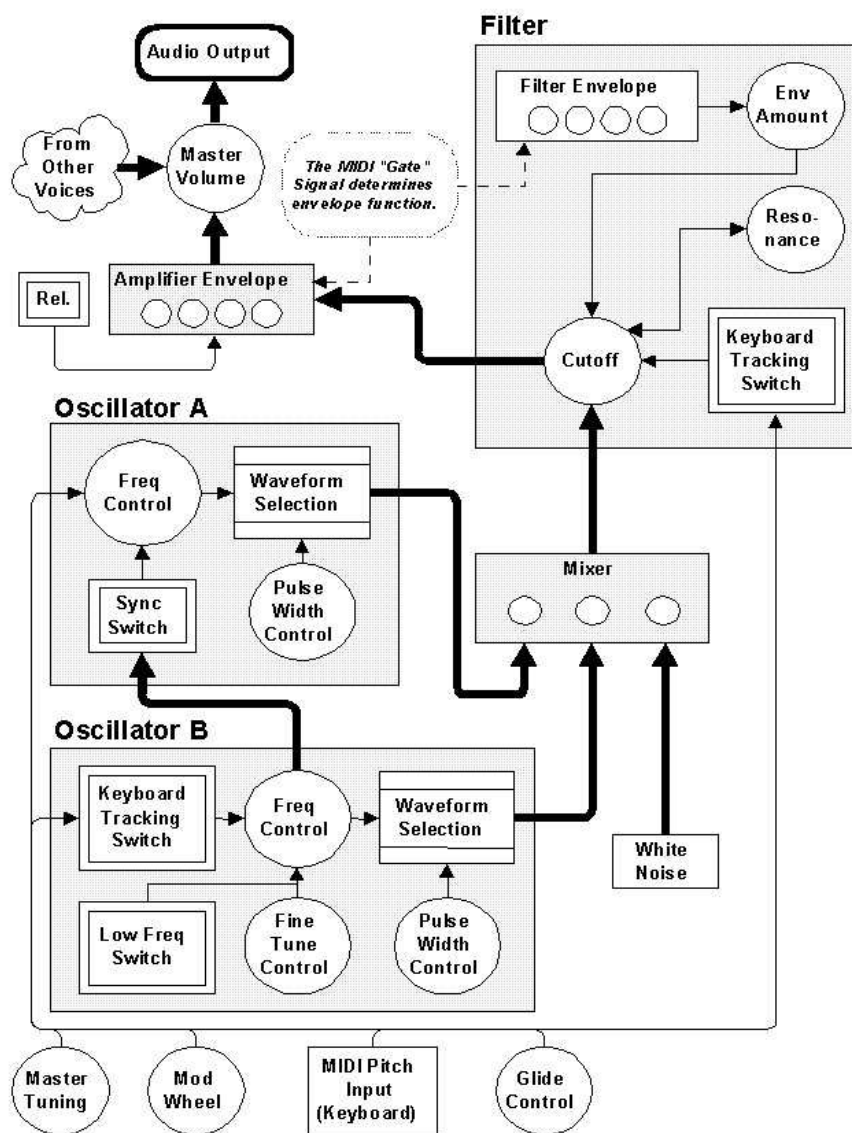
Discography

Collins, P. (1981). In the air tonight. *Face Value*. Atlantic Records: CS-16029

Appendix A. The signal flow diagram of Prophet 5



Appendix B. The signal flow diagram of Pro-53



Appendix C. Audio CD

Tracks:

1. Prophet 5 - Sawtooth, Osc A
2. Pro 53 - Sawtooth, Osc A
3. Prophet - Pulse
4. Pro 53 - Pulse
5. Prophet - Triangle
6. Pro 53 - Triangle
7. Prophet – Mixed waveform – no sync
8. Pro 53 – Mixed waveform – no sync
9. Prophet – Mixed waveform –synced
10. Pro 53 – Mixed waveform –synced
11. Prophet – Filter Sweep
12. Pro 53 – Filter Sweep
13. Prophet – Filter behaviour at near resonance
14. Pro 53 – Filter behaviour at near resonance
15. Prophet – “Swinging Rope” patch
16. Pro 53 – “Swinging Rope” patch
17. Excerpt from “In the air tonight”

Appendix D. “Rope Swinging” preset for Prophet 5

