Practical Flute Synthesis

Synth Secrets

- Synthesizers > Synth Secrets, Synthesis / Sound Design

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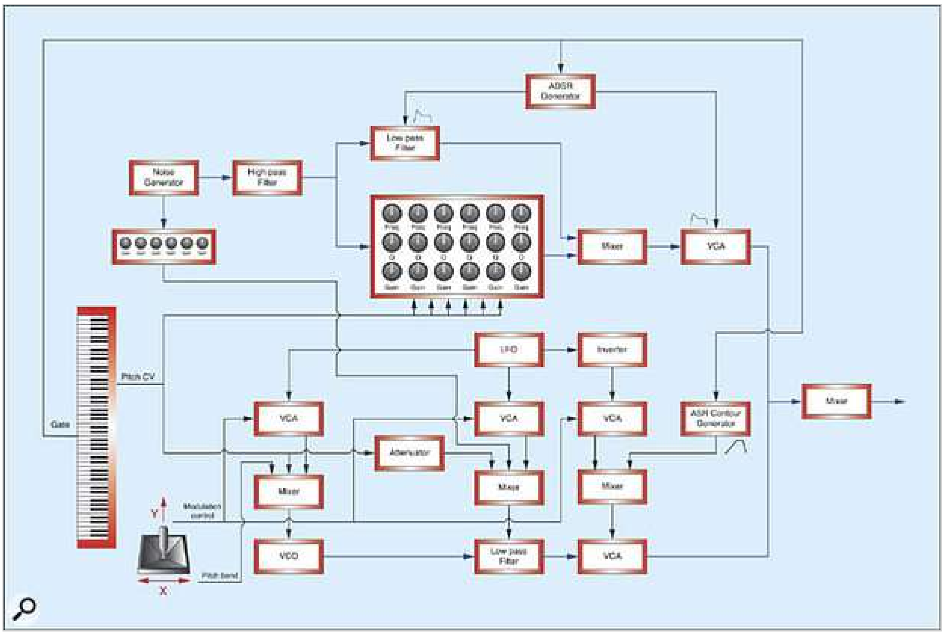

Figure 1: Synthesizing the pan flute.

As we saw last month, there's much to synthesizing a convincing flute sound — and yet basic analogue monosynths have offered reasonable flute patches for 30 years. Surely the process can be simplified?

A couple of months ago, I described and analysed the sound of the pan flute, and at the end left you with a diagram — reproduced above as Figure 1 — which showed, without reference to any particular analogue synth, how you could use such an instrument to create a remarkable simulation of the original pipes. I then told you that I had programmed this to remarkably good effect, but (partly due to space constraints) I didn't show you how.

That omission led some readers to ask to see the patch, so it's shown here, as lovingly crafted on my Analogue Systems Sorceror plus part of the RS Integrator that sits alongside it (see Figure 2). It's possible that I (and indeed you) could create something similar on a huge Moog Modular, a fully populated Roland System 700, a wall-sized Roland System 100M, or a well-endowed Doepfer, but I don't own any of these.

In this article...

In this Series

This, then, suggests a problem: given the non-trivial nature of this patch, it's not one that you'll be able to create on a basic analogue synthesizer. Yet, as I stated at the time, good flute sounds (as opposed to pan flute sounds) pour forth from basic monosynths well past their 30th birthdays. Last month, I tried to reduce the complexity (and therefore the cost) of producing a flute-like sound, programming a recorder patch using the Oddity software synth loaded on the Apple Power Book on which I'm writing this. As expected, the results were far less than convincing, although they were useable in a 1970s sort of way.

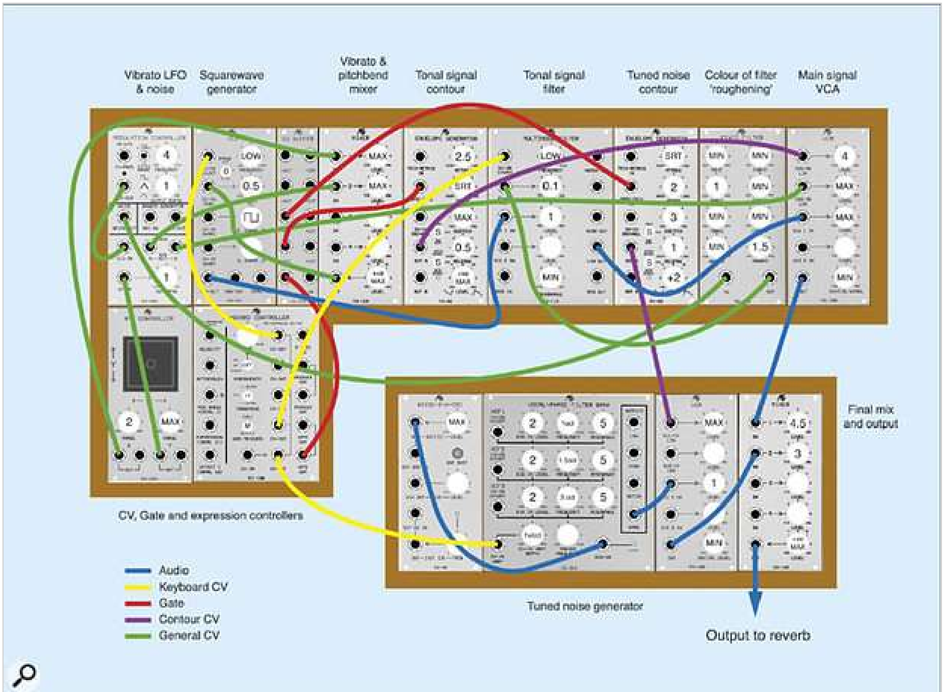

Figure 2: Patching the architecture in Figure 1.

But, just to demonstrate that the complexity and expense of a modular synthesizer isn't always necessary to create a superb sound, I'm going to start by telling you that my favourite analogue flute resides within a small synth that is the antithesis of the Sorceror and Integrator shown in Figure 2. Designed to sit on top of an organ, and to be as much at home in tearooms and dance halls as in rock venues, this is the ARP Pro Soloist, which first appeared in 1972. On the surface, this is a simple VCO/VCF/VCA preset synth that offers the player almost no control over the sounds its produces. But if you delve deeper, you'll find that it's a remarkable instrument that, on another day, might command a complete instalment of Synth Secrets. Unfortunately, understanding the Pro Soloist does not further our understanding of the flute, so we must move on without it. That's because it's now time to look more closely at the flute itself.

The Modern Flute

The transverse flute has been known since antiquity, and has been undergoing a constant process of development and improvement ever since. The current form (shown in Figure 3, below) appeared in the 19th century, gaining the keys and extra holes that allow it to produce (almost) exact semitones without half-holing and all the other palaver that we investigated last month. To be honest, it's still not possible to play a perfect chromatic scale across all the flute's registers, but the modern instrument is close to ideal, so a flute patch played from a keyboard is immediately more likely to be realistic than a recorder patch played the same way.

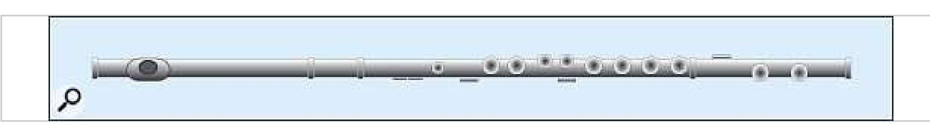

Figure 3: The modern orchestral flute, shown without the levers.

Nonetheless, the size of the holes is still an important factor. Experiments show that larger holes allow the upper partials to 'sound' with greater energy, so the tone is brighter. Earlier, wooden flutes with small holes — generally found in folk music — have a more mellow timbre that can be surprisingly reminiscent of the recorder.

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- Practical Snare Drum Synthesis
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- Synthesizing Acoustic Pianos On The Roland JX10 [Part 3]
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- Practical Flute Synthesis
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- Synthesizing Tonewheel Organs: Part 2
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- Synthesizing The Rest Of The Hammond Organ: Part 1
- Synthesizing The Rest Of The Hammond Organ: Part 2
- From Analogue To Digital Effects
- Creative Synthesis With Delays
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- The Secret Of The Big Red Button

Why surprising? Because, unlike the recorder, the main bore of the flute is almost exactly cylindrical. And, unlike the recorder, most flutes are made of metal rather than wood. Even gold and platinum are suitable materials if the owner is wealthy (and ostentatious) enough. Apparently, instruments made using precious metals sound no better than those drawn from more affordable substances, and even 'affordable' flutes are not exactly cheap, with the best being constructed from an alloy that is 90-percent silver. Cheaper models — those that you would find in a typical high-street music store — are typically drawn from a copper/zinc/nickel alloy covered by a thin layer of silver plating.

Far more important than the material from which the flute is constructed are the shape and angle of the embouchure hole, the height of the embouchure chimney, and the position of the cork end-stop that tunes the instrument. A badly adjusted cork can mis-tune the registers by a full semitone relative to one another, and will limit the upper note that the instrument is capable of producing. However, the existence of the cork — or, more accurately, the cavity between the embouchure hole and the cork — has another profound effect, as shown in Figures 4(a), 4(b) and 4(c) below.

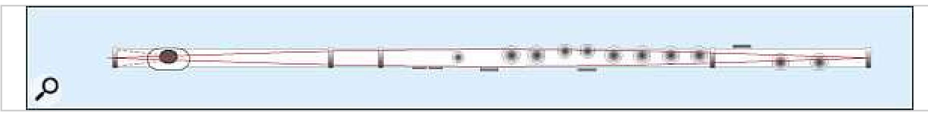

Figure 4(a): The first harmonic (fundamental) of the lowest note playable on a flute.

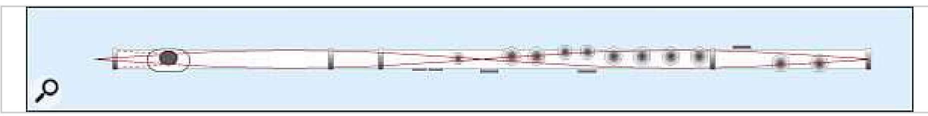

Figure 4(b): The second harmonic of the lowest note playable on a flute.

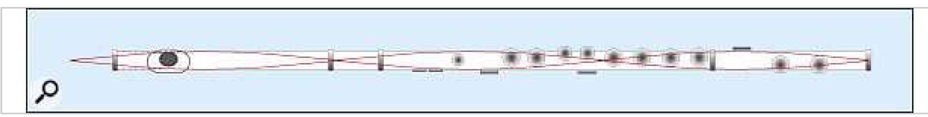

Figure 4(c): The third harmonic of the lowest note playable on a flute.

As you can see, having the embouchure hole a short distance from the end of the bore causes the flute to act in a different way to a simple pipe, with a pressure maximum at the cork, and a wavelength within the bore that suggests that the effective length of the flute increases for higher harmonics! This is analogous to the 'overshoot' I mentioned when we discussed brass instruments, and its effect is to make the harmonic frequencies more and more approximate with increasing harmonic number. Flute manufacturers try to compensate for this by making tiny adjustments to the position of the cork, the shape of the embouchure chimney, and the sizes and positions of the holes.

As the diagrams show, the modern flute has 16 holes (13 large and three small) which seems a little excessive when all we require is 12 pitches per octave, but none are superfluous and, like the recorder, the flute has many complex fingerings.

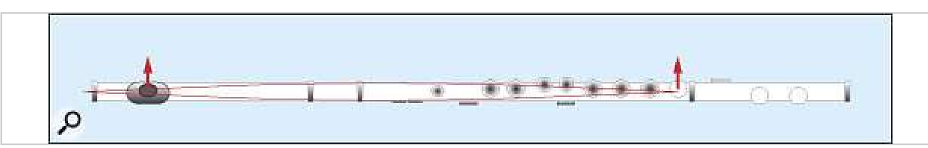

Figure 5: Playing a low 'E' on a 'C' flute.

As with the German recorder, opening holes progressively from the far end makes the effective length of the instrument shorter, thus raising the pitch a semitone at a time. If you open, say, the lowest four holes on a 'C' flute, you obtain a pitch four semitones higher, which is the 'E' shown in Figure 5 (above). However, this is not the only way to obtain pitches, and just as we found last month, the flute is able to play high pitches with lower holes closed. The most obvious example of this appears in Figure 6 (below), in which the player produces the octave 'C' by opening a single hole almost exactly one half of the way along the pipe. I won't 'bore' you *[Groan — Ed]* with the physics of this, because I think that it is intuitively evident why this should be the case (hint: it makes it impossible for the pipe to support any odd harmonics, including the fundamental). Opening other holes at integer fractions of the bore length causes the instrument to jump to even higher octaves, up to its limit.

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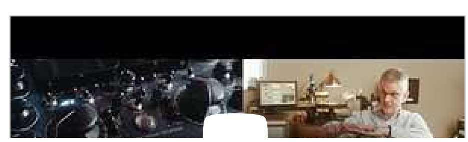

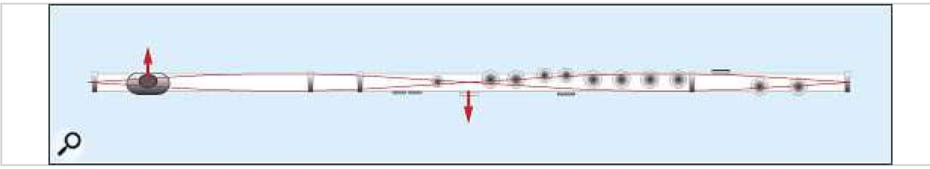

Figure 6: Playing an octave 'C'.

Another way in which the flute is similar to the recorder is in the sound produced at low volumes. This is dominated by the fundamental, with rather weak harmonics. But as you blow harder, higher harmonics appear and, as their amplitudes increase, the flute's tone becomes increasingly complex and more sonorous. Strangely, the flute does not get much louder when you blow harder, but does so when you relax your lips to allow a greater cross-section of air to pass.

If you continue to blow harder still, you will eventually 'overblow' the flute and cause its pitch to jump an octave. This is not true of all woodwind instruments, because cylindrical pipes with one closed end have no even harmonics, so overblowing jumps to the third harmonic, one-and-a-half octaves above the fundamental. This has a significant downside: it is not possible to re-use the fingering of one register in another, higher register.

Now, let's consider the sound radiation from a flute. If it were a trumpet, you might expect it to be loudest when the bell is pointing directly as you. However, it is not a trumpet, and the radiation properties are mind-bogglingly complex. Even in the simplest case, when all the holes are closed and the flute is acting as a pipe open at both ends, the embouchure hole and the open end are acting as roughly equal amplitude sources. This would be bad enough, but — for perhaps obvious reasons — the odd harmonics of the note are in phase at the two ends, whereas the even harmonics are 180 degrees out of phase. This means that there are complex phase interactions between the sources, wherever you listen in the soundfield.

But things get worse! When any of the holes are open, they also radiate sound energy. Given that numerous holes may be open, each radiating at different phases, the tone at different points in the soundfield can differ considerably. Fortunately, you will usually hear a flute played in a reverberant space in which the various cancellations and reinforcements cancel out to give a smoother spectrum. This explains why the use of a good reverb unit is so critical when synthesizing a convincing flute sound. Which brings us neatly to...

Synthesizing The Flute

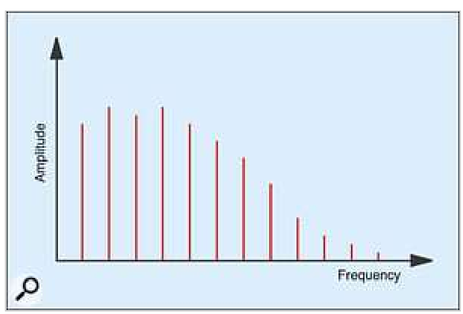

Figure 7: The spectrum of a low 'C'.

Although it may seem that we've just investigated the flute in some detail, we have barely scratched the surface of its complexities. Seemingly trivial things such as the porous properties and rigidity of the inner surface of the bore, the smoothness of the bore, the height of the chimneys beneath the holes, the thickness of the pipe at various places along the instrument... all these and more affect the timbre. Of course, there's no space to investigate these here, and even if we did, it would take us into areas of acoustics and mathematics that are best avoided. So let's ignore the flute's secondary characteristics, and concentrate on its primary attributes. We'll start by looking at its harmonic spectrum, and the way that the sound changes in time.

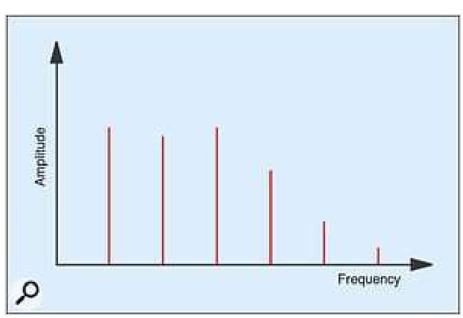

Figure 8: The spectrum of the octave 'C'.

Figure 7 (above) shows the spectrum of a low note such as the bottom 'C'. Played with moderate force, it is rich in harmonics, with strong contributions from the second, third and fourth harmonics, followed by a reasonably '1/n'-like shape from the fourth upward, until the spectrum disappears at some upper frequency. The 'C' played with the same force an octave higher demonstrates a similar pattern, with a suppressed fundamental and second harmonic, but the '1/n' shape for the third harmonic up to the same upper frequency (see Figure 8). If we jump an octave higher, we find that a '1/n' shape is demonstrated for all harmonics, but that there are very few of these, because the upper frequency limit still applies.

You might wonder why the harmonic spectrum is so truncated, but the reason is clear: As the frequency of the oscillation in the pipe increases, it strays further and further from the true resonant frequencies supported by the pipe, and eventually the two are far enough apart to ensure that no standing wave is supported. This is the consequence of the behaviour shown in Figures 4(a), 4(b) and 4(c). In the standard orchestral flute, the cutoff frequency is 2kHz or thereabouts, which explains why all the spectra in Figures 7, 8 and 9 are truncated at this frequency, no matter what note is played.

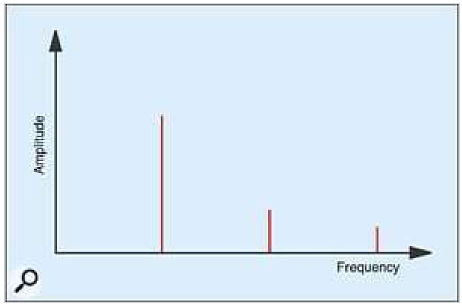

Figure 9: The spectrum of the 'C' in the next register.

You might think that this is not something that we can synthesize without recourse to additive synthesis, but fear not... there is a simple way to achieve all three of these spectra using three analogue modules: a sawtooth oscillator, and voltage-controlled low-pass and high-pass filters.

Consider Figure 10 (right), and you can see how the fundamental and low harmonics can be suppressed for a low note but not for a higher one, and how a similar, if not identical upper cutoff frequency can be imposed on all notes, regardless of pitch. Experiments show that, depending upon the filter slope, the cutoff frequency of the high-pass filter should be in the region of a few hundred Hertz. The cutoff frequency of the low-pass filter resides — as discussed — at 2kHz, although I have found that pitch tracking of a few percent is necessary to ensure that high notes are reproduced with the correct brightness relative to low notes.

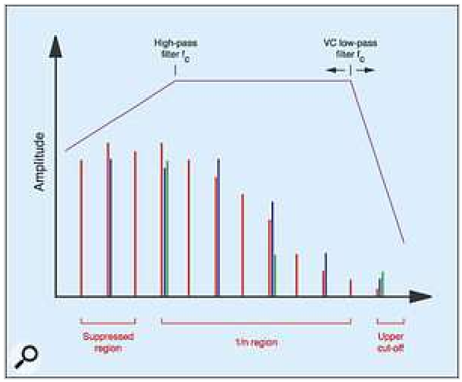

Figure 10: Creating the flute's harmonic spectrum.

The requisite architecture is shown in Figure 11, and is common to many analogue monosynths. This is an elegant result, although it is complicated slightly if we take into account notes played with different blowing pressures. Measurements show that the fundamentals and low harmonics of softly played notes are just as loud as forcefully played notes, but that the upper harmonics are attenuated to a greater extent.

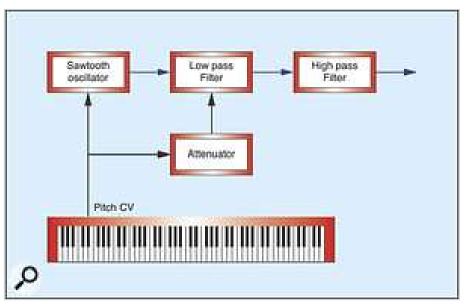

Figure 11: Creating the spectra in Figures 7, 8 and 9.

This means that, with a pressure-sensitive synth, we need only route aftertouch to the low-pass filter cutoff frequency to achieve a realistic result, as shown in Figure 12. This is, of course, what the ARP Pro Soloist offers, and one of the reasons why its sound is so satisfying... Press harder, and the sound becomes brighter. Press less hard, and the sound becomes less bright. The equivalence to blowing pressure could not be closer.

By the way, the spectra in Figures 7 to 9 are idealised representations that make no mention of the noise that is inherent in the flute's sound. Unfortunately, we cannot synthesize this accurately without recourse to large synths. Some programmers add a little white noise to the primary oscillator signal, but personally, I think that this is a mistake, detracting from the authenticity of the patch rather than adding to it.

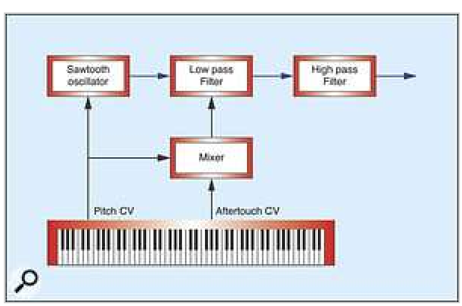

Figure 12: Imitating changes in blowing pressure.

Now let's determine the amplitude contour of the sound. Because the flute is to some extent 'on' or 'off', this proves to be simple. To a first approximation, the Attack must not be instantaneous, but neither must it be too slow, there need be no Decay stage, the Sustain must be at maximum, and the Release is quick (see Figure 13, above).

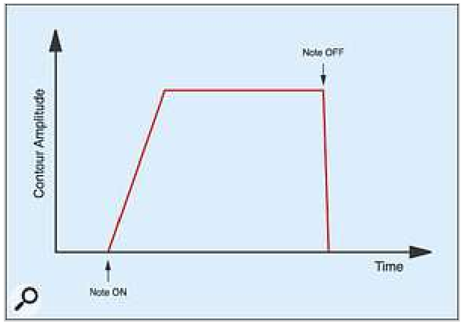

Figure 13: The loudness contour of a flute played without a 'chiff'.

However, this proves to be less than ideal, because the synth will reinitiate its envelope from zero whenever a fresh note is played, resulting in the unnatural 'sucking' sound represented by (although exaggerated in) Figure 14 (see right).

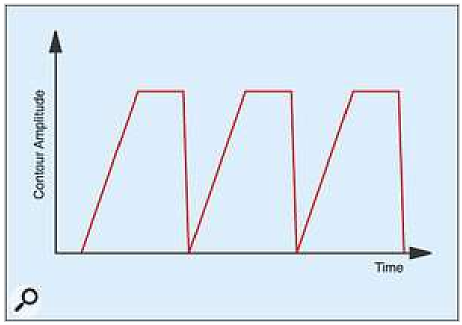

Figure 14: This sucks!

We compensate for this by increasing the Release time (see Figure 15) to the point where it overcomes this (see Figure 16) without adding an inappropriate, slow release to the sound. When set correctly, this gives a nice, natural articulation between the notes in a legato passage, while still allowing you to play in a moderately staccato fashion if desired.

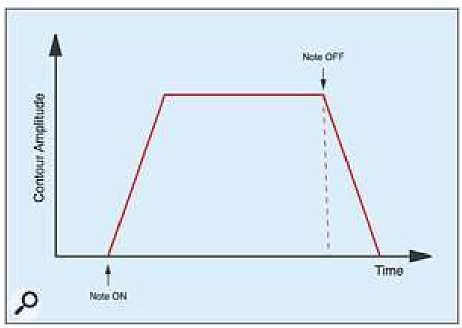

Figure 15: Extending the Release time..

Although I've already discussed the next point, the following sentence is the key to synthesizing the sound of the flute, so I'm going to make a big issue of it:

A flute does not get significantly louder or softer as the player alters the blowing pressure; it becomes brighter or duller.

This means that we can use the same contour for the low-pass filter as for the amplifier. Furthermore, unlike almost all of the instruments we have studied so far, the flute does not exhibit pitch modulation (vibrato) or even loudness modulation (tremolo) but rather tonal (brightness) modulation. Tests show that trained players tend to vary the blowing pressure by about ±10 percent with a frequency of around 5Hz to 6Hz, and we can synthesize this easily using the simple patch in Figure 17 (below).

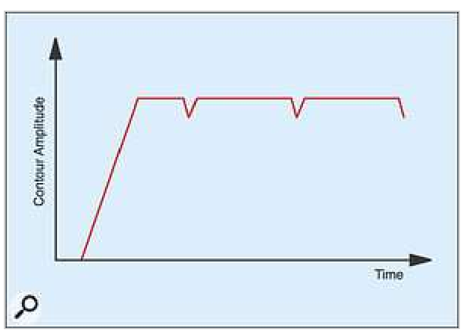

Figure 16: This does not suck!

Adding pressure-sensitivity is also easy, as demonstrated by Figure 18, in which I have routed the pressure CV to both the overall brightness and to the amount of modulation. If your synth is able to respond in this fashion, it will add immeasurably to the expressiveness of the sound. Nevertheless, the expanded patch remains much simpler — and therefore cheaper — than the huge patch in Figure 1.

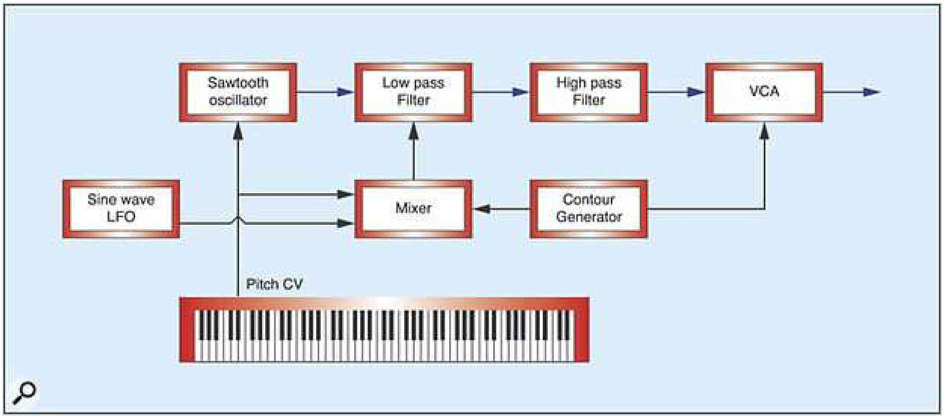

Figure 17: A simple flute patch.

Returning to the 'insensitive' patch in Figure 17, there's only one family of synths that reproduces the basic flute sound as well as I would like. The Minimoog won't do it; neither will the Roland SH101. The Yamaha CS-series and the Korg MS10 and MS20 also fall short of the mark, although the Minikorg 700S is capable of a remarkable flute patch.

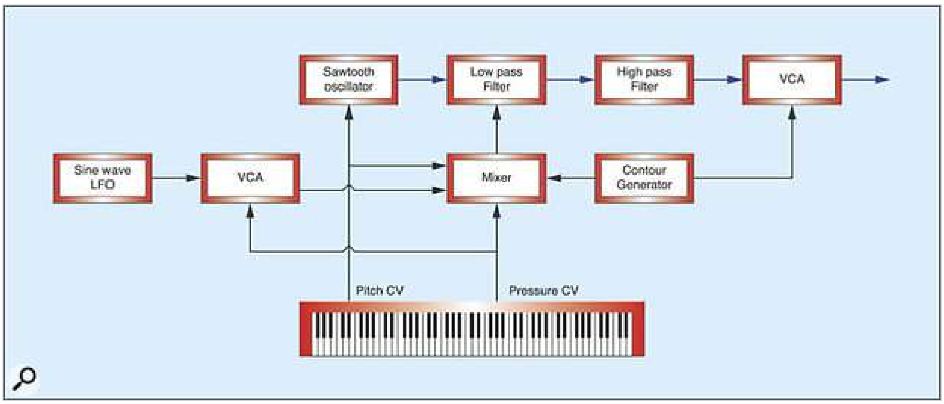

Figure 18: Adding pressure sensitivity.

Nonetheless, I always return to ARP synths for my analogue flute patches. Other than the pressure-sensitive Pro Soloist, the Odyssey is my instrument of choice, not because it has two oscillators and all manner of other sophisticated gubbins, but because it has a high-pass filter. However, even the lowly Axxe is capable of a superb flute, as I will now show.

The Axxe Flute

We'll start by determining the pitch and pitch modulation for each note. As you can see in Figure 19 (below), nothing other than the keyboard CV affects the oscillator pitch. And, because there is no pulse wave in the sound, the positions of the PWM controls are irrelevant.

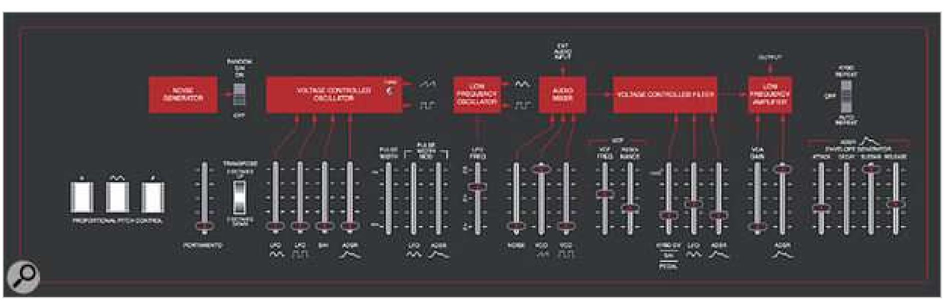

Figure 19: The Axxe flute.

The same diagram shows that the LFO frequency is set in the correct range of 5-6Hz, and is applied to the low-pass filter cutoff frequency, together with a little pitch CV tracking and a smidgen of ADSR contour. Delayed modulation would be even better here, helping to imitate the way in which a flautist would introduce the movement in the sound after the initial chiff, but the Axxe has no way to produce this.

The filter itself is set to exactly 2kHz using the tuning trick I described in Synth Secrets 49 (see SOS May 2003. You'll also notice that I've applied a moderate amount of filter resonance. Used carefully, this acts a little like a high-pass filter, adding an edge to the sound without making it sound electronic or synthetic.

Looking further to the right of Figure 19, you can see how the patch is completed by the application of the appropriate contour to the audio signal VCA. If you don't have access to an Axxe to try this, you'll just have to accept my word that the results are more than acceptable. This, then, begs the question, "Why do ARP synths get this sound right in a way that many other synths do not?" The answer is the same as I've offered before when I've raised this question: not all synth oscillators, filters and signal paths are created equal, or even equivalent. The ARP 4034 filter used in the Pro Soloist and Explorer, and the 4075 found in the Axxe and Solus happen to excel at brass and flutes, although there are many sounds for which they are not the devices of choice. That's why it's so important to have access to a range of electronic instruments whenever possible.

Epilogue

In the past three months, we've learned much about recorders and flutes, such as the effects of turbulence in pan flutes, of adding holes to create shakuhachis and recorders, and the difference between vibrato, tremolo, and the filter modulation that is so important this month. With knowledge like this, you'll be able to program all manner of realistic and not-so-realistic flute-like sounds, instead of stepping through 1000 presets to find a sound that merely approximates what you want.

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