More Creative Synthesis With Delays

Synth Secrets

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In the penultimate instalment of this long-running series, we delve deeper into what can be achieved with just a few delays and some creative routing...

Here we are, at the far end of our synthesizer's signal path. We've generated the waveforms, created multiple signals, filtered and sculpted them, applied modulation, mixed the results, and... well, it all sounds a bit thin, doesn't it? Despite the techniques we've employed, the results totally lack the depth of a nine-foot six-inch Bösendorfer, or a four-manual cathedral organ. Yet, if you think back to the early 1960s, there was — apart from a choir or the string section of an orchestra — little that was musically lush, and the electronic sounds that we now take for granted were still in the future. If you wanted to record the semblance of multiple instruments playing at once, you either paid a few dozen instrumentalists to do their thing simultaneously, or you bought a MkII Mellotron. Either way, the costs were crippling.

Things began to change in the mid-1960s, when the affordable 'chorused' organ was born. Consider the way in which a cheap electric organ creates its sound. In general, the outputs of high-frequency oscillators are 'divided down' by integer factors to create the correct pitches for all the notes of the top octave of the keyboard, and these are then further divided by factors of two to generate each octave beneath. However, organ designers discovered that they could divide the master oscillators in different ways to generate two frequencies for each note that were almost, but not exactly the same.

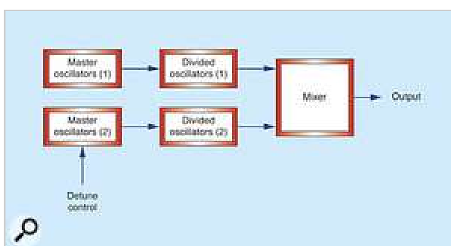

Figure 1: Creating a chorus effect by 'dividing down' master oscillators.

These small discrepancies — which were not even identical from note to note — were not dissimilar to the differences between the pitches of two pipes tuned to the same pitch, or between the three strings that comprise a note on the aforementioned Bösendorfer. Consequently, manufacturers began producing electric organs that generated a primitive chorus effect using dual sets of dividers. More sophisticated designs incorporated two independent sets of master oscillators, each with a set of frequency dividers, and some even offered a global detune for the second set (see Figure 1).

Of course, there was also the principle of using multiple electronic sound sources playing in unison to recreate the effect of multiple physical sound sources playing in unison. So, long before the appearance of the modern chorus effect in 1975, keyboards were using multiple oscillators per note to thicken up what would otherwise have been bland and uninteresting patches. Of these, the most sophisticated was the prototype of Ken Freeman's String Symphoniser. This used three banks of detuned oscillators, applying vibrato to each to create a rich chorus effect. To this day, synth programmers often use detune, pulse-width modulation and frequency modulation to obtain richer timbres than would otherwise be possible (see the box on the previous page).

Nevertheless, this is not what we now mean when we use the word 'chorus' and, of course, it can't be applied to externally generated signals such as a human voice or a note played on a

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guitar. What's more, despite the complexity of detune/vibrato/PWM programming, timbres generated in this fashion still don't sound as lush as even the cheapest and cheesiest 'string synths'. On the surface, this is rather surprising. In contrast to a sophisticated multiple-oscillator-per-note synth, the initial waveform produced within a string synth is almost always a single, 'divide-down' sawtooth which, at the best of times, sounds weedy and uninspiring. Yet, passed through the instrument's internal chorus/ensemble unit, it sounds animated, lush and full of body. So... what is chorus, and why does it sound so good? To answer that, and before Synth Secrets departs through the output socket of history, it's time that we took a look at that most popular and most useful of all keyboard effects: the chorus/ensemble.

Creating Chorused Sounds Without Chorus

If a polyphonic synth has dual oscillators (or better still, three) per voice, it will be capable of creating thick, quasi-chorused sounds, even without a chorus unit.

To create these sounds, you must first select the sawtooth wave option on one of the oscillators (because this has the correct harmonic content for a string sound) and the pulse wave on the other. Secondly, you must detune one oscillator against the other to create a 'detuned' sound. Next, you must add pulse-width modulation (or PWM) to the pulse wave.

As I showed in the March 2003 instalment of this series pulse-width modulation generates two 'virtual' signals, with one being pitch modulated with respect to the other (see Figure A).

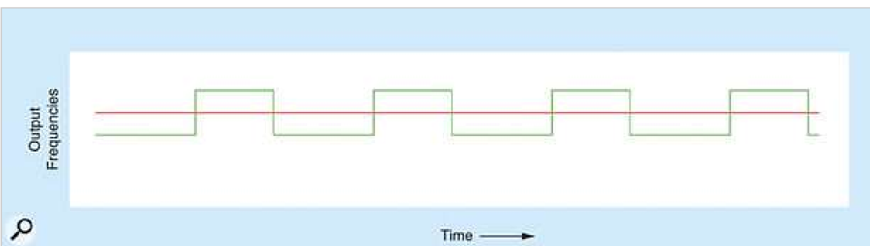


Figure A: Thickening the sound by modulating the duty cycle of a pulse wave.

PWM alone creates a 'chorused' timbre, but if you detune the sawtooth wave with respect to the pulse-width modulated wave, there are, in effect, three pitches present in the output, and this further thickens the sound (see Figure B).

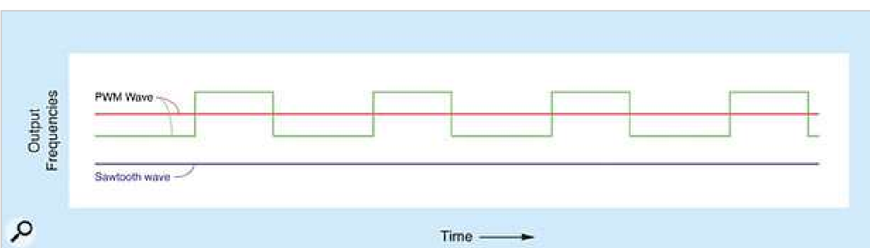


Figure B: Adding another signal to further thicken the sound.

Finally, adding vibrato to the sawtooth wave will complicate the relationships between the three pitches, especially if the synth can modulate the vibrato and PWM at different rates (see Figure C).

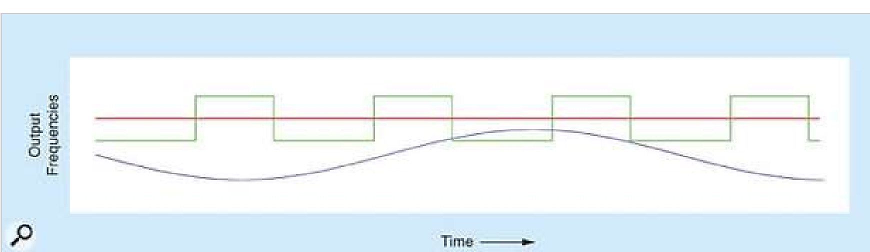


Figure C: Creating a lush sound using two oscillators per voice.

The key here is to ensure that there is so much activity that your ear becomes unable to recognise the limited number of pitches present. When programmed carefully, the sounds produced by this method can be superb, as evidenced by the remarkable 'ensemble' patches produced by the Prophet 5, OBX and, in particular, the Roland Jupiter 8.

A Basic Chorus Effect

The secret to this effect is fooling the ear into thinking that it is hearing multiple performances of the same note when it is not. This may sound tricky, but the key to doing so already exists in my explanation of modulated BBD delay lines, which I introduced in March 2004's instalment of this series. In short, if you don't have access to multiple, closely related timbres and pitches, why not split a single signal into multiple paths, apply pitch modulation to one or more of these, and then remix them? It's a simple idea, and it works beautifully.

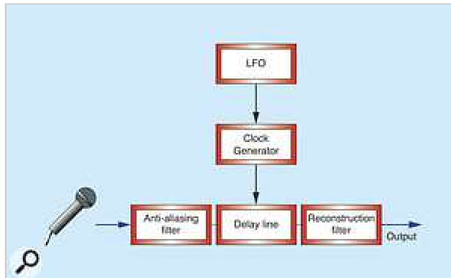


Figure 2: A modulated delay line.

Figure 2 shows the structure of a modulated delay line. You can present any signal to the input, whereupon it will be low-pass filtered to eliminate aliasing, sliced into samples, and then passed through the line before being reconstructed at the far end. This, by the way, is as true for a digital delay as it is for an analogue BBD. The speed at which the samples travel down the line, and their precise temporal relationships (ie. how far apart they are spaced) are determined by the clock generator and the oscillator modulating its speed. I hope that it is obvious that, if the clock is running faster when a bunch of samples reach the end of the line than it was when they entered, the samples will be closer together, so the pitch will be higher. Conversely, if the clock is running slower when those samples reach the end of the line, the samples will be further apart, so the pitch will be lower. Clearly, this allows us to modulate the pitch of the signal, and if the LFO in Figure 2 were generating a sine wave, the output from this diagram would exhibit a pronounced 'wow' effect, like a vinyl record with the hole punched in the wrong place.Now, let's add a second signal path to Figure 2, which allows the unaffected signal to pass to the output, as shown in Figure 3 above (from which, for clarity, I've omitted the anti-aliasing and reconstruction filters). We now have the situation where the modulated signal is sometimes at a higher pitch than the 'straight-through' signal, sometimes at a lower pitch and, on two occasions in each cycle, at the same pitch. Figures 4 and 5 (below) demonstrate this, showing how the delay in the upper signal path changes in time, and how this affects the pitch relationships between the upper and lower signal paths.

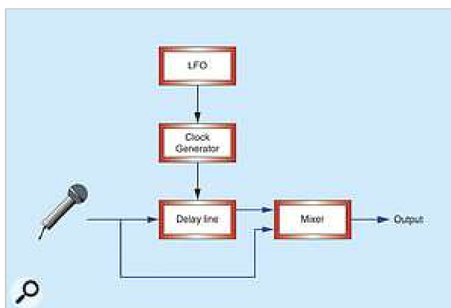


Figure 3: Adding the unaffected signal to the pitch-modulated signal.

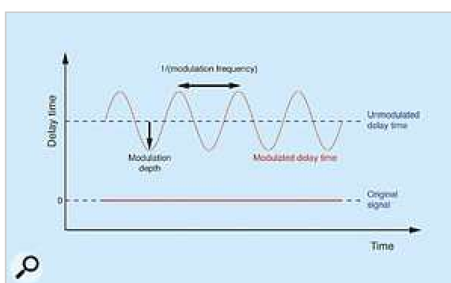
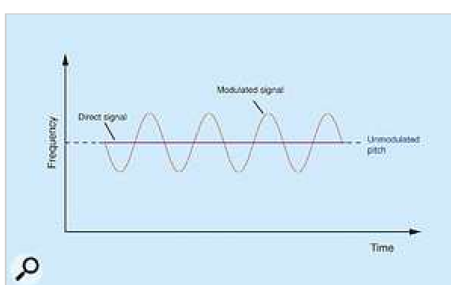


Figure 4: A simple delay modulation.



We can patch Figure 3 very easily using just four modules from a modular synth: a multiple to split the incoming signal into two paths; an LFO to modulate the rate of the Echo unit (which combines the delay line and clock generator in a single module); and a Mixer to recombine the two audio signals. In Figure 6, I have shown the original signal and output in blue, the modulation path in green, and the modulation signal in red, just to make things clearer.

Of course, this patch will produce nothing like the desired effect unless we choose our parameters sensibly. Firstly, you'll find that the barest minimum of modulation is needed. If you can't obtain a low enough modulation level from the Level knob on the LFO, place an attenuator in the modulation signal path to

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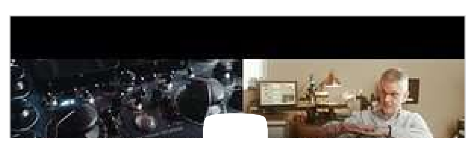


reduce the amplitude even further. In contrast, you have a wide choice of modulation rates. A slow sweep at a fraction of 1Hz will provide a gentle chorus, while a faster rate — say, 5Hz to 7Hz — will result in a more typical 'synth' ensemble. The other vital factor is the delay time. Set this to be too long, and you'll hear a distinct delay. Set it too short, and you'll obtain a version of another effect: flanging. But get it right — somewhere in the range 10ms to 50ms, as your taste dictates — and then mix the two signal paths in equal measure, and you'll obtain a serviceable chorus, reminiscent of the cheapest '70s string synths. Hang on... the cheapest '70s string synths? The individual modules in this patch (or an equivalent software modular synthesis application) could cost a couple of hundred quid, so you've a right to expect something a bit better. What's going on?

Figure 5: The pitch-shifts resulting from the modulation in Figure 4.

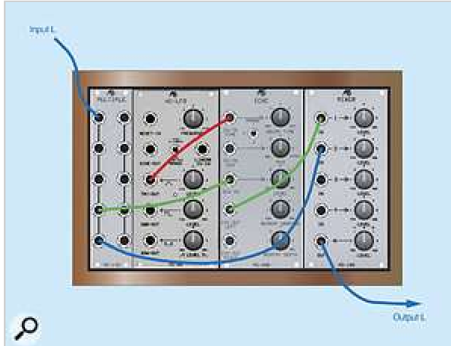


Figure 6: A simple, two-path chorus unit.

Unfortunately for us, our ears — which evolved to locate the rumbling tummy of a sabre-toothed tiger at 500 paces — are not fooled by the two signals generated and mixed in Figures 3 to 6, so this implementation of chorus is not perceived as particularly deep, nor indeed as particularly lush. In effect, it's the equivalent of hearing just two singers, or just two violinists, when what you're after is the choir and orchestra performing Mahler's Ninth in the Royal Albert Hall. So we overcome the problem by adding more signal paths to the existing scheme, and by modulating all of them differently.

I have shown an efficient way to do this in Figure 7, which shows that we can use a single LFO to modulate each of the delays, provided that the phase of each instance of the LFO waveform is shifted by some amount. Without these shifts, the three audio paths would be modulated identically, and we would create vibrato, nothing more. If the three paths are modulated at relative phases of 0 degrees, 120 degrees and 240 degrees, we obtain the pitch relationships shown in Figure 8. As you can imagine, this is a far more complex sound, and the relationships between the three modulated signals provide a thicker and warmer chorus effect.

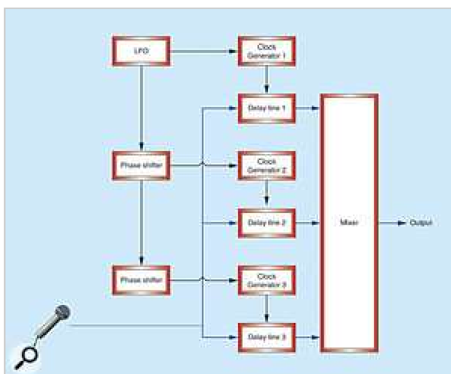


Figure 7: Using a single LFO to modulate three delay lines.

Improved Chorus Effects

The chorus described in Figures 7 and 8 is a classic '70s design, and was used in numerous string ensemble keyboards, but it still does not have the richness and depth that we have come to associate with the best of such effects. This is because synthesizer designers continued to dream up better ways to modulate the input signal, the first of which was to modulate each delay line with not one LFO, but two.

This was conceptually simple, although debate raged over the speed and depth that creates the most pleasing effect. Many manufacturers opted for two very different speeds — one of the order 0.5Hz to 0.7Hz, with a second closer to 6Hz to 7Hz, but with no discerned integer relationship between the two, so that the modulation didn't repeat for a long time. Figure 9 shows two such waves, and the resulting modulation signal. As you can appreciate, it's going to be more difficult for Ugg the Caveman to perceive this as a simple, repeating waveform.

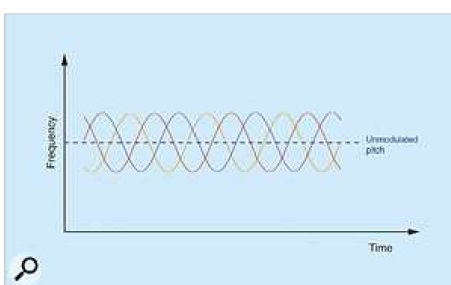


Figure 8: The frequency modulations of the three signal paths in Figure 7.

Now consider Figure 10. This shows the input split into four paths — the original signal plus three delayed versions of it. Each of the six LFOs in the patch can have a different modulation rate, and each of the mixers in the modulation paths can be designed so that each of the LFOs contributes a different depth. The result is a lush, complex swirl of sound that is forever evolving, and which adds movement and texture to even the most basic of initial waveforms.

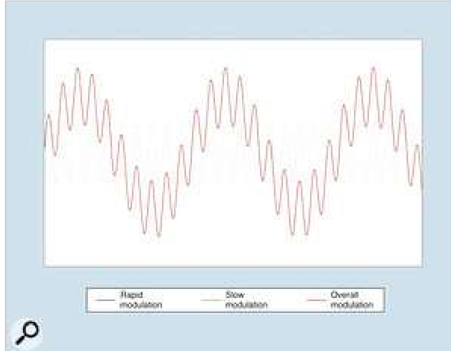


Figure 9: Creating a more complex modulation from two sine waves.

Another variation on this approach rearranges the LFOs so that one of each pair modulates the frequency of the other. This arrangement, which I've shown in Figure 11 produces the waveform in Figure 12, creating yet another form of pitch modulation and, therefore, a subtly different chorus. One could go even further, for example using another LFO to modulate the depth of the modulating waveform as well as its frequency and, if cost were no object, you could keep slinging LFOs, mixers and, where necessary, VCAs at the problem to create the most complex modulations imaginable. You can even use a random waveform as a modulator, which goes some way towards imitating the genuine pitch instabilities of human singers and players.

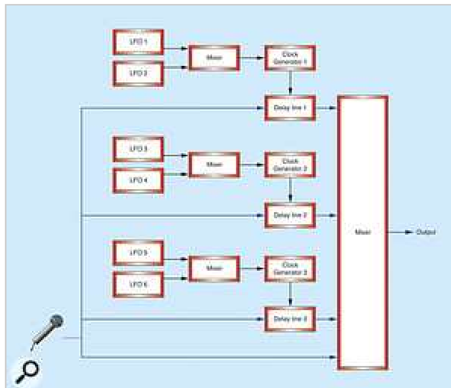


Figure 10: A four-path chorus unit.

As you might imagine, circuits such as Figure 10 can be expensive to build, and although this design produces a superb ensemble sound, it may not be economical. To overcome this, many manufacturers combined the ideas set out in Figures 7 and 10, employing a trick that fools the ear into believing that it's hearing multiple, complex modulations, when in fact only one is present (see Figure 13, below).

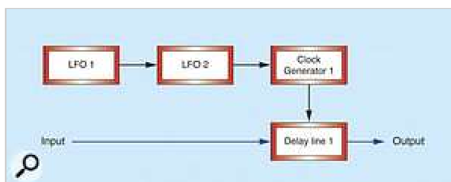


Figure 11: Reconfiguring the LFOs to produce a modulation signal with vibrato.

This involves the use of just two LFOs (which cuts costs) and four phase-shifters (which are cheap), and generates three instances of a single complex delay modulation. As before, these are out of phase with one another, typically by 120 degrees, and the result, while not quite as lush as you can obtain using six independent LFOs, is nonetheless gorgeous. This is why this method — or close variations of it — became the standard for almost all the best-loved chorus/ensemble keyboards.

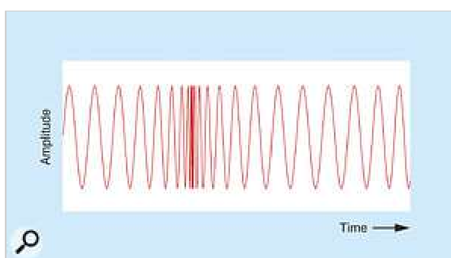
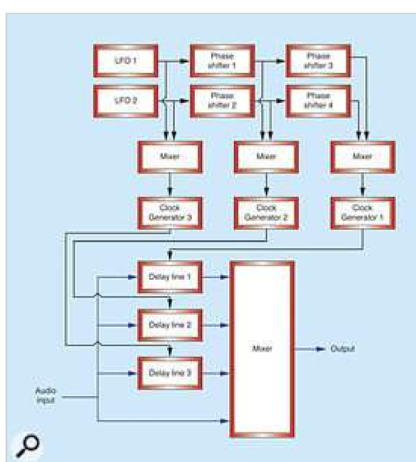


Figure 12: Modulating the speed of the modulator.

Stereo Chorus

Nice as monophonic chorus might be (and is), it doesn't make the most of the techniques described above. Indeed, when Roland first designed the chorus/ensemble pedal, they created a CE1 mountain, because nobody bought the things. It wasn't until a handful of players discovered the 'Stereo' output (which sits less than an inch to the right of the Left/Mono output) and directed this to a second amplifier and speaker that the world sat up and started to take notice.



As we now appreciate, stereo chorus is the classic synthesizer effect, and it's easily created if you

Figure 13: The classic three-phase chorus unit.

have access to the signals being produced by the multiple delay lines. Figure 14 shows a triple-path configuration in which the signals generated by the first and second delays are mixed and sent to the left output, while the signals generated by the second and third delays are mixed and sent to the right. In this scheme, you can leave out the 'straight-through' signal, because the dual inputs to each mixer will be chorusing differently, and — far from contributing to the result — the original might actually damage the impression of width and depth.

Some Real Examples

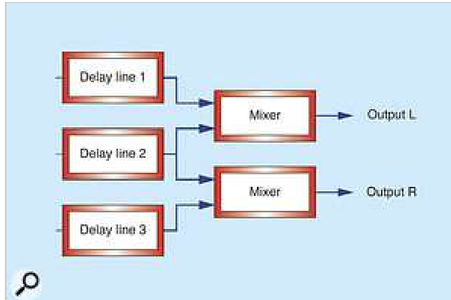


Figure 14: The output stage of a triple-path stereo chorus unit.

Although some people think that string synths sound much like one another, this is not true. Sure, they all share the same class of sound, they are almost without exception based upon quasi-sawtooth waves generated by organ-style 'divide-down' technology, and if you switch off their chorus/ensemble effects, they are all about as interesting as a bunch of boring things on a very boring day. Nonetheless, there are marked differences in the way that they generate their chorus effects.

For example, the Eminent Solina (1974) uses the chorus structure depicted in Figure 11, with two LFOs, one running at around 1Hz and the other at about 6Hz, phase-shifted to produce modulating signals at 0 degrees, 120 degrees and 240 degrees. In contrast, the Roland VP330 (1978) has a thinner string ensemble sound generated by just two delay lines with dual LFOs. The altogether richer-sounding Korg Polysix synthesizer (1981) incorporates another triple-delay chorus, but dispenses with the phase-shifters and uses a configuration of independent LFOs similar to that shown in Figure 10 (above).

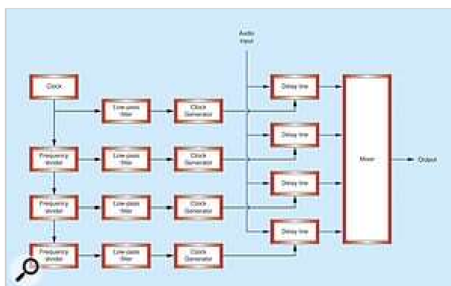


Figure 15: A 1978 chorus design by Roland Corporation.

One of the cleverest of chorus designs was developed by Roland (see Figure 15). This uses just a single square wave LFO (generated, would you believe, by one of the flip-flops that I described a couple of months ago) and three frequency-dividers that output modulation signals at the clock frequency F_C, at 1/2 F_C, 1/4 F_C and at 1/8 F_C. These 'square' signals are low-pass filtered to 'round off' the waveforms into approximations of sine waves, and these are in turn used to modulate the clocks driving four BBDs. The outputs of the delay lines are then mixed into a single sound, and emerge in glorious mono. There is no 'straight-through' signal present in the output.

The major advantage of this configuration is one of cost; clocks, dividers and simple low-pass filters are cheap. However, there is an additional benefit, which was the true raison d'être of the design: due to the nature and relationships of the four modulating waves (shown in Figure 17, later) the chorus effect is less susceptible to the 'warbling' effect that you hear generated by other low-cost circuits.

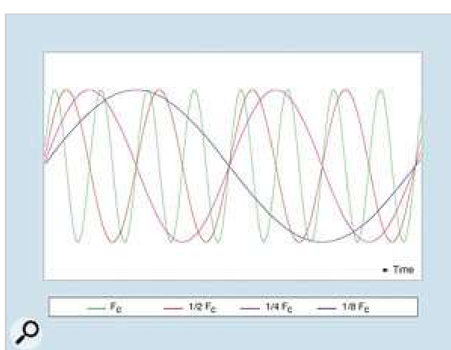


Figure 16: Converting the Roland chorus in Figure 15 into a stereo unit.

Roland even suggested ways in which Figure 15 could be improved. For example, you could mix the outputs from the first and third BBDs and from the second and fourth, to create a stereo chorus (see Figure 16). The designer also suggested inverting the phase of the second and fourth modulating waves to create an even richer 'spread' of the ensemble effect, and using frequency dividers that used other integer factors of F_C, such as one third or one fifth. Yet another Roland design dispensed with sine-wave modulators and substituted sawtooth waves, eliminating the pitch discontinuities by modulating a set of VCAs that silenced the delay lines while the modulating waves reset to the start of their cycles. Yet another incorporated signal gates that disconnected the modulation waveforms when there was no audio signal present at the input, thus eliminating the characteristic 'swishing' noise that mars many chorus effects. The permutations are almost endless.

Epilogue

Despite the obvious benefits of chorus units, BBDs are rather noisy, so many (although not all) 1970s manufacturers treated them as a necessary evil that added interest to cheap, single-oscillator keyboards and synthesizers, but which were not suitable for top-of-the-range instruments. But while the high-brow approach was good in principle, the synthesizers that eschewed chorus and relied on other techniques to create lush sounds were expensive: multiple VCOs per voice, the ability to detune independent banks of oscillators against one another, the ability to modulate the pulse width of one bank and the frequency of the other... it all added up.

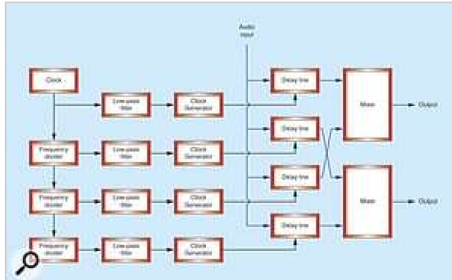


Figure 17: The modulations generated by the clock and dividers in Figure 15.

Then, sometime in the 1980s, chorus effects became legitimate, and started to appear on multi-oscillator-per-voice synths as well as single-oscillator instruments. Ask yourself, what's the thing that most synth fans mention first when discussing the Elka Synthex? The oscillators? The filters? The modulation? No... it's the superb chorus unit at the end of the signal path. Even Sequential Circuits conceded defeat in the late '80s, by adding chorus to the Prophet VS. And what do people most often decry about some of the most powerful 'pure' synthesizers yet developed? It's that they didn't sound lush, so Yamaha redesigned the DX series, restoring the chorus unit that they had removed when they discontinued the GS1 and GS2 in 1983 or thereabouts.

By the late '80s, it had become clear to everyone that you could take the less animated sounds from DCO-based synthesizers, or the relatively sterile waveforms from early digital synthesizers and workstations, add a well-designed chorus unit, and the thing would sound gorgeous. Hmm... a bland waveform enlivened by a chorus/ensemble... we used to call that a string synth, and it's one of the enduring absurdities of our industry that instruments such as the Solina and ARP Omni now sell for more than double the price of a well-preserved DX7.

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