Synthesizing Tonewheel Organs: Part 2

Synth Secrets

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By Gordon Reid

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Photo: Original Richard Ecclestone

If you followed last month's advice, you'll know how to synthesize a basic Hammond tone on a Roland Juno 6. But can the same technique be applied to any other synth?

You may recall that last month, I described how, many years ago, I embarked upon a quest to find an affordable and manageable synthesizer to replace my ageing Crumar Organiser and Korg BX3. I left you with the solution I found, a Hammond patch created on a Roland Juno 6 (shown here as Figure 1 below).

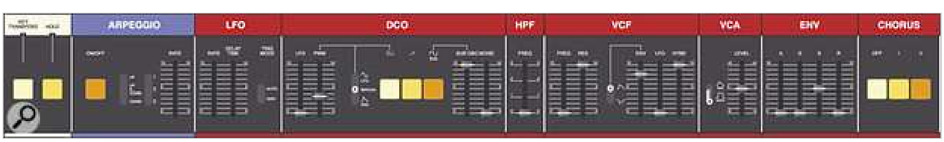

Figure 1: Last month's Juno 6 Hammond 88 8000 000 patch.

If you refer back to last month's article, you'll remember that the harmonic spectrum of this patch is as shown in Figure 2, where the three red squares represent the amplitudes of the first — and only — three harmonics present in the sound; the basis for a fine emulation of the 88 8000 000 registration. (For an explanation of the curious axes on the graph in Figure 2, and why they are particularly well suited to depicting the harmonic spectrum of the output from a tonewheel organ, I again refer you back to last month's instalment of this series).

Now, you might think that these diagrams reveal the secret for synthesizing all manner of Hammond registrations on the Juno. After all, the self-oscillating VCF — which is responsible for the presence of the third harmonic — can be tuned to any frequency, so in theory, we should be able to create any patch that uses three drawbars, provided that two of them, those generated by the sub-oscillator and the main DCO, are an octave apart.

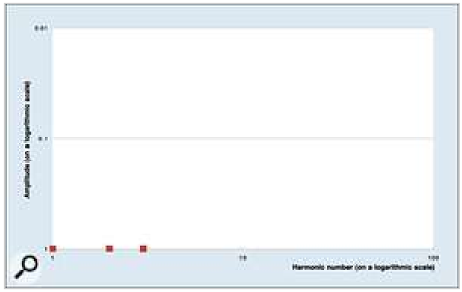

Figure 2: The harmonic spectrum of the patch shown in Figure 1.

For example, if we slide the VCF cutoff up to the next drawbar frequency (the fourth harmonic of the fundamental, which is the 4' drawbar) we obtain strong components at the first, second and fourth harmonics, with a reduced contribution from the third harmonic; maybe something along the lines of an 82 8800 000 registration. But when we try this, something doesn't sound quite right. While the basic tonality is much as you might expect, the patch is too bright, and lacks the character of half a hundredweight of pickups, valve preamps, and rotating steel.

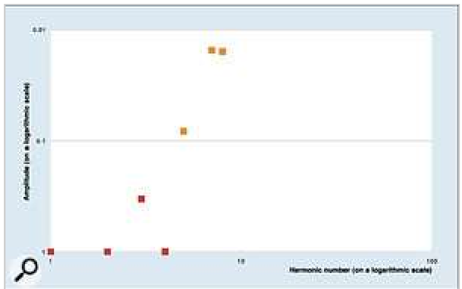

Figure 3: Trying to synthesize 80 8800 000.

To explain this, I've calculated the amplitudes of the frequencies present in the new patch, and shown the results in Figure 3. As you can see, the first four harmonics are present in the expected amounts, but three more — which I have shown in orange — are also present, albeit at lower amplitudes. We might be able to excuse the rightmost of these because it lies on the eighth harmonic, and therefore represents a bit of leakage from the 2' drawbar. But the contributions from the fifth and seventh harmonics are not so welcome. They don't sound 'wrong' exactly — after all, they lie in their correct positions in a perfect harmonic series — but their contributions are inappropriate, and it is these that make the patch sound too bright (the 6th harmonic is entirely absent, but I'll leave you to work out why).

The situation deteriorates further if we raise the cutoff frequency any more. There are two reasons for this. Firstly, the filter passes all the harmonics that lie below the cutoff frequency. This is no good because, as shown last month, the idealised spectrum generated by the Hammond tonewheel engine — which goes as high as the 16th harmonic of the 16' drawbar — does not include the fifth, seventh, ninth, 11th, 13th, 14th or 15th harmonics. Secondly, the densely packed higher harmonics are not attenuated as rapidly as the widely spaced lower harmonics, so we hear many overtones above the cutoff frequency of the self-oscillating filter.

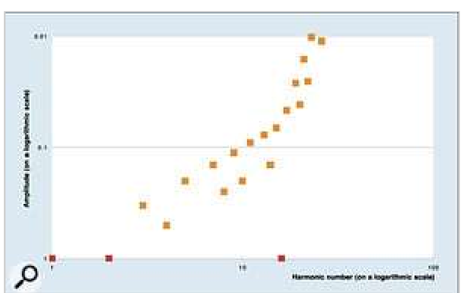

Figure 4: Failing to synthesize 80 8000 008.

To demonstrate this dramatically, I have calculated 80 8000 008 as recreated by the 'Juno method' as described last month. This is a perfectly acceptable Hammond registration which, when patched on the synth, is a sonic mess. Again, the desired harmonics are shown in red (see Figure 4), and the unwanted ones in orange. As you can imagine, it sounds nothing like the real thing.

If this weren't bad enough, the tracking of the Juno's filter becomes very unstable at higher frequencies. It is superb at low multiples of the fundamental because it 'locks onto' the strong second, third and (just about) fourth harmonics, producing a pure, stable tone at pitches that relate precisely to the 8', 5 1/3' and 4' drawbars. But as the harmonic number rises, its ability to lock on diminishes, and it starts to float around. The result is a strange, tuned noise that is interesting, but nothing whatsoever to do with the sound of a Hammond organ. When it comes to the crunch, the 'Juno method' is capable only of synthesizing the 88 8000 000 registration with any degree of realism. So perhaps we should now look elsewhere to synthesize a more flexible imitation of the Hammond.

Another Method Of Hammond Synthesis

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- Synthesizing Drums: The Bass Drum
- Practical Bass Drum Synthesis
- Synthesizing Drums: The Snare Drum
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- The Secret Of The Big Red Button

In 1981 and 1982, Genesis were on tour promoting their Abacab album. For keyboard player Tony Banks, this must have been a very different experience compared with the tours of the 1970s. Gone was his Mellotron, gone was his RMI Electrapiano, and gone was his ARP Pro Soloist. And, most relevant to this month's discussion, gone was his Hammond T-series organ, to be replaced by a dual-manual Sequential Circuits Prophet 10.

Figure 5: The voicing of the Prophet 10.

As well as being hideously expensive, the Prophet was, and is, a large and heavy synthesizer, which means that it is just as much a pain in the posterior as an organ. Given that it is not particularly reliable, it seems odd that Tony should have adopted it in this fashion. Indeed, he told me many years ago that he carted two of them around on tour (with one as a spare), although he preferred not to use the second instrument because it sounded different from his favoured one. I'm not surprised... the tuning of the 20 oscillators and the 10 low-pass filters on the Prophet 10 is not what you would call 'precise'.

Nonetheless, Tony produced a fine organ sound on that tour, and the method he used illustrates a useful principle, so I thought that it would be interesting to recreate his patch.

Figure 5 (above) shows the voice structure of a Prophet 10. It's huge, even though I've omitted the patch selection and housekeeping section of each of its two control panels for the sake of practical representation. Hang on a second... two panels?

Of course, the Prophet 10 has only one physical panel, but it really is two synths, each similar to a Prophet 5. Each has a dedicated keyboard, and each offers dual oscillators per voice, a 24dB-per-octave low-pass filter, dual ADSR contour generators per voice, an LFO, plus the Prophet 5's renowned Poly-Mod section.

In Normal mode, the Upper synth is played from the upper manual, while the Lower synth is played from, well... the lower one. This means that we can take either one, and patch it using the 'Juno method'.


Figure 6: Setting up the Prophet 10's dual oscillators.

We'll start with the VCOs. Figure 6 shows that I have selected a pulse wave for Oscillator B, and set the pulse width to '5', which is the setting at which it produces a square wave. You'll also see that I have tuned it to the lowest pitch available, with no fine tuning offset, and that the 'Keyboard' LED is lit, which shows that the oscillator will track the keyboard in a conventional manner. Oscillator B is, therefore, performing the same task as the sub-oscillator in the Juno patch.

Oscillator A is also programmed to produce a pulse wave, but on this occasion, the pulse width is 33.33 percent, just as it was last month. The Frequency knob is tuned by ear to produce a pitch that is precisely one octave above Oscillator B. Once this is set correctly, we can adjust the relative amplitudes of the oscillators (which are, in effect, the drawbar settings of the 16' and 8' pitches) in the Mixer.

Figure 7: Setting up the filter.

Next comes the filter section (shown in Figure 7). Firstly, the 'Keyboard' switch must be on (ie. with the red LED lit) so that the filter tracks the keyboard. Then, as with the Juno patch, we set the cutoff frequency so that it lies precisely on the 5 1/3' pitch, and increase the resonance until the filter begins to oscillate and produces a sine wave.

The Prophet 10 has a dedicated ADSR contour generator for the filter, and I have set all its knobs to zero. This is because the P10's envelopes are not the snappiest in the world, and we need to use the minimum settings to obtain the 'key-click' sound (see Figure 8, above) at the start of each note, as explained last month. You determine the amount of click by adjusting the Envelope Amount knob to taste.

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The next part of the patch is easy. We want an 'organ' envelope, so we can set the amplitude ADSR as shown in Figure 9, with instantaneous Attack, maximum Sustain level, and no Release. The Decay segment of this contour is, of course, irrelevant (see Figure 10, below).

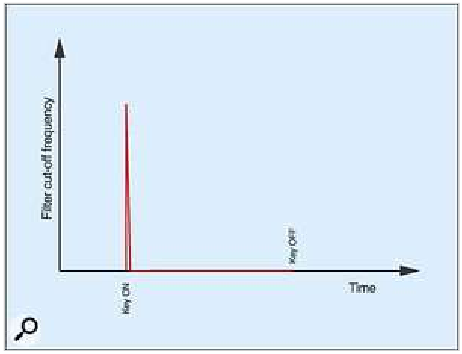

Figure 8: Creating the 'key-click' sound using the filter cutoff frequency contour.

Figure 9: The 'organ' amplitude envelope settings.

And there you have it: defeat all the modulation sources and you have programmed the wonderful Prophet 10 organ patch, a gorgeous sound from one of the greatest synthesizers ever built. Fantastic! Or is it? For one thing, the Prophet 10 hardly answers to my required description, 'affordable'. And then there's the sound itself. Sure, it's nice, and has a warmth and presence that you would be proud to use, especially if you use the onboard EQ section to boost the middle frequencies. But, just as I suggested last month, for this purpose the Prophet is still the inferior of the vastly cheaper Juno. Why?

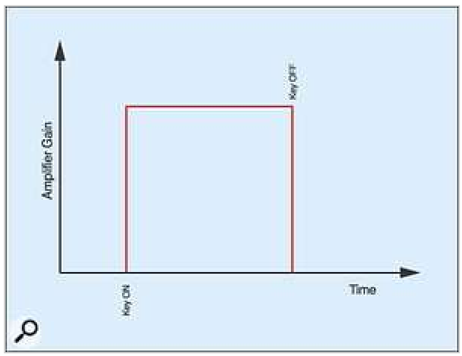

Figure 10: The amplitude contour.

The answer lies in the aforementioned instabilities of the Prophet 10. Despite the microprocessor that lies at its heart, it is a truly analogue synth, and you can press the Tune button until you get blisters, but you still won't get its oscillators in perfect tune, much less its filters. What's more, the quantisation of the controls is very apparent, and this makes it impossible to use the 'Juno method' effectively. Back in Part 21 of this series (see SOS January 2001), we discussed the reasons why analogue synths with memories must have quantised controls. So, while you might be able to tune any one of the Prophet's filters to precisely the correct pitch, the one in the next voice might be far enough removed that, when you turn the filter knob a tiny amount to bring it into line, the cutoff frequency jumps so far that the situation is worse than before. On my Prophet 10, one of the filters on the Upper keyboard is always a few cents out of tune, and, while it tracks correctly, the voice that contains it sounds significantly different from the other four. You may choose to call this 'analogue warmth', but it's not. It's just plain wrong.

Two Is Better Than One

So how can we overcome this? The old Genesis videos demonstrate that Tony's Prophet 10 was capable of a much better likeness to the old Hammond, so there must be a way... And there is.

The secret lies in the 'two synths in a box' nature of the big Prophet, and the four keyboard modes that it offers. Up until now, I've been assuming that we've been in Normal mode which, if the 'Juno method' had been successful, would have allowed me to create different patches for each keyboard, and to play the Prophet 10 as a dual-manual organ, or as a single-manual organ plus a string ensemble, or brass section, or whatever. But the method was not successful, so now I'm going to place the synth in Double mode (see Figure 11, right). This allocates Upper Voice 1 and Lower Voice 1 to the first note you play, Upper Voice 2 and Lower Voice 2 to the second note you play... and so on. In other words, I have placed both synths under the control of one keyboard (the Prophet 10 was one of the first instruments to


Figure 11: The Prophet 10's four voice-allocation modes.

offer layering). This makes it possible for us to patch registrations containing four pitches, and without having to use the filter as an oscillator.


Figure 12: Using four oscillators to emulate four drawbars.

Consider Figure 12 (above). This shows the Upper and Lower Oscillator and Mixer sections simultaneously, with Double mode selected, and all four oscillators tuned and balanced to produce the 88 8800 000 registration. The Lower section is identical to Figure 6, with one exception: I have switched off the square waveform in Oscillator B (the oscillator producing the 16' pitch) and selected the triangle wave instead. This is as close as the Prophet will come to emulating the (near) sine wave produced by a tonewheel generator. The Upper section is set up using the same waveforms, but tuned so that oscillators B and A produce the pitches of the 5 1/3' and 4' drawbars respectively.

Of course, there's nothing forcing us to use these pitches, and we no longer have to use the self-oscillating filter to produce the 5 1/3' pitch. So, in this way, the Prophet 10 patch is superior to the Juno's.

Now we must reprogram the filter sections for both synths, eliminating the resonance, but keeping the cutoff low enough to attenuate the unwanted harmonics generated by the triangle and pulse waveforms (see Figure 13, below). The amplifier ADSRs should, of course, be identical to each other and to that shown in Figure 9, and all modulation should be defeated. Having set all of this, we should now be able to create and play any registration, provided that it uses only four drawbars at a time.


Figure 13: The filter and amplifier settings for a four-oscillator Hammond emulation.

Nevertheless, the Juno still sounds the better of the two. Far from being the millstone that some anoraks would have you believe, the precision offered by its digitally controlled oscillators and its superb filter tracking ensures consistency across all the notes played, and this is exactly what a Hammond patch requires.

A Better Mousetrap?

I don't know about you, but I feel decidedly uneasy that the Juno has outshone the mighty Prophet. Nevertheless, this set me thinking... there must be a synth that's not too expensive, but which combines the stability and tuning accuracy of the Juno's DCOs and filter, and also offers the flexibility of four oscillators and dual signal paths.

Of course there is! It's the Roland JX10, which has a the 'two synths in a box' architecture, but is digitally controlled. Surely this is the best of both worlds, and must sound superb? Well... no, it doesn't. I used a JX10 as my main stage keyboard/controller for more than a decade, and after numerous abortive attempts, I never again attempted to use it for organ patches. Experience showed that JX10 organ patches are at best unconvincing, and that's perhaps the reason that my Juno 60 survived as a gigging instrument for as long as it did.

Hmm... what other affordable analogue synths can we try? The Oberheim OB-series? Far too inaccurate. A Memorymoog? You've got to be joking... How about the Prophet 600, or the Korg PS3200, or the Crumar Bit One, or the Akai AX60, or the... Stop it Gordon, take a deep breath, and relax. None of these fit the bill.

One of the author's favourite synths of all time: the Kawai K3.

When it comes down to it, the Junos really are remarkable little synths, and it is no wonder that they often sound superior to instruments worth many times as much.

Nonetheless, there is at least one low-cost analogue/digital hybrid does an even better Hammond emulation. The sound quality is superb, and it is completely flexible, being capable of any of the 387,420,489 registrations that you care to name (did anybody check my maths?). Yet its second-hand value is close to zero, and you would probably walk past one if you saw it in a car-boot sale. It's one of my favourite synths of all time. It's the Kawai K3 (shown above right).

HARMONIC NUMBER	1	2	3	4	5	6	... up to 128
VALUE	31	31	31	0	0	0	... all zero

It All Adds Up

Last month, I mentioned that dedicated additive instruments such as the Kurzweil 150, Kawai K5 and Kawai K5000 were capable of some fine Hammond sounds, as are the larger DX-series FM synths. But the thing that makes the K3 special is its combination of a primitive form of additive synthesis plus one of the scrummiest analogue filters ever designed by man, the SSM2044.

KAWAI K3: HAMMOND 88 8000 000 REGISTRATION			
OSC 1			
1	Wave	32	The additive wave
2	Range	16'	
3	Portamento Speed	0	No portamento
4	Balance	-15	Only OSC1 used
5	Pitch Bend	0	
6	Auto Bend	0	
OSC2			
7	Wave	n/a	
8	Coarse Freq	n/a	
9	Fine Freq	n/a	
FILTER			
10	Cutoff	65	Sounds about right
11	Resonance	0	
12	Low Cut (HPF)	0	No high-pass filtering
13	Env Amount	31	Maximum amount
14	Attack	0	
15	Decay	0	A fast key-click 'blip'
16 Not used			
17	Sustain	0	
18	Release	0	
AMPLIFIER			
19	Level	31	Maximum amplitude
20	Attack	0	
21	Decay	0	
22	Not used		

23	Sustain	31	A 'square' amplitude contour
24	Release	0	
LFO			
25	Shape	n/a	
26	Speed	n/a	
27	Delay	n/a	
28	Oscillator Amount	0	
29	VCF Amount	0	
30	VCA Amount	0	
TOUCH SENSITIVITY			
31	Velocity -> VCF	0	
32	Velocity -> VCA	0	
33	Pressure -> OSC Balance	0	
34	Pressure -> VCF	0	
35	Pressure -> VCA	0	
36	Pressure -> LFO OSC Amount	0	
KEYBOARD TRACKING			
37	VCF	9	Approximately 100-percent tracking
38	VCA	0	
CHORUS			
39	Chorus	0	Off

Unlike the dedicated additive instruments mentioned above, the additive section in the K3 allows you to create just one spectrum (and, therefore, waveform) at a time, but this comprises up to 32 partials distributed anywhere among the first 128 harmonics of the pitch. Setting this up is a doddle; you just select the harmonic number and dial in an amplitude between zero and 31. Simple!

This means that we can construct any conventional registration using the first, second, third, fourth, sixth, eighth, 10th, 12th and 16th harmonics, or reproduce the extended drawbar set offered by a handful of rare Hammonds, or even imitate the 'EX' mode of the new, DSP-driven Korg CX3 and BX3 emulators. Think about it; we no longer need to resort to trickery to obtain the spectrum in Figure 2. We simply select harmonic #1 and give it an amplitude of 31, select harmonic #2 and give it an amplitude of 31, select harmonic #3 and give it an amplitude of 31, and then press the 'Write' button to calculate the waveform, as shown in the smaller value table opposite. We then reduce the filter cutoff frequency a little to remove some stray upper frequencies that, in a perfect additive world, wouldn't be there in the first place, and the result is...? Superb.

We construct the rest of the patch exactly as before, with a 'spitty' filter contour as shown in Figure 8. We do this by setting the ADSR values for the filter (parameters 14, 15, 17 and 18) to be 0, 0, 0, 0... which is the same as the Prophet 10 knobs shown in Figure 7, but represented in numerical form in the K3's 'digital parameter access' user interface. Likewise, the amplitude ADSR (parameters 20, 21, 23 and 24) is set to 0, 0, 31, 0... the same as the knobs in Figure 9, and therefore defining the 'square' amplitude envelope of Figure 10.

Next, we defeat the velocity sensitivity and pressure sensitivity (neither of which are appropriate for a Hammond patch), reduce all the modulation amounts to zero, and... bingo! The complete patch is shown in the large table opposite.

So there we have it... We started with the little Juno, which is cheap and cheerful, and synthesizes just one Hammond registration extremely well. We then graduated onto the mighty Prophet 10, which is far from cheap, but is limited to four 'drawbars' and — unless every voice is tuned absolutely precisely — produces no meaningful Hammond registrations well. Finally, we ended up programming an almost unknown, valueless analogue/digital hybrid. Yet it is this that is best suited to Hammond emulation, which proves to be the most flexible, and which has produced the most satisfying result. You might think that I've cheated by introducing additive synthesis (and you would probably be right) but given that my original aim was to program convincing registrations on something that was cheap and physically light, but sounded as good as a Korg BX3, I'm happy. The answer, ladies and gentlemen, is the Kawai K3.

Epilogue

As with last month's Juno patch, and despite what I've just written, the K3 patch described here doesn't sound all that much like a real Hammond. As I explained last month, this is because these patches make a good fist of synthesizing the sound of an unadorned tonewheel generator — as yet, I've made no attempt to reproduce the chorus/vibrato, percussion, and overdrive effects that really 'make' the Hammond sound. Next month, we'll do what we can to emulate these, and see whether we can use the Juno to produce entirely convincing imitations of the big Hammonds. Until then... enjoy your organ!

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