Modelling a Vox Continental

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1 Introduction

The Vox Continental is an electric organ first released in 1962. It set itself apart from its predecessors, such as the Hammond organ, by using transistors to generate oscillations rather than tonewheels.

Synthesis of the Hammond organ is a well-trod path; the tonewheels are easily modeled as outputting pure sine waves. The Vox Continental is less well understood, and sources attempting to document its timbre are rare and often contradictory; some sources claim it is a square wave, others claim it is a sawtooth wave, others still claim it is a triangle wave. Determining which claim was most accurate was a key motivation for this project.

2 Analysis

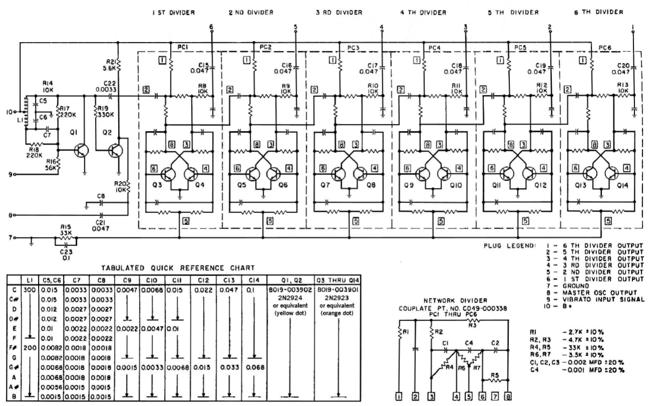
As purchasing a Vox Continental for the purpose of a class project was deemed outside of an appropriate budget, the decision was made to use Combo V, a free VST of a Vox Continental created by Martinic. While not a perfect analogue to a real Continental, it should be noted that Martinic heavily advertises the fact that its products are designed by analysing the circuitry of the instruments they wish to emulate.

The original Vox Continental features four[1] register drawbars and two tone drawbars. The first four register drawbars are labeled as they would be on a pipe organ, with 8' denoting concert pitch, 16' an octave lower, and 4' an octave higher. The fourth, IV, is a mixture of higher partials, ranging from a fifth, octave, tenth, and 2 octaves above the 4'. The tone drawbars affect the tone of the whole organ. The Reed drawbar, as its name suggests, is much brighter and filled with higher overtones, whereas the Foundation drawbar is more flute-like and pure.

2.1 Circuit Analysis

Figures 1 and 2 are taken from schematics for the circuitry of a Vox Continental. Figure 1 shows the tone generation circuitry for a given pitch class. A master

[1] Later models of the Vox Continental included additional register drawbars.



TABULATED QUICK REFERENCE CHART

	L1	C5, C6	C7	C8	C9	C10	C11	C12	C13	C14	Q1, Q2	Q3 THRU Q14
C	300	0.015	0.0033	0.0033	0.0047	0.0068	0.015	0.022	0.047	0.1	8019-003902 2N2924 or equivalent (yellow dot)	8019-003901 2N2923 or equivalent (orange dot)
C#		0.015	0.0033	0.0033								
D		0.012	0.0027	0.0027								
D#		0.012	0.0027	0.0027								
E		0.01	0.0022	0.0022	0.0022	0.0047	0.01					
F		0.01	0.0022	0.0022								
F#	200	0.0082	0.0018	0.0018								
G		0.0082	0.0018	0.0018								
G#		0.0068	0.0018	0.0018	0.0015	0.0033	0.0068	0.015	0.033	0.068		
A		0.0068	0.0018	0.0018								
A#		0.0056	0.0015	0.0015								
B		0.0015	0.0015	0.0015								

Figure 1: Circuitry of the tone generator for a given pitch class.

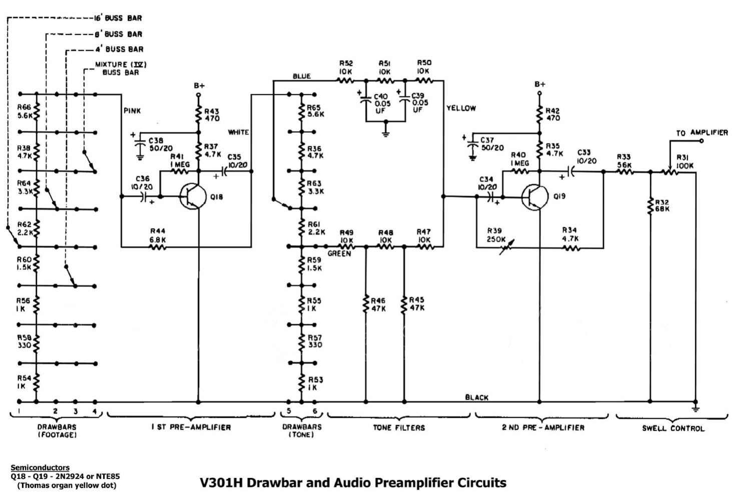


Figure 2: Diagram of the drawbars and filtering of the tone.

oscillator generates the waveform for the highest octave, and the waveforms for the lower octaves are obtained using the frequency dividers.

Ones the tones have been generated, a series of wires sends the current to the relevant keys. Pressing the key connects the tone circuitry to the drawbar and audio processing circuitry (Figure 2). This figure can be misleading at a first glance: the connections in the sections labeled "Drawbars (footage)" and "Drawbars (tone)" are not fixed, and vary along the bank of resistors based on the position of the drawbars. These resistors are used to control the volume of each drawbar. The current from the tone generators are sent through one preamplifier and then split into two for the Reed and Foundation tones. Filters are applied to both currents, which are then recombined and sent through another preamplifier and finally to the exterior amplifier.

Two key elements to elucidating the sound of the Continental can be inferred from these figures:

- As resistors have a flat frequency response, at least within the range of pitch detection, there is no global filter on the Reed tone. The filtering of the Reed tone is therefore done in the tone-generator circuit.
- The Foundation tone is the Reed tone fed through a global filter.

3 Synthesis

Recordings of the 8' and Reed drawbars pulled out to their maximum were sampled and their spectra and waveforms compared to that of various candidate waves. Ultimately, the most likely candidate was found to be a square wave with a second-order filter of the form

$$H_r(s) = -\frac{G}{\left(\frac{s}{\omega_o}\right)^2 + \frac{s}{Q\cdot\omega_o} + 1},$$

where

$$\begin{aligned} G &= 0.15, \\ Q &= 0.9, \text{ and} \\ \omega_0 &= \pi f_0, \end{aligned}$$

where f_0 is the fundamental frequency of the desired waveform (that is to say, ω_0 is half of the angular fundamental frequency of the waveform).

The "Foundation" tone is achieved by applying a global filter to the output of the "Reed" tone. Analysis of the filter in the circuit (figure **??**), shows that the filter is a second-order filter formed by feeding the results of one first-order filter into another with the same parameters. The transfer function of the filter as a whole has the form:

$$H_f(s) = \frac{1}{1 + 3RCs + s^2R^2C^2}$$

Where

$$R = 10^4\Omega, \text{ and}$$
$$C = 510^{-7}f.$$

3.1 Bilinear Transformation

One does not simply use the coefficients of a continuous transfer function for the discretised version. The whole transfer function must be discretised. This was done using the bilinear transform. While Matlab has a built-in bilinear function, oddities in getting it to work led to the requirement of calculating the formulae by hand.

$$H_{r_d}(z) = \frac{G + 2GK^2z^{-1} + Gz^{-2}}{(\frac{K^2}{\omega_0^2} + \frac{K}{Q\omega_0} + 1) + (2 - 2\frac{K^2}{\omega_0^2})z^{-1} + (\frac{K^2}{\omega_0^2} - \frac{K}{Q\omega_0} + 1)z^{-2}},$$

where $K = 88,020$, while the discretised Foundation filter was found to be

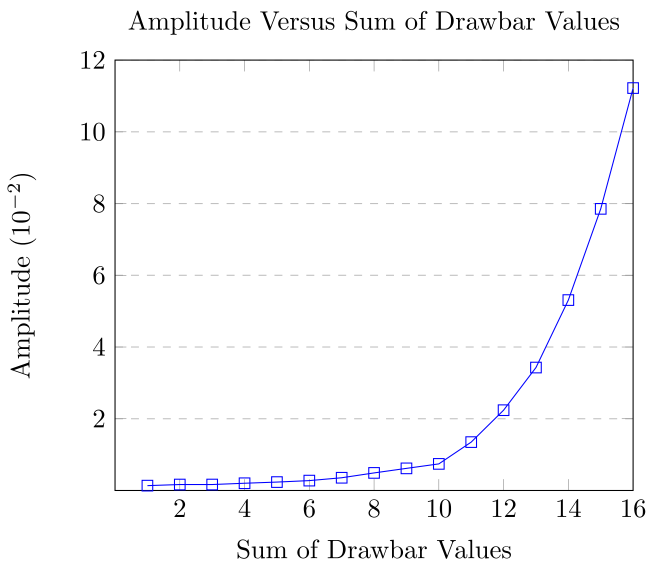
$$H_{f_d}(z) = \frac{1 + 2K^2z^{-1} + z^{-2}}{(RC^2K^2 + 3RCK + 1) + (1 - 2RC^2K^2)z^{-1} + (RC^2K^2 - 3RCK + 1)z^{-2}},$$

with K being the same as above.

For the sake of simplicity, it was assumed that the bandwidth of the two preamplifiers was within the range of pitch detection, that is to say, they could be modeled as a frequency-independent effect on the value of the voltage at any given time.

Based on samples of the Combo V, it appears that, for a given combination of a register and tone, the amplitude of the sound is a function of the sum of the values for both drawbars[2]. Curiously, this holds true for both the Reed and the ostensibly quieter Foundation tone. A graph of the amplitude versus the sum of the drawbar values is shown in Figure 3.1.

[2]This is not true of the mixture register, but it holds for each individual component thereof.



3.2 Implementation

The Matlab code for the implementation of this is provided at `https://github.com/CThierrin/Vox-Continental-Model`. For a given MIDI note, we calculate the proper notes for each register. Then, we calculate the Reed waveform for each register. We then pass the Reed waveforms through our Foundation filters to obtain the Foundation tone. We then adjust the volume of each register based on the drawbar settings. To obtain a more accurate tone, one can convolve the result with an impulse response for an amplifier.

4 Conclusion

4.1 Limitations

The current implementation is highly inefficient, and cannot be run in real-time. It currently only generates a second of a single note at a time, though this would be easy to change.

Many simplifications were made in the name of time. Notably, a vibrato effect found on the original instrument is missing from this model. In addition, the attack and release of the keys produce an audible "click" which is missing from the model.

The way the Continental is currently modeled assumes that the phase of the waves will reset to zero every time the key is pressed. In a real Continental, the oscillators are always oscillating, thus the phase of each note depends on when the key is pressed. Not implementing this could lead to phasing issues; if one were to place a C4 followed by a C5 a fraction of a second later with the 8', 4', and Reed drawbars pulled, then depending on the size of the gap between notes the C5 could get canceled out.

One way to improve on many of these limitations would be to implement the Reed waves using wavetable synthesis.

4.2 Extensions

The methods used in this project, analysing the Vox Continental from both the pers, can be used to analyse and synthesise other electronic organs, such as the Lowrey DSO-1, the Gibson G101, and the Farfisa Compact.

References

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