CHAPTER 5:
ANALYSIS OF INTERACTIVE TECHNOLOGY IN THEA MUSGRAVE'S *NARCISSUS*, FOR CLARINET IN B-FLAT AND DIGITAL DELAY

My interest in Thea Musgrave's *Narcissus* began after hearing clarinetist F. Gerrard Errante's recording in 1991.[46] McGregor Boyle, my major advisor at the Peabody computer music studios, was the technical director for one of the first performances of *Narcissus*, and had had first-hand experience with the original equipment as well as direct supervision from the composer in the concert production. Advice from both Boyle and Errante was invaluable in preparing a performance of *Narcissus* using my own digital delay equipment in April of 2000. The experience of implementing Musgrave's directions using new equipment led me to wonder if the process could be formalized for the benefit of other players. A number of performers interested in the piece have expressed their enthusiasm for such an effort as well. The result is the following analysis of Musgrave's digital delay system.

5.1 HISTORICAL BACKGROUND

Narcissus was written in 1987 for flute and digital delay, as one of four works resulting from a National Endowment for the Arts Consortium Commissioning Grant. The commissioning flutists were Wendy Rolfe, Harvey Sollberger, Patricia Spencer, and

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[46] Burton Beerman and F. Gerrard Errante, "Electric Clarinet," (CPS – 8607, Brooklyn, NY: Capstone Records, 1991), track 5

Robert Willoughby.[47] Clarinetist F. Gerrard Errante, a noted specialist in music for clarinet and electronics, served as technical consultant to Musgrave during the composition of this work. In return, the composer made a transcription of *Narcissus* for clarinet.[48] Novello Music now publishes both flute and clarinet versions of this work.

Narcissus requires a digital delay system controlled from the stage by the performer. Though relatively simple, the electronics are notated for the particular model of digital delay equipment used by the composer, a Vesta Koza DIG-411. This instrument is no longer manufactured. Even so, *Narcissus* is performed often, using alternate equipment. Musgrave's technical notes included in the score refer to several other delay devices used by performers who were involved in the creation or early performances of this work. However, the specificity of the notation for the DIG-411 poses a few problems in reconstructing the digital delay system for those who do not have the benefit of advice from either the composer or the handful of performers who had experience with the original implementation.

The score includes three pages of technical notes, compiled by Musgrave, Patricia Spencer, Karen Bennet, and F. Gerard Errante, explaining the digital delay system. The notes include stage diagrams, a sketch of the front and back panels of the DIG-411, and a list of warnings and recommendations for performance setup and preparation. These notes are very helpful since they provide some insights into the composer's intentions, as well as recommendations for handling certain common performance problems. However,

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[47] Patricia Spencer, "The Musical Shape of Technology," *Flutist Quarterly* 19, no. 3 (1994), 47.

[48] F. Gerrard Errante, email to the author, March 8, 2004.

several key digital delay effects are not explained in general terms, but are instead expressed only as DIG-411 knob positions. In order to reconstruct the digital delay system using updated or alternate technologies, the exact nature of these effects and their parameters must be explicitly understood. This information is not contained in the technical notes accompanying the score, nor is it to be found in any of the available literature on this work to date.

The original Vesta Koza DIG-411 Digital Delay used by Musgrave to create this piece has been in the possession of flutist and *Narcissus* co-commissioner Wendy Rolfe. Dr. Rolfe has very kindly lent me the DIG-411 for this research, and I have compared the functions of the original instrument to my own software-based reconstruction. With this comparison, I have analyzed and defined the digital delay system as a set of signal processing algorithms and related parameters, rather than as proprietary settings specific to one now-obsolete device.

5.2 MUSICAL ROLE OF TECHNOLOGY

Narcissus is programmatic, musically illustrating the Greek myth of Narcissus, who was so drawn to his own reflection in the water that he drowned trying to grasp it. Musgrave provides the following program text, fragments of which appear throughout the score:

> Narcissus wanders through the forest, observing, enjoying … unselfconscious but self-absorbed.
>
> He sees a pool of water and then as he approaches notices his reflection in the water. He is intrigued and then jumps back in fright. Once more he approaches … it is still there.

> Narcissus steps away from the pool to consider this phenomenon. Several times he approaches, the figure is always there watching him.
>
> In the shimmering sunlight Narcissus seems to see this glorious and attractive being moving in the rippling water. He is dazzled and slowly holds out his arms. To his amazement the figure responds.
>
> In awe and wonder Narcissus approaches closer and closer. With a sudden change of mood Narcissus dances happily and playfully … the figure echoing him. But then Narcissus begins to question anxiously the lack of any independent response … is he being mocked? He gets more and more agitated and finally in a fury he rushes headlong into the water to grapple with the figure. The waves surge up and Narcissus is drowned. There is a distant shimmering vision of Narcissus and his reflection. Then in the setting sun the vision disappears, the forest is empty and the pool lies undisturbed.[49]

Narcissus contains a great variety of moods and textures, from the unaccompanied opening melody to a playful scherzo, and angular and agitated semi-improvised sections. The digital delay is more than an effect in this piece. Programmatically, it assumes the role of Narcissus' reflection, and at the end, the water itself. Musically, the delay extends the solo instrument in time, creating a sonic reflection that very nearly takes on a life of its own. Repeating delay effects are used to create harmonies out of a single melodic line, and continuous delay-time modulation is used to bend the pitch of the delayed sound.

Duration is listed in the score as 14 minutes, but this is variable considering the numerous indications for rubato, open-ended pauses designed to allow electronic effects to fade before moving on, and the variability of the semi-improvised segments. All electronic sounds are generated in real time directly from the sound of the live clarinet

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[49] Thea Musgrave, *Narcissus, for Solo Clarinet in Bb with Digital Delay,* (London: Novello, 1989).

using the basic features of a digital delay, and there are no pre-recorded elements. Therefore, the electronics should be viewed as a flexible extension of the solo clarinet rather than as an accompaniment.

5.3 ANALYSIS OF TECHNOLOGY COMPONENTS

The electronics required for Narcissus can be broken down into three basic parts: a sound reinforcement system (microphone, amplifier, and loudspeakers), the digital delay system (creating echo effects with several variable parameters), and a control interface (foot switches, pedals, and other devices used to change delay settings during performance). The following is an explanation of the required effects, the technical methods for implementing them, and the musical contexts in which they appear.

5.3.1 Sound Reinforcement

The sound reinforcement requirements for *Narcissus* are straightforward and will generally pose no special problems in adapting to available equipment. Musgrave suggests a contact microphone to provide audio input from the clarinet to the digital delay system.[50] Other microphone systems can work equally well for this piece provided they offer enough isolation from the loudspeakers to prevent signal feedback or other extraneous noise.

The setup diagram included in the score specifies that the signal output from the digital delay should be routed to a loudspeaker placed stage-right, while the amplified but

[50] Musgrave, *Narcissus* score.

otherwise unaffected ("dry") clarinet signal should be routed to a second speaker placed stage-left.[51] This relatively simple arrangement is intended to force an aural separation between the clarinet and its digital "reflection."

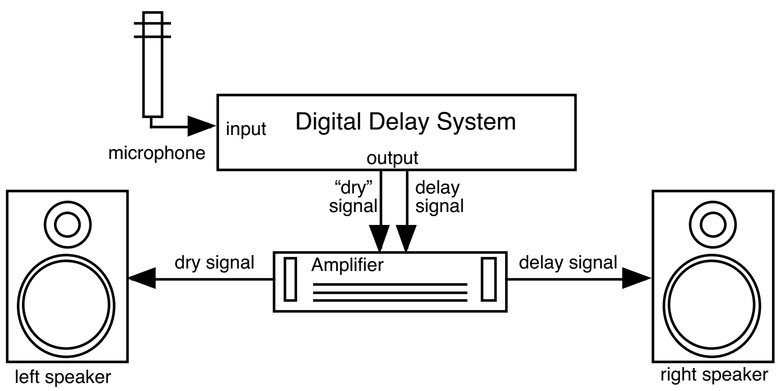

Figure 5.1. Audio system setup

5.3.2 Digital Delay System

A digital delay is a standard effect found on most commercially available signal processing equipment. In its basic form it creates a simple echo – the input signal is played back after a specified time interval has elapsed. This time interval is usually expressed in milliseconds, but may range up to several seconds. Various manipulations of the delay can produce interesting sonic results, some of which are called for in *Narcissus*. Six digital delay parameters must be controlled during performance of this work: delay interval (time), feedback, time modulation, hold, volume, and bypass.

[51] Musgrave, *Narcissus* score.

Delay Time. Musgrave indicates three distinct delay times to be applied at various points. The DIG-411 delay time was set using two separate knobs. The first determined the base delay time (labeled “range”), with available settings of 2, 8, 32, 128, and 512 milliseconds. The second selected a multiplier of the base delay time, with values ranging continuously from 0.5, to 2 (labeled “time”). Therefore, the base delay time could be set anywhere from one half to double the base delay time. Narcissus calls for a base delay time set to 512 milliseconds throughout. Multiplier values of 0.5, 1.0, and 2.0 are used, resulting in 3 separate delay times: 256, 512, and 1024 milliseconds.

In Figure 5.2 the delay time is set to 1024 milliseconds (512 x 2). With the sound of the clarinet echoing approximately one second later, the first note, F, is repeated over the E-flat, which is repeated over the D. In this passage, feedback (see below) is set to 6 (the highest setting in the piece), and therefore, the F is also heard repeating again (but softer) over the D.

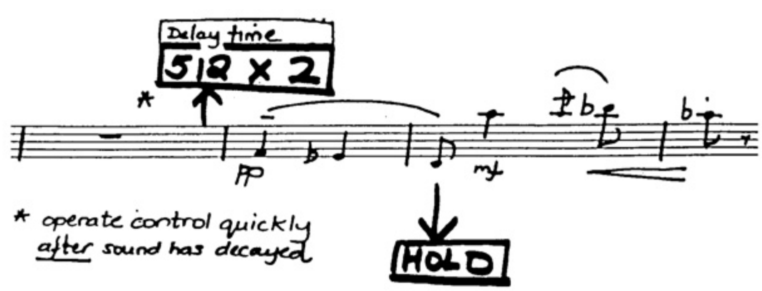

Figure 5.2. Score example: delay time

Delay feedback. Delay feedback creates a repeating echo by routing a portion of the delay output back to its own input. Normally, the signal being fed back is at a lower volume than the output, and the repeating echoes fade away gradually, with a duration that depends on the amount of feedback. Musgrave uses this technique very effectively to portray the environment and character of *Narcissus*:

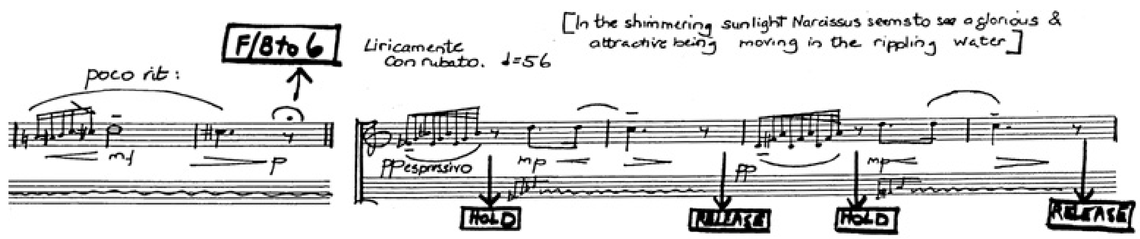

Figure 5.3. Score example: delay feedback

In the passage shown in Figure 5.3, delay feedback creates a fairly thick texture. The “shimmering sunlight” and “rippling water,” referred to by the program text, are expressed in the accelerating and ascending arpeggios, which continue to repeat while fading away (the “Hold” feature is explained below).

Delay feedback is indicated in *Narcissus* according to settings specific to the DIG-411: values are indicated from 0 to 6 (on a scale from –10 to10).[52] Musgrave describes feedback settings as controlling the “number of repeats” in the delay.[53] This should not imply that these repeats are discrete repetitions of a musical phrase, or that a feedback setting of 6 will yield six repeats. In fact, a standard digital delay with variable feedback will route an *attenuated* portion of the delayed signal (usually scaled from 0-

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[52] Settings between 0 and –10 are not audibly different in any way from settings between 0 and 10. It is not completely clear, in the absence of a DIG-411 user manual exactly what the purpose of negative feedback values might be. Since negative values are not used in *Narcissus* I will defer a definitive explanation of this curious feature of the DIG-411 to future research.

[53] Musgrave, *Narcissus* score, 1.

100 %) back to the delay inputs. The result is that sound repeating in the delay gradually diminishes in volume as less and less of it is fed back each time. A feedback setting of 0 will simply produce a single echo of the input signal, with no portion of the echo redirected to the delay input. The DIG-411 operates on this principle as well, so alternate implementations of the delay system should be constructed using scaling factors equivalent to the DIG-411 settings used by the composer.

The most logical assumption is that the settings from 0 to 10 would correspond to feedback gain from 0 to 100% of the original signal, with each number on the dial representing a 10% increment. Therefore, the maximum setting in the score, feedback at 6, would be interpreted as 60%. However, the DIG-411 behaves quite differently. Settings above 6 actually produce some very undesirable effects: rather than diminishing and fading away, the repeated echoes become louder and begin to distort, eventually overloading the system. Apparently, settings above 6 create feedback levels effectively greater than 100%, so that even the quietest sounds introduced into the system quickly build into an overwhelming noise. It would seem that by limiting the delay settings in *Narcissus* to 6 and below, Musgrave was simply working within the idiomatic boundaries of the equipment on hand, rather than choosing settings according to any arbitrary rules—a clear demonstration of Musgrave's "hands on" approach to composition with technology noted by Patricia Spencer in her description of this work and its inspiration.[54]

The practical question remains: using an alternate system, what levels of delay feedback would most closely match the DIG-411 settings indicated in the score? To

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[54] Spencer, "The Musical Shape of Technology," 47.

answer this question, I measured the output of the DIG-411 using a test application created with Max/MSP software. With delay time set to 512 milliseconds (512 x 1), a synthesized test signal was sent to the DIG-411 input, and the delay output was recorded into an AIFF sound file for each of the three feedback settings (2, 4, and 6).[55] A feedback setting of 6 yielded approximately 18 seconds of diminishing repetitions (or 36 repeats). With feedback at 4, repetitions lasted for 5 seconds (10 repeats). Feedback at 2 created 2.5 seconds of echo (5 repeats).

The same signal was then put through a software-based delay with variable feedback (also in Max/MSP), in order to simulate the results of the DIG-411 test. The DIG-411 feedback setting of 2 corresponded to a software delay feedback setting of 25%. DIG-411 feedback of 4 was equivalent to 50%, and the DIG-411 setting of 6 corresponded most closely to 75% feedback in the software simulation.

It should be noted that on the DIG-411, feedback is not limited to discrete settings. The feedback control knob is a potentiometer that allows for settings anywhere along the range between the minimum (0) and maximum (10) values. Considering the fact that the performer is required to quickly change these settings manually while handling a flute or clarinet as well, it is likely that some variation would occur in performance from the notated values. In actual practice with this machine, feedback settings of 2, 4, and 6 would be rough targets. Furthermore, differences in microphones

[55] A test tone (sine wave at 440 Hz) was used to first calibrate the DIG-411 input so that the incoming signal would be as close to 0dB as possible (using the front panel “Headroom” LED as a guide). The same synthesized tone (440 Hz sine wave with an immediate attack and linearly descending decay envelop (1-0) over 500 msec) was sent to the DIG-411 input for each of the three feedback settings. The “bell-like” sound of this test signal enabled easy counting of repetitions.

(and their placement), individual playing style, and concert hall acoustics will produce slightly different results in actual practice. My analysis of the DIG-411 feedback settings, as 25, 50, and 75 percent of the delay output signal, should be used only as an approximate guide for recreation of the digital delay. Some variation or adjustment may be necessary to account for real-world performance situations.

Modulation. The modulation effect is not clearly defined in the score or in any other published article to date concerning this work. According to clarinetist F. Gerard Errante (who assisted the composer in designing the electronic effects), “the modulation effect is meant to be a gradual, ‘undulating’ pitch transformation, like a slow, wide vibrato.”[56]

The modulation effect is applied at the end of the piece, as the character of Narcissus drowns in the reflecting pool (“The waves surge up, the figure is shattered & Narcissus is drowned”). In Figure 5.4, the modulation effect makes its debut, portraying Narcissus’ watery demise. The short delay time in this passage (512 x 0.5, or 256 milliseconds) creates a very close mirror of the solo clarinet, warped slightly by the oscillating pitch of the delayed signal. Delay feedback, set to 6, adds thickness to the texture.

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[56] F. Gerard Errante, email to the author, March 9, 2000.

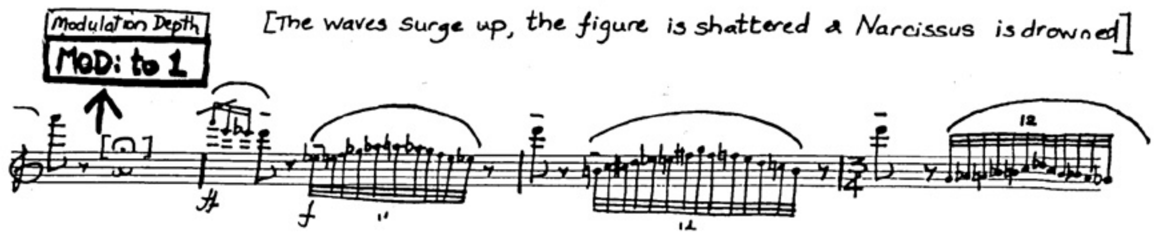

Figure 5.4. Score example: delay time modulation

Pitch fluctuation of this sort can be achieved by continuously varying (modulating) the delay time by a small amount, similar to a typical "flange" effect. As the delay time shifts, audio samples in the delay buffer are played back at a shifting rate of speed. As playback speed increases, the pitch rises. As playback speed decreases, the pitch falls. This phenomenon is similar to the "Doppler" effect on pitch from a moving sound source, and it should be noted that this pitch shifting effect created by a continuously variable delay only occurs while the delay time is still changing. Once the delay time is set, the pitch stabilizes at its original pitch level. Furthermore, the amount of pitch shifting is directly related to the amount of offset from the original delay time and the speed of modulation. Larger offsets at faster speeds create more radical pitch shifting effects.

The score indicates that "[m]odulation *speed* remains at 0 throughout, modulation *depth* ranges from 0 – 10 (0 – 3 [*sic*] used)."[57] According to the front panel of the DIG-411, modulation speed is actually scaled from .1 Hz to 10 Hz, with a continuous range of settings available between the minimum and maximum settings. Therefore the

57 Musgrave, *Narcissus*. Although the technical notes indicate modulation values from 0-3, the score contains only modulation settings from 0 to 2.

modulation speed setting of zero indicated in the score should be implemented as 0.1 Hz when using other equipment. The score indicates depth values of 0, 1, and 2 on a scale of 0-10. An analysis of the of the DIG-411 output, with an input signal of a sine tone at 440 Hz, shows that a modulation setting of 0 causes no pitch deviation, a setting of 1 causes a pitch fluctuation between 338 and 442 Hz, and a modulation setting of 2 produces a pitch variation from 442 to 258 Hz. Using a modulated delay constructed in Max/MSP software, I was able to produce the same pitch variations as the DIG-411 and record the amount of delay time modulation required to produce such results in terms of variation from the base delay time in milliseconds. In other words, to produce the ± 2 Hz pitch variation recorded from a modulation setting of 1, the delay time should be varied by approximately 7 milliseconds in either direction, i.e. delay time continuously fluctuates between 1017 and 1031 milliseconds at a rate of one cycle per 10 seconds (0.1 Hz). For a mod setting of 2 (pitch fluctuation between 422 and 458 Hz), a delay time modulation of 21 milliseconds is required, i.e. delay time fluctuates gradually between 1003 and 1045 milliseconds.

One caveat: on the Vesta Koza DIG-411, the knob control for modulation depth allows for continuous adjustment between values, rather than discrete settings. Therefore, the exact values for pitch variation may be slightly different from one performance to the next. The values I have come up with should be used as a guideline only, and not as absolute values. However, I believe that this analysis is precise enough to serve as a guide for future implementations of the modulation effect.

Hold. The hold function allows the performer to capture a short duration of sound in the delay line that loops continually. While the hold is engaged, no new sounds are added to the delay, so the hold loop becomes a background to whatever the performer plays at that time.

The DIG-411 had a particularly smooth hold feature, with no audible clicks or other artifacts creeping in to the sound when the feature is engaged or released. Musgrave mentions this requirement as an absolute necessity for any performance implementation of the delay system.[58]

The hold effect is used quite effectively in Narcissus, especially at measure 247 (*Giocoso – Dopio movimento*, “Narcissus then responds playfully, happily …”). Figure 5.5 shows delayed arpeggios synchronizing to form brief ostinato chords that accompany the continuing melody in the clarinet. The four notes before the hold is engaged (B-G#-G-F) align as a chord, since the delay time coincides with the eighth note pulse, and they continue to repeat as background accompaniment for the next two and a half measures until the hold is released.

Figure 5.5. Score example: delay hold

[58] Musgrave, *Narcissus* score.

Volume. The volume of the delay output is to be controlled by foot pedal. Several places in the score call for the delay signal to gradually fade in or out to silence. The original setup used a simple analog volume pedal between the delay output and the loudspeaker. This technique is used programmatically in *Narcissus* to illustrate the main character approaching or retreating from the reflecting pool where he sees his own image:

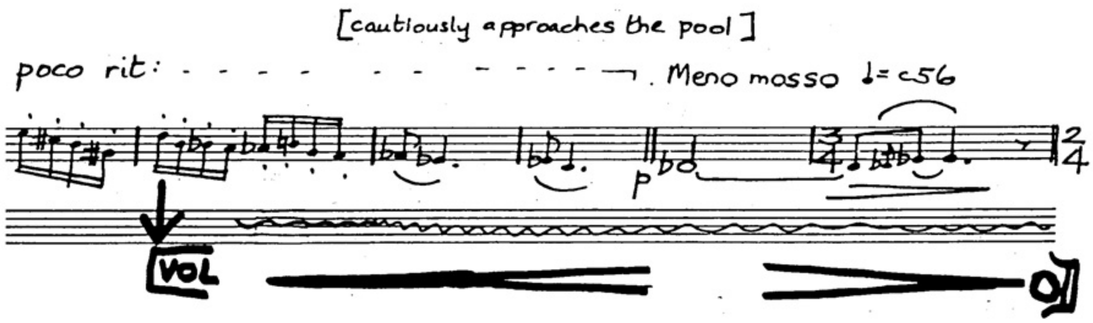

Figure 5.6. Score example: delay volume

Bypass. The bypass function is used in *Narcissus* to turn the entire delay system on or off. This feature is used at the opening of the piece so that the unaccompanied introductory section ("Narcissus wanders through the forest …") is unaffected by the digital delay. Once the bypass is disengaged (by foot switch control), the delay system is active.

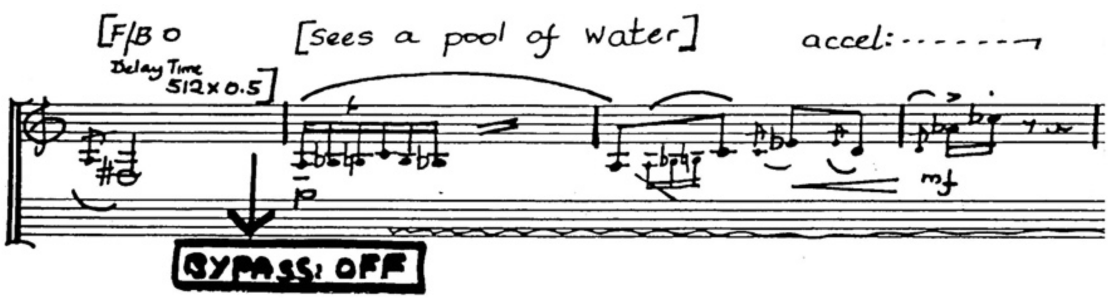

Figure 5.7. Score example: delay bypass

Digital Delay System Summary. The digital delay system for *Narcissus* consists of: 1) an audio input source (a microphone); 2) an echo effect with variable delay time, feedback, time/pitch modulation, and functions for delay hold, bypass, and volume control; and 3) audio output via amplifier and loudspeakers. The delay effects can be easily described in terms of standard audio signal processing algorithms and the DIG-411 settings given in the score can be translated into specific effect parameters. Table 5.1 (below) summarizes the required effects and their variable parameters as notated in the score and as actual values to be used as a guide for reconstruction with alternate equipment.

Table 5.1. Delay effect parameters: notated and actual values

Effect	Notated	Actual Values
Delay Time (time interval between input signal and its echo)	512 x 0.5 512 x 1 512 x 2	256 milliseconds 512 milliseconds 1024 milliseconds
Feedback (amount of delay output signal routed back to its input; duration of repeating delay)	0 2 4 6	No feedback (1 repeat) 25% 50% 75%
Modulation Depth (slow cyclical pitch shifting; Speed = 0.1 Hz)	0 1 2	No change Delay time +/- 7 msec Delay time +/- 21 msec
Hold (delay loops continuously in background allowing "ostinato" effect)	On/Off	Feedback = 100%, Input Off
Bypass (disengages the entire delay system by cutting input)	On/Off	Input Off
Volume (output level from the delay system)	< >	Continuous control from 0 to full volume

Figure 5.8 shows the complete digital delay system and the signal flow between the various components:

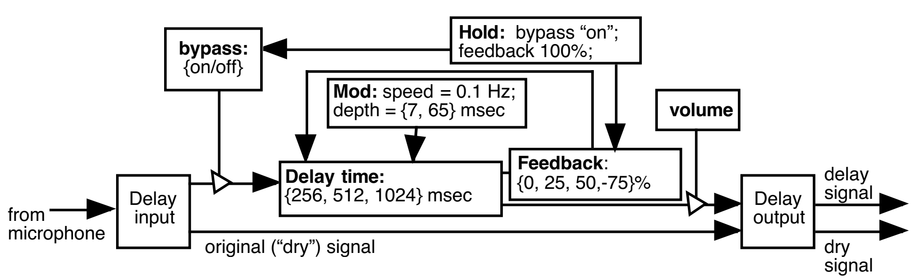

Figure 5.8. The complete digital delay system

5.3.3 Control Interface

Because variable parameters must be changed during performance, an interface of some sort is necessary to control the delay system from the stage. Musgrave's directions in the score are so specific to the DIG-411 that any new realization of the work will require some departure from the notation. The DIG-411 has back panel inputs for a hold pedal, a bypass pedal, and a volume pedal. On the front panel are knob controls for "Input" (0 – 10), "Feed Back" (-10 – 10), Modulation 'Speed" (0.1 – 10 Hz) and "Depth" (0 – 10), Delay ""Range" (2, 16, 64, 128, 512) and "Time" (0.5 – 2.0), and "Delay" (0 – 10) and "Dry" (0 – 10) Output levels. Additional on/off switches control "Hi-Cut" (filter), "Bypass," and "Hold." The Vesta Koza DIG-411 front panel is shown in figure 5.9.

Figure 5.9. Vesta Koza DIG-411 front panel

In practice, the performer would be required to manipulate knobs 2 (feedback), 4 (modulation, depth), and 6 (time) by hand. Bypass, hold, and volume are controlled by two foot-switches and a connected to inputs on the back panel of the DIG-411 and a volume pedal placed between the DIG-411 output and the amplifier.

Alternate delay systems (whether hardware- or software-based) may not feature the same physically accessible controls for the aforementioned variable parameters. Aware of this fact at the time the clarinet version was published, Musgrave mentions the possibility of using a third footswitch to advance through a sequence of pre-set delay settings.[59] Such an arrangement allows the performer to easily change delay system parameters while remaining focused on the music. The points in the score that require changes to these three parameters are as shown in Table 5.2.

Table 5.2. Pre-programmable effects changes

Score Event	Delay time	F/B	Mod.
1. m. 1 - "Narcissus wanders through the forest, observing …"	512 x 0.5	0	0
2. m. 78 - "Is 'It' Still there?"		2	
3. m. 89 - "Narcissus steps back from the pool …"	512 x 1	4	
4. m. 172 - "In the shimmering sunlight …"		6	
5. m. 247 - "Narcissus then responds playfully, happily …"	512 x 0.5	4	
6. m. 316 - "Narcissus anxiously questions…"		6	
7. m. 370 - "The waves surge up … Narcissus is drowned"			1
8. m. 387 - "All that remains is a distant shimmering vision …"			2
9. m. 398	512 x 2		
10. m. 426			1
11. m. 428 – "The vision disappears … the forest is empty …"			0

Therefore, eleven pre-programmed delay system changes are required, two of which require changes to two parameters simultaneously (events 3 and 5). Many strategies currently exist for cycling through a series of effects changes, either by footswitch control or by other means. More than likely, new strategies will emerge in the near future for controlling parameter changes within an interactive computer music system, to which this list of control events should be easily adaptable.

[59] Musgrave, *Narcissus,* performance notes preceding the score ("Requirements").

5.4 SUMMARY

The digital delay system required for *Narcissus* could be easily reconstructed using a wide range of equipment or software-based audio processing environments. I have based my analysis of the digital delay system, and its use in the score, on a close examination of the original Vesta Koza DIG-411 system used by Musgrave. Therefore I hope that it leads to future performance realizations that are faithful to the intentions of the composer. By translating DIG-411 settings into specific parameter values for standard signal processing algorithms, I hope to provide enough information to serve as a reliable guide for anyone attempting a recreation of the digital delay system for *Narcissus* using alternate equipment or technology. My own software-based realization of the digital delay system is discussed in detail in chapter 9.