Responsive performance strategies with electronic feedback: Shaping intrinsic behaviours

Andy Keep

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University of the West of England, Bristol
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Abstract

This practice-led research contributes to the field of live, improvised, and experimental electronic music by offering a range of responsive performance strategies that instrumentalise electronic feedback. In contrast to electro-acoustic feedback, which incorporates microphones, speakers, and the acoustic space, electronic feedback utilises closed electronic loops. Sonic activity is derived purely from the circuitry and component domain. Electronic feedback instruments can be created as simply as connecting the audio output back to the audio input of studio sound equipment.

Technical principles for the creation of electronic feedback are explained, giving categorised examples of its use by performers and artists. The study seeks a responsive relationship between the feedback circuit and the performer, aided by defining recurring sonic activity. This begins with the collation of commonly cited sonic features by existing artists. The practical methodology refines the notion of instrumentalising found objects, outlining an accountable and rigorous research approach. Operational details relate to the aesthetic positions of what constitutes an instrument and at what level of scrutiny or awareness one performs with it. These work in conjunction with an assessment of the object's control interface and playability, and a three tiered listening strategy. Analysis and knowledge are developed, verified, and presented through live performance. Documentation includes audio recordings, visual representations of sounds heard, and written text.

The findings develop causal explanations, which subsequently underpin a conceptual model of intrinsic sonic attributes. Five interconnected topological sonic behaviours are identified - *nothing*, *resonance*, *iteration*, *saturation*, and *turbulence* – which are used to interpret emerging sonic activity during performance. Responsive performance strategies are then suggested, focusing on the possibilities of manipulation in the configuration, excitation, and interactions of closed feedback loops. Techniques for sound-shaping can facilitate and influence emerging sounds, or create outer morphologies that externally impose spectra and gesture. Four performances are documented as examples of the strategies in action, detailing configurations and performance activities used to evoke sonic results.

The combination of causal appreciation, awareness of the scope of sonic activity, and practical performance techniques offer the performer powerful tools to create responsive interaction and sound-shaping with the intrinsic behaviour of electronic feedback instruments.

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Introduction

This practice-led research contributes to the field of live, improvised, and experimental electronic music by offering a range of responsive performance strategies that instrumentalise electronic feedback. It identifies causal phenomena behind its intrinsic sonic features, enabling a conceptual model of recurring topological sonic behaviours. In contrast to electroacoustic feedback, which incorporates microphones, speakers, and the acoustic space, electronic feedback utilises closed electronic loops. Sonic activity is derived purely from the circuitry and component domain. An electronic feedback instrument can be created by wrongly rewiring studio sound equipment, simply connecting the audio output back to the audio input. This approach to sound making has its roots in the 1950's *cybernetic* circuitry experiments of Louis and Bebe Barron's *Fordibben Planet* (1956) and, perhaps more directly, in the live electronic work of David Tudor through the 1970s and 80s (Adams 1997, Chadabe 1997).

The research seeks to define a sonic palette of electronic feedback, looking for common or recurring audible features, in order to develop a more responsive relationship between the feedback circuit and the performer. The aim is to move beyond retrospective or codified uses of the technology within the current resurgence of electronics in experimental improvisation. The research findings also enable a move away from experimental displays of feedback instabilities, toward structured and collaborative improvisations.

The context chapter explains the technical principles and creation of electronic feedback, giving categorised examples of how performers and artists use it, and collating commonly cited sonic features. Existing approaches for exploring electronic feedback are discussed in the opening of the methodology chapter. In this study the practical methodological design is a detailed instrumentalising technique that encompasses a performance approach, an assessment of the electronic feedback instrument's physical interface, and a three tiered listening strategy. Analysis and subsequent new knowledge is developed, verified, and presented through live performance. Documentation also includes audio recordings, visual representations of sounds heard, and written text.

Research findings are cumulative, beginning with an assessment of the commonly cited traits collated in the Context chapter. Performers and artists discussing insights into the nature of electronic feedback use a combination of metaphor, analogy, and technical explanation. Although the language may vary, a strong theme of perceived behaviours emerges. These are confirmed, and a clear reading of underlying causal phenomena is offered. This knowledge is then orientated toward a real-time performance aid by the use of a conceptual model of available sonic behaviours. Combinations of five behaviour types are used to interpret the emerging sonic activity, enabling informed performer decisions. These findings and interpretations have led to the development of performative strategies that focus on the possibilities of practical manipulations in the configuration, excitation, and interactions of closed feedback loops. It is these strategies that allow a fully responsive performance approach, shifting the instability-to-control ratio toward a combination of decisive internal influencing and externally imposed sound-shaping.

The thesis is presented as a written paper interlinked with four documented solo performances. The written thesis is divided into the three main chapters of context, method, and findings. The findings chapter includes a CD of audio extracts used for reference, and sonogram or waveform images were beneficial. This written thesis is not an analysis of the performance work, but contextualising documentation and discussion of the methodology and findings through the project. The practice-led research developed conceptual models and approaches to performance that would not have been possible without exploratory performance practice. The four solo concerts are presented in their entirety on a separate audio CD, supported by detailed accounts of research rationale and technical practicalities. Although many developmental performances occurred during the research period, these have been chosen both for clarity, as they are all undisturbed by collaborations, and their ability to highlight developments in the thesis.

Context

- **What is Electronic Feedback?**

- **Defining technological approaches**
    - Signal input / Circuit design
    - Signal input / Reconfigured audio equipment
    - No signal input / Circuit design
    - No signal input / Reconfigured audio equipment

- **Common features of electronic feedback**
    - Oscillation
    - Unpredictability
    - Instability
    - Predictability

- **Summary of context**

This chapter addresses the two main areas needed to contextualise the study. The first area defines what electronic feedback is, and how it is used within music making. A discussion of these clearly situates the technical perspective of the performance practice used in the research, as indicated by the flow chart in figure 1. The documentation of how electronic feedback is utilised by artists or works is grouped according to several performer options. It can either process incoming sounds, or exploit the feedback system's potential to create recursive sonic activity using no external sound stimulation. There is also the practical option of creating feedback systems from either a circuit design and component level, or whether to simply reconfigure off-the-shelf audio equipment. Brief chronological examples of the musical use of option combinations are presented. Reconfigured audio equipment with no external signal input is highlighted in the flow chart, indicating the practical approach to performance practice used here.

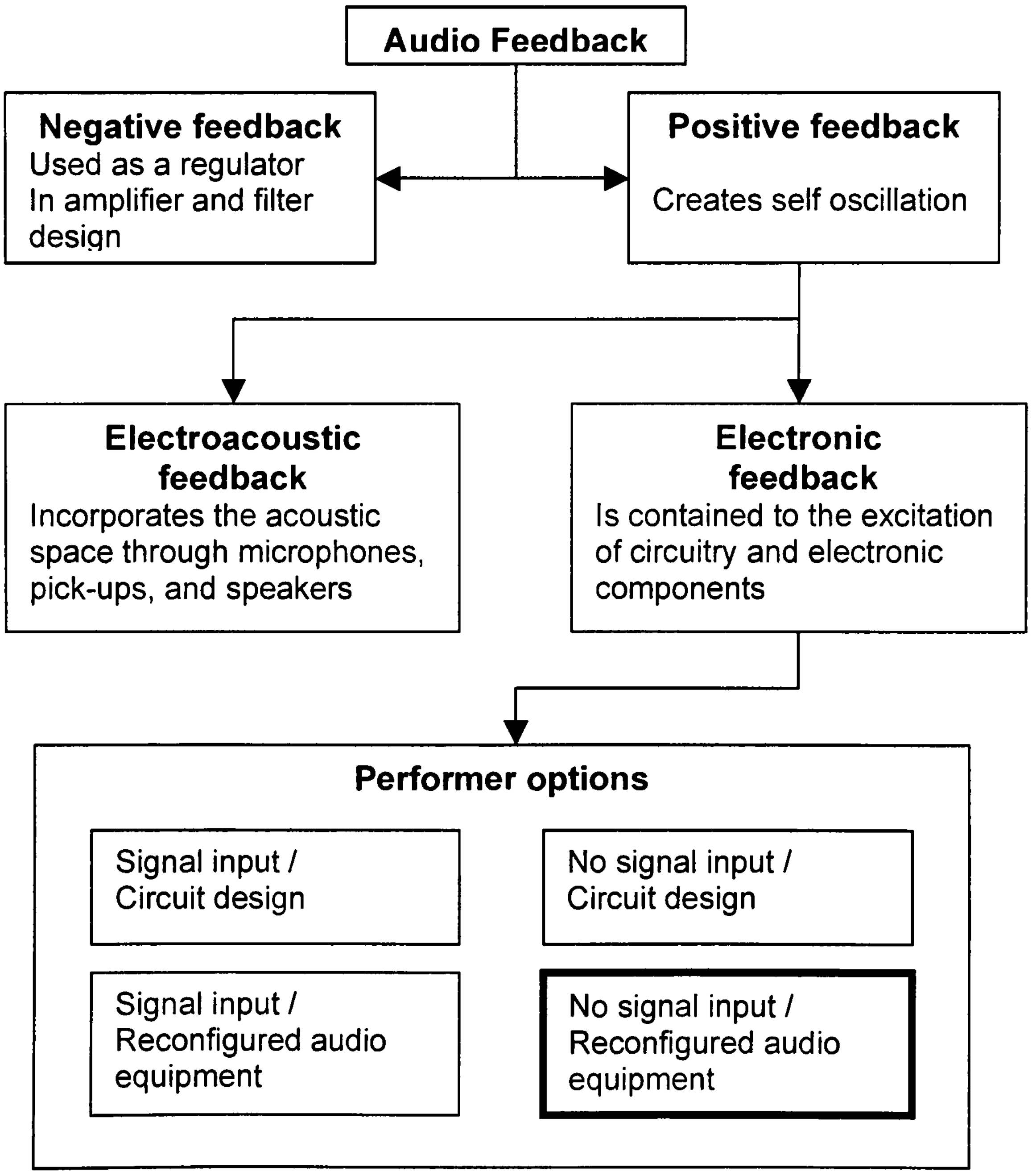

Figure 1. Situating the technical performance approach used in the research.

The second area collates existing notions as to the sonic features of electronic feedback. This is from the perspective of how the resulting sound of a feedback system behaves as opposed to a typological classification of all possible sounds. Existing documentation of artists and composers working in this field has provided many ideas as to its nature, alongside occasional insights into technical and poietic perspectives (Chadabe 1997, Holmes 2002, Marley et al 2005, Nyman 1999). Only recently have several more detailed analyses been entered into. For some the use of anecdotes and metaphors of chaotic behaviour have moved toward more precise analogies and interpretations of the non-linear dynamical systems at play in electronic feedback.

What is electronic feedback?

In its broadest sense, feedback involves the sending of a proportion of a system output back into its input. This action is utilised in many types of systems: mechanical, electrical, biological, and even in communication. As deeper appreciations of the concept of feedback developed during the 1930s and 40s the understanding and design of self-regulating and non-linear systems advanced (Kelly 1994: 143-64, Tofler 1980: 315-8, Weiner 1965). Two basic types of feedback configuration were identified, *negative* and *positive*. Negative feedback, when used in electronic circuit design, predominantly functions as a regulator. It is achieved when the signal fed back arrives out of phase, and at a gain level less than 1. This allows the feedback to attenuate the circuit output, reduce bandwidth, or modulate against itself in some way (Tooley 2003: 152). Many audio processes use this principle, such as the design of filters, spatial effects, various synthesis techniques, and amplifier construction. Positive feedback, on the other hand, creates circuits that can potentially become oscillators: amplifiers that generate an output without the need for an input. The two primary conditions that must be fulfilled to achieve this state are described here by W. Oliver.

> 'First [the] feedback must be positive. [Meaning that] the phase must be such that the feedback signal re-entering the input of the valve, transistor, FET or other device forming the heart of the oscillator, is adding to, not counteracting or subtracting from, signals already present. [...] The second requirement concerns amplifier gain. The gain of the amplifier and feedback loop must be equal to or greater than 1, or oscillation cannot be sustained' (Oliver 1972: 9).

The resulting positive feedback circuits will also display varying degrees of non-linear characteristics (Flind 1996, Tooley 2003).

Since the advent of electrical audio technology the artistic use of positive feedback to create sonic results has been explored in the studio creation or performance of compositional works, sound art and installations, and in improvised or interactive performances. However, there are two distinct configurations of positive feedback within music, *electroacoustic* and *electronic*, as clarified by David Lee Myers. Electroacoustic feedback incorporates microphones or pickups, the acoustic space, and loudspeakers. 'The component elements are electronic *and* acoustic [my italics], the latter involving air movement and vibration of physical objects' (Meyers 2002: 12). Several key examples of its use are Steve Reich's *Pendulum music* (1968) (Mertens 1983), Nicolas Collin's *Pea Soup* (1974-76) (Collins 2002), Alvin Lucier's *Small waves* (1997) (Lucier 2002), and even Jimi Hendrix's famed 1969 performance of *The star spangled banner* at Woodstock.

Electronic feedback systems 'never receive signals from the outside world, and instead feed on a diet of their own product' omitting the element of acoustic space (Meyers 2002: 12). Activity is purely on a circuitry and component excitation level.

Defining technological approaches

To further focus the context of this study I will situate my practice amongst a variety of approaches to electronic feedback. Within its use in music making two important performer options define the practicalities and technical configuration of set-ups used. The first concerns the physicality of the feedback system. One can either design and build bespoke circuits at a component level, or reconfigure existing off-the-shelf audio equipment into internally looping systems. The second option concerns the creation of the musical material. It is possible to generate sound purely from the recursive activity of an internal loop, or one can use the feedback system as a signal processor or enhancer. External signals introduced into the system can either derive from live acoustic and electronic sources, or pre-recorded material on tape. Figure 2 is an extract of figure 1, and shows the potential polarities of the two options.

Signal input / Circuit design	**No signal input / Circuit design**
Signal input / Reconfigured audio equipment	**No signal input / Reconfigured audio equipment**

Figure 2. Performer options in the use of electronic feedback.

Below are examples of key performers and works for each of these various positions. Of course, these approaches need not always be clearly defined or mutually exclusive. It is possible to work with both circuit design and reconfigured audio equipment. It is also feasible to perform with a combination of pre-recorded, live input, and real-time generated musical material. An example of this can be seen in David Tudor's *Untitled* (1972) discussed in the first category below.

The following sections mainly present examples of historical explorations in each of these categories. Although the choice of artist discussed is based on the fact that they all created some form of electronic feedback as a core part of a musical process it is by no means a comprehensive anthology. All varieties of feedback used have been a key element in much experimental music in the last 50 years, resulting in a web of artists and performers too numerous to mention here. I do however offer more detailed and up to date references in the 'no signal input / reconfigured audio equipment' category. This is in part due to the fact that its use is easier to distinguish then the other approaches, but also because it is the area in which my work resides.

Signal input / Circuit design

This category includes artists and works that use feedback as a key form of signal processing within home-made and bespoke designed electronic circuitry. Gordon Mumma's early custom made circuits dating back to 1963 involved a large proportion of feedback activity. Mumma considered his circuit designs "cybersonics", which he describes as 'derived from the Greek "kybernan", meaning "to steer or guide". The [word] "sonics", derived from the Latin "sonus", pertains to sound' (Mumma 2002). These performance electronics used a combination of live instrument input, electroacoustic feedback influenced by the acoustic space, and electronic feedback processing through recursive internal loops on the incoming instrumental signal. Examples of this method can be found in *Medium sized monograph* for piano and cybersonics (1963), *Horn* for tenor horn and cybersonics (1965), *Mesa* for bandoneon and cybersonics (1966), and *Hornpipe* for French horn and cybersonics (1967).

David Tudor became involved in electronic circuits and internal feedback loops 'through experiments in generating electronic sound without the use of oscillators, tone generators, or recorded natural sound materials' (Tudor 1996). As a composer, performer, and designer of homemade circuitry Tudor also explored multi-dimensional performance set-ups like Mumma's, but relied more heavily upon internal feedback to both generate and modulate sound. His explorations into designing and performing with a prolific array of hand built, adapted, and 'off-the-shelf' technology, make some of his works straddle all of my suggested categories.

Due to the complexity of the number of components and parameters involved in *Untitled* (1972) its realization involved the use of pre-recorded material during performances. Tudor describes the situation:

> 'The generation of *Untitled* begins with two chains of components, each chain linked together with multiple feedback loops having variable gain and variable phase shift characteristics. The configuration of devices and their inter-connections, was conceived as a "giant oscillator", with random characteristics variable by the performers response and consequent actions. The number of controls to be simultaneously manipulated being very large, the output of the two chains was recorded several times, each time as a live performance' (Tudor 1996).

The essential characteristics of the custom electronics remain central to the piece. However, the density of the musical material, and the manageability of contributing circuitry, required pre-prepared contributions. Tudor devised the distinction of 'Source Generation' and 'Performance Processing' in his, often complex, feedback pieces. In this instance 'Source Generation' involved double chains of amplification, equalisation, fixed and variable phase shift circuits, and a couple of modulators designed by Gordon Mumma. The resulting combination produced feedback-generated sounds that Tudor recorded to tape. 'Performance Processing' took the pre-recorded material from the 'Source Generation' phase as its input (Rogalsky 2002: 9).

Only four of Tudor's compositions were solely based on electronic feedback. Three use this technique of contributory pre-recorded improvisations, created on the same equipment as that in the live performance (*Untitled* (1972), *Pulsers* (1976), and *Neural synthesis nos. 1-9* (1992-4)).

Signal input / Reconfigured audio equipment

The potential to create recursive signal processing by connecting the output back to the input of a tape recorder was perhaps the most ubiquitous use of electronic feedback. Schrader considers Schaeffer's early use of tape delay one of *musique concrète's* 'basic tape manipulation techniques' (Schrader 1982: 14). He differentiates between the techniques of 'straight-line delay' and 'feedback delay'. Whilst straight-line delay simply utilises the output routing options of multi-track tape heads, feedback delay 'is created by feeding the signal back into the record head of the channel that it was originally recorded on. This creates a feedback loop that may involve one or more channels' (*Ibid*: 43).

Though subtle compared to later practices, Otto Luening's *Low Speed* (1952) is an early example of tape feedback delay applied to pre-recorded flute statements. Stockhausen's *Kontakte* (1959-60) is more experimental with the technique. Modification techniques used on impulse sound material combined ring modulation, spectrum filtering, and sound processing by 'connecting the output of a tape recorder to its input. The aural effects are regulated by volume controls, or potentiometers, and range from slight tape delay to a massive, howling sound' (Ernst 1977: 45). The piece also utilised sound material collected from similarly constructed feedback loops with reverb units (*Ibid*).

By the mid 1960's Pauline Oliveros was among a number of composers experimenting with tape feedback. In *I of IV* (1966) a key compositional element involved 'methods of controlling timbre by regulating the resultant density of an initial sound via feedback loops and time delay' between two interconnected tape machines (*Ibid*: 71-2).

Tape feedback delay in these examples is activated by excitations from incoming sound material. Additionally to imitating decaying spatial acoustics it can be used for spectral smearing, requiring a careful manipulation of gain controls to initiate and capture the desired results.

After the initial explorations of tape feedback delay the documented instances of current performers or composers citing this timbre processing approach are rare. This is perhaps due to the fact that many time based sound processors, both analogue and digital, increasingly offered a feedback or regeneration parameter in delay lines and reverberation as standard. In fact, a broad acceptance of feedback delay began developing as early as 1958, reflected in the sales success of the 'Watkins Copicat' echo unit released in that year, marketed to the commercial recording industry (Watkins 2000).

No signal input / Circuit design

These next two categories do not rely on the introduction of external signals to excite recursive activity. Instead they exploit the existence of a high noise floor found in many electrical components. When amplified this noise floor has enough presence to activate sonic activity. This section looks at creating electronic feedback on a circuit design level, but from a more experimental approach then the functional oscillators used for synthesisers and test equipment. Far from needing to be stable and dependable, the nature of electronic feedback circuits here takes instability and non-linear attributes as a given.

Inspired by new cybernetic theories proposed by Norbert Wiener in his original publication of *Cybernetics: or Control and Communication in the Animal and the Machine* (1948 / 1965) Louis and Bebe Barron sought to 'design and construct electronic circuits which function electronically in a manner similar to the way that lower life-forms function psychologically' (Barron 1989). Their seminal soundtrack to *Forbidden Planet* (1956) was created entirely from the careful composition of sound material generated by studio improvisations on circuits that explored feedback. These were both regulated and non-regulated systems, often inducing high degrees of entropy.

> 'Nobody had thought of employing these circuits to create music or sounds. Cybernetic theory held that the identical laws applied to humans, other life forms, and even some types of machines. Louis took some of these circuits and adapted them to produce sound [...] which we would amplify and record. It was strange – they would seem to have a beginning of their own, and then we would change them by giving them more or less wattage – we used very primitive ways to bring about change' (Bebe Barron quoted in Juno and Vale 1994: 195).

Through the 1960s the experimental use of home-made feedback circuits was being explored in a more performative way by a number of artists. Here the nature of dynamical systems was being accessed through the use of short-circuiting hobbyist audio amplifiers and radios. Although pre-designed circuits were the starting points for many electronic feedback instruments, manipulations and subsequent adaptations were at a component level. Circuits were being interfered with, or 'hacked', to generate sonic results. The circuit's key areas of activity could either be affected by 'touch' or by adding variable components. Michel Waisvisz recalls the development of his 'crackle box' instrument in collaboration with Geert Hamelberg.

> 'Sometime in the early sixties I started touching the inside of my fathers short-wave radio receivers. [...]. Through touch I was able to start playing with short-wave sounds.' 'This experimentation continued with the development of musical instruments by hacking the circuits of early audio equipment, and led to the creation of original instruments based on short circuit feedback.' '[The Crackle Box] was

> simply a wooden frame with some print boards mounted rear-side up to be touched by the fingers. The circuits were 'malformed' oscillators that were very unstable and highly sensitive for finger connections' (Waisvisz 2004).

Similarly, the use of touch is described by Nicolas Collins, as a way to create oscillators by short-circuiting AM radio circuitry.

> 'By bridging different locations on the [exposed circuit] board with your fingers you are effectively – if haphazardly – adding free-range resistors and capacitors to the existing circuit. Your body literally becomes part of the circuit. Varying the pressure (or dampness) of your fingers changes the value of these components. Depending on the location [...] you may change the radio into a very different kind of circuit, like an oscillator. This happens when the output of a gain stage (such as an amplifier) flows back through your skin into an input – voila, feedback' (Collins 2006: 60).

Reed Ghazala was also discovering the sonic potential of short-circuit feedback in the 1960s. In 1967 the accidental short-circuiting of exposed components within a battery powered transistor amplifier became the founding moment of Ghazala's Circuit Bending approach to electronic instruments. The term Circuit Bending is used to describe his 'found-by-chance creative short circuit instruments' (Ghazala 2005: 8) and consciously positions his aesthetic approach. Many of Ghazala's musical instruments are created through the use of touch contact controllers attached to unstable short-circuits discovered in battery powered children's instruments and sounding toys. He explores the sonic results of adding combinations of resistors, diodes, capacitors, photocells, to these unstable points. 'I discover places on the circuit that, if touched, would howl' (Ghazala 2004: 98).

Collins suggests that 'the proliferation of electronic components and information in the early 1970s caused the widespread development of idiosyncratic "homemade" electronic instruments' (Collins 1991: 73). Also, by this time a number of early notable composers that made their own electronic instruments were beginning to disseminate their knowledge. In 1973 Mumma, Tudor and David Behrman ran a series of workshops called "New music in New Hampshire" at the request of younger composers wanting an insight into customised circuit design for sound making and manipulating (Holmes 2002: 230). Many of those who attended continued to collaborate with Tudor within the aptly named group 'Composers Inside Electronics'. A title Tudor 'purposely selected [...] because the people who were working with [him] were working in that manner. That is, instead of using electronics as given instruments, they were working with the circuitry, trying to alter it, influence it, discover what it can do' (Quoted in Hultberg 1988).

Circuit design, including the making of oscillators, is common in hobbyist electronics, and in itself does not constitute an act of electronic feedback in this study's context. However, the creation of short-circuits in an existing circuit that result in unstable sonic behaviour does. Since the existence of postings by enthusiasts and artists on the internet there is now more access to aesthetic and technical knowledge then ever (hacking tips, schematics, component suppliers, etc. See 'Web sources' in Washington 2005).

For many the practice of bespoke performance instrument designs employing short-circuit or internal feedback has continued even as the technology in music incorporated integrated circuit chips. Influenced by circuit bending and creative abuse, current artists such as John Richards (2006), Tom Bugs (2006), and Sarah Washington (2005) have taken to designing or hacking personalised feedback circuits for improvised performances.

Basic IC chips can also be exploited in adapted or hacked amplifier circuits, but as the chips become smaller and more complex it proves very difficult to work at a component level. One documented example that overcame this was the collaborative development of David Tudor and Forrest Warthman, designing the neural network-chip. The aim was to 'integrate the proliferation of electronic devices in David's performance environment' into a single controllable chip (Warthman CD liner note in Tudor 1994). The finished 'neural synthesiser' combined 64 non-linear amplifiers and 10,240 possible internal feedback routing paths, resulting in *Neural synthesis nos. 1-9* cited earlier (1992-4).

No signal input / Reconfigured audio equipment

Artists in this category again exploit the inherent noise floor in electrical components to initiate feedback but, rather then designing and building feedback circuits, chose to work with off-the-shelf audio equipment. Creating sonic activity can be as simple as connecting the audio output back to the audio input of something like an amplifier, equalizer or a guitar effects pedal.

Dick Raaijmakers' 1967 studio compositions *Plumes* and *Flux* were based entirely on the captured results of destabilising studio equipment through this type of electronic feedback. His CD liner notes make it clear that no control voltage oscillators were involved in the creation of sounds heard, and describe the compositional process.

> 'By disturbing the prescribed connections between filters, modulators and such to reconnect them in all possible configurations and then increasing the voltage as far as possible, the authentically classical, and thus 'stable' studio became an enormous unstable super-generator' (Raaijmakers 1998: 96).

As mentioned earlier, Tudor's works with electronic feedback potentially straddle all of my four categories, but to aid the process of differentiation I have separated them by their dominant performance and construction methods. Out of a large body of work between the early 1960s right up to 1995, *Toneburst* (1974/5) is the key example that exclusively uses internal feedback without the use of pre-recorded material. Its physical configuration consisted of numerous off-the-shelf amplifier circuits and guitar effects pedals, 'designed in such a way that it had no beginning, no point [...] where sound originated. The manner of making the hook-up was to connect the end of every chain to the beginning in a complete feedback loop' (Quoted in Chadabe 1997: 273).

Another technique used to create the density of sound achieved in many of Tudor's works is the routing of an electronic feedback system to a number of processing chains, that themselves are based on recursive activity (Adams 1997). These parallel activities can be considered 'Source Generation' and real-time 'Performance Processing', as mentioned in connection with *Untitled*. Tudor continued to use off-the-shelf audio hardware as oscillators. 'By the mid 1980s [he] was using many commercial devices, but not in the manner for which they were designed. Many of these instruments were guitar-effects pedals that he used as modules of his tabletop setup' (Gray 2004: 42).

During the 1980s a new era of sound studio equipment was being built around microchips rather than multiple components, bringing new multi-effects units that could be programmed to internally chain a number of effects processes together. Many of these units enabled access to effect parameters through the new MIDI protocol. A single rack unit, and a suitable MIDI control interface such as a fader bank, could constitute a rich feedback performance instrument for artists inspired by the likes of Tudor such as Matt Rogalsky, Phil Durrant, and David Lee Myers (Aufermann 2002b). Rogalsky's *Tudor Loops* (1996/7) involved a redesigned homage to Tudor's *Tonebursts* within a single multi-effects unit, performed on MIDI fader controllers assigned to phase-shift speed and graphic equaliser parameters (Rogalsky 2002).

Myers performs with many reconfigured chip based off-the-shelf effects processors.

> 'The outputs of electronic devices [. . .] are fed, via custom-built mixers, to their own inputs. In this way, these devices never receive signals from the "outside world"... A whole new function of these devices appears, bearing little relation to their intended purposes' (Meyers 2005).

As with many of the artists mentioned so far, the physical elements of Knut Aufermann's electronic feedback set-up evolve through discoveries encountered during performance. He states that he has 'not yet found a piece of audio equipment that could not be used to produce feedback when placed in a loop... With every new idea about feedback [he checks his] set-up for the possibility of new connections or the integration of a new device' (2002a: 9). He performs on a combination of internal loops created from existing commercial audio products such as multi-effects processors, a mixing desk, and even a short range FM transmitter/receiver pairing.

Rather than seeking new equipment to explore, Japanese feedback artist Toshimaru Nakamura continues to perform on what he calls a 'no-input mixing board'. He describes the practicalities of it below.

> 'If you connect the output of the mixing board to the input, it's going to make a loop, it's going to feedback. If you don't control it, it's going to get bigger and bigger until lit becomes a huge, harsh noise. So you use subtle movements to control the feedback. Every single knob on the mixing desk that you shift varies the sound' (Quoted in Young, R. 2004).

Interestingly a number of commercially available 'virtual' audio environments have been found to allow internal recursive signal routing, and composer Christopher Burns has been generating feedback music purely within the digital domain. As with the chip based multi-effects processors, access to processing parameters involves working with mapped external MIDI controllers. Burns has also been exploiting the ability of digital software to record MIDI controller movements during improvisations, then subsequently edit and refine these parameters movements for future playback. This has allowed the feedback activity to be shaped through repeated audition (Burns 2003b).

Although there is much scope for artists blurring these broad categorisations of practical approaches to working with electronic feedback it does help in clearly positioning my own practice. This final category of No signal input / Reconfiguration is where my work is concentrated. Explorations and performances with off-the-shelf, or 'found', instruments enable an awareness of the sonic features common to electronic feedback systems. The ease and speed of reconfiguration, over that of circuit design and construction, has led to explorations with an array of audio equipment across different eras of technology. An avoidance of additional audio input maintains focus on actual sonic results from the recursive activity of audio equipment used. Detailed descriptions of the equipment and configurations used in this study can be found in the documented performances section.

Common features of electronic feedback

This section collates the aural perceptions of electronic feedback from those that perform with it. Many theories about the sonic traits have resulted from the experimental or exploratory approaches of the previously mentioned artists. These are qualitative and practice-led, derived through performance, for use during performance, often with no need for documentation beyond the sonic result itself. The focus of their readings is more about the underlying nature or phenomena of the feedback circuits, rather than precise sonic classifications.

Regardless of historical era, technological make-up, or aesthetic rationale, a number of common understandings as to how the sonic activity behaves can be seen to emerge. All of the metaphors, analogies, or scientific explanations collated here present the consistent theme of dynamical system traits, often specifically chaos theory. The accuracy of interpretations and the appropriate uses of related terminology vary. On one level, many artists seem to enjoy the sense that something 'otherworldly' is creating the 'inexplicable' sound emitting from a feedback loop, and it is here that the general metaphor is often used. For example, Meyers' uses the mythical *ourobouros* symbol of a self-eating snake as an explanation of his feedback systems (2005).

The umbrella of chaos theory offers knowledge of behaviour patterns and traits displayed within non-linear dynamical systems such as those created in closed circuit feedback. Many artists cite non-scientific texts about chaos theory such as Gleick (1987), Stewart (1990), Lewin (1993), Kelly (1994), Cohen and Stewart (1995) as an influence or inspiration to their work. Those whose documented practice ventures a little deeper into more specific theories of nonlinear dynamics, such as Aufermann, Dunn, and Burns, have been able to make clearer correlations and technical explanations. The qualitative approach of chaos theory is very useable in the context of performance-led research in that 'it seeks to know the general nature of a system's long-term behaviour, rather than seeking numerical predictions about a future state' (Exploratorium 2004).

Oscillation

The most fundamental feature of electronic feedback is that it promotes recursive activity, or oscillation. Descriptive terms such as 'giant oscillator' (Tudor 1996), 'malformed oscillator' (Waisvisz 2004), and 'feedback oscillation' (Adams 1997) make literal references to this. The 'attractor' is the first key chaos theory trait that is commonly cited, directly or indirectly. Whilst discussing Tudor's *Untitled* Kuivila highlights that 'feedback tends to "lock" on a single frequency.' He feels it is 'apparent that the attractor phenomenon is something that anyone working closely with electronic feedback discovers, regardless of what technical explanation, metaphor, or analogy they assign to it' (Kuivila 2004: 22). Once a dynamical system is active it will be drawn to an attractor, aurally perceived as the frequency at which it oscillates. 'The essence of an attractor is that it is some portion of the phase space such that any point which starts nearby gets closer and closer' (Stewart 1990: 99), where 'phase space' is a type of map of all possible activity in a given system.

Ralph Jones exemplifies a number of artists that display an appreciation of the phenomenon, even though he may use a the terminology of a different era. He describes the 'singing point' referenced in the title of his *Star networks at the singing point* (1978) as 'the particular tuning at which the gain in a feedback circuit produces oscillation' (2004). Aufermann refers to the attractor in electronic feedback as 'the frequency that is defined by the value of the components and which displays a minimum impedance' (Aufermann 2002a: 15)[1]. As an exploration of this he documents results from an experiment that sought to influence the 'resonant tuning inside a reverb unit' by using a +12dB equalisation boost within the loop to 'form the attractor of the system' (*ibid*). The potential of equalisation to affect a current attractor state is also observed by Collins when highlighting the technique of multiple, routable, feedback loops. He states that 'feedback matrices benefit greatly from the inclusion of some kind of equalisation, to aid in steering pitch response' (Collins 2006: 183).

Sonic behaviours that appear unpredictable or instable are also commonly perceived in electronic feedback. Unpredictable as to what will be the outcome when parameters are changed, and unstable when erratic or inexplicable activity occurs without any performer intervention.

Unpredictability

Many artists have commented on the unpredictability of working with feedback and suggest that it involves more a collaboration with the system than any real control over it. Meyers states that 'the sounds generated by my feedback systems are almost totally unpredictable', 'the devices speak their own hidden voices' (2005). Nakamura comments on the 'equal relationship' with his no-input-mixing-board by saying that his 'music is just happening' (2002). More specifically Rogalsky describes the sense of unpredictability of sonic outcome.

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[1] Impedance is a more general notion of resistance that covers devices other than resistors. For more detailed technical explanation see Hayes and Horowitz (1989)

> 'Sometimes small changes can cause enormous sonic shifts, and sometimes in surprising ways. For instance boosting high frequencies with the graphic equaliser can have the effect of bringing out low frequencies in the feedback loop.' (Rogalsky 2002: 10)

Editing or manipulating a system's parameters whilst it resides in one particular attractor state may cause such a change to the system that a new attractor becomes dominant. If it is possible for a feedback system to have many attractor states, or resonant tunings, how does a performer access or move between them? Aufermann again offers an insightful explanation when describing the shifts between different attractors. He borrows 'the idea of bifurcation points from the science of thermodynamics. At these points of instability the [feedback] instrument is forced to change its behaviour to accommodate the system change brought about by the player' (Aufermann 2002a: 17). He goes on to say that there may be 'no necessary correlation between the changes of the player and the resulting sound' (*ibid*). Regardless of whether discontinuous changes are actually true bifurcations, they may account for some of the unpredictability experienced by performers. These transitional points or nodes are also referred to as 'catastrophe' (Cohen and Stewart 1995: 211) or 'critical' points (Buchanan 2000: 79-81).

Instability

Although the line between the unpredictable and the unstable may be difficult to clearly define, Barron's interpretation of sonic results implies more of a sense of instability.

> 'The same conditions that would produce breakdowns and malfunctions in machines made for some wonderful music. The circuits would have a "nervous breakdown", and afterwards they would be very relaxed, and it all came through in the sounds they generated' (Quoted in Juno and Vale 1994: 200).

A possible reason for instability is that the attractor may be aperiodic or even chaotic. In this instance the duration of instability is much longer term, even indefinite. 'Stable states [...] are point attractors; stable periodic cycles [...] are closed-loop attractors. The attractors of chaotic dynamical systems are far more complicated' (Cohen and Stewart 1995: 205). They are also known as 'strange attractors' (Stewart 1990: 85-114). David Dunn describes the resulting compositions from his hyperchaotic systems as 'based upon a prescribed set of zones where particular chaotic behaviours reside' (Quoted in Toop 2004: 193). Jones consciously cites chaotic attractors too, as foundational to his *Star networks...* (1978). Through the addition of a more complex set of system connections or nodes, his circuit 'produces an oscillator that is inherently unstable. Tuned to what is called in chaos theory a "tipping point", the circuit sings unpredictably of its own accord' (Jones 2004).

The occurrence of instability can also be related to the circuit's 'internal time'. This is another key trait that Aufermann discusses when analysing his own feedback instruments. He uses the analogy of 'the time oriented nature-of-order' or 'chaotic-time' discovered by Belgian chemist Ilya Prigogine.

> 'One parameter that influences the reaction time of the instrument is what I would like to call the 'internal time' of the respective feedback loop. [Feedback loops] have different, sometimes variable, internal times which depend on electronic component values, AD and DA conversion latencies and delay effect settings which range from microseconds to seconds. The stability of a loop is roughly proportional to the speed of its internal time; the faster the time the easier the system will act on perturbations and so change its output and vice versa' (Aufermann 2002a: 17)[2].

This means that after disturbance, a system takes a relative duration to stabilise. This process of stabilisation is known as *self-organising*. David Dunn's real-time performances for live computers 'explore the global behaviour of hyperchaotic analogue circuits modelled in the digital domain', and feature a creative exploitation of this phenomenon. 'The opening and closing of virtual switches determines various combinations of structural coupling [...] allowing different self-organising behaviors to arise' (Quoted in Toop 2004: 193).

Predictability

One very important addition to this general notion of unpredictability has been presented by Christopher Burns. He also discusses the feedback loop's extreme sensitivity to current conditions, and its dependence of these current conditions for the 'next moment' of activity. However, observations whilst composing *Letters to André* and *Calyx* (1996-98), involving MIDI controllable multi-effects processors in recursive loops, revealed a different insight into the nature of electronic feedback.

> 'The network was not genuinely chaotic. If musical events were generated from stable rest conditions, they could be reproduced again from those same conditions, not only in broad outlines but also in their precise sonic details... Because the sequencer facilitated stable, reproducible output (as embodied in a system configuration and sequenced, time varying MIDI parameter data), the system's "performances" could be, and were, shaped and revised over many months' (Burns and Burtner 2003a: 3).

A further point of reference in the 'not genuinely chaotic' nature in systems can be found in the discourse that surrounded Leon Chua's chaotic oscillator design in 1992. Often referred to as 'Chua's oscillator' (Mayer-Kress *et al* 1993a), it was initially offered as a 'sonification of

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[2] References to his inspiration in audio feedback from his studies in biochemistry can be found in Aufermann 2002b and 2005. In particular the work of Belgian chemist Ilya Prigogine (1985. *Order out of chaos – Man's new dialogue with nature.* Fontana: London).

chaotic systems behaviour' in the field of engineering. Its design is now regularly used for educational lab exercises in that field. The circuit was also explored as a dynamic approach to synthesis, and more specifically digitally modelling acoustic instruments; a type of dynamical Physical Modelling 'investigated the properties [of attractor classes] in the context of sound synthesis and musical composition'. 'The Chua circuit has a remarkable capability to produce sounds that inherently display many sought-after characteristics that are difficult to construct using traditional synthesis methods' (*ibid* 1993b).

Where the attractor states, or phase space, have been quantitatively mapped, it allowed them to be accurately revisited and assessed for physical modelling through repeating parameter settings. Phase-space is a notional map of a system's potential activity, as mentioned under 'oscillation' above. Like Burns, Mayer-Kress et al explored the MIDI protocol to control parameters to reproduce the transitions between attractors (*ibid* 1993a). They described this phenomenon as 'the boundary between periodic and chaotic characteristic of sounds' (*ibid* 1993b).

As stated in the introduction to this section, what appears vitally important from all performer insights and readings is that the common features of electronic feedback are recognitions of its causal phenomena rather than specific sounds. Figure 3 summarises these phenomena.

Common features	**Interpreted cause**
Oscillation (*Audible system feedback*)	• Attractor phenomenon • Frequency dependent of minimum impedance
Unpredictability (*Unknown outcomes*)	• Transitions between attractors
Instability (*Unstable activity*)	• Chaotic attractor • Slow internal time
Predictability (*Ability to reproduce sonic activity*)	• Mapping of the system's phase-space

Figure 3. Common features of electronic feedback, showing interpreted cause.

Summary of context

This chapter has contextualised the use of electronic feedback from the perspectives of technological practicalities and existing knowledge about the sonic activity heard. The first initially highlighted the differences between electroacoustic feedback that introduces the acoustic space, and internal or electronic feedback loops that exploit the notion of positive feedback within audio circuitry. When using electronic feedback the performer has the option to process incoming sound material through the recursive signal path, or to create entirely new sound material using the system as a type of oscillator. There is also the option of designing and building a feedback system at a circuit level, or configuring existing audio equipment so as the audio output signal is reintroduced back into the audio input. The act of creating internal sonic activity with reconfigured audio equipment is the approach used in this study.

Commonly cited sonic features and their possible causes have been summarised at the close of the previous section. The more detailed studies by Aufermann, Burns, and Kuivila, explain many generalities expressed by artists and performers in the field. Later in the thesis a confirmation of these common features forms the basis of a proposed intrinsic sound to electronic feedback. Before developing this idea further the methodological approach used to evoke, explore and confirm this intrinsic sound is discussed in the following chapter.

Methodology

- **Existing methodologies**

- **Practice-led methodological design**

- **Instrumentalising electronic feedback**
    - What is an electronic feedback instrument
    - The playability of an electronic feedback instrument
    - Listening strategy
        - Interiority focus
        - Source cause identification
        - Technological listening
    - Performance approach
    - Instrumentalising summary

- **Documenting the research**
    - Documented performances
    - Written thesis
    - Audio extracts
    - Visual representation

- **Summary of methodology**

The previous chapter mapped out the context and boundaries of the research, giving a technical description of what electronic feedback is, and approaches to its musical use. The practice of configuring off-the-shelf audio equipment into self-oscillating feedback systems was defined as the technical basis of this study, with the aim of identifying intrinsic sonic traits found in electronic feedback. This chapter gives a detailed account of the methodological approach used in the identification process. After a brief initial overview of existing methods used in the study of electronic feedback it addresses the philosophical perspective of a practice-led study. The bulk of the chapter is then occupied with documenting the design and use of a practical performance method. This method of instrumentalising combines performance approach, physical interface assessment, and a listening strategy to critically focus on and interpret emerging sonic activity. The final section addresses the practicalities of documenting the findings and representing sonic performances.

Existing methodologies

General musicological overviews that include live electronics and improvisation with both electronic and electroacoustic feedback offer insights into technical and aesthetic approaches. These are often integrated with historical perspective gained from interviews and personal experiences (Chadabe 1997, Ernst 1977, Holmes 2002, Nyman 1999, and Schrader 1982). A small number of musicological studies are more specific to the field of electronic feedback. Examples can be found in Gray, Kuivila, and Rogalsky (all in Collins (Ed.) 2004), all of which make close readings of the technology and techniques used by Tudor. Whilst Rogalsky has catalogued the function and make up of performance 'boxes', Gray and Kuivila discuss the use of noise-gates, ring-modulation, and filtering within Tudor's feedback loops. James Wiezbicki's text on the Barrons' use of feedback circuitry in *Forbidden Planet* (1956) uses a more objective 'composer profile' format, addressing contextual influences, technology, and musical content (Wiezbicki 2005). Although Wiezbicki does discuss the sound of the work, his use of traditional musical analysis fails to appreciate the sonic material, reducing it to a limited collection of descriptive words such as 'howls', 'rasps', 'clicky percussive sounds' and 'sputtering noises' (*Ibid*: 65-98).

There is relatively little documented discussion about the actual nature of sonic activity found in electronic feedback systems. The previous chapter's collated interpretations and impressions from performers practice-as-research approaches are the most enlightening. Each explores the phenomena of electronic feedback and presents new or developing appreciations of it through performance. Each has also chosen to document insights and findings beyond the performance, but the styles and approaches range from personal artistic statements revealing technical or aesthetic rationale, through to academic discourse. Aufermann's process of mapping and documenting the sonic features goes well beyond descriptive analogy. Focused lab recordings with sonogram representations are used to demonstrate key chaotic system behaviours discovered during improvised performances (Aufermann 2002a, 2005).

This use of lab style recordings indicates that a quantitative methodology could be used in the exploration of electronic feedback, with a more systematic mapping of sounding properties. A more specific example of the quantitative process used on a 'found' instrument can be seen in Sturm et al (2004). The project collected the data of possible sounds from a particular soft drink can, and presented the findings as a statistical analysis. This data format is often used for modelling sounds in the digital domain or as 'parameter estimations' for resynthesis (Roads 1996: 596). However, the electronic feedback systems in this study, although sometimes simple in initial design, involve complex combinations of parameter settings, as well as being regularly augmented or reconfigured. A huge amount of quantitative data would be needed to accommodate the non-linear and chaotic elements of electronic feedback. The resulting overload of statistical variants may not facilitate the design of performance orientated results.

Another approach that appears not to have been employed in the exploration of electronic feedback practice is ethnographic. Bowers' participant observation project within electroacoustic improvisation is a good example of ethnographic research (2002). Results from the method offer many insights into performance practice, choices of technology used, and nuances of collaborative interactions. However, this study is not concerned with musical aesthetics, performance context, or collaborative interactions.

Practice-led methodological design

There has not been a study that maps the emergent sounds of electronic feedback and presents them as a conceptual tool for use during performance. To support this aim an 'ends driven' methodological was designed. It was shaped by the desire to answer the following questions -

- What is the intrinsic sonic palette of electronic feedback?
- Do recurring sonic features exist in all electronic feedback instruments?
- Can a causal understanding of the sonic activity offer insights into performance?

- If so, can strategies be developed to make electronic feedback more responsive in structured or improvised performance?

To answer these questions the methodology needs to incorporate a robust method for exploration and analysis based on how practice is executed in the context of a performance. It should also be fluid enough to accommodate the shifting outcomes of a dynamical system. Initially performance work was quite open and experimental in nature. The original research question simply sought to explore the range of sonic palette available in electronic feedback. Through many improvisations clear hypotheses were formed and a more focused methodological style emerged. Windsor states that

> 'In carrying out an empirical study, hypotheses [...] must be generated before comparing, describing, coding, or collecting data. This is because it is only in the light of such hypotheses that you can decide precisely what data are relevant' (Windsor 2004: 197).

It became evident that a vast amount of unique sonic material could be created from a small combination of feedback systems. However, if viewed topologically rather than typologically a small number of key behavioural states were repeatedly exhibited in all systems. Subsequent performances became more observational, testing the credibility and limits of a topological model. Empirically based knowledge depends on observation and interpretation, a trial and error process where 'interpretations develop, with observation leading to interpretation and interpretation in turn guiding observation' (Cook et al 2004: 3). This dialog between hypothesis and practice refined the topological states into a conceptual model, navigable during improvisation.

Approaches to discovering, developing, testing, and presenting knowledge were contextualised in the act of performance. Resulting new knowledge may be documented to enable discussion, but ultimately the knowledge needs to be easily contextualised back into performance practice. Over time clear relationships became apparent between the traits found in dynamical systems and those in electronic feedback, so strong causal links could be made. Performances that focused on key areas of the model became contextualised presentations of developing theory.

Methods of 'testing out' and comparative analysis involved repeated performances on the same technical set-up, using a variety of technical set-ups, and mapping against commonly cited traits. This affirmation process led to the proposal of an intrinsic sound of electronic feedback, based more on the behaviour of the sonic activity then actual typological classifications, as stated earlier. From this the final hypothesis was developed, which suggests a responsive performance strategy that can influence and shape these sonic traits both internally and externally to the feedback system.

The operational research method, both for collecting and interpreting sonic data, has been the process of 'instrumentalising' electronic feedback systems, detailed in the following section. It seeks knowledge about what is being performed on during the act of performance, thus enabling further developments and options in performance.

Instrumentalising electronic feedback

The process of instrumentalising seeks to discover both the intrinsic sonic nature and the possibilities for imposed sonic manipulation of found or created sounding objects, acoustic or electronic. The concern of this section is not with the act of designing a particular musical instrument, but in clarifying the premise of instrumentalising existing objects. Although it is not new, and need not be particularly complex, refining it as an investigative approach has led to more rigorous and accountable operational details. The resulting discussion is a deconstruction of a process that in context can be a very fluid set of activities, often functioning as the performance itself.

Instrumentalising can be seen to consist of four component elements. The first is an aesthetic approach that encompasses the potential of converting off-the-shelf audio technology into music-making devices. The second involves the assessment of the newly created instrument's playability, and the third is the aural analysis of its sounding properties. These two practical activities are enabled by the final element, which is an approach to performance. The following four questions relate to each element in turn, and are used as sub-headings through this section.

- What is an electronic feedback instrument?
- How is its playability assessed?
- What listening strategies are used to gain knowledge about its sonic potential?
- What performance approaches facilitate this instrumentalising process?

The summary presents the combined practical approach used in this study.

<u>What is an electronic feedback instrument?</u>

In order to fully establish what a feedback instrument actually is there are three areas that need to be discussed; a broad notion of a musical instrument, found instruments, and the act of creative abuse. Dodge and Jerse suggest that musical instruments are 'devices designed to transform the actions of performers into acoustical energy. Each instrument gives the musician a limited set of physical parameters that can be manipulated to produce a particular sound' (Dodge et al 1997: 404). A broader more general definition could be 'a device constructed or modified with the purpose of making music. In principle, anything that produces sound, and can somehow be controlled by a musician, can serve as a musical instrument' (Wikipedia 2006). Explorations into the physical and sonic potential of such a sounding object can be made through its 'performer input' and 'sonic output' diversity potential, discussed in the following section on playability.

A process of 'instrumentation' is used when designing computer music instruments. 'In music system design, instrumentation extends from the mechanical design of sensors and controllers, through the electronics and software interfaces and finally to the modelling of the higher-level relations between performer and composition' (Ryan 1991: 9). There are many discussions of sophisticated developments in instrument interface design (Dean 2003, Di Scipio 2003, Pressing 1990, Roads 1996, Rowe 2001, Winkler 1998), but in contrast to this perspective electronic feedback instruments essentially fall into the category Hugh Davies called 'found instruments' (Davies 2002). After 'finding' a suitable piece of audio hardware, creating recursive audio connections is often the only design that need occur. Perhaps Joel Chadabe's definition of a musical instrument presents a visualisation more focused for our purposes. 'An electronic musical instrument can look like modules in a rack, or like a computer, or like a lot of grey boxes on a table, or like a violin, or for that matter, like virtually anything.' (Chadabe 1997: 215). Nakamura offers an example of this within contemporary experimental improvised electronics by stating that 'the Mackie [mixing] desk [...] in my case is the musical instrument itself' (Quoted in Yokogawa 2003).

As well as being 'found', a general notion of 'creative abuse' is also key here, defined as 'using instruments, objects and/or digital protocols for use in manners that differ greatly from those known generally' (Atkinson et al 2004). John Richards' 'bastardisation' is perhaps a more poignant realisation of the approach within post-digital (Cascone 2000) improvised live electronics. 'Bastardisation implies forcing a system into a state in which it was never intended, or appropriating something for a use other than what it was initially designed for. For example, in analogue terms, this may involve circuit bending or hacking a sound generating device, or forcing a circuit to oscillate through a feedback loop' (Richards 2006). Both definitions describe a conceptual approach to, rather than a 'recommended use' of, technology, epitomised again by Nakamura's 'no-input mixing desk' reconfiguring the 'technologies of reproduction to acts of production' (Henritzi 2001: 37).

So, at this initial conceptual stage, the practicality of instrumentalising electronic feedback is achieved through the bastardisation of found audio technology. This could be as simple as connecting the audio output to the audio input of a guitar effects pedal, using a 'Y' connector in the output to enable both the recursive activity and an audio feed to the outside world. It could also be the creation of a complex interconnected feedback web that has both internal and external sound-shaping possibilities, allowing detailed behavioural, spectral and temporal manipulations. The audio equipment and feedback configurations used in this study are discussed in the 'documented performances' section of the findings chapter.

The playability of an electronic feedback instrument

Having set a notion as to what an electronic feedback instrument is, I will discuss the practical process of assessing its playability. This initially involves defining the physical interface. As mentioned in the previous section, part of the aesthetic of electronic feedback instruments is that they are 'found' rather than designed. Unless the studio hardware being instrumentalised has the potential for mapping additional external controls to its parameters, the physical interface is dictated by the equipment's available controls. These are often limited analogue transducers in the form of fixed scope knobs and latching buttons. Barry Truax describes the process of using such controllers by stating that the

> 'manipulation is continuous and the result is understood as a qualitative difference. A knob is turned and adjusted until the right pitch or loudness is achieved. In filtering and equalizing, the qualitative aspect of timbre is quite amenable to this kind of modification. A simple TOTE operation (test, operate, test, exit) suffices to describe the type of interaction involved' (Truax 2001: 252).

Performer feedback has a primary role in learning any instrument (Pressing 1987 1990). Of the three recognised sensory receptors involved - auditory, tactile and visual - aural feedback is deemed essential, and is discussed as a set of listening strategies in the following section. The use of tactile feedback does come into play here, but it is in no way akin to a more haptic exchange (Gillespie 1999, Pressing 1987 1990). The dials and buttons inherent on a found feedback instrument have no responsive mechanical behaviour. Their movement may result in the sound becoming saturated through gain or even degraded into complete collapse, but nothing in the feel of the controls would indicate this. Only if considered in conjunction with aural feedback would the sense that a button was in or out, or a dial had reached the end of its scope, be useful information.

Dodge and Jerse add the dimension of latency to the responsiveness of controllers. 'Control latency measures the time between the action of the performer and the production of the acoustical event. Unless it is excessive, performers quickly measure this while playing their instruments and adjust their timing accordingly' (Dodge and Jerse 1997: 405). This latency in a computer instrument is based on the systems processing speed, whereas the latency of an electronic feedback instruments relates directly back to Aufermann's notion of 'internal time' discussed as instability in the previous chapter (Aufermann 2002a).

Pressing indicates the importance of visual information when learning a musical instrument, particularly on instruments where the physical interface is clearly mapped out, and its affects are 'literal', such as on a guitar or piano (1990: 15). Through experience it may be possible to visually set a feedback instrument's control parameters prior to exciting a system into oscillation and achieve an approximate area of 'known' sonic palette. However, controllers are both relative and non-linear in feedback, and definitely not literal. The range of possible controller affect is dependent on whatever 'state' the system is in at that moment in time, and therefore not always repeatable at another time. A further complication with regard to the use of visual feedback is the possibility that most audio equipment has assignable, or multi-function controllers. This means that a fader or dial can sometimes be used for a large number of parameter editing functions dependant on what 'patch' or mode the equipment is in. From an audience perspective, such performance actions could well fall into the 'mechanical causality' category of Emmerson's 'acousmatic dislocation' (1994a, 1994b), as physical movements can be subtle, and are not always consistent with a resulting sound.

The physical interface attributes can be discussed in terms of their potential playability within Sergi Jorda's instrument 'diversity' mapping (2004a, 2004b). Success rating within his model is dependent upon an instrument being neither too simple nor too complicated, and having a potential for progression toward virtuosity with a learning curve that is rewarding to the performer. Jorda's main assertion is that a successful instrument 'will allow its performers to play music and not only to *play with music'* (Jorda 2004b: 707).

The diversity levels of 'macro, mid, and micro' reflect possibilities of expressivity and 'the freedom the instrument can offer the performer' (*ibid*). Macro-diversity 'determines the flexibility of an instrument to be played in different contexts, music styles, and varied roles'. A High *MacD* would be an all purpose instrument, such as the harmonica, whereas a low *MacD* 'denotes a highly specialised and less adaptable instrument' such as the double bass. Mid-diversity 'indicates how different two performances on the same instrument can be'. '*MidD* is an essential component in order to turn a music gamer into a music-performer'. The lower the

MidD the less variety of musical contexts is possible. Finally, Micro-diversity also has an affect on 'how two performances of the same piece can differ', but here it is more related to expressivity. 'Differences and nuances from one performance to another, from one performer to another.' '*MicD* is indeed essential for turning a musician into a potential virtuoso'. (*ibid*: 707-8). For Jorda the notion of successful performances can either be based on accuracy and similarities or the inclusion of new and challenging details, depending on aesthetic choice.

Although there is much difference between a simple oscillating circuit and recursive activity in a multi-effects processor, electronic feedback instruments generally have a low *MacD* due to a limited control interface and an 'abstract' sonic palette. However, many allow high *MidD* potential, as a vast amount of variation is possible from performance to performance on some instruments. It also scores well in the area of *MicD*. With enough practice and acquired knowledge high degrees of sonic nuances and individual performer approaches can be achieved. When assessing the potential of an electronic feedback instrument it is obvious that non-linearity, control, and predictability are important considerations.

> 'Instruments with a certain randomness or non-linearity cannot be absolutely predictable, making two performances always different. It may seem that as randomness and non-linearity increase, the instrument can become less and less masterable and learnable, but non-linearity should not inhibit the performer from being able to predict the outputs related with small control changes, which seems necessary for the development of a finely tuned skill and expressive control.' 'A balance between randomness and determinism, between linear and non-linear behaviours, needs therefore to be found' (Jorda 2004b: 709).

As mentioned above, the controls on a feedback instrument do not always work in a linear fashion, and should be considered relative rather than absolute. The balance is biased toward non-linearity, and the diversity of input controllers is often limited. This makes an awareness of the relevant dynamical systems behaviour that underpins the resulting sound essential for the performer to develop beyond subservience. This study hopes to demonstrate that, in an appropriate musical setting, electronic feedback can be instrumentalised to a high level of playability and expressivity.

The diversity reading of a musical instrument is equally dependent upon its physical attributes and its corresponding sonic results. Assessing sonic results requires some form of listening strategy.

Listening strategy

Perhaps the most crucial part of this research project is the listening strategy used to analyse the sonifications exhibited in electronic feedback. Consciously acquiring information through aural perception involves 'active listening' (Truax 2001: 11, Oliveros 2005: xxii, Chion 1994: 32). John Young suggests that aural analysis 'for the composer is a process of gaining understanding of the materials that will give rise to the musical 'outcome', and for the musicologist, analysis dissects and contextualises the final musical 'fact'' (Young, J. 2004: 8). A third type of aural analysis is needed in the context of this methodology, which forms a core component in the notion of instrumentalising. It is a real-time analysis method, informing performer responses to emerging sonic information.

Real-time listening attention for the performer shifts focus between the three levels of interiority, causal bonding, and technological interpretations. Although it is not the intention here to analyse a fixed compositional work, existing methods used in acousmatic music offer a number of established notions and terminology for discussing each of these listening focuses.

Interiority focus

This listening focus is essentially addressing the 'typo-morphology' of a sonic event, or 'sound object', as proposed within Pierre Schaeffer's 'reduced listening' technique (Schaeffer 1998: 53). It involves identifying, typologically classifying, and also describing the temporal morphology, of isolated sound objects (*ibid*). Bruno Bossis suggests that in using reduced listening 'the context is forgotten and a phenomenological reduction such as the analysis of the physical signal is carried out' (Bossis 2004: 92). He goes on to suggest that 'such a step is endogenous', indicating that no apparent external cause is considered (*ibid*). Denis Smalley's 'Spectromorphological' analysis method, which incorporates adaptations and developments on Schaeffer's original 1966 *Traité des objects musicaux*, restates the importance of reduced listening when using aural perception as a form of sound analysis. 'In adopting a spectromorphological approach we should use reduced listening as the main investigative strategy' (Smalley 1986: 64).

Rodolfo Caesar suggests that the endogenous process of reduced listening reveals a sonic event's 'interiority' (Caesar 1992: 52). Attention to a sound's interior will focus on qualities such as mass, grain, spectral content etc., rather than its relationship to the 'exterior' world, such as physical cause or musical meaning. The ability to achieve such an interiority listening focus in this study involves a feedback instrument to be initiated into sounding unaffected by performer intent. For example, experimental parameter adjustments that lead to changes in the sound heard can be detached from aesthetic decisions and prior knowledge. This objective process enables real-time descriptive classifications of emerging sounds, thus informing the performer of the potential scope of sonic palette available in a particular instrument. The resulting knowledge can be used when making future musical decisions during performance. It also enables a degree of cross referencing against commonly recurring sonic traits described by existing artists, as discussed in the previous chapter.

However, Caesar's interiority, Schaeffer's typo-morphological classification, and the general notion of reduced listening, have a limited use beyond an initial analysis in this methodology's listening strategy. The reduced listening method was devised for working with what Bossis terms a 'sound trace' (Bossis 2004: 92). That is, sonic material captured as a recording that can be repeatedly played back, enabling the assessment of different levels of sonic detail. As has been stated earlier, the analysis in this study is often real-time, and sounds are generally emergent or in constant flux. Additionally, the sonic readings of electronic feedback vary greatly across different equipment, configurations of equipment, and even different instances on the same feedback loop. Attempting to map every sonic possibility is outside the focus of this research. It may even prove a futile activity considering the, often vast, extent of variety and potential from a single instrumentalised sound processor. As the previous chapter's correlation of common sonic traits concluded, it is the 'behaviour' traits of the sound that offers a more fluid knowledge base for the performer, rather than a set of fixed typological classifications.

Source cause identification

In order to fully appreciate the particular palette found in electronic feedback the sonic traits cannot be considered in isolation from the dynamical systems phenomena that cause them. One is the sonification of the other. Schaeffer's reduced listening methodology advises the dislocation of sound and cause, but a recognition of the limitations in adopting this reductionist approach have been discussed by many in the field (Chion 1994: 30, Windsor 1994: 86 etc.). Emmerson offers a simple footnote: 'The idealised notions of *ecoute reduite* [reduced listening] and *object sonore* [the sound object] have given way to a more liberal approach to including the sound origins' (Emmerson 2000: 213). Chion suggests that 'a seasoned auditor can exercise causal listening and reduced listening in tandem, especially when the two are correlated' (Chion 1994: 32/3).

Smalley's spectromorphology embraces perceived interpretations of both intrinsic and extrinsic connections to sounds heard (Smalley 1986, 1994, 1997). To aid the discussion of possible extrinsic influences on sounds and their behaviour he uses the notion of 'source bonding'. 'Source bonding is extrinsic – it refers to sounding experiences outside the work' (Smalley 1994: 37). Smalley adds a further interpretive layer by stating that 'extrinsic links also involve a wide range of real and imagined non-sounding phenomena' (*ibid*). Reading source bonded causal relationships when working with emergent electronic feedback sonorities greatly aids performer actions and responses. The sounds heard are the result of unseen activities of electrical and digital circuitry, so the initial extrinsic connections rely on 'it sounds like' type approximations (Smalley 1997: 110). As an understanding of the behavioural phenomena found in dynamical systems develops these connections move to more literal 'it is' type bondings.

As with any empirical interpretation, causal listening can be reduced to a purely speculative activity. Chion points out that 'we must take care not to over estimate the accuracy and potential of causal listening, its capacity to furnish sure, precise data purely on the basis of analysing sound. In reality, causal listening is not only the most common but also the most easily influenced and deceptive mode of listening' (Chion 1994: 26). There may be a point at which the aural analysis of causes behind a feedback circuit's sonic activity may simply become what Smalley calls 'bonding play' (Smalley 1997: 110).

Technological listening

The initial interiority listening focus is used simply to describe what is heard. A secondary focus is concerned with causality mapped to perceived dynamical systems phenomena, regardless of any particular medium or technology. This third and final listening strategy has a technological focus. As a performer demands more responsive shaping of an instrument's feedback behaviour it becomes necessary to track the relationship between parameter adjustments and resulting sonic activity. Within the scope of spectromorphology Smalley warns against a listening focus that he terms 'technological listening'.

> 'Technological listening occurs when a listener 'perceives' the technology or technique behind the music rather than the music itself, perhaps to such an extent that the true musical meaning is blocked' (Smalley 1997: 109).

However, as the aim in this methodology is to design a listening strategy that can assess and map the palette and playability of an electronic feedback instrument a technological listening approach becomes very useful.

Interpretations of sonic results need to consider the instrumentalised system's processing parameters. Some of these will be generic, such as gain and equalisation, but many will be specific to that piece of audio processing equipment. A processor that is in self-oscillation will incorporate a high percentage of sonic coloration and behaviour that are artefacts of its own processing routines. After all, the processor is recursively, and often exclusively, processing itself. Being able to differentiate dynamical phenomena from the local processor's own artefacts will give the performer more detailed control options. Changes in sonic activity can be aurally mapped against manipulations of the equipment's available parameters. Parameter movements may also be repeated to assess the potential of re-accessing or repeating fruitful sonic results.

An extension to this use of technological listening can be found in Barry Truax's notion of 'analytical-listening'. In particular, his more focused use of the technique, which includes editing within sound synthesis. 'Because one has precise control over each [. . .] parameter during synthesis, each change one makes must be evaluated by listening analytically to the result in order to effect further changes'. 'It involves the designer in an interactive process where each change in a knob or other setting leads to a corresponding change in sound' (Truax 2001: 168). On a basic level there are many parallels between electronic feedback instruments and the principles of sound synthesis. Both generate or originate sound, and both have editable parameters to manipulate their sound. However, as stated in the playability section, the parameter adjustments in a dynamical system will be relative rather than absolute.

These aural focuses form this methodology's listening strategy. The interiority focus assesses potential sonic palette, and a source cause identification maps it to dynamical systems traits. The technological listening distinguishes between the sonifications of a dynamical system and the self-oscillating equipment's inherent processing artefacts. The following section looks at an incremental approach to performing, and leads to a more holistic appreciation of instrumentalising that combines the listening strategy, the instrument's physicality, its playability, and a performance approach.

Performance approach

Performance within this methodology actively seeks to develop knowledge about, and a relationship with, instrumentalised audio technology. It combines physical playability, a mapping of potential sonic palette, and an awareness of the connections between the two. In this section I would like to propose several philosophical approaches to performance that support and correspond with the development of this knowledge. Of course, these approaches are by no means indicative of 'musical' decisions.

The terms 'experimental' and 'improvisation' embody complex webs of possible meanings dependent upon aesthetic, historical, and cultural contexts[3]. It is not my intention to reduce the landscape of approaches in live experimental and improvised music to a simple set of oppositions, or to resolve any semantic confusion, but merely to suggest that there are axes of approaches. Within the practice of performer – instrument interaction a broad distinction could be made between experimental and improvisational aesthetics. According to Alvin Lucier experimental performance involves a reduction of self-expression in order to display sonic phenomena, whereas improvisation brings personal choice and preferences into unfolding sounds and structures. 'If you improvise it is your past and your personal preferences and your ideas about what sounds should or can be that you are thinking about' (Lucier 1995: 108). Within Lucier's work this is an important distinction as most of his 'pieces are about physical or acoustical principles' rather than performer statements' (Lucier 1995: 122).

It could also be seen that improvisation occurs across a continuum between 'exploratory' and 'informed' approaches. An exploratory improvisational approach would typically be heuristic (Prevost 1995, 2004), often led by spontaneous unpredictable discoveries of properties in the sonic media used, subsequently developed and exploited during performance by personal choice. For example, Cage's *Improvisation 1 – Child of tree or branches* (1975) involved the use of contact microphones on cacti and plants. Cage states that his 'reason for improvising on them is because the instruments are so unknown that as you explore, say the spines of a cactus, you're not really dealing with your memory or your taste. You're exploring' (Quoted in Holmes 2002: 3).

A more extreme version of this approach can be achieved when the actual objects being performed on are allowed to be in flux. Pentos Fray Bentos' 'unstruments' are 'a form of real-time 'sonic Lego'. The starting point is a 'feedback element' – which could be a simple oscillator or something more complex – to which electronic components are spontaneously added' (Bentos 2002). Similarly, Bowers' 'ad hoc instruments' are constructed during the course of performance through responsive interaction (Bowers et al 2006). 'Next moves' are

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[3] Much discussion highlighting the diversities of improvisation in music can be found in Bailey (1993), Bowers (2002), Jost (1974), Kenny et al (2002), Marley et al (2005), and Pressing (1987), among others.

driven by spontaneous discoveries rather than based on prior knowledge or external processes.

At the other end of the continuum from exploratory is an informed approach that would typically encourage the development of instrument knowledge gained through accumulative improvisations. This is in the form of practiced operational skills, or an awareness of how to access particular timbral nuances available in the object being performed upon. Although the aesthetic merit of some objects is the very fact that they have limited possible palette (Bowers et al 2005), higher degrees of familiarity gained through instrumentalising enable more decisive excitation and sound shaping.

Hugh Davies often details playing instructions, highlighting techniques to extract extended dynamics and sound palette from 'found instruments' such as eggslicers (*Eine kleine eierschniedermusic: eggsliser quartet* 2000-1), toy squeakers (*Squeakbox* 1969), and metal grill trays (*Eargong* 1973) (Davies 2002). Lee Patterson works with the same premise as Davies, clearly describing his process in the following quote:

> 'Often, when a new kind of object is identified as a source of interesting sound, or as a potential instrument, then almost obsessive collecting of similar objects ensues. This is done in order to explore the range of sounds available from any particular type of object'. 'Sound as a material property of objects is uncovered by detailed sonic investigations'. 'As part of the same process, new playing methods are developed' (Patterson 2005: 127-8).

Although there may be less predictability of precise outcomes when working with electronic feedback, Aufermann recognises that 'after some time a player will develop some intuitive understanding of the instrument and will be able to predict roughly how and when the sound will change' (Aufermann 2005: 493). It has been pointed out that 'Tudor's manipulation of gain stages is legendary. His ability to control multiple stages of amplification without the system "taking off" was simply virtuostic' (Adams et al 2001), indicating a developed knowledge base and practiced operational skill. Tudor also reminds us that any distinction between exploratory and informed approaches is not rigid. Gray suggests that 'Tudor's goal was always to control the situation. If ever he fully achieved this goal, he would change the parameters of the whole setup to force himself once again into a new level of complexity. In many ways he enjoyed the hunt as much as the end result' (Gray 2004: 45).

Roger Dean and Hazel Smith add a valuable perspective on performance approaches such as those of Tudor. They suggest delineation between 'pure improvisation' and the preparatory process of 'applied improvisation'. Pure improvisation consists of completely unprogrammed events unfolding in front of an audience. In contrast, applied improvisation does not normally occur in public, and it is a step toward producing a work that will eventually be played to audiences. It is not looking for the 'right' solution, and has a readiness to accept any possible outcomes' (Smith et al 1997: 27). Through the perspective of this model Tudor's actions are consciously seeking purer improvisational situations.

The instrumentalising process can also be exercised as a preparatory activity. Often it is through the use of applied improvisation, sometimes referred to as process improvisation, that initial knowledge is acquired.

> 'Another useful distinction often made in discussion of improvisation is between referent and non-referent work. A referent improvisation is one which is based on pre-arranged structure, procedure, theme or objective which dictates some features of the work' (Smith et al 1997: 29-30).

Much referent material is acquired during the process of mapping the physical and sonic attributes of an electronic feedback instrument, whether this is in pure or applied improvisation settings. Patterson's use of this accumulative knowledge frequently goes beyond developed improvisation techniques to actually becoming compositional strategies (Patterson 2005: 128).

I would suggest that all the previous approaches are needed, along with a corresponding set of learning and listening strategies, in the process of developing knowledge on a newly 'found' instrument. Performers can reside in a particular place on the continuum, but can also seamlessly move along it. This can be in different phases of their work, for different performance situations, during a performance, and even within a single performance gesture. The model is not intended to be restrictive or prescriptive, but is offered here as a way of contextualising my approach of interpreting and understanding an electronic feedback instrument.

Instrumentalising summary

The act of instrumentalising is the central performative methodology in this study. It takes a found piece of audio hardware, and through an act of creative abuse converts it into an instrument. Each instrument requires a learning curve to develop knowledge about the physical interface, the available sonic palette, and the relationship between parameter adjustments and the resulting sound. The sound and sonic behaviour is mapped aurally through a progressive listening strategy. Instrumentalising has three phases or modes that correspond to the experimental, exploratory improvisational, and informed improvisational performance approaches discussed above.

In the experimental phase the performer is a facilitator, allowing the electronic circuitry to display its sonic potential. A feedback loop is achieved by connecting an audio output to an audio input in a chosen piece of audio equipment. If more than one loop configuration is possible then variations are tested. Listening is focused on the interiority of the resulting sonic palette, rather than mapping to any causal or referential source. What does this feedback loop sound like once activated? Sounds heard can be classified and cross-referenced against existing artists' descriptions and recordings, and previous experiments with other equipment.

Exploratory improvisation makes extrinsic bondings to the dynamical systems behaviour being displayed. This phase also begins to engage with the physical interface, and explores the audible affect of adjusting available editing parameters. Although the physical interface may have a diversity limited to a few dials and buttons, their function and affect may be non-linear, and initially unpredictable. To move beyond a sense of unpredictability an appreciation of the phenomena of dynamical systems is necessary. The performer is mapping the relationship between action and the resulting change in sound by influencing the system into new areas of activity, but actions are always relative rather than absolute due to the nature of the dynamical system. Whether this is an applied improvisation, or occurring live in front of an audience, areas and boundaries of possible sound palette are becoming a type of referent, that can be drawn upon in future performances.

An indication of entering an informed improvisation phase would typically be the recognition of a developed referent web of knowledge about the instrument. Playability will have been mastered enough to re-access particular sonic behaviours and, through an appreciation of the dynamical system's cause and any residual processing artefacts, the sound can be decisively shaped by parameter adjustments. Technological and analytical listening enable configuration possibilities to accommodate for internal and external sound shaping (discussed fully in the following chapter), and an ability to identify the nuances of different equipment. It is at this stage that a responsive performance strategy can be fully considered.

Figure 4 displays the three phases as discrete, but as previously stated, the movement between each may be seamless. Related focuses of playability, cause, and the resulting sound are not always uniformly developed. After a number of electronic feedback instruments and configurations have been explored the process becomes more efficient, shifting the performances from being exposed information gathering toward more coherent displays of timbral choices and manipulations.

Performance Approach	Physical Interface Assessment	Listening Strategy	Result
Experimental →	Configuration →	Interiority →	Facilitating sound Sonic classification
Exploratory Improvisation →	Interface Controls →	Causality →	Influencing sound Mapping dynamical phenomena
Informed Improvisation →	Playability Detailed control →	Technological / Analytical →	Shaping sound Nuances of dynamical phenomena and processing artefacts

Figure 4. Stages of the instrumentalising methodology. All stages can be performed as pure or applied improvisation, can create referents, and can be moved between fluidly.

Documenting the research

To enable this study's aim of contributing to performance practice the results and interpretations of real-time aural analyses are supported by audio and visual representation. Subsequent strategies for sound-shaping and interaction during performance are also presented as audio, embedded in performances, and discussed in written documentation. This section defines the relationship between these documentation perspectives, outlining the function of the documented performances and the corresponding written thesis.

Documented performances

Performances focusing exclusively on electronic feedback throughout the research period have been the method of developing and testing theory. Live performances are the contextualised demonstrations of the thesis findings. They range from concert hall, club events, conference presentations, and process or applied improvisations that occur in a more laboratory style environment.

Although my practice includes the roles of collaborator, ensemble leader, and ensemble member, solo performances yield the most rewarding and exposed demonstrations of the sonic activity under discussion. In particular there are four solo performances documented in this thesis, enabling discourse beyond the actual live events. Three of them are from the later research stages, highlighting clear uses of the research findings. The fourth contribution is an extended solo from the first year of registration, and is included both because of its early testing of the 'behaviour' hypothesis, and as a contrast in the degree of sophistication it exhibits.

Each performance is presented as a stereo audio recording, the later three from open microphones, thus including the venue ambience. The earlier piece was recorded straight from the mixing desk output, and is therefore lacking in ambience. The most recent contribution is also presented on DVD as a video recording, although in general the performances are focused on sonic activity rather than performer activity. It is also the case that many performance venues offer very poor lighting conditions and do not invite visual documentation. Accompanying the documented performances is a brief rationale and reflective notes encapsulating the technical configuration, and findings being addressed. There are also annotated diagrams of technical configurations, thus allowing the physicality and intention of the performance to be revisited.

It is not essential to document every exploration or live performance. Often many improvisations are exercised in order to gain an informed understanding of a particular system or configuration. Applied laboratory improvisations occurred in a studio environment, unhindered by durational restraints, making it possible to prepare for concerts by exploring new equipment. This approach often leads to the consolidation of a particular combination of equipment and a related referent strategy for performance. Occasionally the applied improvisations are captured as audio recordings if the sonic activity is deemed to offer a contributory display or perspective of a key trait being tested. However, as the topological mapping of sonic traits has developed less process or preparatory work is needed, leaving new explorations to be the focus of live performances.

Although my intention is to present as neutral a reading as possible of the sonic behaviour of electronic feedback it is perhaps likely that perception, and subsequent presentation, is mediated by my own aesthetic bias or artistic intention. This may be particularly poignant within the context of a study such as this, where both the exploratory process and the presentation are through performance. It is hoped that the findings are distinct enough to enable their use in performance or musicological research of the broadest possible range.

Written thesis

This written thesis is not the analysis of the sonic activity of electronic feedback or of the performance work. The practice-led research developed theory, conceptual models, and approaches to performance that would not have been possible without exploratory practice. As a result, the performances offer a more appropriate way of presenting research findings. However, clear written and diagrammatic explanations of the conceptual sonic behaviour model, and responsive performance strategies, offer valuable insights. The written thesis is also intended to collate existing knowledge, contextualise research findings, and detail the practical methodology used in performance.

Writing about sonic phenomena introduces much potential for misrepresentation and subsequent misinterpretation. Smalley points out that 'the lack of shared terminology is a serious problem confronting electroacoustic music because a description of sound materials and their relationships is a prerequisite for evaluative discussion' (Smalley 1986: 63). Simon Waters also raised this concern when discussing his devising of collaborative cross-discipline work. 'Descriptive terminology (based on perceived physical properties) was confusing. [...] Nouns indicating 'material nature', and associated adjectives, seemed to be both more medium specific, and more open to dispute' (Waters 1994: 130).

In contrast to Waters' warnings about the vagueness of verbal descriptions of acousmatic sound Smalley's suggests that however vague qualitative descriptions are 'they have the advantage of an immediate, comprehensible identity', and 'are verbal signs that essential qualities have been recognised' (Smalley 1994: 36).

Waters also suggests that 'strategic terminology (dealing with process) tend[s] to be relatively unproblematic. [...] A language describing dynamic processes or characteristic activities seem[s] to carry within it sufficient vestiges of its origin in social activity to be usefully shareable between disciplines' (*ibid*). In an attempt to safeguard against unnecessary misinterpretation the findings and discussion of this study primarily focus on the sonifications of technological process and phenomena, rather than the subjective nature of individual sounds. It also uses elements of, now established, terminology found in acousmatic music analysis. However, occasionally it seems important to introduce new descriptive terms to summarise the interplay between underlying popular scientific phenomena and signal processing principles. 'In music we often need words which are invented specially for defining sonic phenomena' (Smalley 1997: 107).

Audio extracts

A CD of short audio extracts accompanies the findings chapter, exemplifying sonic activity under discussion. As the chapter develops from causal phenomena through the performative strategies, several examples of key sonic attribute are offered, thus highlighting their topological nature. The extracts are taken from the four documented performances or captured laboratory or process recordings when further clarity, away from performance activity or polyphony, is needed. Audio tracks are number indexed and in general are very short, typically about five seconds, but vary dependent upon focus. For example, to present a simple onset transient very little audio is needed, whereas a longer extract is required to exemplify a sonic activity in a state of flux.

Visual representations

In combination with audio extracts selected visual representations from sonogram and waveform data are of benefit when discussing sonic characteristics of single events and general behaviour tendencies[4]. The ability to 'freeze' and magnify specific sounds aids documentation and comparison, and can offer a confirmation of the auditory process, helping to focus the reader on specific elements or qualities. The choice between sonogram or waveform data, and the level of visual magnification, is guided by the sonic quality being focused upon.

A sonogram image (also referred to as a spectrogram) presents frequency over time with the added dimension of amplitude, displayed in the intensity of grey-scale shading. Robert Cogan's extensive study of the sonogram suggests that,

> 'in hearing music we seem to perceive its sound, its tone colors, and its textures immediately and directly. At the same time, these qualities have been especially difficult to understand. Now, by means of spectrum photos, we find the constituent sonic details laid out with an impact that is almost as immediate and direct as the sounds they picture' (Cogan 1984: 3).

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[4] Sonogram images are created in Audacity 1.2.3, a freeware application coordinated by SourceForge.net, and waveform images created in Sound Studio 2.1, a freeware application from Felt Tip Software.

Rosemary Jellis' 1977 study of bird sounds describes an earlier era of sound-spectrogram which repeatedly scanned a section of audio-tape to assess the frequencies present. She suggests that, after learning how to read such an image 'it is possible to 'auralize' an unknown sound, at least to the extent of knowing what type of sound it is' (Jellis 1977: 38). The particular areas that a sonogram can visualise are frequency nodes, formants and harmonicity, spectral range, and temporal intensity. A number of chapters in *Electroacoustic music: analytical perspectives*, edited by Thomas Licata rely heavily on the interpretation of sonogram images. In combination with information as to the technical resources of the composer, they create clear structural production based analysis of acousmatic works (Licata 2002).

In this study images of micro and macro scale perspective, with varying frequency spans, are used. For example, micro level views have enabled insights into spectral activities during fast transitional activity, whereas more macro framing reveals trends in system attractors and internal repartitions amongst seemingly chaotic behaviour. However, although the sonograms can greatly aid interpretation and discussion, the acknowledgement of a number of flaws in their use need to be pointed out before assuming unrealistic expectations.

> 'Spectrum photos, as revealing as they are, are not ends in themselves: they are invaluable sources of information for further structural judgements and insights' (Cogan 1984: 147).

Smalley offers a more specific reason for the restraint that may need to be exercised in their use. 'There is no objective method of achieving a visual spectromorhpological representation [... due to] subjective decision making and alternate readings' (Smalley 1997: 108). Simon Waters further clarifies this by highlighting the unrealistic assumptions of sonogram offering objective or unmediated readings due to the inherently subjective calibration process (Waters 1994: 131). He also raises several related points.

> 'On a representational level the sonogram [...] suffers from the perceptual inconvenience that a single sound object may exist as several widely separated spectral traces on the paper/screen. The FFT analysis threshold and its conversion to graphic data also render insignificant any phenomena which are more than a certain number of dB below peak level, but again, inconveniently, these phenomena may well be perfectly evident aurally' (ibid).

Waveform data represents dynamic activity over time. Although appearing visually different to sonogram there are a number of similarities in the approach to using data. It too can be viewed in micro and macro timescales, and through familiarity it is possible to analyse and 'auralize' certain attributes of sounds seen. Some of the attributes that are clearly visible in a waveform display at macro resolutions are dynamic envelopes, temporal patterns and rhythmic activity, and both outer morphological shaping and degrees of cross-modulation. In this macro zone Gray presents clear examples of Tudor's use of external control systems on complex sounds (Gray 2004).

McAdams et al consider the possibilities of micro scale waveform display, down to a few milliseconds, showing periodic wave activity, and displaying clear indications of noisy content levels (McAdams et al 2004: 179-83). Many successful uses of this level of microscopic focus can be found in Roads' *Microsound* in the discussion of sonic grain qualities (Roads 2001).

As with the sonogram, one needs to be realistic as to the accuracy and neutrality of wave data. Though not particular to this form of visual representation, the practical consideration of computer screen resolutions leading to graphical inaccuracies should be taken into account were precision is needed (McAdams et al 2004: 172).

Summary of methodology

The development of the instrumentalising technique proves a successful practice-led methodology in the exploration of a responsive interaction with electronic feedback. The combination of a conscious performance approach, physical interface assessment, and the threefold listening strategy could also make it a robust performance method beyond the realm of feedback instruments. However, open discourse about research findings relies upon creating a meaningful relationship between developments in performance practice and corresponding documentation. Investigations into the underlying research question in this study have benefited greatly from these dual activities. In particular, the use of sonogram and waveform images have enabled appreciations of the nature of electronic feedback, and a recognition of recurring sonic activity, across concerts from very different contexts and stages in the research period. The following chapter begins by presenting the research findings from the instrumentalising methodology. These findings are subsequently used to create a conceptual model of inherent sonic behaviours, and detailed practical techniques enabling their responsive interaction.

Findings

- **The causal phenomena of electronic feedback**
    - Noise Floor
    - Attractors
    - Transitions
    - Host equipment artefacts
    - Phase-Space

- **Conceptual model of sonic behaviour**
    - Nothing
    - Resonance
    - Iteration
    - Saturation
    - Turbulence
    - Virtual feedback
    - Behaviour combinations

- **Responsive performance strategies**
    - Shaping intrinsic behaviours
    - Configuration
    - Excitation
    - Interaction

- **Documented performances**
    - Foldback Sound Festival 4th August 2006
    - Three Perspectives in Audio Feedback 25th March 2006
    - ‘From Iteration 2003’ Resfest 17th October 2003
    - ‘From Iteration 2007’ RAM symposium 19th May 2007

The research outcomes are addressed over four cumulative sections, which discuss the cause, sonic palette, manipulations, and contextual use of electronic feedback. The first section suggests that the causes behind the key sonic features of electronic feedback systems can be explained through a combination of audio processing principles and dynamical systems phenomena. Although revealed through performance practice over the research period, these findings are verified by recapping the commonly cited features and existing research collated in the contextualising chapter. Section two takes the knowledge of causal phenomena and creates a conceptual model, designed as an aid to performance. The model proposes five key topological states or sonic behaviours, identified by their sonic signatures. The behaviours often exhibit spectral or morphological colourations, resulting both from combinations of states and the artefacts of the equipment or processor used to create the recursive loop.

The third section offers practical performance strategies that are responsive to the behaviour model. It describes technical configurations, excitation methods, and sound shaping approaches that can access, interact with, and shape the intrinsic sound of electronic feedback. In the final section performances that embody the sonic behaviour model and the responsive performance strategies are documented, relating the research directly back to performance practice. Four solo performances of varying lengths are discussed from a technical and aesthetic rationale. Each offers different perspectives on the research findings.

The causal phenomena of electronic feedback

This first section presents causal explanations for recurring traits found in electronic feedback instruments. Findings in this study have been achieved through performance practice, and in particular the listening strategies of the instrumentalising methodology. A number of readings offer more of a confirmation of existing notions than a major progression of knowledge. Many artists working with electronic feedback have proposed notions about its attributes through metaphor, analogy, or technological explanation, as documented in the contextualising chapter. Collating these existing notions has acted as a useful form of verification. In particular Aufermann's interpretation of 'internal time' (2002a), and Burn's realisation that replicating parameter adjustments enabled sonic results to be revisited (2003a/b), have greatly aided this study.

Interpretations offered here that reference dynamical systems theories do not propose to present scientific data, but are more a way of discussing the perceived nature and phenomena of a system's behaviour. It is not my intention to cite chaos theory as an artistic aesthetic, or a catchall technical umbrella to explain anything that appears to contain unstable attributes. Ian Stewart warns that 'chaos has become a metaphor, but far too often the wrong metaphor' (Quoted in Sardar and Abrams 1999: 169). As mentioned in the contextualising chapter, I am using chaos theory 'as a technique for establishing the existence of a hidden order [and subsequently] a method for controlling a system that at first sight seems uncontrollable' (*ibid*). Like Aufermann et al I am interpreting electronic feedback as exhibiting the sonifications of dynamical systems behaviour by mapping it against qualitative non-scientific texts about chaos theory such as Cohen and Stewart (1995), Gleick (1987), Kelly (1994), Lewin (1993), and Stewart (1990).

All of the resultant behaviour from causal phenomena is topological rather than typological, having key defining features but bound by relative rather than absolute qualities. Each piece of equipment explored has different nuances and boundaries in its sound making potential, but all display the same fundamental traits. It seems apparent that these traits form the basic nature of all electronic feedback, and are therefore the intrinsic traits of feedback instruments.

Noise Floor

The configurations in this study are not created at a circuit design level, but at an audio signal path level. An inherent noise floor can be found in all audio equipment that incorporates electrical or electronic components (CD1:1). After the initial configuration, the presence of noise in the system becomes the first causal phenomena of audio feedback. Audio equipment or component noise, often present after preamplifiers or a parameter that exploits signal gain, will excite a feedback system into oscillation.

Certain software audio environments allow internal recursive audio entirely in the digital domain. However, an entirely digital system has no inherent noise floor, and subsequently needs activating from an external source. 'The software networks must be excited by injection of an impulse, a noise burst, an arbitrary sound recording, or a live microphone input' (Burns and Burtner 2003).

Attractors

The frequency or tuning at which a feedback system oscillates can be explained by the phenomenon of attractors. 'The essence of an attractor is that it is some portion of the phase-space such that any point which starts nearby gets closer and closer' (Stewart 1990: 99).

Phase-space is a notional map of all possible activity within a dynamical system, and is discussed as a separate causal phenomenon below. If we combine the attribute of attractors back to the original definition of electronic feedback earlier in the contextualising chapter the relationship of attractor and resulting frequency becomes clearer. Positive feedback is achieved when the signal fed back is at a gain more than 1.0 and in-phase with the signal at the input. Therefore, 'the circuit will oscillate at the frequency at which the feedback network produces 0° phase shift' (Tooley 2003: 152).

A system has a gravity to oscillate at the most dominant attractor dictated by the point of minimum impedance, which is often the point of least phase distortion between the original and recursive signals. However, additional to perceived frequency, the attractor phenomenon can also affect the stability of oscillation. Attractors have one of three characteristic behaviours according to Cohen et al (1995: 2005), which may or may not be accessible within a single attractor basin. The first two are point attractors, heard as stable oscillation (CD1:2), and periodic or closed-loop oscillation (CD1:3). The third type is a chaotic attractor, and can range in its level of instability from aperiodic activity (CD1:4) through to total collapse (CD1:5).

Transitions

An oscillator will change frequency in relation to whatever the most prominent point of 0° phase shift is. 'A dynamical system can have just one attractor, or several. Dynamical systems can also have adjustable parameters – features that are fixed in any particular instance but can change', or be changed by the user (Cohen and Stewart 1995: 209). Therefore, a feedback system more complex then a simple oscillator may potentially have many combinations of sound shaping parameters that result in new dominant 0° phase shift areas, thus offering the potential of many attractors.

If parameter adjustments force the system to stray too far from the current attractor a critical point will be reached. This can happen through either substantial or seemingly small adjustments, being dependent upon cumulative parameter activity. The system then makes a qualitative change to a new dominant attractor through a process of transition (CD1:6, and sonogram image in figure 5).

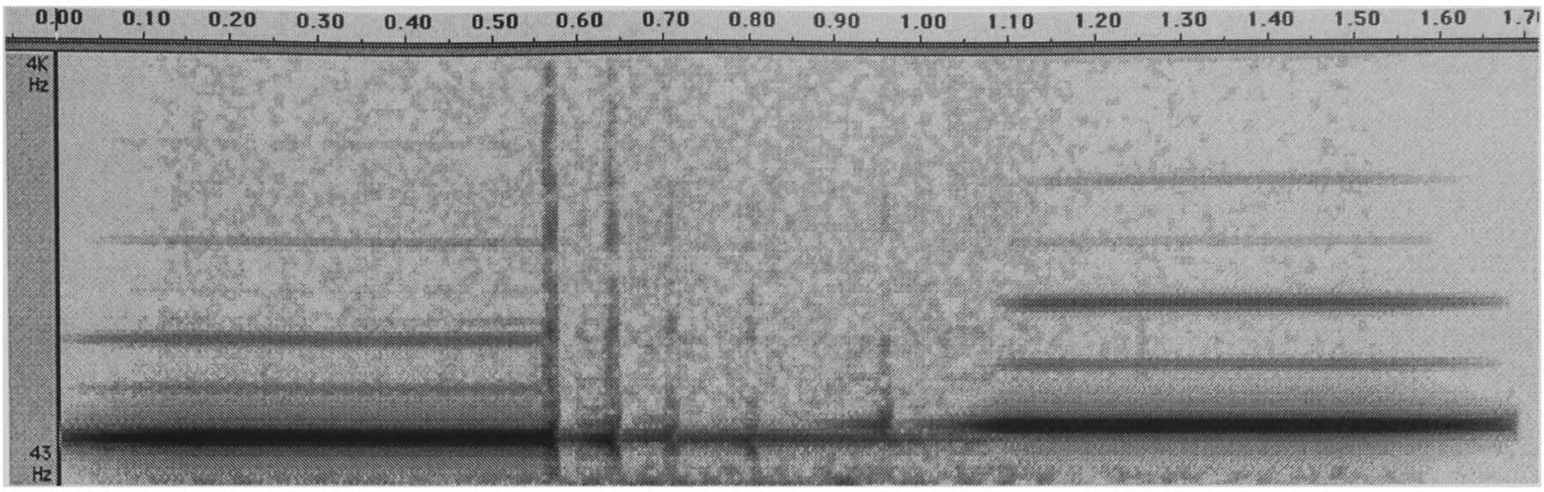


Figure 5. A transition between two attractors.

Host equipment artefacts

Recursively configured off-the-shelf audio technology can be considered a type of 'host' to feedback activity. The intended function and possible limitations of each host, or configuration of hosts, contributes additional artefacts that can greatly affect oscillation activity. Smalley mentions two types of timbre indigenous to all electroacoustic music, that of the loudspeaker and that of sound processors, and proposes that there is a 'processing timbre' (Smalley 1994: 46). 'Synthesis methods and treatment processes often impose their own timbral flavour on musical contexts' (*ibid*).

In the creation of musical instruments from sound processors a high degree of the processor's timbre and nature will be exposed. Effectively the processor is self-processing, and more characteristic host processors will exhibit more complex artefacts. For example, a pitch-shifting effect will destabilise an attractor by attempting to continually shift the oscillator pitch in the direction of its parameter settings (CD1:7). Another example can be found in the use of a 'phaser' guitar pedal in a feedback loop, which will instigate a periodic sweeping of the attractor (CD1:8).

Additional processing timbre may be induced when using audio hardware that incorporates analogue-to-digital / digital-to-analogue converters. Aufermann suggests that the 'sampling rate determines the highest frequency at which a loop can feedback. When ultrasonic frequencies are introduced loop alias frequencies of the otherwise inaudible signals are produced' (Aufermann 2002a: 10). Under normal operating conditions the high frequency filters, set at the Nyquist frequency and not the sample rate, should prevent the introduction of ultrasonic frequencies that can create aliasing artefacts. However, aliasing is sometimes audibly present in such systems during recursive activity, and therefore must either be some form of breach of the converter's filter, or more likely occurring within the DSP's algorithm.

These rogue frequencies become part of the perceived spectral content, and ultimately create or affect attractor behaviour (CD1:9).

Host equipment may also introduce artefacts from slow processing speeds. Aufermann suggests that a processor's internal-time is affected by component values, spatial processing parameters, and digital conversion latency (2002a: 17). A slow reaction time to system changes will have audible affects on the stability of parameter adjustments or transitions. Within a single attractor basin a slow internal time will be heard as an unstable period of transformation when parameters are adjusted, visible in figure 6 (CD1:10).

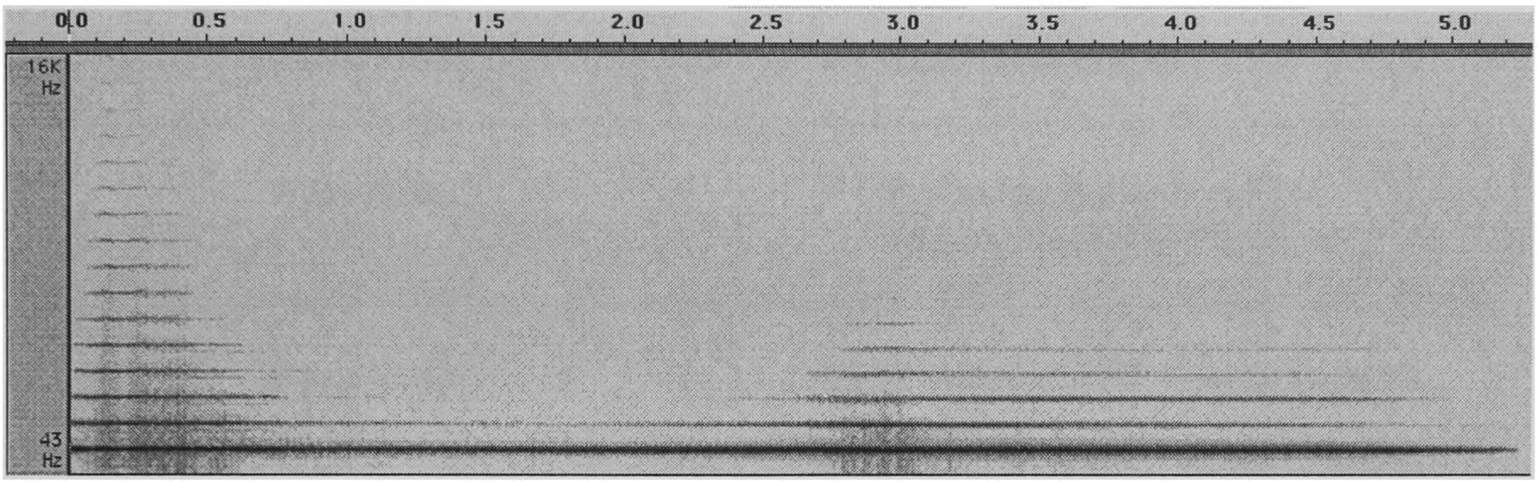


Figure 6. Slow internal time affecting the response rate of parameter adjustments.

Change from transitions will also happen through a period of instability in a system with a slow internal time (CD1:11). Note the dominant fundamental resonance and its related high overtone fading in intensity as a higher frequency pairing slowly emerge over eight seconds in figure 7. Additional spectral detail is also clearly evident during the actual transition.

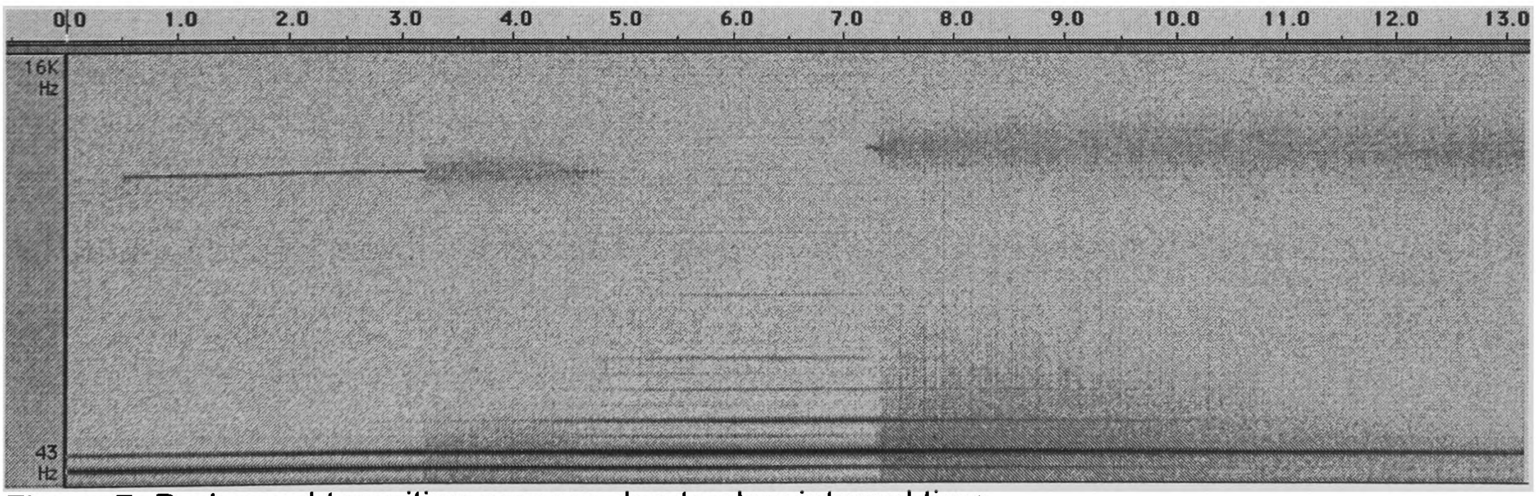


Figure 7. Prolonged transition process due to slow internal time.

Phase Space

Transitions operate as junctions to either related or unrelated areas, but outcomes will always be within the overall potential of the feedback system. Phase-space is a notional map of a system's range of potential activity. If a system is quantitatively mapped it is possible to revisit known areas (Mayer-Kress *et al* 1993a). Burn's research revealed the possibility of exact replication of sonic activity within a digital audio feedback system, through retracing identical parameter adjustments (2003a: 3). In the domain of analogue audio equipment this level of accuracy is very difficult. However, the general outcome of a transition can be influenced to a known attractor basin, or type of sonic activity, by recreating a combination of parameters. As an example, CD1:12 and CD1:13 display very similar sound activity on the same equipment from performances that are over a year apart.

Noise Floor	• Excites oscillation
Attractors	• Guide oscillation tuning - can be Stable, Periodic, or Chaotic
Transitions	• Qualitative shift to new attractor
Host Equipment	• Add processing timbre / Aliasing • Create internal time – o slow parameter changes o unstable bifurcation
Phase-Space	• Recreation of known attractors

Figure 8. Causal phenomena of electronic feedback's intrinsic traits.

Figure 8 maps out the causal phenomena that create the intrinsic sonic traits of electronic feedback. These readings may appear simplistic when compared to a possible quantitative mapping, but results are intended to aid performance and artistic decisions during improvised performance. When interpreted with a combination of audio processing principles and dynamical systems phenomena it is possible to move beyond notions of unpredictability, and work toward the 'informed improvisation' perspective detailed in the methodology. Recognising the intrinsic sonic traits of electronic feedback has enabled the formation of a performer orientated conceptual model, and a set of performance strategies that are specifically responsive to electronic feedback instruments, presented below.

Conceptual model of sonic behaviour

The representation of sonic behaviour in this section is perhaps the key outcome of the research project. The model is designed as a performance tool, underpinned by an appreciation of the causal phenomena discussed in the previous section. It is intended to enable navigation through emerging sonic material, becoming the basis of the responsive performance strategies proposed in the following section. As with the findings of causal phenomena, the model is not intended for use in scientific analysis. Its aim is to inform the performer, and enable musical decisions.

The model consists of five descriptive sonic behaviours -

- Nothing
- Resonance
- Iteration
- Saturation
- Turbulence

The audible behaviour of an electronic feedback instrument is the sonification of causal phenomena outlined in the previous section. These causes may be very complex in scientific terms, particularly when operating in combination with each other. However, if the resulting sonic activity is interpreted topologically it nearly always falls within the bounds of these particular sonic behaviours. Oscillation happens somewhere along the continuum of resonance to iteration, and is often combined with saturation, turbulence, or both. The sonic artefacts of host processors may also come into play, creating strong interiority details, but the overall sound heard may still be described within the model.

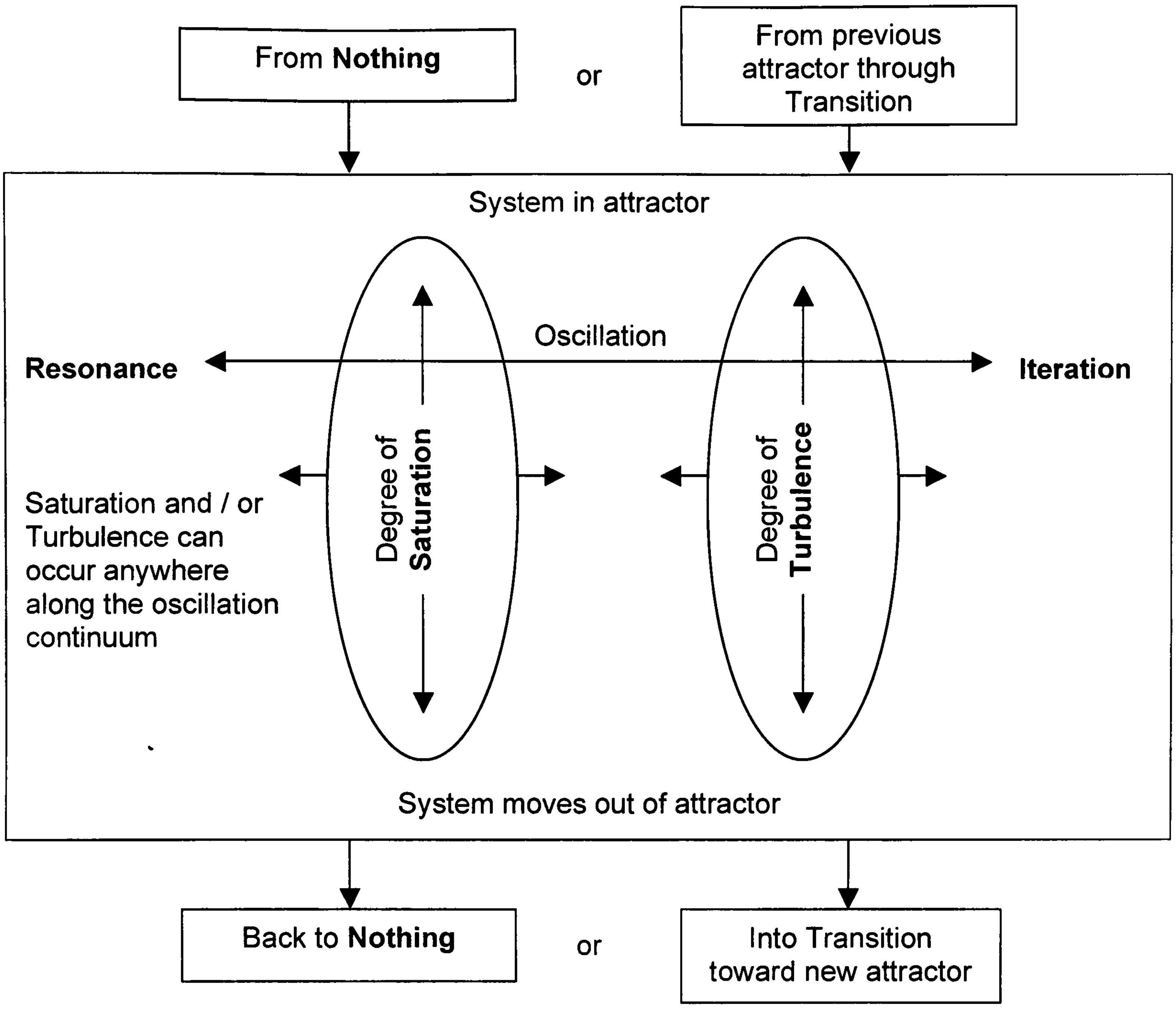


Figure 9. Conceptual model of sonic behaviours in electronic feedback instruments.

During performance one creates periods of musical development within the occupancy of a single oscillation area or attractor. Figure 9 indicates that movement into or away from an attractor happens either through transition or inactivity, referred to as 'nothing'. If another basin is accessed the whole model simply translates to the new area of activity. Some of the audio examples of the basic states are displaying exactly the same characteristics as those used in the previous section. This is inevitable, as the model is based on the causal phenomena described above. However, the emphasis of this model is placed on sonic activity heard during performance, rather than a pure causal identification. Having additional audio examples of similar system activity also exemplifies the topological nature of the sonic behaviour.

Nothing

Nothing, or silence, is an important state when developing musical material. In a performance situation it can indicate a dormant feedback loop, or be a threshold leading to oscillation. Methods of breaking this threshold are discussed as 'excitation' in the responsive performance strategies below.

Resonance

The state of oscillation is heard as a possible continuum of activity, bracketed by the behaviours of resonance and iteration. The term resonance is used to describe many sounding objects and phenomena. It can indicate 'sympathetic' resonance in physical objects, architectural acoustics, and the sound-boxes of musical instruments. The notion of an inherent resonance or set of resonant nodes in a physical object is translated here into the oscillating of electrical or electronic systems. Within an electronic feedback instrument resonance is heard at a frequency dictated by the dominant attractor when the system is in an active but stable state. (CD1:14)

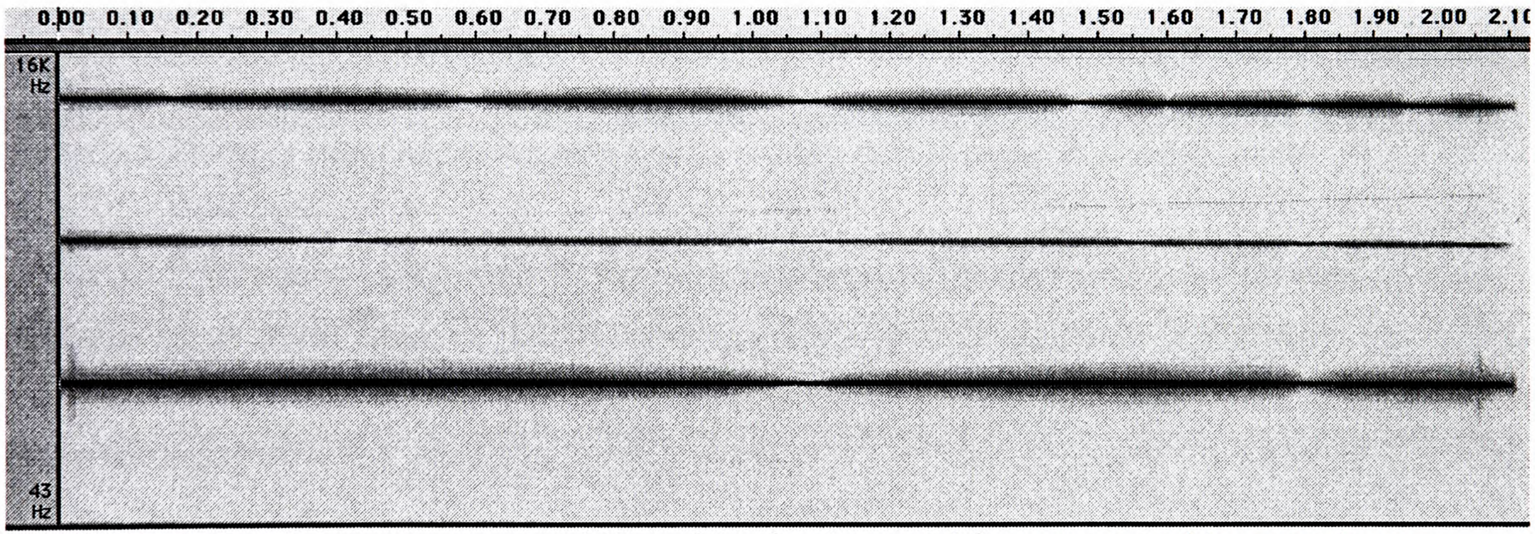


Figure 10. A simple resonance, consisting of the fundamental frequency and two overtones.

Iteration

If the stable oscillation of a point attractor is resonance, broken or fractured oscillation resulting from periodic or chaotic attractors is described as iteration. The word iteration depicts a recursive phenomenon creating the repeated sound. Although any type of system oscillation can be described as iterative, it is only when repetitions are broken or below a certain speed that they can be aurally detected. With electronic feedback it is not about a reading of the performed excitation, as an oscillating system is in a continual state of excitation. This is not the same as Scheaffer's use of the term in the differentiated levels of repeated excitation of sounds, graduating from continuous, through iteration, and on to pulses (Scheaffer 1998/67: 69, and subsequently Wishart 1996/85: 177, and Smalley 1997: 117).

Iterated oscillation will indicate one of three possible phenomena in action. If a steady set of pulses is heard it is likely that the system has a stable point attractor but at a frequency low enough to be perceived as rhythm rather than pitch. A waveform that has pulse or square wave characteristics will result in the audible cyclical or rhythmic activity of DC offset clicks, created as the waveform jumps between positive and negative states. These clicks can range between close grains to widely spaced discrete events depending on the attractor frequency (CD1:15 and figure 11).

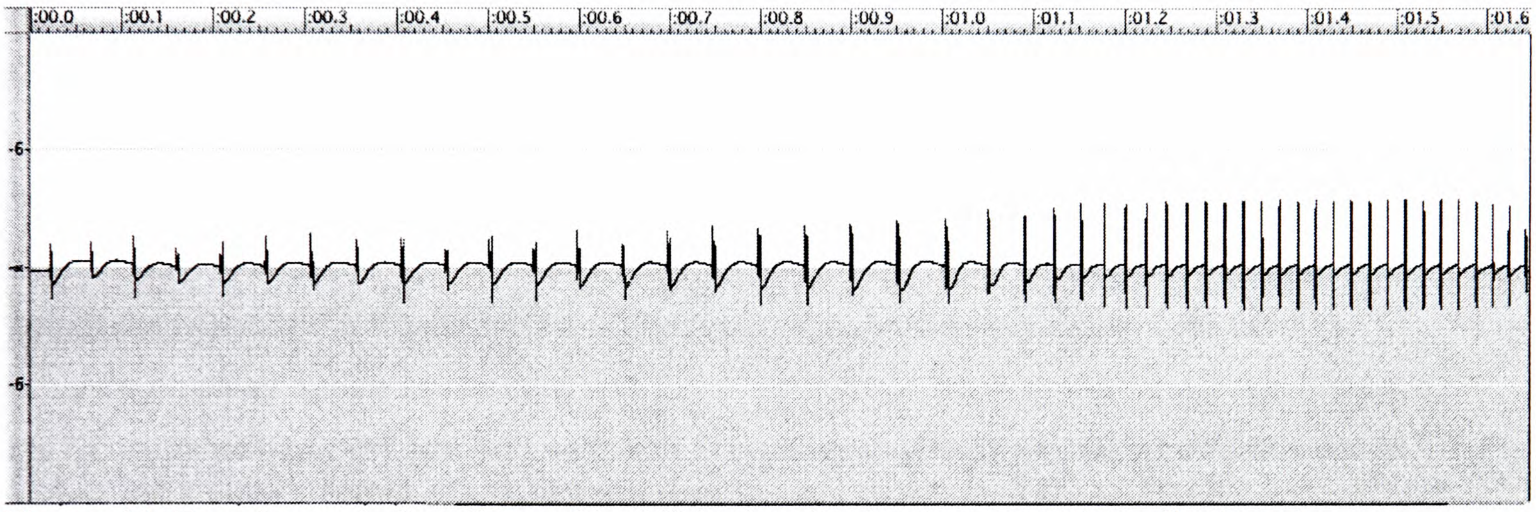


Figure 11. Regular grain iterations with shift in density due to parameter adjustment.

An irregular yet cyclical set of pulses, that may also include fragments of tones or noise, indicates an aperiodic attractor (CD1:16 and figure 12). When completely erratic sonic behaviour is heard the system is most certainly occupying a chaotic attractor (CD1:17 and figure 13).

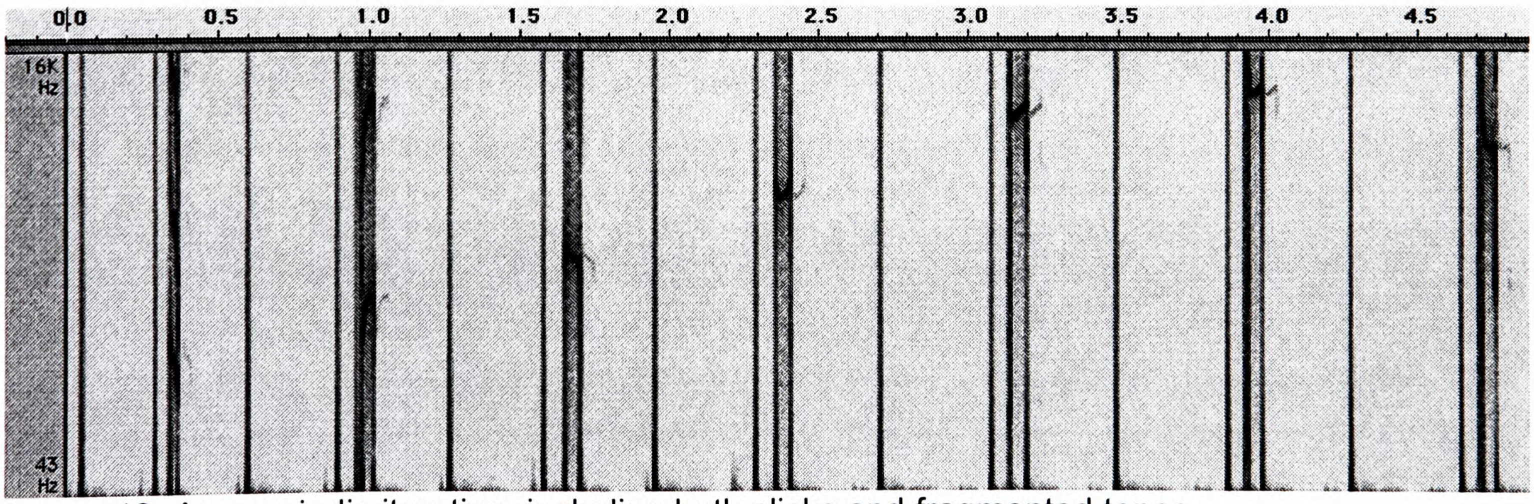


Figure 12. An aperiodic iteration, including both clicks and fragmented tones.

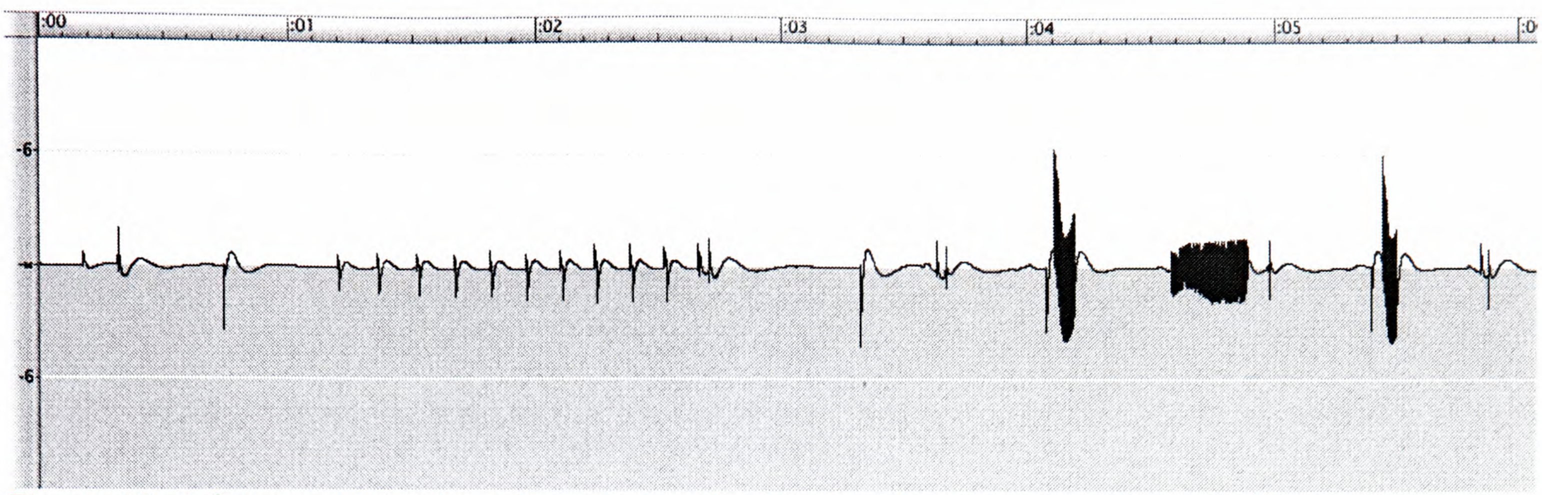


Figure 13. A five second extract from a chaotic attractor displaying erratic shifts between iterative and oscillating behaviour.

Saturation

Saturation is an audiophile and sound engineering principle, and not a phenomenon of dynamical systems. It is also not a behaviour in itself, and could not exist without some form of oscillation, but the artefacts of saturation are a prominent feature of all recursive gain structures. The term is used to describe colouration of timbre exhibited when a signal's amplitude exceeds the head room of a circuit or component within a circuit. Huber et al describe amplifier saturation as 'the result of the input signal being at such a large level that the DC supply output voltage isn't sufficient to produce the required output without severe waveform distortion. This process is known as clipping' (Huber *et al* 1997: 309). They go on to say that the result of a circuit clipping 'is the production of severe odd-order harmonics' (*ibid*). It need only be one component in the feedback loop that is clipping to introduce a form of waveshaping synthesis, where distortion 'produces an alteration in the waveform' (Dodge *et al* 1997: 140).

Low levels of saturation within a feedback instrument can be heard as changes of spectrum or harmonicity (CD1:18 and figure 14). Higher saturation levels may be interpreted somewhere further along the note – node – noise continuum (Smalley 1997: 120). Figure 15 shows complex inharmonicity with no definable overtone structure, induced by a high degree of saturation (CD1:19).

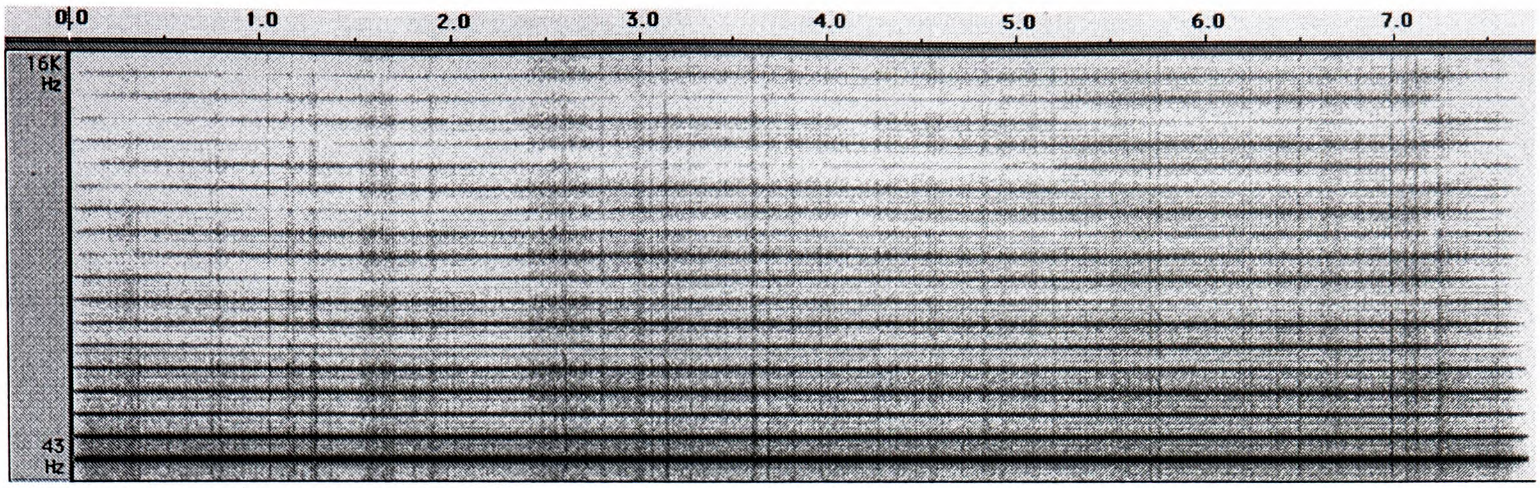


Figure 14. Increased spectrum from low level saturation.

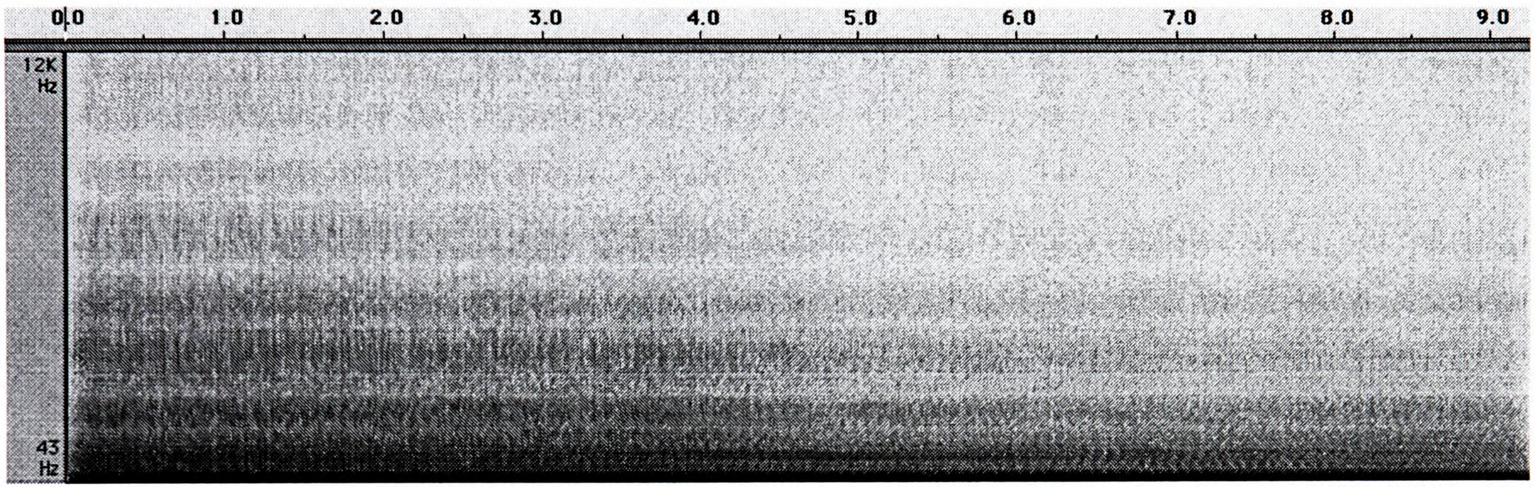


Figure 15. A high degree of saturation resulting in a complex inharmonicity with no definable overtone structure.

Turbulence

The model interprets the causal phenomena of instability as having the sonic signature of turbulence. It is a term most commonly associated with fluid dynamics, describing the complexity of a post laminar state involving the influence of multiple flows (Stewart 1990: 158). Within the behaviour of an electronic feedback instrument it is used to describe degrees of unstable activity from interference and cross modulation. As with saturation, turbulence can only be present when there is oscillation.

Degrees of turbulence are considered a morphological colouration, ranging from simple undulations to complex resultant rhythmic activity. A chaotic attractor can be interpreted as turbulent, as can the affect of a slow internal time on parameter adjustments or the bifurcation process, all discussed previously. More subtle levels of turbulence are perceived when parameter adjustments within one attractor basin have led to the emergence of another attractor that begins to influence the first. In this scenario rhythmic activity is produced by a cross-modulation of the two attractors, and it is often an indication of an approaching transtion (CD1:20 and figure 16).

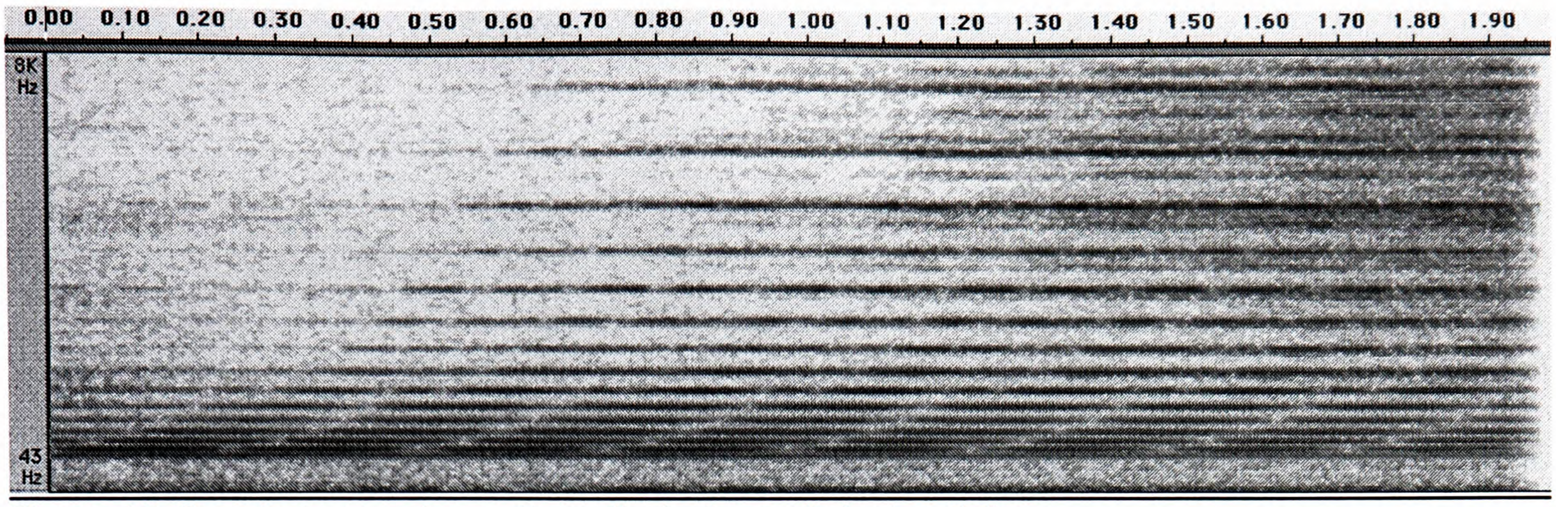


Figure 16. Spectral sweeping pattern displaying turbulent activity.

Virtual feedback

Software studio recording environments and VST sound processors offer virtual versions of the signal processors and audio equipment that have been used in this study. Once excited the sonic behaviour is almost identical to that of comparative analogue electrical, electronic, and hybrid counterparts, and consistent with the sonic behaviour model. This is demonstrated by examples of resonance (CD1:21), a chaotic attractor (CD1:22), and a series of transitions (CD1:23). Spectral and morphological colourations are also the same, but there can be a bias on harsher harmonics due to digital distortion, and the possibility of DSP aliasing. Also, the internal time of a digital audio feedback may be extended by computer processing latency.

Behaviour combinations

Spectral and temporal characteristics can be affected across the entire range of an oscillation by either saturation or turbulence, or both. CD1:24 and CD1:25 exemplify two possible behaviour combinations. The first is a saturated iteration, revealed by figure 17 to contain dense spectrum rhythmic activity. A waveform image of the second combination demonstrates a periodic modulation of turbulent oscillation (figure 18). Notice how the outer morphology almost identically repeats its temporal shaping.

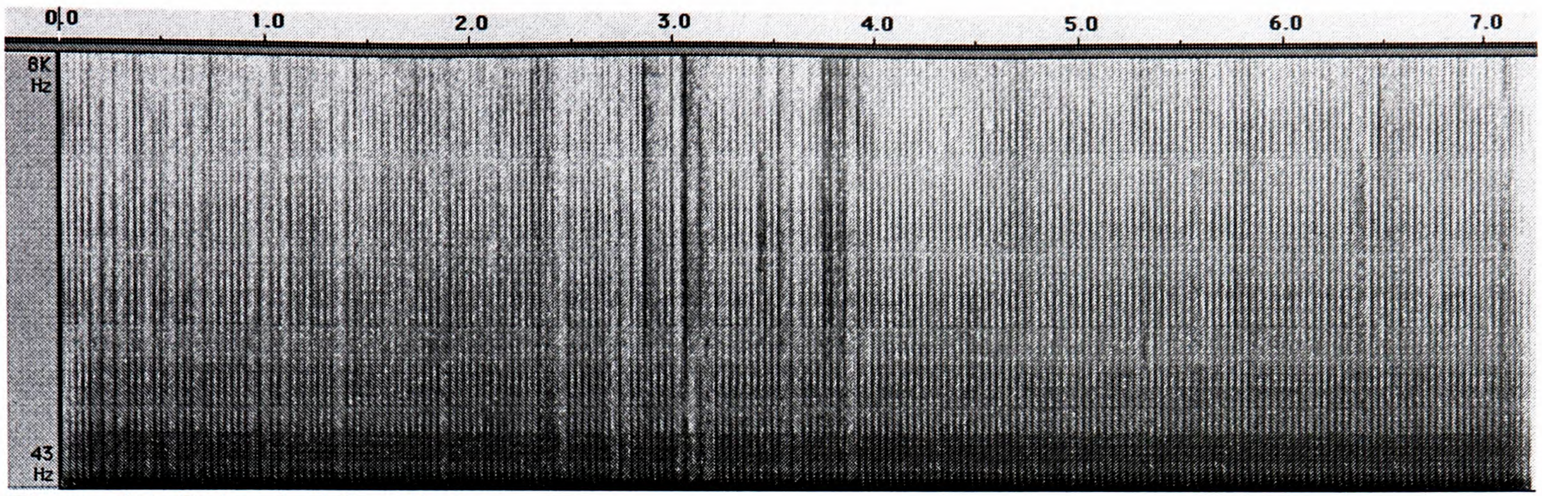


Figure 17. Saturated iteration.

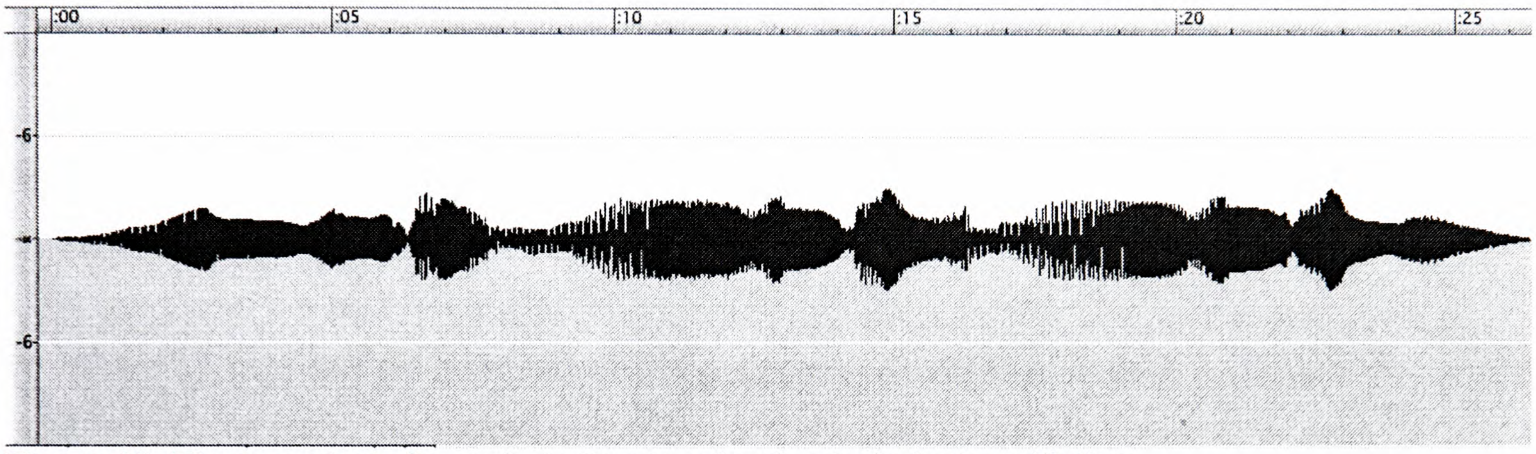


Figure 18. Three cycles of a period attractor shaping turbulent oscillation.

To summarise this section, the perception of sounds intrinsic to electronic feedback has enabled the design of a conceptual performer orientated tool that maps sonic behaviours in a topological model. The model is presented from the perspective of sonic activity heard, with an underpinning rationale that recognises causal dynamical system traits. The five behaviour states of nothing, resonance, iteration, saturation, and turbulence can be used to interpret the wide and fluid sonic palette of electronic feedback. It can also accommodate the spectral and morphological colouration that arises from combined behaviour states and artefacts induced by the host processor.

Responsive performance strategies

An appreciation of the causal phenomena behind electronic feedback led to the design of a conceptual model that maps the sonic behaviour available to the performer. This line of development can now move on to a set of performance strategies that are responsive to intrinsic sonic behaviours and their cause. The strategies are a practical method for sound creation and manipulation with electronic feedback.

Responsive performance strategies can occur at the three distinct stages of –

- Configuration
- Excitation
- Interaction

Configuration covers signal path routings in audio equipment, and excitation covers how a system is brought into a state of oscillation. Interaction involves an array of sound-shaping techniques through parameter adjustments. Each of the three stages enable varying degrees of sound-shaping from both inside and outside of the feedback loop.

Shaping intrinsic behaviours

Wishart suggests that 'any sound has an *intrinsic* and an *imposed* morphology', where an intrinsic sonic shape is predetermined by the object making sound, as opposed to external gestural shaping imposed by the performer (Wishart 1996/85: 177). Young extends this notion for use in the analysis of electroacoustic music. He considers an inner morphology to be 'inherent shape characteristics of naturally occurring sound objects', and an outer morphology to include 'the morphological artefacts of signal processing routines' (Young, J. 2004: 7). Although the shaping strategies proposed in this thesis relate to electronic rather than acoustic sound, it has been established that there is an intrinsic set of sonic activity in electronic feedback. This makes it possible for a performer to shape both the inner intrinsic sound and impose independent manipulations creating an outer morphology.

Within live electronics Stan Templaars adds a third tier to the inner and outer morphology notion, creating a continuum of possibility rather than an opposition. He distinguishes between '*internally generated* micro-modulation, which results from the properties of the instrument itself, and *externally generated* micro-modulation, which results from a performer's input' (Chadabe 1997: 242). The two levels of micro-modulation are seen to cause change instant by instant. Additionally one can make global-modulations 'affect aspects of the entire sound, such as pitch and general loudness, and *micro*-modulation' (*ibid*). The combination allows internal complexities that are either intrinsic to the electronics or the result of performer control, and an outer morphology, also controlled by the performer.

I have adapted Templaars' division of three tiers of performer control for use with feedback instruments. The first tier is the internally generated micro-modulation of electronic feedback, and therefore its intrinsic or internal morphology, which is accessed through the act of 'facilitating'. In the second tier performer actions shape the sound from inside the feedback loop, related to Templaars' externally generated micro-modulations, and can be considered an 'influence' on the sound. The final tier uses Wishart's 'imposed' notion as a recognition that the performer is working outside of the loop creating global modulations. This external activity uses timbre and temporal processing that changes the sound's outer morphology. This external activity is likely to contain the traces of signal processing routines, as pointed out above by Young.

Sound-shaping can consciously move between the levels of facilitate, influence, and impose, but perhaps with feedback it ultimately becomes about an instability-to-control ratio (figure 19). The bias of the ratio is often an aesthetic decision, with levels of control realised through careful manipulation of internal or external parameters.

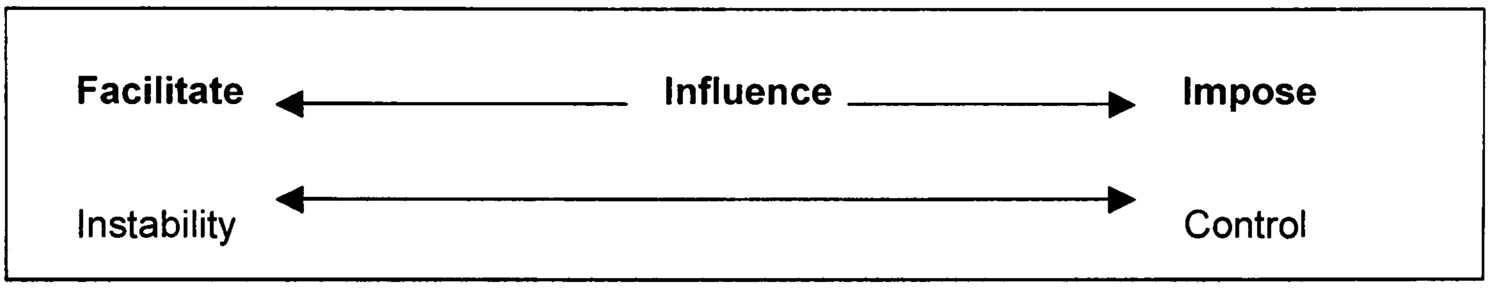


Figure 19. Three levels of shaping intrinsic behaviours.

These levels of sound-shaping reflect the practice-led methodology of instrumentalising, becoming the cumulative result of the performance approach, physical interface assessment, and listening strategy shown in figure 4. They are also responsive to the notion of revisiting known sonic areas, making it possible to devise referent material for concert performances. Each stage in the responsive strategies is now discussed, giving practical examples for the degree to which a performer can facilitate, influence, or shape the intrinsic sound of electronic feedback.

Configuration

The configuration stage of the responsive strategies concerns practicalities of how the feedback loop is created. Choices made about connections and routings have a fundamental affect on the sound and scope of a system. It can often be seen as the cause or availability of elements discussed in the sonic behaviour model earlier. In relation to the instability-to-control ratio 'the control over the sound is partly given over to the architecture of the feedback system' (Aufermann 2005: 493). Configuration can therefore be considered an instrument design activity, and ultimately compositional. Burns et al note that in 'working with feedback, much of the composer's control over the musical result is invested in the original design of the recursive system' (Burns *et al* 2003a: 9). Mumma also recognises the implications of bespoke instrument design as creating or coding a compositional strategy for performance by considering himself as a 'designer-composer-performer' when works incorporate electronic feedback (Mumma Quoted in Schrader 1982: 205).

The basic configuration approach used in this study connects audio outputs back to audio inputs. With the insertion of an audio 'Y' connector at the output stage the resulting sound can be externally monitored and projected. An electronic feedback instrument can be created from a single audio unit such as an equaliser, a guitar foot-pedal, or a multi-effects processor. If a number of units are connected in a serial chain the resulting sound reflects the cumulative affect of units in the chain. It is possible to insert additional controllers and colouration devices internal to the feedback loop, such as amplitude control through variable resistors (such as dials, faders, foot-pedals, switches, etc.), and equalisation or filtering units which can affect spectral colouration or the intrinsic resonance of a circuit (figure 20). The use of multiple independent loops during performance allows explorations of polyphony, contrast, and counterpoint between different sonic behaviours.

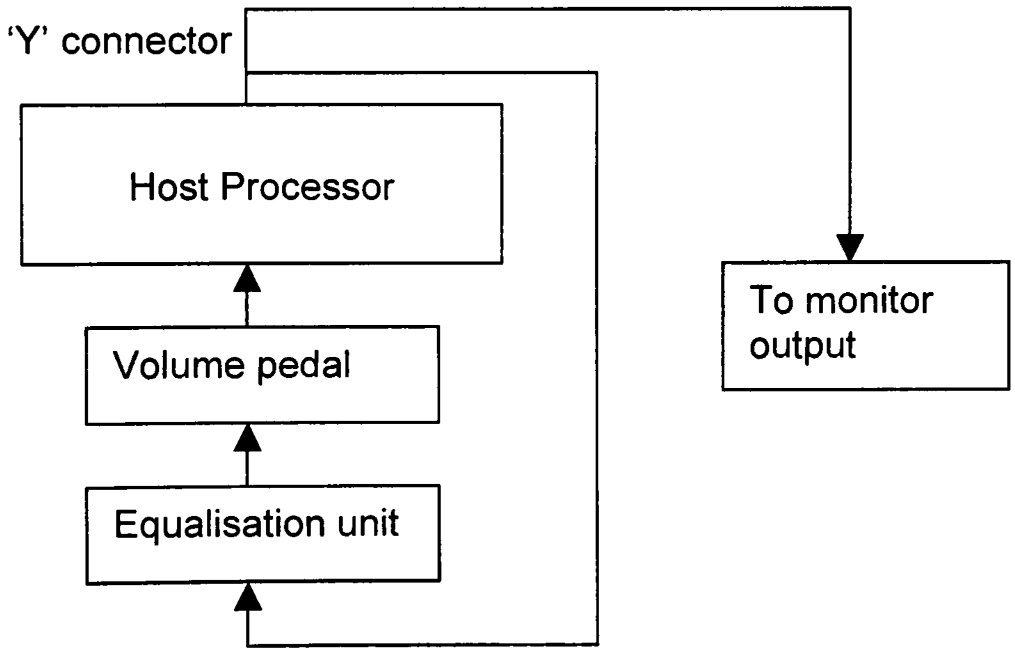


Figure 20. An electronic feedback configuration representing serial connection of a host processor with added internal volume control and equalisation. The duplicate signal outputs are enabled through the use of a 'Y' connector.

It is also possible to create parallel configurations, where the outputs of independent looped circuits are summed together through a 'Y' connector, enabling a complex inter-relationship or cross-modulation. Griffiths describes Stockhausen's technique of 'intermodulation' as 'the causing, by electronic means, of two or more sounds to interfere with each other' (Griffiths

1979: 118). Tudor's work with electronic feedback also explored this principle by using 'mixer matrices to combine relatively simple circuits into networks' creating 'interconnected sound modules with multiple feedback paths' (Collins 2006: 182). The configurations used in this study are not always considered a preparatory activity, as exploring alternative signal path connections with the use of audio cables and 'Y' connectors can be a quick and easy operation during performance.

An instrument or performance configuration can also incorporate temporal and timbre manipulation from outside of the feedback loop, accessing imposed shaping techniques. In particular, the use of volume, equalisation, and spatial processing such as reverb or delay, can all offer extensive control on a feedback loop's final output signal. Imposed amplitude envelopes enable gestural shaping over continuous oscillation. External filtering helps spectral placement when performing with multiple instruments and can also create textural activity in static behaviours. Further external modulation can be achieved when one circuit affects temporal and dynamic shaping on another through the use of a triggered noise gate or an envelope following circuit.

As one gets more complex in configuration design a sounding feedback circuit can be treated as a basic oscillator in a type of modular synthesis, albeit a little 'raw' by commercial synthesiser standards. Figure 21 places a number of key configuration techniques against the continuum of facilitate, influence, and impose, and indicates whether they operate internally or externally to the loop. Technical diagrams of instrumentation used in each documented performance in the next section illustrates many of the configuration possibilities discussed here.

	Internal	**External**
Facilitate	• Gain control	• 'Y' connector (allowing signal monitoring) • Serial connected units
Influence	• Gain control • Equalisation • Spatial processing	• Summed parallel loops
Impose		• Volume control • Equalisation • Spatial processing • Trigger noise gate / Envelope following

Figure 21. Key configuration techniques for sound-shaping.

Excitation

The excitation stage relates to how a feedback instrument is activated during performance. At its most basic this involves facilitating the system by creating the loop, and relying on the inherent noise floor of the circuit to excite resonant activity. This act can involve gain adjustments to allow a circuit to sound immediately or to slowly grow in intensity (CD1:26). The use of switches that can open and close a loop, or instantly shift between internal effects configurations in a multi-effects processor allow fast envelope attacks, limited only by the system's inherent latency (CD1:27). The techniques of using internal gain or switch controls to initiate recursive activity can be considered facilitating or influencing, dependent upon performer intention.

Further onset shaping possibilities can be imposed from the introduction of external signals. If the gain structure of a circuit is set on or near its threshold level of activity a signal input can often initiate oscillation. This can be from the tapping of a microphone or contact microphone, or a triggering sound, routed into the loop circuit (CD1:28). It is also possible to repeatedly excite a circuit that has its gain structure set just below the threshold of recursive activity. When an external sound of the right resonance is introduced into a poised system it can have a strong influence on the oscillation attractor, enabling an imposed tuning (CD1:29). In the earlier discussion of sonic behaviour that is particular to virtual electronic feedback it was pointed out that a purely digital environment has no inherent noise floor to self excite oscillation in a recursive configuration, making the introduction of an external signal or trigger sound a necessity.

	Internal	**External**
Facilitate	Gain control (slow onset) Switch control (fast onset)	
Influence	Gain control (slow onset) Switch control (fast onset)	Resonant input (slow onset)
Impose		Trigger input (fast onset) Multiple triggers

Figure 22. Methods of excitation.

Interaction

Interaction addresses the performance possibilities of responsive control. It is the real-time sound-shaping of intrinsic sonic behaviours, executed by adjusting available parameters. The performer is consciously trying to influence or impose spectrum and morphological development. In the context of these strategies interaction implies that a feedback system's internal state is dependant on performer actions, but can also respond to those actions. Choices at a configuration level are intertwined with this stage, as it is a system's configuration that dictates available parameters, or places additional parameters into the feedback loop. Although the four basic types of excitation mentioned above could also be considered interaction in their ability to shape sound they are kept separate to maintain the clarity of these stages.

Parameter adjustments can be discrete or continuous where discrete adjustments offer immediate change (through switches and buttons) and continuous controls give gradual change (with dials, faders, etc.) (Pressing 1990: 14). However, within a dynamical system continuous change can also lead to sudden qualitative shifts. When shaping resonance the adjustments are primarily about spectral play, whereas with iterating behaviours one is shaping both morphological and spectral elements. Manipulations that aid the approach or occupancy of transition, or explore slow internal times, will interact with degrees of system turbulence. Certain parameter combinations can also push a system into its unstable 'edge boundaries' (Cascone quoted in Nevile 2001).

Techniques of influencing sonic behaviour internal to the feedback loop begin with manipulations of system gain. Any volume control within a dynamical system does not simply operate as an amplitude control. Informed adjustments can initiate spectral or morphological colourations, such as harmonic content through degrees of saturation or signal clipping, tuning the attractor, and pushing the system into another attractor basin through transition (see CD1: 18, 6, and 11). One can attempt to occupy the node or critical point, suspending the transition process by denying a dominant attractor and introducing turbulent activity (CD1:30). In many types of audio equipment lower gain levels tend to produce purer and higher frequency resonances. Extreme levels of recursive gain will result in high noise content and often an eventual chaotic attractor state (see CD1:19)

The manipulation of filtering or equalisation parameters, whether part of the host processor or configured into the feedback loop, can also be key to influencing sound-shaping. As with gain, it can lead to shifts in an attractor's tuning, stability, and type, as there is an inherent gain and phase element to equalisation boosts. An equalisation unit will produce relatively pure tones when a single boost area is set whilst operating without excessive gain (see CD1:14). If a very low frequency area is boosted it may result in a periodic iterating pulse, indicating the cyclical passing of a slow waveform shape (see CD1:3). Multiple areas of frequency boost will add colouration to the most dominant, until one of the additional areas becomes the dominant attractor through transition (CD1:31).

Many audio processors have internal gain controls and some form of filtering potential whose parameter adjustments will possibly mirror the outcomes to those of gain and equalisation mentioned above. If a host processor has spatial effects parameters it will be possible to exploit the artefacts of a slow internal time. This can access turbulent textures or morphologies from the adjustment of relevant parameters and extend the duration of a transition (see CD1:10 and 11). Certain host processor artefacts can also induce chaotic attractor states through the introduction of conflicting or shifting system states related to processor routines (see CD1:7). The use of more specific host parameters may access a wide variety of spectral and morphological shaping. Discussion of all possibilities and their related nuances is beyond the scope of demonstrating the responsive performance strategies.

The final area of the responsive strategies is that of imposing sound-shaping external to the feedback loop. Here the performer is manipulating spectrum and morphology outside of the dynamical system's intrinsic traits. As with internal interactions, the key performer tools are gain, or amplitude, and equalisation. Gestural shaping can be imposed on continuous resonant or iterative oscillations through the use of volume faders, pedals, etc., on the final audio signal (CD1:32). Equalisation can decisively highlight or deny internal timbre details, or place sonic activity anywhere in the frequency spectrum for combining multiple feedback instruments. A more gestural use of filtering or equalisation parameters can add perceived textural morphology (CD1:33). The use of triggered noise gates or envelope following mentioned in the configuration section above has obvious imposed morphological results that can enforce rhythmic qualities or coordinated pulses on a continuous output (CD1:34).

Influenced internally

Technique / Parameter	Result
Gain	Tuning attractor Spectral colouration Transition
High gain	Saturation / waveshaping Noise content Chaotic attractor
Equalisation – single focus	Tuning attractor Transition Period attractor (low frequency attractor)
Equalisation – multiple focus	Harmonic content Transition
Spatial parameters / slow internal time	Unstable parameter adjustments Prolonged / unstable transition
Host artefacts	Chaotic attractor

Imposed externally

Technique / Parameter	Result
Volume control	Gestural shaping Break continuous output
Equalisation	Focus internal timbre details Frequency place system output Texture morphology
Triggered noise gate / envelope following	Break continuous oscillation Rhythmic / pulse morphology

Figure 23. Examples of internal and external techniques for interactions with electronic feedback instruments.

Although the sound-shaping techniques discussed in this section are by no means exhaustive, they do offer a broad range of possibilities. All strategies are affectively interlinked when exercised within a single dynamical system. The following section documents four full concert performances, presenting the responsive performance strategies in the practice context they were devised in, whilst offering a critique and rationale of their use.

Documented performances

This section presents the research findings in the context that they have been developed. Although a number of performances have taken place over the research period only four are documented here. The primary reason for the inclusion of these particular performances above others is that they are solo, thus enabling focused listening on the results of my approach. Having no additional sonic contributions the performances are solely reliant upon the intrinsic palette of electronic feedback and offer clear demonstrations of the behaviour model and a use of the responsive performance strategies outlined above.

Each performance exploits the potential of polyphony by using multiple feedback loops simultaneously, creating complexity, interwoven activity, and contrasts between different behaviour attributes. In particular, the use of a resonant or iterative texture often acts as an affective canopy under which to explore more gestural sound-shaping. A use of contrasting behaviours can also result in independent active voices. These can be accentuated by spectral filtering, internally or externally, and spatial placement, either reverberation or in the stereo field.

Three performances are from the final year of study, whereas the original 'From Iteration' offers an example of earlier hypothesis testing. Its inclusion exemplifies the developments in performance strategies from an aggressive use of imposed spectra and temporal shaping to the more responsive influencing and interactions found in later work. This overall trend has allowed subtler gestures and explorations, and exposed a greater range of nuance in the basic behaviour states and their combinations.

A wide variety of audio equipment has been exploited in performances throughout the study. However, it is apparent from the technical descriptions and diagrams of performance configurations that certain pieces of audio equipment have become key components in my solo practice (listed in appendices p.98). This is due either to their versatility, or the existence of a particular character or behaviour trait.

The Zoom multi-effects processor has a number of very fruitful effects algorithms when self oscillating. The on-board parameter controls initially appear limited to a discrete patch select dial, and only two continuous dials for algorithm specific adjustments (such as spatial decay time or pitch-shift amount). However, the unit's generic parameters for filtering, wet/dry balance, and gain also provide fundamental internal influencing tools for sound-shaping. There is an additional microphone input, which can be used simultaneously with the main input. The connection of a contact microphone allows a number of external excitation possibilities. As can be seen from the configuration diagrams, a volume pedal internal to the Zoom loop, and a graphic equalisation unit on the loop's final signal output have also become regular fixtures.

Equalisation units create immediate tuneable oscillators when configured for internal feedback. As discussed in the performance strategies above, the manipulation of equalisation parameters can influence an attractor's tuning, stability, and type due to their inherent gain and phase based function. Both a three band parametric (labelled Symetrix) and a dual 32 band graphic equalisers have become regularly utilised for performance. The user interface is very reflective of potential sonic activity at lower gain settings, enabling the tuning of frequency specific resonances. The Symetrix parametric equaliser contains a wide spectral span and a vast amount of gain, and can be influenced into the iteration of a very low frequency attractor or saturated chaotic behaviour.

Mixing desks can offer an array of internal routings to create feedback. However, in this study the preference has been for independent looped units whose output is routed through the mixing desk. This enables a high level of external control over final amplitude and equalisation on the input channels, and maintains clear separation between signals. The auxiliary send function is often connected to a basic reverb foot-pedal, which in turn is routed back into a mixing desk channel. This facilitates three types of activity for the reverb unit. Firstly it can be used as intended, and apply spatial processing on signals that are routed through it. Secondly it can be routed back to itself, thus creating another independent feedback loop to add polyphony. Thirdly, the previous two options can be combined, and the final signal from a separate feedback loop can be introduced to the oscillating reverb circuit, creating an affective source of influence or cross-modulation.

The four documented performances are presented below, each giving a diagrammatic overview of the practical configuration, a general rationale behind the performance decisions, and a more detailed focus on salient features that are exemplar of responsive sound-shaping with electronic feedback's intrinsic behaviours. There are no prerecorded sonic materials used during performances, and the instrumentalised configurations offer no facility to capture and represent or resynthesis ongoing sonic material. Each performance is totally reliant upon the emerging activity of electronic feedback loops.

Foldback Sound Festival 4th August 2006

CD2:1. Solo performance, Foldback Sound Festival 2006.

The configuration in this performance consists of three discrete feedback loops as indicated by the dashed line squares in (figure 24). The first loop was based around a Zoom multi effects processor with an additional volume foot-pedal internal to the loop, a contact microphone input, and external equalisation for imposing spectral shaping. The second is a single Symetrix parametric equalisation unit, and the third is a serial linked reverb and graphic equaliser that relies upon the mixing desk's auxiliary send as part of its looped circuit. As mentioned above, the use of the auxiliary send to access the reverb unit's loop opens the possibilty of influence by external signals that are routed through that auxiliary send.

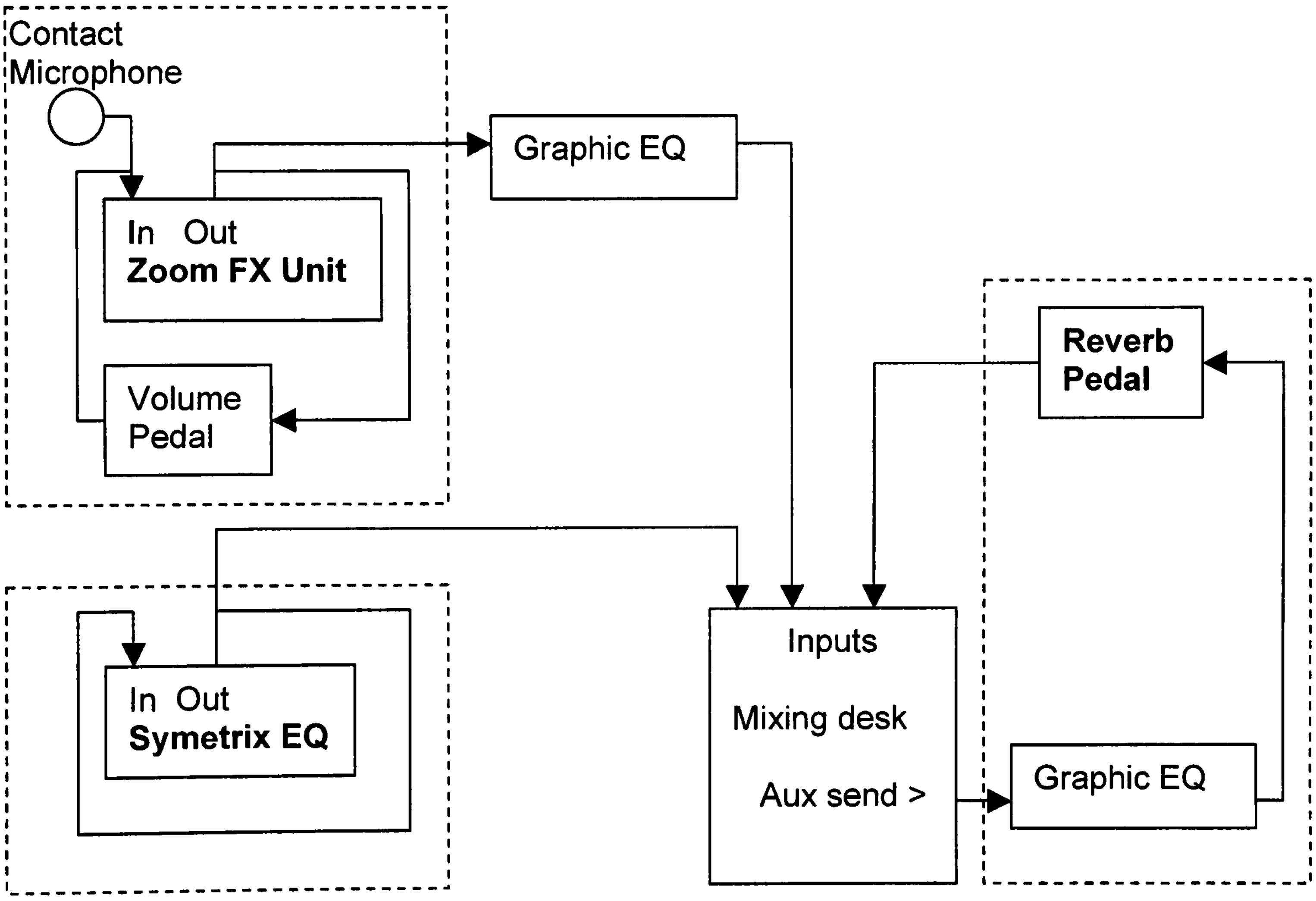


Figure 24. Diagram of electronic feedback configuration for 'Foldback sound festival' 4th August 2006. The dashed lines indicate individual feedback loops.

The overall structure of the performance comprises of five activity areas (see full sonogram in appendices p.94). The opening and closing sections both explore multiple resonances interacting through close tuning and subtle levels of turbulence. The remainder of the piece develops gestural activity, which is accompanied by an iterating period attractor in the central section.

The performance strategy for the opening and closing sections was to demonstrate controlled influence over resonant frequencies or attractors, through a combination of influences. Firstly, a pitch-shifter algorithm in the Zoom loop was being excited by a resonating tuning fork through the contact microphone. The overall gain of the loop was being restrained by the volume foot-pedal in the circuit. This allowed subtle shifts between hearing the tuning fork resonating acoustically, the processed tuning fork, and the processing beginning to resonate through internal feedback. Temporal shaping and resonance complexity were therefore being controlled by the foot-pedal. Incremental shifts in the pitch shift parameter could also be made, resulting in 'cascading' the frequency attractor.

The Reverb loop was set just below the threshold of resonance, so that when an internal Graphic Equaliser frequency was boasted it would initiate and dictate the attractor frequency. The system would also resonate sympathetically with incoming external signals through the auxiliary send, such as from the Zoom. The independent Symetrix parametric equaliser could also be finely tuned to resonate at a fixed frequency depending on the equalisation settings, and could also be sent into the Reverb loop. Between 0:00 and 1:30 the performance explores the interplay between these three tuned feedback loops.

Additional to the resonance onsets and frequency, three levels of gentle turbulence are being explored. Firstly there is the tuning fork frequency introducing resonance into the system. Its frequency is being matched, but at times this is being gently shifted against the pull of an internal frequency node in the Zoom, or the pitch shift is 'jumping' to related frequencies. Secondly, the Reverb, Zoom, and Parametric are being tuned at the same frequency, or very close proximity to each other, causing beating effects. Thirdly the tuning fork can be heard acoustically against the electronic feedback signals from the speakers. Figure 25 shows the first two instances of the tuning fork excitations. As the fork's amplitude reduces the system moves through a very subtle undulation and stabilises to a slightly lower attractor frequency. When the second excitation occurs a more pronounced turbulence is experienced.

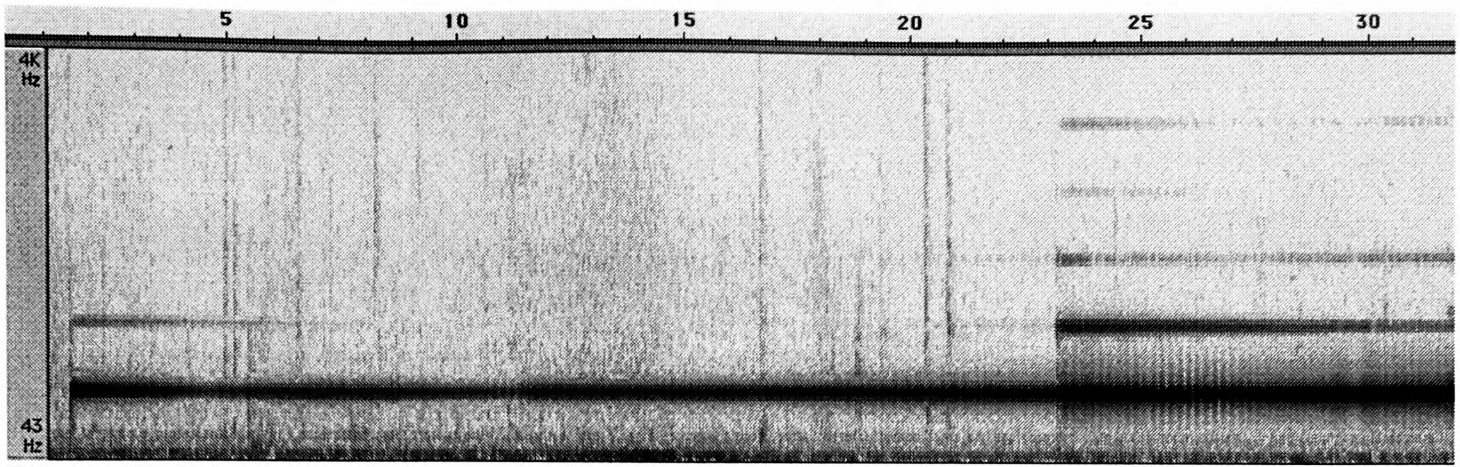


Figure 25. Two tuning fork excitations between 0:00 and 0:32 showing increasing levels of turbulence influenced by beating frequencies.

The performance recapitulates a similar interplay of high frequency resonances between 7:00 and its close at 8:45. At 7:57 an additional strategy for imposing spectural turbulence is used (figure 26). The oscillating signal from the Symentrix parametric equaliser is taken from the main speaker system and routed to a small powered speaker. A combination of physically shaking the small speaker or waving a cupped hand in front of it allow gestured modulations over high frequency signal content.

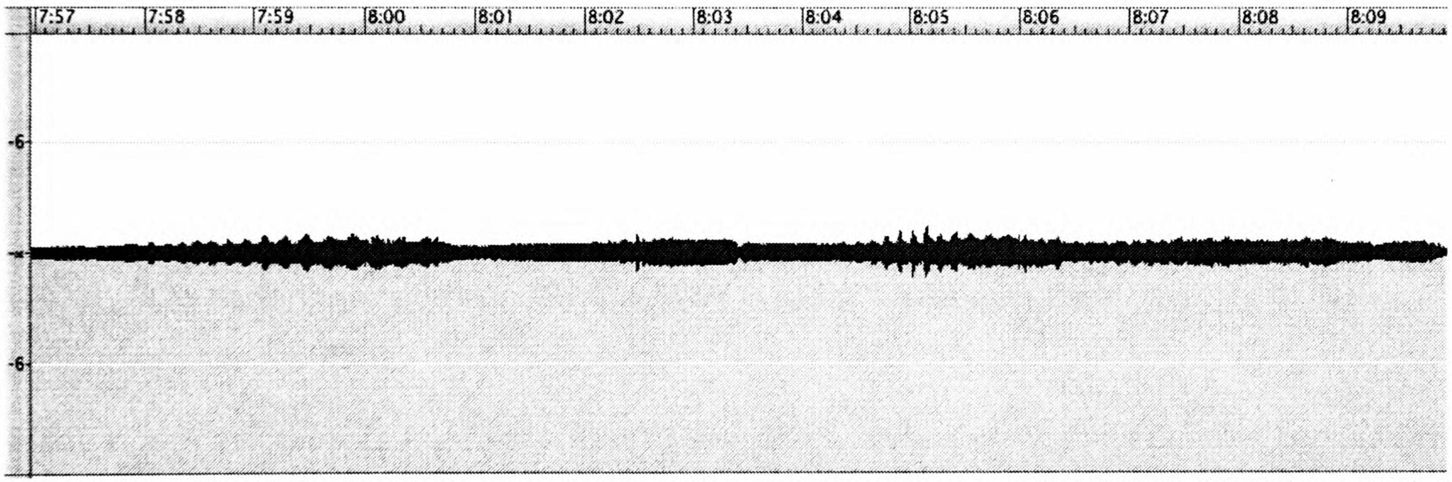
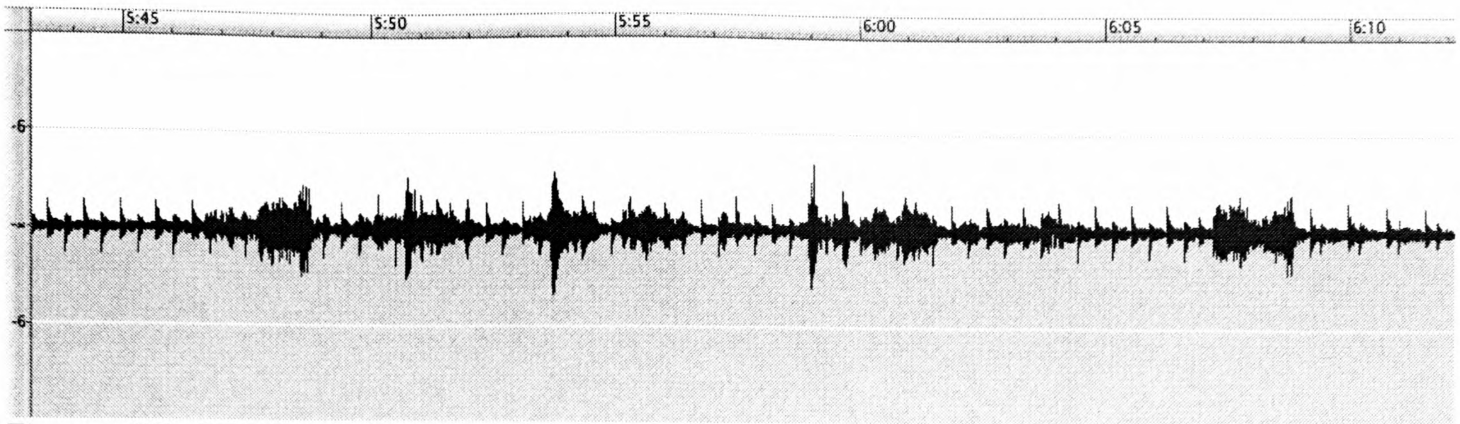
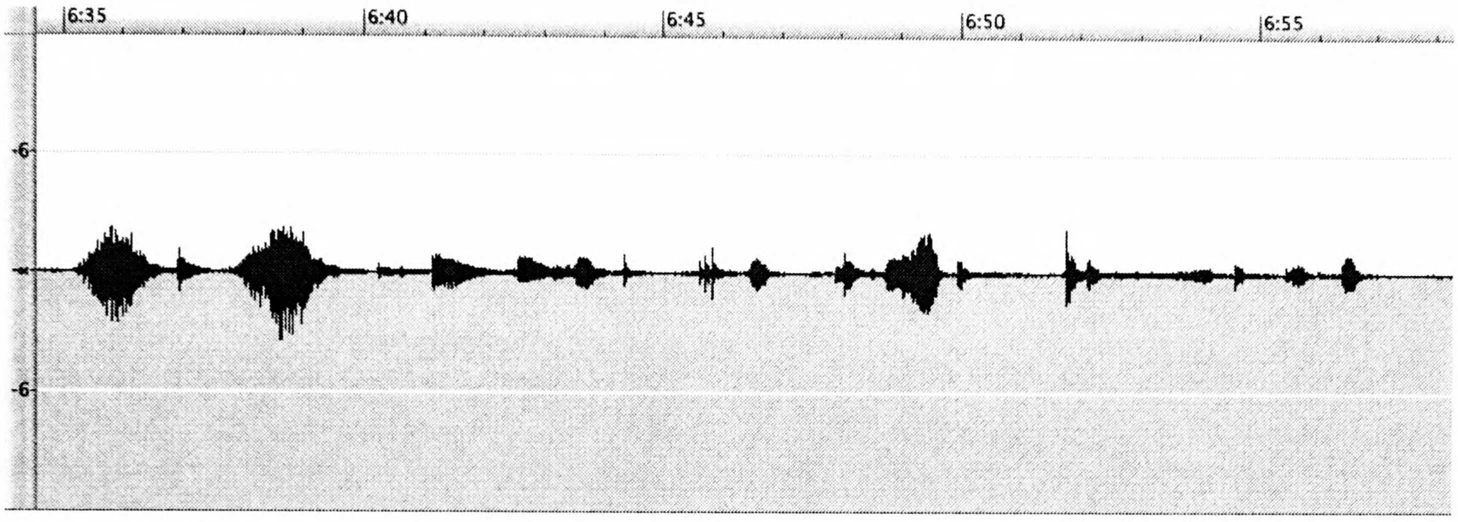


Figure 26. Imposed spectrum modulation with small powered speaker by shaking the speaker or waving a cupped hand in front of it.

The whole centre section is occupied with pronounced gesture activity on a variety of internal and external parameters, influencing or imposing morphological shaping on excited behaviours. A contrast and shift of polyphony is achieved by creating a texture bed of iteration from the Symetrix by saturating a very low frequency attractor, resulting in a period attractor. The wave data images below show an extract of underlying iteration with gesture shapes created by internal volume manipulation (5:45 – 6:10, figure 26), and isolated gestures created from contact microphone excitations into delay time adjustments (6:35 – 7:00. figure 28).



Figures 27. Gesture activity over iterating texture.



Figures 28. Gesture activity in isolation.

Three Perspectives in Audio Feedback 25th March 2006

CD2:2. Solo performance, Three Perspectives in Audio Feedback, Bath Spa University performance series 05-06.

This performance has a primary focus on excitation strategies, exploring the threshold of resonances, and the possibilities of imposing gestural activity on short or faint decay traces. It also plays with the potential of building towards the use of four discrete voices, each occupying different spectral areas, and developing from different excitation techniques.

The improvisation's structure comprises six sections (see full sonogram in appendices p.95). Apart for the last short section the activity is dominated by gesture play. The first and fifth sections both explore exposed excitations. Section two explores the imposed spectral shaping of fluid iterations, created by chaotic attractors. The third and fourth sections are underpinned by a constant resonant oscillation that incrementally descends in frequency. On top of this steady backdrop section three continues the texture shaping of the previous section, but becomes more fragmented as imposed spectral movement merges into imposed amplitude enveloping. Again, over the steady resonance backdrop, section four occupies itself with the enforced excitations of fast discrete parameter adjustments.

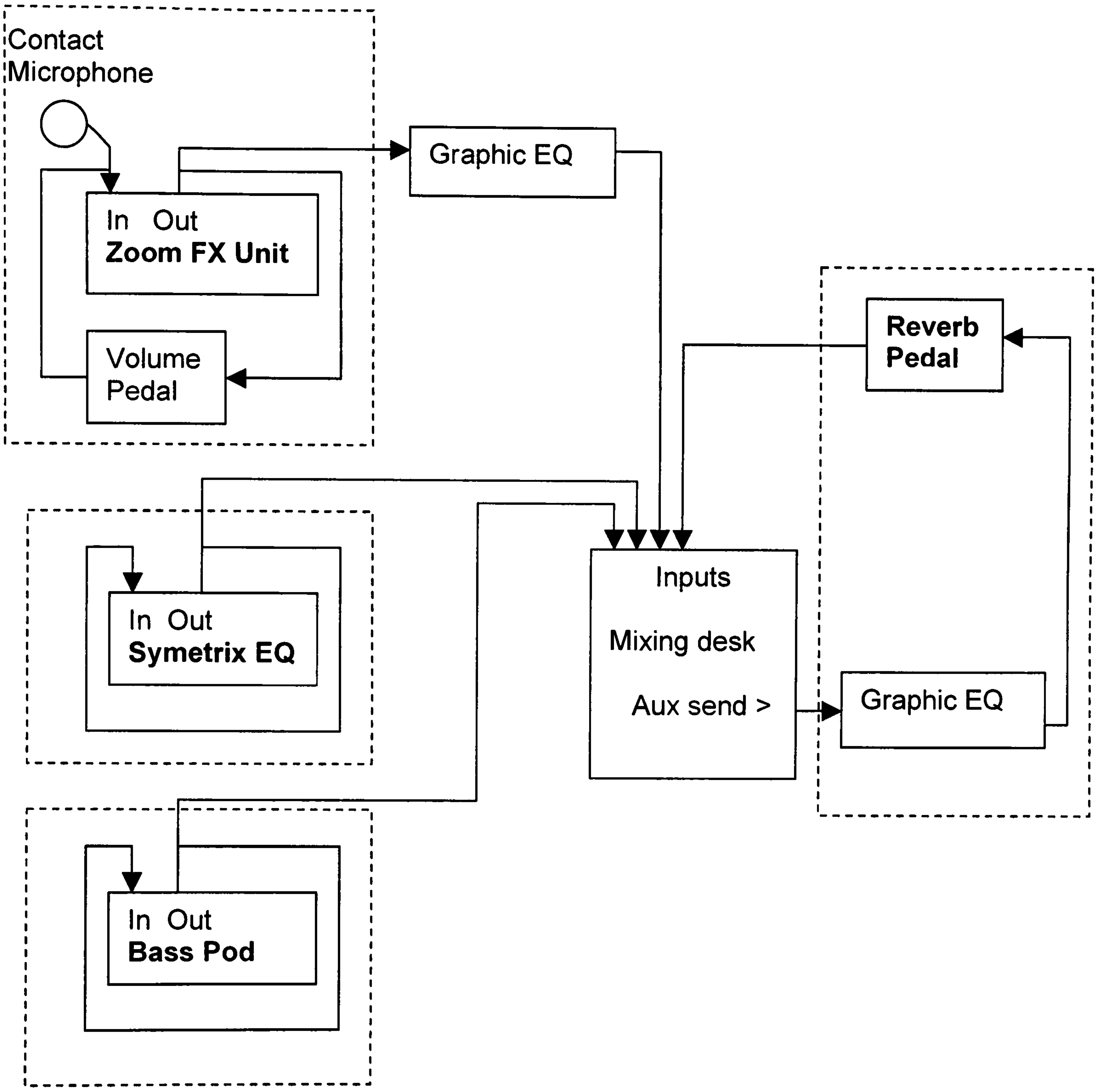


Figure 29. Diagram of electronic feedback configuration for 'Three perspectives in audio feedback' 25th March 2006. The dashed lines indicate individual feedback loops.

This technical configuration offers a quartet of possible voices as indicated by the dashed lines, each with different gestural and physical excitation means (figure 29). As with the previous set-up, a Zoom multi effects processor has an additional volume foot-pedal internal to the loop, a contact microphone input, and external equalisation for imposing spectral shaping. With the host feedback gain set at the threshold of feedback percussive events picked up by the contact microphone give instantaneous oscillation triggering and fast onset transients. The volume foot pedal works in coordination with the excitations, shaping the outer morphology of dynamic intensity and decay envelope, as well as the gesture's saturation level.

The excitations in the opening section are from the percussive tines of a small musical box. With the music box resting on the contact microphone, each event triggered sonic activity into the pitch-shift algorithm of the Zoom effects processor. Adjusting a combination of the internal pitch-shift and filtering parameters, and a volume foot-pedal configured into the circuit, each tine event can be grabbed and shaped in a number of dimensions. Pitch-shift adjustments can modulate the music box's short sustains, shaping the decay frequency. Additionally, raising the gain threshold using the foot-pedal introduces recursive processing, allowing decays to be prolonged into subtle spectral smearing or cascades of processor artefacts, as heard between 0:00 – 2:00. These artefacts can also be influenced to shift direction in real-time through fast adjustments of the pitch parameter (figure 30).

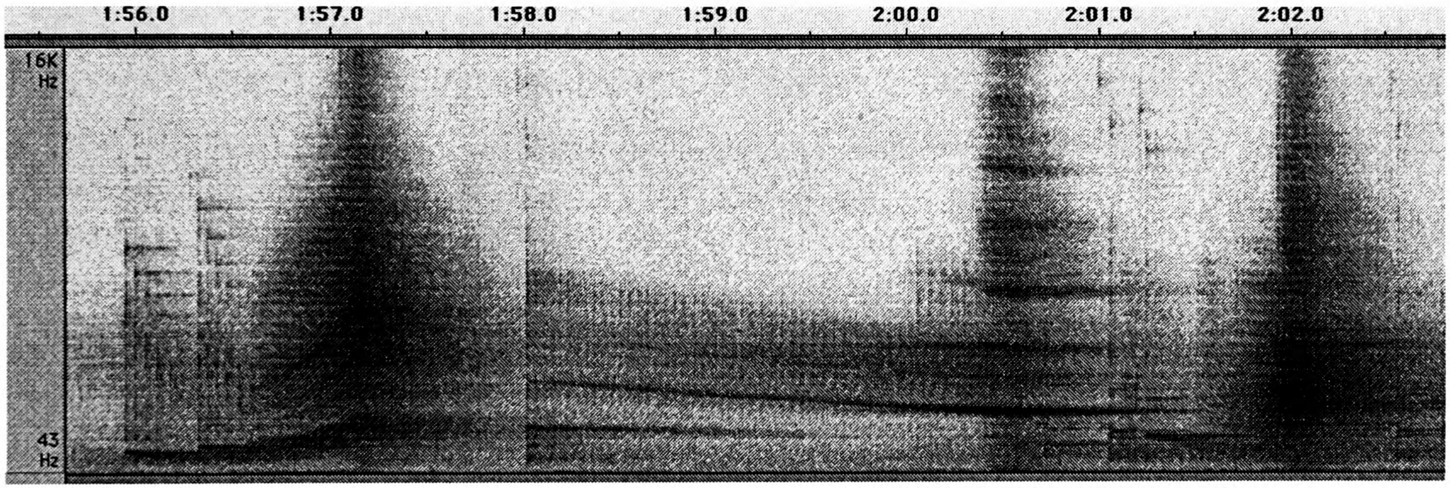


Figure 30. Spectral smearing and shaped processor artefacts from music-box input to feedback pitch-shift processor.

The later section between 10:30 and 12:30 also explores external excitations. The practical technique of creating gestural activity from processor artefacts is the same as above, being reliant on the delicate balance of internal gain and processor parameters. However, this time the focus is on influencing grain density and dynamics (figure 31). A delay algorithm is being used in the Zoom processor, and the excitation is a simple 'tap' of the contact microphone. The delay time is shaped in coordination with feedback gain from the volume pedal.

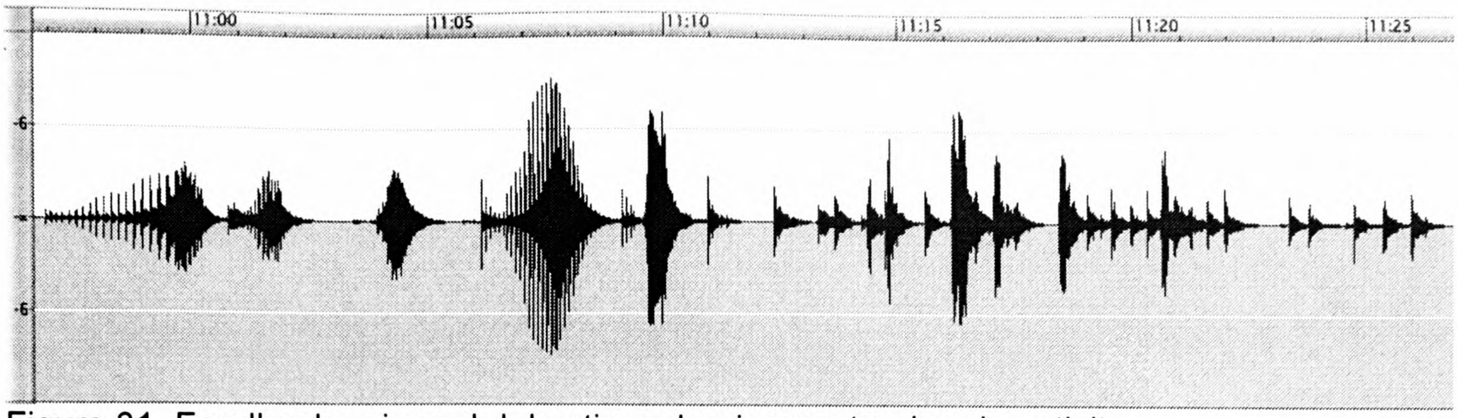


Figure 31. Feedback gain and delay time shaping gestural grain activity.

A Bass Pod amplifier modelling processor is used for the first time in this performance. It was configured as a basic output to input feedback loop, and can be brought to resonance through adjusting the gain related controls. The unit has several dial selectors that can access a choice of amplifier models, virtual speaker cabinets, or effects processors. Once the unit has been excited into activity the dialling of these switches creates instant shifts in algorithm, and subsequently attractors and attractor states. Each forced transition excites a new state, with varying internal times before stabilising. The resulting timbre changes, combined with gain and equalisation control, provide an expressive performance tool, as can be heard between 8:04 and 10:30. Figure 32 shows a brief section of this sonic activity. The constant frequency traces through the extract are discussed below.

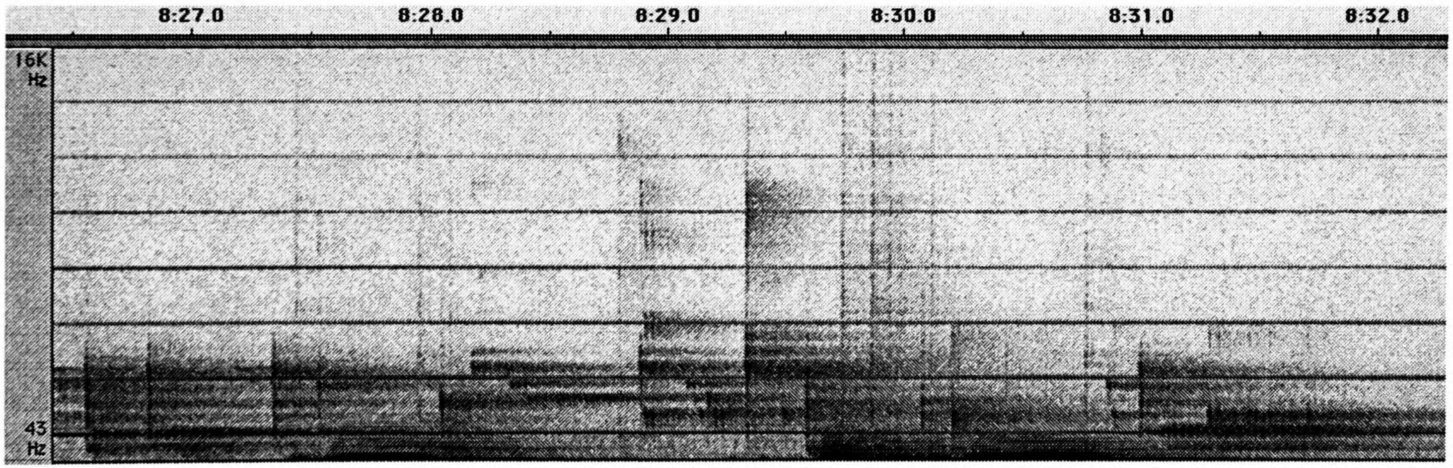


Figure 32. Bass Pod switching imposing fast transition activity.

During the whole of the mid section of this performance an underpinning resonance can be heard slowly shifting down in frequency (5:0 – 10:30 see full sonogram in appendices p.95). This is a low gain oscillation created by the Symetrix parametric equalisation configured as a straight output to input recursive system. The descent is controlled manually by tuning the equalisation frequency.

The final voicing circuit in this piece was the reverb foot-pedal, which could give ambience to other signals via the auxiliary send on the mixing desk, or could be routed to recursively. The characteristic slow onset resonance of this unit is influenced by the mixing desks' send control, and timbre is shaped by saturation and the mixing desk's equalisation.

'From Iteration 2003' Resfest 17th October 2003

CD2:3. 'From Iteration 2003', Resfest 2003. Watershed Media Centre Bristol.

Many performance instruments were in development during the time of this concert, but a number of key components had already been identified (Figure 33). The Zoom multi-effects processor and the Symetrix parametric equaliser are both wired in a self-input configuration, but here they are both connected to the input of a Behringer compressor through an audio 'y' connector. When their output signals are of a comparable amplitude, the combined input into the compressor has the affect of cross modulating the signals together, making them interfere with each other both in spectrum and behaviour. Imposed spectral shaping can also be achieved through a 32 band graphic equaliser.

The third internal feedback loop is another 32 band graphic equaliser, wired to self oscillate, with its output configured through a volume foot controller for imposed envelope shaping. As with the previous performance set-ups, a reverb unit is configured to receive its input from the mixing desk auxiliary send, and its output goes through a mixing channel input. This enables it to be used as both a spatial processor and, when routed back to itself, a fourth self-input instrument.

In addition to the hardware equipment a monitor output signal from the mixing desk is routed through a USB audio interface into a laptop computer. The computer is running a Max/MSP patch that can perform ring modulation against fixed pitched sine or saw-tooth waves. As well as adding inharmonic spectral complexity, spurious frequencies are introduced into the signal when resultant tones breach the Nyquist frequency in the DSP algorithm, causing the perception of aliasing.

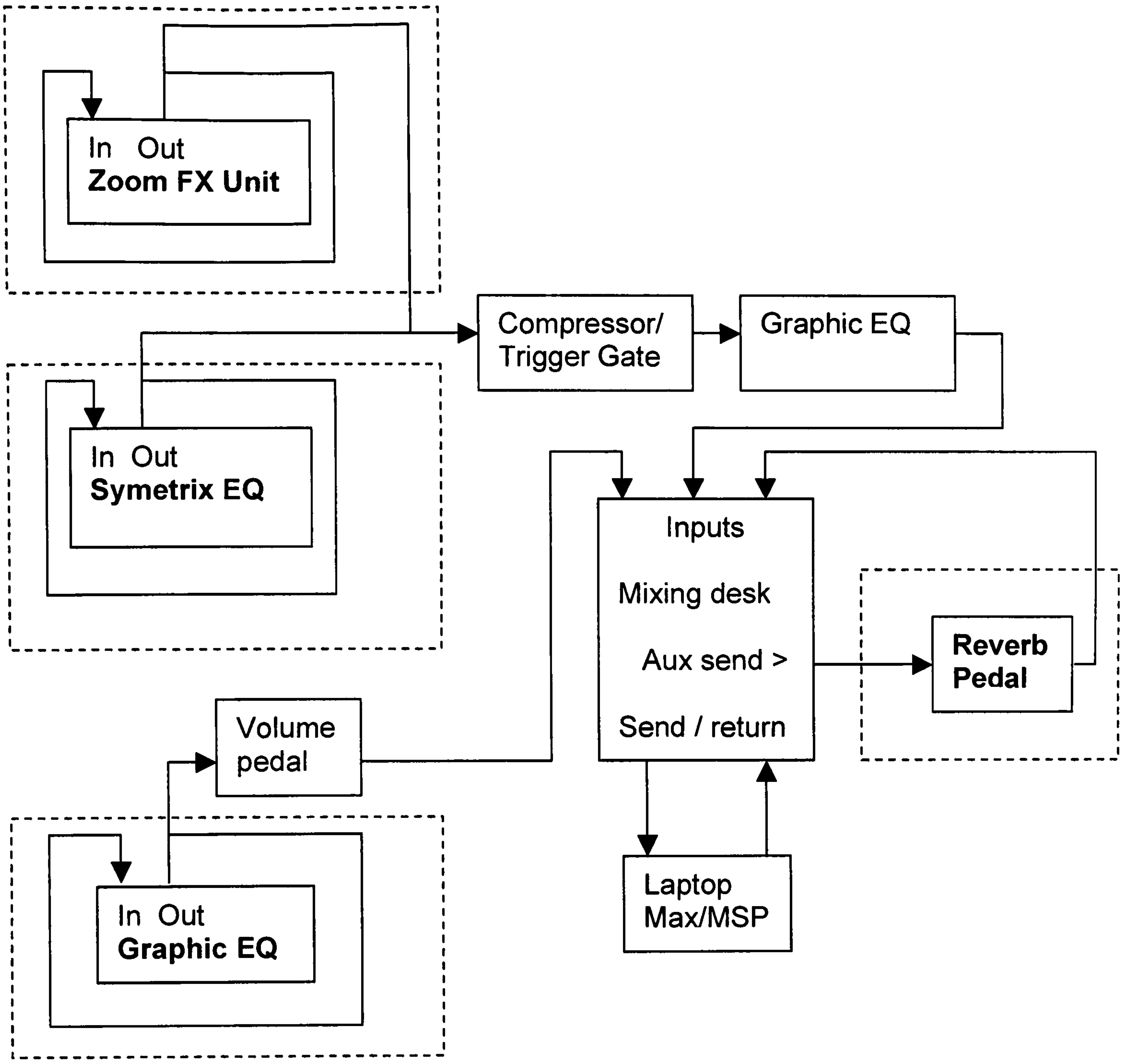


Figure 33. Diagram of electronic feedback configuration for 'From iteration 2003' 17th October 2003. The dashed lines indicate individual feedback loops.

At this stage in the research the basic premise of an intrinsic sonic landscape to electronic feedback was already being tested, but the sonic behaviours were assumed to be incremental, developing from resonance, to turbulence, saturation, and finally to iteration. As the title of the improvisation suggests, the referent structural strategy was to move through these four behaviour states, unpacking the complexity of multiple unstable feedback loops from a fully agitated and iterated cacophony down to simple resonances and silence. Although the overall direction does move from chaotic density to gentle resonant gestures, analysis of the resulting structure shows that a more meandering sonic journey is taken (see full sonogram in appendices p.96). Close listening also reveals that the clarity in presenting turbulent behaviour found in later performances is not evident here. This indicates that the knowledge of turbulence being a modulating behaviour rather than a state in its own right is important when attempting to influence its occurrence.

The opening two minutes of the performance contain the polyphony of multiple iterating states, in varying degrees of periodic and chaotic attractors. Figure 34 shows the complex wave data of a two and a half second extract starting at 0:41.

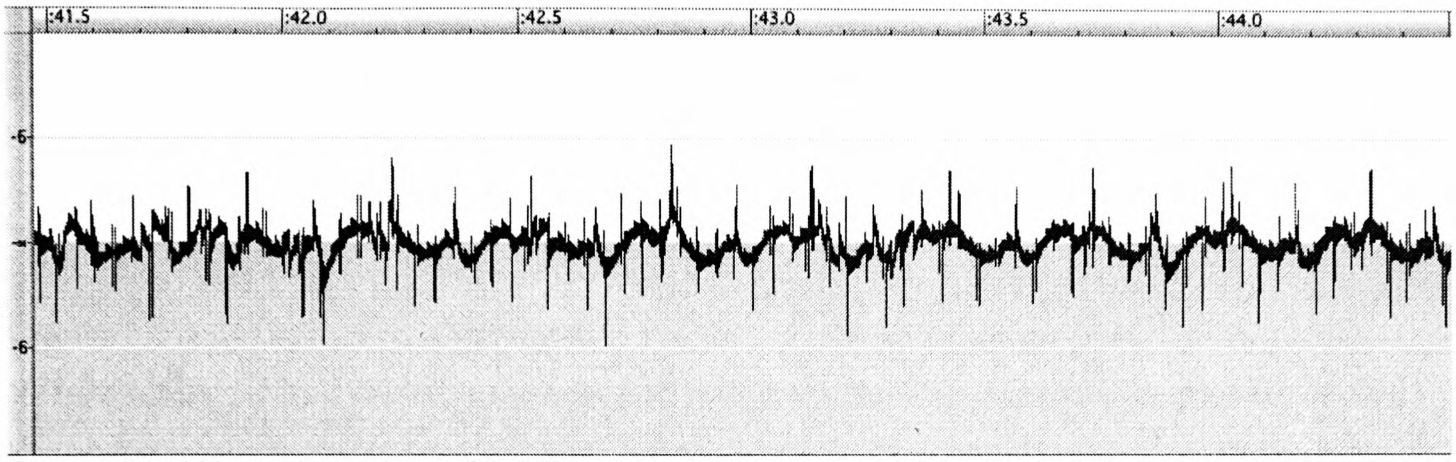


Figure 34. Wave data view of 2 1/2 seconds of combined iterating systems.

A further imposed layer of iterating activity is explored through the compressor's optional control by an external trigger. A simple non-latching foot-pedal is used to open and close the signal path during sections of the performance, imposing iteration or broken behaviour attributes on constant or sustained oscillations. An example of this can be found between 8:30 – 8:37, shown in figure 35

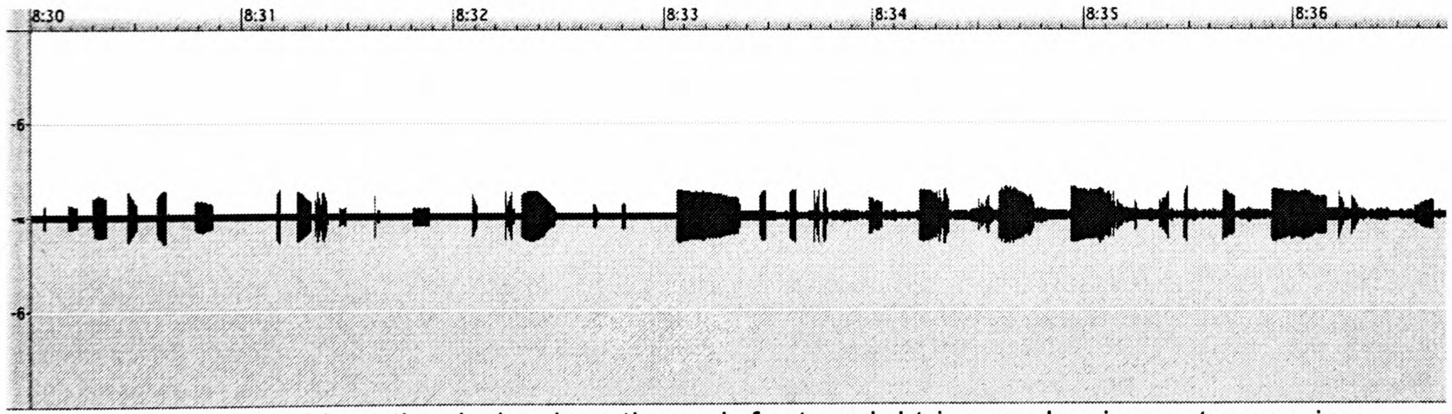


Figure 35. Imposed iteration behaviour through foot-pedal triggered noise-gate opening.

Degrees of saturation used for spectral colouration are created by adjustments in the levels of gain within a loop. The sonogram extract of figure 36 shows a resonant frequency and its overtones moving from a near saturation point at 10:22 back to a cleaner timbre. From 10:24 through to 10:29 there is a steady increase back into saturation until the fundamental frequency and its overtones are almost completely diffused. At the same time as this transition the overall volume is decreasing, indicating an outer morphology decay envelope imposed by a gain control external to the feedback loop.

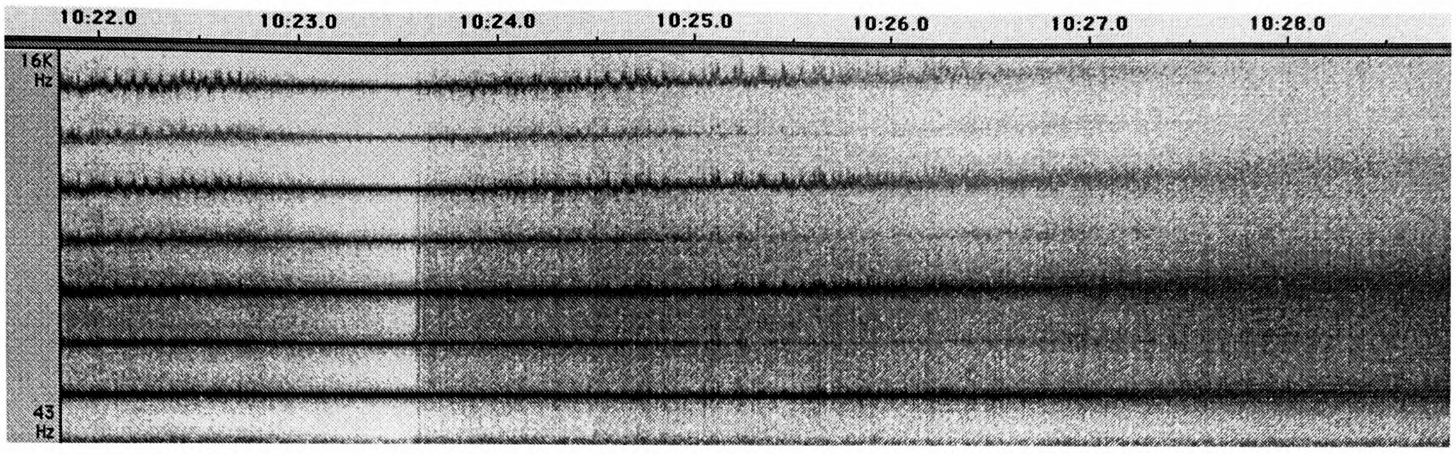


Figure 36. Degrees of saturation on resonating oscillator.

After 15:00, and until the close of the performance, there is a continuous undulating texture created by a period attractor affecting the Zoom processor's pitch-shifter artefacts. The texture's musical function as an underlying ambience is imposed through spectral thinning and a very slow decreasing of an external gain control. The focus in this section is on the sparse activity of resonant gestures. The resonance is from the graphic equaliser feedback circuit, and frequency modulations are created by wobbling its tuning faders. Each gesture is temporally shaped by an external volume foot-pedal. Figure 37 shows the last one and half minutes of the section, displaying the variety of gestures performed, and the decreasing texture amplitude. Figure 38 offers a closer view of the first two gestures from this period detailing internally influenced pitch modulations.

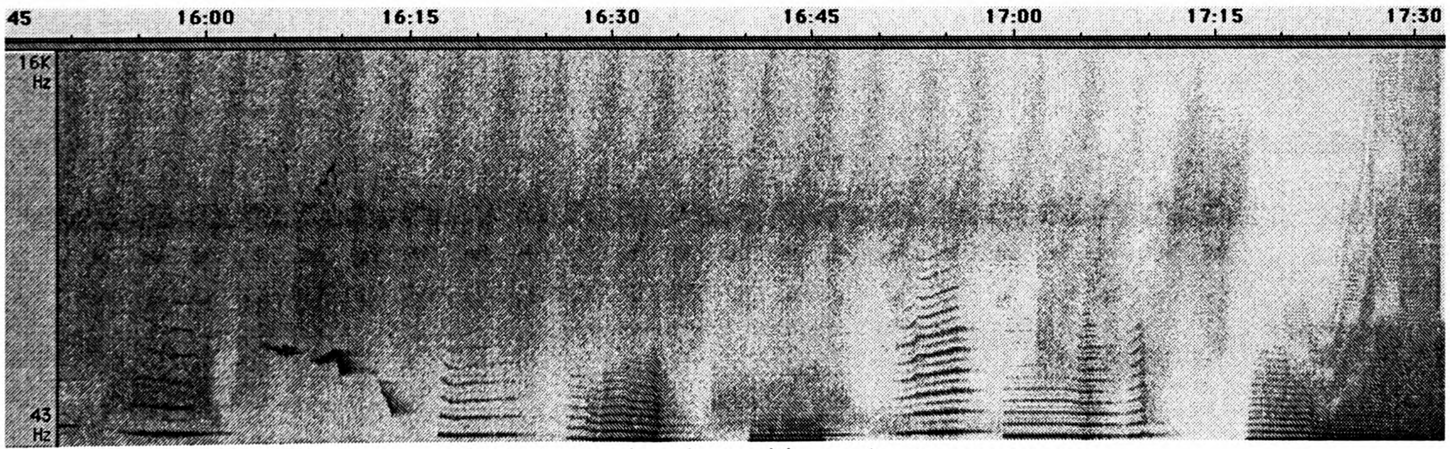


Figure 37. Externally imposed gesture shaping with system resonance.

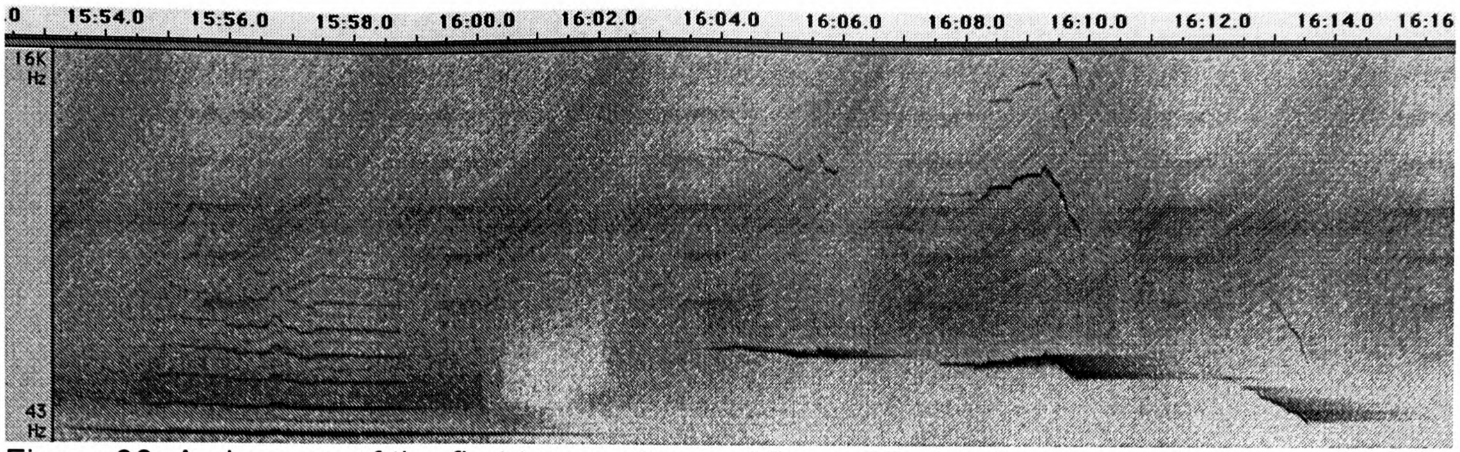


Figure 38. A close up of the first two gestures of figure 37, detailing internally influenced pitch modulations.

'From Iteration 2007' RAM symposium 19th May 2007

CD2:4. 'From Iteration 2007', Real Audio Media - Practice-led research symposium 2007 Bath Spa University. This performance is also presented on DVD. The video footage gives an insight into the physical activity and 'table top' style of the feedback instruments.

As an indication of research developments the referent performance strategy used in 'From Iteration' in October 2003 was revisited in May 2007. As intended in the original performance, activity moves through the four sonic behaviours of iteration, saturation, turbulence, and resonance. The sonogram image of the whole performance shows a clear progression from iterated density to sustained resonances. Each of the sections is arrived at through a transformation, with the approximate cross-over timings of 4:00 and 6:45 (see full sonogram in appendices p.97). A deeper awareness of the behaviours and their causal phenomena has enabled more focused and subtle displays of each using explorations of internal influence, as opposed to the reliance of imposed shaping in the earlier performance. Also, the use of polyphony is made more sophisticated through the use of independent amplitude fades, tighter spectral placement, and spatial movement across the stereo field. To enhance the effect of stereo location the performance was projected through two discrete combo amplifiers, each with their own spectral colouration.

The configuration in the performance consisted of six independent feedback loops, and is designed to offer multiple perspectives of each sonic behaviour (figure 39). The Zoom multi-effects processor, Symetrix parametric equaliser, reverb foot-pedal, and Bass Pod have all been detailed in previous performances. Additional to these are two behaviour specific pieces of equipment. The microphone amplifier / compressor has limited playability and palette when self oscillating. However, it has the ability to create a high internal gain levels when using the balanced microphone input in combination with a high compression ratio. This sends the system into immediate chaotic oscillation, producing a shifting iteration comprising of DC offset clicks and fragmented tones or noise.

A spring reverb unit makes the sixth feedback circuit. It creates resonances that range from almost pure tones to mild levels of saturation, but due to the physical nature of the reverb element its internal time is very slow. This makes it produce long onset envelopes, or move through bifurcation to more dominant resonant attractors over long periods of time. If the spring element is exposed it is also possible to manually influence its vibrations by gently touching nodes along its length. These actions have the affect of isolating harmonic spectra.

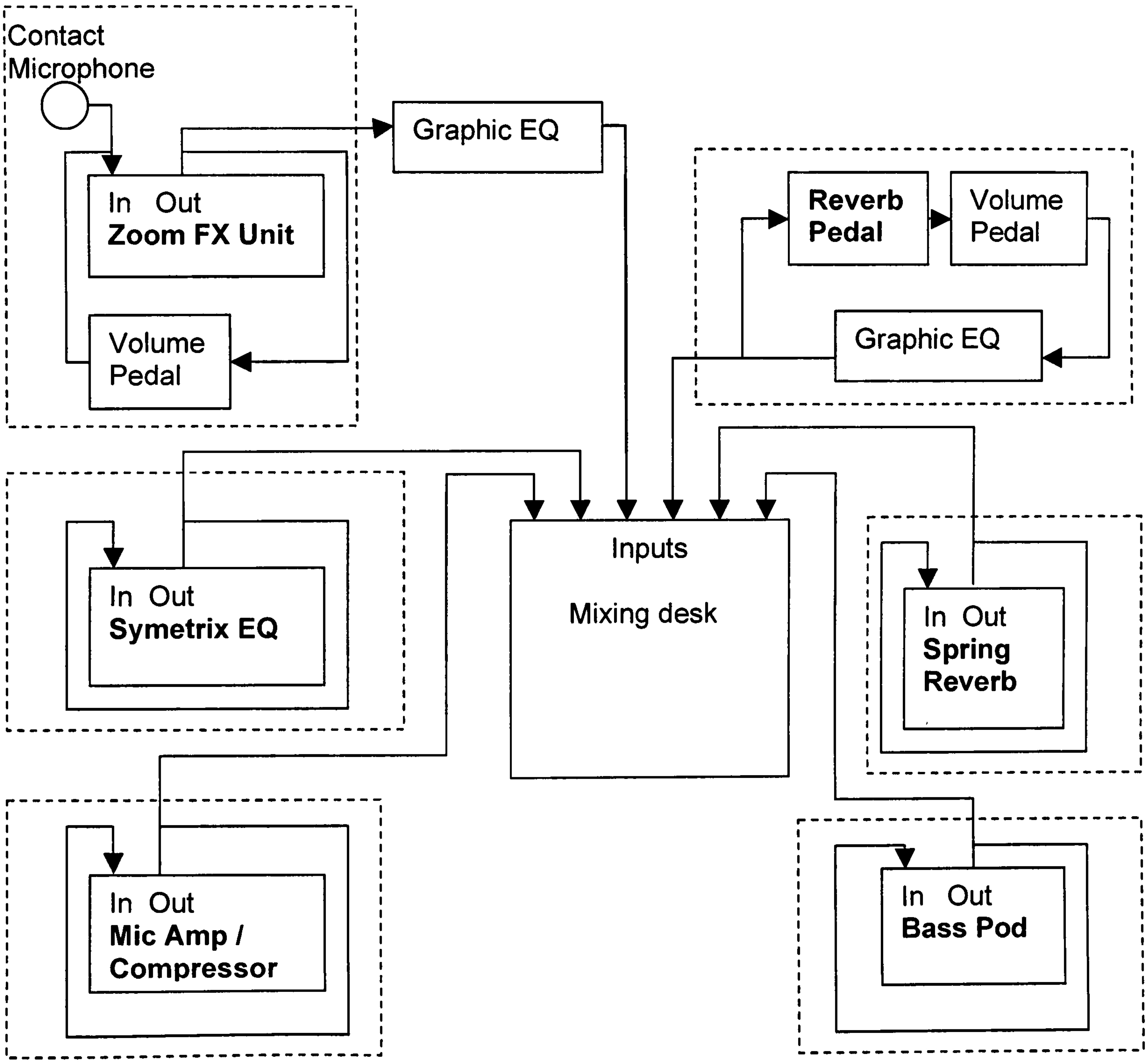


Figure 39. Diagram of electronic feedback configuration for 'From iteration 2007' 19th May 2007. The dashed lines indicate individual feedback loops.

The use of switching power supplies on and off and the triggered gating of circuits, introducing DC offsets and switch noise, contributed to the complex array of iterating circuits during the opening section of this piece in 2003. The instability-to-control ratio is shifted in this recent version, and three circuits in iteration are introduced incrementally, maintaining separation through careful spectral and spatial placement. The first to enter is the Symetrix equaliser, and the wave data image in figure 40 shows thirty seconds of periodic attractor being subjected to slow imposed spectral shaping.

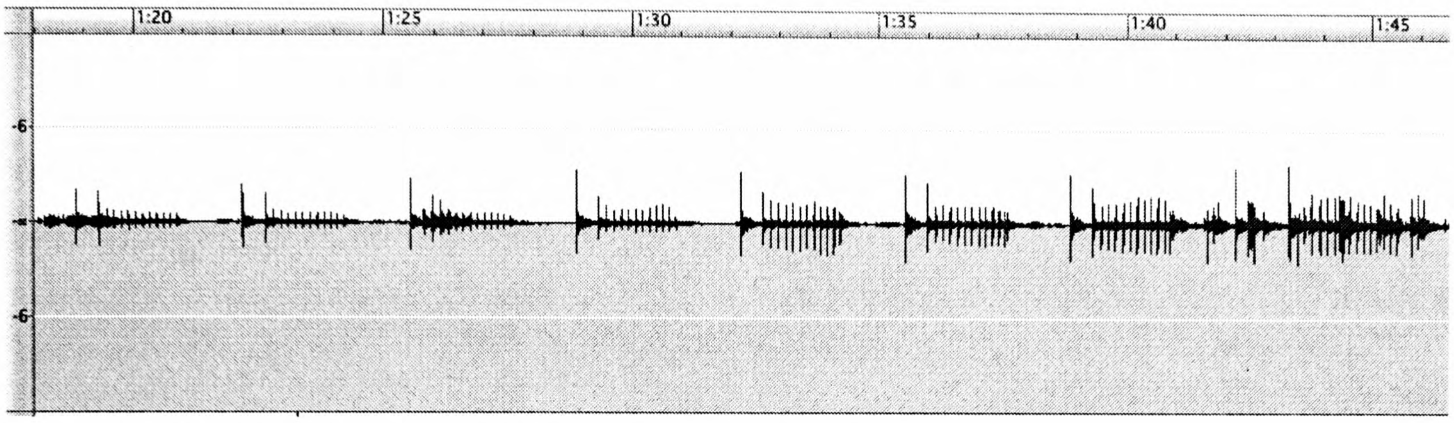


Figure 40. Slow imposed spectral shaping on period attractor.

Once all three iterating circuits are sounding the resultant sonic activity creates complexity from the different levels of periodic and chaotic attractor. This is most pronounced between 3:00 and 4:00, as can be seen in figure 41.

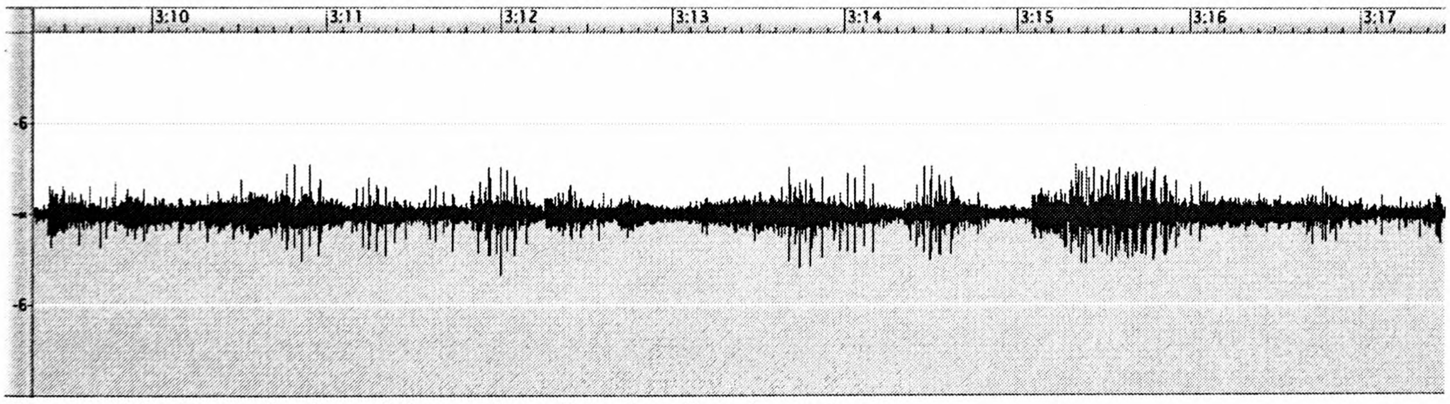


Figure 41. Complexity of three iterating feedback systems.

The saturation section begins at 4:00, transforming into the turbulence section at around 6:45. The developing gestural activity in this section exploits wave-shaping or waveform distortions through the use of high internal gain levels. This spectral complexity is often temporally shaped to coincide with influenced or imposed gestures. Figure 42 shows a short resonance swell that is internally influenced into saturation, indicated by the extension of spectral density.

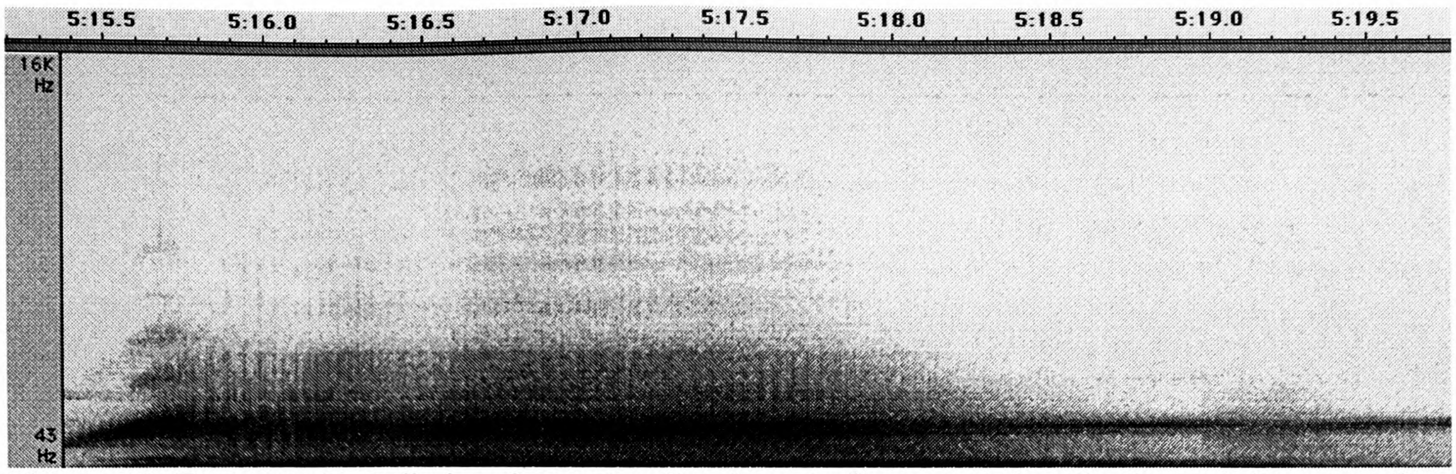


Figure 42. Resonant swell showing saturation boost of spectral density through the use of internal gain.

An initial turbulence is audible in the Bass Pod feedback loop each time certain internal processor configurations are recalled. The system is forced into extending these brief moments by repeatedly switching in and out of the particular parameter setting. The resulting sonic activity is evident in figure 43 where the lower frequency onsets indicate the circuit being switched in, and the overtones exhibit a modulating behaviour.

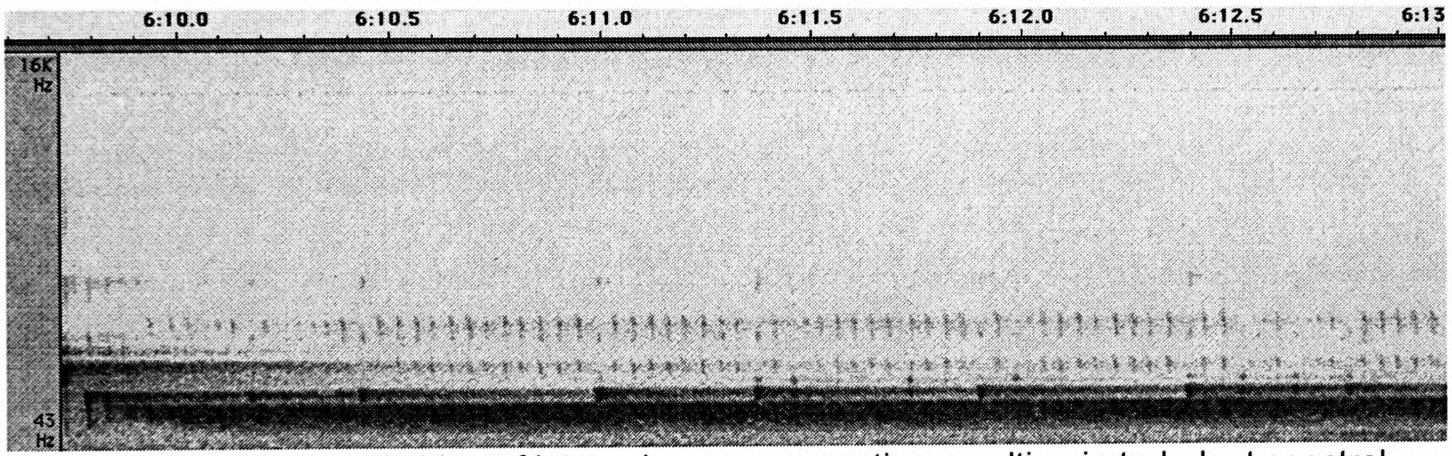


Figure 43. Repeated switching of internal processor routing resulting in turbulent spectral behaviour.

The later half of the performance has a focus on resonance. At first oscillations are excited from an external trigger. A thin steel sheet is being struck whilst resting on the Zoom processor's contact microphone input. This creates immediate onset transients, and influences the frequency node of the resulting resonance (figure 44). It also has an additional quality of creating an audible acoustic resonance that is slowly overridden as the internal influence diminishes.

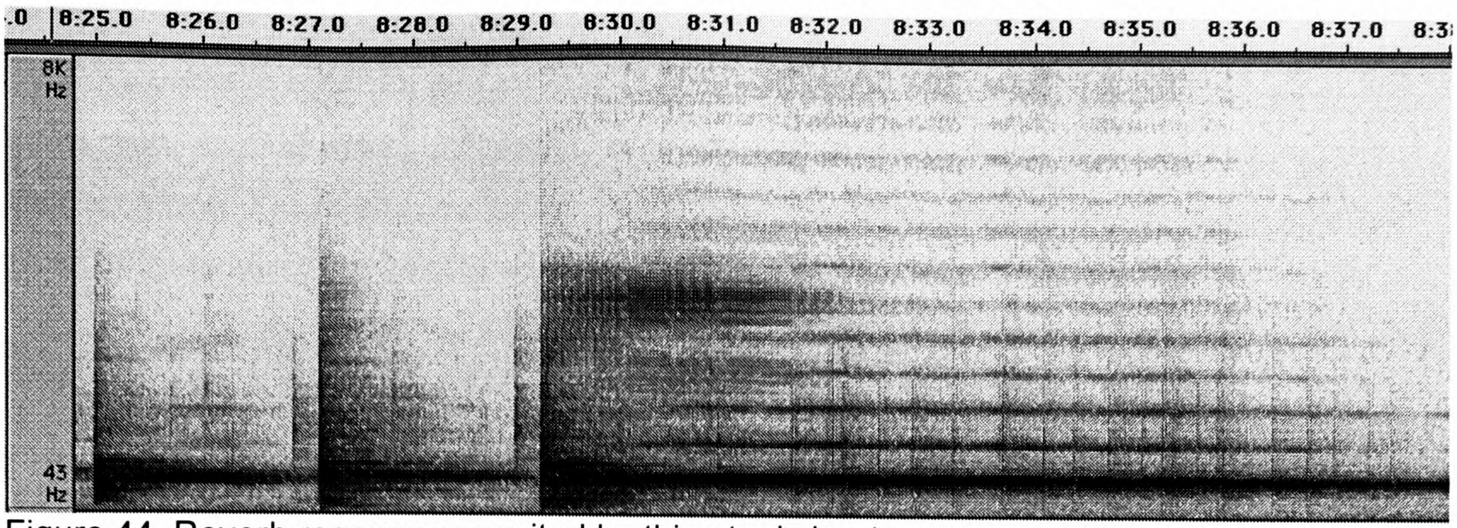


Figure 44. Reverb resonance excited by thin steel sheet.

Over time there is a transformation toward the resonances of three independent feedback loops, all built around reverb units. The spatial processing introduces an inherent slow internal time, creating long onset and decay envelopes as gain settings are manipulated to be just over or just under the threshold of oscillation. As each reaches a state of 'nothing' or inactivity its internal reverb time and filter parameter settings are adjusted, so when the gain is set just above the threshold again a new resonant attractor will be sought, and a new harmonic spectrum will be heard. The slow diminishing resonant swells of the final two and a half minutes are clearly displayed in the sonogram image below (figure 45).

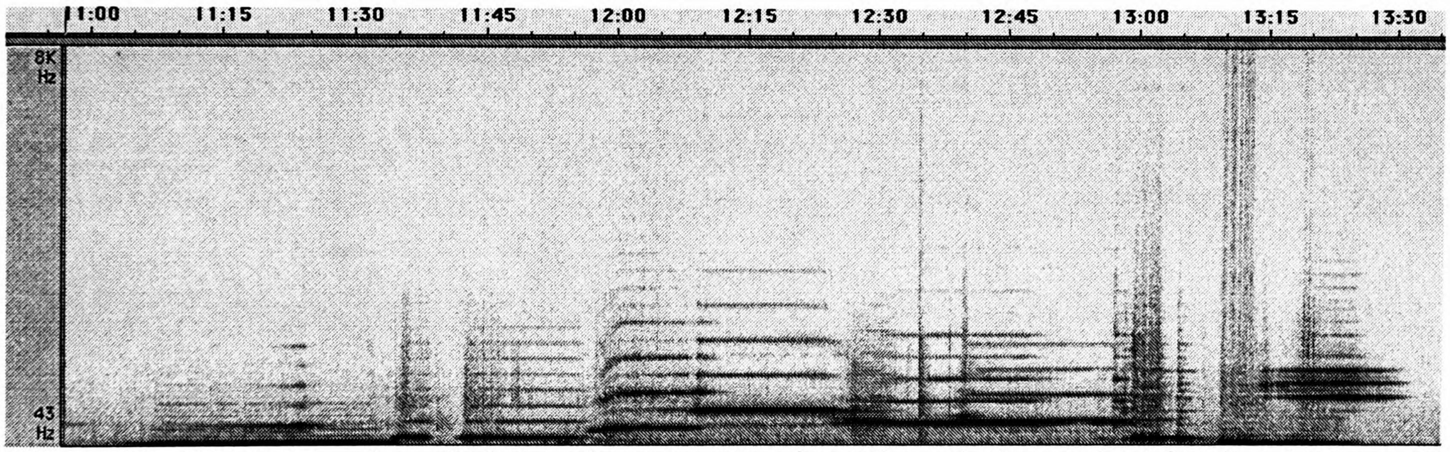


Figure 45. Slow internal excitations of resonances from three independent feedback loops.

Each of the performances discussed above seeks to develop, verify, and display new knowledge about feedback instruments by having a rationale or referent strategy that focuses on a particular facet. In defining the common sonic features of electronic feedback a deeper level of technical causal phenomena can be interpreted. Many characteristic traits can be explained as notions from dynamical systems theory, and in particular chaos theory. However, the recognition of less complex influences, such as system noise floor and host processor artefacts, also aid this interpretation. The design of a conceptual performer orientated model of recurring sonic behaviours, and the relationships between them, offers an important step toward creating responsive performer actions. Subsequent practical strategies differentiate the three distinct responsive stages of configuration, excitation, and interaction, each enabling varying degrees of sound-shaping from both inside and outside the feedback loop. These accumulative research findings have resulted in a comprehensive array of methods to evoke and shape the emerging sonic activity of electronic feedback.

Conclusion

The initial research question - seeking to define the sonic palette within electronic feedback - has been explored through a practice-led methodology. Performer options relating to the feedback loop's construction, and the choice of introducing external signals into the feedback loop, are discussed in the process of contextualising the study. These two dimensions combine into four possible approaches, and it is the use of off-the-shelf audio equipment configured into self-oscillating systems that is explored here. The collated aural perceptions of artists that work with electronic feedback reveal a number of recurring sonic features that are interpretive of causal phenomena rather than descriptive of sounds heard.

The methodology chapter refines the notion of instrumentalising found objects, outlining an accountable and rigorous research approach. Operational details relate to the aesthetic positions of what constitutes an instrument and at what level of scrutiny or awareness one performs with it. This works in conjunction with a practical assessment of the object's control interface and playability, and a three tiered listening strategy for real-time analysis. The notion of 'informed improvisation', based on the knowledge gained through the instrumentalising method, is identified as offering the most decisive performer interactions with electronic feedback systems.

Research findings contribute to the field of live, improvised, and experimental electronic music in a number of ways. Firstly, a clear set of causal phenomena is given for the recurring sonic features revealed in the contextual chapter. The existence of a phase-space containing attractors that are accessed through, often discontinuous, transitions confirms existing research. The need for a noise-floor within a system, and the influence of processor artefacts from the audio equipment in oscillation, also introduce core audio engineering principles. It is suggested that these combined causal phenomena create an intrinsic nature to electronic feedback.

The causal explanations underpin a conceptual model of the sonic traits heard, which forms the second area of research contribution. The model is a performance tool, consisting of five interconnected topological behaviours - *nothing*, *resonance*, *iteration*, *saturation*, and *turbulence.* These can be used to interpret the emerging sonic activity of electronic feedback instruments.

In combination with the feedback configurations discussed in the context chapter these two contributions may lead to interesting future research into the works of artists that use electronic feedback. Audio extracts from performances or works, with the inclusion of photographic or diagrammatic representations of technical set-ups where possible, could be used to exemplify the sonic results of each approach. It may even be possible to attempt analyses of musical works by adapting the conceptual model of sonic behaviours. However, one must be cautious when attempting to convert performance or compositional tools into analysis tools, as the perspectives are not always interchangeable.

A third area of contribution to the field is the responsive performance strategies. These take both an improvisation approach that is informed through the assessment of individual feedback instruments, and the conceptual sonic behaviour model, as a starting point. The 'responsive performance strategies' section in the thesis discusses the sonic implications of a range of technical feedback system configurations, and a variety of excitation and interaction methods are presented. Sound-shaping techniques have been developed that can facilitate and influence emerging intrinsic sounds, or create outer morphologies that externally impose spectra or gesture. Through using the strategies proposed electronic feedback instruments can be decisively manipulated anywhere along the instability-to-control ratio.

Although approaches and performance tools are presented in the context of my own performance practice their transparency should allow them to be adapted for a wide range of musical activity. The documented performances can be seen as examples of the strategies in action, detailing configurations and performance activities that yield sonic results, both intrinsic and imposed. These practical research results display performance approaches that go beyond experimental and retrospective or codified displays of feedback instabilities. Structured and collaborative improvisations become possible by the use of degrees of interaction and control with electronic feedback. The combination of causal appreciation, awareness to the scope of sonic activity, and practical performance techniques, offer the performer powerful tools to create responsive interaction and sound-shaping with the intrinsic behaviour of electronic feedback instruments.

Appendices

- Audio CD1 - Example extracts
- Audio CD2 and DVD - Documented performances
- Documented performances - Full sonogram images
- Documented performances - Equipment used
- List of figures

Audio CD1: Example extracts

Audio CD1: Example extracts
Track listing

1.	Noise floor	00:04
2.	Point attractor oscillation	00:05
3.	Periodic or closed-loop attractor	00:06
4.	Chaotic attractor – aperiodic	00:07
5.	Chaotic attractor – collapse	00:10
6.	Transition to new attractor	00:04
7.	Host processor artefacts – pitch-shifter	00:06
8.	Host processor artefacts – phaser	00:03
9.	Host processor artefacts – possible aliasing	00:07
10.	Host processor artefacts – slow internal time on parameter edits	00:05
11.	Host processor artefacts – slow internal time on transition	00:13
12.	Revisited sonic activity #1	00:05
13.	Revisited sonic activity #2	00:06
14.	Resonance	00:02
15.	Iteration – periodic	00:04
16.	Iteration – aperiodic	00:04
17.	Iteration – chaotic	00:06
18.	Saturation – low level	00:07
19.	Saturation – noise	00:09
20.	Turbulence	00:04
21.	Digital domain – resonance	00:03
22.	Digital domain – iteration	00:05
23.	Digital domain – transition	00:09
24.	Saturated iteration	00:07
25.	Turbulent period attractor	00:26
26.	Slow internal onset	00:09
27.	Fast internal onset – switched	00:03
28.	Fast onset - external influence	00:03
29.	Slow onset - external influence	00:21
30.	Suspended transition by gain manipulation	00:07
31.	Multiple frequency boosts leading to transtion	00:07
32.	Gesture shaping with external gain control	00:05
33.	External filtering as outer morphology shaping	00:21
34.	Triggered noise-gate on continuous oscillation	00:04

Audio CD2: Documented performances

Track listing

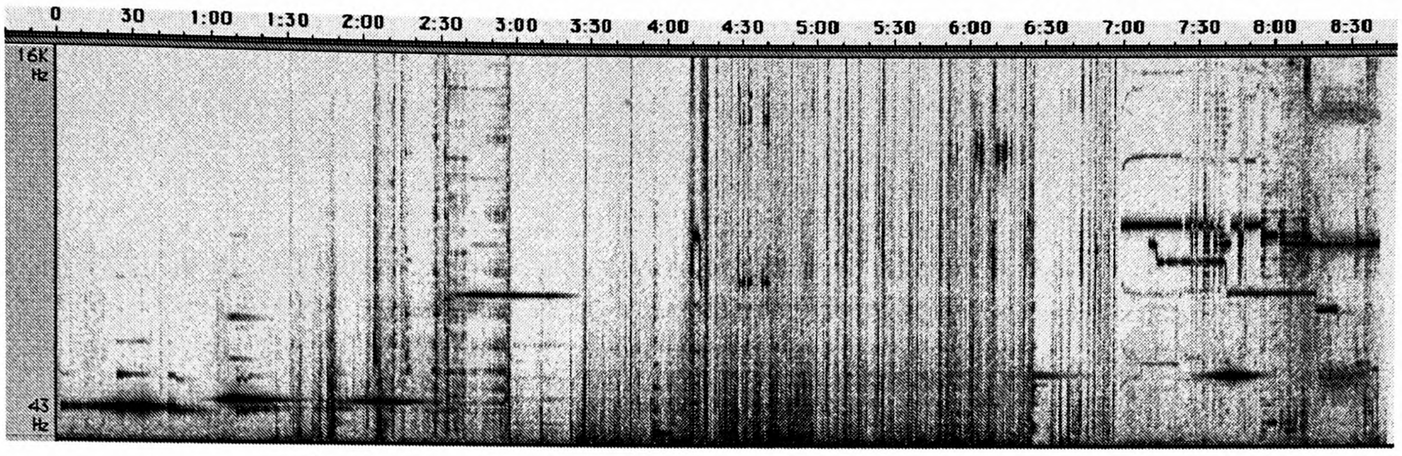
1. Solo performance, Foldback Sound Festival. 4th August 2006. **08:45**
2. Solo performance, Three Perspectives in Audio Feedback, Bath Spa University performance series 05-06. 25th March 2006. **13:11**
3. ‘From Iteration 2003’, Resfest 2003. Watershed Media Centre Bristol. 17th October 2003. **17:41**
4. ‘From Iteration 2007’, Real Audio Media - Practice-led research symposium 2007 Bath Spa University. 19th May 2007. **13:35**

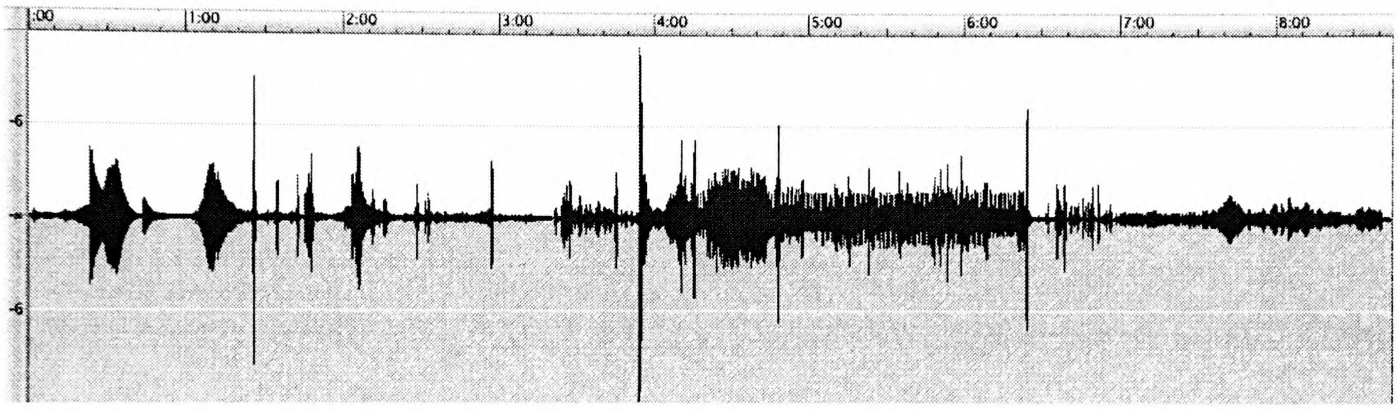
DVD

'From iteration 2007'. Real Audio Media - Practice-led research symposium 2007 Bath Spa University. 19th May 2007. **13:35**

Documented Performances: Full images

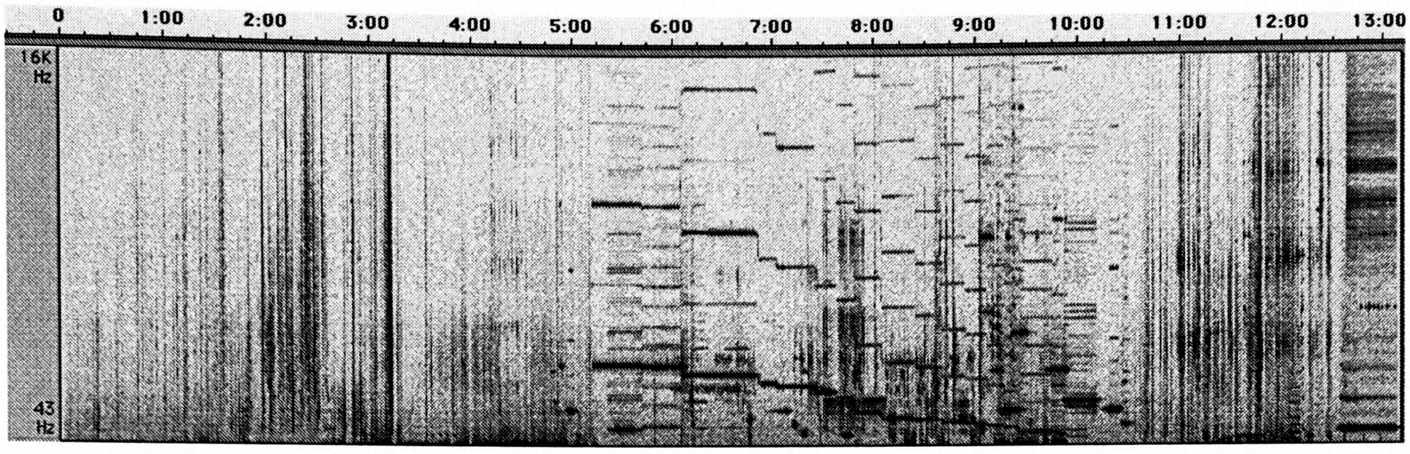
Foldback Sound Festival 4th August 2006

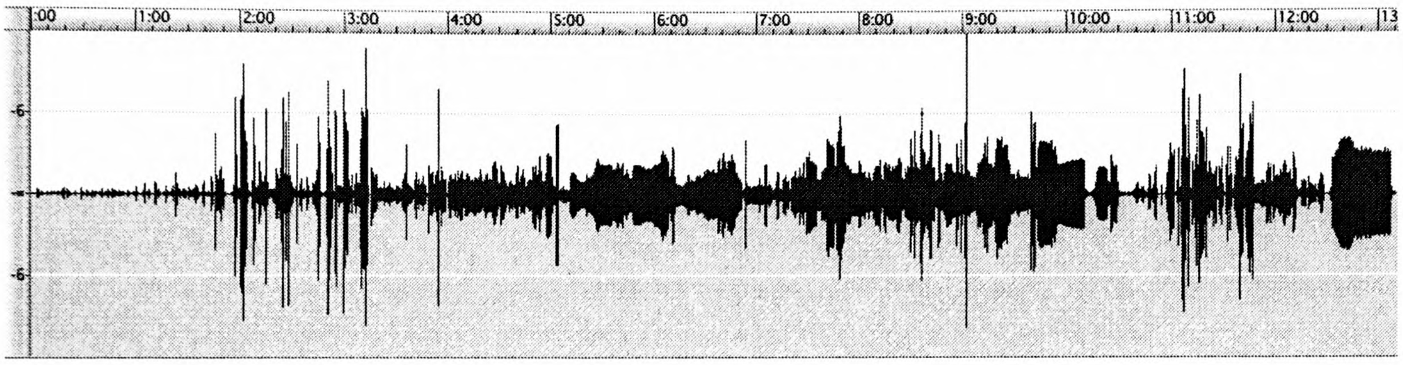




Both the sonogram and waveform image display the same audio performance. When viewed whilst listening to the audio five sections of activity can be clearly identified.
0:00 – 1:30 = turbulent resonances
1:30 – 4:20 = gesture explorations with recursive pitch-shift
4:20 – 6:20 = accumulating gesture activity over iterative texture bed
6:20 – 7:00 = excited gesture activity
7:00 – 8:45 = turbulent resonances

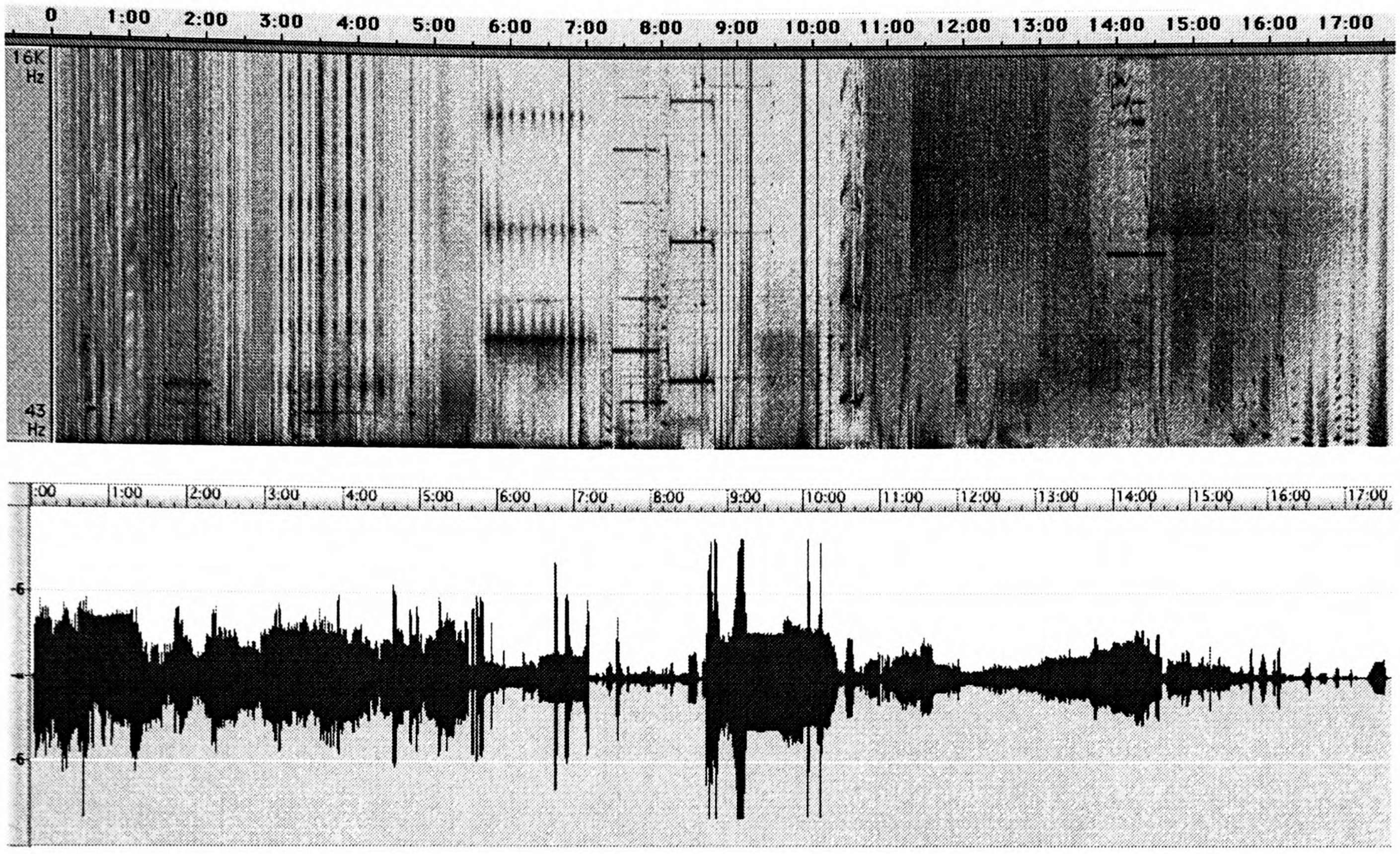
Three Perspectives in Audio Feedback 25th March 2006





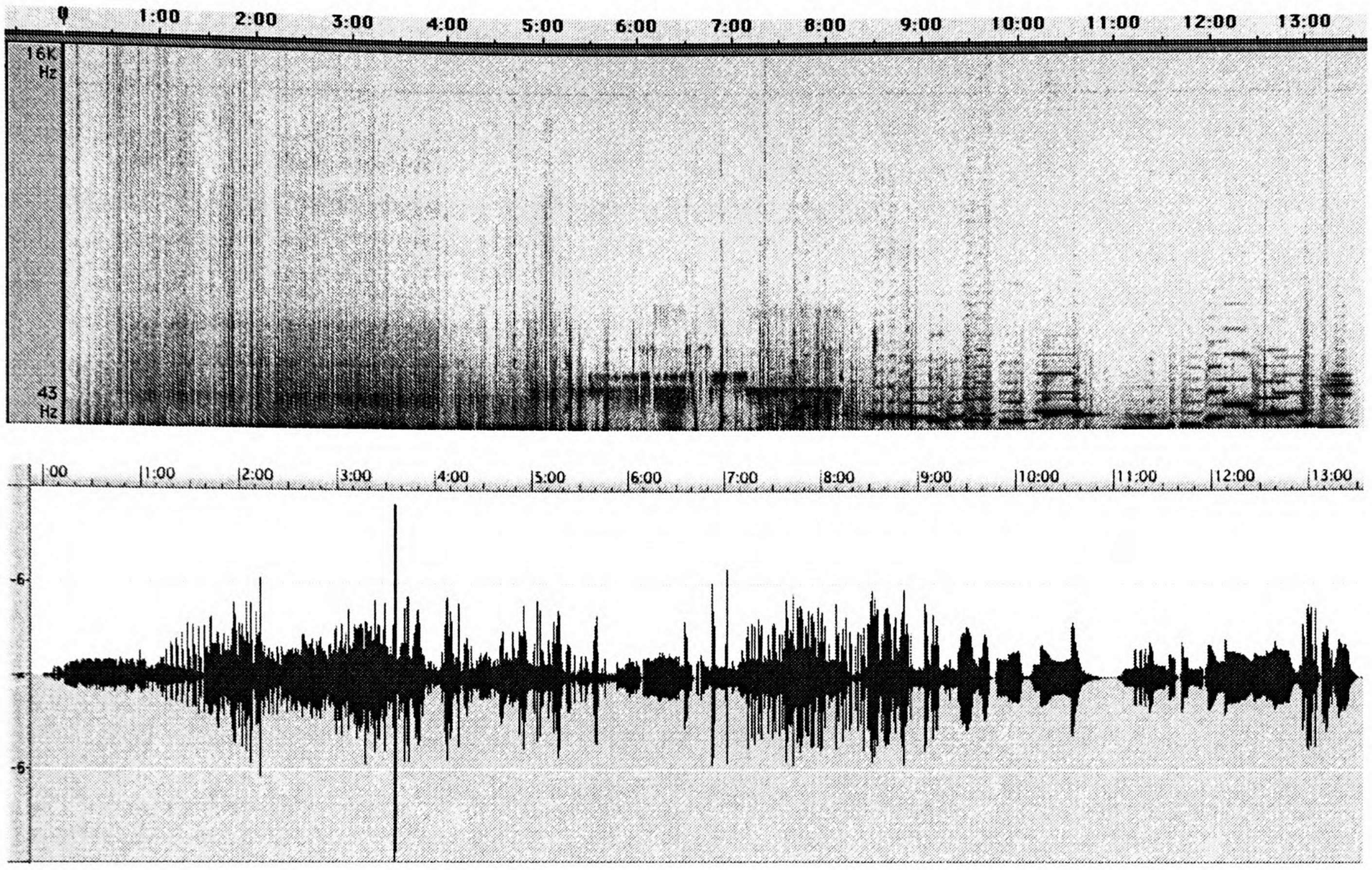
Both the sonogram and waveform image display the same audio performance. When viewed whilst listening to the audio six sections of activity can be identified.
0:00 – 2:00 = excitations and gesture play with pitch-shift
2:00 – 5:00 = texture shaping
5:00 – 8:00 = gradually developing gesture play over slowly descending resonance
8:00 – 10:30 = instant excitations over continued descending resonance
10:30 – 12:30 = 'tapped' delay excitations
12:30 – 13:00 = sustained resonance with shifting degrees of saturation

'From Iteration 2003' Resfest 17th October 2003



Both the sonogram and waveform image display the same audio performance. When viewed whilst listening to the audio the opening section can be seen to contain multiple iterating systems, and the closing section explores gestured resonances over a texture bed of turbulent host processor artefacts. The remainder of the performance takes a more meandering polyphonic journey through saturated and turbulent gestures.

‘From Iteration 2007’ RAM symposium 19th May 2007



Both the sonogram and waveform image display the same audio performance. When viewed whilst listening to the audio four sections of activity can be clearly identified.
0:00 – 4:00 = iteration
4:00 – 6:45 approx. = saturated gestures.
6:45 – 9:00 approx. = turbulence and excited resonances.
9:00 – 13:36 = influenced resonances

Documented performances: Equipment used

- Behringer 'Composer: Audio interactive dynamics processor'. Model MDX2100 (compressor/noise-gate)
- Behringer 'Eurorack UB1002' (mixing desk)
- Behringer 'Ultra-graphic pro GEQ3102' (graphic equaliser)
- Boss 'FV-50' (volume pedal)
- Electro Harmonix 'Holy grail' (reverb pedal)
- Ernie Ball 'PO6166 vp' (volume pedal)
- Hooter Sound 'B1' (mic amp/compressor/limiter/gate)
- JHS 'Reverb SL5300' (spring reverb)
- Line 6 'Bass pod' (bass guitar amplifier modelling)
- Symetrix 'SX201' (parametric EQ/preamp)
- Zoom 'Studio 1204' (multi-effects processor)

List of figures

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