New Renaissance Institute®
Technology White Paper (Preliminary)

Activity Indication, External Source, and Signal Processing Loop Provisions For Driven Vibrating-Element Environments

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Abstract

This whitepaper describes technologies and methodologies expanding the capabilities of electronically-induced audio-frequency vibrating element, environments for one or more mechanically-vibrating physical elements, such as strings, tynes, bars, plates, membranes, etc., as described in U.S. Patent 6,610,917. Although illustrated in the context of musical instrument applications, the systems and methods are also applicable to manufacturing, mechanical testing, micro electro-mechanical systems (MEMS), and other application areas.

One of the technologies and methodologies provides for driving vibrating elements with external audio frequency electrical signals. This facilitates external loop signal processing as well as induced sympathetic vibration stimulated by another signal source. Another provides for visual indication of one or more drive levels in very general electronically-driven vibrating-elements environments. Related considerations include selected pairs of variety of types of sense transducers (electromagnetic, piezo, Hall-effect, optical) and drive transducers (electromagnetic, piezo) in various advantageous configurations, for transducers associated with vibrating elements in isolated or grouped configurations, and for support in a generalized electronic instrument interface.

Further information regarding reference designs for the controller can be provided under negotiable terms. All financial or in-kind proceeds from such arrangements are used to fund academic research at New Renaissance Institute®.

1 Introduction

This whitepaper describes a family of technologies and methodologies expanding the capabilities of electronically-induced environments for one or more mechanically-vibrating physical element such as strings, tynes, bars, plates, membranes, etc., as described in U.S. Patent 6,610,917 [1]. The principle coverage provided by the patent is:

- Visual indication of one or more drive levels in very general electronically-driven vibrating-elements environments. Drive signals may be internally or externally generated;
- External drive signals used to stimulate a given vibrating element:
- External loop signal processing for the vibrating element;
- Induced sympathetic vibration stimulated by another signal source;

A number of related issued and pending patents address extensions of the technology to various musical instruments [2]-[7] and as part of a generalized electronic music instrument interface [8]-[9].

These patents describe the following additional areas which are thought to be patentable within the current active patent family (by virtue of the patent family file date) via one or more future patent filing(s)

- Implementation as part of a rich multi-channel signal processing environment;
- Use of a variety of types of sense transducers (electromagnetic, piezo, Hall-effect, optical) and drive transducers (electromagnetic, piezo) in particularly advantageous configurations;
- Vibrating elements sensed and/or driven in adjustable isolation or group configurations;
- Electromagnetic or other driven excitation of the vibrating elements (tynes, bars, plates, membranes, etc.) in non-stringed musical instruments;
- Structure as an add-on module for an instrument or to be built into an instrument;
- Use of a pitch shifter or octave divider (such as an inexpensive toggle flip-flop) to create a drive signal one octave lower than the string signal, to compensate for frequency doubling effect of a drive coil without a biasing magnet.

Although illustrated in the context of musical instrument applications, the systems and methods are also applicable to manufacturing, mechanical testing, micro electro-mechanical systems (MEMS), and other application areas.

Further information regarding reference designs for the controller can be provided under negotiable terms. All financial or in-kind proceeds from such arrangements are used to fund academic research at New Renaissance Institute®.

2 Driven Vibrating Element Environments

U.S. Patent 6,610,917 [1] provides for vibrating elements within an instrument to be set into vibration via electronically controlled or induced excitation from magnetic field, piezo electro-mechanical, or other electronically-driven or electronically-controlled excitation.

2.1 Single-Channel Pickups and Controlled Acoustic Feedback

Various types of electronic stringed instruments have been in common use within popular music for many years. Typically a single pickup is used to capture audio signals from all vibrating elements on the instrument (although there may be a plurality of such group pickups on a given instrument so as to obtain different selections of timbre).

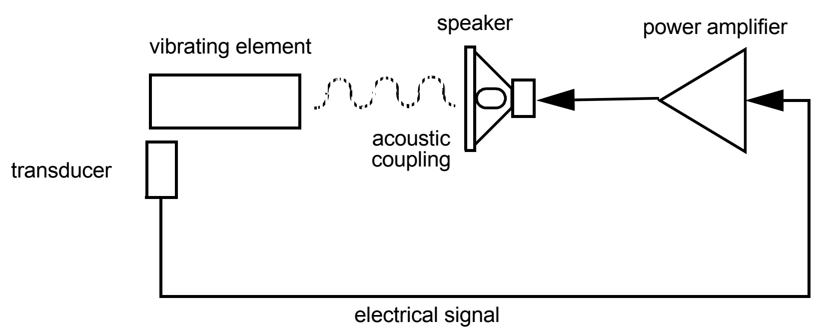

Figure 1

The use of "controlled (acoustic) feedback" with electronic stringed instruments has been in common use in popular music since at least the 1960's. Figure 1 shows the basic idea of controlled feedback as used in such contemporary music, prticularly *circa* 1962-68. A vibrating element within the instrument is coupled (by electromagnetic, optical, or mechanical means) to an electrical transducer (electromagnetic, optical, Hall-effect, piezo, etc.) which converts the vibration to an electrical signal. The electrical signal is applied to a power amplifier which drives a loudspeaker which is acoustically coupled (by means of air, mounting apparatus, etc.) to the vibrating element. This creates a feedback arrangement allowing vibrations of specific frequencies to resonate within the resulting closed-loop system. By exciting or damping the vibrations of the vibrating element, changing the characteristics of the frequency and/or phase response of the speaker's power amplifier, and/or changing the characteristics of the means of acoustic coupling (as in changing the distance between the vibrating element and speaker), the "controlled feedback" methods used in popular music are obtained. Note, however, that the required acoustic coupling characteristics are affected by factors such as volume level (typically this must be relatively high), speaker/room geometry, room acoustics, and other difficult to control factors that can often be unpredictable liabilities.

2.2 Vibrating Element Excitation via Drive Transducers

It has been possible to replace the acoustic excitation of string resonance with electromagnetic excitation for some time. The Heet Sound E-bow provides this only for one string at a time and via hand-held mechanically operated apparatus. A number of patents have developed this over a period of time for the isolated excitiation of individual strings via built-in arrangements that do not require damping of adjacent strings. The (electromagnetic or other) electronically driven excitation of the vibrating elements (tynes, bars, plates, membranes, etc.) in non-stringed musical instruments does not appear to be known or developed.

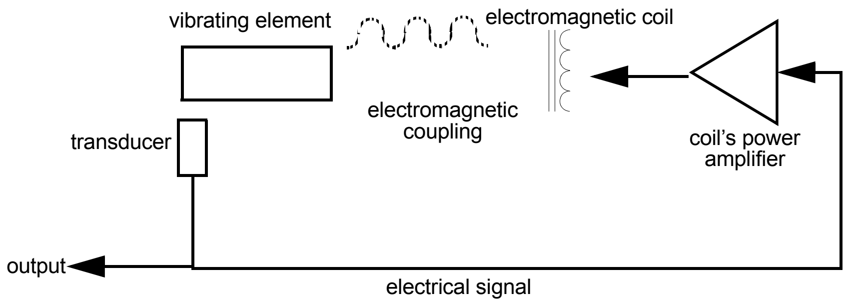

Figure 2

Figure 2 shows an example implementation of a simple approach for replacing acoustic excitation of a vibrating element with electromagnetic excitation. In this case the vibrating element must be ferromagnetic, although the transducer need not use ferromagnetic means itself. Here, rather, the acoustic coupling is replaced by electromagnetic coupling, produced by an electromagnetic coil with an internal magnet or other magnetic bias that replaces the speaker. Without this nominal magnetic field, the string will be excited with a full-wave rectification as the ferromagnetic string is drawn to the coil regardless of the direction of current flow. In this configuration, the power amplifier must now match the coil's electrical drive requirements which can differ from the speaker's, hence the speaker's power amplifier is replaced by the coil's power amplifier. A signal output for subsequent amplification and signal processing can be taken off at the transducer. The result is a system that provides a comparable arrangement to that of Figure 1, without the requirements of high volume level, speaker/room geometry, room acoustics, and other liabilities of acoustic coupling.

U.S. Patent 6,610,917 presents a system using drive transducer excitation of individual vibrating elements (or groups of vibrating elements) of an electronic instrument, to produce controlled feedback relationships with signal processing control of the feedback characteristics, typically hands-free as desired, with either standard parts (for inexpensive mass manufacture and retrofit), or more specialized parts (to provide additional features). The patent provides a number of approaches to replacing the acoustic excitation component of this process with drive transducer excitation.

2.3 Multi-Channel Vibration-Sense and Vibration-Drive Transducers

U.S. Patent 6,610,917 and its technology, pertains to the use of multi-channel electric transducer arrangements, by which each vibrating element (string, tyne, bars, plates, membrane, etc.) of an electronic instrument with multiple vibrating elements, is provided with an independent isolated electrical output, and dedicated signal processing can be applied to the signal of each vibrating element or incomplete combinations thereof, to achieve significantly important musical functions -- all done in a way where the same interfaces, multi-channel signal routing and processing, and internal instrument electronics, can be reused across a variety of instruments.

Traditionally the audio signals responsive to audio frequency vibration of the strings of an electric guitar almost universally employ a large winding-count coiled-wire electromagnetic pickup. To obtain isolated individual string signals, a multichannel transducer must be employed.

Standard vibration sensing transducer elements available to implement individual isolated signal pickups for each vibrating element include piezo contact elements, installed on a bridge acoustically isolated from other vibrating elements, and non-contacting coil-based electromagnetic pickup elements. Additionally, applicable optical and Hall-effect pickup methods have been devised [10]-[12] which do not involve contact with the vibrating element.

Typically a vibration sensing transducer element localized to an individual vibrating element has a small sensing geometry. For the pickup technologies not involving contact with the string (e.g., electromagnetic coils, Hall effect, and optical), multiple small pickups can be aligned along a vibrating element's length. The resulting multi-channel signal may be handled with multi-channel signal processing, selected by a switch, selectively mixed/ morphed, etc., to obtain a wide range of sound qualities, effects, and characteristics. The selection, mixing, and morphing of the multichannel audio signals may be implemented by a rich multi-channel audio signal processing environment operated by control signals.

2.3.1 Electromagnetic Coil Sense and Drive Transducers

The most commonly used approach to implementing individual isolated vibrating element sense transducers for each vibrating string of an electric or steel-string acoustic guitar is to employ a multi-coil electromagnetic pickup technology such as that found in the Roland GK-2 series pickups. Various types of such multi-coil multiple-output pickups, also called hexaphonic pickups, were employed by various manufacturers for guitar-to-MIDI interfaces. This was the case as well for the Roland GK-2 series pickups, but these pickups find wider non-guitar-to-MIDI use now since Roland's perfection of excellent pickup modeling technology for the GK-2 series signals, readily transforming the natively weak sound of the individual small winding-count GK-2 series pickup elements into a wide pallate of timbres. Similar pickups are also made by other manufactures, for example Shadow (Models SH 075-C6 and SH-1550-MU).

The individual transducer elements of early multi-coil electromagnetic pickup were often as simple as a few turns of wire about a small magnet, but more modern versions employ a pair of coils and magnets configured in a standard "humbucking" arrangement (complementary magnet pole directions and complementary winding directions) so as to significantly localize the magnetic coupling region about the coil. This helps reduce the response to adjacent strings, and reduces hum and other electromagnetically-induced noise so that the pickups can be used well at high gain.

Additionally, this type of pickup technology may also be used as a drive transducer, as an electromagnetic coil drive transducer would typically include an internal magnet or other magnetic bias. (Without this nominal magnetic field bias, the string will be excited with (what would amount) to a full-wave rectification as the ferromagnetic string is drawn to the coil regardless of the direction of current flow.) This is convenient, as a standard mass-manufactured item (i.e., Roland GK-2 series, Shadow series, etc.) can be used as a drive transducer.

As an alternate implementation, a pitch shifter or octave divider (such as an inexpensive toggle flip-flop) may be used to create a drive signal that is an octave lower than the string signal, to compensate for the frequency doubling effect of the full-wave rectification. This eliminates the need for the biasing magnet in the drive coil.

Figure 3a depicts an arrangement wherein each string is suspended over the bridge and is electromagnetically coupled to two electromagnetic coil pairs. Here, either coil may be used as the signal source or as the driver. In general, if both the sense and drive transducers associated with a given vibrating element involve electromagnetic processes (for example, using either coils or Hall for the sense transducer with a coil drive transducer), care must be taken to avoid undesirable magnetic coupling, not unlike that of an electric transformer. This effect may be minimized if said signal and drive elements are sufficiently separated and/or shielded, or otherwise localized (for example, with a two-coil/opposite-magnet arrangement).

2.3.2 Piezo Crystal Sense and Drive Transducers

Multi-channel piezo crystal vibration sensing transducer products in the form of guitar bridges and bridge saddles have been, and remain available, (for example, products by Shadow (Model SD 1600) and Graph Tech (GHOST Saddle Pickups). Figure 2 shows a setting where piezo crystal vibration sensing methods may be applied to obtain separate audio signals for each vibrating element of a multiple vibrating element instrument.

Since a general piezo crystal transducer element both converts mechanically-coupled audio-frequency vibrations into alternating current signals and, reciprocally, converts alternating current signals into mechanical vibrations, a piezo group element bridge pickup can be used, in lieu of a coil, either as the audio signal pickup or as a mechanical drive exciting element.

Further, since piezo crystal transducer elements are essentially non-responsive to magnetic fields (although there is a piezo-magnetic effect observed in metals, and appearing as small non-zero terms in the most general piezo behavior equations – see for example the International Union of Crystallography teaching pamphlet at http://www.iucr.org/iucr-top/comm/cteach/pamphlets/18/node3.html), piezo crystal transducer elements are a natural partner to the multi-coil electromagnetic pickup technology, described above, in implementing multi-channel vibration sense drive environments.

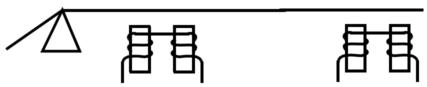

Figure 3a

Figure 3b

Figure 3b shows various combinations of piezo and electromagnetic coil transducers for use as isolated vibration sensing and separately controllable excitation of each vibrating element. In these arrangements, the string is in contact with a piezo transducer element on the bridge, and the string is magnetically coupled with an electromagnetic coil pair. In one implementation, the electromagnetic coil pair may be used as the drive transducer and the piezo transducer may be used for isolated vibration sensing. Alternatively, the roles of the electromagnetic coil pair and the piezo transducer may be reversed since each can act as the driver or as the signal source.

In an alternative piezo drive transducer arrangement, the vibration sense transducer may be optical or Hall effect (described below).

2.3.3 Optical Sense Transducers

Optical multi-channel vibrating string pickup technologies and products have been devised (for example (Ron Hoag [10], LightWave [11], Audio Optics, and perhaps others). These optical vibration sensing methods do not involve contact with the vibrating element.

Like piezo sense transducers, optical sense transducers do not require the string material to be ferromagnetic. Further, like piezo sense transducers, optical sense transducers are effectively not responsive to magnetic fields. Thus optical sense transducer elements are a natural partner in implementing multi-channel vibration sense drive environments utilizing multi-coil electromagnetic drive transducers. As mentioned above, they may also be used in partnership with piezo drive transducer arrangements.

Figure 2 shows a setting where optical vibration sensing methods may be applied for obtaining separate audio signals for each vibrating element of a multiple vibrating element instrument. As indicated above, the drive transducer may be an electromagnetic coil (as shown) or piezo crystal element.

2.3.4 Hall-Effect Sense Transducers

A Hall-effect solid-state semiconductor pickup method has been taught as U.S. patent 4,182,213 [12]. These Hall-effect vibration sensing methods do not involve contact with the vibrating element. Like electromagnetic sense transducers, Hall-effect sense transducers require the string material to be ferromagnetic.

Figure 2 shows a setting where Hall-effect vibration sensing methods may be applied for obtaining separate audio signals for each vibrating element of a multiple vibrating element instrument. The drive transducer may be an electromagnetic coil (as shown) or piezo.

If electromagnetic coils are employed as drive transducers, it is possible that undesirable magnetic coupling (similar to that of an electric transformer) may occur. This effect may be minimized if said signal and drive elements are sufficiently separated and/or shielded, or otherwise localized, (for example, where the electromagnetic coils employ a two-coil/opposite-magnet arrangement).

2.4 Applicable Sense and Drive Transducer Technology Combinations

Some transducer technologies are not applicable to drive transducers (Hall effect, optical) and some combinations of sense and drive transducer technologies (such as piezo drive with pieze sense) are intractable. The table below lists applicable transducer technology combinations and some comments as to particular potential implementation issues. Using electromagnetic drive transducers together with piezo or optical sense transducers are in theory the least problematic, but the other combinations can typically be made viable.

Configuration	**Sense Transducer**	**Drive Transducer**	**String Material**	**Potential Implementation Issues**
1	Piezo	Electromagnetic	Ferro	
2	Optical	Electromagnetic	Ferro, Non-transparent	
3	Electromagnetic	Electromagnetic	Ferro	Electromagnetic coupling of drive stimulus through ferromagnetic string
4	Hall-Effect	Electromagnetic	Ferro	Electromagnetic coupling of drive stimulus through ferromagnetic string
5	Electromagnetic	Piezo	Ferro	Acoustic propagation of drive stimulus through string
6	Hall-Effect	Piezo	Ferro	Acoustic propagation of drive stimulus through string

7	Optical	Piezo	Non-transparent	Acoustic propagation of drive stimulus through string

If both the signal and drive elements are electromagnetic (coils or Hall for signal pickup, coil for drive) undesirable magnetic coupling, not unlike that of an electric transformer, can occur. This effect may be minimized if said signal and drive elements are sufficiently separated and/or shielded or otherwise localized (for example, with a two-coil/opposite-magnet arrangement). If a piezo transducer is used as a drive element, aspects of the drive stimulus signal may acoustically propagate through string, and be picked up in some variate of its native form by the vibration-sense transducer. This may not be a problem, but in some situations the onset attack of the amplitude of the drive signal applied to the piezo drive transducer may be enlongated.

2.5 Groups of Vibrating Elements Sharing One or More Transducer(s)

The patented and patent-pending technology provides for the arrangements described above to apply whether the sense and driver transducers serve an individual vibrating element, or a group of vibrating elements. Also provided for are cases where either the signal source or driver is a single element unit, while the other is a group element unit, plus various hybrids of group and individual sense and drive arrangements with respect to the vibrating elements. In particular the patented and patent-pending technology additionally provides for the case where each vibrating element may be stimulated into vibration by any one or more of the following:

- individual source and individual excitation
- group source and group excitation
- individual source and group excitation
- group source and individual excitation

individually, or simultaenously, as will be discussed.

In most electronic instruments, a single vibration sense transducer (or pickup) is shared by many (in fact, typically all) the amplified vibrating elements. U.S. Patent 6,610,917 provides for the approaches discussed thus to also be applied to such instruments using conventional components. Figure 4 shows an example arrangement involving multiple vibrating elements sharing a common group sense transducer (or pickup) and which are also subjected to common electromagnetic excitation using conventional guitar pickup components. Signal processing may be introduced into the feedback loop as illustrated in Figure 5.

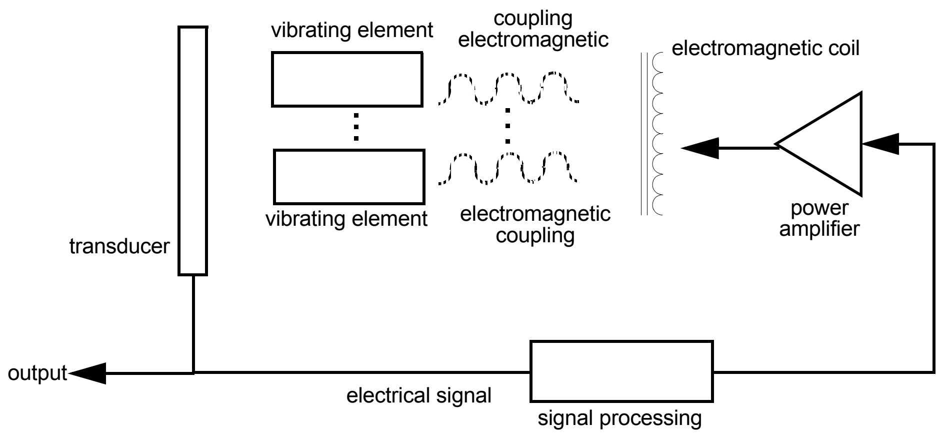

Figure 4

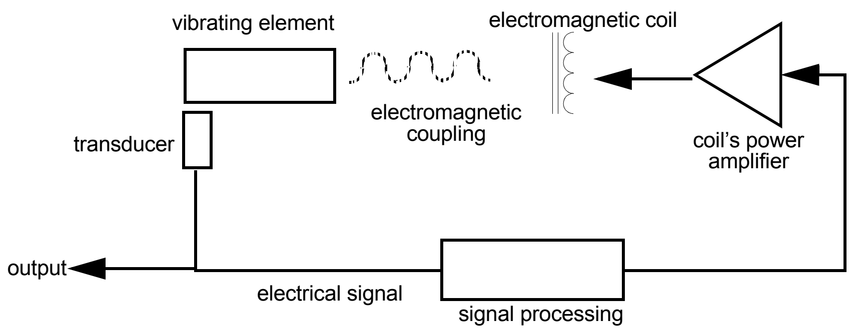

Figure 5

A group of vibrating elements additionally share not only a common group sense transducer (or pickup) but also a common group drive transducer. This arrangement is very simple to implement and very familiar to traditional electric guitarists in that all strings are simutaneously involved in a common feeback environment (just as with the controlled (acoustic) feedback induced by proximity to loud speakers and amplifiers). A simple illustrative demonstration of the general (common group sense transducer / common group drive transducer) principle can be readily made employing the slight rewiring of an electric guitar with two humbucking-pickups. The standard rear pickup can be used as the sense transducer and the standard front pickup can be used as the drive transducer. The humbucking pickups assist in decoupling the coils, decreasing the undesirable "transformer" effect mentioned earlier. Almost any power amplifier of sufficiently high enough current or voltage drive, (for example, even a Fender Bassman tube guitar amplifier) can be used as the drive signal amplifier, directly driving the (front pickup) drive transducer from the amplifier speaker output connector (this works very nicely, despite the significant impedance mismatch).

Less bombastic and more optimized implementations were introduced into a few commercially available mass-produced electric guitar models early in the Year 2000 decade. In fact implementations can be optimized well enough for very low power amplification to be sufficient. Tynes, bars, plates, membranes, and other vibrating elements may be employed in similar ways.

In a further enhancement of this (common group sense / common group drive) shared transducer arrangement described above, individually selected vibrating elements may be additionally excited within the group transducer environment by additional individual sense transducers, drive transducers, and associated isolated feedback loops. The additional isolated feedback loops may simply involve additional gain, but may also comprise additional signal processing, phase adjustment, equalization, special signal handling, or stimulus from external signal sources. This creates a hybrid group/individual electronically controlled feedback environment.

It is additionally possible to create a generalizated implementation which functionally spans all of the arrangements described above. Such arrangements are provided for by U.S. Patent 6,610,917 and other pending patents (see for example U.S. Pre-Grant Patent Application 2004/0069126 [8]). In one such implementation, each vibrating element is provided with its own sense and drive transducers, and one or more matrix mixer and/or switching systems may be used to combine and route signals. The matrix mixer and/or switching systems provide an enviroment where:

- each individual sense transducer signal can be directed to any one or more individually selected drive transducers or signal processors;
- each individual drive transducer can be driven by any individually-selected one or combination of sense transducer signals, signal processor outputs, and externally provided signals (described below);
- the inputs of individual signal processors can be driven by any individually-selected one or combination of sense transducer signals, other signal processor outputs, and (if employed) externally provided signals;
- the outputs of each individual sense transducer signal, each signal processor, and (if employed) externally provided signals, may be selectively mixed to form one or more outgoing audio signals for recording, amplification, or further processing.

Such an arrangement is shown in Figure 6a and Figure 6b. Since each individual drive transducer can be driven by any individually-selected one or combination of sense transducer signals, a common group sense transducer can be flexibly synthesized in fixed, variable, or programmable arrangements. Further, since each individual drive transducer can be driven, at least in part, by the same set of signals, a common group drive transducer can also be flexibly synthesized in fixed, variable, or programmable arrangements. Finally, since any of these common group transducer configurations can be supplemented with additional signal routes added into the various drive signal mixes, the hybrid group/individual electronically controlled feedback environment can also be flexibly synthesized in fixed, variable, or programmable arrangements. More as to this will be discussed in the sections that follow.

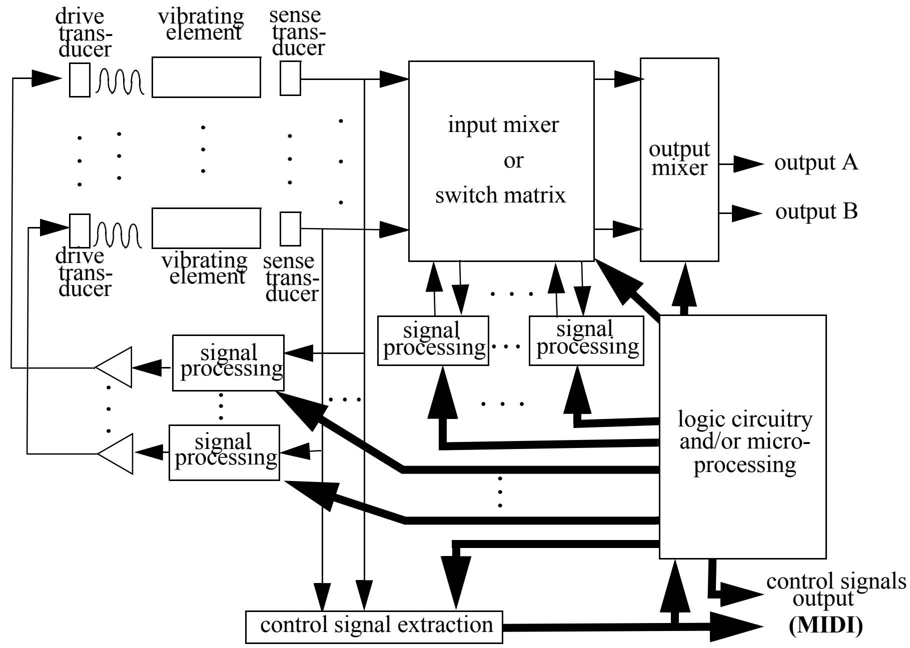

Figure 6a

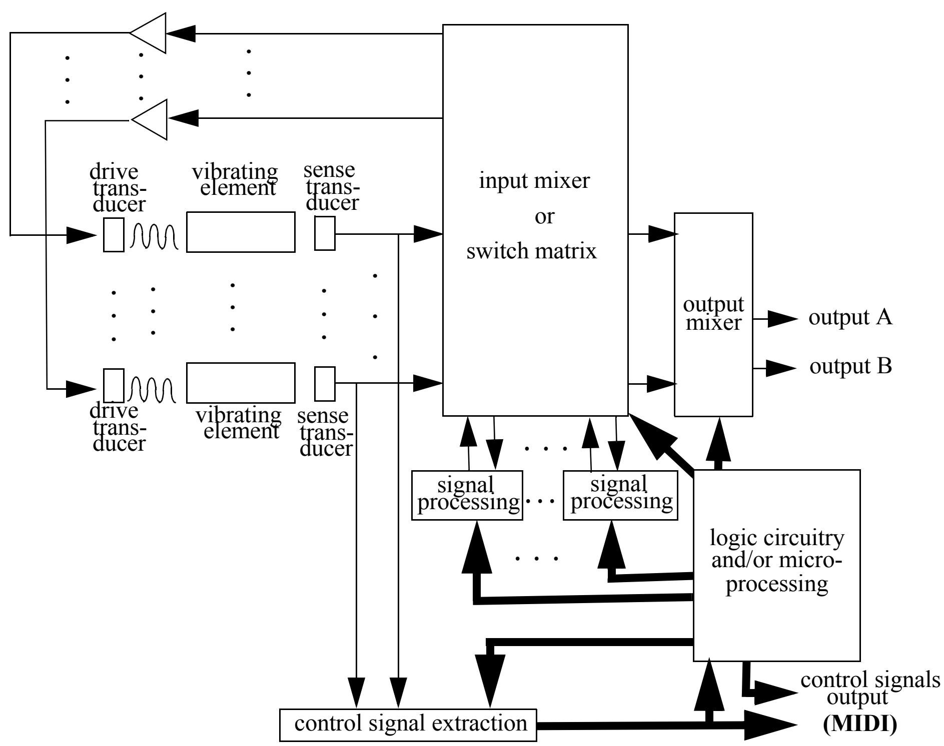

Figure 6b

3 External Drive Signals

U.S. Patent 6,610,917 provides for external drive signals used to stimulate a given vibrating element. A number of related issued and pending patents address explicit application and extensions of this technology to various specific musical instruments [2]-[7] and as part of a generalized electronic music instrument interface [8]-[9].

External drive signals arrangements may be used for external loop signal processing in the feedback stimulation of a vibrating element. Additionally, this arrangement may also be used for inducing sympathetic vibration, stimulated by another signal source. Each of these is described in turn below.

3.1 External Loop Signal Processing

Since drive transducers may be mounted in permanent relation to the vibrating element, it is possible to replace conventional means of altering or replacing acoustic coupling mechanisms with electronic signal processing means. Figure 5 shows the addition of signal processing in the feedback loop for spectral and amplitude control of electromagnetic excitation. Some examples of such signal processing include:

- Fixed, dynamically controllable, or automatic adaptive equalizers can be used to alter the frequency and phase response of the signal/vibrating-element/transducer feedback loop, permitting additional control over which vibrational harmonic(s) are emphasized in the feedback;
- Controllable attenuation can be used to vary the degree of feedback;
- Envelope-generated amplitude envelopes may be used to:
- alter attack characteristics;
- provide a simulous gesture;
- Short delays (where the delay time is integer multiples of a desired audio-frequency period) can be used to alter the attack characteristics of the resonance behavior and other effects;
- Dynamic compressors and expanders can be used to vary the degree and dynamic variation of the resonance behavior;
- Many interesting special effects are possible:
  - Use of pitch-shifters to transfer energy among vibrational modes:
    - alone or in combination with delays,
    - with fixed or time-varying parameter settings,
    - continuously or for limited durations of time;
  - Amplitude-modulation (Tremolo);
  - Frequency-modulation (Vibrato);

- Chorus/phase-shifting (to invoke mild dynamic variation);
- Reverberation;
- User-swept, LFO-swept, or amplitude-envelope-swept bandpass filters (Wah-Wah, Auto-Wah,and Dynamic-Wah/Picking-Wah).

Various aspects of U.S. Patent 6,610,917 provide for driver electronics and/or signal processing to lie in various physical locations:

- internal to the instrument,
- mounted on the outside of the instrument as an add-on module,
- remotely located off the instrument,

or combinations of these.

3.2 External Signal Sources and Externally-Induced Sympathetic Vibration

The patent additionally provides for stimulation of a vibrating element by an external signal source. The elements that are driven into vibration may comprise strings (the usual choice for a sympathetic vibrating element) or other elements such as tynes, bars, membranes, plates, etc. This may be used for inducing sympathetic vibration of one or more vibrating elements, as well as for other purposes.

Groups of sympathetic strings have been utilized to expand the ambience of an instrument. Although most frequently associated with the Indian sitar, groups of sympathetic strings have in the past often been applied to or incorporated into various acoustic instruments:

- In the European Baroque Period, the viola (viola d'amore) and baryton;
- in traditional South Asian music, the dilruba, esraj, saringa, vina, gottuvadhyam/chitravina, sarod, etc.;
- Various other European instruments (Swedish nyckelharpa, Norwegian hardingfele, aliquot/Bluthner piano [14].

More recently, groups of sympathetic strings have been applied to yet other instruments:

- The Dan Electro sitar guitar heard in many popular music recordings;
- The elegant acoustic Bazantar adapted upright bass [15];
- An experimental large-scale electronic harp [16].

Sympathetic string effects are also endenic to many instruments incorporating arrays of strings, providing indigenious ambience effects in instruments such as the harp, koto, zither, autoharp, undampened piano, dulcimer family (Hungarian cymbalom, santour, hammer dulcimer, etc.). Acoustic sympatheic vibration effects of vibrating are somewhat involved in the vibrating tyne Mbira of Africa.

In providing for stimulation of a vibrating element by an external signal source, U.S. Patent 6,610,917 enables a number of ways of adding sympathetic vibrating elements to the sound of an electronic instrument. These include:

- Using pre-existing vibrating elements of an instrument (such as the standard set of guitar strings, Mbira tynes, orchestra bell bars, etc.);
- Adding new vibrating elements dedicated to sympathic applications to the instrument
- Providing remotely-located vibrating elements not attached to the instrument.

These capabilities allow sympathetic vibrating element sounds to be added to arbitrary modified or unmodified amplified or even purely electronic instruments.

Further, U.S. Patent 6,610,917 and other pending patents (see for example U.S. Pre-Grant Patent Application 2004/0069126 [8]) provide for the external signals to be routed to signal processing prior to drive transducers. Some noteworthy signal processing examples include:

- Dynamic compressors and expanders can be used to vary the degree and dynamic variation of the resonance behavior;
- Many interesting special effects are possible:
    - use of pitch-shifters, alone or in combination with delays, and continuously or for limited durations of time, to transfer energy among vibrational modes;
    - amplitude-modulation (Tremolo);
    - frequency-modulation (Vibrato);
    - chorus/phase-shifting (to invoke mild dynamic variation);
    - reverberation;

Applications to an electronic sitar and various East asian Instruments are also patent pending [3]-[4].

4 Incorporation into Multi-channel Rich Audio Signal Processing Environments

Exemplary implementations of a very general combined environment for multi-channel signal processing, mixing, excitation, and program control of overall configuration are provided in Figure 6a and 6b. These and a number of other rich multichannel audio signal processing configurations (simplified, enhanced, alternative) , which may omit, simplify, or expand any of the elements or configurations shown, are also provided for by U.S. Patent 6,610,917 and U.S. Pre-Grant Patent Application 2004/0069126 [8].

Figure 6a shows an arrangement where fixed or programmable signal processors are specifically dedicated to particular feedback loops. Each vibrating element is assumed to be provided with its own sense and drive transducers. One or more matrix mixer and/or switching systems may be used to combine and route signals so as to provide an enviroment where:

- each individual sense transducer signal can be directed to any one or more individually selected drive transducers or signal processors;
- each individual drive transducer can be driven by any individually-selected one or combination of sense transducer signals and externally provided signals;
- each individual drive transducer is provided its own dedicated signal processor which could be as simple as an amplitude control or on/off switch, and (especially if more sophisticated) may include a bypass function;
- the signals provided to each individual drive transducer may be pre-processed by either its dedicated signal processor or any of the pooled signal processors;
- the inputs of a pooled group of individual signal processors can be driven by any individually-selected one or combination of sense transducer signals, other signal processor outputs, and (if employed) externally provided signals;
- the outputs of each individual sense transducer signal, each signal processor, and (if employed) externally provided signals may be selectively mixed to form one or more outgoing audio signals for recording, amplification, or further processing.

Figure 6b shows a modification of the arrangement of Figure 6a, with no dedicated signal processors, but wherein signal processors used to process drive signals may be drawn from a common pool, shared across other function by means of mixers and/or switching elements.

These exemplary rich multichannel audio signal processing environments provide a separate flexibly adjustable and reconfigurable signal routing, mixing, and processing environment supporting one or more signal sources for each vibrating element. Each feedback loop may be allocated one or more signal processors, each with one or more parameters that may be controlled responsive to incoming control signals.

Also shown in each depicted examplary multichannel audio signal processing environment are control signal extraction elements for producing control signals responsive to signals from the individual sense transducers (for example issuing MIDI note-on and note-off messages including pitch and note-velocity information) for use in controlling synthesizers, signal processing elements, lighting, etc. These control signal extraction elements could additionally provide real-time control signals responsive to amplitude variations of the signals from the individual sense transducers. This is useful, as although the depicted exemplary rich multichannel audio signal processing environments are capable of uniformly sustained sounds from driven vibrating elements, the excitation and feedback environments lend themselves to dramatic swelling changes in amplitude and harmonic content. The variations in overall sense signal amplitude may be used to control very complex layered signal processing, synthesis, and mixing as described in U.S. Pre-Grant Patent Application U.S. Pre-Grant Patent Application 2004/0069128 [17]. Additionally, the dramatic The variations in overtone series amplitude distribution can also be measured and used as a control source as described in U.S. Pre-Grant Patent Application U.S. Pre-Grant Patent Application 2005/0120870 [18], enhancing all these capabilities yet further.

5 Role within Generalized Electronic Music Interfaces

U.S. Patent 6,610,917, along with U.S. Pre-Grant Patent Application 2004/0065187 [9], provide for the multi-channel transducers, rich multi-channel audio signal processing environments [8], MIDI components, video elements [19], multi-channel string drive signals, and other aspects to fit in a general framework supporting a wide range of instruments, application settings, and external support equipment configurations.

Figure 7 depicts the basic concept of a generalized electronic music interface capable of carrying a wide range of multi-channel audio signals, along with MIDI, video, string-drive signals, etc. This arrangement permits:

- Support of a wide range of electronic instruments;
- Support of a wide range of electronic instrument enhancements, such as wide multi-channel output, multi-channel drive signals, video, MIDI output, configuration-controlling MIDI inputs, controllable intrument lighting, etc.
- A number of signal transport and connector interface approaches;
- Support of a wide range of signal routing, signal processing, control signal extraction, audio synthesis, video display, video recording, live perfomance, audio recording, and educational recording/presentation systems;
- Simultaneous independent bidirection capabilities;
- Opportunities for a resonable degree of integrated instrument powering support.

The signal routing, processing, and synthesis portion of the arrangement depicted in Figure 7 may host a wide range of instruments, instrument functions, instrument capabilities, and applications [2]-[7]. These may include the multi-channel signal processing environments described U.S. Pre-Grant Patent Application 2004/0069126 [8] and summarized above. The same multichannel signal processing environments can also support an enhanced pedal steel guitar [2], a transcended South Asian multi-channel electronic sitar [3], an expanded East Asian multi-channel electronic koto (Japan), sheng(China) or komun'go (Korea) [4], an adapted African electronic mbira, an adapted European lute/chitarone/theorbo, etc. as well as current and enhanced standard faire of Western electric guitars, basses, and keyboards. Any of these which may employ electronically driven vibrating element excitation (in particular [2]-[3], as well as Western electric guitars and basses) may employ the generalized interface to carry multi-channel vibrating element sense signals, multi-channel vibrating element drive signals, and/or control signals that are useful or relevant in support of the arrangements described in U.S. Patent 6,610,917.

Figure 8 illustrates two example generalized interface cabling and connector arrangements. Figure 8a depicts a tightly integrated, newly-defined formal cabling and connector interface. Signal transport may include optical methods, multiplexed digital formats, etc. as well as analog signals where advantageous (for example in video transport). This tightly inte-

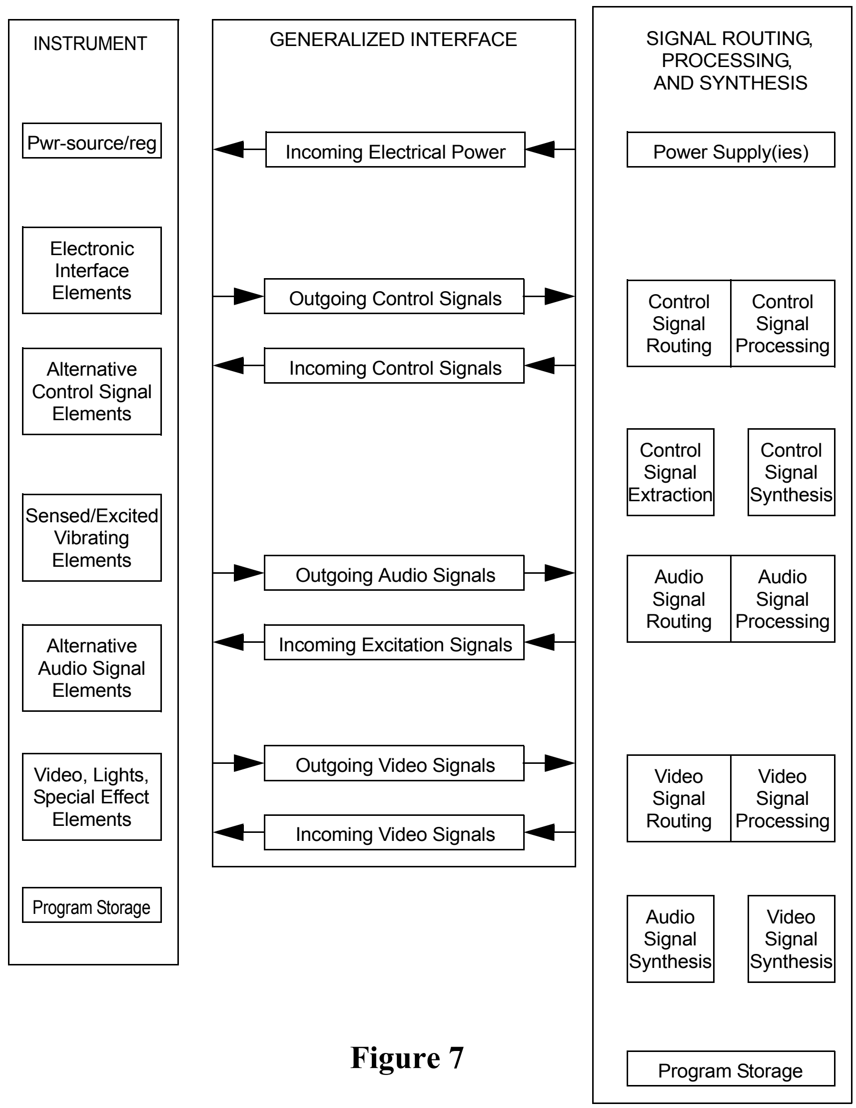

Figure 7

grated, multiplexing-oriented approach also lends itself readily to wireless signal transport. In contrast, Figure 8b depicts a cabling and connector approach leveraging existing standards and connector formalisms. Such a raw "hydra" connector approach (in various forms including or omitting selected connectors and associated sub-cabling) readily interfaces with legacy equipment. The two approaches depicted can readily interwork via interface adapters.

6 Visual Activity Indication

U.S. Patent 6,610,917 provides for light-emitting visual indication, configured on the instrument, of one or more of the drive levels in very general electronically-driven vibrating-element environments. The very general electronically-driven vibrating-elements include vibrating-elements environments internally generated or externally provided drive signals, which may or may not have been signal processed.

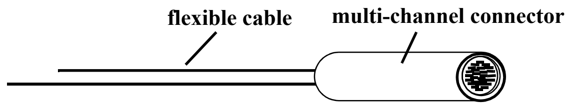

Figure 8a

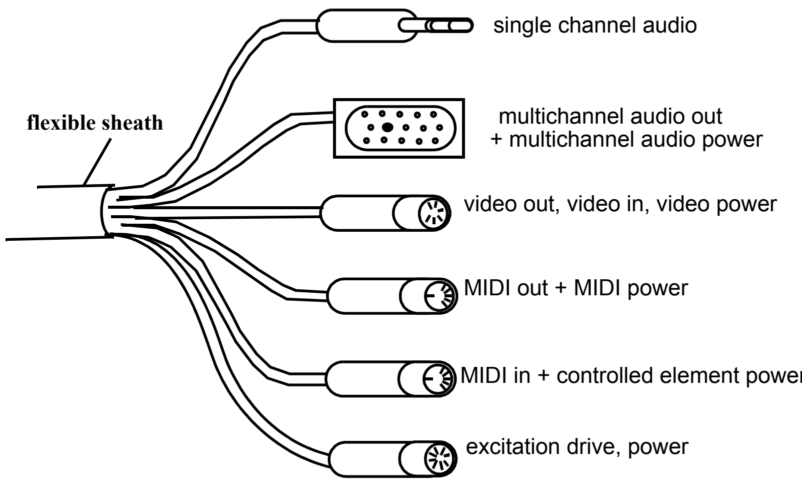

Figure 8b

Individual string drive signal level (or sensed string activity) can be visually indicated by, for example, LED technology. In performance situations, it may be preferred to employ high-brightness light-emitting visual indicators. The patent provides for very general light-emitting arrangements, so other types of lighting (including high-intensity strobe lights) may be used. The light-emiting visual indication may comprise a fixed color, varying color, etc.

A group of such visual activity indication light-emitting elements may be configured on the instrument as an array under or geometrically aligned with the vibrating elements. (In the case of a guitar, this may be located, for example, under the guitar strings, at the bridge, in the area of the tuning heads, on the neck under the associated string, etc.) The light-emitting elements may face the audience or by directed to illuminate the string area or individual vibrating elements. In the case of instruments with translucent vibrating elements, the vibrating elements themselves may be illuminated in response to the drive signals. In the case of instruments with highly reflected vibrating elements, visual activity indication emitted light may be bounced off the the vibrating elements. The light-emitting elements may also be integrated together with the drive transducers, sense transducers, or both.

7 Add-On Module for Electric Guitars

The various technologies described may be packaged in various ways. For some instruments and features it may be more commercially viable to build-in the technology, while for other instruments and features, mass-produced field-installable modules may be a good approach. This section illustrates a few examplary types of modules which may be taylored for factory installation, field-installation, or both.

Some possible approaches to such add-on modules may collocate the drive and sense transducers in a common housing, or employ more than one housing. Alternatively, the add-on module may provide drive transducers but not sense transducers, using signals from commercially available multi-channel sense transducers (such as the Roland GK-2, Shadow series, Graph Tech, etc.).

The forms of add-on modules described below may be further provided with various switches and slider controls, etc., for control of the various features. Further, individual string excitation, or more general string activity, can be visually indicated by an LED (preferably high-brightness) array, under or geometrically aligned with the strings.

Through the use of high-density surface-mount technology, miniature VLSI processors, appropriate shielding, etc., various degrees of electronics (from very low levels to very high levels) may be internally included in the module. For example, each of the examplary modules may, as per product design choices, include drive amplifiers, special effect signal processing, pickup-modelling signal processing, visual activity indicators, MIDI-based control input, control signal extraction with MIDI output, single or multiple-channel audio output, etc. The drive-only modules discussed would require multichannel audio-signal input.

With highly-miniaturized integrated electronics, it is not unlikely that guitar pickups of the future may include separate sense transducers for each string, built-in reconfigable special effect signal processing, pickup-modelling signal processing, visual activity indicators, MIDI or other standardized control signal input, control signal extraction with MIDI or other standardized control signal output, single or multiple-channel audio outputs, etc., with available options for integrated drive transducers.

7.1 Surface-Mount Drive Transducer Modules

Figure 9 illustrates a surface-mount style of add-on module directed towards electric guitars. Figure 9a illustrates a possible self-contained which includes sense transducers and drive transducers. The sense transducers employed may be electromagnetic coil, Hall-effect, or optical, while the drive transducers may be electromagnetic coil. Figure 9b illustrates a possible drive transducer array utilizing signals provided from commercially available multi-channel sense transducers (such as the Roland GK-2, Shadow series, Graph Tech, etc.) located elsewhere.

Each of the examplary modules depicted in Figure 9 are thin enough to mount on the surface of an instrument such as a guitar, pedal steel guitar, bass, etc. without the requirement of a mounting cavity.

Each examplary module is depicted with at least one interfacing cable but may additionally, or instead, utilize one or more connectors for power, audio, and control signals.

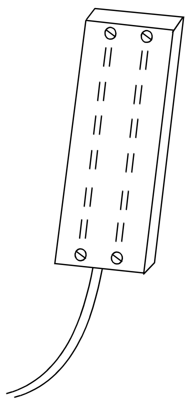

Figure 9a

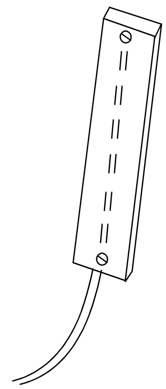

Figure 9b

7.2 Pickup-Style Drive Transducer Modules

Figure 10 illustrates a traditional pickup-cavity style of add-on module also directed towards electric guitars. Figure 10a illustrates a possible self-contained which includes sense transducers and drive transducers. The sense transducers employed may be electromagnetic coil, Hall-effect, or optical, while the drive transducers may be electromagnetic coil. Figure 10b illustrates a possible drive transducer array utilizing signals provided from commercially available multi-channel sense transducers (such as the Roland GK-2, Shadow series, Graph Tech, etc.) located elsewhere. Each examplary module is depicted with at least one interfacing cable but may additionally, or instead, utilize one or more connectors for power, audio, and control signals.

7.3 Bridge-Saddle and Associated Modules

An additional format for transducer modules involves configurations explictly involving bridge-saddle transducers. Although other transducer technologies may be used, bridge-saddle transducers provide a natural setting for piezo crystal transducers.

Hexaphonic piezo crystal bridge-saddle transducers which function as sense transducers are commercially available from Shadow, Graph Tech, and other manufacturers. However, because of their reciprocal nature, piezo crystal transducers may be used as sense transducers or drive transducers. Thus these products may be adapted to serve as drive transducers or dual-use sense/drive transducers. As such they apply in manners decribed earlier. Further, they may be used in either fixed-tension bridges or the bridges built into various types of vibrato tailpieces (such as locking-nut vibrato tailpieces pioneered and patented by Floyd Rose™.

A hexaphonic piezo crystal bridge-saddle transducer may be combined with another second array of transducers of the profile of Figure 9b or Figure 10b. In one possible implementation, the module of Figure 9b or Figure 10b may comprise electromagnetic coils and either can be used as sense or drive transducers in various configurations (including both as sense transducers and both as drive transducers) so as to obtain a variety of effects. Because the bridge area is part of the module, activity indication my involve light-sources in the bridge itself (as well as the pickup).

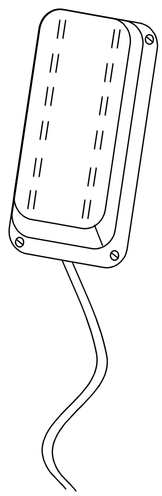

Figure 10a

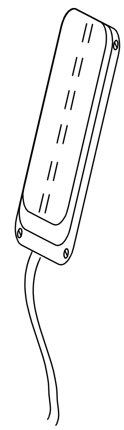

Figure 10b

Figure 11a shows an illustrative example of a hexaphonic piezo crystal bridge-saddle transducer combined with a second transducer array in a common module featuring a fixed-tension bridge. Figure 11b shows an illustrative example of a hexaphonic piezo crystal bridge-saddle transducer combined with a second transducer array in a common module featuring a bridge built in an examplary vibrato tailpiece.

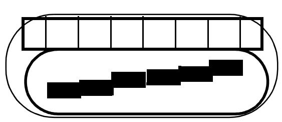

Figure 11a

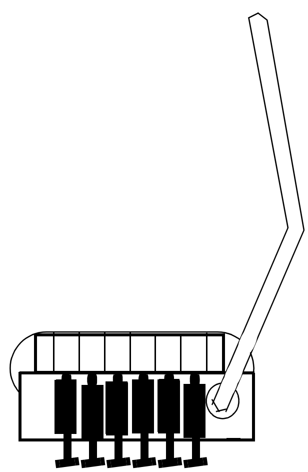

Figure 11b

7.4 Electronics-only Modules

Since commercially available hexaphonic coil and piezo transducer arrays are available from a number of manufacturers, it is possible to provide a pure electronics module to interface with these and provide the types of functionality described in U.S. Patent 6,610,917 and this whitepaper.

Such an electronics-only module may, as per product design choices, include drive amplifiers, special effect signal processing, pickup-modelling signal processing, visual activity indicators, MIDI-based control input, control signal extraction with MIDI output, single or multiple-channel audio output, etc. It can provide mating connectors for one or more Roland GK-2 series multi-coil pickup multi-pin interface connector, Shadow multi-coil pickup multi-pin interface connector, Shadow pickup piezo multi-pin interface connector, Graph Tech bridge pickup piezo multi-pin interface connector, etc. If more than one connector is provided, associated specialized interface electronics can also be included so that all supported transducer products work well. It can also permit any transducer to function as a sense or drive transducer via mode-selection settings.

8 Application to Electric Guitar, Electric Bass, and Pedal Steel Guitar

In this section, application of the technologies described in this whitepaper and associated NRI patents to electric guitar, electric bass, and pedal steel guitar.

Figure 12a illustrates one example application to a fixed-tension bridge guitar. Here a hexaphonic bridge piezeo transducer array and a hexaphonic coil transducer array are used. They may be integrated into a single module, or may be separately installed elements, and may share other functions (acoustic guitar tone emulation, guitar synthesizer interfaces, etc.). Either transducer to function as a sense or drive transducer via mode-selection settings. Any activity indication may be done in either transducer array area, or may be located elsewhere on the instrument. Any supporting on-instrument electronics may be incorporated within the instrument or within surface-mounted control panels. The provided controls depicted may additionally support other uses, such as transmitting MIDI commands. Alternatively, no instrument-mounted controls may be provided, and all may be controlled by incoming MIDI commands.

It is understood that many other configurations are possible. For example, Figure 12b illustrates another example application to a fixed-tension bridge guitar. Here a larger surface-mounted electronics and control module is shown. (This could of course be built into the instrument). Here at least two hexaphonic coil transducer arrays are used. Additionally, the electronics package may support additional transducers, for example a hexaphonic bridge piezeo transducer array and use of, for example, the front electromagnetic coil pickup as a group sense/drive transducer. Any transducer to function as a sense or drive transducer via mode-selection settings. The provided controls depicted may additionally support other uses, such as transmitting MIDI commands. Any activity indication may be done in the transducer array area, or may be located elsewhere on the instrument, for example in the string fan between the bridge and the suspended tailpiece.

As yet another alternative, the basic guitar employed in Figures 12a and 12b could simply replace one of its standard pickups with a self-contained module of the type depicted in Fig-

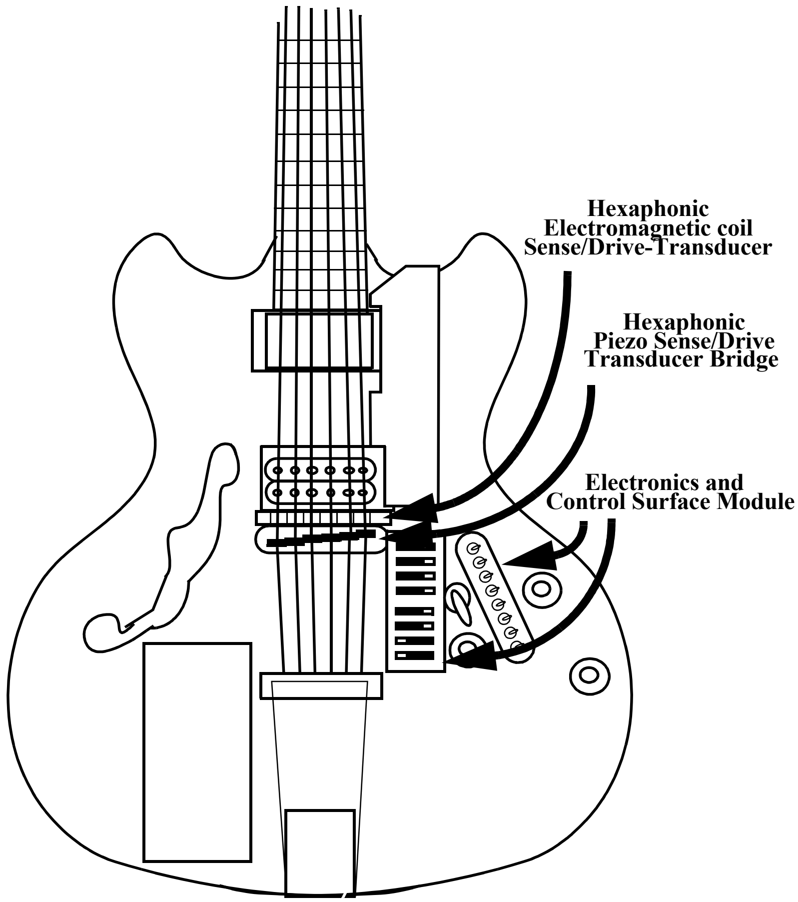

Figure 12a

ure 10b, or add the surface-mounted version depicted in Figure 9b with no replacement of the standard pickups.

Figure 13a illustrates one example application to a sophsticated instrument built around a vibrato tailpiece guitar. A hexaphonic bridge piezeo transducer array, incorporated into the vibrato tailpiece, and a hexaphonic coil transducer array are used. These may be integrated into a single module, or may be separately installed elements, and may may share other functions (acoustic guitar tone emulation, guitar synthesizer interfaces, etc.). Additionally, the electronics package may support additional transducers, for example a hexaphonic coil transducer array and use of, the front electromagnetic coil pickup as a group sense/drive transducer. Any transducer to function as a sense or drive transducer via mode-selection settings. Any activity indication may be done in either transducer array area, or may be located elsewhere on the instrument. Figure 13b shows the principal use of a self contained module of the type depicted in Figures 9b or 10b. Additionally, the electronics package may support additional transducers, for example either (or both) of the two standard pickups and perhaps a hexaphonic coil transducer array.

The sophsticated instrument of Figures 13a and 13b may also includes an additional string array, depicted in the lower left corner. This string array may serve as a mini-harp or zither, or as an acoustically coupled sympathetic string array. However, its strings may be electronically stimulated into vibration by drive transducers.

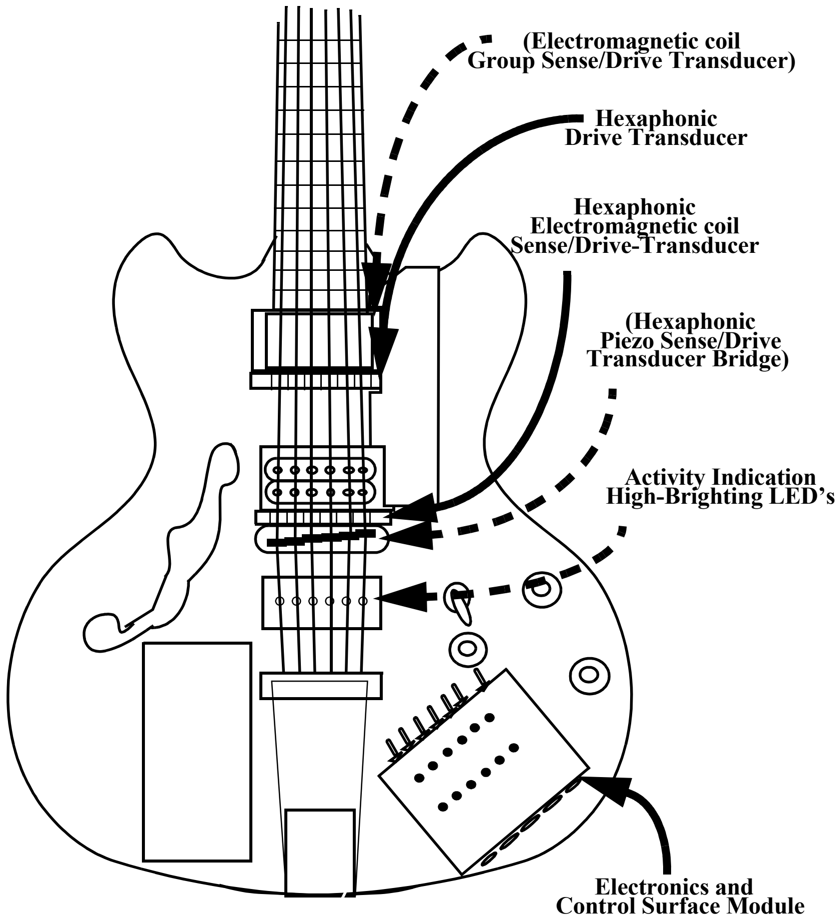

Figure 12b

Although not shown, the same techniques and methods also be applied to electric bass guitar, electric mandolins, and other related instruments.

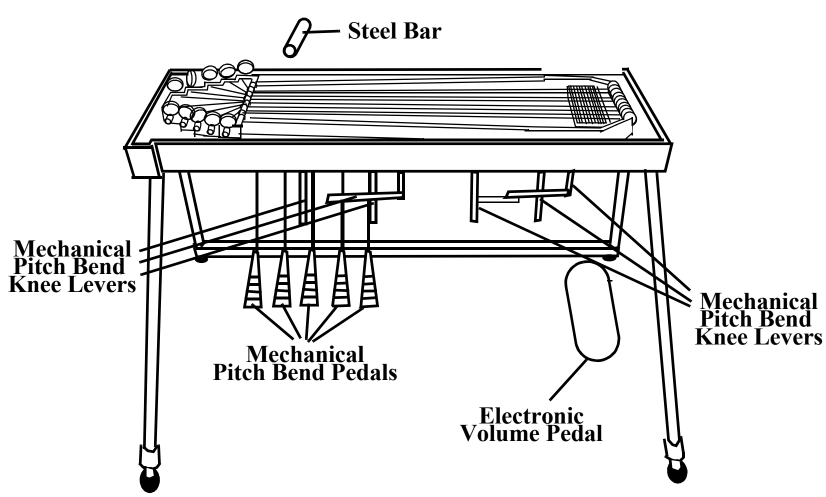

Figure 14

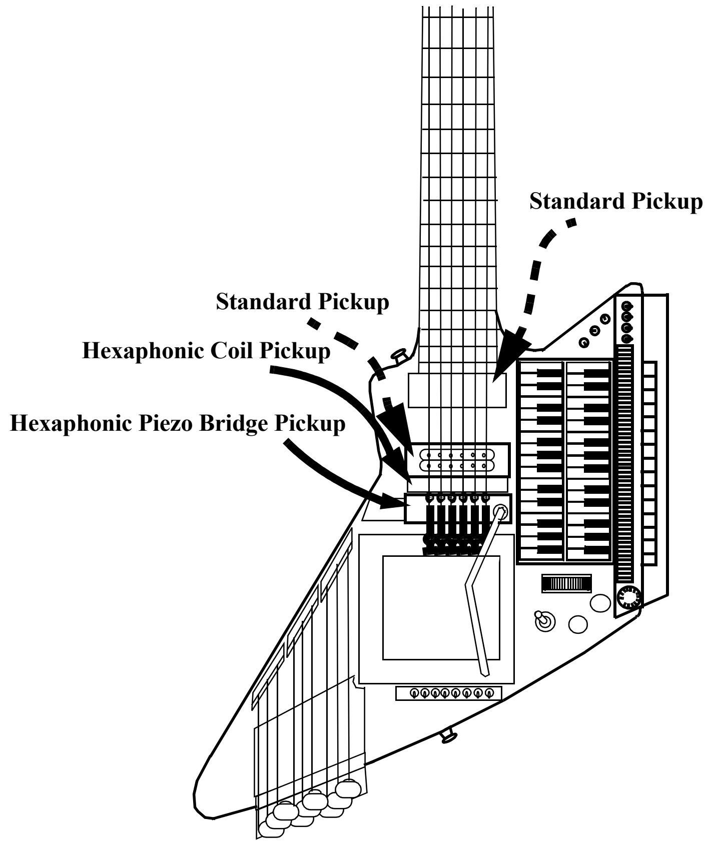

Figure 13a

Figure 14 shows a pedal steel guitar. The methods, techniques, and technologies described in this whitepaper may also be naturally applied to this instrument. In particular, the pedal steel guitar can be extensively enhanced and generalized though use of a rich multi-channel audio signal processing environment as described in U.S. Patent 6,852,919 [2] and extensively discussed in its associated whitepaper [20]. The rich multi-channel audio signal processing environment readily supports the use of drive transducers and signal processing in the contexts considered in the present whitepaper.

9 Application to Asian and African Instruments

Figure 15 illustrates an electronic sitar as described in U.S. Pre-Grant Patent Application 2004/0099131 [3]. The instrument may include both the traditional acoustically-coupled sympathetic strings, as well as an additional string array, depicted in the left side. This additional string array may serve as a mini-harp or zither, or as an additional electronically stimulated sympathetic string. The traditional acoustically-coupled sympathetic strings may also be electronically stimulated into vibration by drive transducers. Additionally, the methods, techniques, and technologies described in this whitepaper may also be naturally applied to other strings of this instrument. In particular, the sitar can be extensively enhanced and generalized though use of a rich multi-channel audio signal processing environment as described in U.S. Pre-Grant Patent Application 2004/0099131 [3]. The rich multi-channel audio signal processing environment readily supports the use of drive transducers and signal processing in the contexts considered in the present whitepaper.

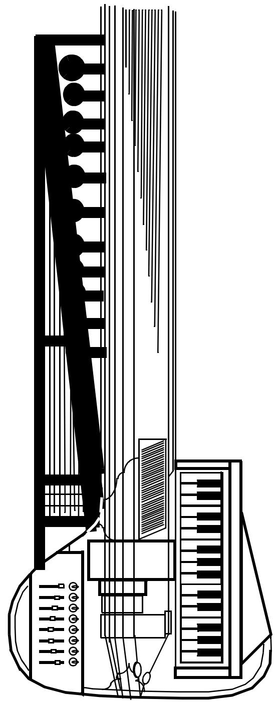

Figure 15

Figure 16 illustrates a traditional Chinese pipa adapted for electronic use as described in U.S. Pre-Grant Patent Application 2004/0069127 [4]. The adaptation depicted also includes two additional string arrays. These string arrays may serve as a mini-harp or zither, or as an acoustically coupled sympathetic string array. These strings may be electronically stimulated into vibration by drive transducers. Additionally, the methods, techniques, and technologies described in this whitepaper may also be naturally applied to principal strings of this instrument. In particular, the pipa can be extensively enhanced and generalized though use of a rich multi-channel audio signal processing environment as described in U.S. Pre-Grant Patent Application 2004/0069127 [4]. The rich multi-channel audio signal processing environment readily supports the use of drive transducers and signal processing in the contexts considered in the present whitepaper.

Figure 17 illustrates a traditional Japanese Koto adapted for electronic use as described in U.S. Pre-Grant Patent Application 2004/0069127 [4]. The adaptation depicted includes both piezo bridge transducer arrays and electromagnetic coil transducer arrays. Either of these transducer arrays may be used to electronically stimulate selected strings into vibration. The traditional koto can be extensively enhanced and generalized through use of a rich multi-channel audio signal processing environment as described in U.S. Pre-Grant Patent Application 2004/0069127 [4]. The rich multi-channel audio signal processing environment readily supports the use of drive transducers and signal processing in the contexts considered in the present whitepaper. The methods, techniques, and technologies described in this whitepaper may thus be applied to strings of this instrument.

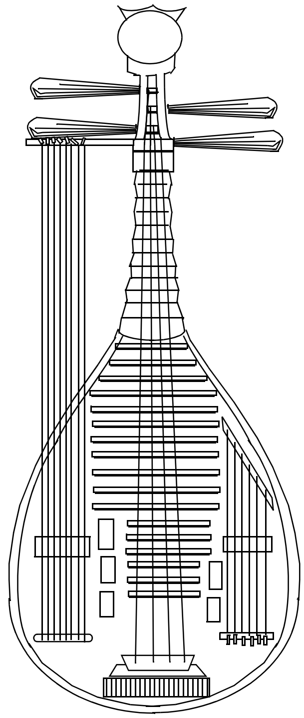

Figure 16

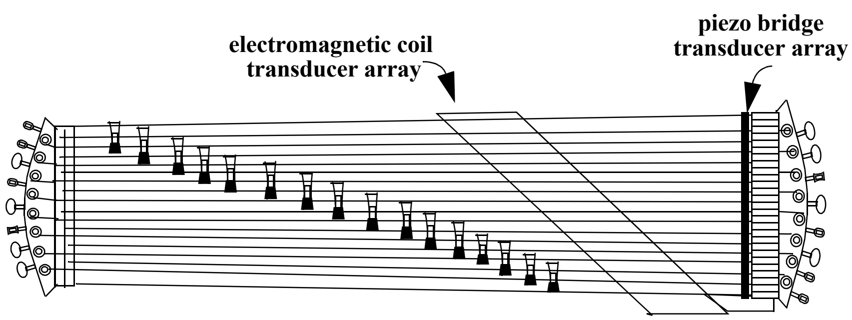

Figure 17

Figure 18 illustrates a traditional African mbira adapted for electronic use. It is one of many multichannel electronic instruments described in U.S. Pre-Grant Patent Application 2004/0069126 [8] and U.S. Pre-Grant Patent Application 2004/0065187 [9]. The adaptation depicted may include both piezo bridge transducer arrays and electromagnetic coil transducer arrays under the vibrating tynes. Either of these transducer arrays may be used to electronically stimulate selected tynes into vibration. The traditional mbira can be extensively enhanced and generalized though use of a rich multi-channel audio signal processing environment as described in U.S. Pre-Grant Patent Application 2004/0069127 [4]. The rich multi-channel audio signal processing environment readily supports the use of drive transducers and signal processing in the contexts considered in the present whitepaper. The methods, techniques, and technologies described in this whitepaper may thus be applied to strings of this instrument.

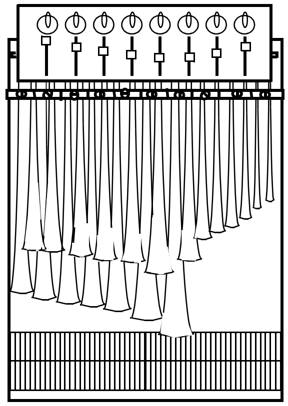

Figure 18

10 Other Non-Musical Application Areas

Although illustrated in the context of musical instrument applications, the systems and methods are also applicable to manufacturing, mechanical testing, micro electro-mechanical systems (MEMS), nanotechnologies, and other application areas.

11 Licensing

This document has sought to explain and illustrate the concept of the technologies as well as demonstrate the potential scope and areas of application. Further information regarding reference designs for these technologies can be provided under negotiable terms. All financial or in-kind proceeds from such arrangements are used to fund academic research at New Renaissance Institute. For further information, please contact New Renaissance Institute at inquiries@newrenaissanceinstitute.com.

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