

## **Extensions and Generalizations of the Pedal Steel Guitar**

### *ABSTRACT*

*This whitepaper describes a family of extensions and generalizations made to the pedal steel guitar by the pending U.S. Patent Application 6,852,919.*

*Separate transducers provided to each string permit fixed or variable pitch and timbre modifications determined by stored program control. Variable pitch and timbre modifications may be controlled by physical devices such as single or multi-parameter foot pedals, knee levers, and wrist controllers. Physical controllers may return to an original position or hold their position after operation. A traditional mechanical tuning changer operated by traditional foot pedals and knee levers may be included; the latter may operate physical controllers. The bar position may be sensed, and the bar may include physical controllers wirelessly linked to the instrument. A miniature keyboard and strum-pad may be provided in the picking area to control synthesizers and produce MIDI output. Strum-pad operation can be controlled with chord buttons, foot pedals, other physical controller devices, and/or measured string pitches. Physical controllers, string vibration, and other types of control devices may also be used to generate MIDI output.*

*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

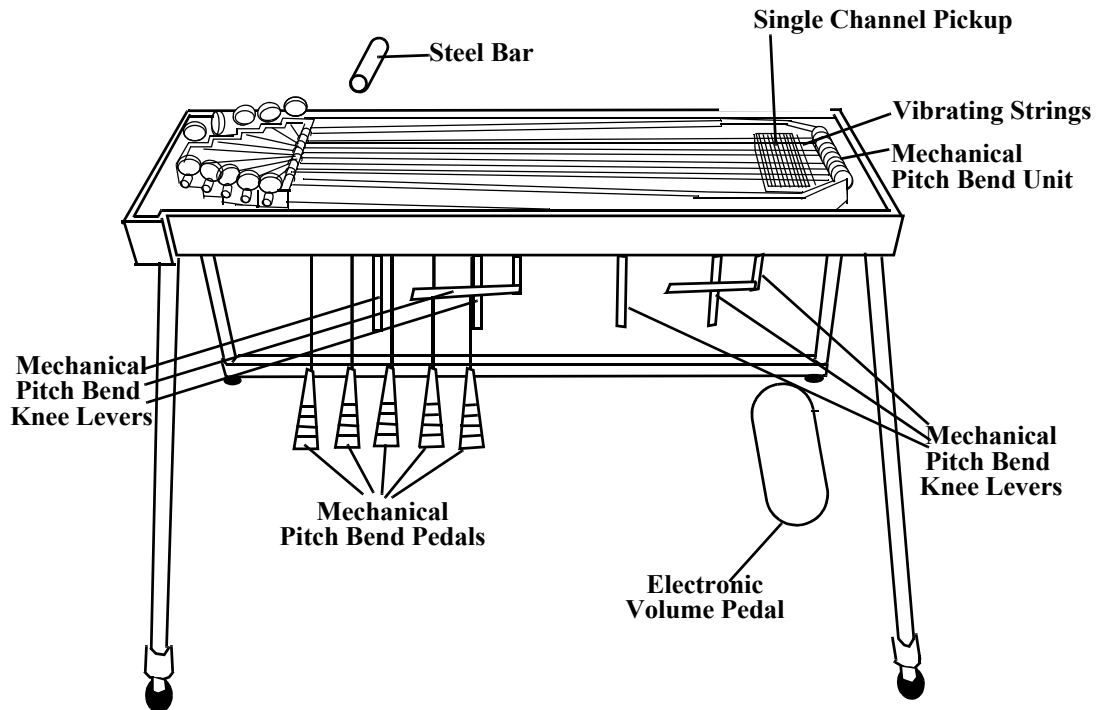
This whitepaper describes extensions and generalizations made to the pedal steel guitar by U.S. Patent 6,852,919 [1]. These extensions and generalizations comprise both technology and methods which include:

- Separate transducers provided to each string permit fixed or variable pitch and timbre modifications determined by stored program control;
- Addition of wrist controllers for volume, timbre, and pitch modification;
- Variable pitch and timbre modifications may be controlled by physical devices such as single or multi-parameter foot pedals, knee levers, and wrist controllers. These physical controllers may return to an original position or hold their position after operation;
- The bar position may be sensed, and the bar may include physical controllers wirelessly linked to the instrument;
- Physical controllers, string vibration, and other types of control devices may also be used to generate MIDI output;
- A miniature keyboard may be provided near the picking area to control synthesizers and produce MIDI output;
- A strumpad may be provided in the picking area to control synthesizers and produce MIDI output. The MIDI output is typically MIDI note events, and specific note pitches chosen, match that of a chord or scale relevant to the music at that moment. The note pitches issued by each strumpad switch during its operation may be controlled with chord buttons, foot pedals, or other physical controller devices;
- Electronic string excitation may be used to induce string vibration by means other than traditional picking. This may be used to create swells, fills, ambience, harmonic variation of a previously vibrating string, and other effects;
- A generalized interface compatible with other multi-channel audio instruments, and potentially also supporting MIDI and video, may also be incorporated into the instrument ;
- Video cameras may be added to the instrument for use in performance, music video production teaching/education, and video-responsive controller systems.
- A traditional mechanical tuning changer operated by traditional foot pedals and knee levers may be included which can additionally operate physical controllers.

Further information regarding reference designs for these and related 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<sup>®</sup>. For further information, please contact New Renaissance Institute<sup>®</sup> at [inquiries@newrenaissanceinstitute.com](mailto:inquiries@newrenaissanceinstitute.com).

## 2 Background of the Traditional Pedal Steel Guitar

The pedal steel guitar, depicted in Figure 1, is already a truly remarkable and well respected instrument. In its basic operation the pitches of individual strings are changed as a group by a hand-held metal slide, and relatively within the group by mechanical bridge arrangement, usually called a "changer," which adjusts the tension on one or more selected strings in response to the action of a given foot-pedal or knee lever. These developments have arisen from a long history of innovation, craftsmanship, and musicianship.



**Figure 1**

The basic sound of the steel guitar is very attractive and it is possible to tastefully play Bach chorales and hymns on the instrument. Years of incremental development have led to specific standard pedal and knee-lever configurations that are widely accepted.

Variations of the standard pedal and knee-level configuration are a continual topic of interest, but are often difficult or nearly impossible to implement because of mechanical limitations of the provided adjustments. Because of the commitment involved in mechanically establishing an alternate pedal and lever configuration, immense experience and/or a computer-aided design tool (such as that developed by NRI [10] ) may be required to make viable progress.

## **3 NRI Technology Enhancements and Extensions of the Pedal Steel Guitar**

In this section, a number of the exciting features and technologies covered in U.S. Patent 6,852,919 and related issued and pending patents, are described. These considerably extend, generalize, and expand the capabilities and applications of this remarkable instrument.

### **3.1 Electronic Pitch Bending**

The electronic pitch bending technology provided for in the patent opens new doors in this area. The electronic infrastructure needed for this, readily supports mixing of timbres, alternate tunings, and a number of other expansionary functions.

By providing a separate pickup for each string, pitch bending and open-string tuning can be done electronically, supplementing or even replacing the traditional mechanical pitch bending mechanisms. This approach offers a large number of progressive advantages:

- " Each string can be a candidate for pitch bending;
- " Pitch bending can be done in arbitrary directions and to arbitrary degrees;
- " The pitch bending of one or more strings may be assigned to any physical controller, and the pitch bending response of each controller (as a function of operational travel) may be readily adjusted;
- " Groups of two or more strings may bend their pitches together, each individually bent in arbitrary directions and to arbitrary degrees;
- " The open string tuning of the entire instrument may be subtly or radically modified without physically retuning the string;
- " An individual string can issue two or more pitches simultaneously (for example fixed octaves, fixed fourths/fifths, modulated intervals, etc.);
- " The audio signal of each string can also be timbrally processed (via equalization, pickup modeling, chorus, flanging, echoing delay, reverb, distortion, waveshaping, tremolo, electronic-vibrato, envelope-modulated filtering, etc.) individually or in groups as desired, allowing for subtle to wide mixes of timbres;
- " The audio signal of each string may be routed to two or more separate audio outputs, mixed into a stereo sound field with various fixed or moving pan-positions, etc., providing a wide range of additional audio sound-field effects;
- " Audio-to-control signal extractions can be used to control lead or background ambience synthesizers, signal processing, lighting, and special effects, either internally or via outgoing MIDI signals.
- " Settings for each of the many attributes listed above may be stored as a recallable and editable configuration. Many of these can be stored and instantly recalled, permitting rapid, flexible, and wide-ranging variation of the instrument at the touch of a button or floor switch.

Figure 2 shows an example of the adapted pedal steel guitar as provided for by U.S. Patent 6,852,919. (A number of other implementations will be described later.) In this embodiment, the traditional instrument arrangement is reorganized for at least some (if not complete) electronic pitch bending. The resulting instrument configuration may omit the traditional mechanical changer and linkages to pedals and levers, and instead all pitch bends may be implemented electronically. Electronic control signals may be issued responsive to one or more pedals and/or knee levers. One or more of the depicted rocker foot pedals may be fitted with side-mounted spring-lever controls to be described shortly.

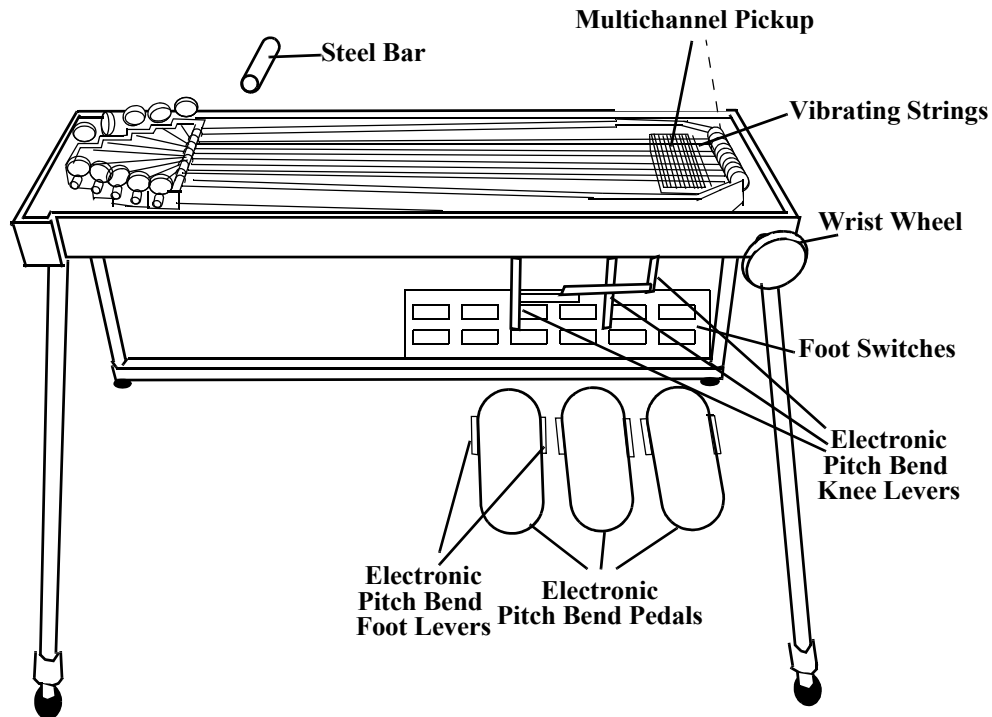


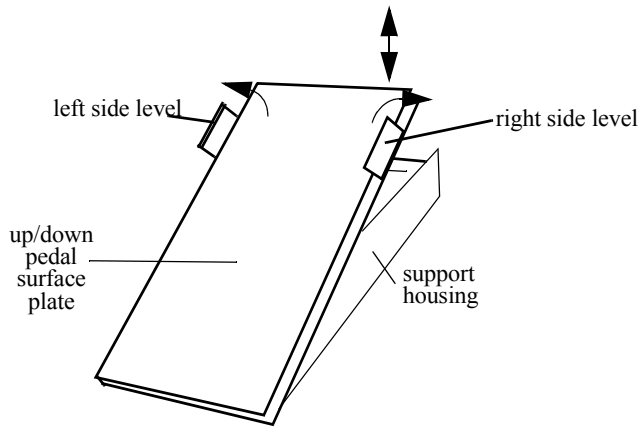
Figure 2

### 3.2 Enhanced Rocker Pedal Controller Technologies

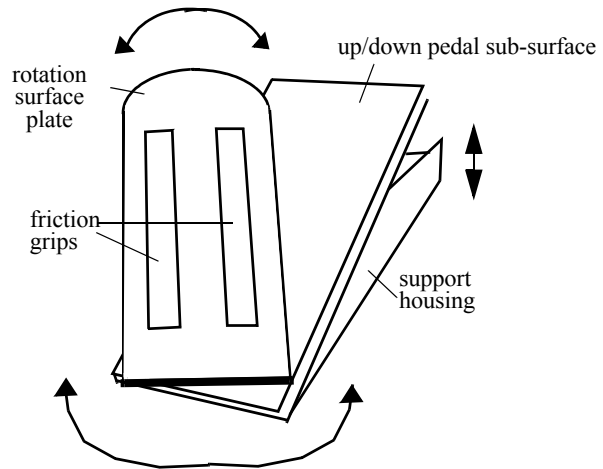
Rocking foot pedal rockers can be used for various control functions, and additionally offer a way of bending pitches electronically, and holding them without having to devote a foot or knee to that purpose. In contrast, the side-mount spring levers, as well as a spring loaded version of a rocker pedal, directly emulate the spring-return operation of a traditional pedal steel guitar's pedals and levers. The pedals can also be used for the introduction or variation of signal processing on one or more selected strings and can be configured to make such effects while simultaneously changing pitch of a selected string or strings.

Figure 3 illustrates some enhanced foot-pedal arrangements which permit simultaneous single-foot adjustment of a plurality of continuous range parameters for use with floor controllers. The use of rocking foot-pedals to control two continuous-range parameters at once may be enhanced by using one or more side-mounted spring-levers. Side-mounted momentary-action switches have been used on rocker foot-pedals for mode control (products by Ernie Ball and Soloton), but side-mounted spring-levers are particularly advantageous for

continuous range parameters that have a specific nominal value, such as the pitch of a pedal steel guitar string. These side-mounted spring-levers can be used in conjunction with pitch-shifters to modulate pitch, as do the foot and knee levers of a pedal steel guitar, or in complementary pairs. Figure 3a shows how one or more side-mounted spring-levers may be mounted on either the base or rocker plate of a foot-pedal. A spring lever may directly operate a slide, geared, pulleyed, etc., potentiometer, an optical sensor, magnetic sensor, pressure-sensor, etc. to produce an electrical signal.



**Figure 3a**



**Figure 3b**

If two side-mounted spring-levers are positioned on opposite sides of the pedal, two mutually-exclusive parameter adjustments can be realized (as found in pedal steel knee-lever pairs, and in the action of a synthesizer modulation wheel or an electric guitar vibrato whammy bar). It is also possible to mount a springed center-return synthesizer modulation wheel at the far end of the rocker plate, if the arrangement and materials used forgo breakage in heavy usage situations.

Alternatively, the arrangement of the once available "volume/tone" floor pedal (manufactured by Fender, among others), sketched in Figure 3b, responsive to control one attribute with up-down motions, and independently control a second attribute with side-to-side motions, may be used for pitch control. Such an arrangement may additionally be modified to employ a spring return to a center position for the side-to-side and/or up-down motion, facilitating sharp/flat or other pitch bending arrangements.

It is possible to add a third control continuous-range adjustment capability on a rocker pedal by measuring the length-axis rotation of the foot. This could be done by various methods:

- " The "volume/tone" rocker pedal just described may be modified to permit length-axis rotation of the foot and to measure it with a potentiometer or sensor.
- " At least two pressure-sensors may be located on the twist plate of a non-modified two-dimensional foot pedal and deriving a control signal from these.

- " A spring-loaded center-return synthesizer modulation wheel may be mounted at the far end of the twist plate if the arrangement and materials used forego breakage in heavy usage situations.
- " A null/contact touch-pad or pressure-sensor array touch-pad may be adapted for foot operation as discussed in U.S. Patent 6,689,947 and U.S. Patent 6,570,078 [12,13,14].

A number of other enhanced rocker pedal and applicable foot controller technologies are described in U.S. Patent 6,689,947 and associated whitepaper [12].

### 3.3 Joint Mechanical/Electronic Pitch Control

In addition to a full electronic pitchbending implementation, U.S. Patent 6,852,919 also readily provides for combinations of mechanical pitch bending and electronic pitch-bending arrangements into a common system.

The mechanical changer and/or related pedals and levers may be adapted to generate electronic control signals corresponding to their mechanical motion. This may be accomplished by attachment of various electronic sensors to the mechanical pitch-bending actuators (pedals, knee levers), their linkage chains, or at the mechanical changer, fitted and calibrated to measure and convert mechanical displacement into electrical control signals.

Figure 4 depicts a comprehensive implementation combining the features of Figures 1 and 2 as well as some additional technologies to be described below.

### 3.4 Mode Control and Note-Issuing Foot Switches

A foot-switch bank for use in selecting stored programs, selecting alternate tunings, controlling signal processing, issuing notes or chords, operating drum machines, etc. is also provided for in the patent. Figures 2 and 4 each depict one possible implementation and incorporation of a bank of foot-switches.

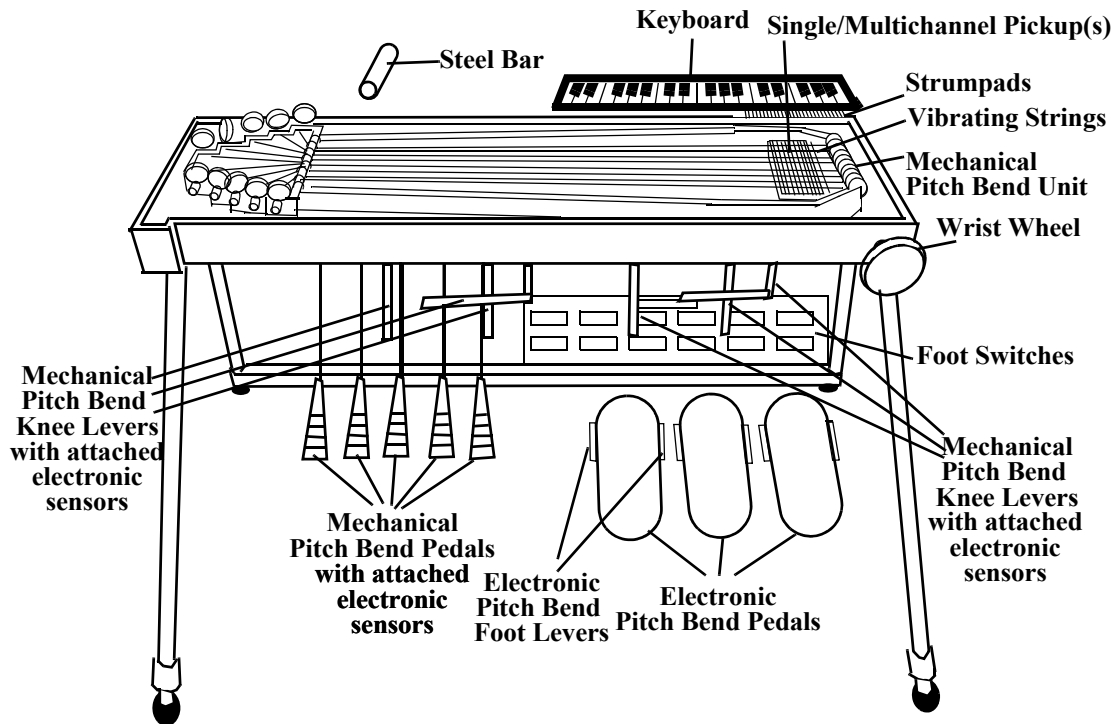
In addition to mode control, foot-switches in the foot-switch bank may issue notes to internal or external synthesizers. The issued notes may decay naturally, sustain as long as the selected foot-switch is depressed, or sustain after release until another note foot-switch or muting foot-switch is operated. The notes issued may involve bass notes, back-ing chords ambiances, a slowly-changing harmony, special effect note sequences, etc.

Lighting and video effects may also be controlled with these foot-switches.

A good general infrastructure is supporting all of these modalities and the general issuances of strings of MIDI commands. Traditional technologies may be used, or any one of a number of NRI's patented enhanced floor controller technologies may be employed [12,13].

### 3.5 The Steel Bar of the Steel Guitar

The traditional movable steel bar (shown in Figures 1,2, and 4) may be unmodified or may be adapted to provide sensors or explicit controls. An adapted steel bar can have a built-in control area (detectors of applied pressure, for example). Such a modified steel bar may



**Figure 4**

have an attached cable, but would preferably have a wireless link to the rest of the instrument.

In more elaborate implementations, the position of the bar over the instrument may be sensed by various means (changes in round-trip string resistance, capacitive sensing, optical sensor arrays, etc.) within the instrument.

The steel bar may also include a video camera as described later.

The steel bar and/or instrument body may also include lighting for purpose of illuminating the string plane, for visual enhancement during performance, etc. Light activation and activity may be controlled by musical processes within the instrument or external MIDI signals as provided for in U.S. Pre-Grant Patent Application 2005/0126373 [11].

### **3.6 Addition of Strumpads, Miniature Keyboards, Wrist Controllers, and Touchpads for use by the Picking Hand**

The often nearly fixed position of the picking hand and the freedom of some fingers in adapted playing techniques allow usage of miniature keyboards, strumpads, in the picking area and use of the wrist of the picking hand to control volume, pitch bends or signal processing parameters. Any one or more of these picking hand area additions could also be made to the mechanical instrument of Figure 1, the electronic only pitch-based instrument of Figure 2, or a combined configuration such as that depicted in Figure 4.

An exemplary incorporation of a miniature keyboard and strumpad in the picking area for use by available fingers is shown in Figure 4, along with an exemplary wrist controller.

One or more miniaturized keyboards may be added to the instrument so as to be played by available fingers of the picking hand. Even while quite actively picking, at least the smallest finger, if not others, is often adequately available for the actuation of a reasonable range of keys. Of particular use here, especially to those steel guitar musicians inexperienced with keyboards, are sustaining-note modalities augmented by footswitches or buttons that toggle between sustain and muting conditions. The provided keyboard(s) may operate an internal synthesizer and/or issue MIDI commands to an external synthesizer. The keyboards may employ traditional approaches or any one or more of the several related enhanced keyboard technologies described in U.S. Pre-Grant Patent Application 2004/0074379 [3]. Chord buttons, as described in U.S. Pre-Grant Patent Application 2004/0069129 [2], may also be used.

Electronic strumpads, as found on the Susuki Omnicord™ and Q-Chord™ products, may be used to simulate the strumming of an array of vibrating strings. Activation of the touch switches within the strumpad are used to issue MIDI commands that can operate synthesizers, lighting, and other equipment or effects. The pitches of synthesizer notes activated by the strumpad are electronically controlled by means of "chord" pushbuttons (as on an auto-harp), foot-switches, last keys operated on a keyboard, or more engaged information sources such as:

- " Information from sensed displacement of mechanical or electronic pedals and levers (and the steel bar position if measured) can be used to control the pitches assigned to a strum-pad;
- " Pitches of individually sounding strings, as measured from multichannel pitch-to-control conversion technology can be used to control the pitches assigned to a strum-pad.

A number of flexible and enhanced strumpad technologies are covered in U.S. Pre-Grant Patent Application 2004/0069129 [2].

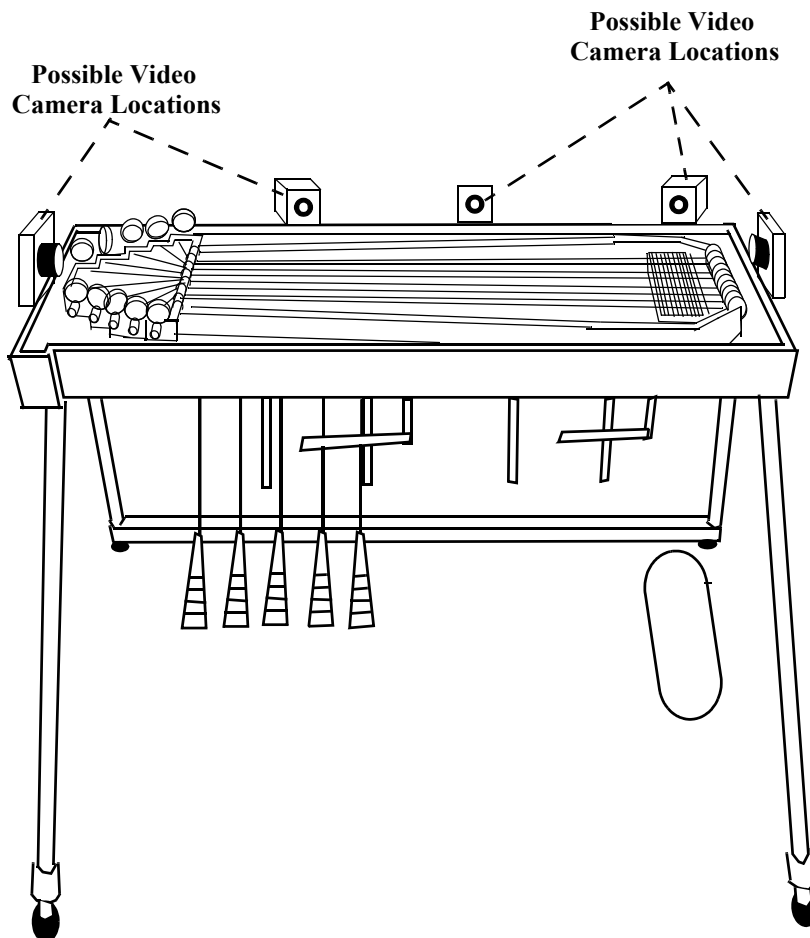
Also depicted in the picking hand areas of Figure 1c is a wrist controller. The wrist controller can be implemented by straightforward adaptation of a synthesizer modulation wheel, and can be easily and expressively operated by slight side-to-side wrist motion or rolling of the picking hand. This wrist controller is a good vehicle for the adjustment of instrument volume, freeing the foot for pitch control, but may also itself be used for pitch control. Other implementation approaches, such as the use of pressure sensor or touchpad technologies, are also possible.

Not shown in Figure 1c is the provision of a touchpad in the picking hand area. The use of a touchpad in this manner as a mounted accessory to a standard electric guitar (as well as several other instruments) is described in U.S. Patent 6,570,078 [14] and an associated set of whitepapers [15, 16, 17]. The touchpad technology used may be a simple null/contact touchpad (as used in the Korg Kaoss™ product), enhancements of it (as described in U.S. Patent 6,570,078), or pressure-sensor array technology (also described in that patent). The latter pressure-sensor array technology has many capabilities, including control of as many as six independent values from a single touch of a finger, independent handling of multiple points of contact, gesture recognition, and many others.

### 3.7 Video for Performance, Education, Improvisational, Chronical, and Gesture-Based Control

One or more fixed or movable video cameras may be attached to various places on the body of the instrument. The video feeds from the camera(s) may be used for display in live performance, in "music video" production, in teaching/education, and/or with advanced gesture video-responsive controller systems such as those found in U.S. Pre-Grant Patent Application 2004/0118268 [9].

Figure 5 shows a number of possible camera locations along the top surfaces of the instrument. These include the positions in the picking area, along the neck, and at the tuning area.



**Figure 5**

Additionally, it is also possible to attach a camera to, or inside, a steel bar as shown in the exemplary oriented steel configuration of Figure 6a. Alternatively, the camera may be mounted inside the steel bar, viewing the string plane or other subject matter through a transparent window, as sketched in Figure 6b.

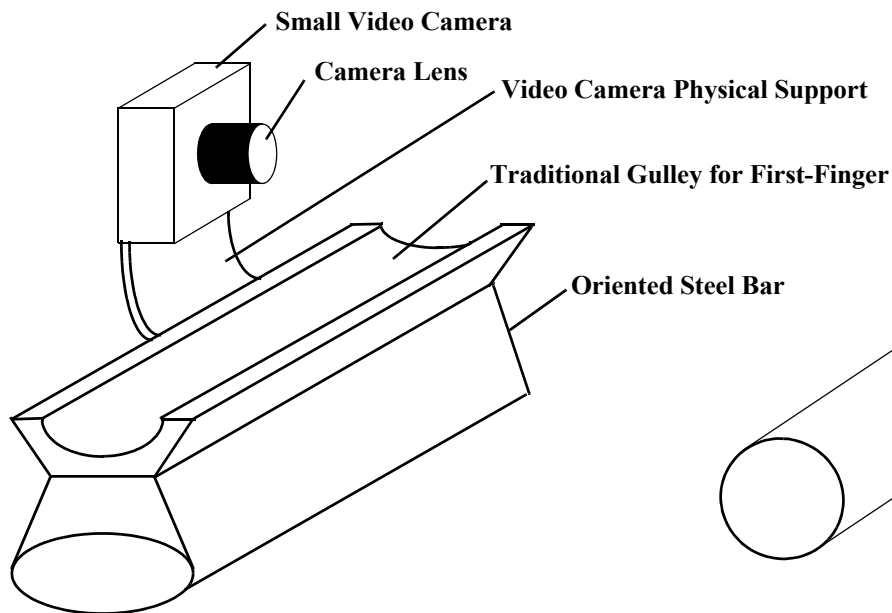


Figure 6a

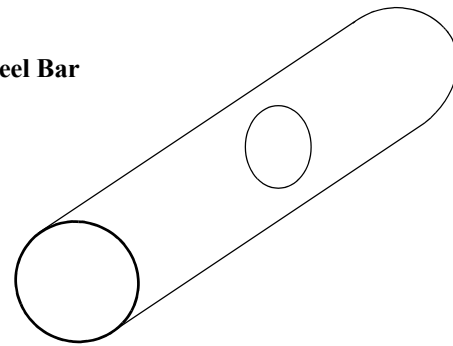


Figure 6b

The steel bar may also include lighting for purposes of illuminating the string plane or other subject matter. This and/or related lighting capabilities may be used to visually enhance a performance, and may be controlled by musical processes within the instrument or external MIDI signals, as provided for in U.S. Pre-Grant Patent Application 2005/0126373 [11].

The steel bar may have an attached cable, but would preferably have a wireless link to the rest of the instrument.

## 4 Multi-channel Audio Processing

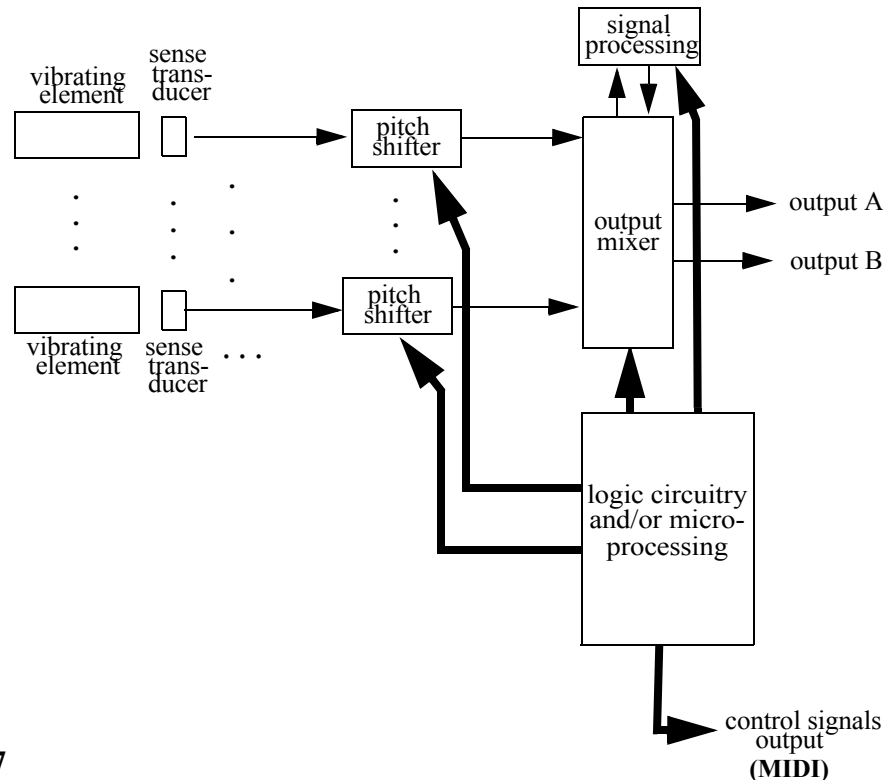
### 4.1 Multi-channel Pickup Technology

The characteristic sound of a steel guitar is liberally colored by the transducer technology, which is almost universally a large winding-count coiled-wire electro magnetic pickup. To obtain isolated individual string signals, a multi-channel transducer must be employed. One approach is to employ a multi-coil pickup technology like that of the Roland GK-2 series pickups. This is a good choice, as Roland also has perfected excellent pickup modeling technology to readily transform the natively weak sound of the small winding-count individual pickup elements into a rich choice of timbres.

Alternatively, piezo individual-string transducer technologies, Hall-effect individual-string transducer technologies [4], and optical individual-string transducer technologies (Ron Hoag [5a], LightWave [5b], Audio Optics, and perhaps others) may be used. Of these, piezo transducer technologies are likely only practical for instrument implementations that comprise pure electronic pitch bending as a piezo transducer element on the rolling string saddle of a mechanical pitch-bend changer. Though hypothetically possible, this may be difficult to make practical for sliding strings.

## 4.2 Multi-channel Pitch-Bending and General Signal Processing Environment

Figure 7 illustrates a simple exemplary signal processing arrangement dedicating a separate pitch shifter to the signal path for each string, and adding further timbral signal processing functions (such as equalization, pickup modeling, chorus, flanging, echoing delay, reverb, tremolo, electronic-vibrato, etc.) at the output mixer stage. Such a system is, in principle, of the order of complexity of the Roland™ VG88 hexaphonic signal processing product.



**Figure 7**

Figure 8 illustrates a more general exemplary multi-channel signal processing environment suitable for implementing electronic pitch-bending as well as other timbral signal processing functions (such as equalization, pickup modeling, chorus, flanging, echoing delay, reverb, tremolo, electronic-vibrato, distortion, waveshaping, envelope-modulated filtering, etc.) directed to individual strings, groups of strings, or the entire instrument. Applicable multi-channel signal processing infrastructure is additionally covered in a pending patent application [6].

In either of the above, it is noted that there are at least two types of pitch shifters that may be used:

- "Simple spliced/sequenced playback of sampled segments where the record rate is faster or slower than that of the playback rate. These alter the timbre of the sound, make strings sound tinny at high degrees of pitch shift, and can be noticeable for pitch shifts as small as a whole-tone or semitone;

- "Format-preserving enhancements where the timbral character of the sound is significantly more preserved. Such technology was pioneered in low-cost products by companies such as Digitech™ with their Vocalist™ series of vocal pitch shifters.

Either or both of these styles of pitch shifters may be used in the signal processing system. In many situations the raising or lowering by at most one semitone may not invoke much of a timbral difference for the simpler pitch shifters. A discerning musician seeking only a classic sound may only be satisfied if the pitch shifting employed is format-preserving.

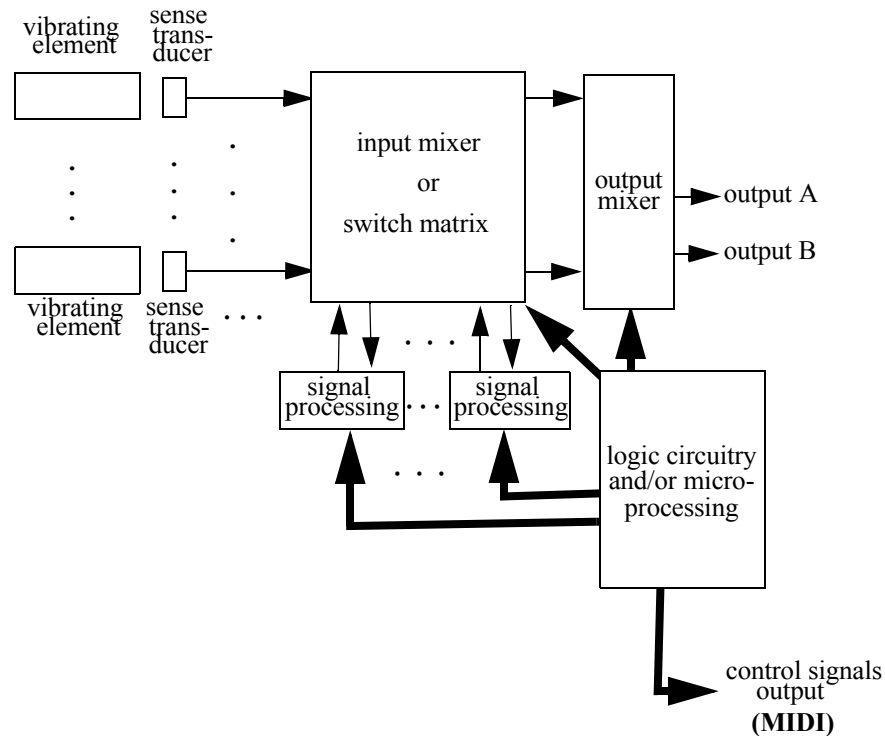


Figure 8

### 4.3 Multi-Channel Control Signal Extraction

The multi-channel signal handling described above, lends itself naturally to interfacing with multi-channel control signal extraction technologies such as envelope followers and pitch detectors. These two multi-channel control signal extraction technologies are co-packaged in the form of so-called pitch-to-MIDI devices, for example those interfacing with the Roland GK-series hexaphonic pickups. Early in the development of this technology, the Pitch Rider™ product line provided such MIDI capabilities to pedal steel guitar applications.

There are a number of ways this technology may be adapted to the pedal steel guitar in the framework of U.S. Patent 6,852,919 and the associated descriptions in this whitepaper. Figure 9 illustrates an adaptation of the multi-channel signal processing environment shown in Figure 8; similar methods may be used for the multi-channel signal processing environment shown in Figure 7. In another implementation, one or two GK-series pickup electrical in-

terfaces may be provided. In another implementation, an internal synthesizer may be additionally or alternatively provided.

U.S. Patent 6,852,919 and other related issued and pending patents provide for yet more enhanced aspects of this type of functionality. In one implementation, a generalized interface (to be described below in more detail) is used to carry multi-channel signals (along with MIDI, video, string-drive signals, etc.) as covered in U.S. Pre-Grant Patent Application 2004/0069126 [7]. Additionally, enhanced multichannel control signal extraction technologies, responsive to the evolving dynamics of the rich overtone structure of pedal steel guitar string vibration, is covered in U.S. Pre-Grant Patent Application 2004/0069128 [18].

#### 4.4 Electronically Driven String Vibration

U.S. Patent 6,852,919 also provides for including multi-channel electronic string excitation, such as found in the Ebow product. The resulting sweet singing, swelling sound, as well as angry aggressive bowed sounds, add interesting musical capabilities to the steel guitar.

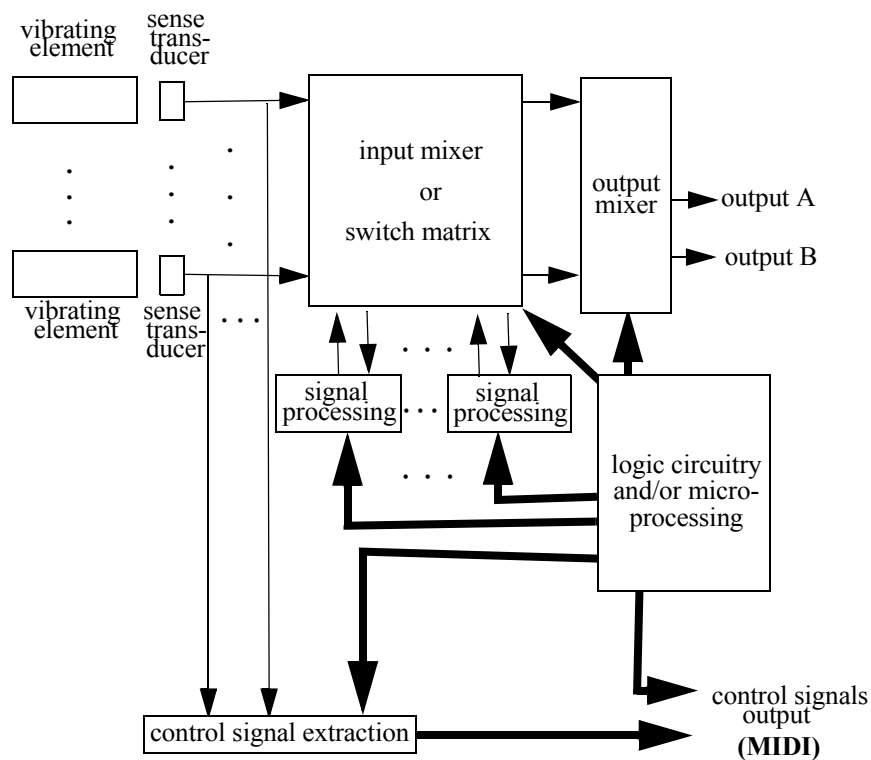


Figure 9

A number of U.S. patents have been issued over many years in this general technology area for electric guitars. The NRI U.S. Patent 6,852,919, along with NRI U.S. Patent 6,610,917 [6], provide for a number of additional enhancements and features. One of these is suggested in Figure 10, where controllable signal processors individually pre-process one or more drive signals prior to providing them to the vibration driving transducers. The arrangement of Figure 10 also depicts explicit integration of the multi-channel electronic drive arrangements into a common general multi-channel signal processing environment depicted in Fig-

ure 9, and may also be readily applied to the simplified arrangements depicted in Figures 7 and 8. These patents cover arrangements where the drive signals are externally provided, allowing the multi-channel signal processing environment to be external to the instrument (as will be discussed in the next section). Also covered are visual activity indications such as instrument lighting elements that are responsive to the drive signal applied to individual strings.

Further, the arrangement of Figure 10 may be reorganized so that the drive signals may

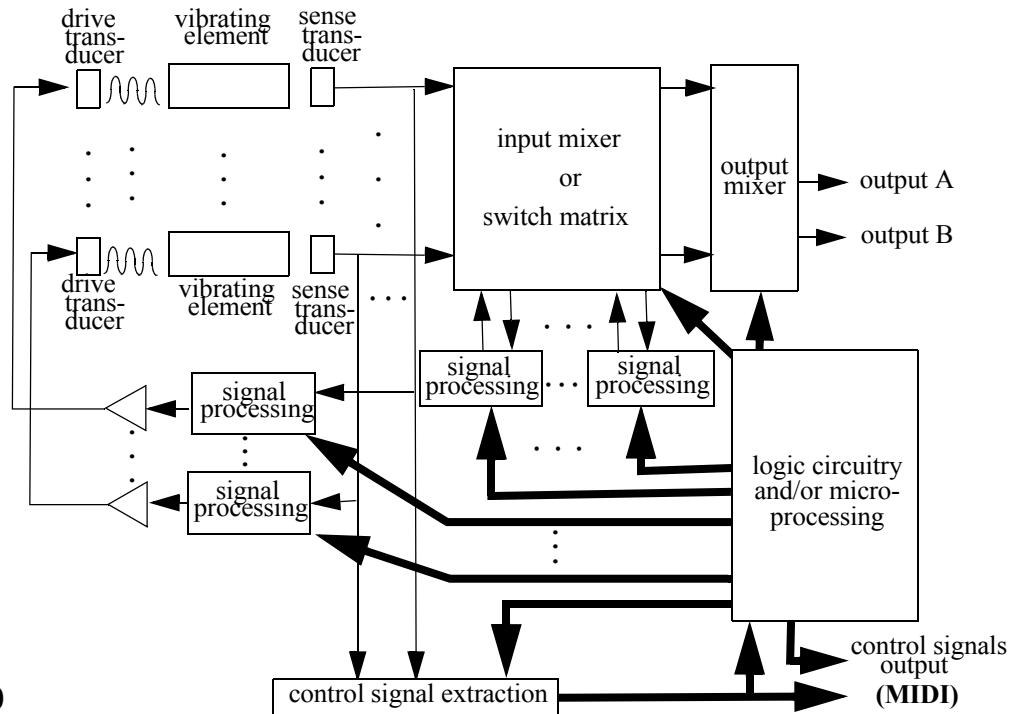


Figure 10

come from the input mixer or switch matrix, allowing for the pre-drive signal processors to be pooled together with the signal processors used for string timbral modification purposes. This arrangement and other configurations provided for in U.S. Patents 6,852,919 and 6,610,917 additionally permits the drive signal of a particular string to originate from other sources, such as other strings, so as to electronically induce sympathetic vibration.

#### 4.5 Generalized Interface

U.S. Patent 6,852,919, along with U.S. Pre-Grant Patent Application 2004/0065187 [8], provide for the multi-channel transducers, multi-channel signal processing environments, MIDI components, video elements, 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 11 depicts the concept of a generalized 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 instrument 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 performance, audio recording, and educational recording/presentation systems;
- " Simultaneous independent bidirection capabilities;
- " Opportunities for a reasonable degree of integrated instrument powering support.

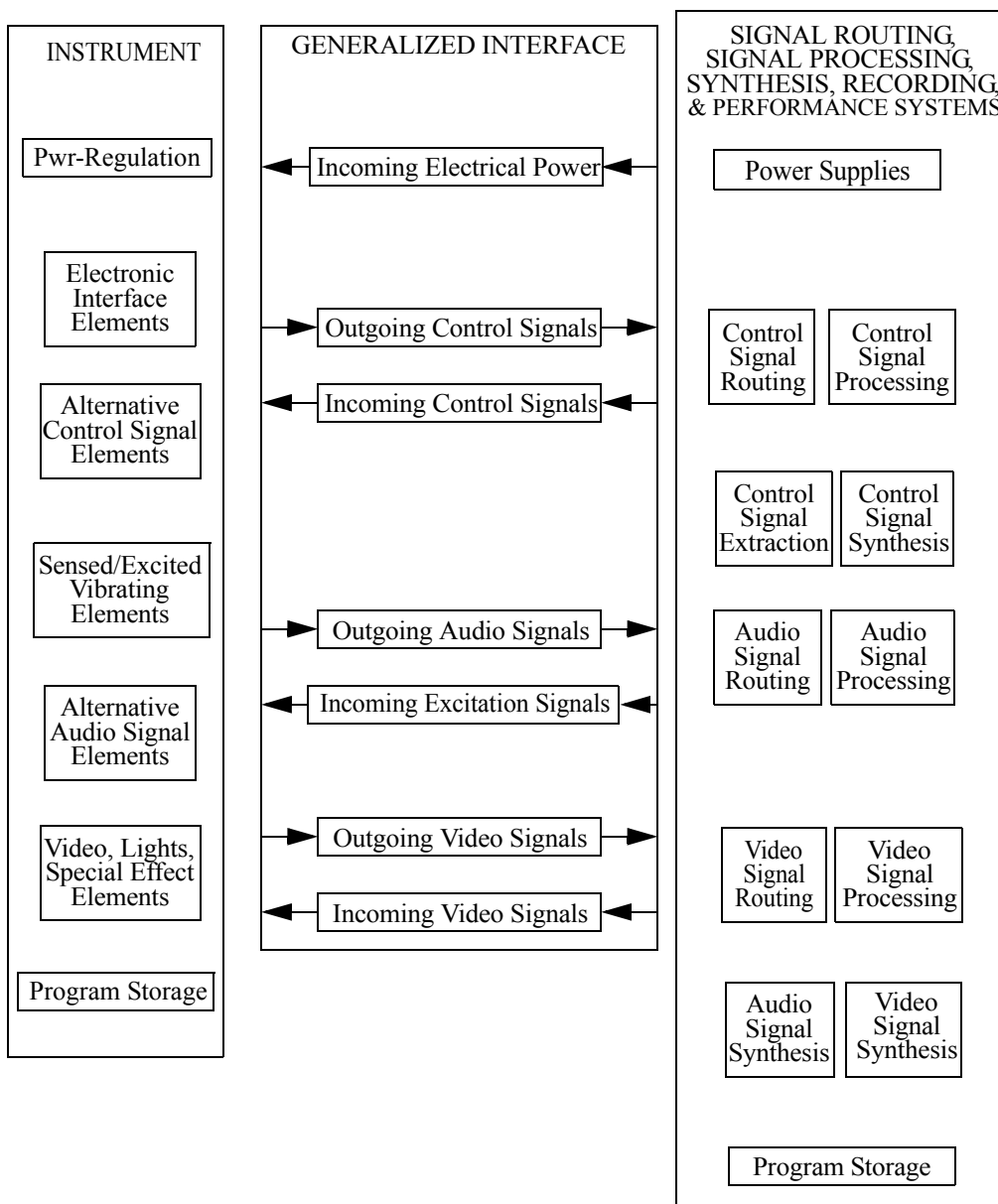


Figure 11

Figure 12 illustrates two example generalized interface cabling and connector arrangements. Figure 12a 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 integrated, multiplexing-oriented approach also lends itself readily to wireless signal transport. In contrast, Figure 12b 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.

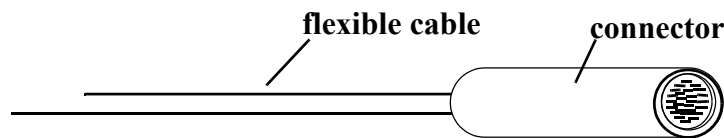


Figure 12a

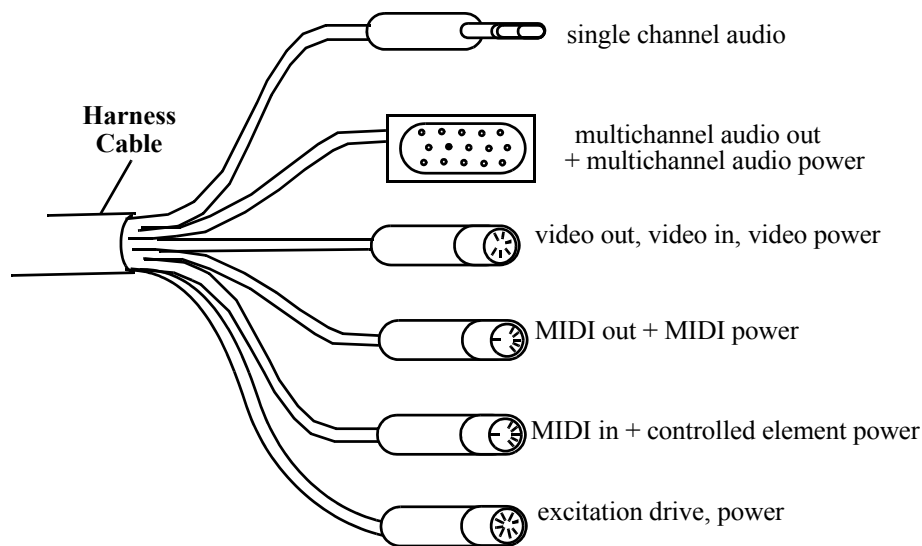
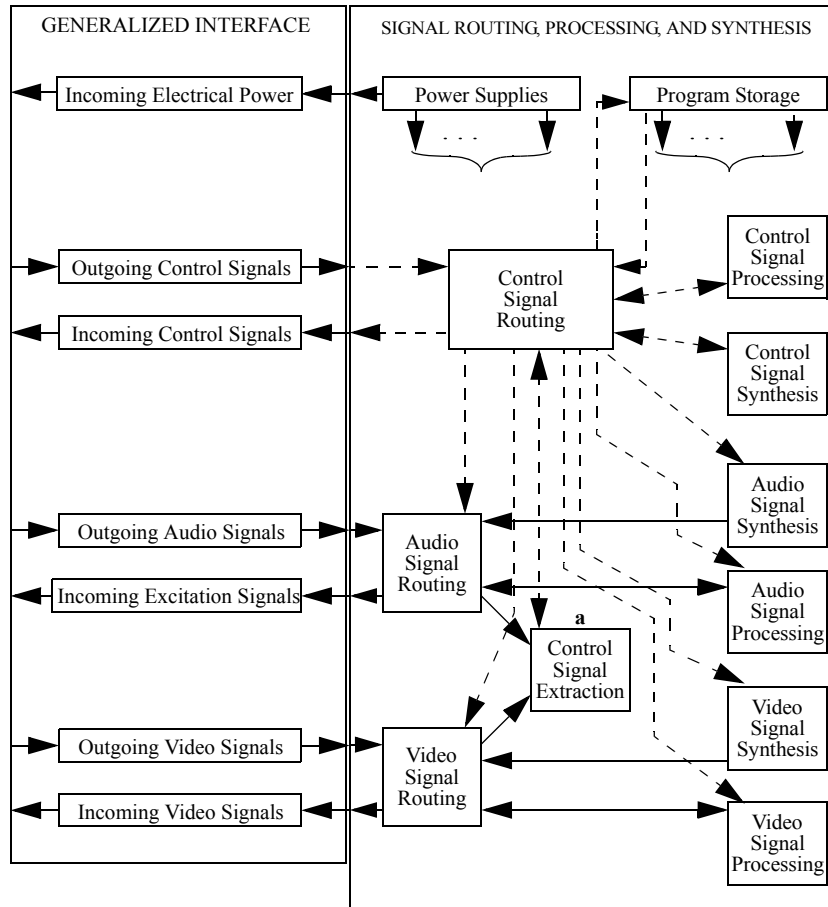


Figure 12b

Figure 13 illustrates an exemplary signal routing, processing, and synthesis environment for hosting a wide range of instruments, instrument functions, instrument capabilities, and applications. This arrangement can include the multi-channel signal processing environments described in this document. The same multi-channel signal processing environments can also support a transcended South Asian multi-channel electronic sitar, an expanded



**Figure 13**

East Asian multi-channel electronic koto (Japan), sheng(China) or komun'go (Korea), an adapted African electronic mbira, an adapted European lute/chitarone/theorbo, etc. as well as current and enhanced standard fair of Western electric guitars, basses, and keyboards.

## 5 Licensing

This whitepaper 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 InstituteR. For further information, please contact New Renaissance Institut-eR at [inquiries@newrenaissanceinstitute.com](mailto:inquiries@newrenaissanceinstitute.com)

## **REFERENCES**

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