Improving the Musical Expressiveness of Tesla Coils with Software

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ABSTRACT

In the past, most performances that have used Tesla coils as musical instruments have been limited by low polyphony and very rudimentary control of musical parameters, culminating in minimally expressive results. This paper outlines recent advances that have been made in improving the musical outputs of Tesla coils by way of software simulation, interfacing and more nuanced control parameters. A description of the hardware interface and the firmware used is provided along with an explanation of the software interface and its simulation capabilities. The result is a new Tesla coil control system that offers an unprecedented level of musical control and expressiveness while also providing a user-friendly interface for real-time composition and performance.

1. INTRODUCTION

A Tesla coil is a resonant transformer circuit that generates very high voltages which are made to arc through the air on command. The effect is like arcs of lightening emanating from a metal ball or toroid propagating through the air as in Figure 1, and it generates a powerful and ever-changing sparking sound as it does so. Musical applications of Tesla coils involve inputting power to the coil in short pulses at the frequency of the desired notes in order to create melodies and other musical content. As electrical arcs grow from the coil, ionizing and heating the air, they create periodic shifts in air pressure in a similar way to the transducer of a loud-speaker, causing a sharp and powerful wave of sound to be emitted to listeners in the area. In this way it is also considered to be a type of plasma speaker, differing primarily in that the duty cycle is much smaller - in the system described here, power is applied for only microseconds at a time.

In order to compose musical sequences to be played back by a Tesla coil, controller hardware is necessary to convert musical control signals, usually in the form of a stream of MIDI data, into pulses to control the coil. The management of the timing and lengths of these pulses, including the length of each pulse relative to its surrounding pulses, is critical to the stability and musical functionality of the system. This paper describes the design and implementation of a Tesla coil control system that makes use of the newly designed 'Chime Red' control hardware, which provides a unique level of flexibility and musical expression to Tesla coil performances. First a brief background of Tesla coils and their use as musical instruments will serve to put this research into context. A summary of the current state of Tesla coil controllers will then be presented. Subsequently, an outline of the hardware implementation of the Chime Red unit will be provided, followed by a description of the software interface and simulation system that has been created. The various new musical capabilities will be described, and plans for future work will be outlined.

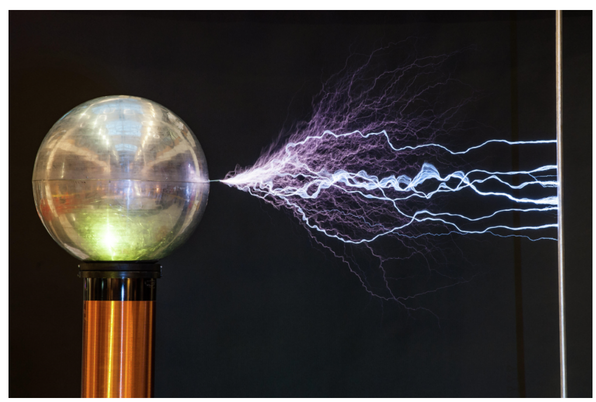

Figure 1. Pyramider - An 8 foot tall musical offline Tesla coil (OLTC) in operation. Pyramider is one of the coils that has been controlled with this system.

2. BACKGROUND OF TESLA COILS

The Tesla coil was named after its inventor Nikola Tesla, who secured a patent for an early implementation as a 'system of electric lighting' in 1891 [1]. They were used in several of his experiments related to fluorescence, x-rays, radio, wireless power, biological effects, and the electromagnetic nature of the earth and its atmosphere [2]. Elements of the Tesla coil design also made their way into commercial products and its circuitry is fundamental to radio transmission [3]. Contemporary usage of Tesla coils generally centers around entertainment, with science museums and other venues around the world utilizing them to provide spectacular lighting shows.

2.1 Tesla coil use in music

A musical Tesla coil, which may also be referred to as a singing Tesla coil, Zeusaphone, or Thoramin is a solid state Tesla coil (SSTC) which is able to use its arc to produce melodies via external control. The practicality of enabling Tesla coils to produce musical notes coincided with the rising attainability of insulated-gate bipolar transistors (IGBTs), which are capable of switching high voltages and extremely high currents, (up to thousands of Amps) for brief periods and at radio frequencies. Though it was possible to generate steady tones with early SSTCs and even older vacuum tube designs, electronic melodic playback was achieved around the year 2000 by Richie Burnett with a small scale coil with a short arc [4]. In 2005 Joe DiPrima and Steve Ward built a larger scale dual resonant type SSTC which was able to create melodies via larger, more impressive arcs, and they delivered the first public performance using musical Tesla coils in March 2006 [5]. Soon afterwards, Scott Coppersmith developed the first true MIDI-based control system [5] followed closely by a video created by Steve Conner in June 2006 which brought widespread awareness of the technique [6].

Steve Ward and Joe DiPrima's musical Tesla coil project would later form the basis of the ArcAttack group which has toured extensively. Other artists that have made use of musical Tesla coils include Björk with her piece entitled 'Thunderbolt' and the Tesla Orchestra [7].

2.2 Musical Telsa Coil Controllers

There are several musical Tesla coil controllers (also called interrupters) available as commercial products, kits, and built for personal use. Examples of commercial products include the Eastern Voltage Universal Handheld MIDI Interrupter, the ClassicTesla MIDI Pro Tesla Coil Controller and the oneTesla MIDI Interrupter. These all receive MIDI data and send corresponding pulse information to the coil in order to generate notes. These units are predominantly monophonic with some options offering duophony, allowing two notes to be played by a single coil simultaneously, but lack any expressive parameters beyond pitch-bend control. Blake Johnston's 'Nico' controller improved on several of these limitations allowing 4-note polyphony, individual velocity control over each of the voices, and providing the option to send control messages via OSC as well as the usual MIDI [8].

3. CHIME RED

A new musical Tesla coil controller named Chime Red was built by James McVay and Josh Bailey and seeks to provide composers and performers with advanced expressive musical control over Tesla coil performances.

Figure 2. The front panel of the Chime Red enclosure.

3.1 Hardware

The front panel of the Chime Red box shown in Figure 2 features a key to arm the unit, a 16x2 character LCD display, LED indicators, and several knobs and toggle buttons. From left to right, the buttons toggle between MIDI and PCM input modes, external and internal signal generation, fixed or variable pulse-width, full or limited maximum level, and acceptance of channel 10 MIDI information. In MIDI performance mode, the lower knobs control the maximum pulse-rate, maximum pulse-width and maximum voltage input parameters. This allows the system to be adjusted to the size and power handling capability of the coil being controlled. The controller's software computes the correct pulse length and relative timing within these maximums according to the requirements of the musician. In the offline signal generator mode, the momentary fire button on the top right enables the output, while the knobs control frequency and pulse length. Currently the MIDI and signal generator modes have been implemented, with the PCM input mode under development.

The rear panel shown in Figure 3 is equipped with a 9V DC power supply socket, a USB socket for USB-MIDI communication and firmware updates, and MIDI In and Thru sockets. To minimize interference on the transmission lines, the signal to the coil is output by way of a fibre transmitter. These pulses control the gate of the IGBT in the coil which controls when power is input. TTL compatible BNC ports provide PCM TTL input, as well as outputs for gate diagnostics, charge enable, and charge level. The charge outputs allow the controller to control both when power is input and the instantaneous input voltage. This feature enables advanced musical features for coil designs that require a fixed pulse size like

OLTCs and works in conjunction with a custom power supply that is currently under development.

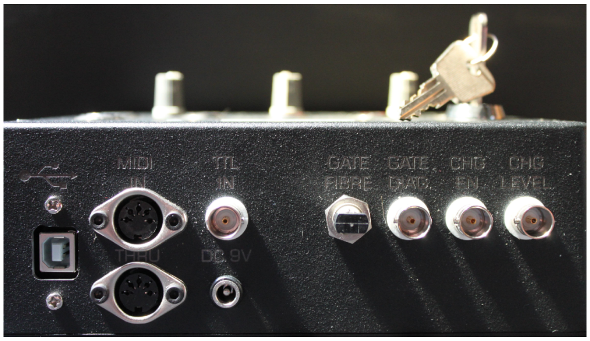

Figure 3. The rear of the Chime Red enclosure.

3.2 Firmware

The Chime Red unit is built around a 32-bit Atmel SAM3X8E ARM Cortex-M3 microcontroller running an 84MHz oscillator. This allows the processor to run up to 16 simultaneous notes of polyphony, a range of musical features and advanced power scheduling. The controller minimizes the overall duty cycle by maximizing the length of time between pulses, which is essential to keep the IGBTs operating within an acceptable performance envelope. It must be capable of handling peak power demands of hundreds of kilowatts, depending on the size of the coil. Without power scheduling, a simple chord could destroy the coil, so the controller must combine awareness of the functions requested by the musician with the power input to the coil at microsecond resolution, and send the optimum pulses as required.

3.3 Musical Capabilities

The two primary parameters of the system, like previous iterations, are frequency and power. In most musical Tesla coil controllers, the frequency parameter is controlled by MIDI note messages and pitch-bend commands, and the power is controlled either by a single Volume parameter or by the velocity bytes in MIDI note messages. In concert situations, this has resulted in overloading the buffer of commercial MIDI interfaces as composers attempted to send detailed pitch bend information in order to construct pitch envelopes, slides between notes and vibrato effects.

To solve this problem, it was decided to implement an array of musical parameters in Chime Red's firmware in a similar way to how digital hardware synthesizers are realized. The parameters are controlled via MIDI Control Change commands, are implemented in the Chime Red firmware, and affect the sound of the Tesla coil accordingly. The features are outlined below.

Both monophonic and polyphonic portamento modes were implemented with the ability to switch between a constant speed or a constant time portamento curve. A legato mode is also available to create a slide between notes only when previous notes are being held. There is a polyphony parameter which allows the user to choose how many voices to make use of, with a value of 1 indicating monophonic mode.

Applying multiple oscillators to frequencies closely surrounding the currently played note induces a flanging or chorus type effect to the sound depending on how they are spread. In Chime Red this is labeled as 'Unison', with the number of oscillators used for the unison, and their distance from the primary note both available as adjustable parameters called Unison Voices and Unison Spread respectively. These unison oscillators are taken from the 16 available notes.

A pair of low frequency oscillators (LFOs) with triangle waveforms modulate the pitch and volume parameters, providing vibrato and tremolo features. Each of these LFOs also have adjustable range and speed attributes. Separate controllers are assigned to manipulate the depth of the effects, with the vibrato assigned to the mod wheel by default. A third LFO is also included with range and speed parameters. This LFO also offers a selectable wave shape and can be assigned to modulate the pitch or volume. A skew control tilts the LFO's waveform between sawtooth and ramp shapes when the triangle source is selected, and adjusts the pulsewidth when pulse source is selected. This LFO can also be set to restart upon the reception of note on commands via the LFO Sync toggle.

A standard ADSR style envelope modulates the volume of the notes played with a selectable linear or logarithmic envelope characteristic. An oscillator with adjustable waveform may also be dedicated to modulation of pitch, volume, or routed to periodically restart the other oscillators, carrying out a function that is often implemented in synthesizers as oscillator sync.

A common problem with MIDI-based setups occurs when a note-on command is received by a sound module and the corresponding note-off command is not received, leaving a note sounding indefinitely. This issue occurs more often when interfacing with Tesla coils, as interference from the coils decreases the reliability of nearby data transmission. As hanging notes can be damaging to equipment and listeners, a note time-out safety feature has been implemented. The length of the time-out is a controllable parameter of the system (from 0.05 to 10 seconds) and any notes that remain active for longer than the specified length are automatically terminated. For passages of short notes, a low time out will aid in reducing the number of hanging notes, and the length of the time-out period should be increased for passages that require longer notes.

3.4 Software Interfacing

With all of these musical parameters, composing music in software sequencers with control change message lanes would become a complex task. It is for this reason that a software interface was created using Native Instruments' Reaktor visual programming environment, shown in Figure 4. This enables composers and performers to load a virtual Chime Red syn-

Figure 4. The virtual Chime Red software interface.

thesizer inside their digital workstations and design sounds for their musical works using an interface that is familiar to them. Standard MIDI controller hardware can be easily assigned to the knobs, sliders and buttons of the interface to provide real-time sound manipulation capabilities with visual feedback. Reaktor also provides preset creation and preset morphing functionality which enables sound artists to build a collection of sounds to be recalled during performances and to merge previously created presets for sound designing purposes.

3.5 Simulation

An audio engine is included within the virtual Chime Red which simulates the sound of a Tesla coil. This helps composers write music for the coils when they are unable to access the Chime Red hardware or the coils themselves. The synthesizer emulates the sound of Tesla coils using pulse-wave oscillators, a digital noise source modulated by the oscillators and a single pole high pass filter. The width of the pulse oscillator, the level of the noise source, the cutoff of the filter and the level of the output are all adjustable via the software interface. This allows users to emulate the sound of the specific Tesla coils for which they are composing.

Excluding the simulator timbre controls, all of the parameter controls on the panel of the virtual module both output MIDI control change messages to the hardware Chime Red unit and control the parameters of the simulated software Tesla coil sound. This delivers a seamless integration between the virtual composition environment and the hardware performance environment. The Chime Red hardware is also equipped with an on-board speaker that outputs the pulse data that is sent to the coils in real time. This provides another opportunity to review the output of the system before activating the coils.

4. FUTURE WORK

Despite all of the newly implemented musical parameters, there remain limitations which will need to be overcome in order to continue to bring new musical expressiveness to Tesla coil performances. The most fundamental of these limitations is that due to the binary nature of switching IGBTs, the oscillator wave-shapes are all based on full-scale pulses. As alluded to by the planned PCM mode, future work will focus on allowing the system to produce arbitrary shapes of waveforms and output PCM audio directly. The optical charge outputs of the unit have also been attached in anticipation of an advanced Tesla coil power supply that is also under development. This power supply will allow offline Tesla coils to make full use of this new control system.

5. CONCLUSIONS

This paper has presented a new system for musically controlling Tesla coils, bringing them a step closer to being fully realized as musical instruments in their own right. The system provides composers with a sizable array of expressive parameters with which to craft new and interesting sounds and will enable a new range of music to be produced by the coils. To make the best use of this new functionality, a synthesizer-like software interface was built which conforms to standard electronic music composition work-flows and provides a method of organizing and manipulating sounds that have been designed. A synthesizer which emulates the sound of the instruments was also implemented as a part of the software interface to aid in offline composition for Tesla coils.

All of these elements combine to create a system that brings intuitive sound design and advanced compositional possibilities to Tesla coils, and enables new, complex, highly polyphonic and expressive music to be created with them.

6. REFERENCES

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