# REAL-TIME DIGITAL MODELING OF THE ROLAND SPACE ECHO

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## ABSTRACT

This paper presents a system for accurately modeling and emulating the audio characteristics of a well-known analog audio tape delay effect, the Roland Space Echo RE-201. Analog emulation is becoming increasingly popular in the world of audio production, thus it is ever more important to accurately represent the audio qualities of analog devices in the digital domain. A measurement-based approach was taken in order to model the wow and flutter, delay ballistics, and tape saturation characteristics of unit. Additionally, simulated results of the Baxandall style tone control circuit was incorporated into the model in order to generate appropriate output equalization. The real-time system was implemented using the MATLAB Audio System Toolbox, and a VST plugin was generated from the MATLAB code to allow the effect to be used in standard digital audio workstation software.

***Index Terms—*** Analog modeling, tape echo, VST plugin

## 1. INTRODUCTION

The work in this paper revolves around the emulation and digital modeling of a Roland Space Echo RE-201 effects unit, first released in 1974. Creating digital models of vintage analog effects units has become increasingly popular due to their unique sound properties, coupled with the expense and inconvenience of acquiring and maintaining these devices. While digital effects can be easily designed to implement the intended effects of an analog device, the resulting sound can be perceived as lacking the ”character” or ”warmth” of classic hardware units, which come from limitations of analog circuit design, such as saturation, unintended alterations in frequency response, and, in the case of magnetic tape-based effects, wow and flutter. Thus, our goal for this work is to design a real-time simulation of the Space Echo incorporating the distinctly analog characteristics which we believe to have the strongest perceptual effect on the sound. Specifically, we model the tape speed characteristics of the echo unit, the amplitude saturation properties of the magnetic tape used to produce the effect, and the frequency response of the output equalization controls.

**Fig. 1**. Roland RE-201 Space Echo, top cover removed

General operating characteristics and schematics of the Roland Space Echo are available in [1]. A survey of simulation techniques and considerations for a similar effects unit, the Maestro Echoplex, is presented in [2]. Arnardottir, Abel, and Smith focus on the measurement of delay time trajectory, as tape echo effects exhibit some fluctuation around their set delay time as determined by the knobs on the front panel. They then propose a model for synthesizing the delay trajectory based on empirical measurements from the unit. The implementation accounts for nonlinear saturation and the output EQ control of the unit, but omits discussion of how these subsystems are modeled. This model presented in [2] is expanded in [3], where the authors also examine modeling Space Echo. This book chapter does propose a method for determining the tape speed control ballistic response, and a simple approximation given for tape saturation characteristics. While the author offers conceptual background on designing and implementing a digital model of these effects, the measurement and characterization of these features is still mostly unexplained. Thus, we document our measurement procedure for characterizing the unit in this work.

The remainder of this paper is organized as follows. In Section 2 we provide a system overview of our model at the block diagram level. In Section 3, we discuss the measurement and modeling procedure used to simulate the tape speed of the unit. Section 4 discusses the tape saturation modeling, which consists of nonlinear amplitude shaping and filtering to account for the tape's frequency response. Section 5 discusses the simulation and subsequent modeling of the output equalization, or tone control circuit. Section 6 discusses the real-time implementation in MATLAB and the generation of the VST plugin. Finally, Section 7 concludes with a summary and discussion of future work.

## 2. SYSTEM OVERVIEW

Figure 2 shows the block diagram of the proposed model of the Space Echo. The input signal is fed into a delay line. The length of the delay line is determined by the current tape speed. At the output of the delay line, tape saturation is applied to incorporate nonlinearities in the amplitude characteristic of the tape, and a bandpass filter is applied to model the tape's frequency response. The output of the filtered delay line is passed to the output along with the direct signal. Additionally, the delayed output is also scaled by a user-adjustable feedback parameter and fed back to its input. Tone controls, modeled by a user-adjustable parametric equalizer, are applied after the summation of the direct and delayed output to allow equalization of the overall output frequency response. While the original Space Echo features three delay playback heads in several settings, we focus on modeling only a single delay tap (corresponding to mode 1 on the mode selector of the Space Echo). The model can easily be generalized to a larger number of delay playbacks from the delay line buffer.

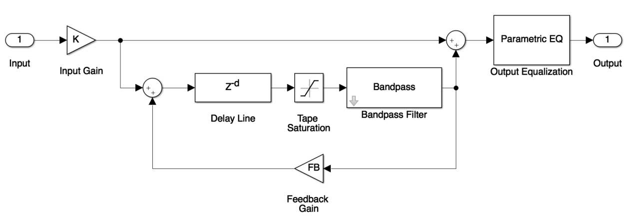


**Fig. 2**. Space Echo digital model, system block diagram

## 3. TAPE SPEED MODELING

### 3.1. Wow and Flutter

Wow and Flutter are inevitable characteristics that exist within rotary-driven audio tape machines. These characteristics provide these machines with some of their distinctive sound. The slight inconsistencies in the rotations of the motor causes a fluctuation in pitch and in the specific case of analog tape delay units, this causes inconsistency of the time between the delayed repeated signal. Wow is defined as a speed fluctuation between 0.1-10Hz, while flutter is defined to be between 10-100Hz [4]. The method we employed to measure amounts of wow and flutter concluded that the intensity of the imperfections in the motor rotation speed was more apparent than initially suspected. We adopt the technique presented in [4] to measure the wow and flutter. Feeding a 30 second, 3.15kHz sine wave into the Space Echo while recording the output caused audible variations in amplitude from phase cancellation due to the inconsistency in the timing of repeats overlapping on one another. The direct test signal sinusoid was inverted out of the captured output in post processing, leaving the sine wave read from the playback head as the residual. Then, a delay time curve was extracted based on the variation between expected (constant) and measured period between zero crossings. A signal model was adopted to synthesize delay time fluctuations based on the observed characteristics of low-frequency drift. The spectrum of the delay speed showed a sharp cutoff at approximately 1 Hz. We measured the variance of the delay trajectory signal fed through low pass filter with a 1 Hz cutoff, and used this measured variance and cutoff to inform our model. The low-frequency drift component was synthesized by feeding zero-mean white noise through the same filter and scaling the amplitude to obtain the same variance. Measurements were carried out to characterize the higher frequency components of the tape speed signal due to the capstan and pinch wheel harmonics. Our goal was to add synthesized harmonic components from these measurements to the delay signal; however, we were unable to include this step in our final implementation due to time constraints.

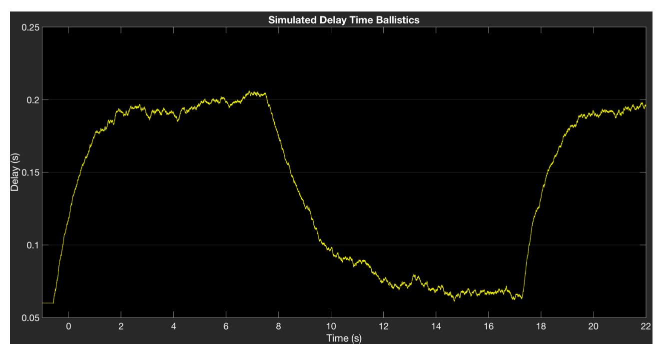


**Fig. 3**. Simulated delay time signal, with tape wow and ballistics

### 3.2. Delay Control Ballistics

In addition to the wow and flutter present within the tape mechanism, the Space Echo also features a distinct ballistic response to user adjustments in the delay time. The Space Echo tape speed does not change instantaneously, and in fact the time required to come within 0.99 of the target speed is on the order of seconds. The result is a gradual speed-up or slow-down sound effect across multiple echos, with a corresponding pitch shift due to the Doppler effect, and is one of the classic tape echo-based sound effects. To characterize the ballistic response, we measured the time taken to reach 0.86 of the desired delay change specified by the control knob by a turn from minimum to maximum time, and also for maximum to minimum time. This time corresponds to a length of two time constants. Our measured time constants were 1.89s for increasing delay time, and 1.07s for decreasing delay time. Our approach is based on that of [3], and our measurements were close to the approximate measurements given by the authors (2s and 1s respectively). We use a leaky integrator filter design to process the delay control signal such that it responds to changes in user input by gradually approaching the target value according to the desired time constant. The figure below displays the ballistic response to abrupt user variable adjustments between minimum and maximum delay times. The response also includes a stochastic drift component derived from the empirical wow and flutter measured from the unit, as discussed in the previous section.

## 4. TAPE SATURATION AND BANDWIDTH

Tape saturation creates a non-linear, distorted input versus output amplitude characteristic due to a combination of attributes such as tape magnetization, tape head construction, tape material, width, speed, equalization, biasing, and the corresponding amplitudes and dynamics of the source signal. A detailed description of the magnetic field hysteresis relationship is provided in [3]. It is then suggested to simply use the Gaussian error function $Erf(x)$ to approximate the tape saturation characteristics, shown in Figure 4. However, we wished to also capture the amplitude characteristic of other circuitry in the echo signal path, such as the playback and record heads, so the amplitude response was measured with a 1 KHz sinusoid input with a linearly ramped amplitude. By measuring the change in minimum and maximum amplitude over time, we obtained an amplitude characteristic curve for use in the simulation.

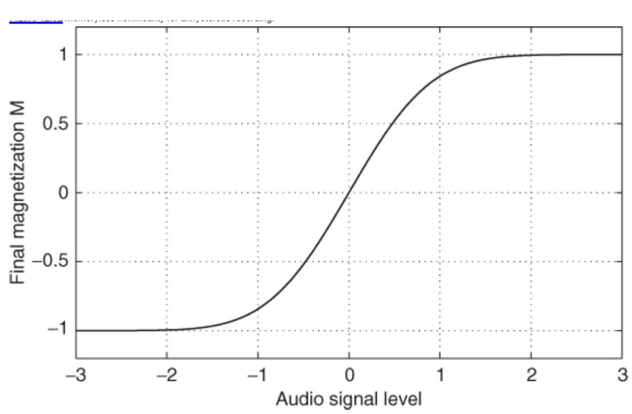


**Fig. 4**. Tape magnetization curve approximated as Gaussian error function, from +++

Tape has also has a limited bandwidth that is determined by the width and construction of the tape. The frequency response of the Space Echo delay path is given in [3]. The frequency response is important to emulate, because unfiltered feedback can produce undesirable low-frequency distortion, and the self-oscillation which occurs at particular frequencies at high feedback settings is integral to many Space Echo-produced sounds effects. We modeled the frequency response by using a 2nd-order Chebyshev bandpass filter with cutoff frequencies derived from the given curves, which provided a good match based on the MATLAB filter visualization tool. This, combined with the saturation characteristics, acheived the desired result of a progressively warming-sounding series of echos at high feedback settings, as opposed to the harsher sound produced without these elements present in the system.

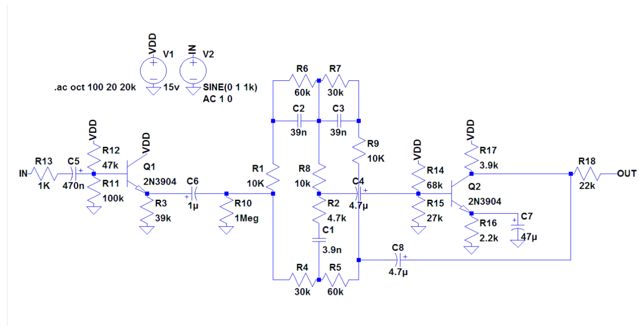


**Fig. 5**. Tone stack SPICE simulation schematic

## 5. TONE STACK

The tone control schematic, shown in [1], resembles a buffered Baxandall filter, which was first proposed in [5]. It employs user variable treble and bass controls via variable resistors. The schematic is reproduced in Figure 5 for the SPICE model of the tone stack. Altering the value of the treble control will slightly amplify or attenuate the bass response. Each potentiometer is independent from one another, but does not independently control the frequency response; instead they function as a network. The signal must is amplified before and after the variable passive filter in order to preserve signal integrity by the BJT amplifier networks shown implemented by Q1 and Q2. The treble variable resistor network (R4 and R5) also employs positive feedback capacitor, and the network is tuned for a crossover frequency of 750 Hz. Intuitively, this means the Treble control attenuates or amplifies frequencies above 750 Hz, while the Bass control (R6 and R7) attenuates or amplifies frequencies below 750 Hz. The simulated frequency response at various EQ settings is shown in Figure 6. The center frequency and bandwidth at each of the shown equalization settings was calculated, and the tone stack was modeled as a pair of parametric EQ filters with the appropriate gain and Q values. The Q and center frequency values were interpolated linearly between the values for the combinations shown.

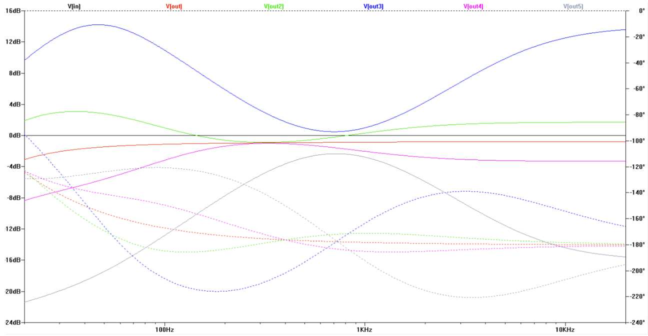


**Fig. 6**. Simulated equalization curves

## 6. IMPLEMENTATION AND FUTURE WORK

The system was implemented as a MATLAB Audio Plugin object using the MATLAB Audio System Toolbox released this year [6]. A test bench MATLAB environment was used to test the plugin on stored audio samples while simultaneously visualizing parameters of interest, for example, the current delay time, in real-time. Additionally, MATLAB was used to generate a VST plugin of the effect for use in conventional digital audio workstations, such as Pro Tools, Cubase, or Ableton Live.

The most challenging part of the implementation was achieving a smoothly interpolated delay line when the delay length is modulated. Delay line interpolation is easy to do when delay time is static, and any artifacts associated with changes in delay length are instantaneous and fade quickly. However, with the addition of the delay signal modeling techniques discussed in this paper, the problem of aliasing becomes more difficult to control. We found that simple linear interpolation did not produce much audible aliasing for small changes in delay time with the ballistic model in place, but when the parameter was swept from minimum to maximum, harsh aliasing was audible sweeping down from Nyquist as the delay length slowly changed from its initial to target setting. Aliasing was even more egregious with the low frequency stochastic component was added to model the tape wow. We settled on using a first order all-pass filter for the interpolation process as described in [7]. With this method, we were able to effectively remove any audible aliasing or other digital artifacts resulting from the constantly modulated delay line which makes up the echo signal path.

Due to time constraints, not all features which were characterized by measurements were successfully modeled in the final system design. As mentioned, the pinch wheel and capstan components were omitted from the delay line synthesis model. Additionally, our current implementation uses the Gaussian error function as opposed to the measured amplitude characteristic. Finally, the tone stack modeling is not yet completed. We verified our design approach using built in MATLAB parametric equalization objects, but we have not yet incorporated the tone stack filters into the VST or audio plugin object itself.

## 7. CONCLUSIONS

In this paper, we have presented the measurement-based design of a real-time digital model of a vintage tape-based audio effects unit, the Roland RE-201 Space Echo. The tape speed, which determines the echo time, was modeled by a low-frequency drift component based on wow and flutter measurements, along with a leaky integrator-based ballistic model informed by measurements of the hardware unit's response to parameter changes. Measurements were taken to characterize the tape's amplitude saturation characteristic, and the amplitude characteristic and frequency response of the magnetic tape were modeled by a Gaussian error function and bandpass filter, respectively. The tone stack circuit was simulated to generate equalization curves to inform a parametric EQ-based emulation of the output tone controls. Finally, a VST audio plugin of the outlined system was generated, which produced subjectively pleasing results that were reminiscent of the original hardware effect.

## 8. REFERENCES

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