Analog Tape Delay Analysis and Emulation

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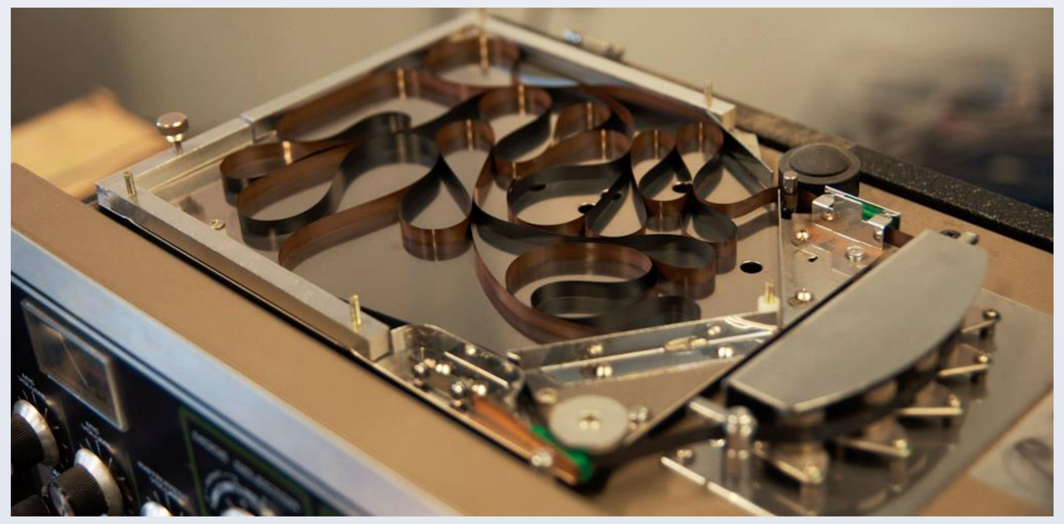
ABSTRACT

This poster presents a system for accurately modeling and emulating the audio characteristics of a famous analog tape delay effect, the Roland RE-201 Space Echo. Analog emulation is becoming increasingly popular in the world of audio production, thus it is ever more important to accurately represent the traits and qualities of analog devices. We take a measurement-based approach to modeling the unit, using empirical measurements of wow and flutter, delay ballistics, and tape saturation characteristics to inform our model. Additionally, we use simulated results of the tone stack circuit to model the output equalization in the final implementation.



BACKGROUND

The work in this paper is centered around the emulation and digital modeling of an Roland Space Echo from 1974. A survey of simulation techniques and considerations for tape echo effects, including the Space Echo, is presented in [1]. While Zozler offers conceptual help on desigining a digital model of these effects, the measurement and characterization of these features is unexplained. Thus, we have investigated measurement techniques to characterize the subsystems of the unit, as well as modeling techniques to generalize our measurements to a complete real-time model.

System Block Diagram

Many analog tape delay emulation approaches exist, although few are based on the Space Echo as proposed in [1]. In this system, the input signal is delayed, saturated by the tape characteristics, and summed with the direct input. The feedback path, with user adjustable gain, has the frequency characteristics of band pass filter, which significantly contributes to an accurate tape delay emulation. Additional equalization controls are applied outside subsequent to the delay and feedback lines to provide control of the overall output frequency response. While the original Space Echo features three delay taps in one of its modes, here we model only a single delay tap.

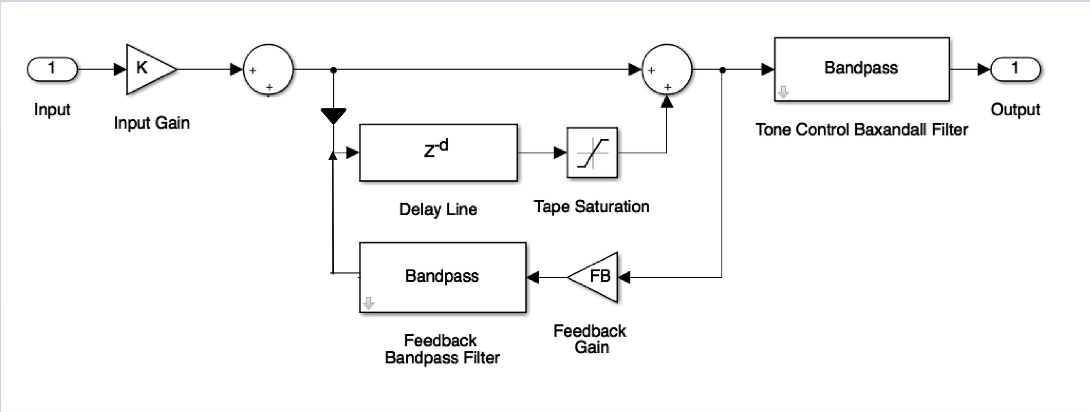


Fig. 1 – Signal Flow Diagram of Space Echo RE-201

WOW FLUTTER ANALYSIS AND EMULATION

Wow and Flutter are found in rotary driven audio tape machines and give analog tape machines much of their signature sound. The inconsistency in rotation causes a fluctuation in pitch and in the case of tape delay units, this causes inconsistent timing between repeats. Wow is considered to be a fluctuation between 0.1-10Hz while flutter is considered to be between 10-100Hz [2]. Our method of testing wow and flutter concluded that intensity of the imperfections in the motor speed was more apparent than initially suspected. Feeding a 30 second, 1kHz sine wave into the input and recording the output of the device caused audible phase cancelation due to the inconsistency in the timing of repeats. Our measurements proved the flutter to be more apparent when the test signal was 30 second, 3.15kHz sine wave. These frequencies were chosen because they are high enough to give appropriate resolution and low enough to not be affected by high frequency loss. Another reason these frequencies are appropriate test signals is because wow and flutter can be easily heard when the frequency is between 1-4kHz. In order to accurately emulate the Roland Space Echo's imperfect capstan motor and tape loop, it is important to include this unique characteristic that modern digital delays do not consider. We adopted a signal model to synthesize delay time fluctuations based on the observed characteristics of low-frequency drift and harmonic action on the capstan.

Delay Balliistics

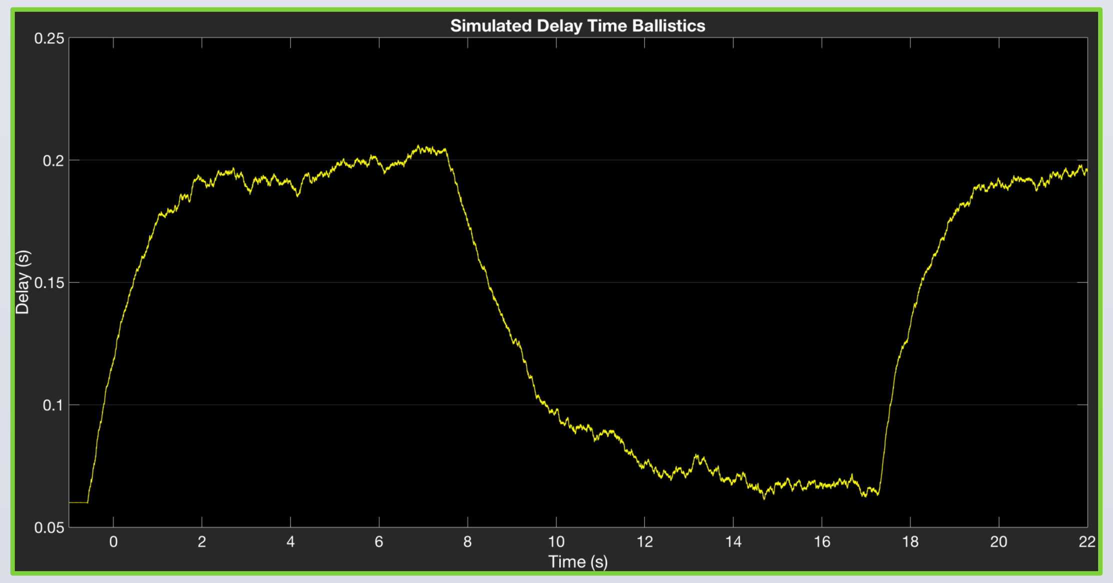


Fig. 2 – Simulated Delay Time Ballistics,
Accounting for Wow and Flutter

In addition to the wow and flutter present in the tape mechanism, the Space Echo also features a distinct ballistic response to adjustments in the delay time. Measurements were taken of the time to reach minimum and maximum delay time values, and time constants were derived from these measurements. The time constant is approximately 2 seconds for decreases in delay time, and 1 second for increases in delay time. In the simulation, we use a first-order leaky integrator with the appropriate time constant to model the ballistic pattern. The figure below shows the ballistic response to abrupt changes between minimum and maximum delay times. The response also includes a stochastic drift component derived from the empirical wow and flutter taken from the unit.

TONE CONTROL MODELING

The tone control schematic below is similar to a buffered Baxandall filter schematic with a Treble and Bass control via variable resistors. Each variable resistor is independent but does not independently control the frequency response, instead they work as a network to either amplify or attenuate specific frequencies. Additionally, the signal must be amplified prior to and subsequent to the variable passive filter in order to preserve signal integrity, hence BJT amplifier networks implemented by Q1 and Q2. The treble variable resistor network (R4 and R5) also employs positive feedback via C8 to more accurately manage frequencies above 750 Hz. Intuitively, this means the treble control attenuates or amplifies frequencies above 750Hz, while the bass control (R6 and R7) attenuates or amplifies frequencies below 750 Hz.

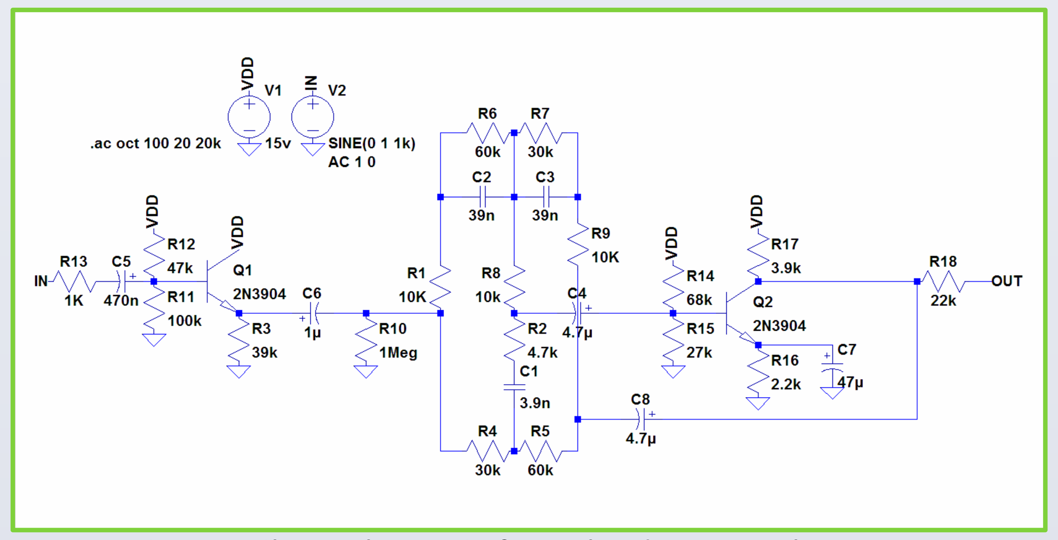


Fig. 3 – Filter Schematic for Roland Space Echo RE-201

The graph shown below, displays the frequency curves with various settings of the treble (R4 and R5) and bass (R6 and R7).

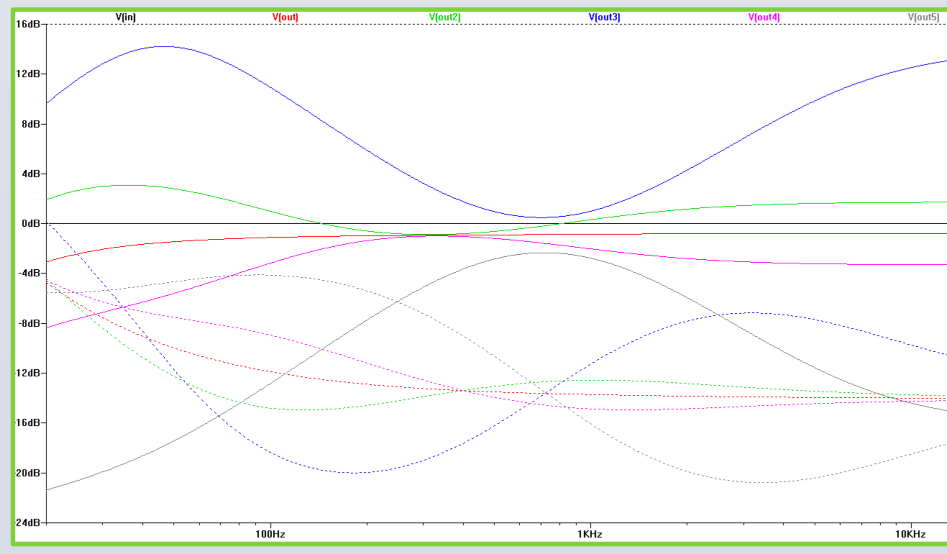


Fig. 4 – Frequency Response for Fig 2. with various settings
Using LT Spice AC Analysis
V(out): Treble (5), Bass (5)
V(out2): Treble (7), Bass (7)
V(out3): Treble (10), Bass(10)
V(out4): Treble (3), Bass (3)
V(out5): Treble (0), Bass (0)

Feedback Filtering

The Space Echo RE-201 also incorporates additional filtering in the feedback network that acts as a band pass filter with a cutoffs at approximately 100Hz-10kHz. The bandpass ensures that harsh high frequencies are not included when feedback is greater than 100% and self oscillates. This filter models the frequency response of the record and playback heads of the tape loop.

TAPE SATURATION

Tape saturation creates a non-linear, distorted input-output characteristic due to a combination of tape magnetization, tape head construction, speed, width, equalization, biasing, and the levels of the source and input gain staging. Tape saturation causes a "warmer" sound due to the overall soft clipping of the signal, unlike the hard clipping present in digital distortion. Tape has a limited bandwidth that is determined by the width and construction of the tape. In order to accurately test the tape saturation of this unit, a 1kHz sine wave with ramping amplitude was fed into the unit, to allow input and output amplitude to be compared at constant frequency. While measuring the amplitude of the output, an S-curve to determine the saturation characteristics of the tape could be constructed.

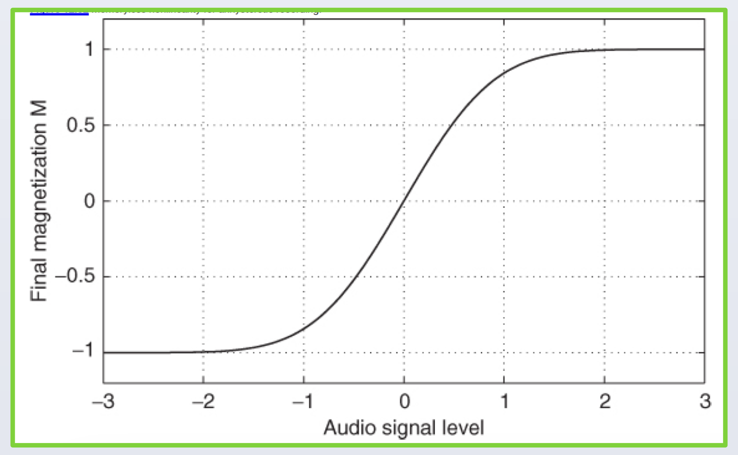


Fig. 5 – Typical Tape Saturation Curve (from [1])

RESULTS

A digital model including the simulated analog characteristics discussed in this poster has been designed using the MATLAB Audio System Toolbox, released this year. The resulting audio plugin can be run offline in MATLAB, or in real-time using the MATLAB Audio Test Bench. Additionally, a VST plugin was generated from the real-time MATLAB code, allowing the simulation to be used in standard digital audio workstations alongside other VST plugins. The results are subjectively pleasing, and are a close match to the sound of the original unit at many combinations of settings. In order to bring our model's sound closer to that of the original Space Echo, we propose a number of improvements for future work, listed below.

FUTURE WORK

- Spring Reverb Tank Modeling and Emulation
- Multiple Playback Head Delay Settings
- Frequency response and of all gain stages in unit in order to accurately represent signal flow
- Low level real-time simulation at component level as in [3]
- Characterize Feedback frequency response

REFERENCES

[1] U. Zolzer. "*DAFX: Digital Audio Effects*", 2nd Ed., 2011.

[2] "Flutter measurement." U.S. Patent 2,762,013, issued September 4, 1956.

[3] K. Dempwolf, M. Holters and U. Zölzer. "*Discretization of Parametric Analog Circuits for Real-Time Simulations*," Proc. of the 13th Int. Conference on Digital Audio Effects (DAFx-10), Graz, Austria , September 6-10, 2010.

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