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# Circuit based classical guitar model

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ABSTRACT

With the growth of electronic gaming, personal electronics and the widespread creation and distribution of digital music, the ability to synthesize realistic instrument sounds is becoming more important. In particular, the ability to synthesize guitar sounds is necessary for a variety of applications. The dynamics of a string with ideal boundary conditions are well known, but the structure of an acoustic guitar presents very different boundary conditions that modify the resulting sound. We propose an approach based on measured transfer functions from a classical guitar. A transmission line is used to represent the output of a vibrating string which is then modified by a filter bank whose transfer function reproduces the driving point frequency response functions from the classical guitar. The result is a synthesized sound that reproduces much of the tonal quality of the actual instrument.



## 1. Introduction

The behavior of strings and string instruments like guitars and violins has been studied and simulated using electrical analogies for more than 70 years. A vibrating string was considered as an electrical transmission line due to the fact that a traveling wave exists on both of them [1]. Later, a violin was modeled as a circuit composed of an electrical transmission line, transformers, resistors, inductors, and capacitors in continuous time domain [2]. As digital technologies mature, strings and string instruments are simulated using digital waveguides or wave digital filters. The digital waveguide consists of two delay lines along which the sampled values of traveling waves propagate oppositely. A physical value like the displacement at the specific location of a string is obtained by summing two values from the delay lines at the corresponding location [3,4]. Models using wave digital filters are accomplished by converting a string instrument into an analog circuit and then substituting analog components with counterparts of the wave digital filter such as one-ports and their connections with adaptors [5]. Of course, there have been many examples of strings and of instruments being modeled numerically. For example, the wave equation governing a flexible string was approximated to a finite difference form [6].

This paper deals with the synthesis of a classical guitar sound with an equivalent electrical circuit. The string is replaced by a transmission line, and the body by a combination of resistors, inductors, and capacitors, simulating a series of plate resonances coupled with air modes of a sound box. The resistors, inductors, and capacitors in the circuit are adjusted such that its calculated admittance conforms to the measured one by modal testing. In the string models built with an analogy to the transmission line, a rigid end to strings had been represented as an open circuit, and the displacement of a string as the current on the transmission line [1,2,7]. However, it turned out that the rigid end corresponds to a short circuit, the displacement to the voltage. Reflecting these discoveries, a transmission line based plucked string model comprising a transmission line, two piecewise linear current sources, and switches was proposed [8]. On the other hand, the existing transmission line based models for strings and string instruments were either developed with rigid ends to strings, or with conceptual models for bodies of the instruments [1,2,7]. In this paper, the circuit for a guitar body is implemented with a RLC circuit based on the equivalent circuit for the well known two-mass model which covers two resonant frequencies with a Helmholtz frequency between them [9]. The circuit is expanded to include additional 19 resonant frequencies over the second resonant frequency of the two-mass model, and tuned according to the measured frequency response function of the guitar body. The expanded circuit is finally integrated with the transmission line based plucked string model to make a guitar model. The implementation of the frequency response function of a guitar body in the models using digital waveguides or wave digital filters would be nontrivial due to the aliasing or the frequency warping resulting from the analog–digital transformation. The proposed circuit model is built and simulated using Pspice. The voltage and current

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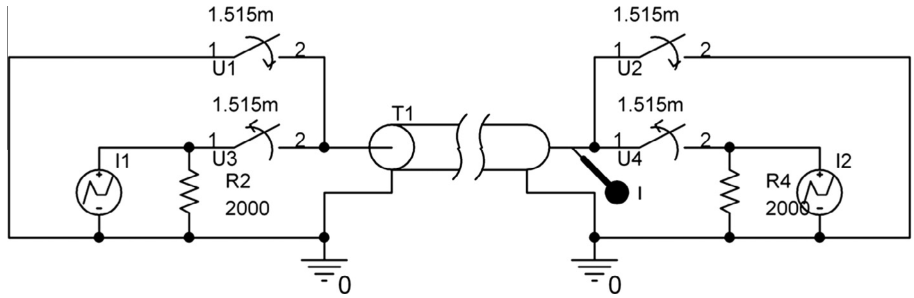


**Fig. 1.** Circuit for an open E-1 string with rigid ends. The delay time of the transmission line is set to 1.515 ms according to the fundamental frequency of the string, 329.6 Hz.

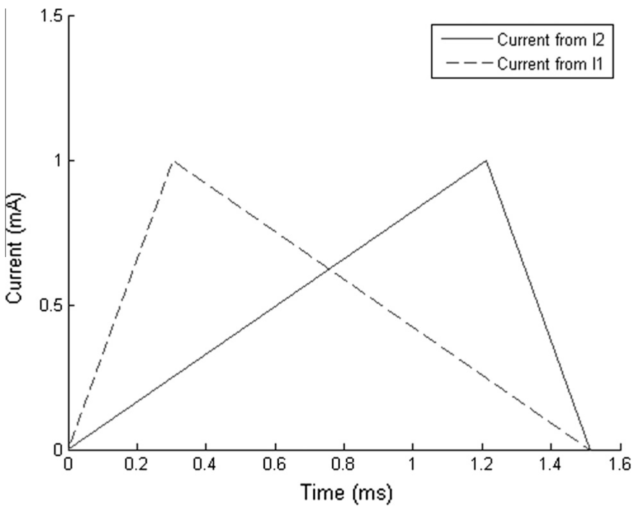


**Fig. 2.** Piecewise linear currents supplied by the current sources of I1 and I2 in Fig. 1. The current from I1 linearly increases from 0 mA at 0 ms to 1 mA at 0.303 ms, and decreases back to 0 mA at 1.515 ms, while the current from I2 is symmetric to that from I1 with respect to the half of 1.515 ms.

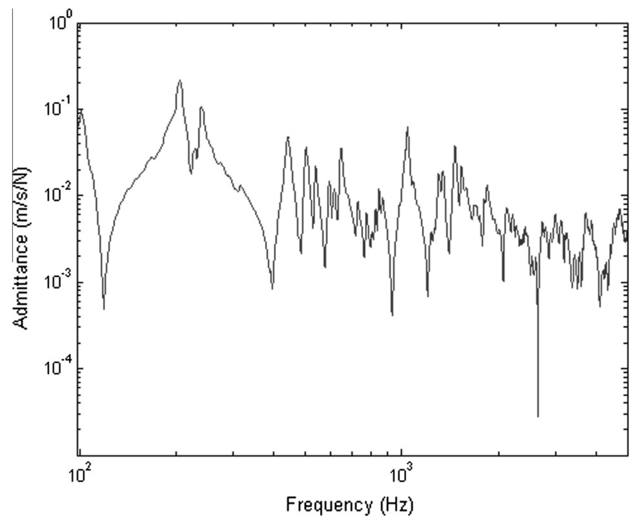


**Fig. 4.** Measured admittance for a guitar body. It shows that the first resonant frequency is 101.6 Hz, the Helmholtz resonant frequency is 118.8 Hz, and the second resonant frequency is 204.7 Hz, etc.

waveform at a node in the proposed circuit model corresponding to a place on the bridge where a string crosses are differentiated with respect to time to get the velocity and the force at the same place on the bridge, respectively. The velocity and the force waveforms, taken as the synthesized guitar sounds, are compared with a real one in both time and frequency domains.

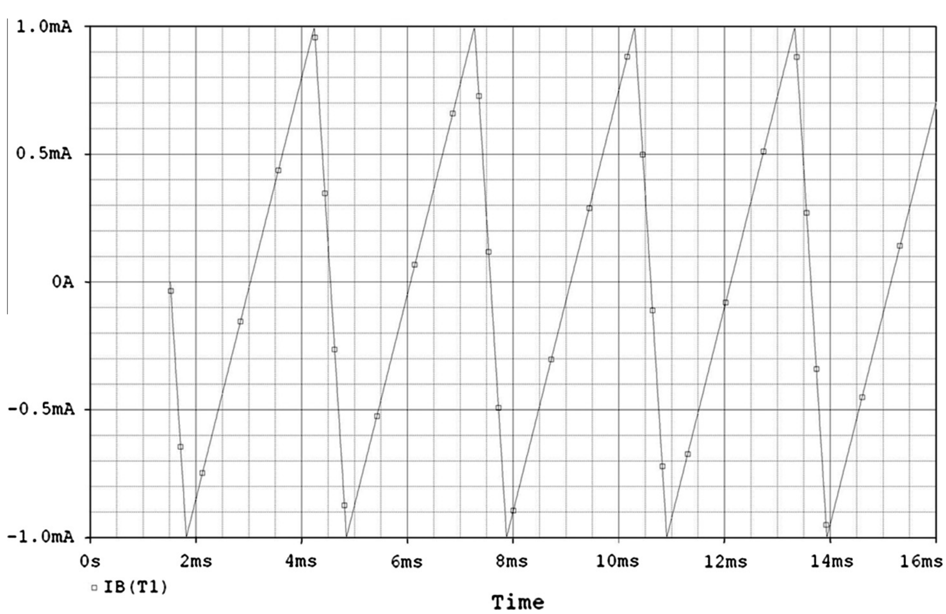


**Fig. 3.** Current waveform at the probe in Fig. 1. It is acquired after 1.515 ms because the voltage distribution along the transmission line at 1.515 ms corresponds to the initial plucking of the string.