REVISTA PERSPECTIVAS

VOLUMEN 7, N°1 / ENERO - JULIO 2025 / e - ISSN: 2661

DOI: https://doi.org/10.47187/perspectivas.7.1.209

MUSIC PLAYBACK BY PLASMA GENERATION WITH FIR FILTER IMPLEMENTATION IN MATLAB

Reproducción de música mediante generación de plasma con implementación de filtro FIR en matlab

James Neira	james.neira@espoch.edu.ec
Carlos Millingalli	carlos.millingalli@espoch.edu.ec
Luis Merino	luisf.merino@espoch.edu.ec
Erick Ordoñez	erick.ordoniez@espoch.edu.ec

Facultad de Informática y Electrónica, Escuela Superior Politécnica de Chimborazo, Riobamba, Ecuador.

RESUMEN

The Tesla coil was invented by Nikola Tesla in the late nineteenth century and produces electrical discharges in the form of high-voltage arcs, unlike the musical Tesla coil, which focuses on the generation of musical sounds through controlled electrical discharges. To create an audio reproduction device by using a physical phenomenon, it is necessary to create a device capable of emitting audio through the modulation of an electrical discharge launched into the air, which mainly consists of two coils. This element is commonly known as Plasma Speaker or Musical Tesla Coil. It was also considered adding an audio amplifier so that the sound has greater intensity, and a virtual bandpass filter designed in Matlab software to record the behavior of the musical Tesla coil to the different frequencies of the musical tones.

Palabras Clave: Music, Plasma, Signal Analysis.

ABSTRACT

La bobina de Tesla fue inventada por Nikola Tesla a finales del siglo XIX y produce descargas eléctricas en forma de arcos de alto voltaje, a diferencia de la bobina de Tesla musical, que se centra en la generación de sonidos musicales a través de descargas eléctricas controladas. Para crear un dispositivo de reproducción de audio mediante el uso de un fenómeno físico, se constituye la creación de un dispositivo capaz de emitir audio a través de la modulación de una descarga eléctrica lanzada al aire, que consta principalmente de dos bobinas. Este elemento es conocido comúnmente como Parlante de Plasma o Bobina de Tesla Musical, también consideramos agregar un amplificador de audio para que el sonido tenga una mayor intensidad, y un filtro pasa banda virtual diseñado en el software Matlab para observar el comportamiento de la bobina de Tesla musical a las diferentes frecuencias de los tonos musicales.

Keywords: Música, Plasma, Análisis de Señal.

I. Introducción

Nikola Tesla (1853-1943), Serbian-American engineer who owes his fame to his contribution to the design of the alternating current distribution system. In 1891 he created a resonant transformer circuit, known today as a Tesla coil. He used the coils to conduct experiments in X-ray generation, electric lighting, electrotherapy and wireless power transmission, among others [1]. Tesla himself already came up with many variations of this design and later new ones were made, but they all have in common that they must consist of two coupled circuits forming a transformer [2].

Fecha de Recepción: 14/08/2023. **Fecha de Aceptación:** 14/05/2024. **Fecha de Publicación:** 20/01/2025

The Tesla Coil is a high-voltage, high-frequency generating device that uses electromagnetism to produce effects such as corona, efflux and electric arcs. Tesla envisioned the possibility of using the Tesla Coil to transmit electrical energy wirelessly, without the need for conductors, although so far this application has been limited by technical difficulties in achieving efficient transmission [3].

The design of a Tesla coil is made considering a primary transformer (with steel core) and from this the parameters of the other elements that compose a Tesla coil are selected [4]. The operation can be seen as two resonant circuits weakly coupled by air. The coupling coefficient between coils L1 and L2 is usually between 0.1 and 0.2 [5].

Experiments that can be performed using the coil are, demonstration of the corona effect, an application of the Faraday cage, the protection of lightning rods, the" presence" of the electromagnetic field in space, the effect of high voltages on gases under low voltages [6].

For the analysis of sound waves, the concatenation of segments is used where each segment is characterized by parameters, these can be different when manipulating the signal and the frequency can be modified by the damping values. To solve the problem of linear transaction time estimates, the poles must be known [7].

By means of MATLAB software where they used the Simulink tool and the guide for the design of the band-pass filters where they analyzed the behavior of the musical Tesla coil for low, medium and high tones considering the respective frequencies for the different tonalities.

The frequencies that can be perceived by the human ear range from 15 Hz to 20,000 Hz, although in music the highest sounds usually reach 5,000 Hz. Sounds below 15 Hz are called infra sound, and above 20,000 Hz ultrasound [8].

Considering the different tonalities we consider the bass tones which is in the frequency range of 25 Hz to 125 Hz, medium tones having a frequency range of 400 Hz to 2 KHz and the high tones which is in a frequency range of 8 KHz to 12 KHz [9].

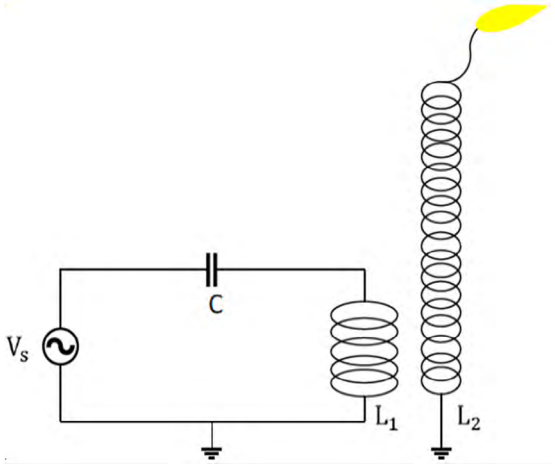

Fig. 1: *Tesla coil elements electronic circuit.*

Music reproduction via plasma is an innovative technology that has emerged in the field of acoustics. It is based on using a plasma discharge as a sound source instead of traditional loudspeakers. Plasma speakers work by ionizing air into small electrical discharges, which create shock waves that propagate through the air and produce sound. One of the strengths of plasma speakers is their ability to reproduce extremely high and low frequencies, which makes them an interesting option for high-quality music playback. In addition, the sound of the plasma speaker is immune to electromagnetic interference, making it ideal for interference-sensitive environments.

When a Tesla coil is connected to an audio system, audio signals can be sent to the coil to modulate the frequency and amplitude of the electrical discharges. This can generate tones and noises that are synchronized with the music being played, the audio modulation produces audible sounds due to the electrical discharges. These sounds resemble clicks, sparks and buzzes, and can be used creatively in experimental musical compositions.

II. Theoretical Foundation

The Tesla coil consists of a resonant transformer that includes a frequency-tuned primary circuit together with a secondary coil. For its operation, a high voltage transformer is used to supply the

required electric current. Using this mechanism, the capacitor in the primary circuit is charged. When the voltage reaches a sufficiently high level, the transformer and capacitor overcome the electrical resistance of the air in the exposer, generating an electric arc that allows the discharge of the capacitor in the primary coil. The primary coil is in resonance with the secondary coil [10].

When current flows through the primary coil, an electromagnetic field is generated which allows the transfer of energy to the secondary coil to increase the voltage. When discharged to ground, a strong electromagnetic field is produced in the toroid, resulting in an electric arc into the surrounding air due to the high voltage, which can be on the order of hundreds of thousands of volts. For optimum operation, it is crucial that the primary and secondary coils are in resonance, which is achieved by adjusting the inductors and capacitors in the respective primary and secondary circuits [10].

In the Figure 1, the Tesla coil electronic schematic is shown, which integrates the following elements:

- Power supply: This frequency control circuit feeds the primary circuit with a square wave signal modulated at the resonant frequency of the circuit to obtain the maximum possible voltage [11].

- Capacitor: a passive device used in electricity and electronics; this device allows storing electric energy by supporting a certain electric field [12].

- Primary Circuit: This is an L-C circuit fed by a switched-mode power supply that generates a square excitation signal at the resonant frequency of the circuit [11].

- Coil L1: The primary circuit coil must have few turns and a larger wire section than the secondary circuit coil to be able to raise the voltage in a similar way to a conventional transformer, the primary coil usually has between 5 and 12 turns, it is calculated using Wheeler's formula expressed in Eq. (1), where: N_1 is the number of turns of the primary coil, R_1 is the radius of the circumference of the base (cm), and H_1 is the height of the primary coil (cm). The primary coil is used to establish the resonance between the primary circuit and the secondary circuit [11].

- Secondary circuit: The secondary circuit is composed of another L-C circuit magnetically coupled to the primary circuit [11].

- Coil L2: The secondary coil must have a higher inductance than the primary coil. The number of turns constituting the secondary coil is much higher than in the case of the primary circuit coil, in the order of a thousand turns [11]. The inductive value of L2 is calculated using Eq. (2), where: N_2 is the number of turns of the second coil, R_2 is the radius of the circumference of the base (cm), and H_2 is the height of the second coil (cm).

$$L_1 = \frac{N_1^2 \cdot R_1^2}{(9R_1 + 10H_1) \cdot 2540} \ [mH] \qquad (1)$$

$$L_2 = \frac{N_2^2 \cdot R_2^2}{(9R_2 + 10H_2) \cdot 2540} \ [mH] \qquad (2)$$

III. Methodology

Extensive research was carried out on the working principles of the Tesla coil, as well as projects related to its use in musical applications. Reliable sources such as scientific articles, books, and online resources are reviewed to gain an in-depth understanding of the theoretical foundations and practical applications of the Tesla coil in the musical context.

Once the concepts necessary to develop a musical Tesla coil have been understood, a block diagram has been made for its implementation, there was helping to understand the construction of the musical Tesla coil as we can notice in Figure 2.

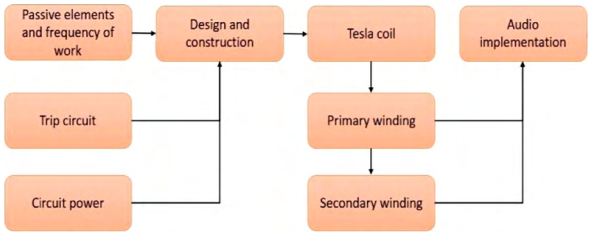

Fig. 2: *Block diagram of Tesla coil elements interaction.*

A. Passive elements and frequency of work

The size of the Tesla coil to be used, that is, the physical dimensions of the coil, must be determined. The resonance frequency of the circuit (f0) depends on the inductance of the secondary coil (L2) and the capacitances that make up the secondary of the circuit, that is, the one that is generated between the turns of the secondary coil (CL2) and the discharge capacitor (Cd) [1].

B. Trip circuit

To carry out the firing circuit, power circuits are used whose core is formed by a MOSFET or power transistors. They are all basic configurations that can be found in any power electronics manual [1].

C. Circuit power

The power of the circuit depends on two variables, the first and main one is the amount of energy required by the firing circuit, the other is the desired mobility of the Tesla coil [1]. Although Tesla coils are powered by direct voltage, they can be connected to the electrical network if preferred. For our Tesla coil we are using a laptop charger that gives us 20V, 7.5A and 150W at the output of the charger, which is more than enough to power our circuit.

D. Design and construction

Based on the knowledge acquired in the preliminary investigation, we proceeded to design a Tesla coil circuit adapted to the specific objectives of the project. We carefully select the necessary components, the primary coil and the secondary coil, considering factors such as power, resonant frequency and modulation capacity. Electrical safety was considered at every stage of the design. Subsequently, the physical construction of the Tesla coil was proceeded following the appropriate assembly guidelines.

E. Tesla coil

The Tesla coil consists of two main components: the primary coil and the secondary coil. The primary coil is connected to a power source, and the secondary coil is magnetically coupled to the primary coil. Both coils are made up of a series of turns of insulated copper wire. When high frequency power is applied to the primary coil, an electromagnetic field is created which propagates through the secondary coil, this induces an electric current in the secondary coil and generates high voltages at its upper end.

In Figure 3, in the light blue box is the Tesla coil circuit consisting of a power supply, a MOSFET transistor TIP41C, but for the realization of the circuit has been used the MOSFET TIP35C for its characteristics mentioned above in the datasheet, also has a resistance of 1 KΩ to 1 W and a primary winding and a secondary winding.

1) Primary winding: For the primary winding, 1.5 mm diameter copper wire was used, which is of a larger diameter than the secondary winding, so it was wound in the secondary winding, which consists of 6 turns.

2) Secondary winding: For the secondary winding they used enameled copper wire AWG 31 of 0.2 mm in diameter, they also used a PVC tube of 2.5 cm in diameter and 30 cm long in which they proceeded to wind the enameled copper by means of the calculations made previously, this coil consists of 1200 turns. Where the coefficient ”44.2 [1/cm]” is a value obtained from the data sheet and h is the height that the winding is intended to have.

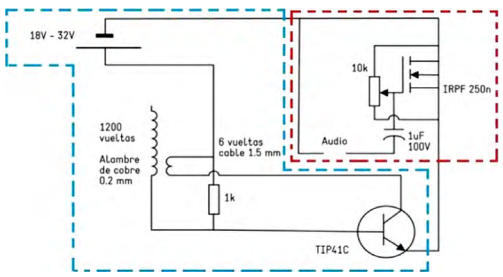

Fig. 3: *Musical Tesla coil electronic circuit.*

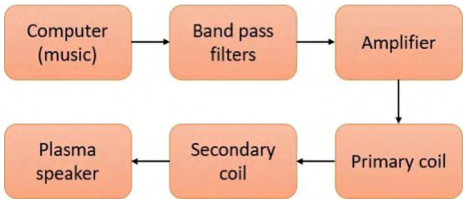

Fig. 4: *Block diagram of final outline of Tesla coil circuit.*

F. Audio implementation

Audio integration into the musical Tesla coil involves synchronizing the played audio with the electrical discharges generated by the Tesla coil. This allows sound effects to be modulated and matched to the music being played. The audio driver circuitry allows audio playback to be modulated and synchronized with electrical discharges from the Tesla coil.

In the Figure 3 the red box shows the driver circuit consisting of a 10 KΩ potentiometer, a 1 uF capacitor at 100V, a 3.5 mm female mini-jack adapter for the audio input and an IRFP250N transistor commonly used to amplify or switch electronic signals.

In the Figure 4, a block diagram shows the components interaction of the musical Tesla coil, which is explained below:

- Computer music: The computer is responsible for providing my audio signal which requires a process that first the sound is generated or reproduced in digital form where the sound card is responsible for processing and converting these digital audio signals into analog signals, then the sound waves are amplified to increase their energy level and finally sent by a 3.5 mm audio jack.

- Band pass filters: The band pass filter allows a specific range of frequencies to pass. The pass band is generally centered around a central frequency and has a certain bandwidth that defines the range of frequencies that are allowed to pass. This filter was developed in Matlab with the objective of analyzing the behavior of bass, mid and treble sounds.

- Amplifier: The amplifier is used to increase the power signal, making it strong enough to drive the Tesla coil and have a greater perception of the sound.

- Primary coil: The primary coil applies an alternating current, when the current flows through the primary coil, it generates a magnetic field that changes direction at a high frequency.

- Secondary coil: The secondary coil is located close to the primary coil and is magnetically coupled to it. When the magnetic field of the primary coil changes rapidly due to the AC current, it induces a current in the secondary coil. This induced current in the secondary coil is amplified and results in the generation of high voltages in the secondary coil.

- Plasma speaker: It is a speaker that creates sound by rapidly modulating an electrical discharge. The rapid oscillation of the electric arc produces a fluctuating column of ionized air, which is plasma. To generate sound the audio signal modulates the intensity of the electric arc, which causes the plasma to rapidly expand and contract in synchrony with the audio signal.

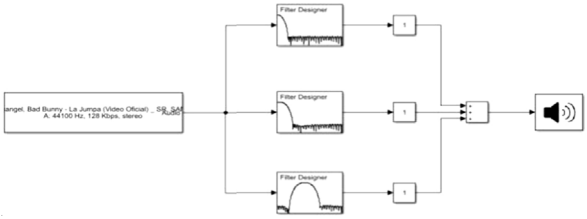

Fig. 5: *FIR Filter design in Simulink/Matlab.*

Fig. 6: *Control interface designed in Guide/Matlab.*

IV. Results

The results obtained in the tests showed that the musical Tesla coil was able to generate high frequency and voltage controlled electrical discharges and modular audio in a synchronized manner. Sound and visual effects were achieved.

Figure 5 shows the design of the FIR bandpass filters, which are of Chebyshev type of order 50 with their respective gain, where the low, medium and high tones are controlled.

Figure 6 shows the design of the sliders that allow to control the frequency range of the different tones and work together with the filters designed in Simulink.

As it can be seen in Figure 7, the implemented musical Tesla coil with the electronic circuit is shown. The computer oversees sending the audio to the coil, where it oversees modulating the frequencies and synchronizing them with the music.

The distance of the arc or electric spark produced by the device was measured, reaching 0.5 [cm] in length, which was more than enough for the visual part.

However, they noticed some inconveniences in the musical part, the volume when playing music is not very high, but it is heard perfectly, the TIP35C transistor works correctly, but it heats up quickly having an operating time of 42 seconds. A solution to this problem is that the transistors have their respective heat sink and thermal paste to increase the time of use.

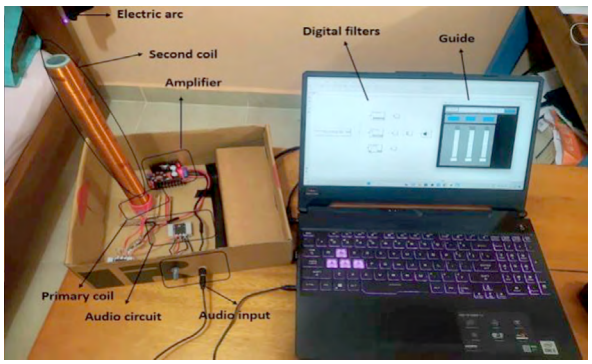

Fig. 7: *Implementation of the musical Tesla coil.*

V. Conclusions

The integration of audio into the musical Tesla Coil allows the modulation and synchronization of the audio playback with electrical discharges. This creates an immersive sensory experience, where the sound effects are coordinated with the visual effects, thus enhancing the viewer's experience.

The Tesla coil is a device that uses the principle of resonance, in this case electrical, to raise the frequency of a voltage signal by means of a special transformer, which generates the emission of surrounding air plasma.

The filter designed in the Matlab software worked as expected, since FIR filters are ideal for discrete signals, thus being able to make the designed circuit play any song, being able to analyze the behavior of the electric arc to the low, medium and high tones.

VI. References

[1] B. Aguirre, "Universidad Tecnológica Nacional Proyecto Final Reproducción de música mediante la generación de Plasma Autores: Facultad Regional Paraná."

[2] "Bobina de Tesla 57." [Online]. Available: http://www.ucm.es/centros/webs/oscar/

[3] L. Y. Generación Control De Alto Voltaje, E. Mantenimiento Eléctrico AUTORES, and B. Arias Francisco Ismael Rivera Chiriboga Diego Roberto, "UNIVERSIDAD TÉCNICA DEL NORTE FACULTAD DE EDUCACIÓN, CIENCIA Y TECNOLOG´IA."

[4] "Héctor Cadavid Ramirez, Oscar Román Tudela, Gillermo Aponte Mayor, Francisco Javier Garcia", "Diseño y construcción de una bobina de tesla", "2001".

[5] E. Pérez, O. Francés, and V. Senosiáin Miquélez, "ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALE Y DE TELECOMUNICACIÓN DISEÑO Y CONSTRUCIÓN DE UNA BOBINA TESLA."

[6] C. E. Laburu, S. De, and M. Arruda, “LABORATORIO A CONSTRUCIAO˜ DE UMA BOBINA DE TESLA PARA CASEIRO USO EM DEMONSTRAC¸ O˜ ES NA SALA DE AULA,” 1991.

[7] “Nelson Aimacaña, Marayma Cují, Alex Llamuca, Isabel Vaca, Tony Flores”, ”Modelado de Seáal por Segmentos Exponenciales y Aplicación en el Análisis de Voz”, ”PERSPECTIVAS”, ”2015”

[8] “Pastor Martíın, Ángel”, ”Matemáticas en la música”, ”Redined”, ”2008”.

[9] Juan E. San Martíın, ”Facultad de Bellas Artes UNLP”, ”Clase 15: Técnicas de Ecualización aplicadas a la mezcla”

[10] F. Pinilla and V. Pinilla, “DISEN˜ O DE UN PROTOTIPO DE BOBINA TESLA CON TENSIO´ N DE OPERACIO´ N PICO DE 280kV.”

[11] A.: Saray and M. Ruiz, “Trabajo Fin de Grado Diseño paramétrico de bobinas de Tesla Parametric design of Tesla coils,” 2017.

[12] L. Y. Generación Control De Alto Voltaje, E. Mantenimiento Eléctrico AUTORES, and B. Arias Francisco Ismael Rivera Chiriboga Diego Roberto, “UNIVERSIDAD TÉCNICA DEL NORTE FACULTAD DE EDUCACIÓN, CIENCIA Y TECNOLOGÍA.”