

**PROJECT TITLE:** *MPOT – Music Playing over Tesla*

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**UNIVERSITY:** *University of Klagenfurt*

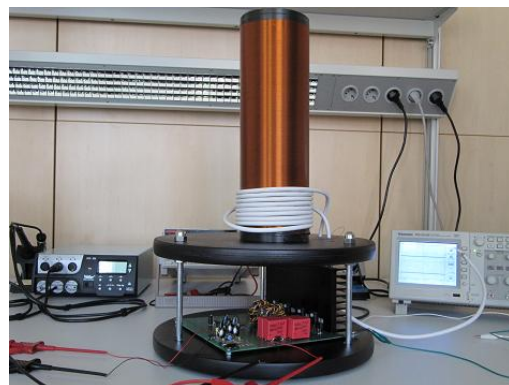
**DATE:** *24/06/2010*

**TI PARTS USED IN PROJECT:**

**1x, TL494CN,** <http://focus.ti.com/docs/prod/folders/print/tl494.html>

**2x, UCC37322P,** <http://focus.ti.com/docs/prod/folders/print/ucc37322.html>

**2x, UCC37321P,** <http://focus.ti.com/docs/prod/folders/print/ucc37321.html>



**PROJECT ABSTRACT (250 words maximum)**

The main idea of this project is to play music with the help of a Tesla-transformer. Therefore, the overall hardware of the project consists of several subcomponents. The Tesla-transformer itself consists of primary and secondary coil and exhibits a certain frequency of resonance. This resonance frequency signal is modulated by an imported audio signal. The modulation process is done with the help of a PWM (pulse-width-modulation) generation circuit, whereas the duty cycle is modified by the imported audio signal. The modulated signal has to be pre-amplified and a galvanic separation has to be done. A so-called H-bridge end-amplifies the modulated signal and fed it into the primary coil of the transformer. The occurring resonance rise at the secondary coil finally results in spark discharges which heat the surrounding air. This fact, on the other hand, leads to pressure differences and expanding and contracting air waves (generation of sound waves). The project flow includes the design of the individual sub-circuits, the PCB (printed circuit board) layout design as well as the assembling of the Tesla-transformer and the required electronic circuit part.

## **1 Introduction**

Tesla transformers (tesla coils, founded by Nikola Tesla in 1891) are devices for the generation of high-frequency alternating voltages. Tesla's goal was to use such a device for the wireless transmission of energy. Thereby, the energy is converted to sparks instead of being propagated through a medium. This was the starting point of many concepts used in radio theory. Nowadays, a similar principle of wireless transmission of energy is used in the field of RFID, where the transponder/tag is supplied with the help of a high-frequency electro-magnetic field, generated by the reader device. For power engineering the Tesla-transformer is almost inconsiderable because of the low power transmission. Furthermore it's only possible to recover parts of the generated energy and it's only applicable for low distances.

## **2 Motivation for project**

It's often seen that there exist approaches to generate amazing spark discharges with the help of Tesla-transformers and additionally used electric bulbs or fluorescent tubes. Our motivation for this project was to proof whether it is really possible to generate such sparks with low circuit complexity. Furthermore it should be possible to superimpose an imported audio signal and so to replay an arbitrary chosen composition with the help of the developed hardware.

## **3 Theoretical background**

This section treats the theoretical background of the project and should give a deep insight into the functionality of the single components and the interaction of the subcomponents to reach the project goals. For that the overall system is analyzed on system and circuit level and the influence of the used Texas Instruments ICs is described.

### **3.1 System analysis on system level**

The overall system hardware consists of following components:

- Importation of the audio signal

The audio signal is imported by using a 3,5mm audio jack plug of a laptop. The output signal is plugged to the input of the PWM generation circuit.

- Generation of the PWM (Pulse-width modulation) signal

Thereby, the frequency of the pulse-width modulated signal has to conform to the resonance frequency of the secondary coil of the Tesla-transformer. Otherwise, the effects of spark discharges and voltage rise couldn't be observed at the secondary side.

- Pre-Amplification of the PWM audio signal

The so-called driver stage is used to pre-amplify the pulse-width modulated signal.

- Galvanic separation of low-voltage and high-voltage parts

The galvanic separation is used for protection purposes. The circuit components on the low-voltage side should be protected against high currents and high voltages, which perhaps can be generated through short-circuited parts at the high-voltage side.

- Full-bridge circuit

The H-bridge circuit amplifies the signal from its input to the level of its high-voltage supply voltage.

- Tesla-transformer

The Tesla-transformer consists of a self-wounded coil at primary and secondary side, respectively. Through appropriate activation it creates spark discharges and is able to replay the superimposed audio signal.

In figure 1 and figure 2 the overall system is pictured on system level.

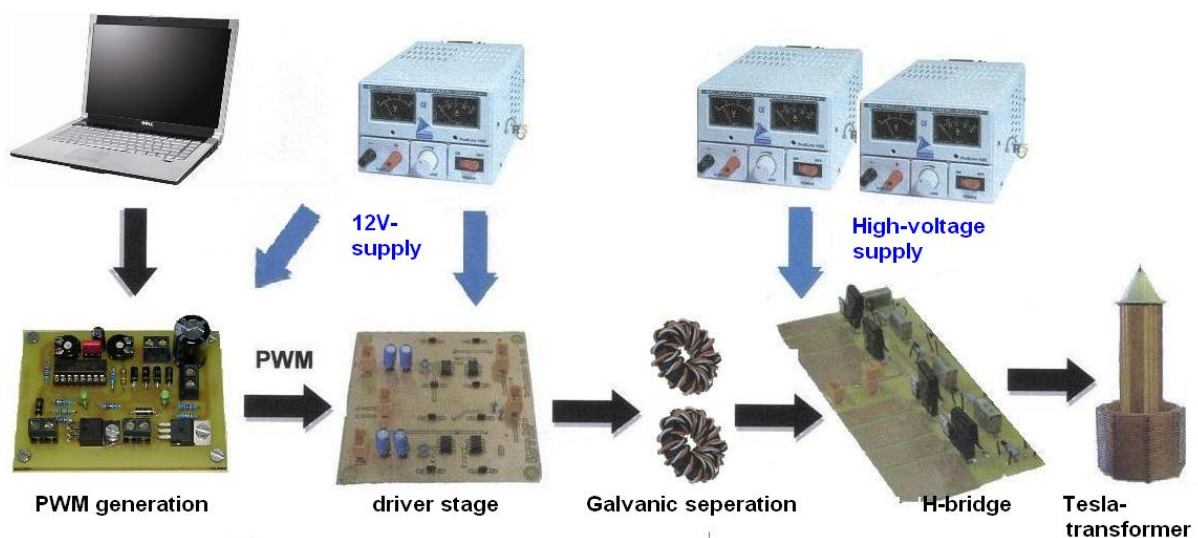


Figure 1: system description of the overall system on system level

Thereby, the goal was to design a single PCB (printed circuit board), which includes all electronic components required except the primary and secondary coil of the Tesla-transformer. For the generation of the supply voltage of low-voltage and high-voltage side, several power supply units were used which exhibit isolated bonding, respectively. If they don't exhibit that property an isolating transformer has to be used. To gain high voltages at the H-bridge power supply units can be switched in series.

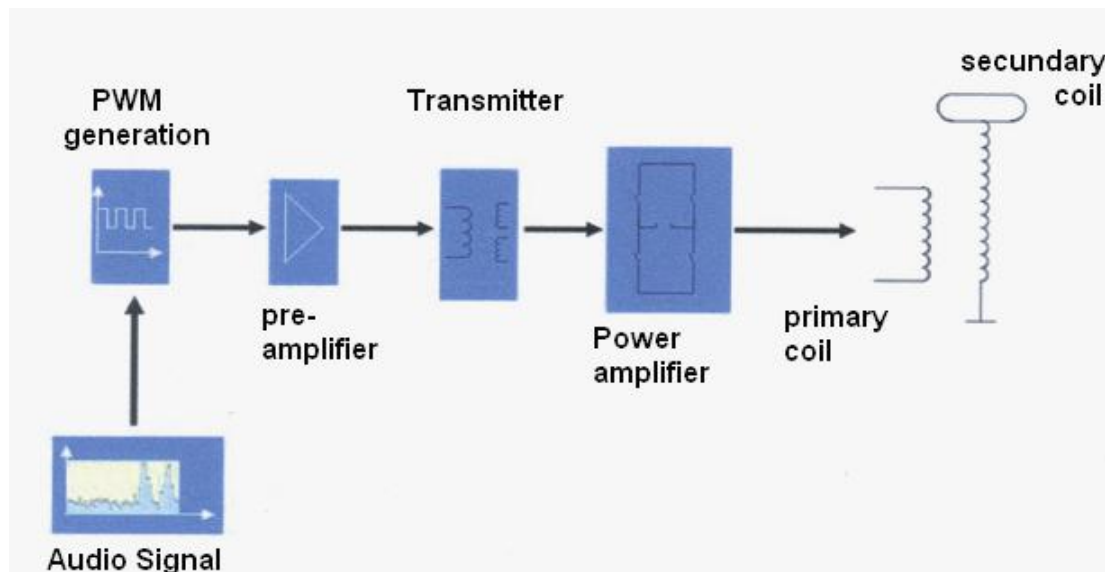


Figure 2: block diagram of the overall system

### 3.2 System analysis on circuit level

In this section all components of the overall system are described in detail.

#### Tesla transformer:

To understand the principle of a Tesla transformer the theory of oscillations is necessary. An oscillation can only occur between two energy storage elements and is defined as permanent clearing procedure. Thereby, the energy is oscillating between the two storage elements. The speed of the oscillation is defined as its frequency and depends on the size of the storage elements. Inductivity and capacitance are such storage elements to store current or rather voltage. These elements can be combined to get electrical resonant circuits which can exhibit the phenomena voltage or rather current superlevation. The bigger the storage capability, the lower the frequency of the oscillations. The reason for that is because the energy transmission process needs more time (Thomson formula).

Through the adjustment of the inductivity value compared to the value of the capacitance, and vice versa, it is possible to adjust the voltage and the current of a certain circuit component. That's because of the fact, that if e.g. the size of the inductivity is increased and that of the capacitance is decreased, the capacitance have to be charged with the same amount of energy which is available from the inductance. It's only possible if the capacitance increases its voltage. For the opposite case, if the value of the inductivity gets smaller and that of the capacitance increases, a higher current will be the consequence (depends on the circuit structure). This effect is exploited in the secondary coil of the transformer.

The transformer itself consists of primary and secondary coil, whereas the number of windings at the secondary side is much bigger than the number at the primary side. The inductivity is formed by the windings of the coils. So the inductivity part at

secondary side is much bigger than that on primary side. The capacitive part is formed by the capacity between the windings, which is almost vanishing. The resonance is built out of inductive and capacitive parts which results in a series resonance with voltage super-elevation at the secondary side of the transformer. As a resonance circuit means exchange or rather ex-charging of energy, the big energy stored in the inductivity has to be mapped to the comparatively low capacitance. So this results in spark discharges on the top of the Tesla coil which additionally generate active oxygen.

The more windings are used on secondary side, the lower the capacitance, the higher the inductivity (quadratic dependency) and the higher the voltage super-elevation on the top of the coil. An additional toroid on the top of the coil would increase the capacitance on this certain point to overcome this problem.

### **PWM generation circuit:**

This circuit consists of a Texas Instruments TL494CN IC with additional components which are responsible for adjusting the output's frequency. The main advantage of this IC is that the adjusted pulse width remains absolutely constant even if the supply voltage or the adjusted output frequency is changed. Furthermore the TL494CN PWM control unit exhibits really good transient behaviour (steep edges). Internally, the component consists of the required subcomponents like sawtooth generator, comparators and latches to produce an appropriate drive signal for the MOSFET devices of the full bridge. Depending on the wiring one or rather two (complementary) drive signals with short dead time between the transitions can be generated. That's important to ensure that the MOSFET devices are not switched-on at the same time (in the case of a half-bridge).

In figure 3 and figure 4 a typically wiring of the PWM generation circuit and the internal block diagram of the TI TL494CN are shown.

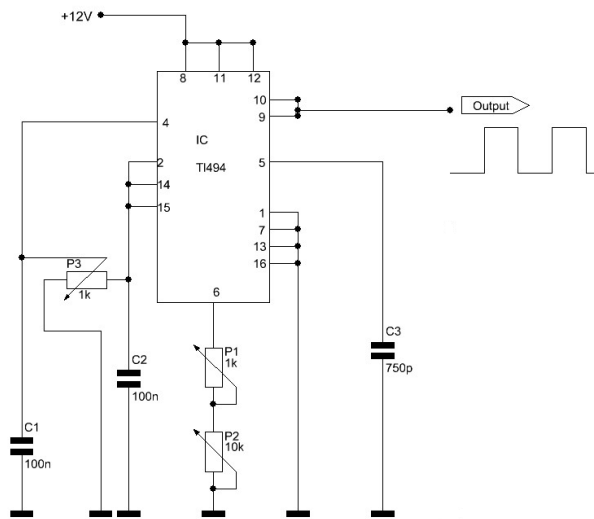


Figure 3 PWM generation circuit

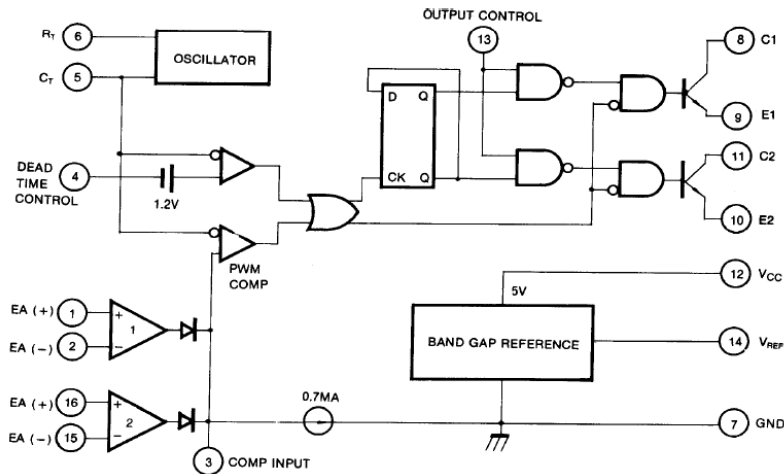


Figure 4 Internal block diagram of TL494CN

Thereby, the resonance frequency is adjusted with the help of the capacitive and resistive parts connected to contacts 5 and 6. The output control pin is connected to ground, that means the circuit is operating in single-ended or rather parallel output. For normal push-pull operation the potential at this pin should match to the potential at pin 14.

**Driver stage:**

The driver stage consists of two different kinds of TI MOSFET drivers. Its goal is to pre-amplify the pulse-width modulated signal to ensure a safely switching process of

the MOSFET transistors of the H-bridge. If their MOSFETs should switch a signal of high frequency the signal at the input of the H-bridge has to be amplified because of the capacitive input of the transistor stages. So the interconnected inputs of the MOSFET transistors of the H-bridge become low-resistance again and the switching process is eased.

As MOSFET drivers the TI devices UCC37322P/UCC37321P were used. In figure 5 and figure 6 a typical driver stage or rather the internal block diagram of a UCC37321P/UCC37322P is shown.

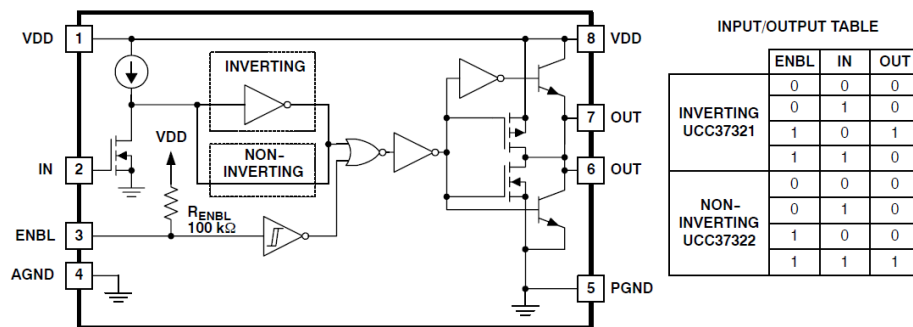


Figure 6 Internal block diagram of power MOSFET driver

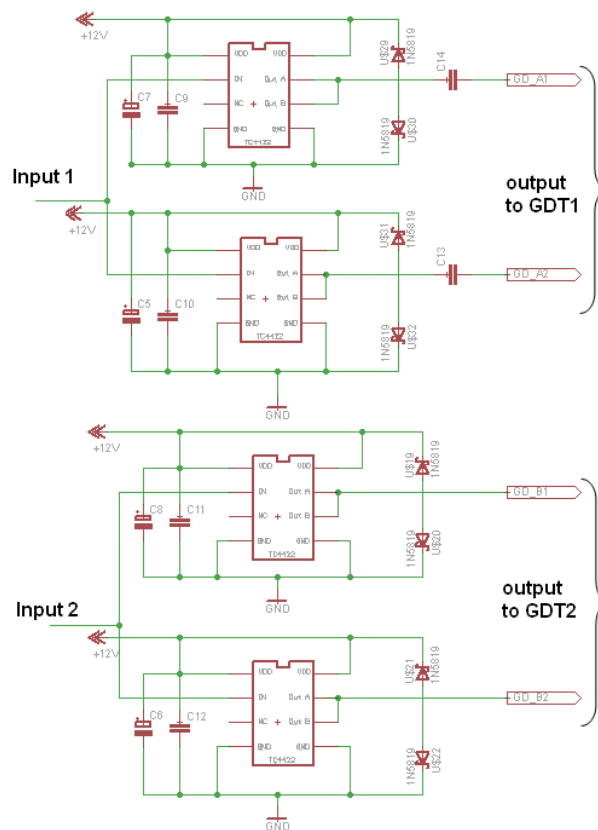


Figure 7 driver stage circuit

Input 1 and Input 2 represent the generated PWM-signals. Depending on push/pull- or parallel output mode of the PWM-generation circuit the inputs exhibit different or

rather the same signal shapes. In our case the PWM generation circuit were operated in parallel output mode. So the two inputs exhibit the same signal shape. By using two UCC37321P MOSFET drivers for output 1 and its non-inverting version UCC37322P for output 2 the outputs exhibit different (inverted) signal shapes. The enable pin can be left open for standard operation.

### **Gate Drive Transformer (GDT):**

The GDT is used to support a galvanic separation of the low and high-voltage part of the overall system. In our case the GDT itself consists of a circular ferrite core with winded inductivities (one primary coil, 2 secondary coils) on it. So the fed input signal is split to two output signal which are transmitted to the H-bridge. Depending on the quality of the ferrite core the output signal of the GDT exhibits the same shape or rather a distorted version of its input signal. Due to separated secondary coils, which are wound out-of-phase, potential-independent signals are generated. The number of windings depends on the pre-amplifier and directly affects the shape of the output signal of the GDT. Too few windings results in a high current and cooling problems. An insufficient number of windings result in a high-impedance and inductive GDT and the signal at the output nearly exhibits sinusoidal behaviour. Due to the fact that two signal paths are present two separate gate drive transformers are used.

The GDT isolates the sensitive low voltage control circuitry from the high power MOSFET side. Furthermore it couples the drive signals to the gates of the bridge's MOSFET.

## **4 Implementation**

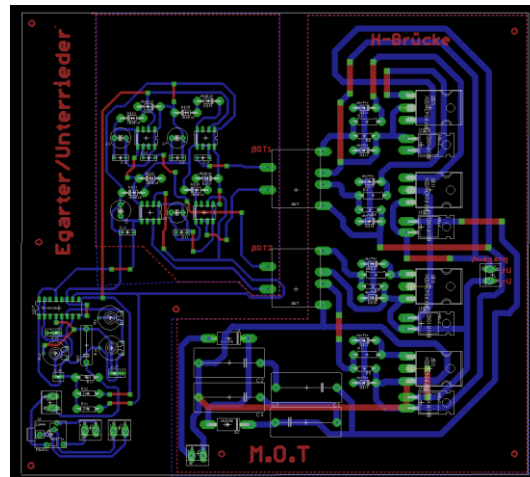


Figure 8 Eagle Layout Board

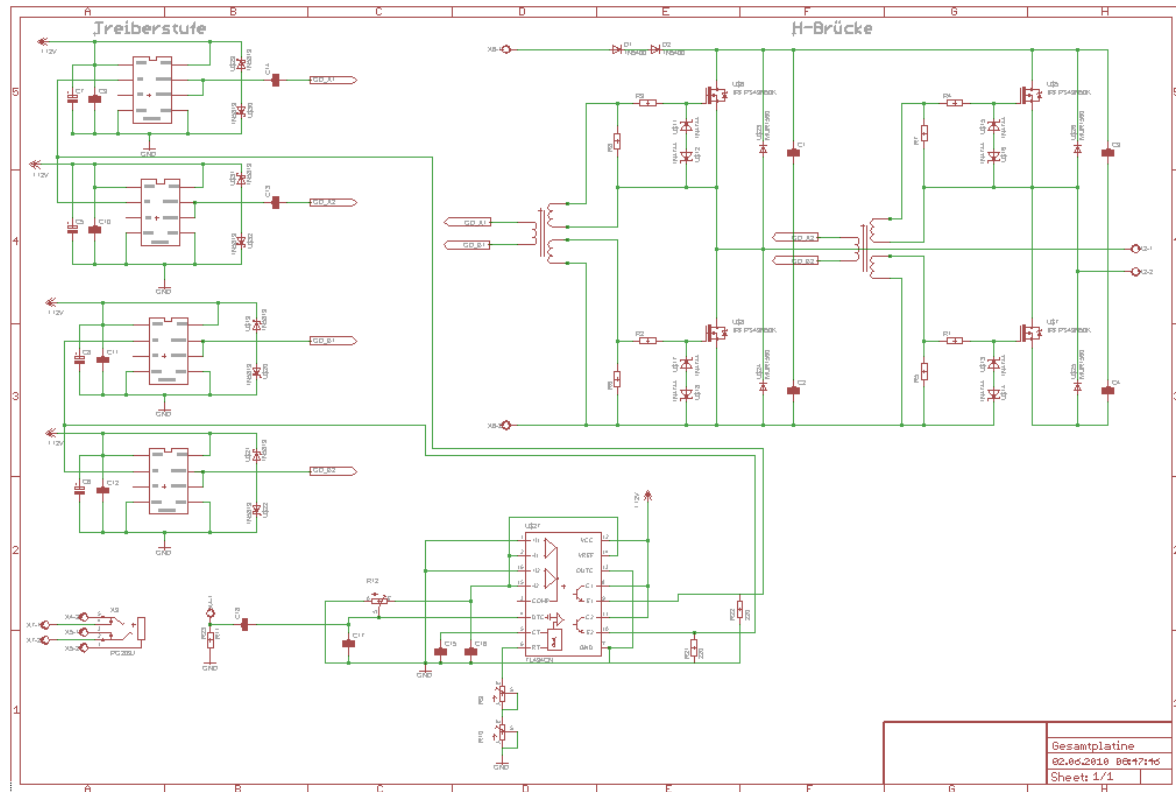


Figure 9 Eagle Layout Schematic

## 5 Experimental results

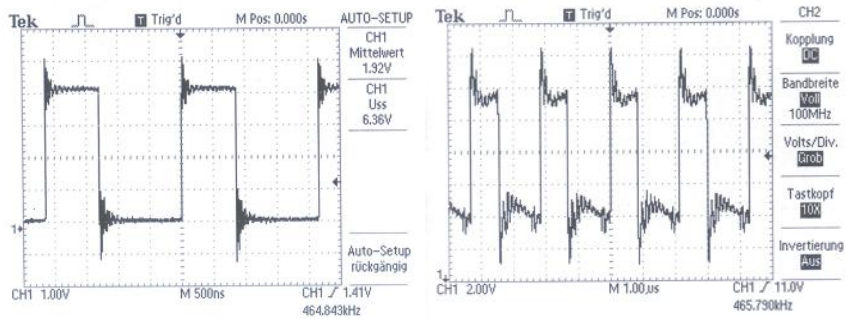


Figure 10

PWM generation output

pre-amplifier output

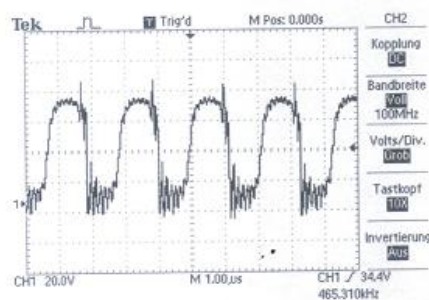


Figure 11 H-bridge output

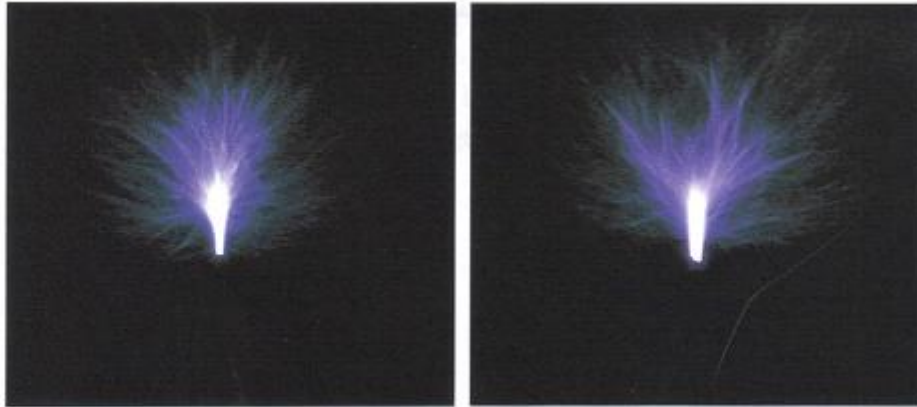


Figure 12 Spark discharges

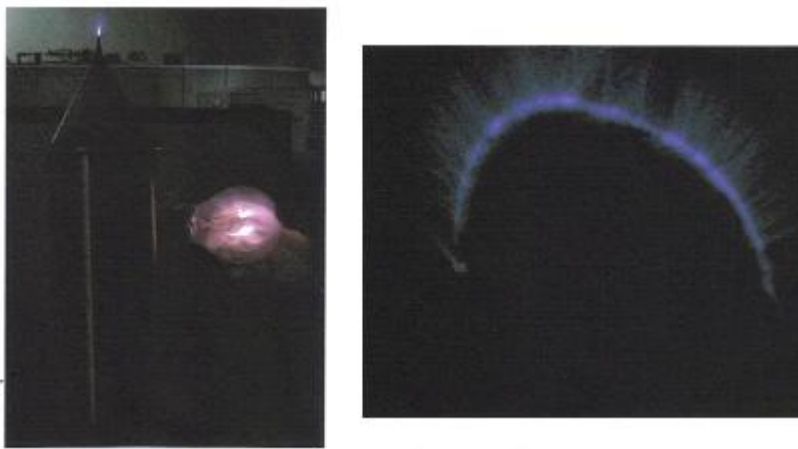


Figure 13 Spark discharges using corona ring or rather light bulb

## 7 Summary & Conclusions

All in all, the project goals were reached. The replaying of an audio file works well and the spark discharges look amazing. The TI devices were simple to use, the datasheets easy to understand. So in the end we would like to thank Texas Instruments for the great support and our project supervisors at University of Klagenfurt for their help and time.

## 8 Future plans

During the measurement & experimental session part of the project certain problems of the chosen PCB design were found. If there will be time, we plan to do a redesign of the actual PCB and to refit certain things regarding the PCB part. Furthermore, we perhaps plan to extend the project by adding a DSP board for audio signal processing or rather doing a redesign of the Tesla transformer.

This project should constitute an interesting demonstration model for advertisement of future students at our university. Because it is sometimes difficult to convince young people of doing a technical study it should act as presentation object.