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Simple electrical circuit to light up a gas discharge lamp

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Abstract: *In order to successfully monitor achievements of scientific and technology revolution, modern society invests growing efforts in popularizing technical sciences. In order to motivate pupils and students to realize the importance that their knowledge has in everyday life, teachers often use experiments and laboratory methods in the schooling. This paper is devoted to a simple construction of Tesla coil with electrical circuit where transistor is used as amplifier and switch too. Tesla coil can be used as a teaching tool to demonstrate the high frequency currents, i.e. for causing electrical discharge in the gas discharge lamps. Also, some problems that can occur during the preparation of this experimental set up as well as on laboratory excersises with participants of the Regional Centre for talents in Cacak, are explained.*

Keywords: *Tesla coil; electrical circuit; transistor*

1. INTRODUCTION

This year marks 160-th anniversary from the birth of Nikola Tesla, Serbian the most famous scientists who had more than 700 protected patents and innovations. His contribution to science is so great that eight US states (New York, New Jersey, Pennsylvania, Colorado, Nevada, Minnesota, Arizona and Indiana) declared Tesla's birthday as their national holiday [1]. In the field of wireless transmission of energy, Tesla has invested considerable time and effort, but his research has been left unfinished.

Tesla coil, which is supposed to be the basis of wireless energy transfer, can be made in different ways, while as a power source both alternating and direct current can be used. This paper is devoted to a simple construction of Tesla coil, using direct current power source, which is also safe, and involves the use of electronic parts that are in electronic kit for the subject Technical and informatics education, in the eighth grade of primary school. The realization of Tesla coil was demonstrated to the participants of the Regional Centre for talents in Cacak, after which they were given the task to realize the same. Therefore, this paper also discusses the problems that they encountered during its preparation. In this way designed Tesla coil, can also be applied for the various teaching subjects: physics, technical and informatics education, basis of electrical engineering, etc., in order to acquaint students with Tesla's work in the field of high frequency currents.

The original design of the Tesla transformer for the first time appears in US Patent No. 454.622 from 1891, and was planned to be used for, at that time new and efficient lighting

[2]. It consisted of medium or a high voltage AC power source, one or more high-voltage capacitors and a sparker, connected in the primary circuit of the transformer (Fig. 1).

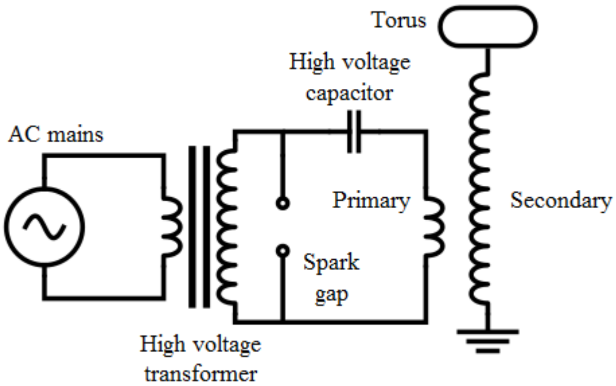

Figure 1. *Construction scheme of Tesla transformer*

Sparker consists of two electrodes, between which, there is a small gap which optionally can be decreased or increased, thus affecting the frequency of the current in the primary coil. In this way, the primary winding is excited with periodic pulses of high frequency currents.

At the secondary winding, there is a large number of turns (hundreds or thousands), in which voltage is induced by electromagnetic induction from the primary. Primary and secondary are resonant circuits, so the voltage increase is also achieved with resonance, and not only with the increasing of the number of turns in the secondary winding. The resonant frequency of Tesla's transformer is typically between 25 KHz and 2 MHz.

2. TESLA COIL FOR TEACHING PURPOSES

In this paper, for the purpose of implementation in the teaching process, construction of Tesla transformer, which is shown in Fig. 2 - left is proposed. The development of electronics has contributed to the construction of Tesla coil, so that the sparker gap can effectively be replaced with the transistors of different types, which did not exist in Tesla's time. The advantage of such a coil is that a transistor can be used as a switch and the amplifier at the same time.

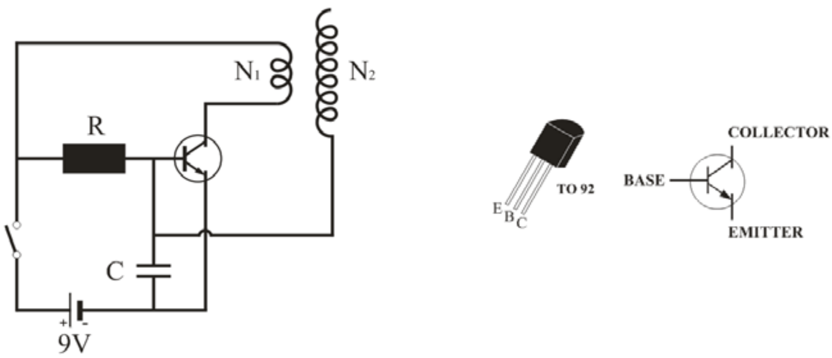

Figure 2. *Scheme of Tesla coil with bipolar NPN type of transistor*

For this purpose, different NPN transistors may be used, although the characteristics of individual transistors constitute some of them more suitable for the application than the others. The basic parameters of the coil are: *diameter of the frame D, wire diameter d, wire diameter with isolation k, the length of the coil l, the length of the wires without leads a, the number of primary windings* N_1, *the number of secondary windings* N_2, *the inductance L, the self-capacitance* C_S, *and self-resonant coil frequency f* (Fig. 3).

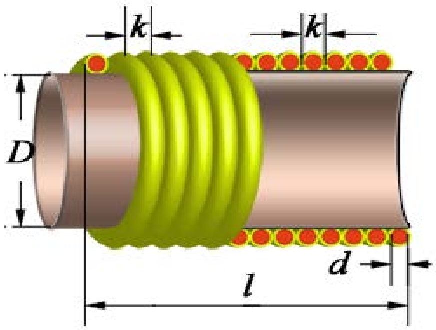

Figure 3. *One-layer coil with close winding*

Inductance of the secondary winding can be calculated from Wheeler's equation (1) [3]:

$$L = \frac{N^2 \mu_0 \pi \left(\frac{D}{2}\right)^2}{l}. \quad (1)$$

Self-capacitance of the coil can be determined from equation (2), where the value of the diameter *D* is given in centimeters and the value of the capacitance in picofarads [4].

$$C_S = \frac{\varepsilon_0 \pi^2 D}{(N-1)\ln\left((\frac{p}{d}) + \sqrt{(\frac{p}{d})^2 - 1}\right)}, \quad (2)$$

where: ε_0 is dielectric constant, *N* is the number of windings, *p* is the distance between the centers of neighboring turns. Using the equation for calculating oscillation of *LC* circuit (3), one can approximately calculate the frequency of oscillation of the secondary.

$$f = \frac{1}{2\pi\sqrt{LC_s}}. \quad (3)$$

3. EXPERIMENTAL RESULTS

In the paper the use of bipolar NPN transistor 2N2222A, with housing TO-92 (Fig. 2 - right) is proposed [5]. The reason for this selection is the simplicity of application in the teaching process, since it requires the use of a low voltage DC source (up to 40 V) with low current (up to 0.6 A at the input). In our case, 9 V battery was used as the power source.

Besides the issue of safeness for pupils or students, the reason why this type of transistor is commonly used, is that for the realization of the electrical circuit in Fig. 2, the use of capacitor is superfluous [6]. The use of a capacitor may cause overheating and even burning of a transistor. Applying the circuit in Fig. 2 without the capacitor, there is a higher frequency range in which the frequency of circuit oscillation can be harmonized. For this type of coil is characteristic that it does not produce sparks, or they are very small since it works with low power at very high frequencies (> 10^6 Hz). This represents a limitation of the Tesla coil made in this way. On the other hand, it produces a high enough voltage to light and neon bulb which has power up to 36 W. Fig. 5 shows a graphical representation of the oscillation frequency of the coil, obtained with OriginPro softer [7], on the base of oscilloscope measurement.

Figure 4. *Oscilloscope display of the oscillation frequency, of the small Tesla coil*

Fig. 4 shows the Tesla coil made with aforementioned transistor. The number of turns in the primary winding is $N_1 = 3$, and in the secondary winding $N_2 \approx 350$ (Table 1). The ratio of the coil height H and the coil diameter D needs to be in the range $4 < H/D < 6$. For the secondary windings it is necessary to use lacquered copper wire of diameter 0.2 – 0.4 mm (AWG 32-26). In the electronic kit for the subject Technical and informatics education for the eighth grade of primary school, there is the wire d = 0.25 mm, which can also be used. At the primary it is necessary to use the insulated copper wire of larger diameter (AWG 19 <), whereby there is no influence whether wire is solid-core or stranded. The value of the resistor is not crucial since it has a role to take the current when it is not flowing through the transistor. Its value can be taken in the wide range. In the electronic kit for the eighth grade there are three resistors that can be used for this purpose: 6.8 KΩ, 38 KΩ and 82 KΩ. In the realization of the coil in Fig. 4, 22 KΩ (metafilm, power ¼ W, 1% tolerance) resistor value was used. The parameters of a one-layer coil (close winding) were obtained using *coil32* software [8] (Table 1).

The value of the self-resonant frequency of the secondary, obtained with *coil32* software is f = 6.882 MHz and quite well corresponds to the lowest measured value of the oscillation frequency of the coil f = 6.849 MHz, experimentally obtained with the oscilloscope.

In addition to the mentioned type of transistor, construction of Tesla coil in Fig. 2 was also tested with bipolar NPN transistor MJE3055, with housing TO-220. On this transistor, it is necessary to set a cooler of the type HL SK35-51 or a cooler with similar characteristics whose thermal resistance is ≤ 9 K/W. Transistor with a cooler need to be moved away from the primary and secondary coils, to prevent interference with their electromagnetic field.

Table 1. *The parameters of one-layer coil (with close winding) obtained with coil32 softver*

Entered data	Obtained data
Diameter of the frame D: 18.2 mm *Wire diameter d: 0.2 mm* *Wire diameter with isolation k: 0.22 mm*	*Winding length l: 78.075 mm* *Length of wire without leads a: 20.47 9m* *Number of turns of coil N_2: 353.545* *Inductance L: 474.924 µH* *Self-capacitance C_S: 1.13 pF* *Coil self- resonant frequency f: 6.882 MHz*

This transistor in the contrast to the previously described has a lower coefficient of the current gain β (20-100), and to achieve the same or better performance of the circuit, it is necessary to use the equivalent capacitance C ≥ 300 nF. Using capacitors, there is much narrower frequency range in which harmonization of the frequency of circuit oscillation can be achieved. However, after the circuit achieved the optimal frequency of oscillation, this type of coil will give sparks on the secondary coli with the size up to several millimeters.

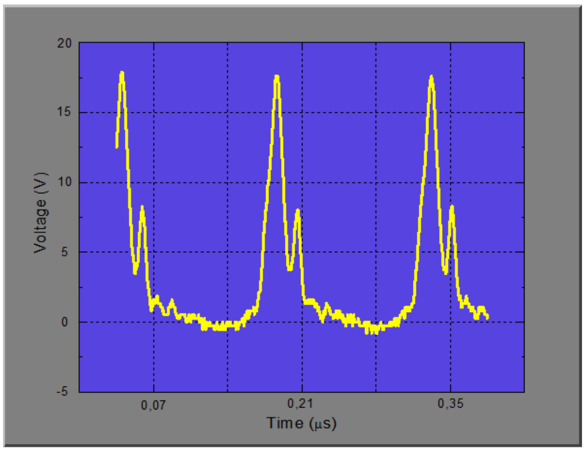

Figure 5. *Graphical display of established frequency oscillation of the circuit, measured on the oscilloscope*

Described realizations of Tesla coil were experimentally performed by the participants of the Regional Centre for talents in Cacak. During construction, they encountered with various problems, due to which the coil did not work, so here are allocated the basic items that need special attention during the experimental realization:

- The direction of the winding of the secondary should be opposite to the direction of the winding of the primary coil.
- One of the most common mistakes for which the coil will not work is when the

connection ends of the primary coil with the rest of the circuit are permuted.

As noted above, described type of Tesla coil does not produce sparks, or they are very small. Considering that small sparks leave less impressive impression on the viewer, to obtain coil that will make larger visual sparks it is necessary:

- Reduce the frequency of oscillation of the coil with introduction of additional electronic components in the electrical circuit. This further complicates the circuit, since it is no longer such easy for construction (especially for pupils and students), and also it is not cheap.
- To increase the dimensions of the coil, by increasing the diameter and the number of the windings turns. This will reduce resonant frequencies of the secondary and primary.
- Use of a larger DC voltage source, which is the easiest and the simplest solution.

It should be noted an interesting fact, which is that complete of electronic kits for the subject Technical and informatics education in eight grades of primary school, has two transistors 546B and BC327, with which is possible to create a small Tesla coil. However, they are not the best choice due to the small value of the input current of 0.1 A.

4. CONCLUSION

This paper describes the experimental realization of Tesla coil which is demonstrated to the participants of the Regional Centre for talents in Cacak. The most important characteristic of the construction of Tesla coil is it is safe, since the circuit produces current frequencies above 20 KHz, which are completely harmless because they do not cause muscle contraction and are transmitted through the skin. On the other hand, this Tesla coil does not produce sparks because it has low power (powered by a 9 V battery), but it is powerful enough to light up any gas discharge lamp. Another important characteristic of the demonstrated Tesla coil is that its technical realization is very economical and convenient. Because of this, electrical circuit made in this way, can be used as a teaching tool in order to introduce students with Tesla's work in the field of high frequency currents, as well as encouraging their experimental and practical work.

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