*Journal of Engineering Research and Reports*

*4(2): 1-9, 2019; Article no.JERR.47593*

# Design and Construction of an Atmospheric Pressure HF Plasma Source

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/JERR/2019/v4i216900
*Editor(s):*
(1) Dr. Okan Özer, Professor, Department of Engineering Physics, Engineering Faculty, University of Gaziantep, Turkey.
*Reviewers:*
(1) Anil Kumar Koneti, GVR & S College of Engineering and Technology, India.
(2) Subramaniam Jahanadan, Kolej Matrikulasi, Labuan, Malaysia.
Complete Peer review History: http://www.sdiarticle3.com/review-history/47593

***Received: 02 December 2018***
***Accepted: 23 February 2019***
***Published: 22 March 2019***

***Original Research Article***

## Abstract

Atmospheric pressure plasma sources used in many industrial, environmental, light sources, biological, and medical applications. Aiming these prospects, an effort has been remunerated for the design and construction of a cost-effective atmospheric pressure high frequency (30 KHz) plasma source. The major sections include in this source are, (i) DC power suppliers, (ii) A set of Class A push-pull power amplifiers, (iii) Ferrite core high-frequency power transformer, (iv) Impedance matching network, and (v) Electrode design for plasma production. Two power suppliers have been considered; one is a 12V DC for biasing the base of the 2N3055 power, and the other is a 90V DC for biasing the Class A push-pull power amplifier. Class A push-pull power amplifier is chosen because of its high efficiency of about 50% concerning other types of amplifiers. Ferrite core high-frequency power transformer is designed with a turn ratio of 1:3 in order to step up the voltage to a certain level for producing atmospheric pressure plasma. An impedance matching network is designed to transfer maximum power from the source to the plasma load.

*Keywords: Atmospheric pressure; plasma source; power amplifier; impedance matching; electrode*

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*design.*

# 1 INTRODUCTION

An amplifier is an electronic device which increases the amplitude of a electrical signals. In class A power amplifier the output signal varies for a full 360 degree of the cycle. Figure 1, shows that this requires the Q point to be biased at a level so that half of the signal swing of the output may vary up and down without going to high enough voltage [1]. A push-pull amplifier is an amplifier which has an output stage that can drive current in either direction through the load. The output stage of a typical push-pull amplifier consists of two identical BJTs or MOSFETs one sourcing current through the load while the other one is sinking the current from the load. Push-pull amplifiers are commonly used in situations where low distortion, high efficiency, and high output power are required [2].

A plasma or gas discharge resembles an ionized gas. It is one of the four states of matter next to solid, liquid or gas. It is generated by applying a sufficiently high electric field to a gas, which partially breaks it down, turning some atoms or molecules into positive ions and generating free electrons. These free charges make the plasma electrically conductive, internally interactive and actively responsive to electromagnetic fields and surfaces. These unique properties make plasma the fourth state of matter [3]. The collective behavior originates from the motion of charged particles, which causes local concentrations of positive or negative electric charges. These charge concentrations create Coulomb fields that affect the motion of many other charged particles away from the original charges. Thus elements of the plasma continuously affect each other, giving the plasma its characteristics collective behavior [4]. These local charge perturbations are confined to volumes of small dimensions. The characteristics dimension of such a charge perturbation is called Debye length [5].

In this work we design a cost-effective atmospheric pressure high frequency (30 KHz) plasma source which comprise several section including, (i) DC power suppliers, (ii) A set of Class A push-pull power amplifiers, (iii) Ferrite core high-frequency power transformer, (iv) Impedance matching network, and (v) Electrode design for plasma production.

# 2 EXPERIMENTAL DETAILS

## 2.1 DC Power Supply

The operation of power supply circuit built using filters, rectifiers, and the voltage regulators. Starting with an AC voltage, we obtain a steady DC voltage by rectifying the AC voltage, then filtering to a DC level and, finally, regulating to obtain a desired fixed DC voltage [6]. Figure 2 shows that, the AC voltage is connected to a transformer, which steps the Ac voltage down to the level for the desired DC output. A diode rectifier then provides a full-wave rectified voltage. Which is initially filtered by a simple capacitor to produce a DC voltage. This resulting DC voltage usually has some ripple or AC voltage variation. A regulator circuit can use to provide a DC voltage that not only has much less ripple voltage but also remains the same DC value.

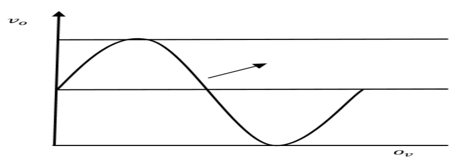



Figure 1: Amplifier operating classes.

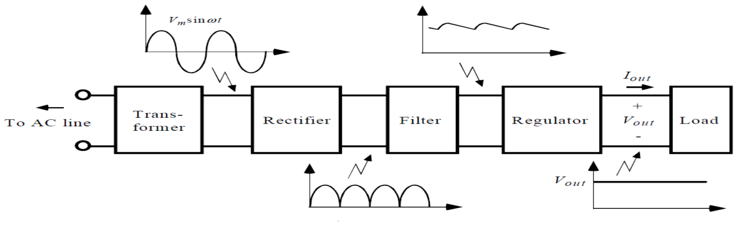



Figure 2: Block diagram of a DC power supply.

## 2.2 Ripple Voltage

The representation of ripple voltage is shown in Figure 3 and defined as [7],

$$r = \frac{ripple \quad voltage(rms)}{dc \quad voltage} = \frac{v_r(rms)}{v_{dc}} \times 100\% \tag{2.1}$$

Voltage regulation is defined as,

$$VoltageRegulation = \frac{no \quad load \quad voltage - full \quad load \quad voltage}{full \quad load \quad voltage} \tag{2.2}$$

And percentage Voltage Regulation is defined as,

$$\%V.R. = \frac{V_{NL} - V_{FL}}{v_{FL}} \times 100\% \tag{2.3}$$

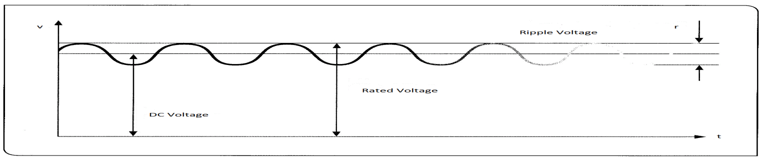



Figure 3: Representation of ripple voltage.

## 2.3 12V DC Power Supply

A power supply is an electronic device that supplies electric energy to an electrical load. The primary function of a power supply is to convert one form of electrical energy to another. A low voltage power supply is designed and constructed to bias the pre-amplifier [8]. A step-down transformer (TR1) is used to prepare the 12V DC power supply. The output of the transformer is 8V AC. A bridge rectifier is used to convert 8V AC to 12V DC and four diodes of PR3002, 3A are used for rectification. The bridge rectifier is produced pulsating DC, hence a filter circuit is used to generate pure DC as shown in Figure 4. An electrolytic capacitor of 220F, 200V is used for filtration. A resistance of 5W, 10K is used for the desired output voltage [9]. This output voltage is used for biasing the pre-amplifier.

## 2.4 90V DC Power Supply

For 90V DC supply we use 220V AC supply line as an input of bridge rectifier. This AC voltage is rectified by abridging rectifier using four 6A10 MIC diodes (shown in Figure 5). However, the output of the bridge rectifier is not pure DC voltage so a filter is needed to convert this pulsating DC to pure DC. A filter is made by using two 220F(450V)electrolytic capacitors. The positive terminal is connected to the positive terminal of the capacitors and negative to the negative. Two non-polar capacitor 102J(2000V), 562J(1600) and an inductor of 100mH are used for removing the high-frequency spikes [10, 11]. This DC power supply is used for Collector to Emitter voltage, for required optimum atmospheric pressure plasma.

## 2.5 Pre-Amplifier Operation

Pre-amplifier is an electronic amplifier that prepares a small electrical signal for further amplification or processing. It is used to boost the signal strength to drive the cable to the main instrument without significantly degrading the signal-to-noise ratio (SNR) [12, 13]. Figure 6 shows the circuit diagram of a Pre-Amplifier. The network employs an npn transistor, the equations and calculations apply equally well to a pnp transistor configuration by changing all current directions and voltage polarities. The current flows through the resistance 5W, 125R to the base, the voltage is defined by the standard double-subscript notation [14]. For the dc analysis, the network can be isolated from the ac levels by replacing the capacitors with an open-circuit equivalent because the reactance of a capacitor for dc is, $X_c = 1/(2 \times 3.1416 \times f \times C) = 1/(2 \times 3.1416 \times (0) \times C)$ [6, 1, 15]. Besides, the dc supply Vcc can be separated into two supplies to permit separation of input and output circuit which reduces the linkage between the two to the base current.

## 2.6 Operation of Class A Push Pull Power Amplifier

The circuit diagram of a typical Class A push-pull amplifier is shown in the Figure 7. There is four set puss pull transistor used in the amplifier. Q1 and Q5 are two identical transistors, and their emitter terminals are connected to the ground. R1 and R2 are meant for biasing the transistors. The power supply is connected to the collector to emitter terminal through an inductor. The input signal is applied to the base terminal of those transistors. A high-frequency power transformer is connected to the output of the collector of each transistor. The quiescent current of Q2 and Q1 flows in opposite directions through the corresponding halves of the primary of the output transformer, and as a result, there will be no magnetic saturation [10, 4].

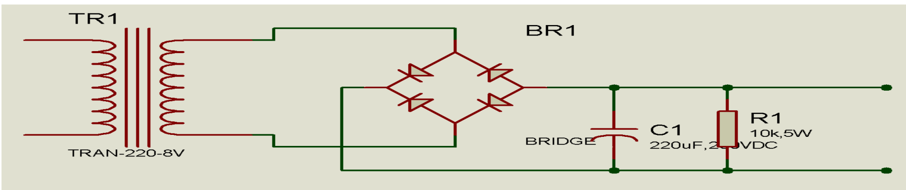



Figure 4: Circuit Diagram of a 12V dc power supply.

Class A design produces good linear amplifiers, but are wasteful of power [2]. The output power they produce is theoretically 50%, but practically only about 25 to 30%, compared with the DC power they consume from the power supply. In order to achieve the maximum symmetrical swing of current and voltage, the Q point should be located at the center of the dc load line. In that case, the operating point is $I_c = V_{cc}/2R_c$ and $V_{ce} = V_{cc}/2$. Maximum, $V_{ce(p-p)=V_{cc}}$ and $Maximum, I_c(p-p) = V_{cc}/R_c$.

Maximum ac output power,

$$\begin{aligned} P_o(max) &= V_{ce}(p-p) \times (I_c(p-p))/8 \\ &= V_{cc} \times (V_{cc}/R_c)/8 \end{aligned} \tag{2.4}$$

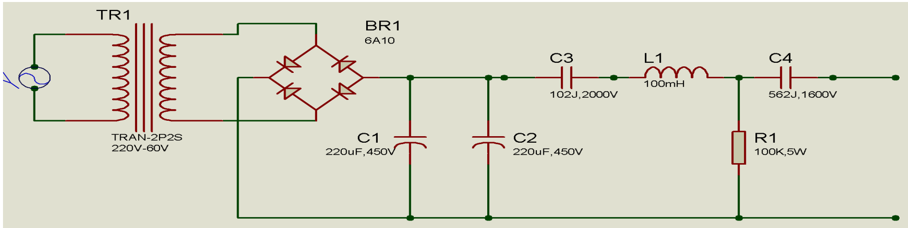



Figure 5: Circuit diagram for 90V power supply.

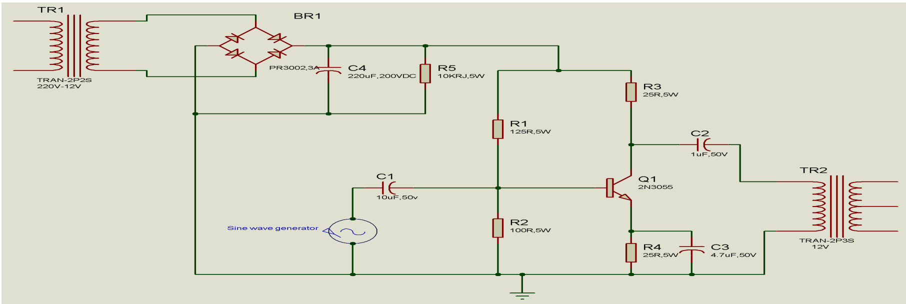



Figure 6: Circuit diagram of pre-amplifier.

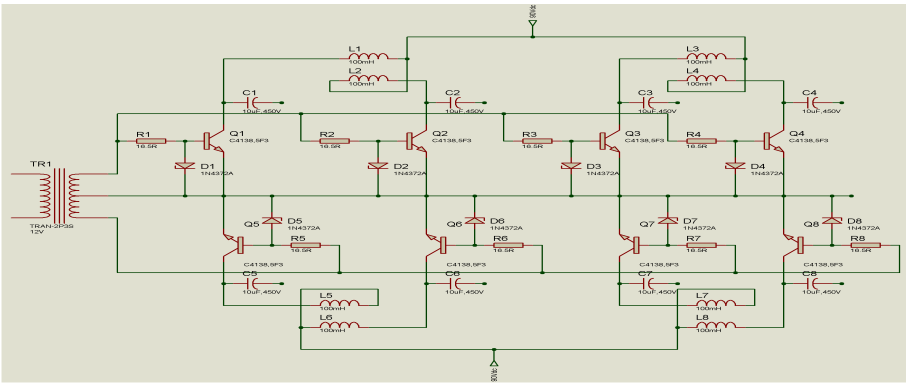



Figure 7: Circuit diagram of class A push pull power amplifier.

DC power supplier,

$$P_{dc} = V_{cc} \times I_c$$
$$= V_{cc} \times (\frac{V_{cc}}{2R_c}) \quad (2.5)$$

The power dissipated by a transistor is given by,

$$P_{dis} = P_{dc} - P_{ac} \quad (2.6)$$

Clearly in class A operation the transistor must dissipate less heat when signal is applied and therefore runs cooler. Maximum efficiency is given by the following equation,

$$Efficiency_{(max)} = ((V_{cc} \times V_{cc})/8R_c)/((V_{cc} \times V_{cc})/2R_c) \times 100\% \quad (2.7)$$

# 3 RESULTS AND DISCUSSION

High-frequency (HF) transformer is designed to operate over a wide range of frequencies with minimum X_LandX_(C). This required a high permeability core with a relatively small winding for the HF spectrum. Most HF power transformers use ferrite cores. Ferrite cores are manufactured in a wide variety of shapes, EC, ETD, EF, U, RM, E, and many other shapes. For instance, an E-core has been recommended to be used for an HF power transformer having permeability 10010% [23, 5, 16, 17].

## 3.1 Impedance Matching Network

The power transformer from the power amplifier will be maximum only if the amplifier output impedance equal to load impedance RL [15]. Hence for transfer of maximum power from the amplifier to the output device matching of amplifier output impedance with the impedance of output device is necessary. This is accomplished by using two capacitors and an inductor. The circuit diagram of an impedance matching network is shown in Figure 8.

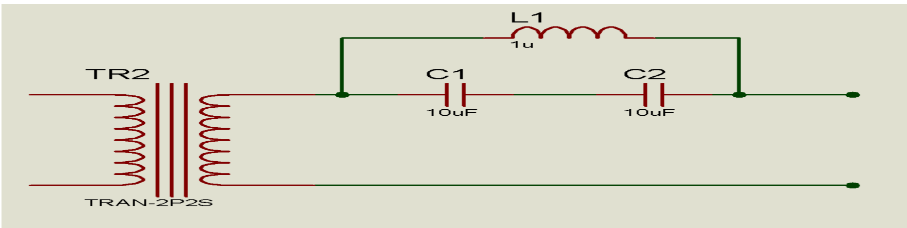



Figure 8: Circuit diagram of impedance matching network.

The analysis is as follows. Consider a real source impedance of $R_1$ and real load impedance of$R_2$. If a reactance $X_1$ is in parallel with the source impedance, the combined impedance can be written as [9, 1]:

$$\frac{jR_1X_1}{R_1 + jX_1} \quad (3.1)$$

If the imaginary part of the above impedance is canceled by the series reactance, the real part is,

$$R_2 = \frac{R_1X_1^2}{R_1^2 + X_1^2} \quad (3.2)$$

Solving for $X_1$,

$$X_1 = \sqrt{\frac{R_2R_1^2}{R_1 - R_2}} \quad (3.3)$$

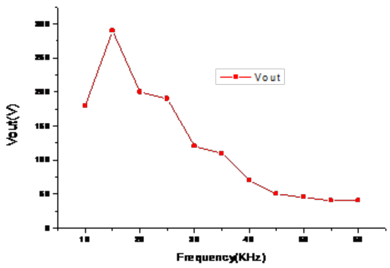
If $R_1 \gg R_2$, the above equation can be approximated as,

$$X_1 \approx \sqrt{R_1R_2} \quad (3.4)$$

The corresponding frequency versus output voltage and impedance characteristics are shown in the Figure 9 and Figure 10 respectively.

| Frequency, f(KHz) | Output Voltage(V) |
|---|---|
| 10 | 180 |
| 15 | 290 |
| 20 | 200 |
| 25 | 190 |
| 30 | 120 |
| 35 | 110 |
| 40 | 70 |
| 45 | 50 |
| 50 | 45 |
| 55 | 40 |
| 60 | 40 |

(a)

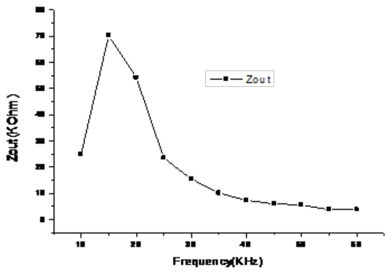



(b)

Figure 9: (a) Corresponding values of Frequency vs output voltage, and (b) The output characteristics of power transformer (Frequency vs output voltage).

| Frequency, f(kHz) | Output Impedance |
|---|---|
| 10 | 24.9 |
| 15 | 70.1 |
| 20 | 54.1 |
| 25 | 23.4 |
| 30 | 15.5 |
| 35 | 10.1 |
| 40 | 7.33 |
| 45 | 6 |
| 50 | 5.6 |
| 55 | 3.78 |
| 60 | 3.78 |

(a)




(b)

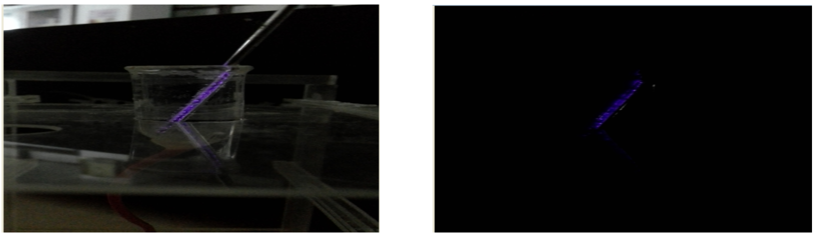
Figure 10: (a) Corresponding values of Frequency vs output impedance, and (b) Frequency vs output impedance characteristics of the input coupling.

## 3.2 Dielectric Barrier Discharge

Dielectric barrier discharges were used to generate relatively large volume diffuse plasmas at atmospheric pressure and applied to inactivate bacteria. This eventually led to the development of a new field of applications, the biomedical applications of plasmas. This field is now known as plasma medicine [18, 3]. A dielectric barrier discharge is one method of plasma treatment of textiles at atmospheric pressure and room temperature. The treatment can be used to modify the surface properties of the textile to improve wettability, improve the absorption of dyes and adhesion, and for sterilization [19, 11]. An excimer lamp can be used as an authoritative source of short-wavelength ultraviolet light, useful in chemical processes such as surface cleaning of semiconductor wafers. The lamp relies on a dielectric barrier discharge in an atmosphere of xenon and other gases to produce the excimers. This dielectric barrier discharge plasma source can be used for mosquito larva treatment [20, 21].

## 3.3 Electrical Measurement

The electrical measurement characteristics of the used plasma source is shown in figure 12, based on the reference [22].



(a) (b)

Figure 11: Dielectric barrier discharge (DBD) Air Plasma Production.

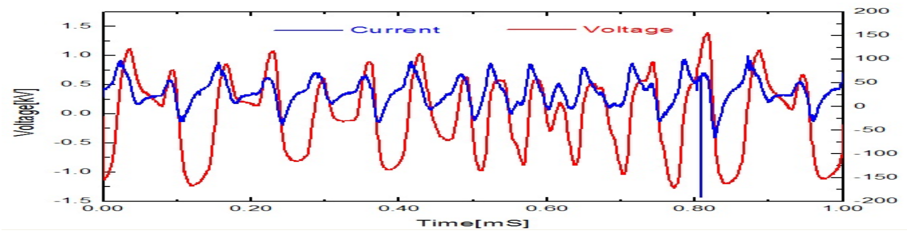



Figure 12: Graph plotting for Electrical Measurement of the Plasma Source.

## 4 CONCLUSION

The high voltage amplifier can generate up to 2 KV to 3 KV. To construct a power amplifier, the main features is to select the dc operating point. The appropriate figure selected the operating point. One of the main problem to construct a power amplifier is the impedance matching. The power transferred from the power amplifier to the load will be maximum only if the output impedance is equal to the load impedance RL. It is operated at high frequency, and the resonance occurs at 25 to 35 KHz. The signal of the amplifier has some distortion. This high voltage power supply is used to generate atmospheric pressure DBD plasma. The discharge voltage and current are measured including the Spectroscopic measurement.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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