A Technical Seminar Report

on

"Radio Frequency Light sources"

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

in

ELECTRONICS AND COMMUNICATION ENGINEERING

by

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Certificate

This is to certify that the technical seminar report on the topic entitled "Radio Frequency Light Sources" submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electronics and Communication Engineering is a bonafide work done by S.Tejaswini Harshitha.

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ABSTRACT

The idea of radio frequency (RF) lighting, as well as the first RF lamp patent, appeared long before the first fluorescent and high-pressure lamps came onto the market. It took over a century for the first commercial RF lamp to appear, introducing a new era in the production of light. Progress in semiconductor power switching electronics, along with a more thorough understanding of fundamental processes in RF plasmas, have resulted in commercially viable RF light sources.

RF light sources follow the same basic principles of converting electrical power into visible radiation as conventional gas discharge lamps. The fundamental difference between RF lamps and conventional lamps is that RF lamps operate without electrodes (anode and cathode). This has profound consequences on RF lamp characteristics and features.

We consider different kinds of RF discharges and their advantages and restrictions for lighting applications. We also describe examples of successful realizations of different kinds of RF lamps.

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INTRODUCTION

RF lighting is one of the newest applications of microwaves. Also known and the "sulfur light bulb", this technology was first developed in the late 1980s by startup company Fusion Lighting of Rockwell Maryland. The basic premise is to place a small amount of sulfur in a bulb, then excite it using a 2.45 GHz magnetron (the same type of microwave tube that is used in microwave oven). The result is a highly efficient, long-lasting, high intensity lamp with pleasing colors, and very low harmful UV radiation, which might be described as the perfect industrial light bulb except for one perceived flaw... it could leak just enough energy to mess up your satellite radio reception.

After years of research and development, radio frequency light sources are just now becoming a mainstream lighting option. Lighting isn't exactly the first thing you think of when you hear radio frequency. More comfortable in the lexicon of HAM radio operators, the term is just now making headway in the business of illumination, thanks to designs that employ RF technology and offer appreciably longer.

A typical hot cathode fluorescent lamp has a cathode — also called an electrode — located at each end of the glass tube. The electrode consists of a tungsten filament, similar to that of an incandescent lamp. Unlike its purpose in an incandescent lamp, here the filament's purpose is to emit electrons, not to directly produce illumination. And in this case, the cathode filament has an emissive material coating to accelerate the electrons' release.

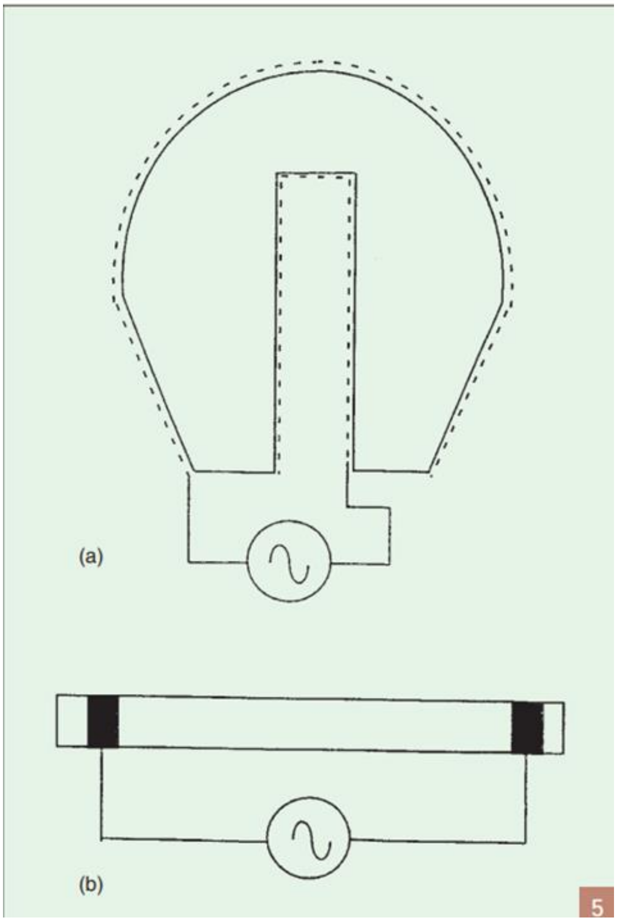
The resistance of the path, or gap, between the two electrodes is broken down when sufficient voltage is created between the electrodes. And the resulting continuous mercury arc, or ultraviolet energy (electromagnetic radiation), created along the length of the lamp activates the phosphor coating on the lamp's interior surface. These phosphors receive the invisible ultraviolet energy and change it into visible energy.

DISCHARGE TYPES

Discharge Types There are three practical ways to energize RF light sources, though there are more ways to create RF plasmas. These three ways correspond to different types of interaction of the electromagnetic fields with the bounded plasma and to different kinds of RF discharges. They are: capacitive, inductive, and wave-sustained discharges.

Capacitive discharge

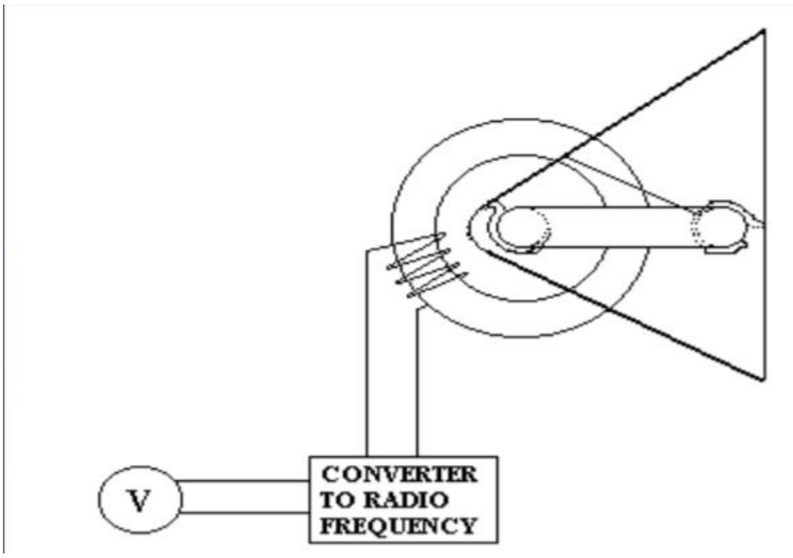
Capacitive RF discharges (CRFD) may be energized by RF electrodes placed inside or outside the discharge vessel. The current path in a capacitive RF discharge plasma is closed by displacement currents in the RF electrode sheaths (whether the electrodes are inside or outside the discharge vessel). CRFDs operate at gas pressure considerably lower than atmospheric pressure and are excited by an RF electric field E with frequency lower than 1 GHz and wave length λ much larger than the discharge size L, ($\lambda \gg L$) .



A schematic of a capacitive RF discharge and a qualitative space distribution of electron density ne, ion density ni and dc potential Φdc. The voltage applied to the lamp is mainly dropped in the sheath, and the sheath impedance controls the discharge current of a CRFD. The figures (a) and (b) are RF capacitive fluorescent lamps.

Inductive RF Discharge

In an inductive RF discharge, the plasma RF current is closed within the plasma without forming RF sheaths. The electric field that maintains the discharge is induced by an RF current flowing through an induction coil outside or inside the plasma.



Inductive RF discharges (IRFD) or inductively coupled plasmas (ICP) operate over a wide range of gas pressure and frequency for which $\lambda >> L$. The utility of an IRFD as a light source is defined by its power transfer efficiency $\eta = Pp/(Pp+Pc)$, where Pp and Pc are the power delivered to the plasma and that dissipated in the inductor. To obtain an RF lamp efficiency equal to, or better than electroded discharge lamps, η should be no less than about 90%. Power transfer efficiency depends upon many factors, such as filling gas, gas pressure, discharge topology and geometry, driving frequency, and inductor construction. Lamp power also has a significant influence on power-transfer efficiency. Contrary to capacitive RF discharges, where the fraction of RF power transferred to the plasma falls with increasing discharge power, η usually increases with power in an IRFD. Thus, the maximal benefits of inductively coupled plasma are generally achieved in a high-power regime. The extremely low power-transfer efficiency of RF lamps and the absence of effective and affordable RF power converters have prevented commercialization of RF inductive lamps in the past.

Wave sustained discharge

Wave-sustained RF discharges (WRFD) are maintained by electromagnetic waves that are incident on the plasma surface or propagate along a plasma boundary. Wave discharges are usually maintained by microwave power sources at frequency in the GHz range. The application of microwaves is advantageous for the excitation of high-pressure HID light sources where relatively high-power density is needed to achieve a near-equilibrium plasma.

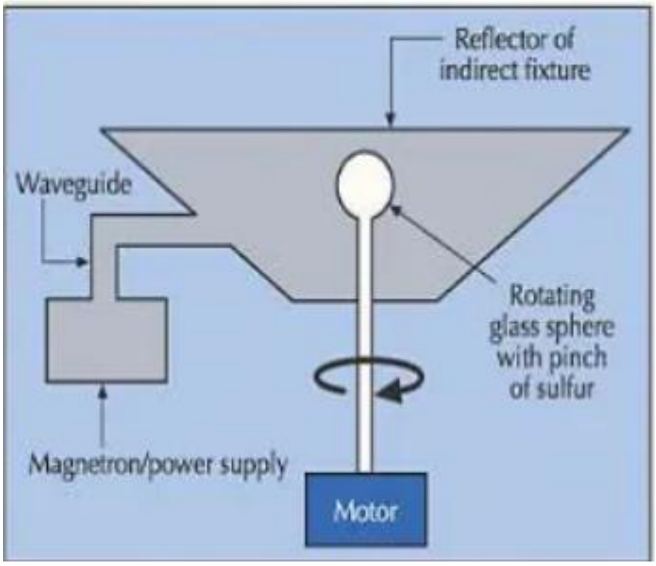
Choice of Frequency and Discharge Type

The most suitable frequency range is 2.2-3.0 MHZ for RF lighting devices. An RF generator (RF ballast) is the essential yet most expensive part of modern RF lighting system. Compliance with regulations on frequency and allowed levels of RF emission to prevent interference with communication strictly limits the frequencies available for RF light sources. The frequencies allocated for industrial applications differ from country to country. There are also different limitations for the magnetic and electric components of EMI emitted by RF light sources. The discharge type depends upon the application or the lamp that we are using.

Commercial RF Light sources

Five companies have RF lighting products on today's market, and all of them are practical realizations of old concepts. It took decades of effort in developing core lighting technology, relevant gas discharge physics, solid-state physics, material science, and electronics to bring RF lighting concepts to engineering and finally, in the beginning of the 1990s, to a commercial product. The sources that are available now are

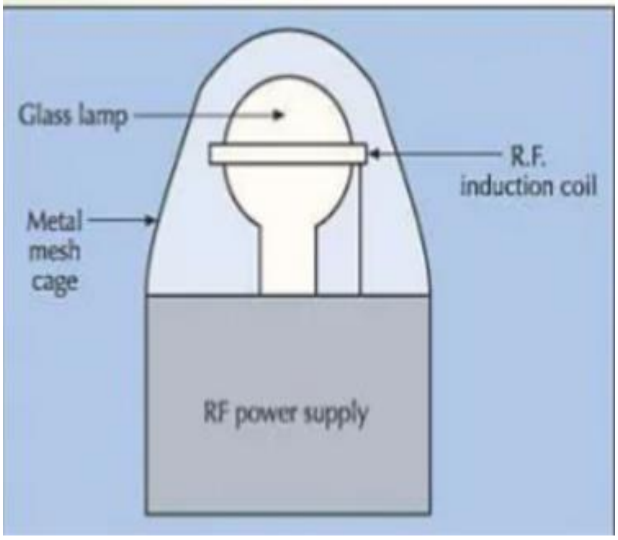
- Microwave powered sulphur lamps.
- Spherical external coil induction lamp.
- Re-entrant cavity induction lamp.
- Self-ballasted re-entrant cavity lamp.
- Low frequency extended coil induction lamp.



Microwave powered sulphur lamps

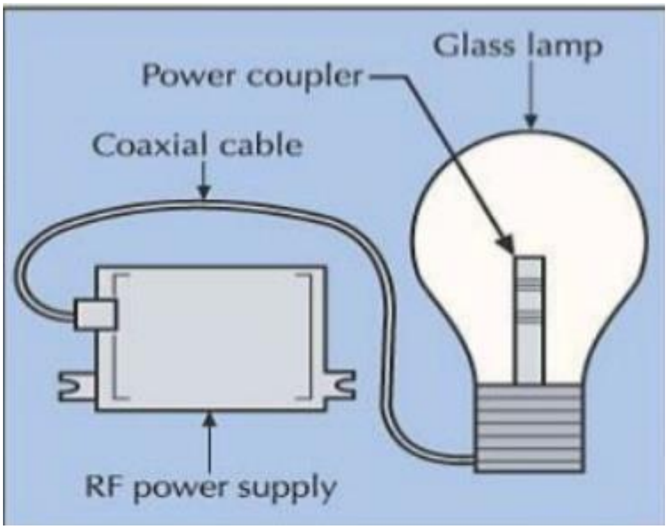
In 1995, the very first concept of the wireless light proposed by Tesla was realized in a microwave-driven lamp. This light source is remotely energized by a microwave power source of about 1.5 kW at 2.45 GHz generated by a magnetron. A quartz bulb (about 3 cm in diameter), filled with argon and a dose of sulfur, is rotated (for discharge stability) within the microwave resonant cavity, which has a light transparent window. White light radiation from this lamp is due to excited sulfur molecules. This lamp has an impressive efficiency of about 100 lm/W and has a life rating of 15,000 hours.

Spherical external coil induction lamp



The first RF induction lamp by Hewitt was reincarnated in Japan in 1991. This is a small, 4.5-cm diameter, fluorescent lamp driven inductively at 13.56 MHz by an integrated RF ballast. The lamp is filled with neon and mercury vapor and has a multiturn induction coil. A screen cage surrounds the lamp to reduce EMI emission to an acceptable level. The system power of this lamp is 27 W, and its efficiency is 37 lm/W. The main application of this lamp is as an incandescent lamp replacement in areas that are difficult to access.

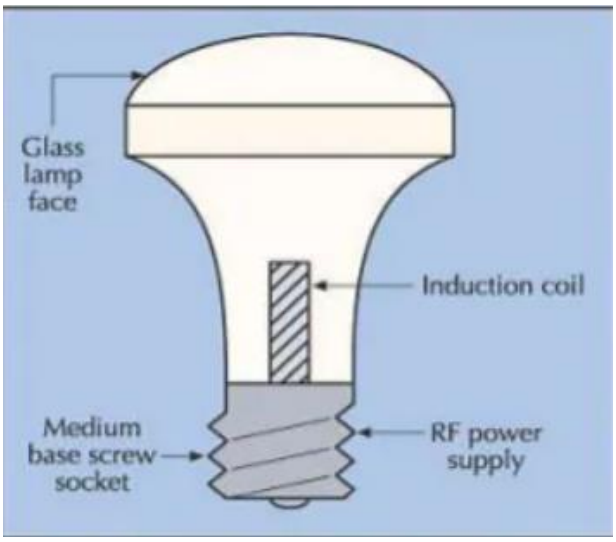
Re-entrant cavity induction lamp



A commercial reentrant cavity induction lamp with the coupling inductor hidden in the reentrant cavity was introduced in 1991. This electrodeless fluorescent induction lamp is shown in Fig. It operates at 2.65 MHz with system power of 85 W and an efficiency of 70 lm/W . This lamp is now made in two other sizes: 55 and 165 W. The lamp is filled with argon at 0.25 Torr. Mercury pressure is controlled by two amalgams: one is for lamp starting and the other maintains optimal mercury pressure over a wide range of ambient temperature. These lamps are driven by remote ballasts connected to the lamps by a coaxial cable. Separating the ballast from the lamp results in a cooler running ballast, thus extending the overall system life. Self-Ballasted Reentrant Cavity Lamp Another embodiment of an RF induction lamp.

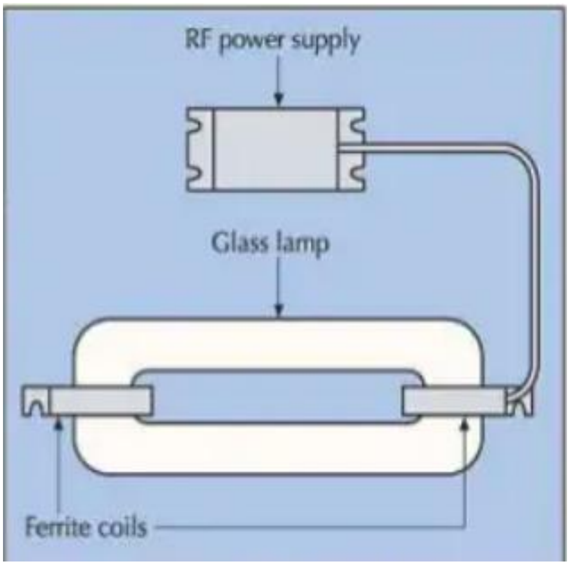
Self-ballasted re-entrant cavity lamp

Another embodiment of an RF induction lamp as a direct substitution for an



incandescent reflector lamp was offered in 1994. The lamp is shown in Fig with cutaway versions exposing the lamp's interior. This compact fluorescent RF lamp has a reentrant topology and is integrated with an electronic ballast operating at 2.65 MHz. The lamp power is 23 W at 48 lm/W, and lamp life is rated up to 15,000 hours. Significant efforts have been made in this lamp for suppressing magnetic and electric components of EMI to comply with existing regulations. Low-Frequency External-Coil Induction Lamp.

Low frequency extended coil induction lamp



The last lamp examined is a successful realization of the 1970 Anderson RF lamp with ferrite coupling core inductors. The understanding of the fundamental relationship between the plasma's electrical characteristics and the ferrite's power loss made it possible to redesign the Anderson lamp and reduce the core losses by an order of magnitude. This resulted in the most efficient and highest light output RF induction fluorescent lamp on the market. Moreover, decreasing the working frequency to 250 kHz has reduced problems with EMI, ballast complexity, and cost compared to those RF lighting systems working at 2.65 MHz. The system is shown in Fig. The resemblance to a regular transformer is more apparent for this lamp than for any other inductive lamp. The lamp is made from a 5.4-cm diameter Pyrex tube encircled by two ferrite cores that close upon themselves. The lamp length is 35 cm, and the system power is 150 W at 80 lm/W. Due to the closed magnetic path of the ferrite cores, power-transfer efficiency in this lamp is extremely high (98%). The rated lamp life is 60,000 hours. High system efficiency is achieved by the distributed power deposition along the lamp in contrast with RF lamps using reentrant cavity technology where power transfer is localized around the coupling inductor, causing local thermal stress and overheating that limits maximum lamp power.

ADVANTAGES

It has long been recognized that the most attractive feature of RF lighting is the absence of electrodes. Electrodes are the main factor limiting discharge lamp life. The loss of cathode emissive material, due to its evaporation and sputtering caused by ion bombardment, limits the life of these lamps to between 5,000-20,000 hours, while the life of some RF electrodeless lamps on the market today reaches 100,000 hours. This makes it attractive to use such lamps in applications where lamp maintenance is expensive.

Inherent to all electrode discharges are cathode and anode voltage drops having inefficient electric power conversion to radiation. Thus, lighting discharges should be long and slim so that the voltage drop (and power) in the vicinity of the electrodes is just a small fraction of the total discharge voltage (power). The elimination of electrodes opens up unlimited possibilities in the variety of possible lamp shapes.

The presence of hot electrodes puts a limitation on the filling gas pressure and its composition to avoid chemical and physical reactions that destroy the electrodes. It is interesting that the fill gas pressure within a conventional fluorescent lamp is an order of magnitude higher than that corresponding to maximal lamp efficiency. Any attempt to reduce gas pressure results in a significant shortening of lamp life due to increased electrode evaporation. There is no such limitation in electrodeless RF lamps, where gas pressure is optimized for maximal efficiency. The cathodes in gas discharge lamps operate in a “hot-spot” regime, where cathode emission takes place from a tiny spot heated by the discharge current.

Electrodeless RF lamps have instant and harmless starting and are more convenient for dimming. Since the thermal regime of the cathode is governed by lamp discharge current, the dimming of conventional fluorescent lamps requires an additional means to prevent the cathode temperature from falling and subsequent cathode sputtering.

DISADVANTAGES

- Cost is higher than fluorescent lamps.
- With increase in frequency efficiency will decrease.
- If frequency changes there will be problems with electromagnetic interference.
- More complex design.
- Maintenance is not easy.
- It works efficiently for some particular frequencies, if frequency changes there are problems with electromagnetic interference (EMI).

FUTURE SCOPE

The trend is clear, technology innovation will increase at an even faster rate in the future. This has been particularly true in communications as RF technology becomes ubiquitous in daily life. Radio Frequency (RF) technology is critical to many aspects of modern electronics. This is because RF engineering is incorporated into almost everything that transmits or receives a radio wave across the whole of the RF spectrum (3 KHz to 300 GHz), including mobile phones, radios, Bluetooth, Wi-fi and as a light source as well.

These RF lighting has features like being highly economical for many plants. Induction lamps are sustainable for a range of installations, including general lighting within the plant as well as outdoor areas. Gas discharge lighting science and technology has developed over this time, and a variety of mature fluorescent and HID products are now on the market. Progress in electronics and an easing of EMI regulations have made it possible to drive commercial discharge lamps with RF power.

CONCLUSION

It has taken nearly a century from the first ideas and the first RF lamp proposals to make commercially viable RF lamps. Gas discharge lighting science and technology has developed over this time, and a variety of mature fluorescent and HID products are now on the market. Progress in electronics and an easing of EMI regulations have made it possible to drive commercial discharge lamps with RF power. The elimination of electrodes opens up great opportunities for increased durability, light output, and efficiency, and it removes many of the lamp-shape restrictions of conventional electrode discharge lamps.

The first commercial RF lamps have been mainly directed towards niche applications where the high cost of installation and maintenance offsets the rather large initial cost of the lamp. The initial cost of RF lighting products is the major barrier to the widespread use of RF lamps, but with further development of the many components of RF lighting technology, the range of applications should increase. The biggest challenge for RF lighting is the development of high-power fluorescent light sources for outdoor applications and compact fluorescent lamps to replace inefficient incandescent bulbs that are now the main light source in residential areas. Energy conservation and environmental concerns will inevitably bring about a new generation of compact residential RF lamps.

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