RF Amplifier: Design Aspects and Development Procedure

Jinal Modi
EC Dept.
Kalol Institute of Technology and Research Centre,
Kalol, Gujarat 382721, India
modijinal92@gmail.com

Sunil Kumar
Institute for Plasma Research,
Bhat. Gandhinagar, Gujarat 382428, India

Ms. Mayuri Prajapati
EC Dept.,
Kalol Institute of Technology and Research Centre,
Kalol, Gujarat 382721, India,

Abstract -- High power RF is an essential part of the future fusion reactors and the high power RF technology is still under development. There are only two companies in the world who manufacture MW level RF generators in the frequency range of 10 to 100 MHz The project for the design of RF Amplifiers consists of Understanding of HF amplifiers, understanding distributed design aspects of RF amplifier and then actual RF design of the amplifier in the form of circuit design and also the design of input and output cavity and coupling to make a complete system using CST software as well as analytical formulae.

Index Terms— RF Amplifier, RF power, Tube-triode

*****

I. INTRODUCTION

RF power is required to heat the plasma to ignition temperature of fusion reaction which is around 40 Kev and the RF power required is around 30MW in the frequency range of 10-100 MHz which is the ion cyclotron frequency (or its Harmonics) corresponding to the central magnetic field in a tokamak. Although the final RF power requirement for generator is 24 MW. The building block of RF system is 1.5 MW. One can combine RF generators with the help of Transmission line. The major responsibility of ICRH division is to develop high power RF systems. Therefore main purpose of ICRH is introduce RF power to do experiments like pre-ionization, current ramp-up, heating, wall conditioning in tokamak like ADITYA and SST-1. One can combine RF generators with the help of combiners and introduce RF power in the tokamak through coaxial transmission line and multiple antennas.

Now, firstly we understood the RF concept and understood the design of Transmission line, then we made low power design circuit which is made in TINA software and the value of power for RF amplifier is 25w. Then we made the higher Power design in form of hardware which is 200w. First we check the power supply of the circuit. Then we will check the whole circuit. Then we made actual cavity design of RF Amplifier in the CST Software.

Finally we match the theoretical value and simulation value. Both values are approximately same. The whole design of RF Amplifier would be done. RF Amplifier is used tetrode tube because triode tube is not tolerate high power above 20KW. The reason is parasitic oscillation occurred at high power. And also transistor cannot tolerate high power and temperature.

Elements	Diode	Triode	Tetrode	Pentode
Plate	√	√	√	√
Cathode	√	√	√	√
Control grid		√	√	√
Screen grid			√	√
Suppressed grid				√

Table-1 Types of vacuum tubes

This Paper describes RF Amplifier using Tetrode vacuum tube. In future, it is planned to use RF Amplifier for the purpose of MW generator for heating plasma in a tokamak reactor.

II. TUBE BASED AMPLIFIER CONCEPTS

1. TUBE

The "Fleming diode" was based on an effect that Thomas Edison had first discovered in 1880 which is consisted of an incandescent light bulb with an extra electrode inside. So, using this light lamp AC signal can be converted in to DC. Fleming's diode was first used as a sensitive detector of the weak signals produced by the new wireless telegraph. Later, the diode vacuum tube was used to convert AC into DC in power supplies for electronic equipment. Lee de Forest, in 1907 patented a bulb with the same contents as the Fleming diode, except for an added electrode. This "grid" was a bent. Wire between the plate and filament. So this type of tube is known as triode. Various tubes were developed for radio,

 ISSN: 2321-8169
XXX – YYY

television, RF power, radar, computers, and specialized application.

In its usual form, the vacuum tube includes a cathode capable of emitting electrons when heated, an anode that attracts the electrons emitted from the cathode and by some means of controlling the flow of electron from the cathode to the anode. These electrodes are enclosed in gas tight volume with high vacuum.

There are mainly diode, triode, tetrode, pentode here triode and tetrode symbol are as shown in Figure1.

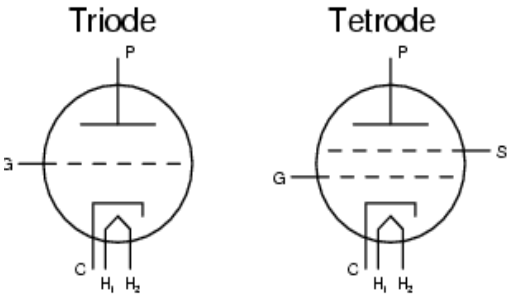

Figure-1 Types of vacuum tubes

2. RF Amplifier

Working of RF power amplifier is a type of electronic amplifier used to convert a low-power radio-frequency signal into a larger signal of significant power, typically for driving the antenna of a transmitter. It is usually optimized to have high efficiency, high output Power (P1dB) compression, good return loss on the input and output, good gain, and optimum heat dissipation.

As shown in definition RF Amplifier have good gain, high efficiency, high output power (P1dB) compression and good return loss on input and output and also optimum heat dissipation. So we get the all parameters through tested in TINA software. We can see from Table2.

3. Basic Block diagram of RF Amplifier

The basic block diagram of this RF system is shown in Figure 2. This system's design is developed for high power application which is required at plasma whose main aim that is to develop electricity for commercial area. This block diagram is describing whole system required four power supply. There are plate power supply, screen greed power supply, control greed power supply and filament power supply. Filament power supply is continuously applied to filament of tube. Output of the system is transmitted to the dummy load through transmission line. The compact cwrf free running Amplifier will be integrated with DC power supplies, control systems, user friendly control panel etc. this conceptual block diagram of RF Amplifier is for high power application where cooling system, controlling and monitoring required.

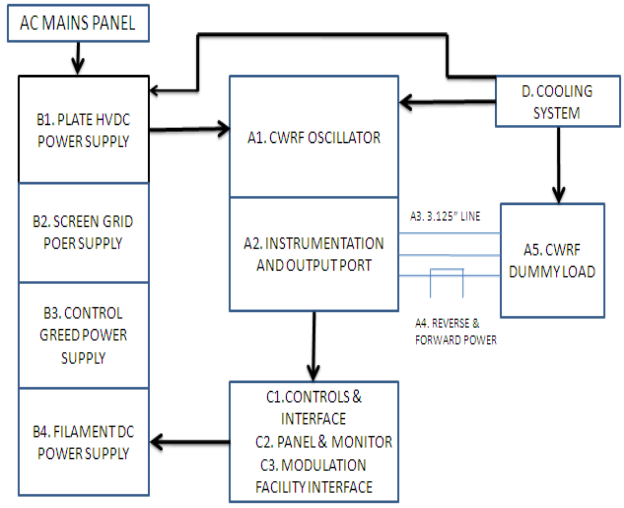

Figure- 2 Block Diagram RF Amplifier

4. RF Amplifier for lower application

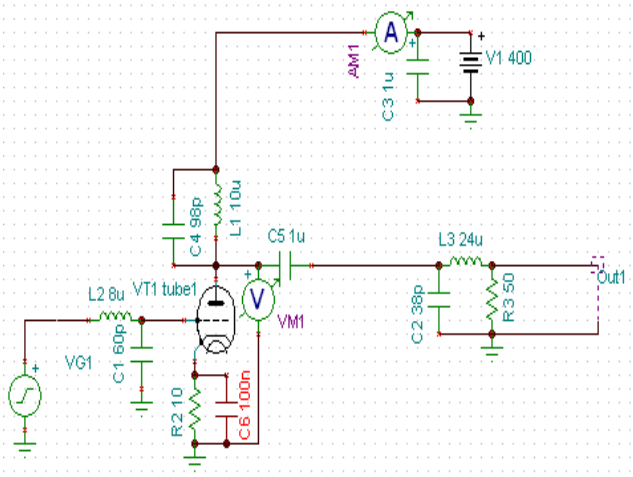

Figure-3 Circuit Diagram of 25W Class C Amplifier

As shown in circuit Diagram, we can use Triode tube instead of transistor. Triode contains three terminal: - Anode, Control Grid and cathode. Firstly we can give the supply AC voltage. Here LC matching circuit is used at input side and output side.LC matching circuit connect to the control grid. And pass the current and voltage correspondingly. At cathode side we connect the R and C to maintain the DC voltage. In this portion only DC can flow. Here for matching purpose we can connect the input matching circuit at input side and output matching the RF current. At upper side DC voltage is give so in that portion only DC is flow. At anode side L and C is only flow the DC. Here C5 is the DC blocking capacitor. Only RF

is passed through C5 capacitor. Here Ammeter and Voltmeter is connect for measure circuit at output side.

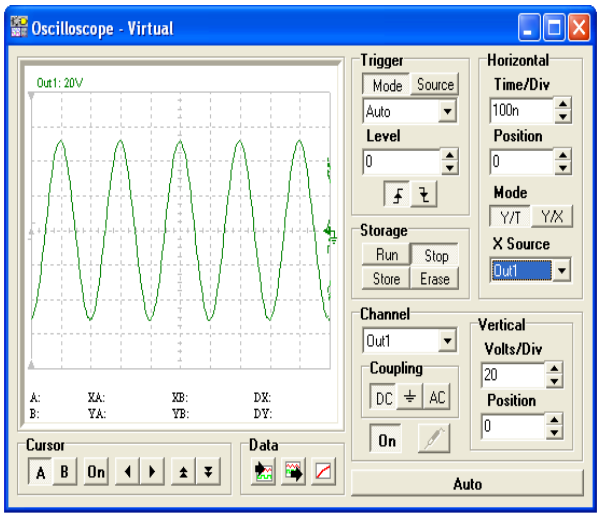

Figure-4 Simulate Waveform of RF Amplifier

Sr. no.	Parameter	Value
1	Input DC Power	19.076W
2	RF Output Power	25W
3	RF Input Power	1.6mW
4	Efficiency	76.30%
5	Gain	42dB(15,625)
6	Harmonic Distortion	58.667%
7	Frequency	5MHz
8	Bandwidth	Narrow(Notch Filter)

Table 2 Calculated Parameters of RF Amplifier

III. SELECTION OF TRANSMISSION LINE

For high power application, we introduced transmission line for transmission of power from output to the dummy load that is described in block diagram of RF oscillator. This paper provide selection of transmission line size by the equation,

$$Z_0 = \frac{138}{\sqrt{\varepsilon_r}} \log \frac{b}{a}$$

Where:-

b- Outer diameter
a- inner diameter

ε_r-dielectric material for air = 1

Reflection co-efficient -- The reflection coefficient measures the amplitude of the reflected wave versus the amplitude of the incident wave. The expression for calculating the reflection coefficient is as follows

$$\Gamma = \frac{Z_L - Z_0}{Z^L + Z_0} = \frac{VSWR - 1}{VSWR + 1}$$

VSWR – VSWR evaluates the ratio of the peak amplitude of the voltage of the wave on the transmission line versus the minimum amplitude of the voltage of the wave. A VSWR of 1 is ideal; this indicates that there is no reflected power at the port. When the transmission line are not perfectly matched, reflections travel back towards the source and cause a standing wave to form.

$$VSWR = \frac{V^{MAX}}{V^{MIN}}$$

Return loss -- This is measure of the power loss due to reflection of the signal due to impedance mismatch of the transmission line, given by

$$RL = -20 \log_{10} |\Gamma|$$

IV. SIMULATION DETAILS

There are number of commonly available software Packages which allow the simulation of electromagnetic parameters. Some of the best known are: HFSS, CST, ADS etc.

The software uses the model and simulate the proposed tube based RF Amplifier is HFSS or any other software which is design and optimization of devices operating in a wide range of frequencies. Software supports every step of the design process- capture, layout, design rule checking, frequency-domain and time-domain circuit simulation, and electromagnetic field simulation-- allowing the engineer to fully characterize and optimize an RF design without changing too. Here low power application is simulate in TINA software for basic understanding. But for high power application is not simulated in TINA software because it is not consists characteristic of tube. Since we can simulate it in CST software.

V. CONCLUSION

This paper represents how RF Amplifier works in low power applications. First we studied how RF Amplifier works in low power application and calculated its parameters using TINA Software. Further design aspects of RF Amplifier will be designed and its parameters will be calculated using CST Software for high power application.

REFERENCE

[1] Tetsuo Seki, Ryuhei Kumazawa,Takashi Mutoh,Fujio Shimpo,Gord Nompura and Tetsuo Watari "Steady-state amplifier at megawatt level for LHD ICRF heating "August 25,2000
[2] Sharifah Fatmadina Wan Muhammad Hatta, Norhayati Soin and Member IEEE"Design of an RF-BJT-Low noise amplifier at 1GHz", 2006
[3] S.som,Saikat pal, A.K.Mukherjee,D.S.Bhattacharya, P.Gangopadhyay,J.S.Prasad,Mondal,S.seth,P.R.Raj,S.K.Manna,M.Banerjee,K.V.Krishnaiah,M.S.Saha,S.Biswas,S.Saha "Development of 100KW RF amplifier for superconducting cyclotron at VECC",2007
[4] Sunil Kumar,Bhavesh Kadia, Raj Singh, Atul Varia, Y.S.S.Srinivas, S.V.Kulkarni and RF-ICRH group "Design aspects of 13.56MHZ, 1KW, CW-RF Oscillator for plasma production",2008
[5] Sunil Kumar, Azad Sinh Makwana, Y.S.S.Srinivas. S.V.Kulkarni and ICRH-System "Development of pre pre-driver amplifier stage for generator of SST-1 ICRH system", 2008

Books

[6] Microwave Principles by Herbert J. Reich, LITTON Educational Publishing INC., 1976
[7] RF and Microwave Power amplifier design by Anderi Grebennikov, McGraw-Hill Professional Engineering, ISBN No. 0-07-144493-9,2005
[8] Frederick Emmons terman, Radio engineering, 2nd edition, McGraw-Hill Book company Inc.: New York and London, 1937.
[9] Thomas L. Floyd, Electronic Device, 7thedition. Pearson Education Inc., 2005.
[10] Jerry C. Whitaker, Vacuum Tube Handbook, 2nd edition, CRC Press LLC, 2000.
[11] M. Kulkarni, Microwave and Radar Engineering, 4th edition, Umesh Publication, 2010.

Online sites

[12] www.ipr.res.in, 17/8/14.
[13] http://www.radio-electronics.com/info/antennas/coax/rf-coaxial-cable- impedance.php, 21/8/2014.
[14] http://www.vacuumtubes.net/How_Vacuum_Tubes_Work.htm, 15/9/14.
[15] http://www.radio-electronics.com/info/data/thermionic-valves/vacuum-tube-theory/tube-electrodes.php, 17/9/2014.
[16] httpS://www.google.co.in/webhp?sourceid=chrome-instant&rlz=1C1DFOC_enIN621IN621&ion=1&espv=2&ie=UTF-8#q=basic%20principle%20of%20amplifier,18/9/2014.
[17] https://www.google.co.in/webhp?sourceid=chrome-instant&rlz=1C1DFOC_enIN621IN621&ion=1&espv=2&ie=UTF-8#q=how+amplifier+works, 20/9/2014.
[18] http://www.ti.com/tool/tina-ti, 15/11/14.
[19] http://www.allaboutcircuits.com/vol_6/chpt_4/16.html, 20/11/2014.

Datasheets

[20] Multi-Phase Cooled Power Tetrode 4CM2500KG
[21] M513C diode datasheet
[22] BEL-300 Natural Air Cooled Triode

Tutorial

[23] Oscillator Resonator Design Tutorial