Design Aspects of 13.56MHz, 1kW, CW-RF Oscillator for Plasma Production

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Abstract. RF produced plasma has many applications in plasma processing and also it is useful in studying the fundamental characteristics of the plasma. A 1KW RF Hartley oscillator is designed and tested at 13.56 MHz. This has been built at RF section of Institute for Plasma Research by using EIMAC (3CX1200A7) triode tube. The RF source is operated in the grounded cathode mode. Triode 3CX1200A7 is operated in class AB and the feedback is Cathode grounded. The tube has sufficient margin in terms of plate dissipation and Grid dissipation that makes it suitable to withstand momentarily load mismatch. To optimize the RF source along with HVDC power supply many mechanical and electrical aspects have been thought of to enhance the overall quality of the system. This source mainly has three sections (The RF section, HVDC Power supply and soft start Filament Power supply). The system is compact and is housed in a 80 cm × 60 cm × 1800 cm aluminum panel. This paper describes the specifications, design criteria, circuit used, operating parameters of 1KW Oscillator along with HVDC power supply with necessary interlocks, tests conducted and results obtained of this 1 KW grounded grid Hartley Oscillator on 50 ohm dummy load. This system has been tested for 8 hours of continuous operation without any appreciable deterioration of the RF output power.

1. Introduction
The cwrf applications are increasing with the ongoing developments in the areas of broadcasting, defense, industrial and research. Free running cwrf oscillator of 1KW rating at 13.56MHz has various applications including Plasma Related Experiments. The 1KW cwrf source at 13.56MHz, integrated with all required biasing power supplies, controls, monitors and interlocks is in house designed, fabricated and tested. The oscillator may be fine-tuned within a bandwidth of 1MHz at the selected frequency of operation and is commissioned to provide 1KW for a period of many hours for the utility in industrial and research lab plasma applications.

2. Generator Outline
The integrated source has mainly three sections i.e. rf oscillator, plate power supply and the soft start filament supply. The system is compact and is housed in an aluminium rack of 1800mmX800mmX600mm. The integrated source in general consists of variable HVDC plate power supply, AC filament supply, control panel, various monitors, interlocks & protection circuitry, plate cooling blower, four inch diameter cooling fans, RFI filters, tunable tank circuit and power grid tube based Hartley Oscillator.
The Hartley Oscillator circuit is chosen. This is proven for simplicity in fabrication and better in economy as the costly high voltage fixed ceramic or vacuum capacitors are not needed in the tank circuit. High frequency response and better efficiency can always be obtained. This type is popular with industrial induction heating and commercial grade systems for power levels up to few hundreds of KW in HF range.

The circuit is biased with a HVDC plate supply only, as the cathode is self-biased. The variable HVDC plate supply provides rf output power variability whereas cathode self biasing provides higher efficiency at high power by changing the class of operation. This way, an optimised operating point is automatically chosen for a selected output power. Primary of the filament supply transformer is provided with a set of resistances, timer, contactor based circuit for 1min preheating before the full voltage is applied. This ensures jerk free longer life and lesser cold in rush current to the tube filament.

All power supply cables and control connections are provided with rf feed through capacitors and L-section rf filters for smooth and reliable operation. The integrated rf source is space and quality optimized in terms of mechanical and electrical aspects to enhance the overall look, reliability and performance of the system.

3. Oscillator Description

The Hartley Oscillator, well known for rf applications is designed and fabricated for more than 1KW cwrf output at 13.56MHz. The triode (Eimac Brand) 3CX1200A7 is operated at plate with 4KV and 500mA in Class AB at more than 50% efficiency. The feedback is cathode grounded and negative self-biasing is applied. The frequency fine-tuning within few MHz is done by means of tank variable 20 to 70pf teflon lining capacitor that is indigenously developed at IPR.

The output rf power is tapped at plate RFC by means of a indigenously developed and fabricated 30pf teflon insulator based capacitor. The capacitor is breakdown tested for more than 10KV. The 50 Ohm output terminal is provided at N-type connector via adaptor. The absolute maximum ratings of the triode tube 3CX1200A7 as per manufacturers technical data are following.

| Parameter              | Value     | Parameter              | Value     |
|------------------------|-----------|------------------------|-----------|
| Plate operating voltage| 5.0kV     | Plate current          | 800mA     |
| Plate dissipation      | 1200W     | Grid dissipation       | 50W       |
| Cathode Voltage        | 200V      | Operating frequency    | 110MHz max|
| Power output (G. Grid) | 2055W     | Power input            | 100W      |
| Filament voltage       | 7.5V      | Filament current       | 21A       |
| Air cooling            | 40 CFM    | Pressure drop          | 25mm WG   |

4. Operating Parameters of the Circuit

Using manufacturers data for the tube 3CX1200A7, the load line is drawn at the quiescent point 3.8kV and 400mA with cathode at 0V and following operating parameters are obtained.

| Parameter              | Value     | Parameter              | Value     |
|------------------------|-----------|------------------------|-----------|
| Plate operating voltage| 3.8kV     | Plate operating current| 513mA     |
| Cathode voltage        | 0V        | Cathode current        | 655mA     |
| Power output           | 1090W     | Power input            | 12W       |
| Plate dissipation      | 860W      | Grid dissipation       | 15W       |
| Power Gain             | 20dB      | Efficiency             | 56%       |
| Load impedance         | 2350 Ohm  | Source impedance       | 458 Ohm   |

Integrated fully protected HVDC floating plate supply is fabricated and tested for the following specifications.

| Parameter              | Value     | Parameter              | Value     |
|------------------------|-----------|------------------------|-----------|
| DC plate voltage       | 5kV max   | DC plate current       | 0.8A max  |
| Variability at plate   | 1 to 5kV  | Voltage set precision  | < 100V    |
| Ripples at any voltage | ± 1%      |                        |           |
Fault turn off time 10m sec pulse block feature at the power controller
Load regulation ± 1% max at 100% load change
Line regulation ± 1% max at ±10% mains change
Temperature sensitivity < 0.02% per degree C
Arc Protection 100 Ohm series resistance
Other Protections Over Current, Over Voltage and C. Grid Over Current

5. Performance Test and Results
Based on the above design details many of the similar rf sources are made and delivered. Following are test results of one of the recently fabricated sources.

| Parameters                  | Readings                  | Observations And Remarks |
|-----------------------------|---------------------------|--------------------------|
| Tuned frequency             | 13.5656MHz                | Spectrum analyser at 100W |
| Frequency stability         | 0.007%                    | Tested as above for 15min. |
| Power output                | 1000+W                    | At 3.8KV/ 500mA;          |
| Efficiency                  | >53%                      | Tested for 30min.         |
| Harmonic distortion         | 1st is –34db              | At 100W with 50db Power sampler |
| Radiation level at 1kW      | 0.0001W/m2                | WG EM (EMR20) Radiation meter |
| Controls                    | Plate voltage, Filament & Filament sequence switching, Plate voltage variation and Frequency variation |
| Protections                 | Over current, Over voltage and C. Grid over current |

![Grounded Cathode Hartley Oscillator Diagram](image-url)
6. Photographs of 13.56MHz, 1KW CWRF Oscillator

7. Conclusion
Performance of the self contained, integrated commercial grade source is found satisfactory and in tune with the design calculations. Testing is performed with through line power meter and 50W dummy load. Source efficiency may be improved by driving the oscillator in the class C for the industrial applications where reduced harmonic distortions are not important. The tube and tank components were found heating up at output power of more than 1KW. Sufficient rating margins exist with the tube and other components. Better cooling may provide output power of more than 1.5KW. Scrapping margins and including latest technology will drastically reduce the existing source size. This circuit may be altered in frequency and increased in power with small modifications.