Power and Efficiency Enhancement of the Reltron Using Dual RF Output Cavities

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Abstract — *In this paper, a dual RF output cavity based reltron is proposed to enhance the efficiency as well RF output power. It uses two RF output cavities of different quality factor. The quality factor of the first output cavity kept low whereas the quality factor of the second output cavity is kept higher. The output cavity with low quality factor extracts maximum RF output power whereas the second output cavity with has higher quality factor extracts remaining output power. With typically selected electrical parameters, the proposed reltron delivers ~ 270 MW output power with ~ 42.4% efficiency. The obtained results show the improvement in the device performance in terms of RF output power as well as efficiency as compared to the conventional reltron.*

Keywords—high power microwave; klystron; reltron; microwave tube; vacuum electronics devices

Introduction

High power microwave (HPM) generation requires synchronization between the phase velocity of the RF waves and electron beam velocity propagating in the device interaction structure. Various HPM sources such as backward wave oscillator (BWO), magnetically insulated line oscillator (MILO), virtual cathode oscillator (vircator), and reltron, etc. uses explosive emission cathode. During the explosive electron emission process plasma is generated over the cathode which performs as an ironic source of electrons. As this plasma layer expands, it effectively changes dimension of the cathode or cavity walls which can lead to the instability of the device resonance condition. Further, this plasma layer becomes sufficiently conductive to act as boundary for applied potential as well as RF electric field. This phenomenon also causes problem of pulse shortening in the explosively driven HPM sources [1]- [2].

Reltron is comparatively simple, efficient and compact HPM source and has various anticipated applications such as directed energy weapon, e-bombs, particle acceleration, plasma heating and radar, etc. Reltron key features over other HPM sources are higher efficiency, larger pulse width, light weight and elimination of the external mode converter. Reltron is an O-type device in which the electrons are excited far away from the walls of RF interaction structure. As a result of it, radial plasma motion would take longer time to affect the RF generation. On the other hand, axial motion of plasma is small as compared to the anode-cathode gap. Therefore, pulse shortening in reltron is less as compared to the other HPM sources.

The cathode emits dense electrons, side coupled modulation cavity acts as an RF interaction structure where electrons are velocity modulated and get bunched, the post-acceleration gap reaccelerates these electron bunches and helps in reducing the beam energy spread thus enhancing the RF energy. A beam dump is used to collect the unused electrons. More device details and its operating phenomenon are given in [3]- [9].

Reltron was first experimentally demonstrated by Miller *et al.* [3]. With 1 GHz Reltron, they achieved > 400 MW peak power with ≥ 50% efficiency while with 3 GHz reltron delivered peak RF power outputs in the range of 200-250 MW, with 30-40% efficiency. In 1994, Miller *et al.* [4] also demonstrated frequency adjustable reltron. In 1998, Miller [10] demonstrated the physical mechanisms of the velvet cathode briefing the explosive electron emission condition in reltron. In 1998, Miller [11] has pulse shortening phenomenon in reltron tube. In 2009, Kim *et al.* [12] have used MAGIC3D PIC code to investigate an ultra-compact, reltron oscillator. In 2012, Soh *et al.* [13] have explained the dual mode reltron to increase RF power. In 2016, Mahto and Jain [5]-[9], reported the design methodology, oscillation condition and PIC simulation of the reltron. The electrons bunching and virtual cathode formation in the device is also described.

In the present paper, reltron with a modified RF output section is proposed to increase the device power and efficiency. Here, we have used the concept of multiple output cavity extraction. The conceptual diagram of the proposed reltron is shown in Figure 1 which has two output cavities as compared to a single output cavity used in the reltrons [5]. The quality factor *Q* of the first extraction cavity is kept low where as the *Q* factor of the second extraction cavity is kept higher. This type of arrangement allows to extract maximum output from the first output cavity while remaining RF power is extracted through the second output cavity.

Result and Discussion

The schematic of the proposed reltron is shown in Figure1. In the present reltron, two RF output cavities are used, marked as OC-1 as the first output cavity and OC-2 as second output cavity (Figure 1). Both the output cavities are loaded to achieve the desired quality factor *Q*. To achieve the desired loading of the output cavities, alumina is proposed to be used. The first output cavity quality factor is adjusted to ~ 30 whereas for the second output cavity quality factor to ~ 50. We have applied two waveguide ports, one at OC-1 and another at OC-2. The device electrical parameters chosen as: cathode DC voltage 100 kV, post-acceleration DC voltage 750 kV and beam current of 750 A. After setting up the required parameters, to analyze the device behavior 3D PIC simulation is carried out using a commercial code "CST Particle Studio". The developed RF electric fields at OC-1 and OC-2 are shown in Figs. 2 (a), 2 (b), respectively. Their corresponding frequency spectrums are plotted in Figs. 3(a) and 3(b), respectively. The RF output powers obtained at the output ports OC-1 and OC-2 are ~ 210 MW and ~ 60 MW, respectively. As a result, total RF output power received is ~ 270 MW with an efficiency of ~ 42.4 %. While the conventional reltron with single output cavity is ~ 225 MW with ~ 36 % efficiency. Thus, the HPM source - reltron with dual RF output cavity enhances the device output power as well as its efficiency.

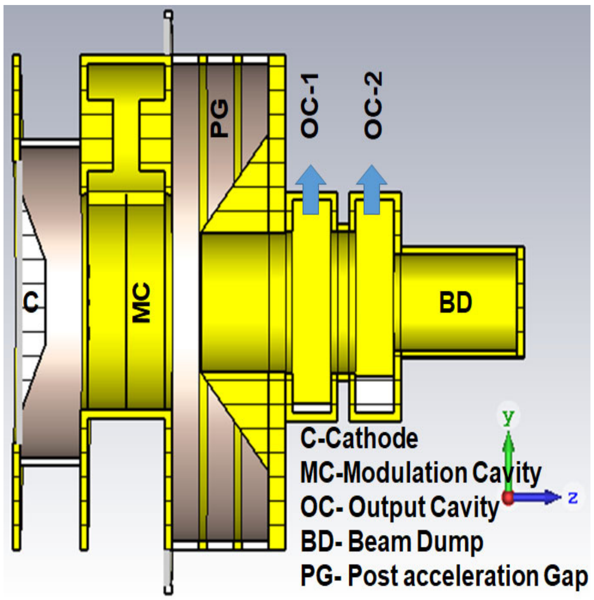

Figure 1. Schematic diagram of a two output cavity reltron.

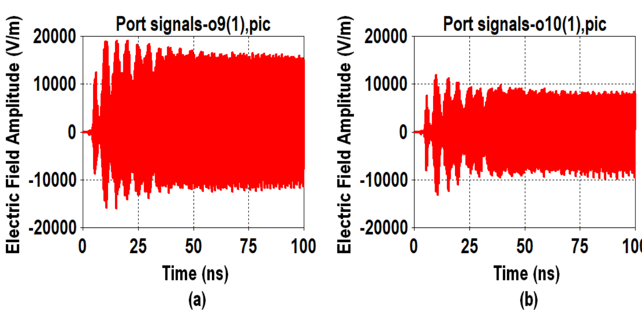

Figure 2. RF electric field amplitude at (a) output cavity-1 (b) output cavity-2.

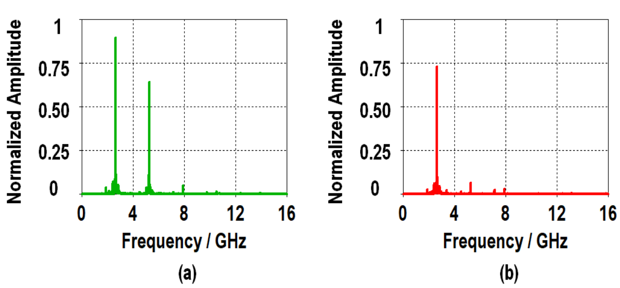

Figure 3. Frequency spectrum of the RF electric field at (a) output cavity-1 (b) output cavity-2.

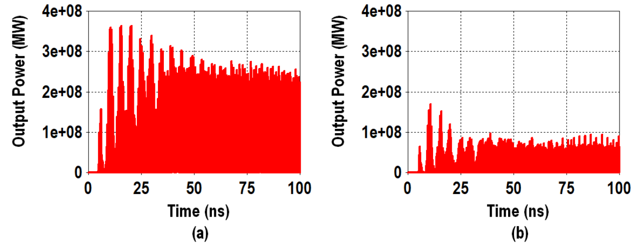

Figure 4. RF Output power obtained from ***(a)*** output cavity-1, ***(b)*** output cavity-2.

Conclusion

A reltron oscillator with dual RF output cavity is proposed here for performance enhancement in terms of RF output power and efficiency. In this device two output cavities are used to extract the RF power as compared to a single output cavity used in the conventional reltron. The first output cavity quality factor is kept ~ 30 which provides an RF output power of ~ 210 MW, whereas the second output cavity quality factor is adjusted to ~ 50 which provides an RF output power of ~ 60 MW. The total RF output power achieved from the device is ~ 270 MW with ~ 42.4% efficiency. However, the conventional reltron with same electrical parameter and single output cavity delivers only ~ 225 MW RF output power with ~ 36 % efficiency. Hence, the proposed device modification would be useful in improving reltron performance and capable of providing higher RF power with increased device efficiency.

References

[1] James Benford, John A. Swegle, *High Power Microwaves,* Taylor & Francis. CRC Press, 2007.

[2] D. Price and J. N. Benford, “General scaling of pulse shortening in explosive-emission-driven microwave sources,” *IEEE Trans. Plasma Sci.*, vol. 20, pp. 256–262, 1998,

[3] R. B. Miller, W. F. McCullough, K. T. Lancaster, and C. A. Muehlenweg, “Super-reltron theory and experiments,” *IEEE Trans. Plasma Sci.*, vol. 26, pp. 332–343, 1992,

[4] R. B. Miller, C. A. Muehlenweg, K. W. Habiger, and J. R. Clifford, “Super-Reltron progress,” *IEEE Trans. Plasma Sci.*, vol. 22, pp. 701–705, 1994.

[5] M. Mahto, and P. K. Jain, “Design and Simulation Study of the HPM Oscillator—Reltron,” *IEEE Trans. Plasma Sci.*, vol. 44, pp. 743–748, 2016.

[6] M. Mahto and P. K. Jain, “Oscillation Condition and Efficiency Analysis of the Reltron,” *IEEE Trans. Plasma Sci.*, vol. 44, pp. 1056–1062, 2016.

[7] M. Mahto, and P. K. Jain, “Electromagnetic Analysis of the HPM Oscillator—Reltron,” *Phys. Plasmas*, vol. 23, p. 093118, 2016.

[8] M. Mahto, and P. K. Jain, “Study of Virtual Cathodes Formation during Beam-Wave Interaction in the Reltron Oscillator,” *Phys. Plasmas*, vol. 24, p. 093107, 2017.

[9] M. Mahto and P. K. Jain, “PIC Simulation Study of the Formation Mechanism of Periodic Virtual Cathodes in the Reltron,” *IEEE Trans. Plasma Sci.*, vol. 46, pp. 518-523, 2018.

[10] R. B. Miller, “Mechanism of explosive electron emission for dielectric fiber (velvet) cathodes,” *J. Appl. Phys.*, vol. 84, no. 7, p. 3880, 1998.

[11] R. B. Miller, “Pulse shortening in high-peak-power Reltron tubes,” *IEEE Trans. Plasma Sci.*, vol. 26, no. 3, pp. 340–347, Jun. 1998.

[12] H. Kim, J. Choi, B. Lee, J. Kim, and J. Lee, “MAGIC3D simulation of an ultra-compact, highly efficient, and high-power reltron tube,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 16, pp. 961–966, 2009.

[13] S. Soh, R. B. Miller, E. Schamiloglu, and C. G. Christodoulou, “Dual-Mode Reltron,” *IEEE Trans. Plasma Sci.*, vol. 40, pp. 2083–2088, 2012.