Design and Simulation of an S-Band Tunable Solid-State Power Amplifier as an RF injector into a Miniature ECR Ion Source

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Abstract

A continuous-wave solid-state-based power amplifier is designed and simulated in this paper to work as an RF injector into an ECR ion source chamber. Employing a solid-state radio frequency power amplifier, instead of magnetrons, leads to having higher efficiency, lower price, compact size, and longer lifetime. Also, a modular design can be achieved for designing higher output power by repeating lower power sources and combining them. The designed RF source is simulated using Advanced Design System (ADS) based on the measured scattering parameters of components. Simulations show an output power of more than 57dBm with a tunable frequency bandwidth from 2.3 to 2.5GHz.

Keywords: Power amplifier, Solid-state transistors. Power efficiency, RF Source

Introduction

Transistor-based power amplifiers are much more efficient than magnetrons and have a longer lifetime, higher efficiency, and more compatibility to be designed with other electronic components [1]. It significantly improves the minimization of size, cost and can have better control on power management and impedance matching [2]. As a result, these features give them the ability to be utilized in miniature Electron Cyclotron Resonance (ECR) ion sources [3], [4].

The main solid-state-based design considerations are the number of high-power transistors, efficiency, and matching networks. Usually, microstrip-based matching networks are used for delivering the maximum output power. Also, the number of high-power transistors is important because several power combiners should be used which can dissipate power before reaching load [5], [6]. In this paper, we hired an internally matched transistor, on both the output and input sides which can deliver up to 57dBm power at S-band frequencies. The dimension of the target plasma chamber is 50*50 mm^2 which utilizes an alumina window as a lens for microwave power coupling to focus the wave into the chamber.

The Proposed RF Source

The block diagram of the proposed structure is shown in Fig. 1. The proposed chain consists of Voltage Controlled Oscillator (VCO), Variable Gain Amplifier (VGA), preamplifier, 90-degree hybrid power combiner, and Doherty power amplifier. As the selected power amplifier doesn't need negative gate voltage, there is no need to design a bias sequence for it and the source will become more reliable. All part numbers and power limit values are shown in this figure.

Results and discussion

The simulations were performed by ADS and the precise and practical model of the components in the S-Band. Fig. 2 shows the output power in dBm where 53 dBm and 56 dBm stand for 200 W and 400 W, respectively. The output frequency can be easily adjusted by changing the

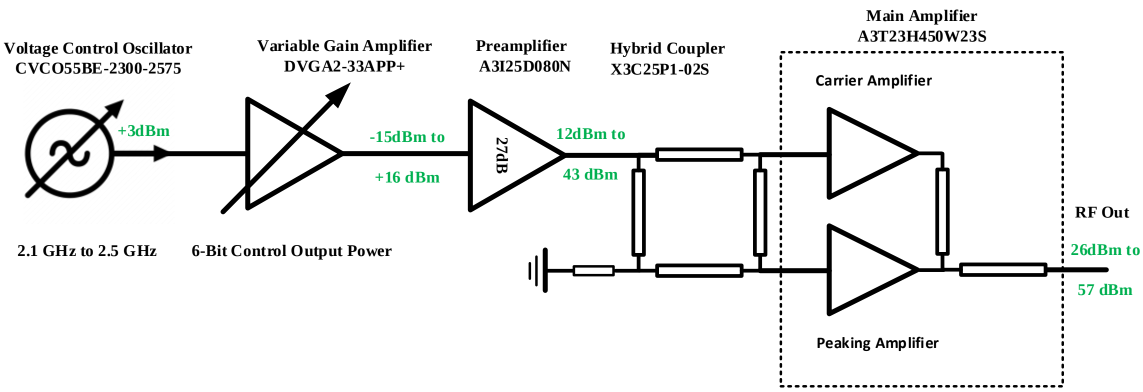

Figure 1. The proposed block diagram of RF high-power source.

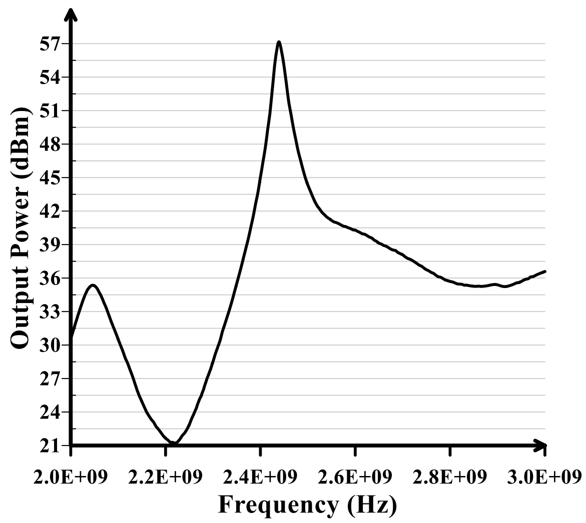

Figure 2. The simulated output power of the proposed microwave source.

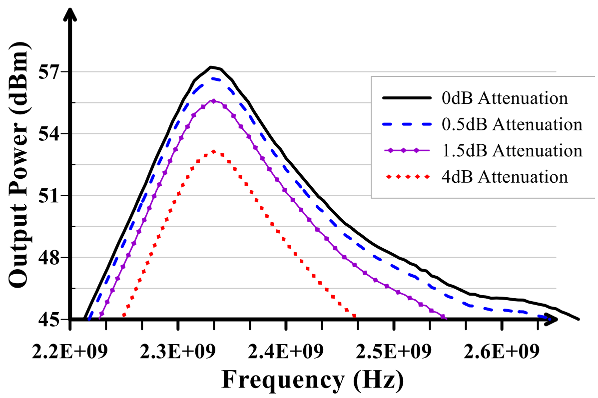

Figure 3. The simulated output power for different attenuation value

VCO voltage level which can be tuned from 2.1 to 2.5 GHz. The output power of the designed RF source is adjustable by the VGA 6-bit control bits which can be fined tune from 25 to 57 dBm with resolution of 0.5 dB. Some selected control states are shown in Fig. 3. The frequency response of the RF source output matching is shown in Fig. 4. The frequency location of the peak power can be changed by adding a simple matching network to the output and, changing the VCO voltage.

Table 1. Comparison of our results to other related studies.

	Frequency (GHz)	*power (dBm)*	*type*	*Efficiency %*	*year*
[7]	1.7-2.7	52.7-54.3	Doherty	<50	2015
[5]	2.7-3.1	<44	B	<44	2017
[8]	2.7-2.9	< 45	AB	<48	2020
Present study	**2.3-2.5**	**25-57**	**Doherty**	**<45**	

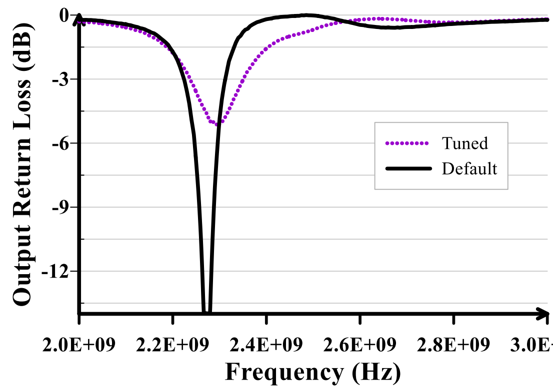

Figure 4. The simulated output return loss of the proposed microwave source.

Conclusions

A single transistor-based ECR ion source was presented in this paper with the ability of fine-tunable output power and center frequency. The proposed structure can deliver more than 400 W to the miniature ion chamber. The designed RF source has a good power efficiency and is reliable because there is no need to use an external matching network and bias sequence for a high-power RF transistor startup. We would try to implement the proposed structure in future works.

References

[1] C. Piel, B. Aminov, A. Borisov, S. Kolesov, and H. Piel, "Development of A Solid State RF Amplifier in the KW Regime for Application with Low Beta Superconducting Rf Cavities," in *Proceedings of the 2005 Particle Accelerator Conference*, pp. 1–3. doi: 10.1109/PAC.2005.1591793.

[2] K. Nakatani and T. Ishizaki, "A 2.4 GHz-Band 100 W GaN-HEMT High-Efficiency Power Amplifier for Microwave Heating," *Journal of electromagnetic engineering and science*, vol. 15, no. 2, pp. 82–88, Apr. 2015, doi: 10.5515/jkiees.2015.15.2.82.

[3] R. Fatkullin, S. Bogomolov, K. Kuzmenkov, and A. Efremov, "Compact 2.45 GHz ECR Ion Source for generation of singly-charged ions," in *EPJ Web of Conferences*, Apr. 2018, vol. 177. doi: 10.1051/epjconf/201817708003.

[4] J. M. Wen *et al.*, "A miniaturized 2.45 GHz ECR ion source at Peking University," *Chinese Physics B*, vol. 27, no. 5, May 2018, doi: 10.1088/1674-1056/27/5/055204.

[5] X. Chen, W. Chen, Q. Zhang, F. M. Ghannouchi, and Z. Feng, "A 200 watt broadband continuous-mode doherty power amplifier for base-station applications," in *2017 IEEE MTT-S International Microwave Symposium (IMS)*, Jun. 2017, pp. 1110–1113. doi: 10.1109/MWSYM.2017.8058790.

[6] L. Hoang Duc, A. Nguyen Dinh The, D. Bach Gia, M. Jobs, R. Ruber, and D. Dancila, “High-power low-loss air-dielectric stripline Gysel divider/combiner for particle accelerator applications at 352 MHz,” *The Journal of Engineering*, vol. 2018, no. 5, pp. 264–267, May 2018, doi: 10.1049/joe.2017.0793.

[7] Y. Yang, M. Zhang, W. Che, H. Chen, and Q. Cai, “High power S-band GaN-based power amplifier for radar systems,” in *2015 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP)*, Jul. 2015, pp. 1–3. doi: 10.1109/IMWS-AMP.2015.7324922.

[8] M. Ali Belaïd, A. Almusallam, and M. Masmoudi, “RF performance reliability of power N-LDMOS under pulsed-RF aging life test in radar application S-band,” *IET Circuits, Devices & Systems*, vol. 14, no. 6, pp. 805–810, Sep. 2020, doi: 10.1049/iet-cds.2019.0552.