Development of a Pulse-Driven Phase-Controlled Magnetron

Tomohiko Mitani, Naoki Shinohara

Research Institute for Sustainable Humanosphere, Kyoto University,
Gokasho, Uji, Kyoto, JAPAN, 611-0011
mitani@rish.kyoto-u.ac.jp

Hiroshi Matsumoto

Kyoto University,
Yoshida-Honmachi, Sakyo-ku, Kyoto, JAPAN, 606-8317

Abstract: *The objective of the present study is development of a pulse-driven phase-controlled magnetron (PCM) in order to expand an application range of a magnetron. The pulse-driven PCM consists of a 2.45GHz cooker magnetron, a high-voltage pulsed power supply, a reference signal and frequency/phase control circuits. The frequency and phase of the pulse-driven PCM are locked into those of the reference signal by an injection locking method and a phase-locked loop circuit. From experimental results, a kHz-class pulse-driven PCM was successfully developed.*

Keywords: phase-controlled magnetron; pulse operation; injection locking; phase-locked loop.

Introduction

A phase-controlled magnetron (PCM) is a CW magnetron whose frequency and phase are locked into those of a reference signal. The PCM has been originally developed by Brown, with injection locking and external magnetic field control by a "buck boost" coil [1]. A PCM by mechanical tuning of the output load impedance has been developed at the University of Alaska Fairbanks [2]. Tahir *et al.* have developed a current-controlled PCM with the injection locking and phase-locked loop (PLL) technique, and investigated its frequency/phase modulation performance [3, 4].

Our research group has developed another type of a current-controlled PCM [5]. We have also developed a phase-and-amplitude-controlled magnetron (PACM) by tuning both the anode current and the external magnetic field simultaneously [6]. Our PCM and PACM were designed for a highly-efficient wireless power transmission system of a future solar power station/ satellite (SPS) [7].

The objective of the present study is development of a pulse-driven PCM based on the conventional CW PCM. Its performance requirements are high-speed response, frequency/phase stabilization and phase repeatability of the pulse-driven PCM at "on" state.

Configuration of a pulse-driven PCM

Figure 1 shows a schematic diagram of a pulse-driven PCM. The pulse-driven PCM consists of a 2.45GHz cooker magnetron, a high-voltage pulsed power supply, a reference signal and frequency/phase control circuits. The frequency/phase locking method of the pulse-driven PCM is a combination of an injection locking method and a PLL circuit, the same as that of our conventional PCM.

The injection locking method is used for locking the magnetron frequency in the frequency of the reference signal. The reference signal at 2.45GHz is injected into a 2.45GHz cooker magnetron through a circulator. For the effective injection locking, the magnetron frequency should be close to the reference frequency. Then, the PLL circuit controls the anode current for tuning the magnetron frequency within range of the injection locking. The PLL circuit also contributes to the phase locking of the magnetron in the reference signal. Finally, both the frequency and the phase of the magnetron can be automatically locked in those of the reference signal.

A high-voltage pulsed power supply is used for pulse operation of the magnetron, whereas our conventional CW PCM was operated by a high-voltage DC stabilized power supply. The pulse frequency of the pulsed power supply is adjustable from dc to 20 kHz. The duty ratio was fixed to 0.5 in the experiments.

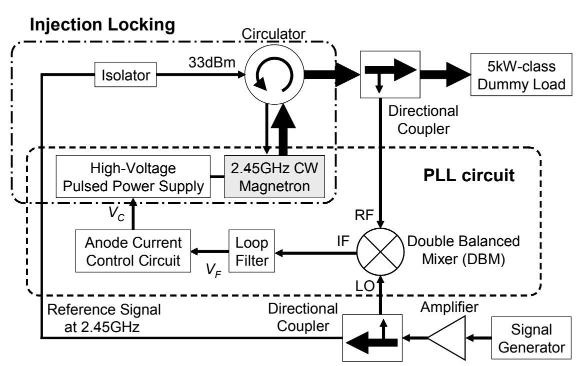

Figure 1. A schematic diagram of a pulse-driven phase-controlled magnetron

Experimental Results

Figure 2 shows the experimental results of the pulse-driven PCM at a pulse frequency of 1 kHz. The control

1-4244-0633-1/07/$20.00@ 2007 IEEE

voltage of the power supply V_C and the output voltage of the loop filter V_F are shown in the upper and lower graph in Figure 2, respectively. V_C controls the anode current of the magnetron and the magnetron is turned off at V_C=0V. V_F is related to the phase difference between the reference signal and the output of the pulse-driven PCM.

When the magnetron is started, the frequency and phase of the pulse-driven PCM are stably locked into that of the reference signal within 0.1ms, as shown at "on" state in Figure 2. The phase stability of the pulse-driven PCM during phase locking was estimated to be about +/- 6 degrees from the amplitude vibration of V_C. The poor phase stability is caused by the anode current ripple of the pulsed power supply. The free-running frequency of a magnetron is expressed as a function of the anode current. As the phase difference between the reference signal and the PCM output depends on the frequency difference between the reference signal and the free-running magnetron, the anode current ripple resulted in the degradation in phase stability of the pulse-driven PCM.

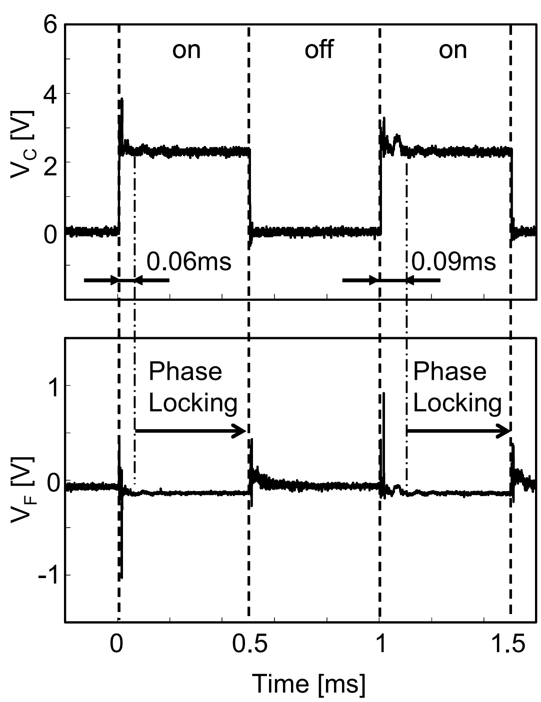

Figure 2. Experimental results of the pulse-driven phase-controlled magnetron (upper: control voltage of the power supply V_C, lower: mixer output V_F)

Conclusion

We successfully developed a kHz-class pulse-driven PCM. Improvement of the phase stability and development of a MHz-class pulse-driven PCM are challenging future tasks.

References

1. Brown, W. C., "Update on the solar power satellite transmitter design," Space Power, Vol. 6, pp. 123–135, 1986.
2. Hatfield, M. C., "Characterization and Optimization of the Magnetron Directional Amplifier," Ph.D. dissertation, the University of Alaska Fairbanks, 1999.
3. Tahir, I., Dexter, A. and Carter, R., "Noise Performance of Frequency- and Phase-Locked CW Magnetrons Operated as Current-Controlled Oscillators", IEEE Trans. Electron Devices, Vol. 52, No.9, pp2096-2103, 2005.
4. Tahir, I., Dexter, A. and Carter, R., "Frequency and Phase Modulation Performance of an Injection-Locked CW Magnetron", IEEE Trans. Electron Devices, Vol. 53, No.7, pp1721-1728, 2006.
5. Shinohara, N., Matsumoto, H., and Hashimoto, K., "Solar power station/ satellite (SPS) with phase controlled magnetrons," IECE Trans. Electron., Vol. E86-C, No. 8, pp. 1550–1555, Aug. 2003.
6. Shinohara, N., Mitani, T., and Matsumoto, H., "Development of Phase and Amplitude Controlled Magnetron," in Proc. IVEC 2005, pp. 61–64, 2005.
7. Matsumoto, H. "Research on Solar Power Station and Microwave Power Transmission in Japan: Review and perspectives", IEEE Microwave Magazine, Vol. 3, No. 4, pp. 36-45, 2002.