Experimental Study on Frequency Modulation of an Injection-Locked Magnetron Based on Full Wave Voltage Doubler

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Abstract: *In this study, we show that a 2.45 GHz magnetron can follow the frequency modulation of the injection signal, working as an amplifier. A full-wave voltage doubler was improved from the power source of a microwave oven and used as the power source of the injection-locked magnetron. By injecting a frequency modulation signal to this CW magnetron, the frequency of the magnetron was locked with the injection signal. 2 Mbps data transmission by frequency-shift keying was achieved at an anode voltage ripple rate of 4.16%.*

Keywords: magnetron, injection locking, frequency-shift keying, full wave voltage doubler circuit

Introduction

Magnetrons have been widely used as microwave heating applications typified by microwave ovens. The advantages of magnetrons include high efficiency, low cost, and lightweight. However, the magnetrons have poorly stable output frequency and high noise. An ordinary approach was utilizing an injection locking method to stabilize the magnetron oscillation frequency. By the injection locking method, a reference signal is injected to the magnetron to lock the oscillation frequency. The injection signal frequency is set to close the self-oscillation frequency of the magnetron, and the locking frequency range is expressed by Alder equation [1]. Our research group has overcome these disadvantages and developed the phase-controlled magnetron as the transmission apparatus of a wireless power transfer system [2]. Also, another group has developed a phase-locking 15 kW magnetron for coherent power combining [3]. Regarding frequency and phase modulations by an injection-locked magnetron as a transmitter for communication, the transmission of phase-shift-keying data at 2 Mbps has been achieved by Tahir *et al*. [4].

However, all these power supplies of the low noise magnetron systems are stabilized power supplies [2]- [4] which are hundreds of more expensive than magnetrons. It's limited the magnetrons to practical applications, like as communication and wireless power transfer. In this paper, we utilized a full wave voltage doubler, which was improved from a power source of microwave ovens and whose cost is almost nearly a magnetron. Then we developed a frequency-shift keying (FSK) transmitting system by the improved injection locked magnetron.

Full wave voltage doubler

A circuit schematic of our utilized full wave voltage doubler is shown in Fig. 1. The AC voltage (100 V, 60 Hz) supplies to the transformer, the D1, D2 (Hio CL01-12), C1 and C2 constitute the full wave voltage doubler rectifier circuit and L makes the output smoothly. Here, the C1 and C2 are 2.06 uF, the L is 15 H. This full wave voltage doubler output from −3730 V~ −3570 V which fulfills the magnetron oscillation voltage. The ripple rate of magnetron anode voltage was 4.16%.

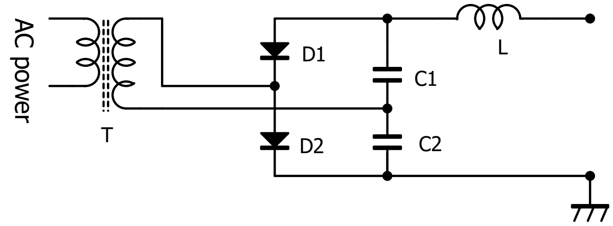

Figure 1. Schematic of the full wave voltage doubler

FSK by injection-locked magnetron

Figure 2 shows a block diagram of the FSK system by using an injection-locked magnetron. 2 MHz (=2 Mbps) pulse signal was created as FSK data by a signal generator (Agilent N5183A). The modulation frequency was set at 2.448 GHz and 2.45 GHz. This FSK modulated signal was amplified to 10 W and via a circulator, injected to the magnetron (Panasonic M236-M42). The oven magnetron was locked with the FSK modulated signal and amplified it. Then the FSK modulated microwaves were transmitted through the antenna. The transmitted microwaves were received and demodulated by a frequency demodulator (Pakite PAT-260) in the receiver. Then 2 Mbps FSK data were obtained. The demodulated result is shown in Fig. 3.

The fastest transmission data rate f_{max} was limited by the magnetron oscillation frequency range. The magnetron FSK system only worked in the frequency-locking state. Increasing the injection power could improve the lock frequency range $f_{lock,}$ as shown in Fig. 4. Here, the power source ripple would affect the magnetron oscillation frequency. Figure 5 shows that the oscillation frequency was changed by the magnetron output power, and the anode voltage could change the output power. It is difficult to define the relationship between the ripple rate and the oscillation frequency range because the power

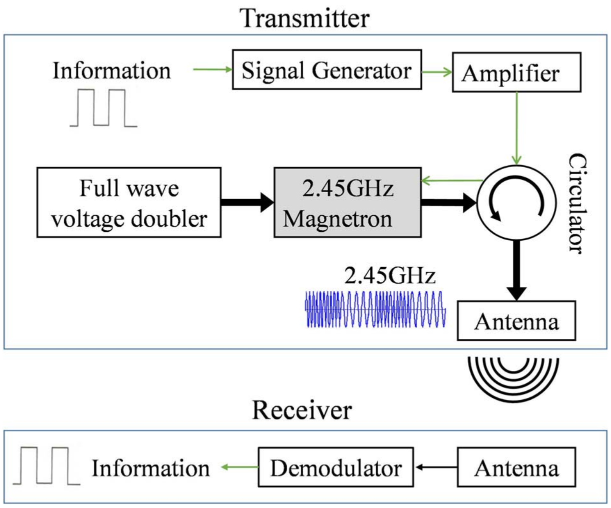

Figure 2. FSK system block diagram

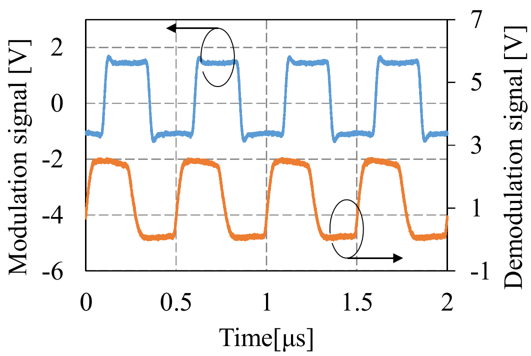

Figure 3. FSK modulation/demodulation result

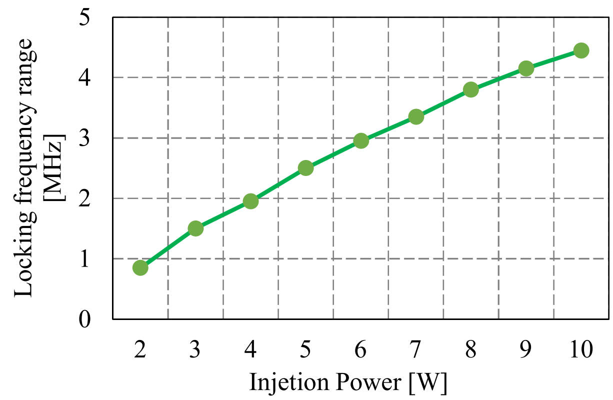

Figure 4. Injection power vs. lock frequency range

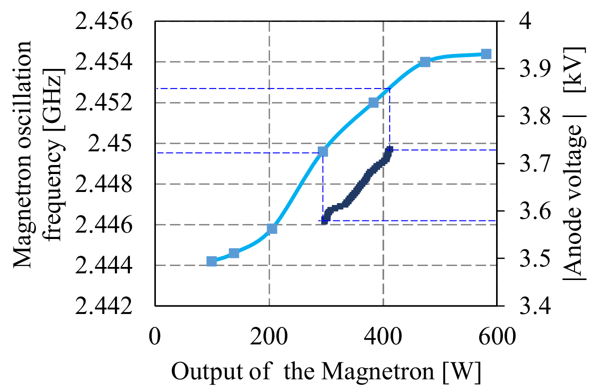

Figure 5. Characteristics of the magnetron (upper trace: oscillation frequency vs. output power, lower trance: anode voltage vs. output power based on the full wave voltage doubler)

level was changed, and the voltage should be kept above the magnetron oscillation voltage all the time. However, in this FSK system the magnetron worked at a ripple rate of 4.16% and the output power was changed from 300 W to 400 W. The oscillation frequency shifting f_o was 3MHz (2.4495-2.4524 GHz), and their relationships can be defined as follows:

$$f_{max} < (f_{lock} - f_o)/a$$

(If $f_{lock} < f_o$, the magnetron goes off the injection locking)

Here, a is the modulation index. To achieve a faster transmission rate, the injection power should be improved, which could also improve the locking frequency range f_{lock}, or the ripple rate should be reduced, which could reduce the oscillation frequency shifting f_o as well.

Conclusions

We demonstrated FSK data transmission by an injection-locked magnetron with a full wave voltage doubler. At 10 W injection power and 4.16% power source ripple, 2 Mbps FSK data transmission was achieved. Increasing the injection power and reducing the voltage ripple, the transmission data rate can be faster.

Acknowledgments

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