Application of the Gyrotron FU II Submillimeter Wave Radiation Source to Plasma Scattering Measurements

APPLICATION OF THE GYROTRON FU II SUBMILLIMETER WAVE RADIATION SOURCE TO PLASMA SCATTERING MEASUREMENTS

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Abstract

Gyrotron FU II has been successfully applied as a submillimeter wave radiation source to plasma scattering measurements on the Compact Helical System (CHS) in National Institute for Fusion Science (NIFS) in Japan. The gyrotron operates in a long pulse mode (the pulse width is about 600 ms) at a frequency of about 350 GHz (the corresponding wavelength is 0.85 mm). The output power is about 110 W. The output power is transmitted along a circular waveguide system and converted to a Gaussian-like beam by a quasi-optical antenna. After that, the beam is directed onto the CHS plasma and the scattered signal is detected by a homodyne detection system. The frequency and the wave number of the scattered signal are analyzed. The results suggest that a broad band low frequency (several tens to several hundreds kHz) density fluctuation is excited in the CHS plasma only during neutral beam injection (NBI) or ion cyclotron resonance (ICR) heating.

Key words: Gyrotron, Submillimeter wave, Scattering measurement, Plasma

1. Introduction

In the Research Center for Development of Far-Infrared Region in Fukui University (FIR FU), high frequency, medium power gyrotrons known as Gyrotron FU Series[1)] are being developed as millimeter to submillimeter wave sources. Up to the present time, the gyrotron series has achieved many important goals and allowed the investigation of many important subjects, namely: 1) Frequency step tunability over a wide range from 38 GHz to 889 GHz, 2) Moderately high power (from 0.1 to 10 kW), 3) High harmonic operation up to the fourth harmonic[2], 4) Study on mode competition[3] and mode cooperation[4], 5) Amplitude modulation (AM)[5] and frequency modulation (FM)[6] of the gyrotron output, 6) Stabilization of both power level and frequency[7], 7) Complete cw operation (up to 15 hours duration), 8) High purity mode operation[8] and 9) Accurate measurement of frequency by using a FIR molecular laser as a reference[9].

Such achievements have enabled us to present our gyrotrons as high-quality, frequency tunable radiation sources with stable frequencies and output power levels. The frequency stabilization $\Delta f/f$ and the frequency fluctuation levels $\delta f/f$ are below 10^{-9} and $3 \cdot 10^{-10}$, respectively. These properties allow our gyrotrons to be applied to plasma scattering measurements and to the electron spin resonance (ESR) experiments.

The Gyrotron FU II[3] has been already applied to the studies on submillimeter wave scattering on the CHS plasma.[10] Similar measurements of plasmas by using gyrotrons as radiation sources have been carried out on the WT-II tokamak in Kyoto University[11] and the TORTUS tokamak in University of Sydney.[12]

Plasma scattering measurements have been carried out as very important plasma diagnostics for tokamaks and helical devices. For example, gyrotrons[13)-15)] and CO_2 lasers[13), 16)] have been employed for the collective Thomson scattering measurements and HCN lasers[17] and other radiation sources[18), 19)] for the plasma scattering measurements.

In this paper, the plasma scattering measurements on CHS using Gyrotron FU II and the analysis of the results are described in detail.

2. Experimental devices and procedures

2-1 Gyrotron FU II

The gyrotron FU II is one of high frequency, medium power gyrotrons developed in Fukui University. In this gyrotron, as well as the other gyrotrons in the series, a narrow resonant cavity with high Q value is employed in order to achieve high separation between the cavity modes. This is particularly important for the high harmonic operation of high frequency gyrotrons.

The Gyrotrn FU II consists of a sealed-off gyrotron tube, an 8 T superconducting magnet and water-cooled gun coils. Fig. 1 is a schematic drawing of the gyrotron. The triode magnetron injection gun operates in the magnetic field generated by the gun coils. The electrons emitted from the

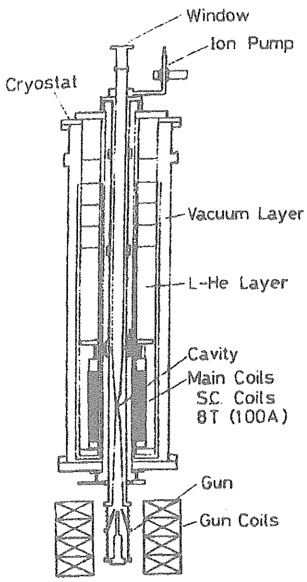


Fig. 1 The cross section of Gyrotron FU II

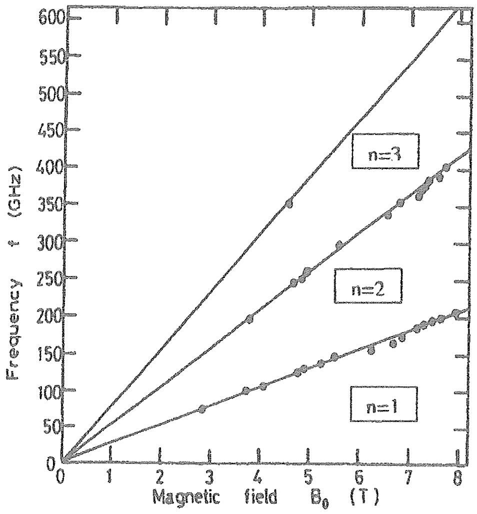


Fig. 2 All of observed frequencies as functions of magnetic field intensity. n is a harmonic number.

differences between a cathode and an anode, an anode and the body of the gyrotron which includes the resonant cavity. The rotational energy of the electrons is increased by the gradient of the magnetic field intensity till they reach the cavity. In the cavity, a part of the rotational energy is transferred to electromagnetic waves if the electron cyclotron resonance condition or a harmonic coincides with a cavity mode. The electromagnetic wave generated in the cavity travels along circular waveguide and passes through the vacuum window. By adjusting the intensity of the magnetic fields of both the superconducting magnet and the gun coils, the gyrotron can be tuned to operate in many cavity modes.

Fig. 2 shows all the frequencies observed up to the present as a function of the magnetic field intensity in the cavity region. It is seen that the gyrotron operates at the fundamental (n=1), the second harmonic (n=2) and the third harmonic (n=3) of electron cyclotron frequency. In Table 1, the results of detailed observations are summarized. All frequencies as well as corresponding field

Table 1 Observed frequency, together with corresponding magnetic field intensities, cavity modes, harmonic numbers and some of the output powers

Magnetic field B_0(T)	Frequency f(GHz)	Cavity modes	Harmonic number n	Output power P (kW)
2.86	76	TE_{011}	1	5.46
3.75	104	TE_{411}	1	
3.81	200	TE_{031}	2	
4.09	107	TE_{121}	1	
4.67	247	TE_{431}	2	
4.77	125	TE_{511}	1	
4.86	252	TE_{721}	2	
4.88	259	TE_{241}	2	
4.93	131	TE_{221}	1	
4.93	263	TE_{041}	2	
5.25	138	TE_{021}	1	10.08
5.52	150	TE_{611}	1	
5.54	299	TE_{631}	2	
6.23	155	TE_{321}	1	
6.56	336	TE_{541}	2	
6.68	165	TE_{131}	1	
6.84	172	TE_{711}	1	
6.84	354	TE_{161}	2	0.92
7.16	183	TE_{421}	1	
7.16	363	TE_{641}	2	
7.25	372	TE_{931}	2	
7.28	192	TE_{811}	1	
7.32	377	TE_{451}	2	
7.41	383	TE_{261}	2	1.4
7.45	195	TE_{231}	1	9.8
7.61	388	TE_{061}	2	
7.62	200	TE_{031}	1	
7.83	402	TE_{551}	2	
7.92	208	TE_{521}	1	

intensities, cavity modes, harmonic numbers and some of the output powers are listed. The operations are in short pulse. When these measurements were obtained, Gyrotron FU II was delivering short pulses, less than 1 millisecond.

We used the TE_{161} cavity mode at the second harmonic (n=2) resonance for our plasma scattering measurements. The frequency is 354 GHz (the corresponding wavelength is 0.85 mm). For the application, we turned to long pulse operation. The pulse width was about 600 ms, the output power was 110 watt, the electron beam energy was 28 keV and the current was 300 mA. Fig. 3 shows the results. This pulse length and the output power are both sufficient for plasma scattering measurements.

2-2 The plasma scattering measurement system

Fig. 4 shows a top view of CHS and the installation of the measurement system including the gyrotron. As seen in the figure, are installed the neutral beam injection system (NBI), the electron cyclotron heating system (ECH) at the frequency of 28 GHz and 56 GHz, many measurement instruments, for example, the Thomson scattering measurement system, an HCN laser interferometer, a soft X-ray array. Fig. 5 is the schematic of a block diagram of the scattering measurement system. The output power of the gyrotron is transmitted by a cylindrical waveguide system and converted to a Gaussian-like beam. It is injected into the plasma region of CHS. The scattered signal is picked up by a horn antenna installed inside the plasma vessel and analyzed by a homodyne detection system. The scattering angle θ is kept at 8.8 degree. The frequency spectra of the scattered signal are observed on the spectrum analyzer. The analyzer is scanned from 0 to 1 MHz in the time interval of 20 millisecond. One spectrum after another appears on the analyzer. The corresponding wave number of scattered wave is about 11 cm^{1}, when the frequency of incident wave is 354 GHz (the corresponding wave number is about 74 cm^{-1}).

3. Experimental results and considerations

Fig. 6 shows the time evolution of observed frequency spectra of thescattered signal. Shortly after the beginning of the gyrotron pulse, the plasma is fired by the electron cyclotron heating (ECH) and then heated by the neutral beam injection (NBI). Each spectrum appears in the time interval of 20 milliseconds. During the NBI heating (t=26~126 ms), broadening of the spectrum occurs in the frequency range of several hundred kHz. Before and after the NBI pulse, no such broadening is observed. We consider that this frequency broadening results from the density fluctuation due to the excitation of a drift wave instability.

Fig. 7 shows two frequency spectra of scattered signal in more detail. At the time of 65 ms, a maximum of the spectrum is seen near 160 kHz, while at the time of 105 ms, it has disappeared. The electron temperatures at the times are

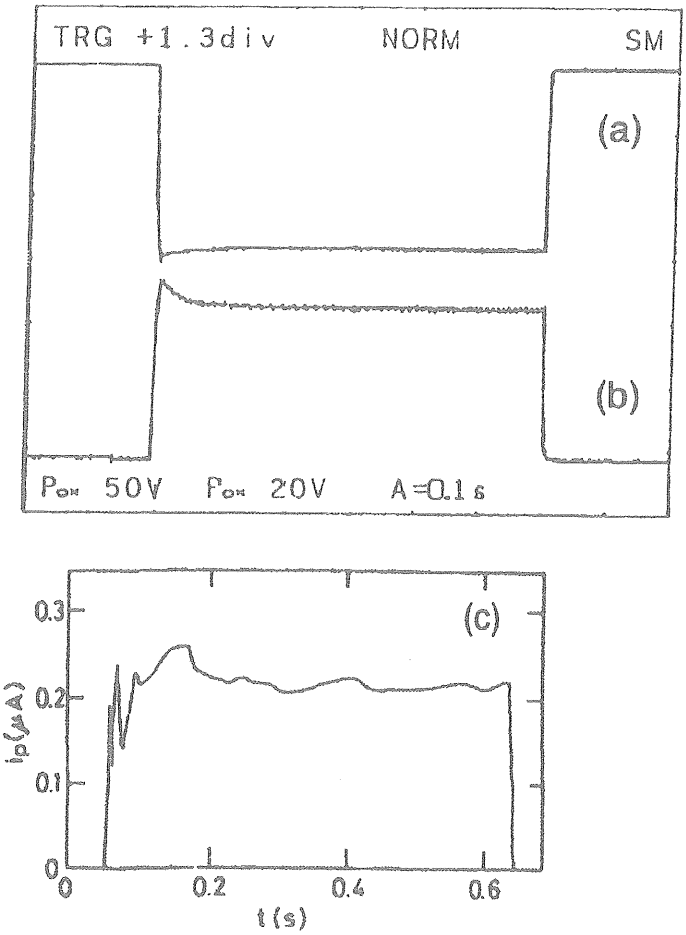


Fig. 3 Result of long pulse operation of Gyrotron FU II. (a) electron beam energy, (b) electron beam current and (c) Output power.

280 and 160 eV, respectively. The drift wave frequency estimated in the first case is about 330 kHz. Following these experimental results and considerations, the scattering signal is possibly explained as a manifestation of the spontaneous excitation of a drift wave instability in CHS during NBI heating.

A similar scattering measurement was carried out on the CHS plasma during

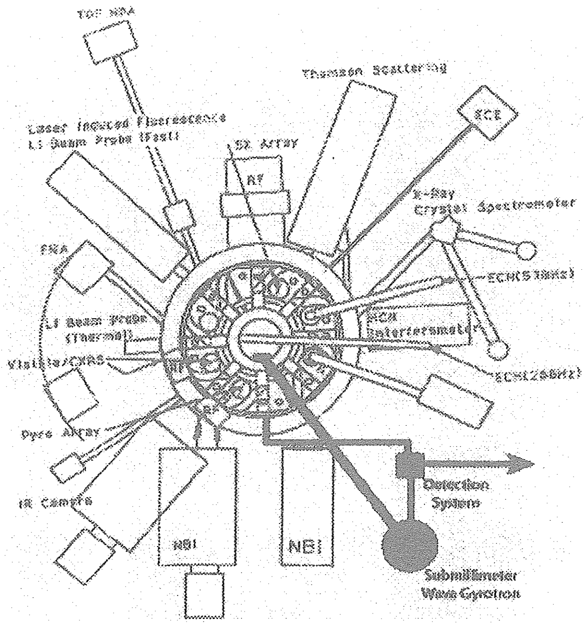


Fig. 4 The top view of CHS

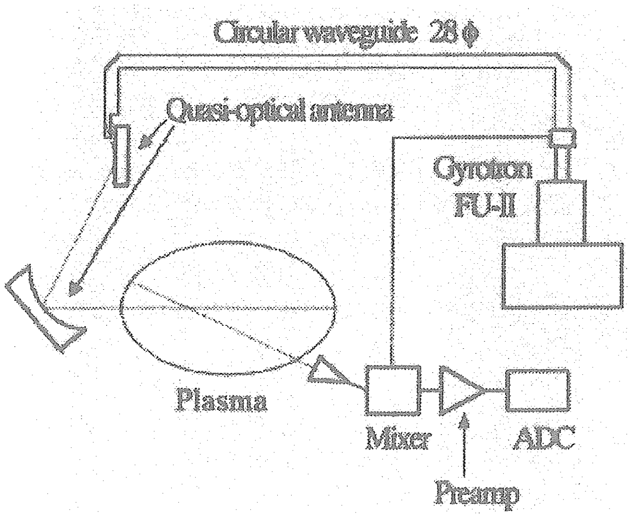


Fig. 5 Block diagram of scattering measurement system

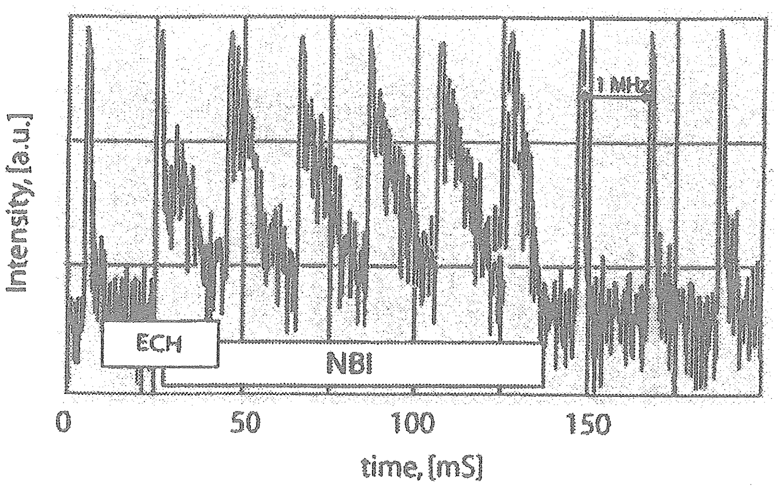
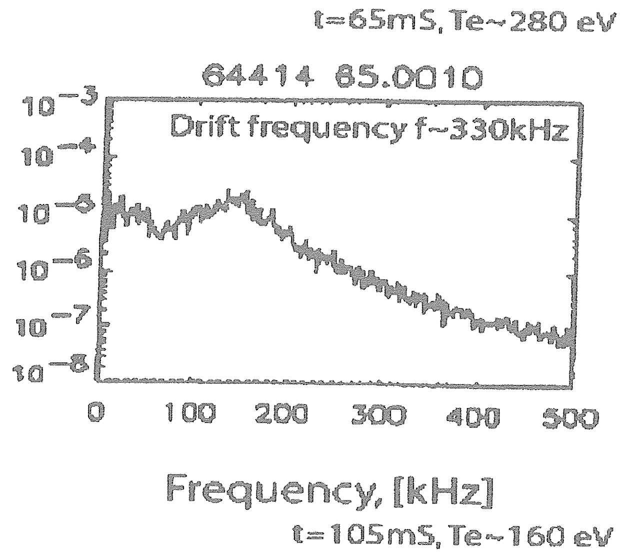


Fig. 6 Time evolution of observed frequency spectra for scattered signal

ICR heating. Fig. 8 shows a typical result. The properties of the incident wave were the same as in the previous case for NBI heating. In Fig. 8 (a), are shown time evolutions of scattered wave powers included in the respective frequency intervals indicated in the figure. The plasma is fired by ECH. ICR heating begins at the time of 60 ms. It is seen that the power of scattered wave increases with time and reaches higher level by about one order afler about 30 ms. It seems that the density fluctuation due to the excitation of drift wave instability occurs during ICR heating.

Fig. 8 (b) shows the signals observed by 39 GHz microwave reflectometry made at the same time. In this reflection measurement, the density fluctuation at the cutoff layer corresponding to the microwave frequency is observed directly. The features of time evolutions in the three frequency intervals are similar to those shown in Fig. 8 (a), which supports the results obtained by the plasma scattering measurements.



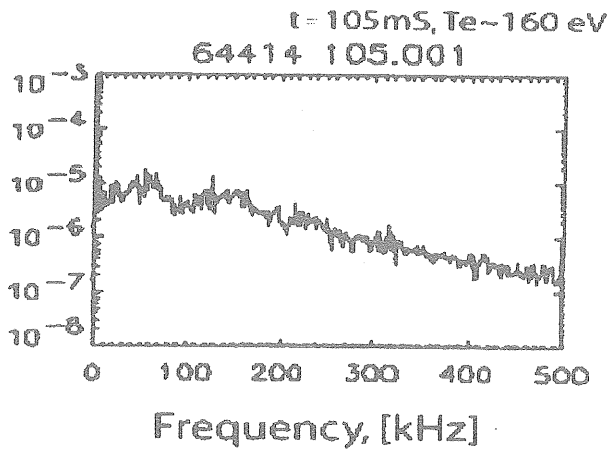
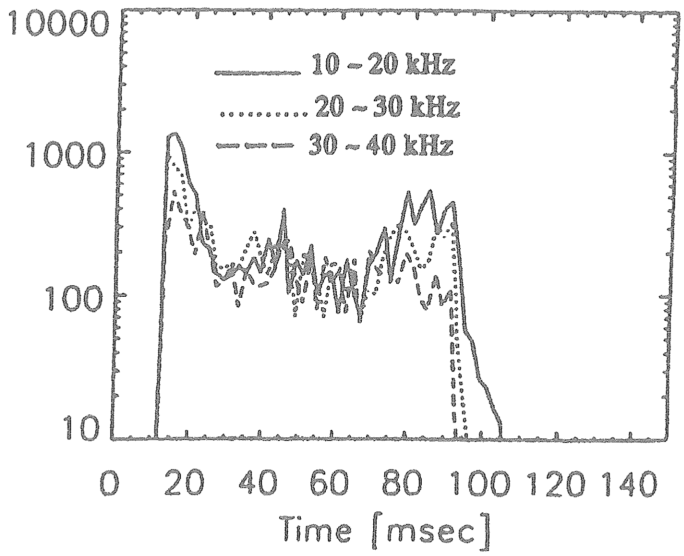


Fig. 7 Frequency spectra of scattered signal. Time t=65 ms (left hand side) and (b) t= 105 ms (right hand side).

(a)



(b)

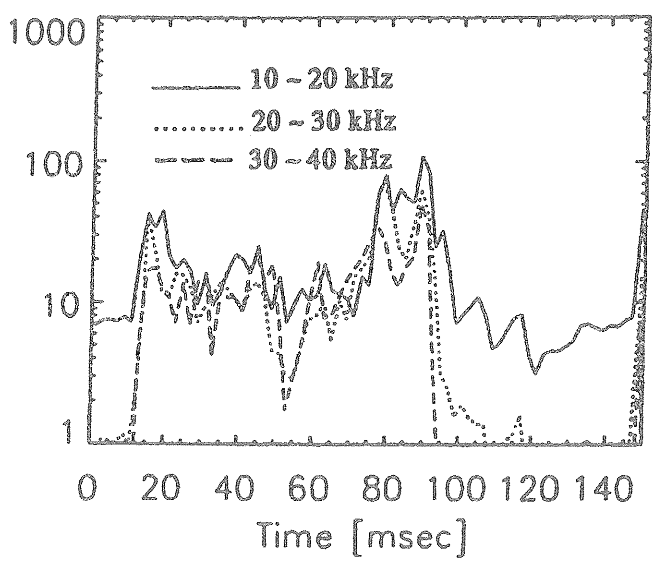


Fig.8 Time evolution of (a) scattered wave power and (b) signal of reflectmetry at the frequency of 39 GHz.

4. Conclusion

One of high frequency, medium power gyrotrons developed in Fukui University, Gyrotron FU II has been applied to plasma scattering measurements on CHS in NIFS. The operational parameters of the gyrotron were improved for the application. The pulse length was extended to 600 ms by keeping the output power at 110 watt. These parameters are sufficient for the plasma scattering measurements.

The scattered signal from the CHS plasma was picked up by the horn antenna installed inside the plasma vessel and analyzed by a homodyne detection system. During NBI or ICR heating, the spectrum of the scattered signal in the frequency range from several tens to several hundred kHz was observed. The feature that appears during NBI or ICR heating is possibly explained as the manifestation of a drift wave instability in CHS.

Drift wave instabilities are undesirable for the good confinement of plasma. Therefore, studies of the effects of the instabilities on plasma confinement by the use of the submillimeter wave scattering measurement are important.

Acknowledgement

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