LONG PULSE 95 GHz GYROTRON WITH ROOM TEMPERATURE SOLENOID

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Abstract

95 GHz gyrotrons are usually based on superconducting magnets, which limits the applicability of these gyrotrons to laboratories with the supportive auxiliary equipment. There are gyrotrons with regular magnets, but these are limited to either lower frequencies (~30-40 GHz) or short pulses. Few solutions for CW operation of 95GHz gyrotrons were suggested, but there are no publications on operational devices. In this work a 95GHz gyrotron that is based on a copper magnet is presented. The magnet is water cooled and capable of continuous operation. The gyrotron was built and operated, results of up to 10 s operation of the magnet and the gyrotron are obtained. A ~1.8T magnetic field is produced in a stable manner after a 0.3 s rise time. While a constant magnetic field is maintained, the electron gun is operated and 95GHz radiation is obtained. The radiation is obtained in both relatively long pulses and in a repetitive manner. The pulse duration and the radiation duty cycle of the gyrotron are currently limited by the power supply and the capability of the uncooled collector to absorb power and not by the magnetic field. The experimental results as well as possible applications are presented.

Introduction

Gyrotrons[1-3] are used for the generation of high power millimeter waves. Their operation is based on a cavity with an annular electron beam guided by a magnetic field. The output frequency of the gyrotron corresponds to the angular rotation of the electrons. Therefore, higher operating frequencies require greater magnetic fields. One approximation for the operation frequency is (in GHz) $f \sim s \times 28 \times B$ (s is the harmonic index, B is the magnetic field in T). Millimeter wave gyrotrons that operate in CW, long pulses, or high repetition rate of short pulses for long durations are usually based on a superconducting magnet. The superconducting magnet requires cryogenic cooling that results is many hours of turn on time for the magnet. When the superconducting magnet is cooled, it is not turned off and kept operative because of the long initial cooling procedure. The power consumption of cryogenic cooling can reach a steady state value of a few kilowatts.

In previous works, a 95GHz gyrotron was built based on a ferro-electric cathode[4] working at the fundamental cyclotron harmonic with a radiation pulse duration of 0.5µs. A thermionic version was also designed and experimentally tested[5] at first cyclotron harmonic with a typical radiation pulse duration of 10µs. Both of those gyrotrons operated with pulsed copper solenoids at a repetition rate of ~2 pulses per minute. In light of these previous works a second harmonic gyrotron with a water cooled DC solenoid was designed[6,7].

The implementation and operation of a 95GHz gyrotron with a water cooled copper magnet is presented in this work, together with radiation observation both with diagnostic setup based on radiation detector as well as with the use of a thermal target responsive to accumulated energy.

Experimental setup

The electron gun of the gyrotron was a magnetron injection gun (MIG) with triode configuration based on a thermionic cathode, operated at -40kV. The resonator diameter is designed to fit a cylindrical TE02 mode at 95GHz, and its length is designed for a single longitudinal half-wavelength. The resonator was placed inside a water-cooled DC solenoid[8] made of copper, producing a magnetic field of ~1.8T, with longitudinal homogeneity[9] of ~0.5%. The solenoid power consumption is 18kW. It has immediate turn on time, operates with a DC current of ~ 700A, and requires cooling only when it is turned on. The electron current is measured by a Rogowski coil at the collector. The system is pumped to $\sim 1*10^{-8}$ mbar with an ion pump. The generated mm wave was guided through a straight collector and sapphire window out of the gyrotron. The gyrotron with the DC solenoid is presented in Fig. 1. The output power was measured by an oscilloscope using a diagnostic setup based on a receiving chain placed in front of the gyrotron[10].

Fig. 1: The 95 GHz gyrotron.

During a later stage, the diagnostic setup was removed and a mode converter was connected to the gyrotron output. The mode converter converts the TE02 mode to a TE01 mode[11] and feeds a dual reflector focusing antenna[12] (Fig. 2). A directional coupler was used to monitor the radiated power. A target was placed in front of the antenna to absorb the radiation. A thermal camera was used to monitor the target and detect the temperature change.

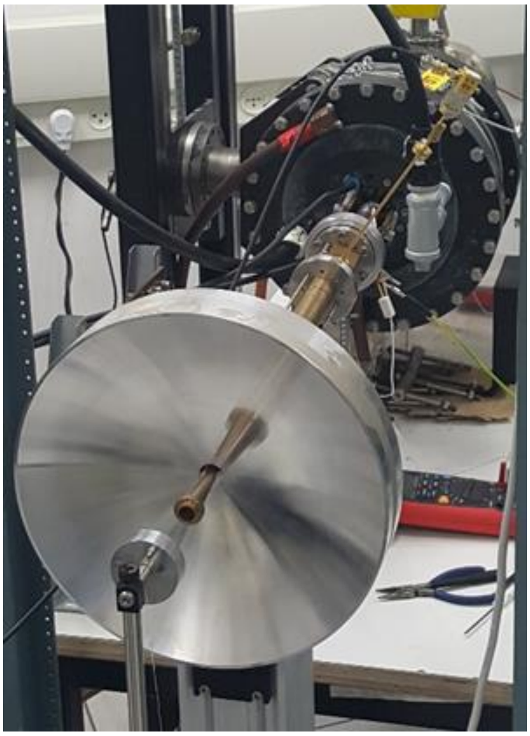

Fig. 2: The 95 GHz gyrotron connected to a mode convertor and a dual reflector focusing antenna.

Experimental results

The measurements of the output power emitted by the gyrotron are presented in Fig. 3. A single pulse of 100μs is presented in Fig. 3a. As can be seen, a sharp square pulse is measured. The power during the pulse is ~ 5kW. The limitation of the pulse duration is mainly due to the limited power of the power supply. It can deliver only 0.6A while the beam requires 1A as seen. Therefore, extending the duration would cause a voltage drop and the tuning would be lost. If the beam is discontinued, however, the power supply voltage recovers and another pulse is possible since the magnetic field is stable. This action is seen in Figs. 3b and 3c. The cathode is operated in a repetitive manner and a train of 100μs is obtained during 6 s at Fig. 3b and 9 s in Fig. 3b. As seen, the pulses are stable which reflects the stability of the magnetic field during the entire operation. In these long term operations the uncooled collector heats up. Therefore the duration of this mode is also limited in order t avoid damage to the collector.

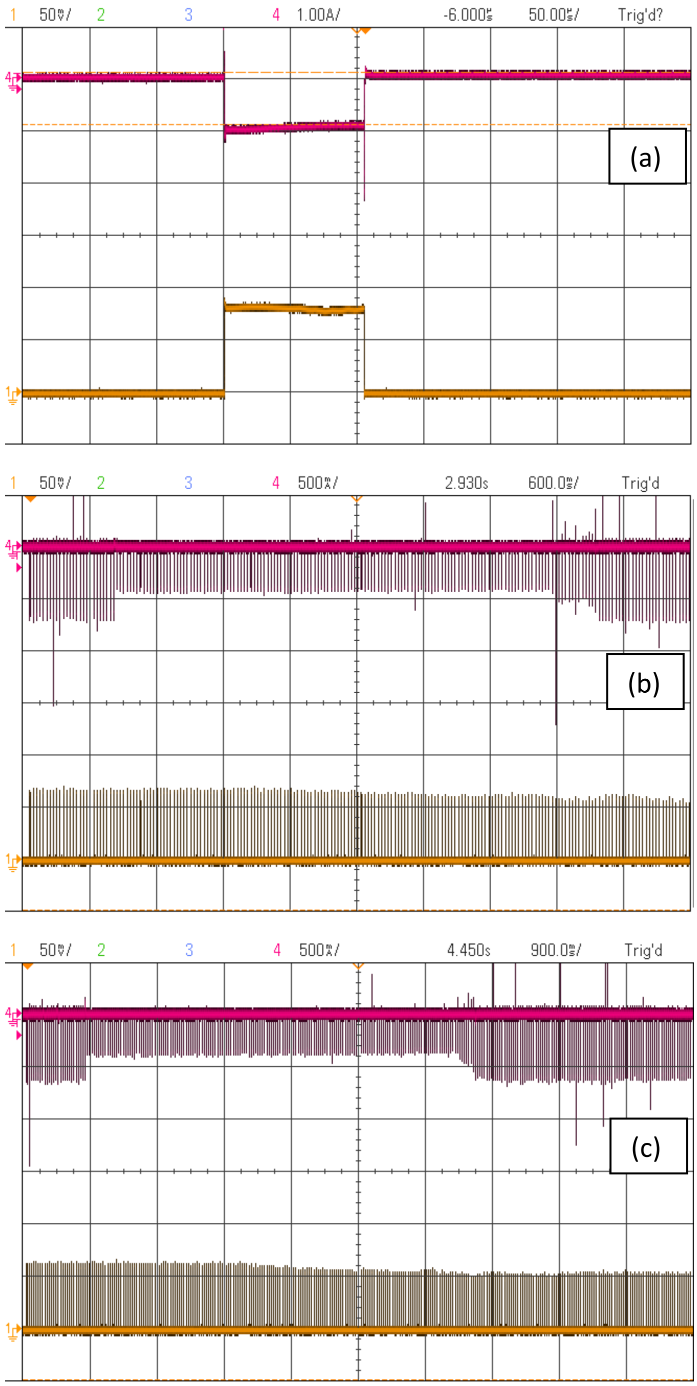

Fig. 3: Radiation results of the gyrotron. The upper curve is the current (1A/div) and the lower curve is the detector voltage (mV/div). (a) a single pulse of ~100µs. (b) a repetitive operation of 6 s, of pulses similar to the pulse presented in (a), and (c). a 9 s repetitive operation of the same pulses.

After the power measurements, the setup was reorganized to include the dual reflector focusing antenna. As mentioned, the gyrotron was operated in front of a target which was monitored by a thermal camera. The result is seen in Fig. 4. A clear shape of the TE01 mode is seen on the target.

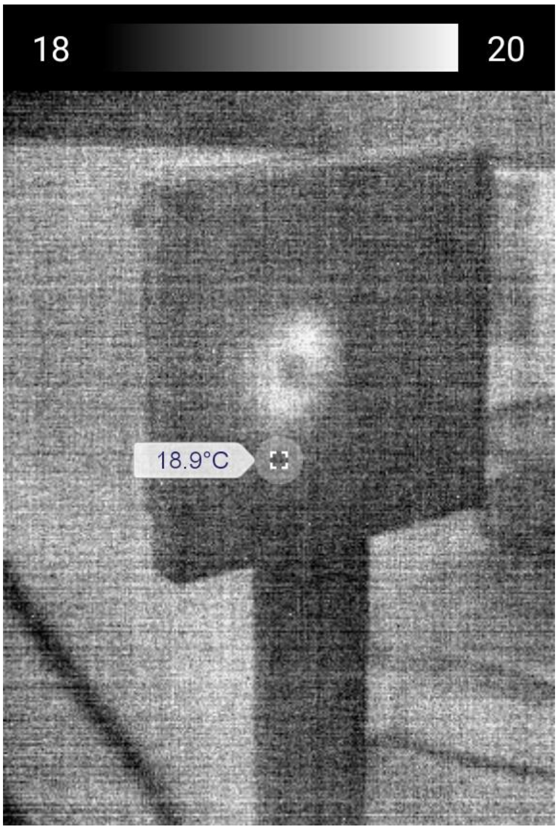

Fig. 4: A thermal image of a target. A clear heated circle is seen due to the radiation of a TE01 mode radiated on the target.

Conclusions

A compact 95 GHz gyrotron without a super conducting magnet is presented. The gyrotrons operates for long durations with repetitive pulses limited by the power supply and collector overheating, but not limited by the magnetic field. Typically, gyrotrons are more compact then other high power millimeter wave tubes such as free electron lasers[13], but still they require a cryogenic cooling system that complicates the device. On the other hand, the free electron lasers have a broad frequency tuning capability while the gyrotron's frequency is restricted by the resonator[14]. In the gyrotron presented here, only water cooling is used which simplifies the device and allows immediate operation. Also, when the gyrotron is in standby mode, it does not consume power - unlike its super conducting counterparts. These features give the presented gyrotron an important practical advantage which fits the needs of an industrial device. For a defined frequency up to 100GHz and a power level of tens of kW, such a gyrotron can be realized. Practical applications[15] can be energy remote transfer[16], industrial remote heating, sterilization, medical treatments[17], long range high resolution radars[18] and more.

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