RF Measurement Techniques For Pulsed Gyrotron

Hasina Khatun, Om Ranjan, Nalini Pareek, D Rathi, K Satyanaryan, S V Kulkarni and Anirban Bera
Microwave Devices
CSIR-Central Electronics Engineering Research Institute, Pilani, Rajasthan-333031
[1]hasina@ceeri.res.in

Abstract- **The paper presents two experimental techniques of RF measurement for high power pulsed millimeter wave gyrotron: (1) direct and (2) free space measurement. As comparison to direct, the free space measurement is cost effective and suitable only for window frequency gyrotron. For pulsed mode operation, time gated measurement is more effective and accurate. The paper also discussed the power and frequency measurement techniques of 42GHz/200kW pulsed gyrotron.**

I. INTRODUCTION

Millimeter (mm) wave gyrotrons oscillators with medium to high power and long pulse to CW used for various applications like electron cyclotron resonance heating, material processing, plasma diagnostics, radioactive material detection, etc. [1-2]. The technological and industrial applications require stable RF with single mode frequency. In gyrotron, the electron beam gyrates and accelerates under high magnetic field (few tesla) and high voltage (few tens of kV), respectively. The electron transfers its kinetic energy to over moded resonator. Thus, the output RF consists of competing modes with desire excited mode. Therefore, the most important figure of merit in evaluating the mm-wave gyrotron source includes output power deliver by the specific mode as well as the competing modes [3].

The paper discussed the different techniques for real time measurement of absolute power and frequency of pulsed gyrotron under vacuum (direct) as well as free space condition. In addition, the paper also reported the measurement techniques of recently developed 42GHz/200kW gyrotron.

II. FREQUENCY MEASUREMENT

Spectrometer is a device which gives information on the frequency content of the input signal. The spectrometer consists of heterodyne receiver or a direct receiver [4]. A heterodyne receiver shifts the spectral power density of the input signal on the frequency axis to an appropriate intermediate frequency (IF) range. The Fourier transform of the autocorrelation function will take place at the IF signal. In contrast, the direct receiver processes the input signal at its original frequency. The heterodyne receiver consists of three essential parts: the mixer, the local oscillator (LO) and the IF part. The non-linear characteristic of the mixer generates all possible multiples and combinations of the input signal frequency, f and LO signal frequency, f_{LO}, in principle at the IF port. The filters at the input of the IF port select the desired mixing signal, f_{IF} where

$$f = nf_{LO} \pm f_{IF} \qquad (1)$$

where n is an integer. The spectrometer operates within a specified bandwidth (BW) with a spectral resolution, δf. To avoid discrepancies in measurements, the changes in f_{IO} have to be less than the δf of the spectrometer. The heterodyne receiver is a cost effective spectrometer, where real time high frequency (few tens of GHz to few hundreds of GHz) can be measured by scaling down using spectrum analyzer or high end oscilloscope. In addition, the time gated measurement of the output RF signal is required to measure accurate frequency of the signal. The heterodyne receiver is triggered by the HV pulse signal and the signal is gated for the HV pulse width for accurate measurement.

In direct measurement, oversized transmission waveguide is required to propagate the output power after the window and collect in the dummy load. To measure the RF frequency, a multi-hole coupler with an attenuator and a heterodyne receiver are used in between the window and the dummy load. Whereas, the free space frequency measurement setup does not require any oversized transmission line. An antenna is placed on the line of sight to feed the output signal of the source as shown in schematic of free space measurement set-up (figure 1). Further, signal is feed into a heterodyne receiver to measure the desire frequency as well as competing frequency by changing the operational parameters like accelerating voltage and magnetic field. The above mentioned measurements procedures also help to optimize the operating parameters like accelerating voltage, beam current and magnetic field.

III. POWER MEASUREMENT

In pulsed gyrotron, the true power of the gyrotron is averaged over one period of the RF signal. The water load calorimetric technique is the oldest technique to measure power by converting RF into heat, which is determined in terms of change in temperature, time, volume and material parameters of the absorber. The disadvantage of the technique is unable to measure the output power of short-pulse gyrotron system due to long thermal time constants of the calorimetric instruments. In direct measurement, the coupler-based technique gives accurate and real time power. A single-mode waveguide is required to couple a portion of the power from oversized transmission line between the gyrotron and the load. The calibrated single-mode waveguide with attenuator is connected to a detector to determine the absolute power.

For free space measurement, calibrated attenuator with detector placed on the line of sight of output signal and within few tens of centimeter distance to measure the power. Alternatively, for free space measurement, a surface calorimeter, which is originally used for laser power measurement, can be placed on the line of sight to measure the power [5]. The response time of the surface calorimeter is within few seconds. The surface calorimeter measures the temperature difference of thermal sensors embedded within it and converts this difference to energy.

IV. Characterization of 42GHz/200kW Gyrotron

The testing of 42GHz/200kW gyrotron was carried out in pulsed mode i.e. 500μs. Figure 2 shows the schematic of RF power and frequency measurement of 42GHz gyrotron. A multi-hole coupler and a single-hole coupler were inserted in between the dummy load and window. The small fraction of the output power was coupled to the calibrated coupler to estimates the generated microwave power and frequency. For power measurement, the sampled power was feed into a diode detector through an attenuator (10dB attenuation). At 51 kV and 13 A, the detected power was 125kW. A 20 dB attenuator was used to measure the frequency by using mixer and spectrum analyzer.

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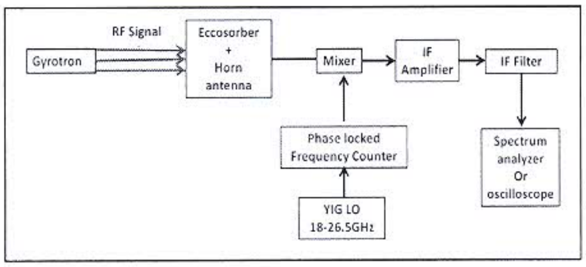

Figure 1. Schematic of free space frequency measurement set-up

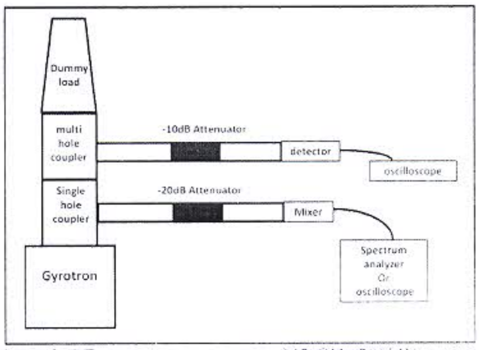

Figure 2 RF measurement set-up of 42 GHz 200kW gyrotron