N-9

RECTANGULAR CAVITY HIGH HARMONIC GYROTRON AMPLIFIER

Altan M. Ferendeci
EEAP Department
Case Western Reserve University
Cleveland, Ohio 44106

ABSTRACT

A gyrotron amplifier operating at the higher harmonics of the cyclotron frequency using a slotted rectangular waveguide is described. Axial grooves on the upper wall of the cavity allows strong interaction of the electrons with the electromagnetic fields. π and 2π modes of the cavity are analyzed for mode competition and optimum interaction.

INTRODUCTION

Gyrotrons are now considered as powerful oscillators and amplifiers at millimeter wavelengths. Theoretical analysis /1/2/ and experimental results /3/ showed that the gyrotrons are highly efficient devices when operated at the fundamental cyclotron frequency of the electrons. As the frequency is increased, it becomes necessary to use higher magnetic fields which require superconducting magnets. Higher harmonics of the cyclotron frequency can be used to reduce the magnetic field but due to the larger radius of the gyrating electrons, it becomes necessary to use oversized waveguides, increasing the problems associated with mode competition. Oversized waveguide also reduces the efficiency of the device mainly due to the weak coupling of electrons with the fields.

Experiments with the relativistic electron layers showed that there is a very large enhancement in radiation of certain modes of a cylindrical cavity when magnetron type slotted waveguide is used for the interaction region /4/. Following these results, a low field circular magnetron type "gyromagnetron" device using a pencil type electron beam inside a slotted circular guide is proposed /5/. The device configuration is suitable for tapering to increase the bandwidth, uses low operating voltages and the same port for input and output coupling. Calculations of the interaction impedance of travelling wave gyrotrons show that magnetron type slotted circuits have the highest impedance values /6/ enhancing the concepts of using grooved cavities. As the frequency of operation is increased, the physical realization of this device will be difficult due to very small circular dimensions of the electron beam and the cavity.

In this paper, a low field gyrotron amplifier using an axilly slotted rectangular waveguide and operating at higher harmonics of the cyclotron frequency is described. Possible modes of the cavity will be discussed with emphasis on π and $\pi 2$ modes. Reduced mode competititon and possible coupling schemes will also be explained.

DESCRIPTION OF THE DEVICE

Figure 1a shows the essential parts of the proposed gyrotron amplifier. It consists of a planar sheet of electrons and an axilly slotted rectangular waveguide. The cross section of the waveguide and the associated dimensions of the electron sheet is shown in Fig. 1b. The external magnetic field is in the axial direction.

The cavity consists of N grooves equally spaced at the upper wall of the waveguide cavity. The electron beam has a thickness of $2\rho_L$ where ρ_L is the larmor radius of the electrons. The width of the electron sheet and the number of grooves are determined by the selected mode of operation of the device. The input signal coupling is through the bottom wall incorporating an array of cross-guide couplers. A similar port is located at the output end for extracting the amplified signal. Exit end of the cavity can also be used for input and output coupling as suggested for the cylindrical gyromonotron /5/. This type of coupling would also allow grooving of the lower wall of the cavity to further enhance the coupling of the electron beam with electromagnetic fields.

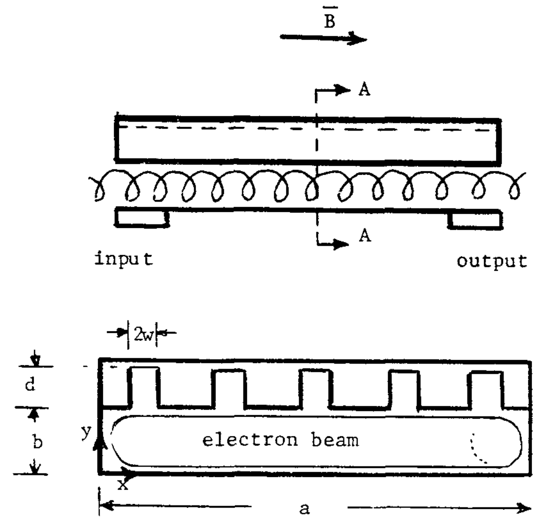

Fig. 1 a) Gyrotron amplifier
b) Transverse cross section AA (N=5)

CAVITY FIELD CONFIGURATION

To calculate the modes of the cavity, the TE fields inside the cavity are expanded in terms of the normal modes using rectangular coordinates. In addition to the usual boundary conditions at $x = 0$, $x = a$ and $y = 0$, the electric field in the x direction is assumed to have the variation shown in Fig. 2 at $y = b$.

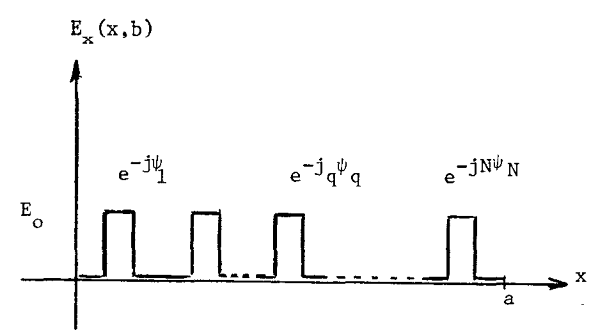

Fig. 2 $E_x(x,y)$ at $y = b$

The constant magnitude E_o is determined by the width and height of the grooves and the arbitrary phase ψ_q is introduced to take into account the possible phase variation of E_o at different groove locations.

The electromagnetic fields are:

In Region I

$$H_z = \sum_{n=-\infty}^{\infty} B_n \cos(\frac{n\pi}{a}x)\cos(k_{yn}y)e^{j\omega t}$$

$$E_x = \sum_{-\infty}^{\infty} \frac{j\omega\mu k_{yn}}{p^2} B_n \cos(\frac{n\pi}{a} x)\sin(k_{yn})y)e^{j\omega t}$$

$$E_y = \sum_{-\infty}^{\infty} \frac{-j\omega\mu}{p^2}(\frac{n\pi}{a}) B_n \sin(\frac{n\pi}{a} x)\cos(k_{yn}y)e^{j\omega t}$$

Region II

$$E_x = \frac{E_o \sin[k(d+b-y)]}{\sin(kd)} e^{-jq\psi_q} e^{j\omega t}$$

$$E_y = 0$$

$$H_z = \frac{jp^2 E_o}{\omega\mu k \sin(kd)} \cos k[(d+b-y)]e^{-jq\psi_q} e^{j\omega t}$$

From the assumed boundary conditions at y = b, we find

$$B_n = \frac{p^2(\sum')}{j\omega\mu k_{yn}\sin(k_{yn}b)} \frac{4E_o}{n\pi} \sin(\frac{n\pi}{a} w)$$

$$n = \begin{cases} 2mN \text{ for } \psi_q = 2\pi \\ (2m+1)N \text{ for } \psi_q = \pi \end{cases}$$

Here

$$(\sum') = \sum_{q=1}^{N} \cos[\frac{n\pi(q-1)}{2N}] e^{-jq\psi_q}$$

And

$$(\frac{n\pi}{a})^2 + k_{yn}^2 = k^2 = p^2$$

From the continuity of the average magnetic field at y=b, we find the dispersion relation for 2π mode

$$-\sum \frac{4aN}{(n\pi)^2} \sin^2(\frac{n\pi}{a} w) \frac{\cos(k_{yn}b)}{k_{yn}} = \frac{\cos(kd)}{k}$$

A plot of this equation will give the cut-off frequencies of the various TE modes inside the cold cavity.

Resultant modes of the cavity are determined by the choice of ψ_q. The two modes that will very effectively interact with the electron sheet are the "π-mode" and "2π-mode" as shown in Fig. 3. These lowest order modes correspond to phase differences of $\psi_q = \pi$ or $\psi_q = 2\pi$ respectively between the adjacent grooves. The number of grooves for both of these modes can be either odd or even.

Interaction of the mildly relativistic electrons with the cavity fields will be analyzed using the equations of motion for the electrons and the vacuum fields of the cavity. Calculations similar to the nonlinear analysis of electron motion in over-moded gyrotron devices /7/ will be made for evaluating the device parameters of the gyrotron amplifier.

CONCLUSIONS

The gyrotron device, proposed in this paper, incorporating a slotted rectangular waveguide can be considered to be the rectangular counterpart to the cylindrical gyromonotron and N peniotrons /8/ connected in parallel. The sheet of electrons dispenses with the pencil-type electron beam used in the above devices and increases the number of interacting electrons with increased power output. The operating voltage of the device is low and mode competition is minimized by choosing odd number of slots. There are separate ports for

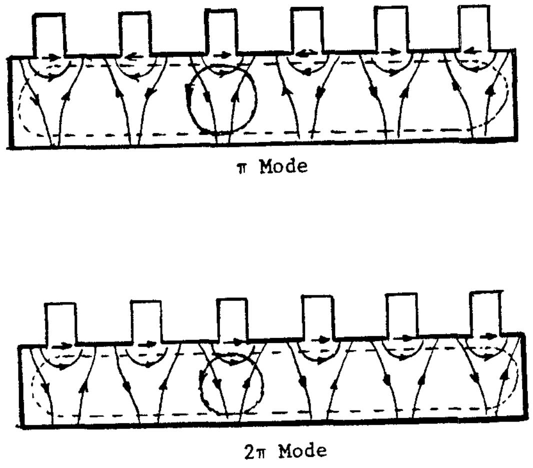

Fig. 3 - Lowest order π and 2π modes of the cavity

input and output signal coupling. If higher bandwidth is desired, the cavity may also be tapered in the axial direction with appropriate magnetic field tapering.

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