ANALYTIC THEORY OF THEGYROTRON

by

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Abstract

An analytic theory is derived for a gyrotron operating in the linear gain regime. The gyrotron is a coherent source of microwave and millimeter wave radiation based on an electron beam emitting at cyclotron resonance $\Omega$ in a strong, uniform magnetic field. Relativistic equations of motion and first order perturbation theory are used. Results are obtained in both laboratory and normalized variables.

An expression for cavity threshold gain is derived in the linear regime. An analytic expression for the electron phase angle in momentum space shows that the effect of the RF field is to form bunches that are equal to the unperturbed transit phase plus a correction term which varies as the sine of the input phase angle. The expression for the phase angle is plotted and bunching effects in and out of phase (0 and $-\pi$) with respect to the RF field are evident for detunings leading to gain and absorption, respectively. For exact resonance, field frequency $\omega = \Omega$, a bunch also forms at a phase of $-\pi/2$. This beam yields the same energy exchange with the RF field as an unbunched, (nonrelativistic) beam.

The frequency pulling equation, $\Delta \omega / \omega_0$, as a function of detuning, field amplitude, and interaction length is also derived in the linear regime. The linear theory predicts that a gyrotron can be tuned an amount $|\Delta \omega / \omega|$$_{\text{Tot}} \equiv Q \beta_p \lambda / \beta_p \beta_L^2 L$, where $\beta_p$ ($\beta_L$) is the perpendicular (parallel) velocity divided by c, and $L$ is the interaction length.

The gain process is shown to depend explicitly on the use of the relativistic equations of motion and the variation of electron mass with beam velocity. These analytic results give a simple explanation for gain in the gyrotron that is useful to those learning about this device. It also provides a relatively simple framework for understanding the physics of the gyrotron in detail without use of numerical techniques. Some of the results derived are believed to be new, and have not been found by other, more rigorous techniques.

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