GRIDLESS IOT FOR ACCELERATOR APPLICATIONS

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Abstract

The klystron is the established microwave amplifier in accelerator driver applications, enjoying high power, gain and efficiency at saturation. Disadvantages are large size and reduced efficiency in the linear regime. The IOT, building on its success in the television broadcast market, is gaining wider acceptance as a compact, high efficiency alternative to the klystron for emerging accelerator applications. An integral component of the IOT input cavity is the control grid, which is positioned close to the cathode, not only to enhance the electric field for emission gating at the cathode surface, but also to limit the transit angle. The latter consideration constrains the operation of these devices to the lower frequency end of the microwave spectrum. Power is limited due to grid interception. Therefore, to fully exploit the benefits provided by density modulation, i.e., high efficiency and compact size, without the consequent frequency, power, and gain limitations, an emission gating method that does not rely on a closely spaced control grid is required. The solution is the Vector amplifier, a gridless IOT based on L-3's trajectory modulation technique. This device provides an alternative compact, low cost RF source for the ILC.

INTRODUCTION

Microwave vacuum tube amplifiers use either velocity or density modulation to establish an AC current in an electron beam which is subsequently converted to RF energy at the output of the device. Velocity modulated devices enjoy the advantages of high gain and high efficiency at saturation. However, in the linear region of operation, a significant portion of the DC beam power is not converted to RF power, compromising efficiency. Also, the circuit length required to translate velocity to current modulation is often substantial, especially in low frequency applications. Density modulated devices employ RF gating of the electron flow directly at the cathode surface, making them considerably shorter than their velocity modulated counterparts. Additionally, because electron emission is controlled by the RF drive level, a high degree of efficiency is retained, even in the linear region. This characteristic has motivated the replacement of klystrons by IOTs for UHF television broadcast. IOTs are increasingly popular in Energy Recovery Linacs. RF gating the electron emission is usually accomplished via an input cavity structure with a high electric field region situated between the cathode surface and a control grid. The gain is limited because a substantial amount of input power is required to develop an electric field sufficient to draw a moderate amount of electron beam current. The control grid is located very close to the cathode, not only to enhance the electric field at the cathode surface, but also to limit the transit angle of the electrons. The transit angle consideration constrains the operation of these devices to the lower frequency end of the microwave spectrum. Devices that use grids for RF modulating the electron beam are also limited in power due to control grid interception. Therefore, to fully exploit the benefits provided by density modulation, i.e., high efficiency and compact size, without the consequent frequency, power, and gain limitations, an emission gating method that does not rely on a closely spaced control grid is required. Such a technique is described in this paper.

TRAJECTORY MODULATION

A novel method for RF density modulating an electron beam whereby the cathode emission and RF gating functions are separated is proposed [1]. The concept, referred to as trajectory modulation, is illustrated in Fig. 1. Electron flow is established by a conventional diode gun, from which very high current levels are readily attained. The problem of grid intercept is eliminated, allowing electron beam energies significantly greater than those achievable by IOTs. From the gun, the beam is injected into an RF input cavity, the modulator, which deflects the electron trajectories as a function of the amplitude and phase of the applied drive signal. A collection electrode, the interceptor, is placed downstream from the modulator. The interceptor has an aperture which allows only electrons that have specific trajectories to be transmitted. The result is a modulated electron beam, since the trajectories are governed by the RF drive signal applied to the modulator. Although a portion of the electron current is collected, beam energy loss is minimized by depressing the interceptor voltage below the initial beam potential. The energy of the modulated electron beam emerging from the interceptor is increased by a post accelerator. Power is then extracted by an output circuit.

TRAJECTORY MODULATION AMPLIFIERS

L-3 EDD is currently developing a trajectory modulation amplifier called the Vector-T™. The input system of an annularly configured Vector-T™ is shown schematically in Fig. 2. Integration of the electron gun, modulator and interceptor into a single resonant structure facilitates size reduction. The input resembles a ridge waveguide ring resonator, with the RF ridge fields providing the transverse interaction with the electron beam. The large annular cathode, mounted on the lower side of the cavity, provides substantial beam current when an appropriate anode voltage is applied to the ridge. The interceptor is located at the top of the cavity and depressed below anode potential. Electrons with selected trajectories pass through the aperture, effectively modulating the beam. The emitted electron bunches are post accelerated to beam powers orders of magnitude larger than those achievable in gridded density modulated devices. The low space charge forces of the annular beam enable tight bunching and high RF efficiency. A second, low voltage, power supply is required for the interceptor. Intercepted current is minimized in the Vector-T2™, which employs an interceptor with two slots to generate a pair of annular beams. These are post-accelerated and passed through an output cavity operating in the TM_{020} mode to maintain the correct phase relationship between the inner and outer beams. Careful design may allow elimination of the second power supply. The modulator cavity was modeled using the NRL / SAIC code MICHELLE 2D and the output cavity was modeled using the particle-in-cell code MAGIC 2D. Output power in excess of 10 MW is predicted at an efficiency greater than 70 percent. The unoptimized drive requirement of 6 kW corresponds to a gain of 33 dB, much higher than a conventional IOT.

CONCLUSION

The Vector-T™ gridless IOT has the potential to revolutionize the RF amplifier market. Applications include drivers for scientific accelerators and amplifiers in radar and communications systems currently using IOTs and klystrons. The initial simulations predict performance comparable to an ILC-class MBK. As seen in Fig. 3, the gridless IOT is a much smaller device. The solenoid is also greatly simplified. The Vector-T™ gridless IOT is being developed as a compact, reliable and cost-effective RF solution for the ILC with funding from L-3 EDD's Internal R&D program. The project has also been selected for an FY 2007 Phase I award under the DOE's "Accelerator Technology for International Linear Collider" SBIR topic. L-3 EDD has teamed with NumerEx of Albuquerque, NM to develop "A Novel RF Source to Drive Particle Accelerators".

REFERENCES

[1] M. F. Kirshner et al., "Apparatus and method for trajectory modulation of an electron beam," U.S. Provisional Patent Application 60/838,580, August 17, 2006.

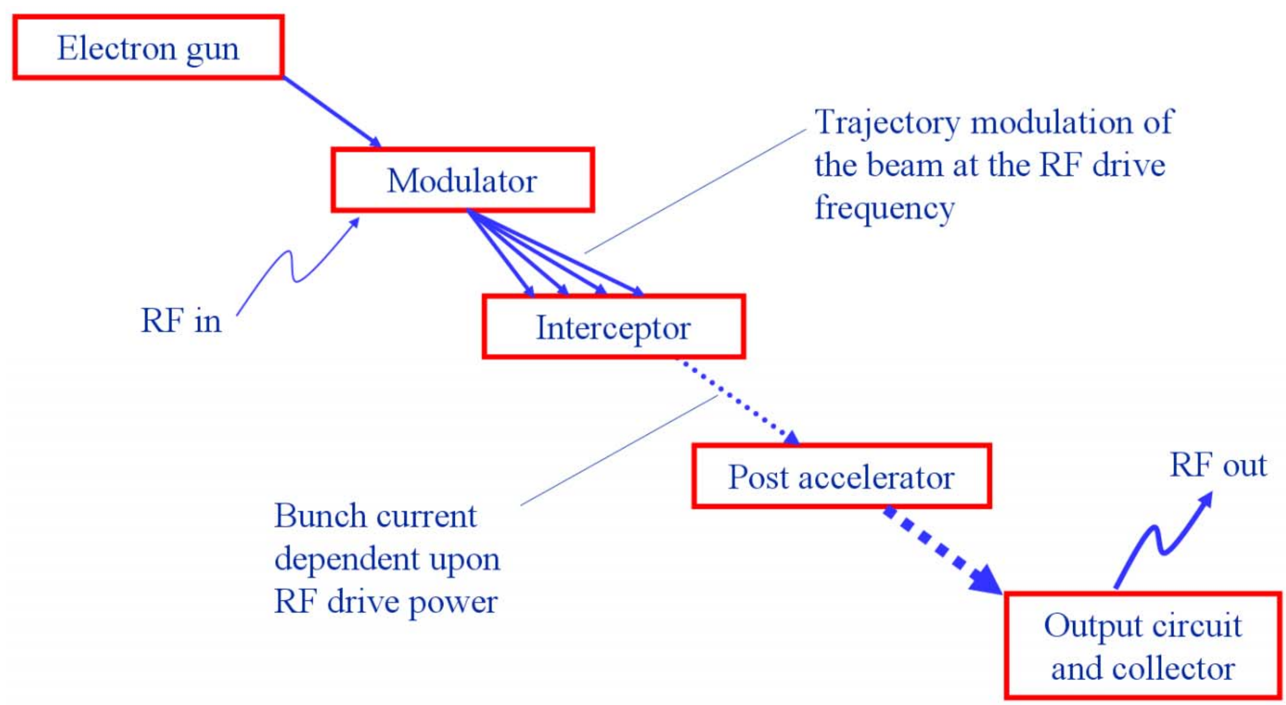

Figure 1: Conceptual layout of the trajectory modulation amplifier.

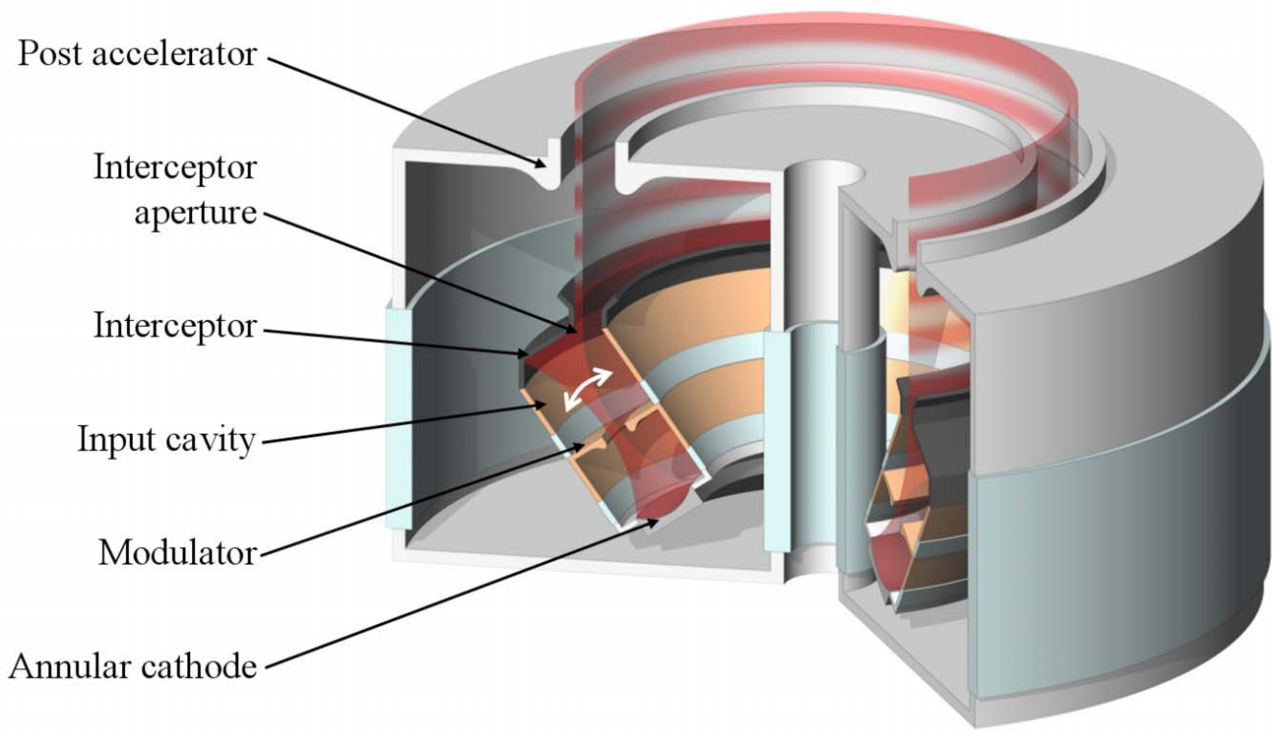

Figure 2: Schematic representation of the integrated input system for the Vector-T™ trajectory modulation amplifier.

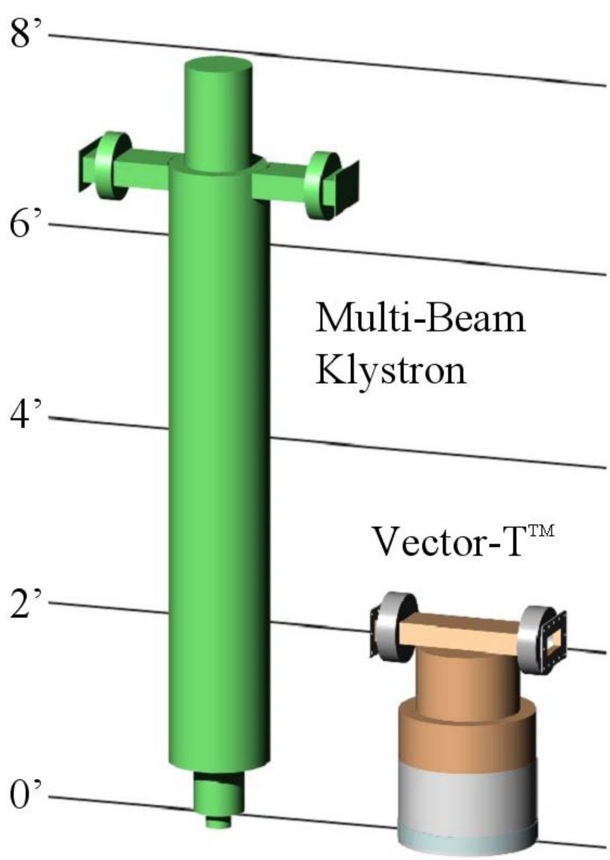

Figure 3: Comparison of approximate dimensions of an ILC-class MBK and the Vector-T™ gridless IOT.

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