Design of a Frequency Tunable 75 GHz Resonant TWT Using Serpentine Waveguides

Mikhail Fuks and Edl Schamiloglu

Department of Electrical and Computer Engineering, University of New Mexico
Albuquerque, NM 87131-0001, USA
fuks@ece.unm.edu

Abstract— **Conventional sources of sub-millimeter wavelength radiation, such as the TWT and BWO, require very small single mode electrodynamic systems in which propagation of intense electron beams is a very complicated problem. An alternative solution is to use oversized slow wave structures; however, this leads to the necessity of providing single mode interaction. The problem of mode selection in such systems is also very challenging. Above all, such a solution strongly limits the range of frequency tuning. Meanwhile, at present there are several designs of sub-millimeter wavelength sources on the basis of serpentine waveguides [1-3], which are essentially traveling wave tube amplifiers. We consider such sources to generate 75 GHz.**

Keywords-millimeter wave sources, serpentine waveguide, TWT

I. Introduction

Conventional sources of sub-millimeter wavelength radiation, such as the TWT and BWO, require very small single mode electrodynamic systems, in which propagation of intense electron beams is a very complicated problem. Many attempts at building such devices have failed because of beam interception. Meanwhile, at present there are several sub-millimeter wavelength sources on the basis of serpentine waveguides [1-3], which are basically TWT amplifiers. We describe such a source design for 75 GHz.

II. Concept of a 75 GHz Oscillator

A 75 GHz frequency tunable source with kW-level radiation using serpentine rectangular waveguide with wide wall a=3.1 mm, as in the standard WR-12 waveguide that has frequency range 60-90 GHz is described. We intend to achieve frequency tuning from 65-85 GHz using a maximal applied voltage U=25 kV that corresponds to a relative electron velocity β=0.30184. During the minimal half microwave period $\tau=f_{max}/2$=5.882 ps the electrons' path is 0.544 mm. Because of this, we choose for the narrow wall of the waveguide b = 0.5 mm. To travel a distance b = 0.5 mm for the same time τ of interaction in the same phase of the decelerated electric field electrons must change their velocity at different frequencies, which can be achieved by changing the applied voltage (Table 1). Such dependence $f(\beta)$ is likely similar to that in a BWO.

This work supported by RDMR-WSS Redstone Arsenal Contract Phase II STTR A11A-001-0471 via TechFlow Scientific, Albuquerque, New Mexico.

We choose period d of the serpentine waveguide to correspond to central frequency f_0=75 GHz from the condition that electrons will be at the same phase passing through an integer number n of periods, $d=n\beta\lambda$ (here λ is the wavelength of the operating wave). We use a periodic magnetic focusing system to guide the electrons. The minimum thickness of the neodymium ring is about Δ_*=0.8 mm (www.apexmagnets.com); therefore, accounting for the thickness Δ of the waveguide, the serpentine period must be greater than $d>b+2\Delta+\Delta_*$; that is, n = 3, d = 3 mm. The dependence $f(\beta)$ is summarized in Table 1.

TABLE I. Dependence of Frequency on Applied Voltage

f (GHz)	65	75	85
β	0.2167	0.25	0.3018
U (kV)	12.43	16.76	25.0

We choose the diameter of the holes for electron propagation as in [1], $2R_h$ = 0.7 mm. Such holes weakly change the dispersion characteristics of the serpentine rectangular waveguide $h=2\pi/\lambda_w=2\pi/\lambda\beta_{ph}=[(2\pi/\lambda)^2-(\pi/a)^2]^{0.5}$ (here λ_w is the guide wavelength and β_{ph} is the phase velocity related to the light speed of the operating TE_{01}-wave). Above all, we can use data from [1] that shows the current of electrons passing through such a hole is 0.2 A when the applied voltage is 21.5 kV. The length of this waveguide at the one period of the serpentine (from one hole to next) must be $L_d=(2m+1)\lambda_w/2$ (for integer m) in order to provide π phase shift (in this case an electron appears in the next hole in the same phase as in the previous one). Relations for d and L_d provide synchronism of electrons with the electric field. Naturally $L_d>d$. Since $\beta_{ph}=\lambda_w/\lambda$=1.3088, λ_w=5.2353 mm, we find the minimal L_d=13.088 mm (m = 2) that consists of two straight parts with each length 1.832 mm and one bend with radius $d/2$=1.5 mm and length πd=9.425 mm. The total number of periods will be found by optimizing the output power in computer simulations.

In order to achieve kW-level radiation we plan to place many such serpentine waveguides placed around a given radius, forming a peculiar kind of electrodynamic system, and to use multi-spike cathode. At the opposite end all waveguides extend up to the standard narrow dimension 1.55 mm (after passing electrons through the last hole) and open onto a coaxial transmission line, in which co-phase radiation from the open waveguides excites the symmetric TM_{01}-mode.

References

[1] G. Dohler, D. Gagne, D. Gallagher, and R. Moats, "Serpentine Waveguide TWT," *IEEE Intl. Electron Dev. Meeting* (Washington, DC, Dec. 6-9, 1987), 455-458.

[2] C.D. Joye *et al.,* "Demonstration of a High Power, Wideband 220 GHz Serpentine Waveguide Amplifier Fabricated by UV-LIGA," *Proc. IVEC 2013* (Paris, France, May 21-23, 2103), 1-2.