Design of Electron Gun and Focusing System for W-Band Folded Waveguide TWT

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Abstract
This paper presents the design of electron gun and focusing system for the W-Band Folded Waveguide Traveling wave Tube (FWTWT) using two available commercial software such as EGUN and TRAK. Pierce type electron gun with isolated beam forming electrode (BFE) and thermionic M-type dispenser cathode with 1.6mm button diameter has been opted for W-Band folded waveguide TWT under development at CSIR-CEERI. Solenoid magnet focusing has been designed to achieve electron beam focusing with controlled scalloping and ripples well within 8% and the beam waist radius less than 0.13mm.

Keywords
Folded Waveguide Traveling Wave Tube, Pierce Electron Gun, Thermionic M-type Dispenser Cathode, Solenoid focusing

1. Introduction
For this high frequency devices where the dimension becomes so small that the conventional fabrication techniques becomes impractical and MEMS/solid state device fabrication technique need to be employed, the generation and transportation electron beam becomes a critical issue. The generation of high density electron beam for microwave tube, Pierce type electron gun using thermionic dispenser cathodes are invariably used as they are unique choice for such devices but at frequencies (100 GHz and more) other planar cathodes based on field emission may be employed. The electron gun with cold emission cathodes like Field Emitter Array (FEA) and Carbon nano tubes (CNTs) would have been an appropriate choice in view of overall size of the device and micron size of the beam requirement. However as reported in the literature the development of FEA and CNT based cathodes are on laboratory scale only as no commercial FEA and CNT cathodes are available. Thus making electron gun with thermionic cathode again a only choice for vacuum microelectronics based THz (> 0.1 THz) devices.

Authors have designed a convergent type electron gun, using code EGUN [1], TRAK [2] to deliver ~40mA beam current (Io) at 13.5kV beam voltage (V0) with beam waist radius (rw) 0.125mm. The electron gun assembly consists of M-type dispenser cathode with 1.6mm button diameter, an electrically isolated BFE and ground accelerating anode. Initial estimation of gun geometry has been obtained for the desired beam parameter in terms of beam voltage, beam current, beam waist radius and cathode emission. Loading using synthesis approach [3]–[5] and gun designed is finalized through simulation with optimized BFE shape, anode-cathode axial distance and potentials with respect to cathode.

A confined flow beam focusing has been adapter and designed with solenoid magnet using code TRAK.

This paper presents an approach for the design of electron gun and of focusing structure using simulation method by using commercially available software. There are many challenges to make an electron gun and beam focusing system at such a high frequency (W-Band) that have to be addressed.

II. Design of Electron Gun
Initially electron gun has been synthesized for the desired beam parameter (V0 = 13.5kV and Io = 40mA & rw = 0.125mm) with the cathode of diameter 1.6mm and spherical radius 9.0mm. A rough estimate of gun geometrical parameter is obtained. Then a gun geometry is completed by incorporating accelerating anode and BFE with proper shape and accordingly input file for gun simulation (e.g. .pol file of EGUN) is made and desired potential are applied at the different electrodes. For instant, in this case, cathode & BFE are kept at -13.5kV and accelerating anode at zero potential. Inter electrode spacing and radial aperture dimension are optimized through simulation for the desired beam parameters along with laminarity. It takes several iterations to arrive at the optimized design. Fig. 1(a) shows the EGUN simulated (optimized) W-Band electron gun. Fig. 1(b) shows the expanded view, depicting beam laminarity and beam waist radius more clearly. Fig. 2(a) shows the TRAK simulated (optimized) electron gun. A comparison of simulated beam parameters from different software EGUN (2D), TRAK (2D) is given in Table 1.

III. Design of Solenoid Focusing
In this device an electron beam of 250 micron diameter has to pass through a beam tunnel of 400 micron having length more than 90mm. Thus this require perfect axial alignment (within 5 micron) of electron gun, rf structure and collector as well as axially aligned focusing structure which can generate magnetic field of the order of 2500 Gauss on the axis. Thus generation of magnetic field of this order by means of permanent magnet or solenoid (with a restriction of having inner diameter ~ 40mm) is a critical issue of research. This would require special design of pole piece with permanent magnet or solenoid.

Generation of axial magnetic field ~2500 Gauss through SmCo5 or SmCo17 seems to be very difficult however using Neodymium Magnet with special arrangement can be explained. Beam focusing by means of solenoid magnet has been accomplished by using a commercially available code TRAK. Fig. 2(a) shows the TRAK simulated electron gun with beam flow characteristic under the influence of the optimized axial magnetic field (see Fig. 3). The expanded view of the focused electron beam (see fig. 2(b)) shows a good laminar beam and ripples are well controlled within 5-8% and also the beam waist radius (~0.13mm) is maintained within the accepted limit.

Confined beam flow focusing is more rugged design and less sensitive to the variations of magnetic and beam parameters in comparison to brilliouin focusing [6]. The pole piece has been designed in such a way that a designed magnetic flux as per Busch’s theorem has been linked to the cathode. To start with, the authors made an attempt of focusing through solenoid.
Fig. 1(a): EGUN Simulated Electron Beam Flow

Fig. 1(b): Expanded view of EGUN Simulated Electron Beam Flow

Table 1: Comparison of Simulated Beam Parameters

<table>
<thead>
<tr>
<th>Software</th>
<th>( I_0 ) (mA)</th>
<th>( r_w ) (mm)</th>
<th>( z_w ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGUN</td>
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<td>0.125</td>
<td>17.50</td>
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<tr>
<td>TRAK</td>
<td>40.60</td>
<td>0.129</td>
<td>16.90</td>
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Fig. 2(a): TRAK Simulated Electron Beam Glow

Fig. 2(b): Expanded View of TRAK Simulated Electron Beam Flow

Peak magnetic field (BP) = 2094 G, Leakage magnetic flux = 33G

Fig. 3: Optimized Axial Magnetic Field Distribution Profile for W-Band Electron Gun

IV. Conclusion

A Pierce type convergent electron gun using thermionic dispenser cathode has been designed for W-Band FWTWT. Electrostatic design of electron gun has been accomplished using code EGUN & TRAK to obtain 40mA beam current at 13.5kV beam voltage. Beam focusing by means of solenoid magnet has been accomplished by using TRAK. Focused beam has good laminarity, ripples well within 8% and the beam waist radius ~0.13mm.

References