Parametric Study of Pin-based Gap Waveguide for Millimeter Wave Slow Wave Structures

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***Abstract*—Gap waveguides have been proposed for the design of slow wave structures (SWS) of travelling wave tubes (TWT) operating at the millimeter wave. In this paper, we consider a SWS based on a metal pin structure and top metal plate to realize the gap waveguide, loaded with a central corrugation for realizing the synchronism condition with the electron beam. Parametric studies are presented to show the impact of variation of certain critical dimensions of the SWS in order to analyze tolerances and optimization for a W-band TWT (87 - 100 GHz).**

***Index Terms*—SWS, millimeter wave TWT, gap waveguide, corrugated waveguide**

I. INTRODUCTION

Travelling wave tubes (TWTs) operating at the millimeter wave (30-300 GHz) have become of great interest in recent years, due to the need to develop high power amplifiers that are robust, easily fabricated and cost effective. Novel applications of such devices include the possibility to achieve long range wireless links at sub-THz frequencies by overcoming the power limitations found in solid-state amplifiers. Advanced slow wave structures (SWS) can be designed to integrate ease of fabrication, low cost and effective beam-wave interaction.

Novel designs of SWSs for TWTs have been proposed in the 100 - 1 THz range based on rectangular corrugated waveguides which are relatively easy to realize [1]. These are suitable for realization via CNC micromachining, LIGA (German acronym for lithography, electroplating and moulding), and deep reactive ion etching (DRIE) [1]. They have shown relatively good output power and gain when used with sheet electron beams [2].

Recently, it has been shown that electromagnetic bandgap (EBG) periodic structures can replace the metal walls of the rectangular corrugated waveguides to aid the design of sheet beam SWSs, [3], [4]. The main advantages of electromagnetic bandgap-based SWS are the inherent filtering capabilities of these structures which can be designed to support only the desired electromagnetic mode and the possibility to alleviate some of the assembly issues of conventional waveguides. In the context of EBGs, the technology of gap waveguides have emerged in latest years to aid the design of millimeter wave circuits [5], [6]. Gap waveguides are based on periodic textured surfaces which mimic the EBG properties, acting as a high impedance surface, placed parallel to a metal conductor with a gap of less than a quarter of the desired wavelength. An example of pin-based groove gap waveguide SWS is reported in [3] and [7]. Dimensions of the pins and gap with the top metal plate affect the design of the electromagnetic bandstop of this periodic structure and the dispersion of the slow wave structure mode. This paper reports a parametric study for a pin-based gap waveguide SWS designed for a W-band TWT with can assist with optimization of the electromagnetic performance and assessment of fabrication tolerance effects.

II. PARAMETRIC STUDY OF PIN-BASED GAP WAVEGUIDE SWS

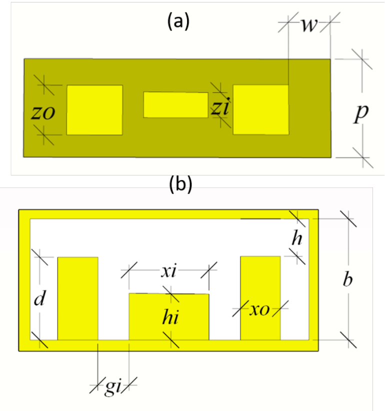

Fig. 1. Schematic of the PG-SWS. (a) Top view. (b) Front view.

TABLE I
PG-SWS DIMENSIONS

Value	Dimensions (mm)
b	1.27
xi	0.6
hi	0.46
zi	0.31
xo	0.47
zo	0.58
w	0.5

The Pin-based Gap Waveguide SWS (PG-SWS) shown in [7] is proposed to operate in the W-band (87-100 GHz), with a bandstop between 40-120 GHz. Fig. 1 shows the schematic of the SWS. The Groove Gap waveguide consists of one row of pins on each side of the central groove. A central corrugation is periodically loaded within the groove to slow down the wave and achieve synchronism with a sheet electron beam. Table 1 details the dimensions of the structure. A parametric study on the phase velocity was conducted, based on the value gi, the distance between the central corrugation and the gap waveguide pin, as shown in Fig. 2. It is shown that this dimension has an effect on the flatness of the phase velocity curve in the band of interest. Maintaining a flat phase velocity variation with frequency is crucial to maximising the beam-wave interaction and operation bandwidth of the SWS. Fig. 2 shows an optimum value for $gi = 0.39mm$ which is synchronous with an approximately 19 kV electron beam.

Fig. 3 shows the parametric study of the phase velocity with respect to the gap height. The gap gi is kept as $gi = 0.39mm$. The height of the waveguide is $b = 1.27mm$, which is the standard WR-10 value. Varying h invariably changes the height of the pin, d. It can be noted that the effect on the phase velocity from varying h is minimal. The height $h = 0.05mm$, and hence $d = 1.22mm$, is selected due to the strong influence these values have on the level of reflections found from the waveguide input/output coupler [7].

In Fig. 4 the effects of varying the period p are considered. The dispersion here is computed for $gi = 0.39mm$, $h = 0.05mm$, and $d = 1.22mm$. It can be seen that a larger period length can significantly increase the phase velocity of the SWS while reducing the mode bandwidth. The value $p = 1.1mm$ is chosen as the optimum value to compromise specifications of bandwidth, beam voltage (below 19 kV) and interaction.

The local interaction impedance is also considered to compare the effects of changes in the dimensions. Varying h has little impact on the interaction. Fig. 5 shows the interaction impedance calculated at 80 microns above the central corrugation for different values of gi. It can be noted that minimal change occurs when reducing gi, while increasing it beyond $gi = 0.39mm$ shifts the frequency band. Fig. 6 shows that increasing p can increase the interaction impedance but also creates a narrower bandwidth.

III. SCATTERING PARAMETERS

The input/output coupler design for the pin-based gap waveguide SWS is reported in [7]. The coupler section includes a taper in height for the central corrugation and a lateral taper for the side pins. The first type of taper enables the conversion between the TE$_{10}$ mode injected at the input into the hybrid mode supported by the SWS while the second widens the groove width between the pins to match standard dimensions of the WR-10. A complete input/output coupler, including the waveguide 90 degree bend and beam tunnel is considered here. Fig. 7 shows the simulated S-parameters for a 10-periods long SWS for different number of periods of the W-band groove gap waveguide included between waveguide bend and start of the central corrugation taper. The impact of reducing the length of this W-band waveguide section

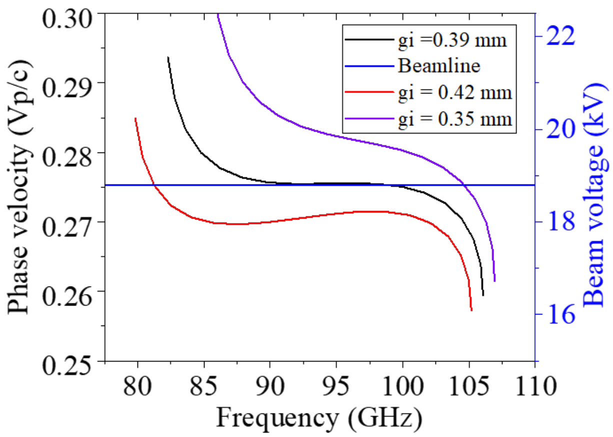

Fig. 2. Phase velocity parametric study on the value gi.

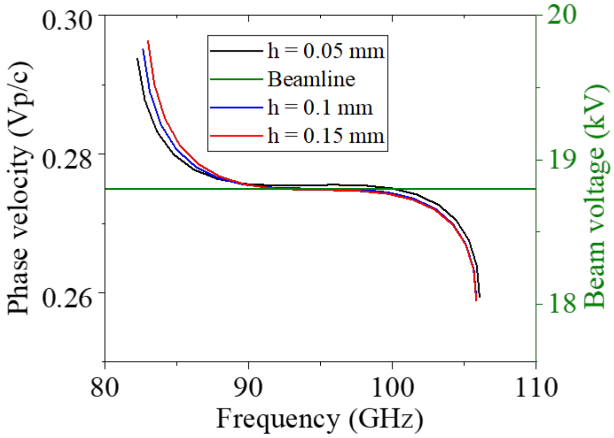

Fig. 3. Phase velocity parametric study on the value h.

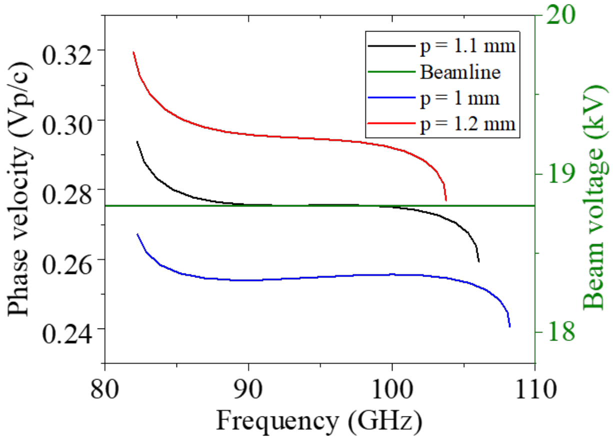

Fig. 4. Phase velocity parametric study on the value p.

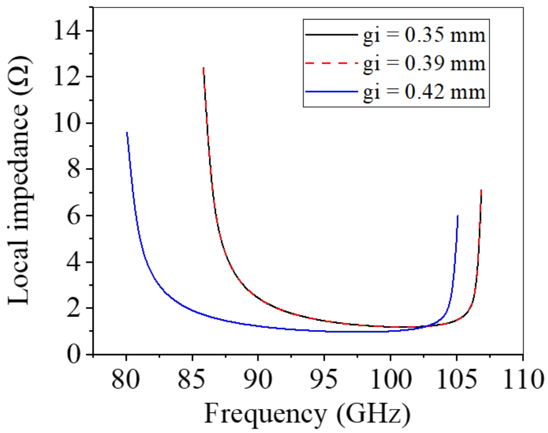

Fig. 5. Local interaction impedance parametric study on the value gi.

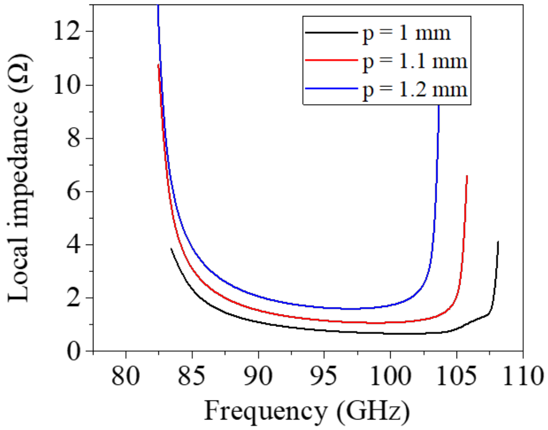

Fig. 6. Local interaction impedance parametric study on the value p.

assisted by lateral pins so that the distance between pins in the transverse direction is 2.54 mm, from 16 periods to 10 periods is shown in Fig. 7. It can be noted that a minimum of 16 periods are needed to maintain reflections below -15 dB and improve transmission of the higher frequencies in the operation band.

IV. CONCLUSION

The parametric analysis of some important design characteristics and dimensions for a pin-based gap waveguide SWS designed for a 87-100 GHz TWT is presented and discussed. Cold parameters for the proposed SWS were considered. It is found that this structure is not very sensitive to a change of gap size, while relatively small variations in the distance between central corrugation and lateral pins can lead to important effect on the propagating mode. In terms of manufacturing tolerances, this analysis suggests that dimensional accuracy approximately around 10 microns should be achieved to ensure electromagnetic performance close to the designed one. The number of straight gap waveguide periods, without any central corrugation, can also lead to important variations in the S-parameters from the input/output couplers.

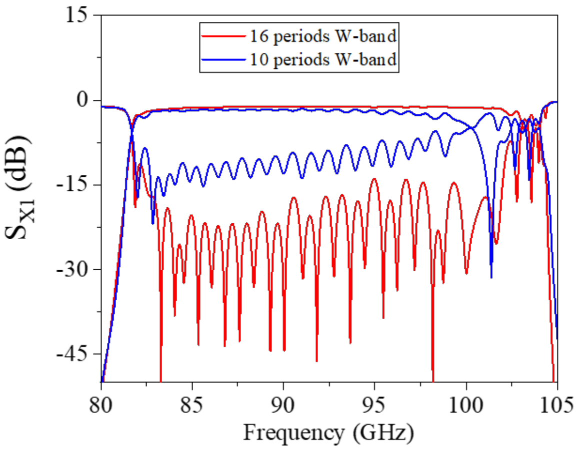

Fig. 7. Scattering parameters parametric study on using 16 period vs 10 period long sections of W-band gap waveguide at the input/output coupler bend section.

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