CAVITY DESIGN FOR A PLANAR MM-WAVE SHEET BEAM KLYSTRON

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Abstract

The design of mm-wave sheet beam klystron cavities is considered. The fundamental mode has an almost ideally flat field. This field flatness is achieved by inductive loading at the transverse ends. The cavities are suited for manufacturing with LIGA, since they are planar and of equal depth. Due to the low beam current a traveling wave output structure is needed.

1 INTRODUCTION

Since several years, electron accelerating structures at about 100 GHz are proposed [1]. One main problem is the availabiliy of a reasonable power source.

The old idea of the sheet beam klystron (SBK), Fig. 1, has been reborn for the following two reasons: On the one hand, the limitations due to space charge are alleviated. The current density and the voltage can be kept at a moderate level achieving a high total current by flattening out the beam. On the other hand, due to its planar nature, the sheet beam klystron is suited for the manufacturing methods of micromechanics, making it more reasonable.

The operating parameters of our SBK are: a beam area of 0.3 mm $\times$ 10 mm, a moderate voltage of 25 kV, a total current of 1 A, and a gun compression ratio of 10:1. The very low perveance per square of only 0.008 μP meets the focusing method with periodic permanent magnets (PPM).

The first proposals for designing sheet beam klystron cavities have been made by Yu and Wilson some years ago [2]. We attack the problem in a similar manner but draw some attention to the suitability of the cavities for the X-ray lithography (LIGA) by having only one depth.

2 GENERAL SBK CAVITY DESIGN

The basic design issue is to establish an electric field, which has a longitudinal component only and which is approximately constant in the region where the beam passes through. To prevent the cavity from having a transverse mode near the operating frequency, one easily chooses the gaplength longer than its depth. Therefore the operating mode is just the fundamental mode the frequency of which depends – in a first approximation – on the depth of the gap only. The flat field is achieved by coupling deeper or/and longer side cells strongly to the transverse ends of the gap, Fig. 2. These cells represent an inductive load parallel to the gap capacitance. In that way, the gap can be seen as a waveguide at cutoff. Hence, once flatness is established, the gapwidth can be chosen as long as desired.

Another design issue is the conventional one of having a large shunt resistance, i.e. maximum gap voltage for given dissipated average power. The three parameters remaining after fixing the frequency are the gap length, the aperture, i.e. the distance between the walls of the beam pipe, and the gap width. To reduce the transit time, one might wish to choose the gap length as short as possible. On the other hand, decreasing the gap length causes the field in the midplane to decrease. It turns out, that for maximum shunt resistance the gap length should equal the aperture. As well known from two-dimensional cavity analysis, the shunt conductivity is proportional to the gap width. Actually, the relevant cavity parameter for sheet beam applications is the shunt conductivity per (beam) width rather than the shunt conductivity itself. Hence, the width doesn't affect the performance of the cavity.

There are at least two potential problems unique for the

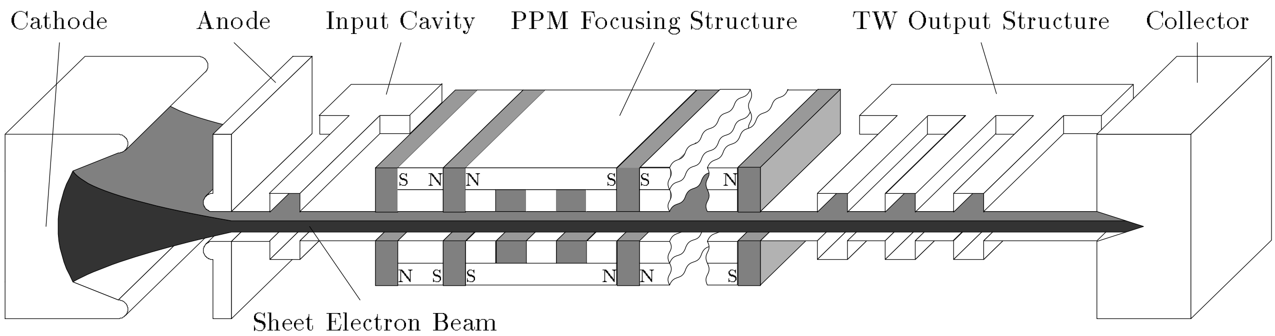

Figure 1: Schematic of the sheet beam klystron

SBK: While in a round beam klystron the beam tunnel can operate below cutoff, the beam pipe of a SBK will operated above cutoff for TE modes. Yu and Wilson [2] proposed the use of some quarter-wave choke cavities inserted in the pipe. - The other problem is the bad separation of the beam coupling TM modes of the cavity due to the field flatness. The wider the gap, the worse the separation. While for the input cavity this situation can be alleviated by a proper coupling to a waveguide, it could be unacceptable for the idler cavities. We tried to shift the higher mode frequencies by cutting slits in the cavity walls, unfortunately without success. With simulations by a PIC code, we will find out the importance of that fact later.

3 INPUT CAVITY DESIGN

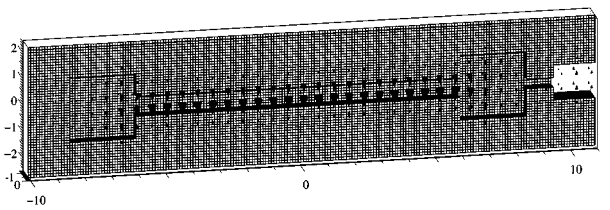

Figure 2: Coupled input cavity monochromatically excited, all dimensions in mm

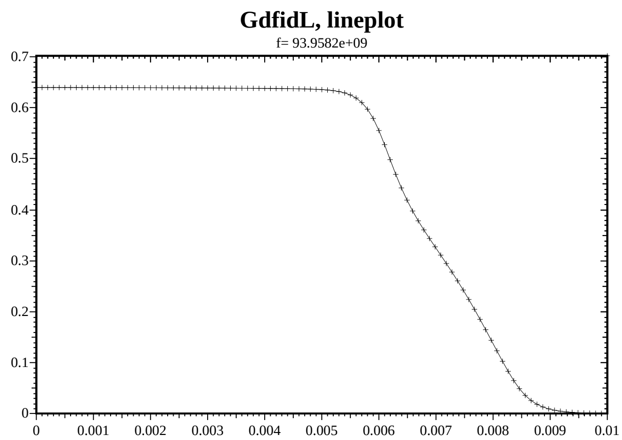

Figure 3: Longitudinal electric field over cavity width

We started the design procedure with the following parameters: a total aperture of $a = 0.8$ mm taking beam scalloping into account, a total gap width of $w = 12$ mm having a little freedom at the edges of the beam, a total gap depth of $d = c_0/2f = 1.6$ mm and two equal side cells of same depth and of quadratic cross section. In a lot of runs with the finite difference program GdfidL [3] we optimized these parameters for a flat field, Fig. 3, and the shunt resistance, where the transit time factor is included. The cavity parameters calculated with GdfidL are $f = 93.96$ GHz, $Q_0 = 2030$, $R_0/Q_0 = 2.97$ Ohms, which yields an unloaded shunt resistance of $R_0 = 4.01$ kOhms. The final geometrical cavity

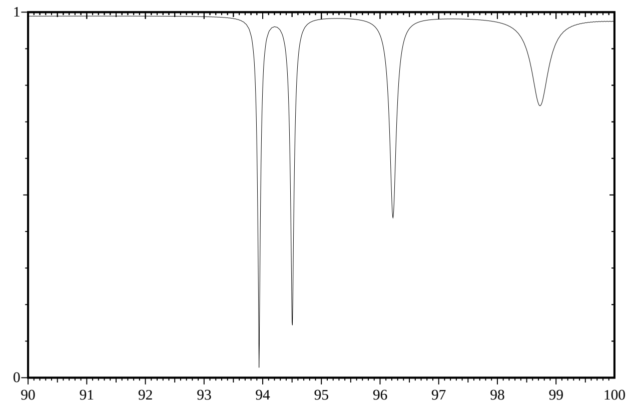

Figure 4: Reflection coefficient versus excitation frequency in GHz

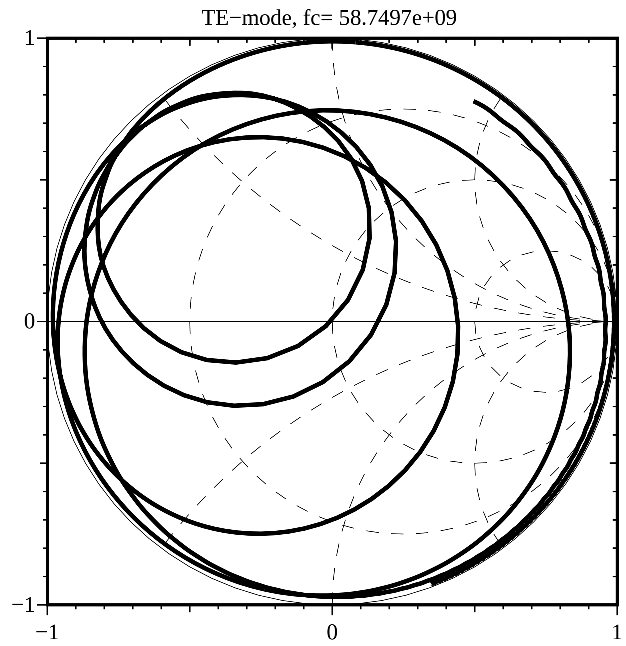

Figure 5: Smith chart of reflection coefficient

parameters are: $a = 0.8$ mm, $g = 0.38$ mm, $d = 1.78$ mm and a length of the side cells of $gs = gw = 2.46$ mm.

The next step was the coupler design. First we tried to couple the waveguide with no slit in the iris, but not enough coupling could be achieved this way. Varying the lengths of the side cells for changing the fields at the coupler didn't result in a better situation. As to be seen in Fig. 2, the incoming wave ”sees” an almost totally closed wall. Anyway, with an iris of $i = 1.0$ mm thickness and a slit of $s = 0.38$ mm width the reflection coefficient can be decreased to about 0.03, as seen in Fig. 4. One fortunate property of the coupler designed is the overcoupling of the higher order modes, Fig. 5. If, for any reason, a higher mode is excited, it will be attenuated fast.

While designing the coupler we realized, that greater depth than that of the cavity is needed for the waveguide due to the

Figure 6: Wake field excited by a charge with rectangular density in x-direction, total width 1 cm

Figure 7: Wake field of a charge distribution that closely matches the E-z component of the fundamental mode

necessity of driving it well below cutoff. So the superiority of our "H-block" cavity with respect to the "barbell" cavity of Yu and Wilson concerning the manufacturing goals is almost totally lost.

4 REMARKS CONCERNING THE OUTPUT CAVITY

The low dc power of only 25 kW gives rise to some problems in extracting the rf power from the beam. With a rf current of about 1 A, a single gap output cavity is capable of extracting only 20% of the beam energy even in the unloaded case. Due to the low beam energy, the transit time effect will reduce that value down to less than 10%. The only way to overcome that unacceptable situation is to increase the unloaded shunt resistance by having an output structure consisting of several coupled cavities, i.e. a traveling wave structure is needed. Unfortunately, such an output cavity chain has not been found yet.

In order to estimate the effect of a bunched beam in an output cavity, we calculated the wake potential of several different shaped sheet beams, assuming that they would have sufficient energy.

It turned out, that the charge distribution in transverse direction has to be adjusted in order not to excite higher order modes in the same passband.

5 REFERENCES

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