Design of a double-gap Hughes-type coupled-cavity for a Ka-band Extended Interaction Klystron

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Abstract: *In this paper, the design of* ***a Ka-band Extended-Interaction Klystron (EIK)*** *working at 2π mode. The interaction structure is a three-gap Hughes-type coupled-cavity. Based on the results obtained with the 3D model developed by using CST, "cold electrical parameters" have been calculated, necessary to measure the interaction with the electron beam. The structure stability and the synchronization with the electron beam are analyzed. The large-signal analysis is performed by 1D software AJDISK. Under the beam voltage and current of 19.55 kV and 0.95 A, respectively, an RF output power value of 3.8 6 kW and a bandwidth gain value of 37.06 dB have been obtained.*

Keywords: extended interaction klystron; coupled-cavity; Hughes cavity; multi-gap.

Introduction

In communication systems and spaceborne remote sensing applications, the demand of wide-band high-power sources operating at millimeter and sub-millimeter wave necessitates the use of more efficient devices [1][2]. Compared to the traditional Klystron, the EIK has a higher shunt impedance which guarantees a lower external Qe, resulting in increased bandwidth. The EIK higher impedance succeeds in overcoming the limitations connected to the reduction of the current density and the beam conductance by the frequency increase. Chodorow and Wessel-Berg analyzed the interaction between the fields and the linear electron beam inside the EIK structure [3]. The analysis was made in a one-dimensional gridded gap, neglecting the space-charge effect on the beam-wave interaction. Over the years, a number of mm-wave EIK amplifiers have been demonstrated [4].

The Hughes multi-gap coupled-cavity

The Hughes multi-gap coupled-cavity is a short slow wave structure, where each cavity is coupled with the next one by a single slot on the common walls, and each slot is shifted with 180° phase difference, as shown in Fig.1.

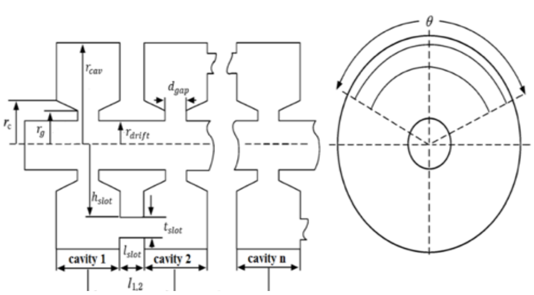

Figure 1. Schematic Model of the Hughes-type multi-gap coupled-cavity: (a) longitudinal section and (b) crossed section.

The first step of the EIK design is the analysis of an N-gap Hughes-type coupled cavity. Based on the space-charge wave theory, it is possible to define a 2D model and calculate the beam-wave coupling coefficient Mn of the structure with N-gap. The interaction between the RF field inside the cavity and the electron beam produces an increase of the bunching current. The beam-load conductance G_b, which represents the capability of the energy exchange between the beam and the EM field at the interaction gap, is given by (1):

$$G_b = \frac{1}{4W}\left(\left|M_N(\beta_e - \beta_q)\right|^2 - \left|M_N(\beta_e + \beta_q)\right|^2\right) \quad (1)$$

The EIK Amplifier design specifications are: $f_0 = 35\,GHz$, $Bandwidth = 350\,MHz, P_{out} = 3.5\,kW,\ Duty - cycle = 13\%,\ V_{beam} = [12 - 20]\,kV,\ I_{beam_{MAX}} = 1.5\,A$. The CST Studio Suite eigenmode solver has been adopted to calculate the cold electrical parameters reported in Table 1 and to analyze cavity EM fields. Fig. 2 shows the schematic model and Fig. 3 shows the simulated electric field. The selected operative mode is the TM type TM_01.

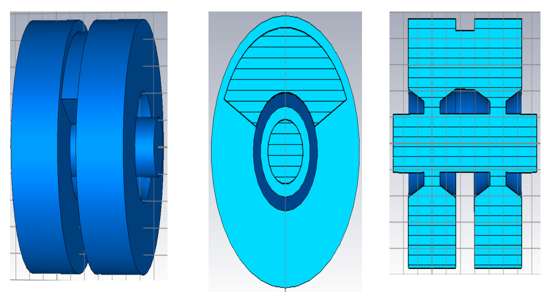

Figure 2. CST 3D Model: EIK transversal and longitudinal sections of the first two cavities

The Hughes-type cavity has the 2π, π, and $\pi/2$ resonant modes. The coupling slot dimensions have been chosen with the aim of obtaining a good decoupling between the lowest mode π and the operative mode 2π. Every cavity has a height of $l_{cav} < \lambda_0/4$, and the transit angle $\beta_e d$ is $\leq \pi/2$ in order to obtain a good coupling with the electric beam. The optimization has made it possible to obtain , $\frac{R}{Q} = 190\ \Omega$ and $f_0 = 35\,GHz$ for the 2π mode. The coupling coefficients M_{gap1} e M_{gap2} are almost identical and equal to $M_2 = 0.675$, assuming a "load factor" of 0.6 and a $\beta_e d_{gap} = 85°$, whereas the synchronous voltage is $V_{0,synch} = 19.55\ kV$.

Table 1. Electrical "cold" parameters for different modes

Mode	f_0 (GHz)	Q_0	$R/Q\ (\Omega)$	$V_{gap,1}(V)$	$V_{gap,2}(V)$
π	31.2	2090	180	$3.82 \cdot 10^6$	$3.87 \cdot 10^6$
2π	35	2580	190	$3.88 \cdot 10^6$	$3.94 \cdot 10^6$
π *slot*	53.1	2880	20	$3.94 \cdot 10^5$	$4.04 \cdot 10^5$

The structure final dimensions are: $r_{cav} = 2.37\ mm, l_{cav} = 1.66\ mm, d_{gap} = 0.56\ mm, r_{drift} = 0.56\ mm, h_{slot} = 1.03\ mm, t_{slot} = 1.13\ mm, l_{slot} = 0.66\ mm, \theta_{slot} = 130°, l_{1-2} = 2.32\ mm.$ By applying $V_{beam} = 19.55\ kV, I_{beam} 0.95\ A$, @ $f_0 = 35\ GHz$, it occurs $K = 0.35, \beta_e = 2.65 \cdot 10^3, \beta_e^+ = 2.78 \cdot 10^3, \beta_e^- = 2.52 \cdot 10^3$, and it is possible to calculate G_b/G_0 and $1/Q_b$ as a function of V_0, emphasizing the chosen "working point" stability.

A first analysis of a three-gap EIK has been carried out with AJDISK tool, as in Fig. 5. As AJDISK, a1D large signal software, is for a single-gap, equivalent parameters are determined to use the software for the three-gap. The obtained optimized input parameters are $V_{beam} = 19.55\ kV, I_{beam} = 0.95\ A, P_{in} = 760\ mW, f_0 = 35\ GHz.$ The three-cavity structure parameters are reported in Table 2.

Table 2. Design Parameters for the three cavities

Cavity	f_0 (GHz)	$R/Q\ (\Omega)$	Q_0	Q_e
1	35.03	95	2450	275
2	35.01	190	2500	9500
3	35.03	95	2450	265

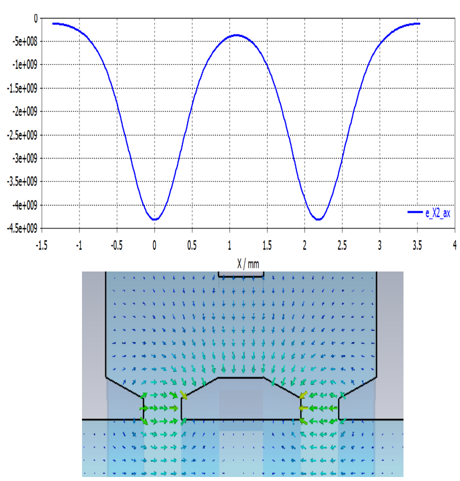

Figure 3. Axial Electric Field and 3d Electric Field simulation for the 2π mode

The coupling coefficient, working on synchronism, is almost identical for the three cavities, and it is equal to $M_{1,2} = 0.675$. The distance between cavities are $l_{cav1-cav2} = \frac{\lambda_q}{4} \approx 11.1\ mm$ and $l_{cav2-cav3} = \frac{\lambda_q}{4} \approx 9.4\ mm$. The output gain and power, are $Gain_{db} = 37.06\ dB$ and $P_{out} = 3.86\ kW$.

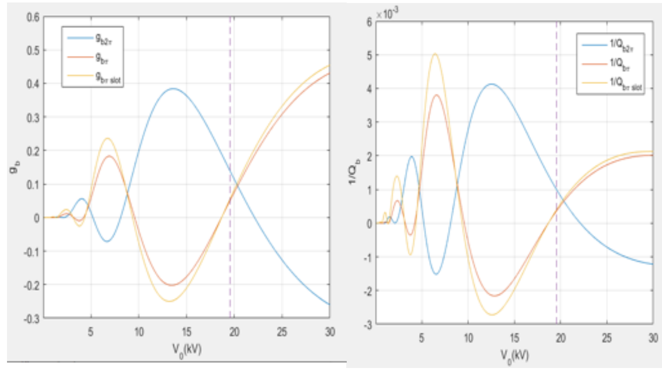

Figure 4. G_b/G_0 and $1/Q_b$ as a function of V_0

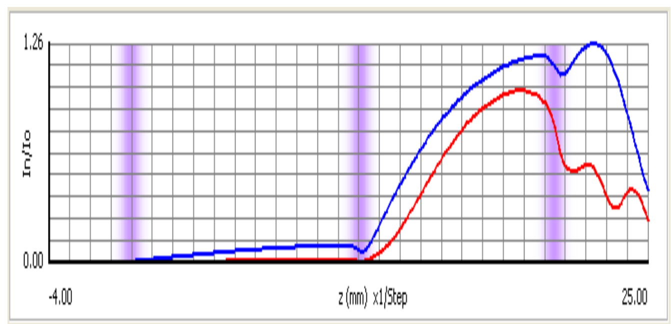

Figure 5. AJDISK Output plot: I_{rf}/I_0 *vs distance* of 1st and 2nd harmonics

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