L and S-band high-efficiency multi-beam kylstron development

BAC method of increasing efficiency

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Two important tasks in the design of klystrons with high output power for accelerators

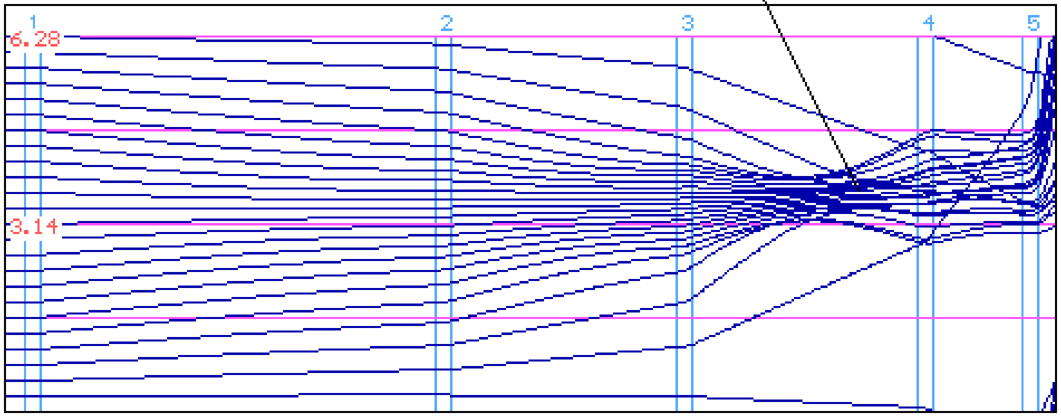
- To get high efficiency
- To reduce the length of interaction space

The most interesting and practically important aim is to combine these two tasks into one, global –

to get **high efficiency** in a **short** space of interaction

How to get high efficiency?

fast particles overtake slow particles



outsiders

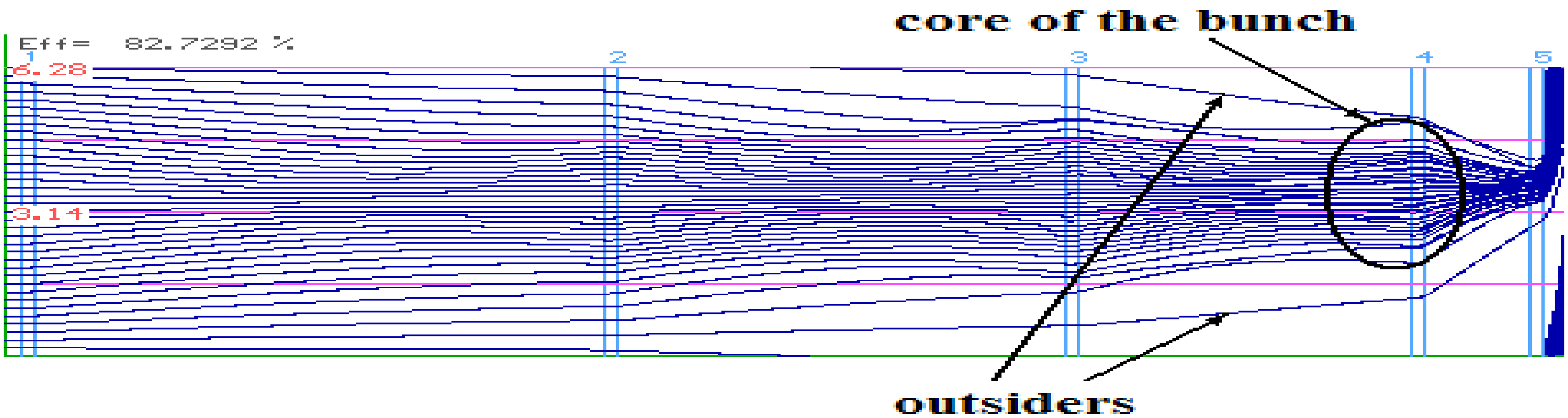
Phase trajectories for 83% efficiency

At first glance it is simple - just collect all electrons in short bunches and slow them down almost to zero velocity.

But there are difficulties for implementation of this plan:

1. The electrons of the core are subjected to the action of the strong forces in the gaps of the cavities and have high difference in velocities.
2. The peripherals – "outsiders" - are subjected by weak forces in the gaps and have a small modulation of velocities. While outsiders reach the core, fast core particles can overtake slow particles, which leads to the destruction of the bunch. Nevertheless, the influence of this part on efficiency is great – if you want to get high efficiency, they must become part of the bunch.

How to get high efficiency? (oscillations of core space charge)



Phase trajectories for 83% efficiency

To avoid the destruction of the core its electrons should make oscillatory movements in drift tubes, first go towards the center of the bunch, then change the direction towards the border of the bunch. These oscillations may occur due to space charge waves.

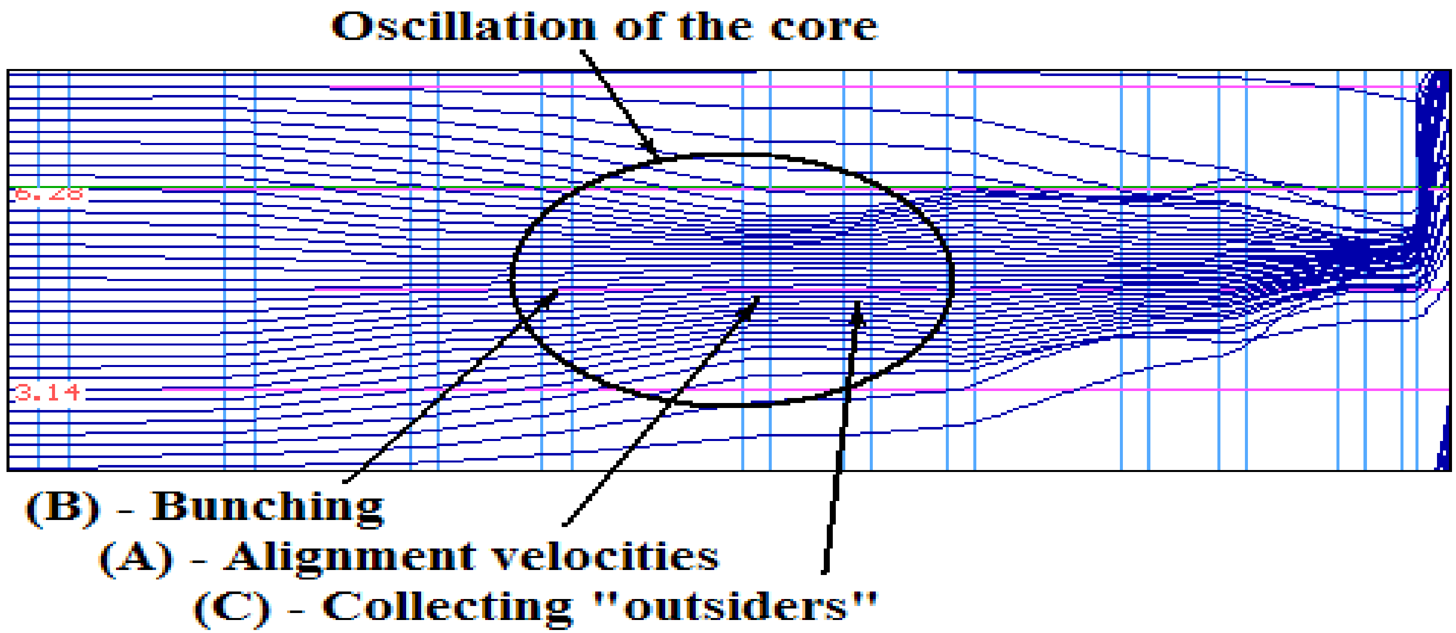
If you want to increase efficiency, you should increase the length of interaction space and wait while outsiders join the bunch successfully.

This traditional way to increase efficiency (up to 94% - A.Baikov)

The main drawback of such approach is **a very long length of interaction space – 17 Le for klystron with 90% efficiency.**

where $L_e = v_0 \cdot T = \sqrt{\frac{2e}{m} U_0} \cdot T$ **- electronic wavelength**

Get high efficiency in a short interaction space (BAC method)



Phase trajectories for 80% efficiency

In order to intensify the process of the core oscillations, you can use the external forces – this is the base of BAC method

Each oscillation in BAC method consists of 3 stages:

- first cavity gap - traditional bunching, which increase the space charge density of the core;
- second cavity gap - alignment velocity spread of electrons;
- third cavity gap – collecting the “particles-outsiders”, which reduce the space charge density of the core.

Comparison of BAC method with traditional way of bunching

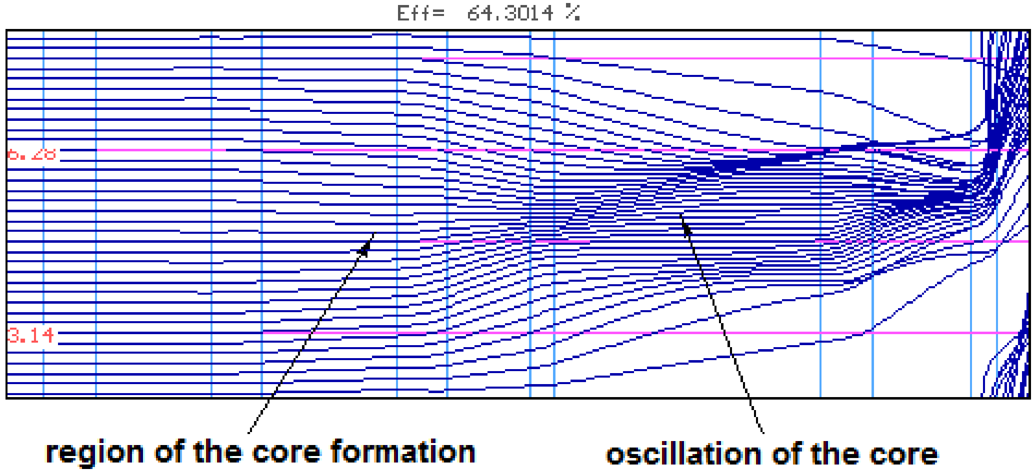
1. Increasing of efficiency for the short length of interaction space (S-band)

Klystron KIU-147

General parameters	Available
Working frequency, GHz	2.856
Output pulse power, MW	6
Output mean power, kW	25
Cathode voltage, kV	52
Gain, dB	50
Mass with focusing system, kg	90
Used in	accelerators

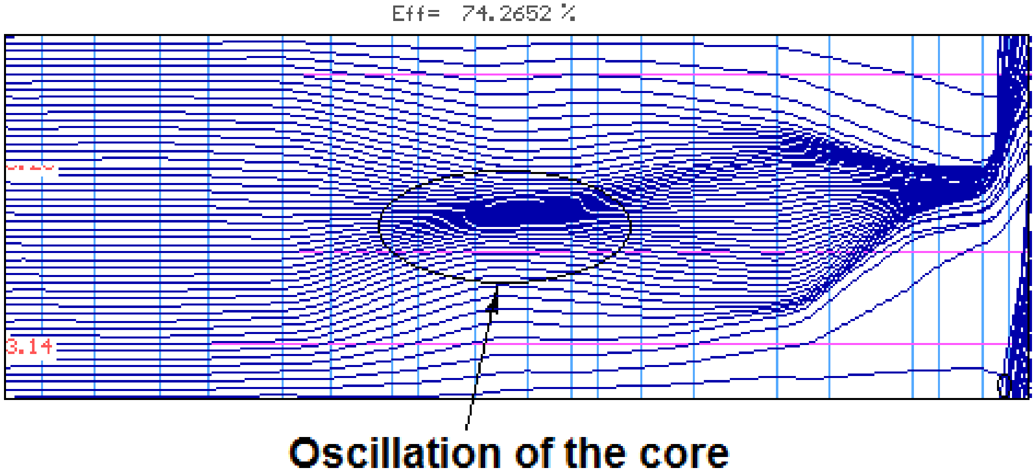
Comparison of BAC method with traditional way of bunching

The length of interaction space is only 4,5 Le, it includes only one oscillation of the core



Traditional bunching – six cavities, oscillation of the core is in the long drift tube between fourth and fifth gaps.

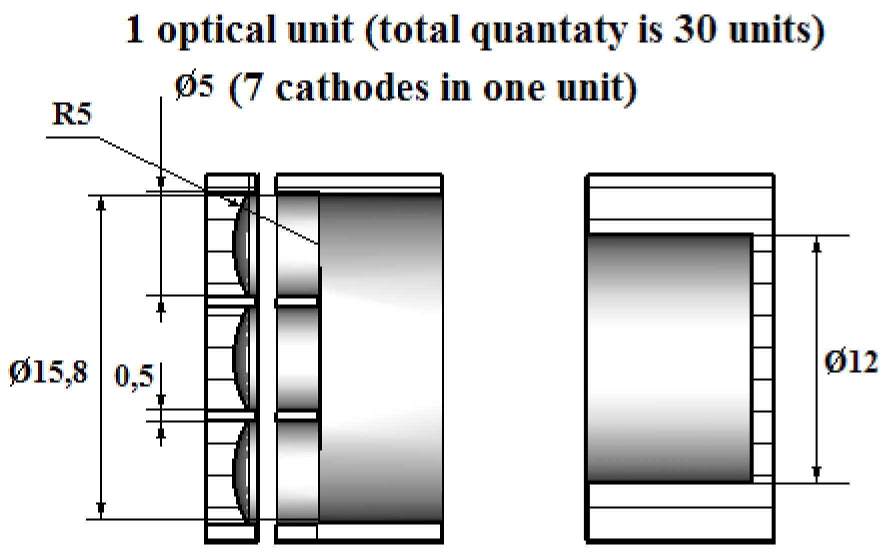
Calculated efficiency is 64%

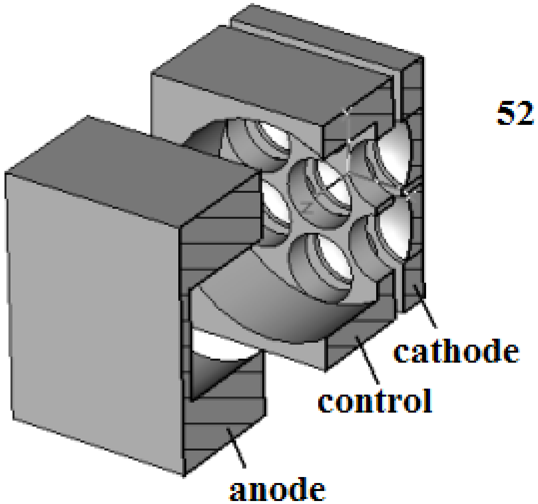


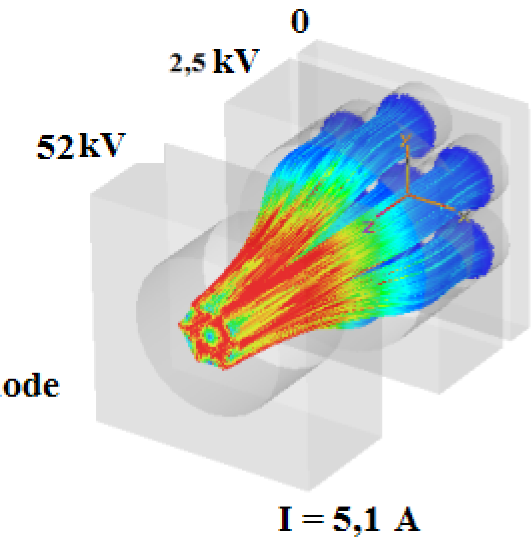
BAC method – ten cavities, oscillation of the core is in the region from fourth to sixth cavity.

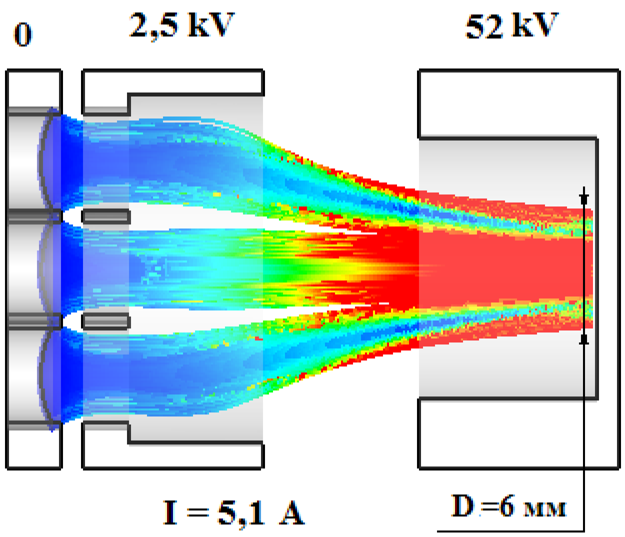
Calculated efficiency is 74%

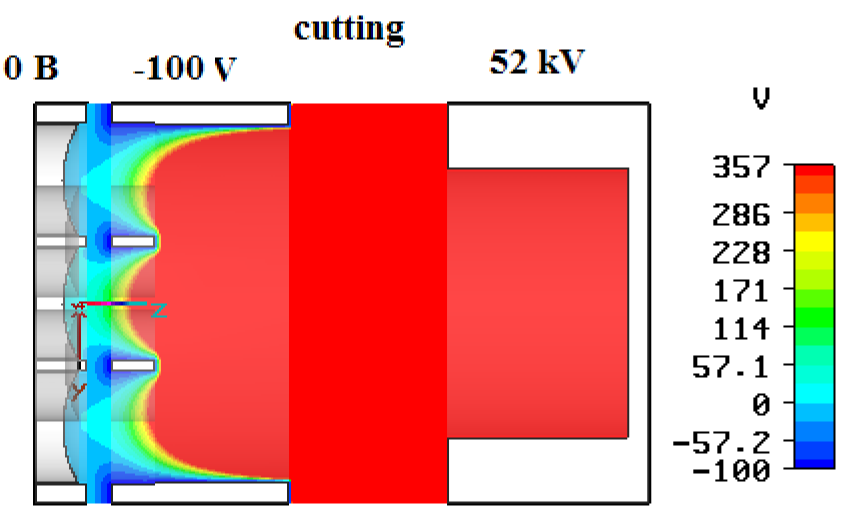
Variant of optics with controlled electrode











Cut voltage for central channel U= -220 B

Comparison of BAC method with traditional way of bunching

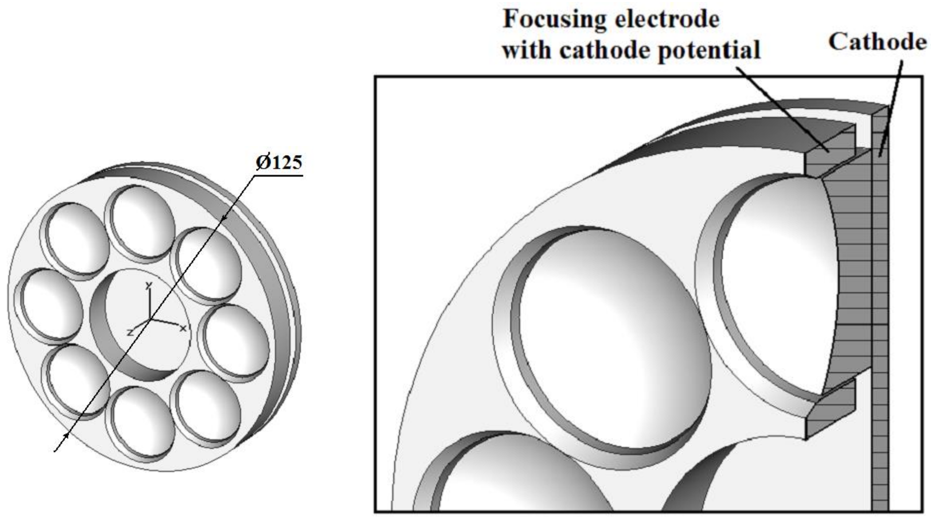
2. Reducing of interaction space length for klystrons with same 80% efficiency (L-band - klystron for CLIC)

Parameter	Value
Frequency, GHz	1,0
Peak output power, MW	20,0
Average output power, kW	150
Efficiency, %	80

Variant	1	2
Beam voltage, kV	162	116
Pulse current, A	155	216
Number of beams	8	30
Cathode diameter (for each beam)	35	22
Channel diameter, mm	20	18
Cathode loading, A/cm^2	2,0	2,4

Comparison of BAC method with traditional way of bunching (L-band - klystron for CLIC)

Cathode unit



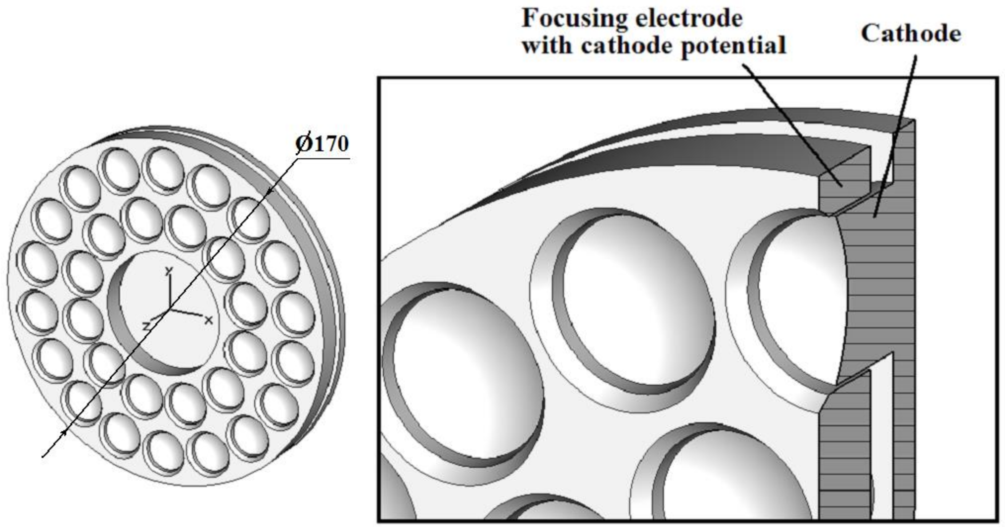
Variant 1

Number of beams 8,

Pulsed current 155 A,

Cathode diameter 35 mm,

Cathode loading, 2,0 A/cm^2



Variant 2

Number of beams 30,

Pulsed current 216 A,

Cathode diameter 22 mm,

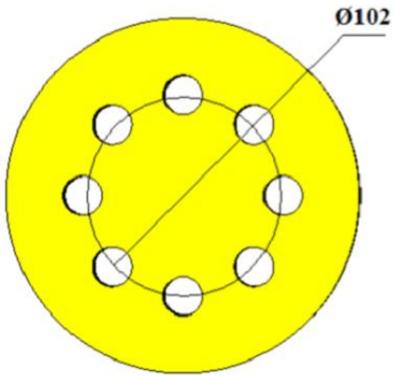
Cathode loading, 2,4 A/cm^2

Comparison of BAC method with traditional way of bunching (L-band - klystron for CLIC)

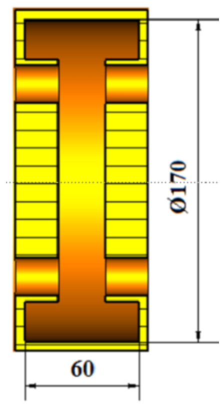
Cavities

1 harmonic | **2 harmonic**

Variant 1

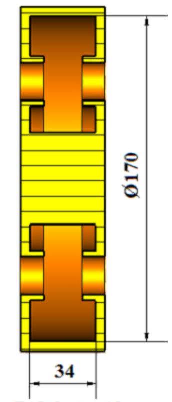


TEM_{010}



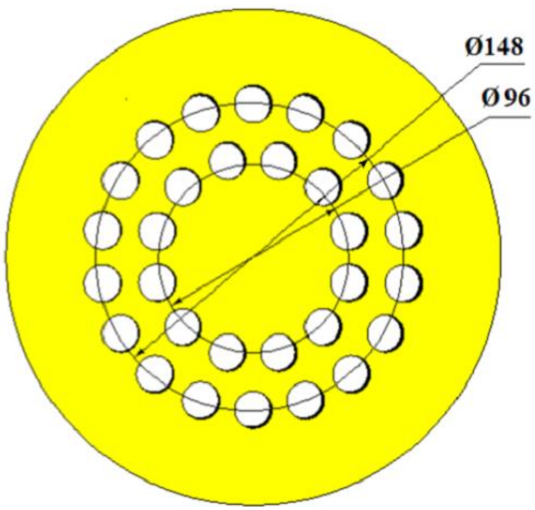
R/Q factor 25

Ring HOM

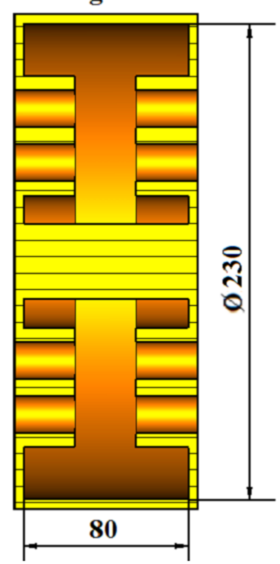


R/Q factor 18

Variant 2

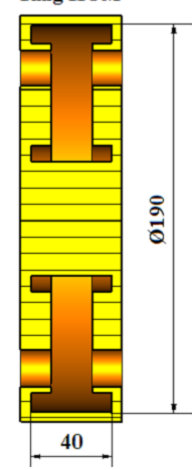


Ring HOM



R/Q factor 22

Ring HOM

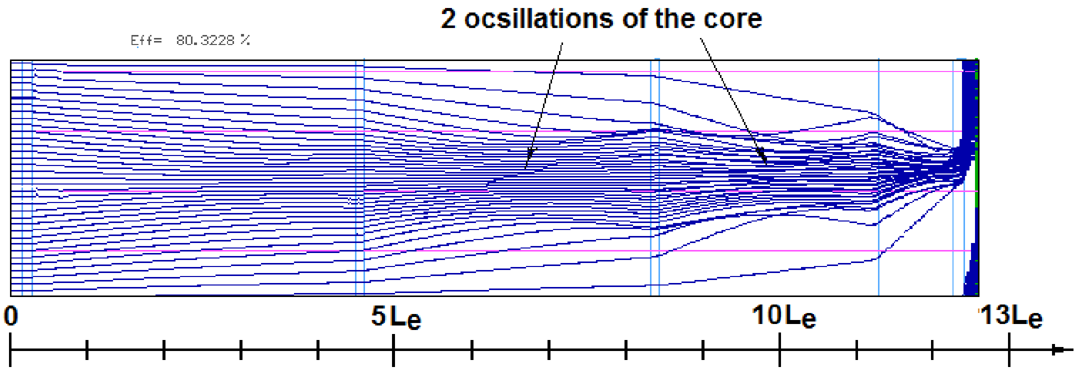


R/Q factor 9

Comparison of BAC method with traditional way of bunching (L-band - klystron for CLIC)

Bunching (same efficiency 80 %)

Variant 1

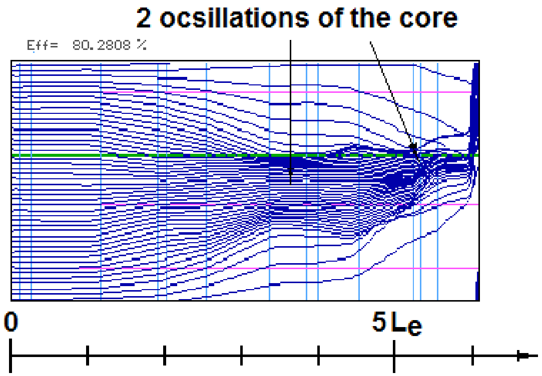


U=162 kV

Le=24 cm

L = 3 m !!!

Variant 2 (BAC)



U=116 kV

Le=20 cm

L = 1,2 m

Reduction of length due to:

1. BAC method – 2,1 times
2. Voltage decrease (from 162 to 116 kV) – 20 %

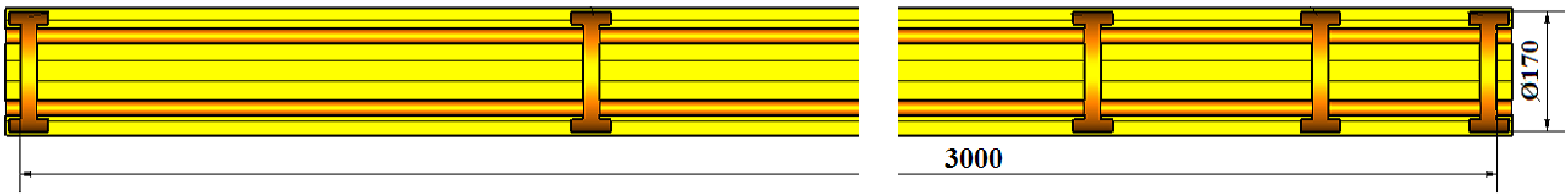
Total: 2,5 times

Dimensions of body for 2 variants
Energy of magnetic field inside the body

Variant 1. 8 beam traditional klystron

R_{b1}=5 мм, I_{b1}=20576 mA, U_{01}=162 kV, $H_{br1}[G]=\frac{46,5}{R_{b1}[mm]}\sqrt{\frac{I_{b1}[mA]}{\sqrt{U_{01}[kV]}}}$=374 G=0,0374 T

V_1=3,14·0,09²·3,0=0,083 m³ $W_{m1}=H_{br1}^2\cdot V_1$

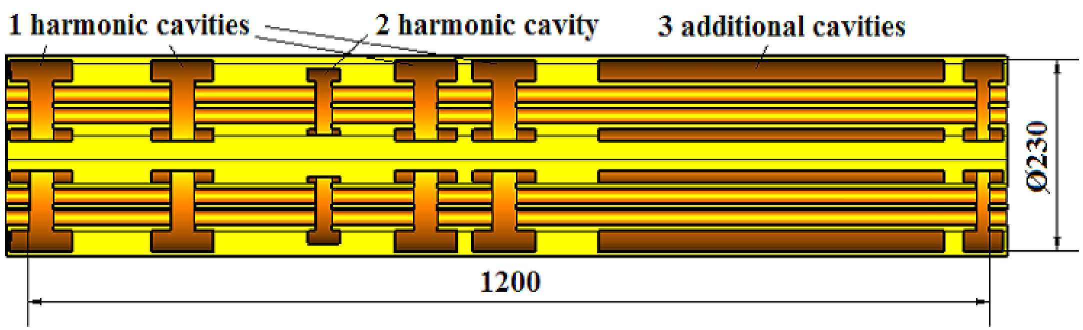


Variant 2. 30 beam BAC klystron

R_{b2}=4,5 мм, I_{b2}=7184 mA, U_{02}=116 kV, H_{br2}=267 G=0,0267 T

V_2=3,14·0,12²·1,3=0,059 m³ $W_{m2}=H_{br2}^2\cdot V_2$

R_b = radius of beam, I_b – beam current,
V – volume of klystron body



$W_{m1}=2{,}76\,W_{m2} >> W_{m2}$!!!

Conclusion

New BAC method of bunching is proposed. The method allows achieving 80% efficiency on a short length due to intensifying of the core oscillations by external forces in the special gaps.

2 comparisons of traditional klystrons and klystrons with bunching by BAC method were made. Here is summary of results:

1. Klystrons with same short interaction space (4,5 Le).

   Usage of BAC method leads to 10 % increase in efficiency (from 64 to 74%).

2. Klystrons with the same efficiency - 2 variants klystrons for CLIC application – 30-beam and 8-beam.

   Usage of BAC method together with reduction of voltage from 162 to 116 kV leads to 2,5 decrease of body length.

Thank you for attention!