High Efficiency, High Power, Lower Voltage MBK BAC-TCC Technology Covering X/C/S-Band.

I. Guzilov, JSC "Vacuum Device's Basic Technologies " (VDBT), Moscow, Russian Federation
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Agenda

- VDBT company introduction
- BAC method
  - The basis of BAC method
  - Several BAC oscillations
  - Comparison with existing core oscillation methods
  - Transverse coupled cavities
  - Useful cathode area for TCC and HOM (ring) cavities
- Why make 3.5MW MBK:s X/C/S-band?
  - NEW 3.5MW multi beam klystrons X/C/S-band design parameters
- Future design concept
  - MBK modulator
  - What can you design?
  - Burst mode pulse

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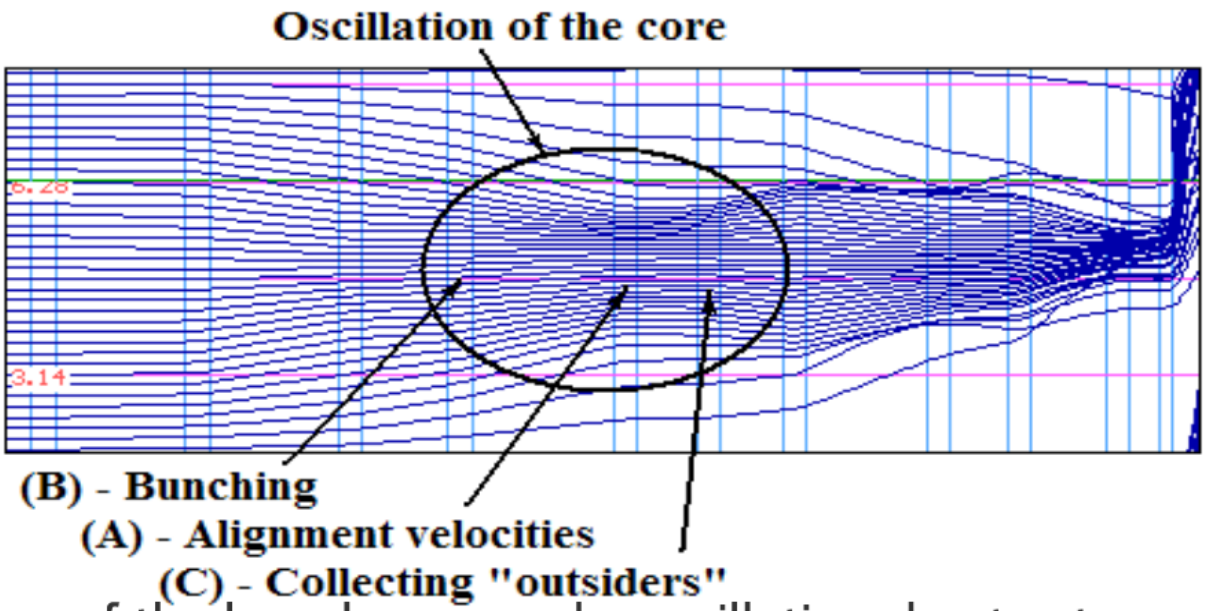
” The basic technology and components for vacuum-tube devices. Ltd.”
VDBT

Evgeniy Demidov, CEO and Co-Owner
Oleg Maslennikov, Vice Director, Dr. in Science
Igor Guzilov, Chief Designer, PhD in Physics

- 100% private company
- Address: 117342, Vvedenskogo 3-1, Moscow, Russian Federation
- Number of staff: 50-60
- Production area: 1000m
- Development and production of high power microwave electron vacuum devices for accelerators and other purposes.
- Main products: BAC MBK:s, cathodes, electron guns, getters, accelerators, TWT, compressors
- www.vdbtc.com

The basis of BAC method



Electrons of the bunch core make oscillation due to strong external forces in the gaps of BAC triplet of cavities, while peripheral electrons (outsiders) monotonically reach the core.

The BAC triplet consists of three cavities:

First – traditional Bunching (B);

Second - Alignment velocity spread of electrons (A);

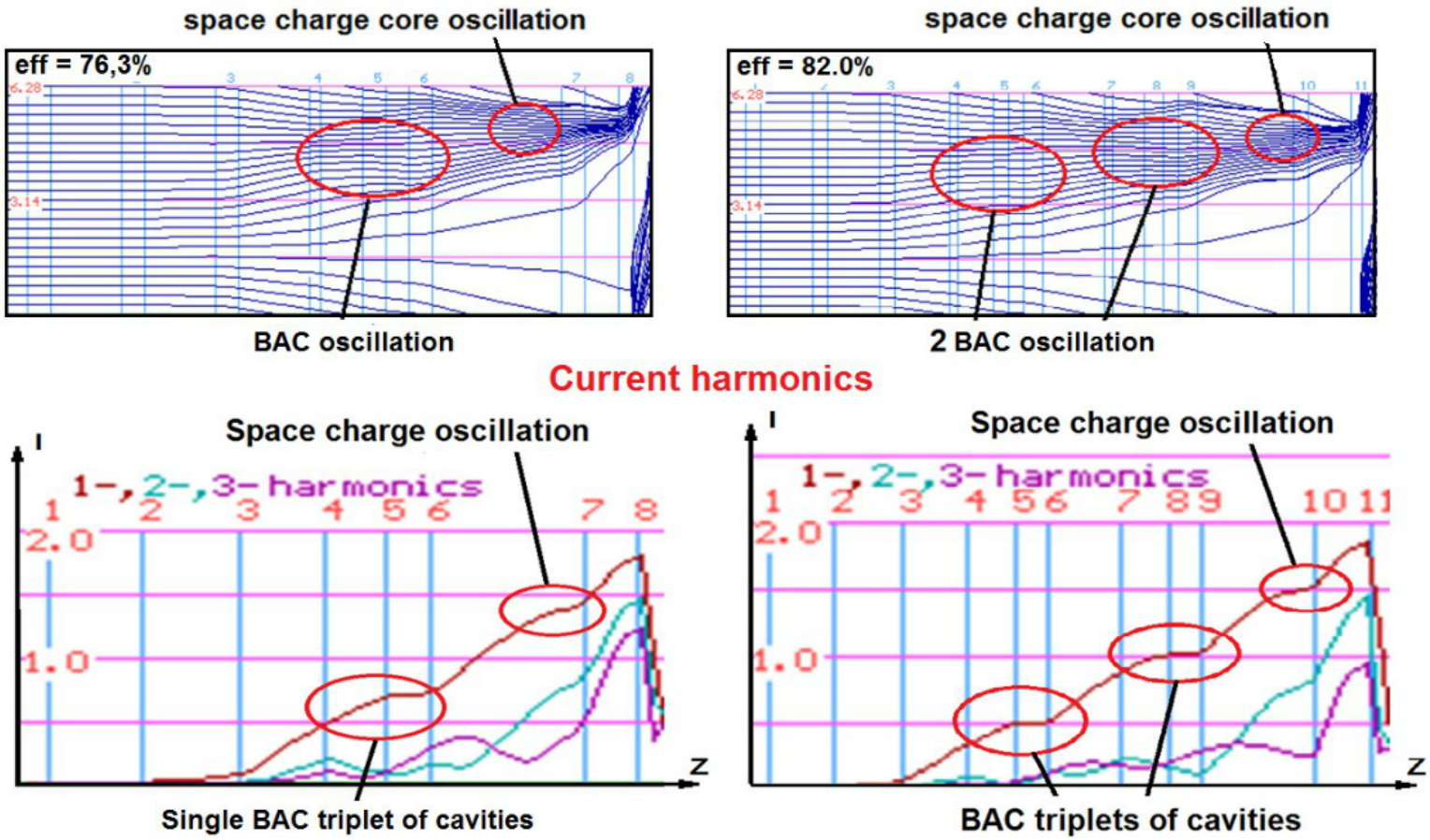
Third – Collecting the "particles-outsiders" (C).

Resonant frequency of cavity A is lower than the working frequency, which allow to accelerate the process of oscillation.

BAC method validated at CERN,2016. 42% to 64.5% Effic. IVEC17

BAC method can also used in CW tubes.

Several BAC oscillations



You can use several BAC triplets which allows to increase the efficiency of more than 80%. Minimum length of RF circuit is 4,5 Le to make one BAC core oscillation and 5,5 Le for 2 BAC core oscillations, where:

$$Le = v_0 \cdot T = \sqrt{\frac{2e}{m} U_0} \cdot T$$ is the electronic wavelength.

Comparison with existing core oscillation methods

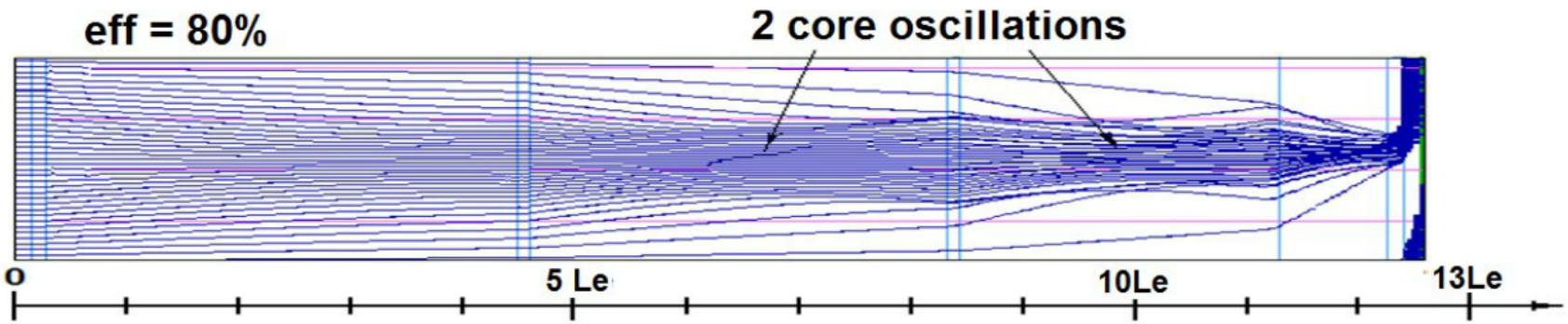
Core oscillation method, COM

A. Baikov, C. Marrelli and I. Syratchev, "Toward high power klystrons with RF power conversion efficiency on the order of 90%", IEEE Trans. Electron Devices, vol. 62, no. 10, pp. 1–1, 2015.

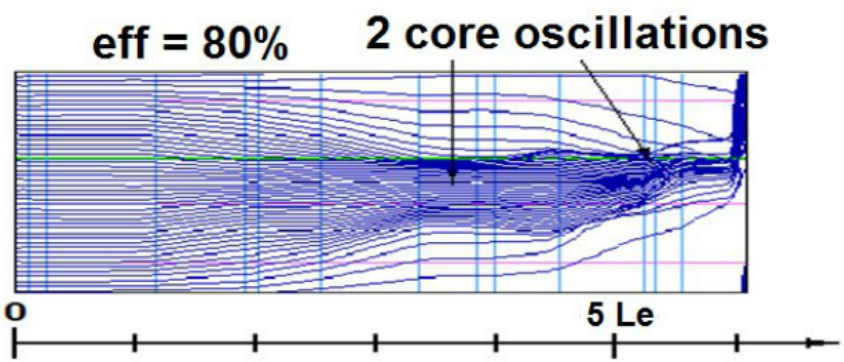
Difference with the BAC method

Core oscillation occurs due to space charge forces of the bunch, which are much less then external forces inside the BAC triplet. As the result very long, very efficient tubes.
Using of BAC method allows to reduce the length of the interaction space more then twice in comparison with COM method, while maintaining high efficiency.

COM



BAC



The main drawback of COM method is a very long tube which makes it difficult to use it in practice

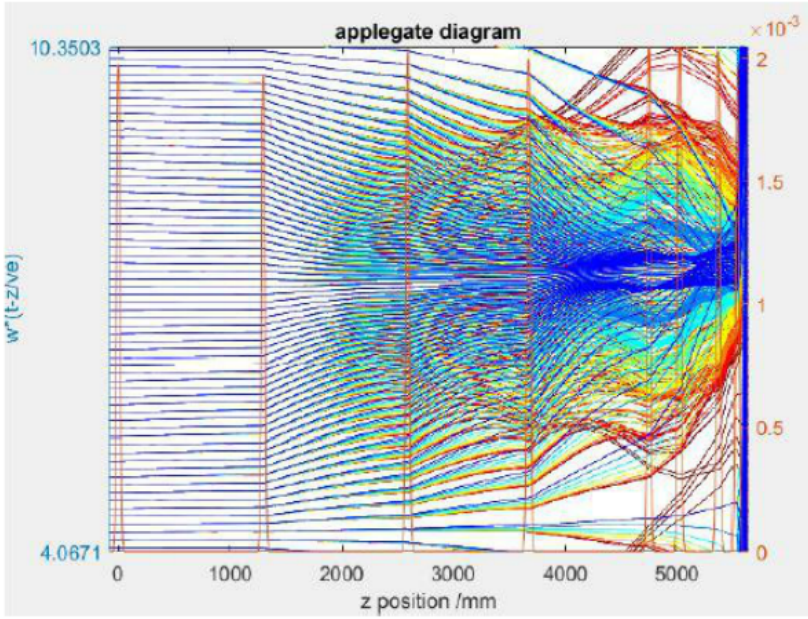
Comparison with existing core stabilization methods

Core Stabilization Method, CSM

A. Baikov, C. Marrelli and I. Syratchev, "Toward highpower klystrons with RF power conversion efficiency on the order of 90%", IEEE Trans. Electron Devices, vol. 62,no. 10, pp. 1–1, 2015.

Difference with the BAC method

Core oscillation occurs due to influence of second and third harmonics cavities doublet. Third harmonic cavity strengthens the movement of outsider toward the core of the bunch, which allow to get 10% decrease of the RF circuit length for the same efficiency. It is required 2-3 cavities less then in BAC method to get the same efficiency.

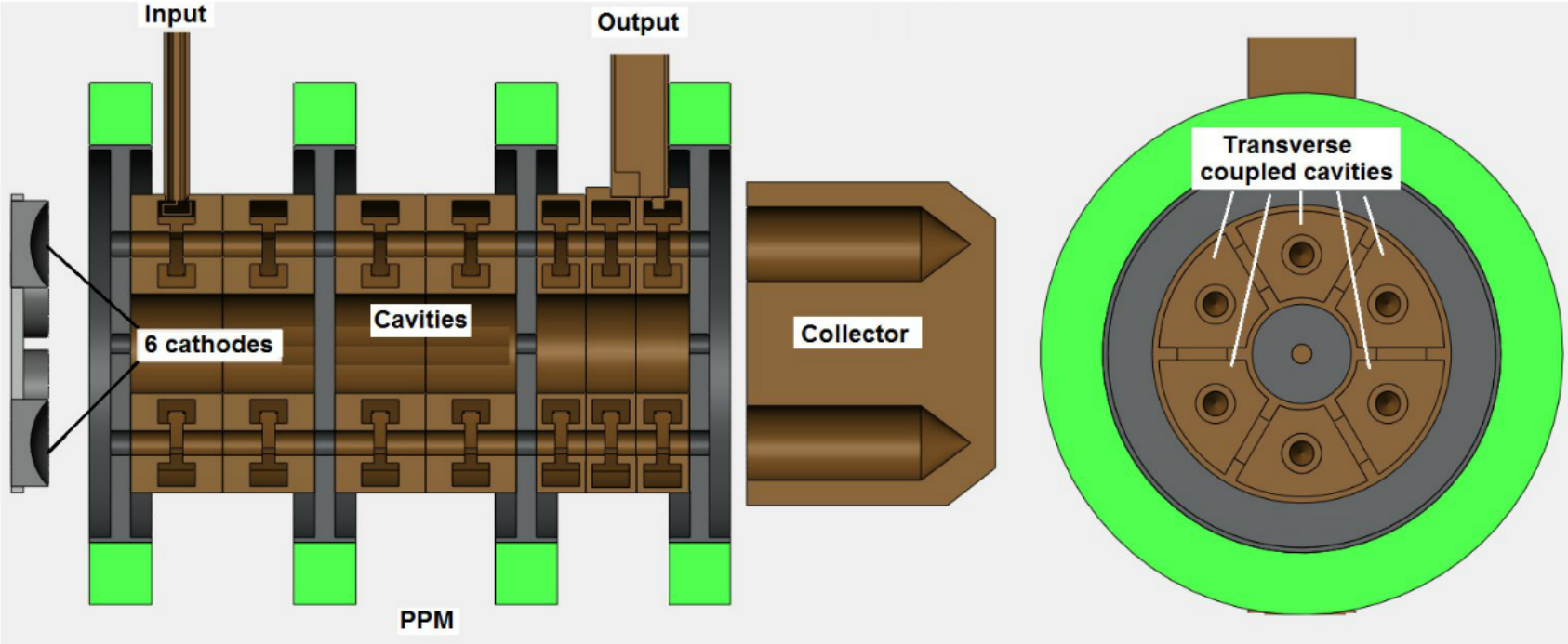


The main drawbacks of CSM method are:

1. Relation around 1:3 between third harmonics cavity gap and channel diameter which leads to big radial stratification of electric field in the gap and as a result strong radial stratification of the bunching.

2. Difficulties of implementation in MBKs, especially for HOM (high order mode) cavities

Transverse coupled cavities- TCC technology



Advantages in comparison with traditional technologies:

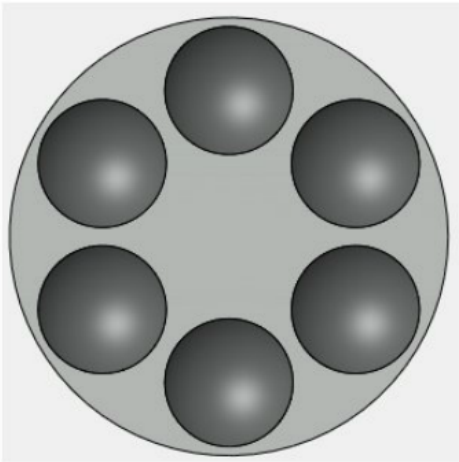
1. Increasing of useful cathode area more than 10 times and, as a result, to increase lifetime more than 3 times for the same output power.

2. Allow to increase output power for high frequencies - up to 100 MW in C-band and up to 50 MW in X-band with long lifetime.

3. Low voltages for high powers - no more then 150 kV for 50 MW klystrons and 55 kV for 3,5 MW klystrons

Useful cathode area for TCC and HOM (ring) cavities

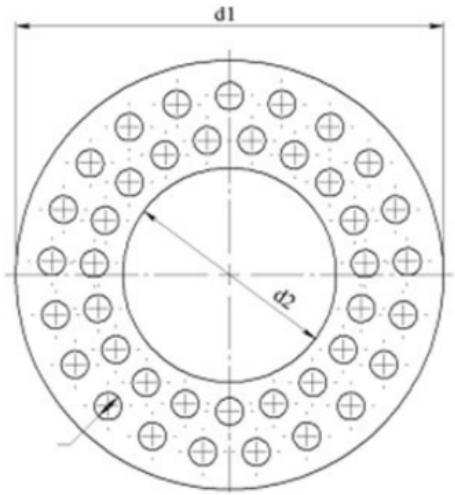
TCC
$6\ \lambda^2$
(18!! Times more)



Optimal optical relation:
diameter of cathode/diameter of channel =3
$\lambda/3$ is the max cavity capacitance diameter
As a result, max diameter of each cathode $3x\lambda/3 = \lambda$

Surface of 6 cathodes is $6\ \lambda^2$

HOM
$1/3\ \lambda^2$
λ is the wavelength



$\lambda/3$ (ring width)x $2\ \lambda$ (circumference)x
0,5(area utilization coefficient) = $1/3\ \lambda^2$

Surface of 40 cathodes is $1/3\ \lambda^2$

Comments: VDBT can increase (step by step):
1. Cathode area for 10-20 times.
2. Value of Cathode current for 10-20 times.
3. Output power for 10-20 times.
4. Lifetime for 2-3 times.
A lot of advantages. And the main one is a decrease of current density.
80 MW for C-band is not problem now (voltage is no more than 200 kV).

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Why make 3.5MW MBK:s X/C/S-Band?

General Comparison: Magnetron- Single Beam Klystron - 3.5MW MBK:s

Magnetrons
- Peak Power: 1- 3.1MW
- Pulse Repetition Rate: 500Hz
- RF Avg. Power: 4kW
- Warranty: 500Hours/one year
- Low Pulse Stability/Flatness
- Pulse Length: 5µs
- Solenoid/PPM
- Easy to handle(about 8kg)
- Know how

Single Beam Klystron
- Peak Voltage, High
- Solenoid
- Heavy, Solenoid PS
- High Pulse Stability/Flatness
- Large size
- Not flexible in various operation

Market
- No need for very high peak power
- Higher pulse repetition rate
- Better pulse stability
- Reliability
- Artificial Intelligence(AI)
- Advanced pulsing method
- Overall compactness
- Limitation of 10MeV

NEW Design of VDBT 3.5MW MBK:s
- BAC Method, TCC
- Peak Power: 3.5MW
- Peak Voltage, Low (42-56kV)
- RF Avg. Power: 10-12kW
- Pulse Length: 1-16µs
- High Efficiency
- Warranty: 5000hours/18months
- High Pulse Stability/Flatness
- Pulse Repetition Rate:
  - >2500pps @ 1µs,
  - 160pps @16µs
- PPM

Magnetron Modulator
- Compact
- HV Cable

Klystron Modulator
- Expensive
- Klystron cathode in oil tank

+ Capability of VDBT
+ Basic Research

Magnetron Modulator
- Add SSA
- Add Ion Pump PS
- HV Cable, no need to put klystron cathode in oil tank

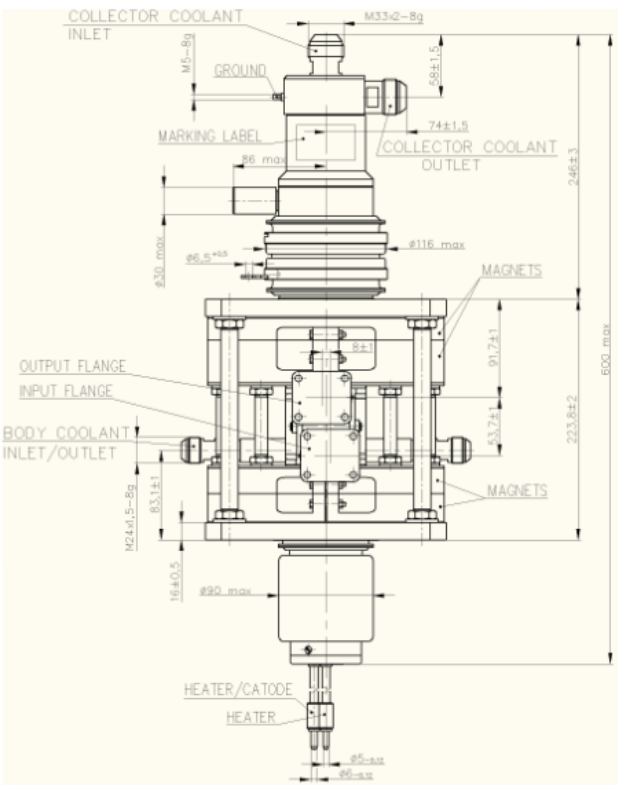
OEM Product

NEW 3.5MW Multi Beam Klystrons X/C/S-Band Design Parameters

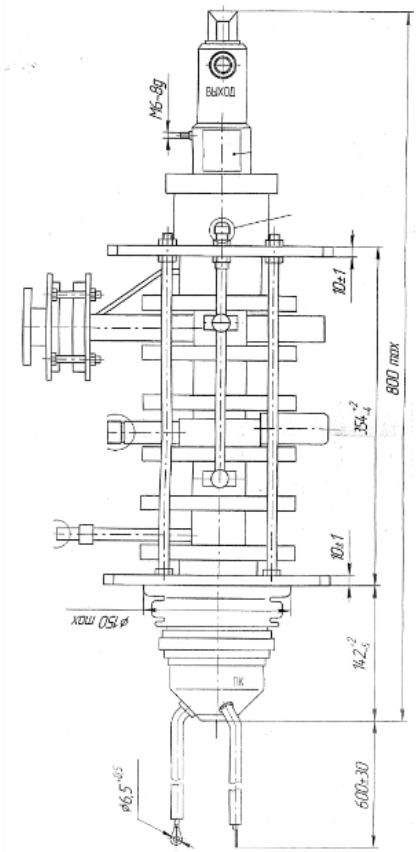
Model Name	Frequency (GHz)	Output Power (MW)	Efficiency(%), min.	Gain (dB) min.- max.	Avg. RF Output Power (kW)	Pulse Length (µs)	Duty Cycle (%)	Pulse Repetition Rate (pps)	Peak Beam Voltage (kV)	Peak Cathode Current (A)	Weight (kg), Approx.	Length (mm), Approx.
BT263	9.3	3.5	50	45-50	10	1-16	0.28	2800@1µs, 180@16µs	56	130	95	770
BT264	5.7	3.5	50	45-50	10	1-16	0.28	2800@1µs, 180@16µs	56	130	85	800
BT262	2.9985	3.5	50	45-50	12	1-16	0.34	3400@1µs, 210@16µs	42	170	70	700

All MBK:s use BAC method and BT263 and BT264 use BAC + TCC, Periodic Permanent Magnet(PPM). Options: BT263 Freq.11.25; 11.4; 11.9. BT262 Freq. 2.856. Efficiency parameter will be updated and we believe it will be around 70%, data sheets will be updated continuously.

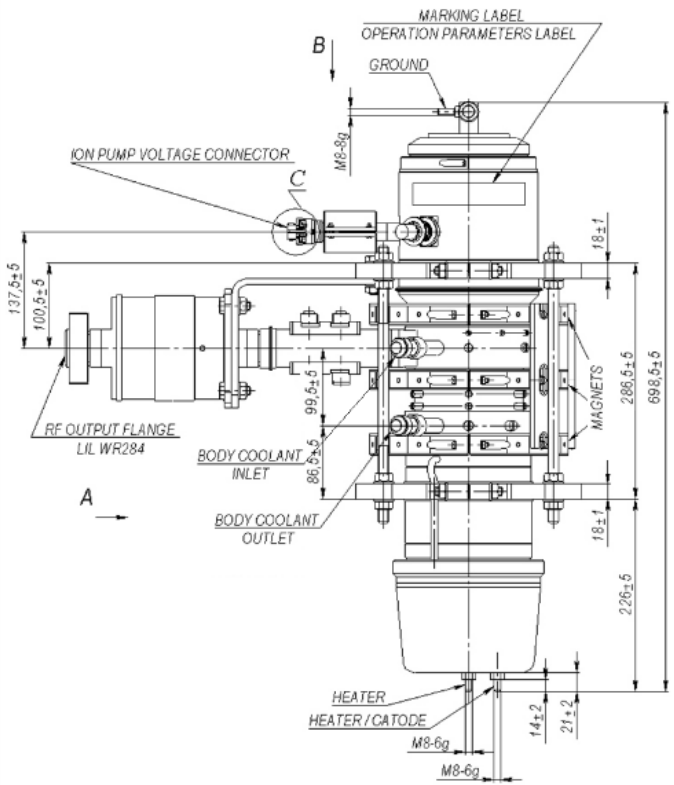
BT263



BT264



BT262



VDBT also offer S-Band MBK, 6-16MW Peak Power.

MBK Modulator
Conceptual design by JEMA ENERGY

Design parameters:

Specification:
Pulse Voltage 40-60kV
Pulse Current 90-180A
Pulse length 1-16us
Modulator Avg. Power 25kW
Pulse Repetition Frequency Range 0-2500Hz
Modulator RF Peak Power 4MW

Included:
Switch
Charger
Filament PS
Ion vacuum PS
LLRF amplifier/SSA
HV Cable connection
Input protection (circuit breaker)
Water cooling piping for HVPS and MBK
Interlocks

1400x600x850 LxWxH

NELSON Comments:
Have a design that also can be divided into two units (Tank Unit and Pulse Unit).
A transformer design which no need of oil.

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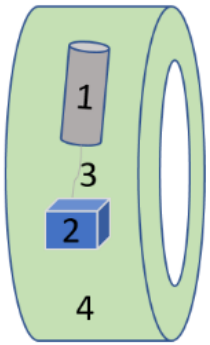
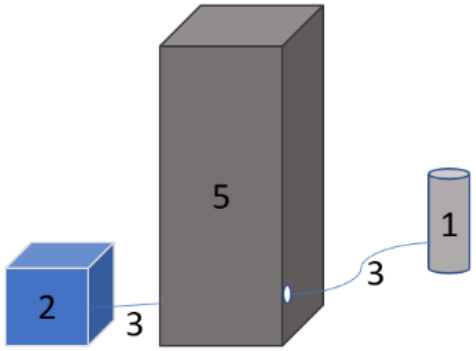
Future Concept Designs

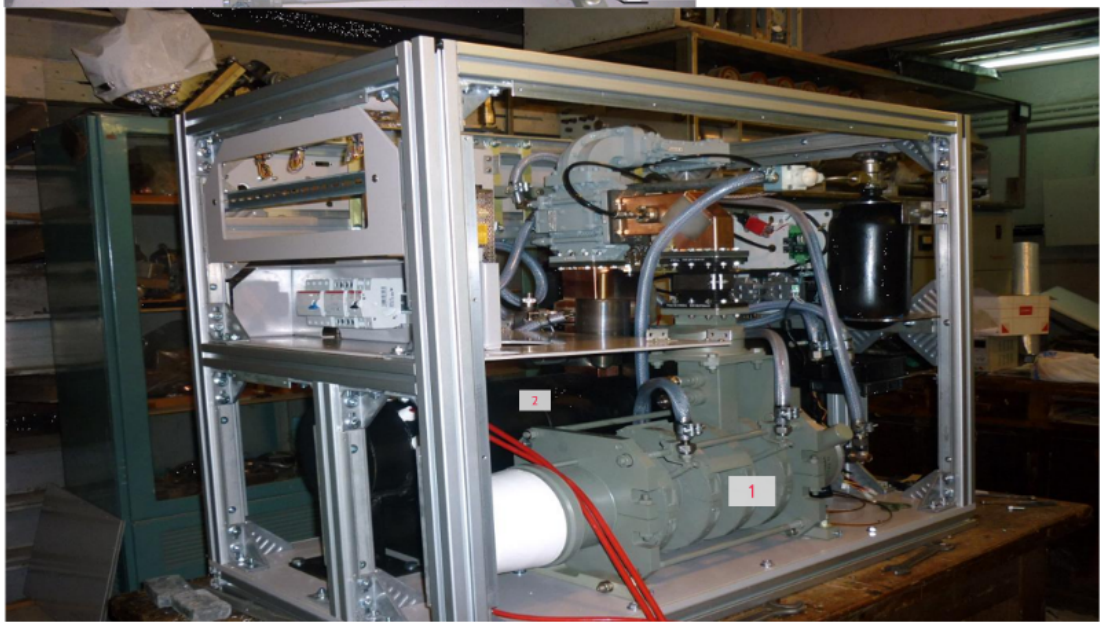
What can YOU design?

1. MBK
2. Modulator
3. HV Cable
4. Gentry
5. Bunker wall



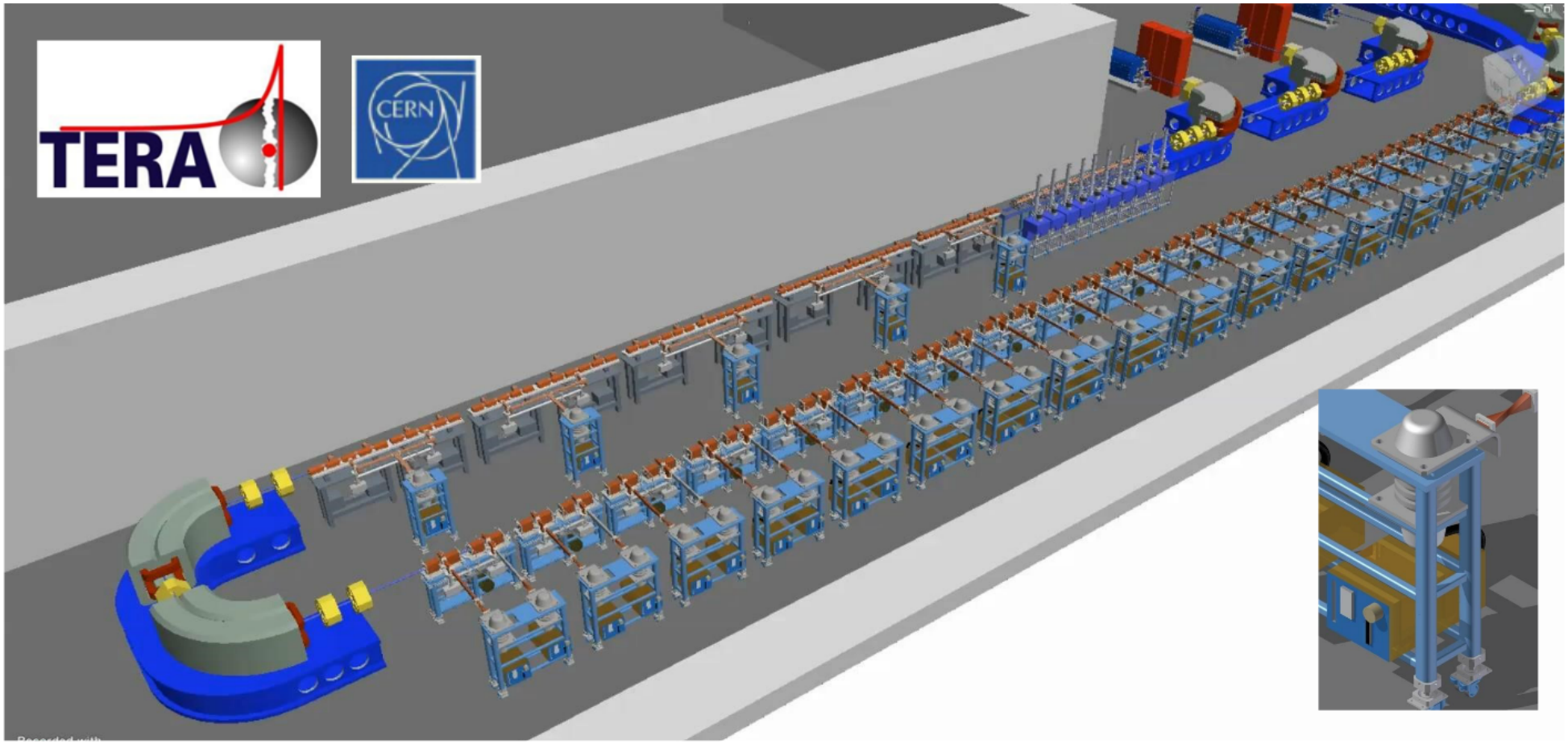


1. MBK
2. Accelerating Tube



Future Concept Designs

A. Garonna on behalf of Prof. U. Amaldi. V. Bencini, D. Bergesio, D. Carrio Perez, C. Cuccagna, E. Felcini, P. Riboni, M. Varasteh
Advanced Linac Solutions for Hadrontherapy, Feb. 2017
Terra Foundation



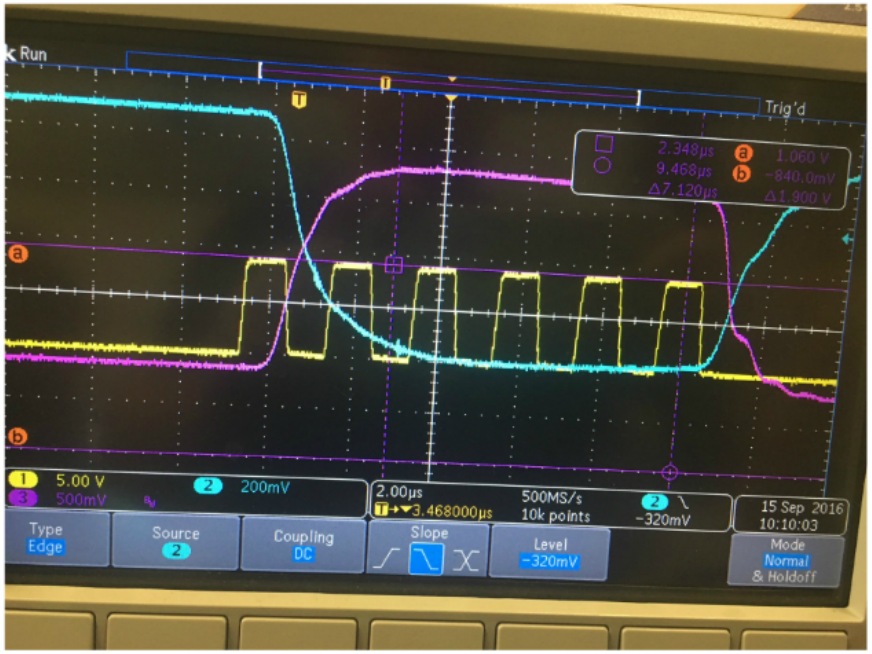
CABOTO

- Will bring the beam up to 430 MeV/u, and be able to vary this energy in the range 100 MeV/u –430 MeV/u
- 34 MBK Klystrons, 34 m long

Future Concept Designs

"Burst Mode Pulsing"

TEST of BT258A at CERN June 2017



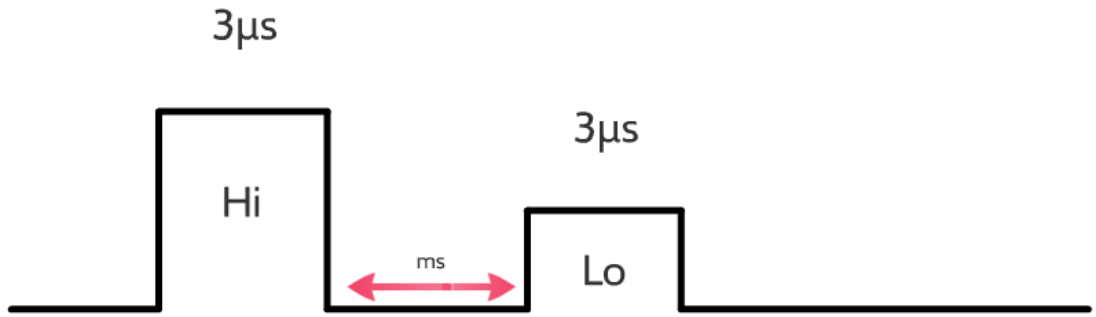
*Courtesy: Gerard McMonagle, CERN, Geneva, Switzerland

Operation set: 6MW peak power, RF pulse length 11µs, burst 1µs.
Modulator pulse length is 10µs.

Future Concept Designs

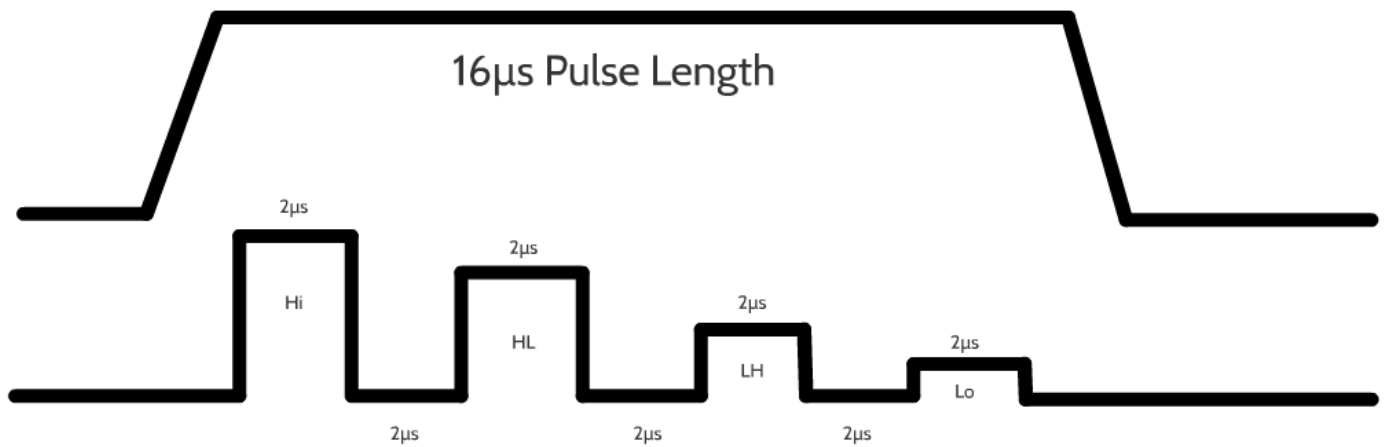
"Burst Mode Pulsing"

TODAY



Magnetron RF Output Power pulse. Or dual energy modulator system

NOW



LLRF signal

Operation set to 16µs, change LLRF signal for different RF Peak Output Power pulses. You can also vary the pulse length.

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Thank you for your attention

...and lets us now enjoy Shanghai evening

A Special Thanks To
Prof. Ugo Amaldi, Tera Foundation
G. McMonagle, CERN
I. Syratchev, CERN
JEMA ENERGY