High efficiency work and MBK development for accelerators

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Beijing Vacuum Electronics Research Institute

High efficiency work

- Project overview
- Physical mechanism
- Compatibility design
- Test result and future work

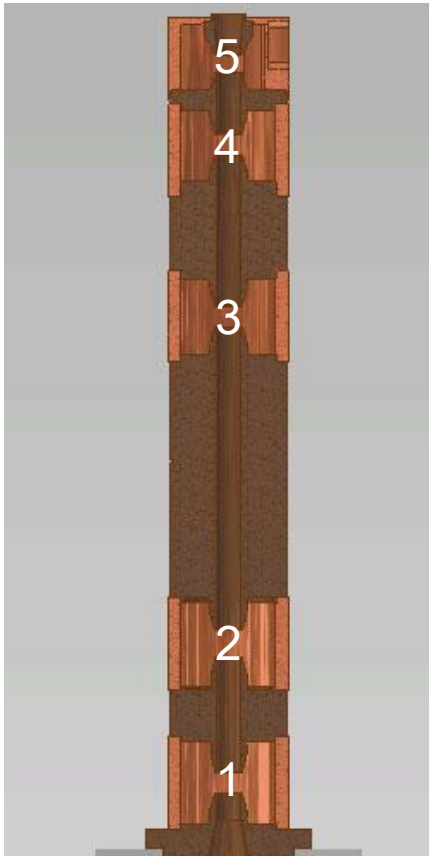
Project overview

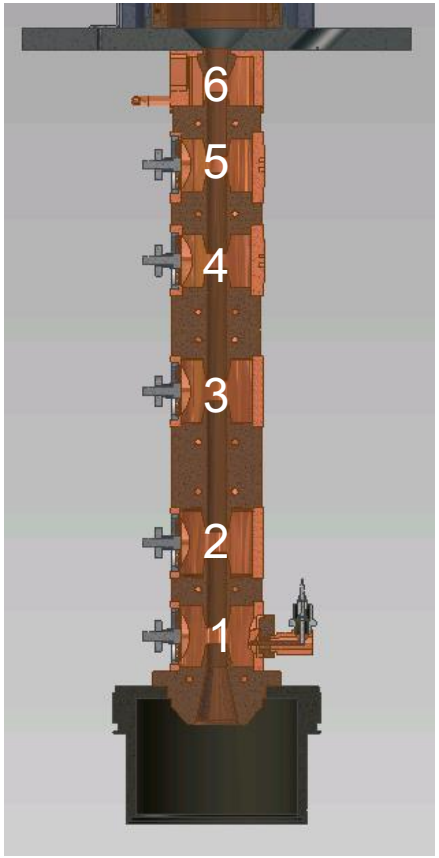
- We simulate and compare several bunching method to help us understand the physical mechanism.
- In consideration of the compatibility with current test system (solenoid and modulator), a plug-compatible klystron has been designed and fabricated to verify our work.
- The redesigned tube has just one more cavity added with the identical tube length.

Technical specification

Center frequency	2856MHz
Peak output power	5.5MW
Efficiency	45%
Gain	45dB
Beam voltage	130kV
Beam current	90A

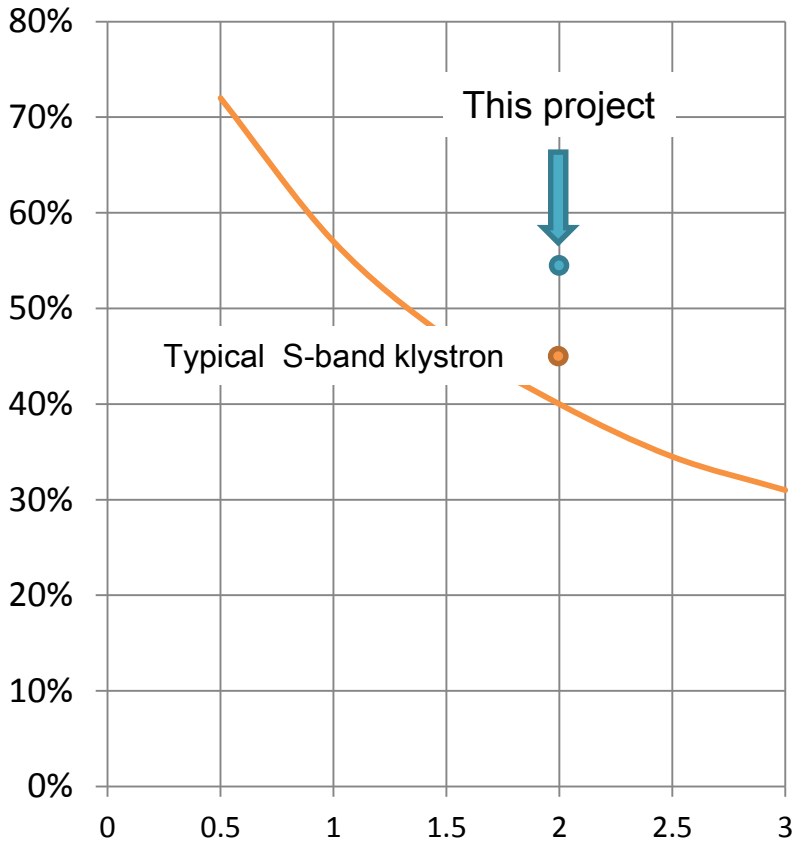
Typical S-band 5MW klystron parameters





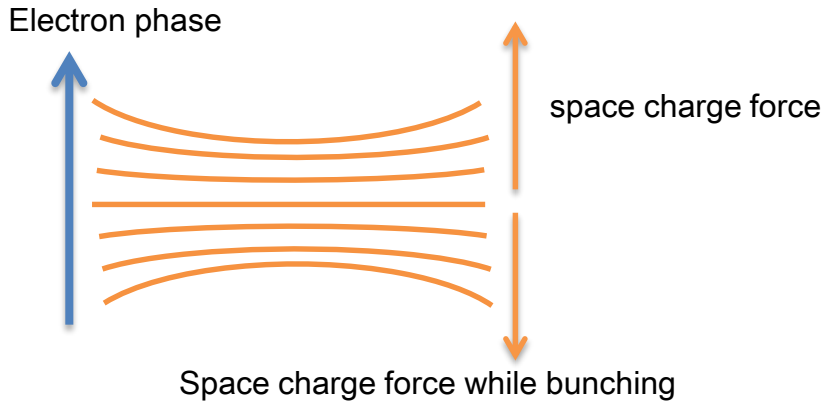
Project expectation

- In the classical efficiency-perveance diagram, a typical one stands slightly above the curve while our tube has a better performance of about 10% increase.

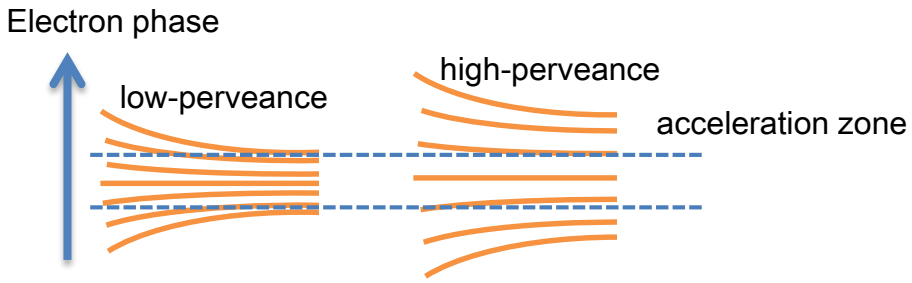


Physical mechanism

- The mechanism of electron bunching has been well studied.
- E-field between the gaps forces them gathered around the phase center while the space charge force drives them away.
- In a high-perveance tube, one cannot expect a narrow velocity spread when enter the output cavity, thus will lead to acceleration of the outside electrons.



Space charge force while bunching

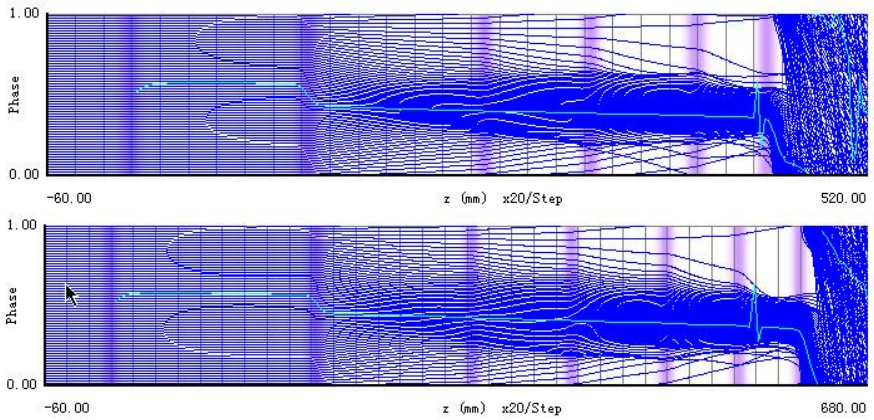


Phase bunching status entering output cavity

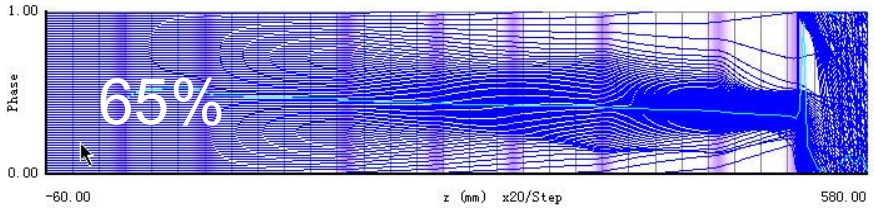
COM/BAC method application

- In the very beginning, we compare several bunching strategy regardless of the tube length and the cavity number.
- Higher efficiency leads to longer tube with more cavities.
- With BAC method, a simulation of 65% efficiency can be reached which gives some idea on how the beam phase can be arranged to maximize efficiency.

BAC method of increasing the efficiency in klystrons
Guzilov I A.
Vacuum Electron Sources Conference



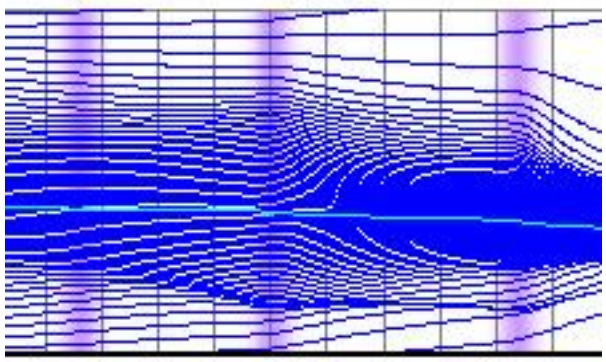
Electron bunching with 6/7 cavities using COM



Electron bunching using BAC

Detail inside bunching

- Within the bunching process, the electrons outside must suffer a greater phase-shift than the inner ones.
- Looks like the inner ones ramble around and wait the outside ones to come.



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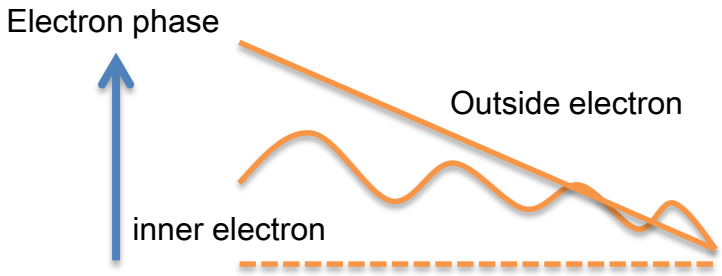
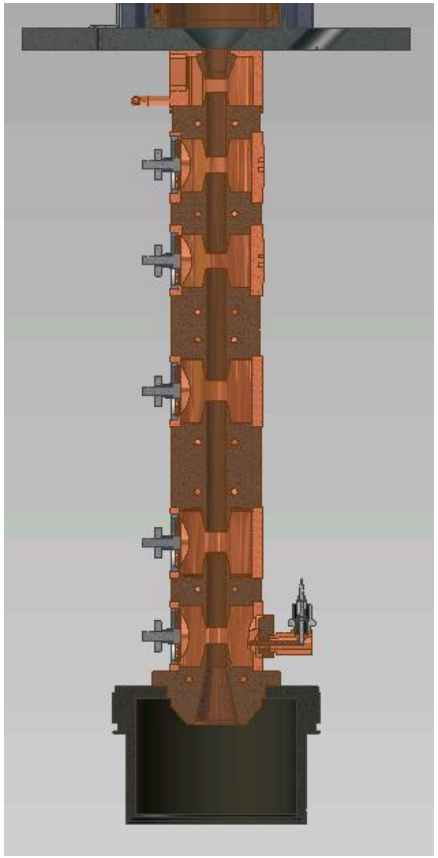


Compatibility design

- With adjustment of cavity distribution, a simulation of 59% efficiency can be reached.
- A plug-compatible test tube was designed and fabricated.
- The former tube has a long drift section, which leaves some space for improvement.



Test result

- Beam voltage is 12
  current is 75A. Und
  peak output power
  the water load.
- An efficiency of 53
  achieved due to th
- Further test is nee
  voltage and duty c
- Fixing the modulat

Test modulator 140kV

Future work

- Fabrication of an identical one for validation.
- A new design with more cavities to verify our understanding of the bunching method.
- A 7.5MW S-band tube will be designed and fabricated. With higher efficiency, we can reach the power with lower voltage.

MBK development for accelerators

- Tube under test in X-band
- Preliminary result of a C-band MBK with 2.7MW peak power

X-band MBK for medical accelerators

Center frequency	9.3GHz	Beam voltage	70kV
Peak output power	3MW	Beam current	110A
Duty cycle	≥0.2%	Heater power	100W
Efficiency	≥40%	Input	Type N
Gain	> 45dB	Cooling system	Oil cooling
Pulse width	10μs	Focusing system	Integrated EM
Layout size	Φ190*350mm	Weight	20kg

Tube parameters for specification

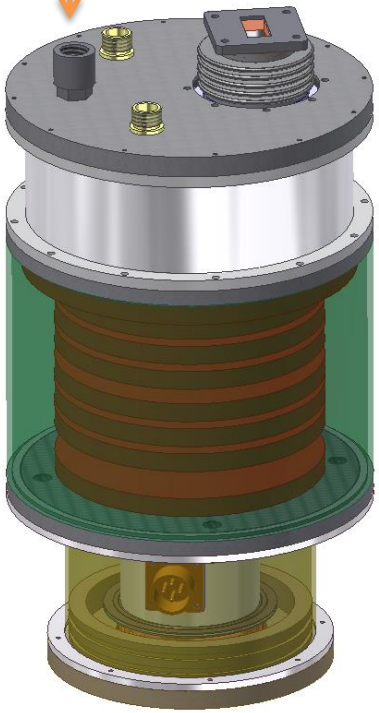
Features

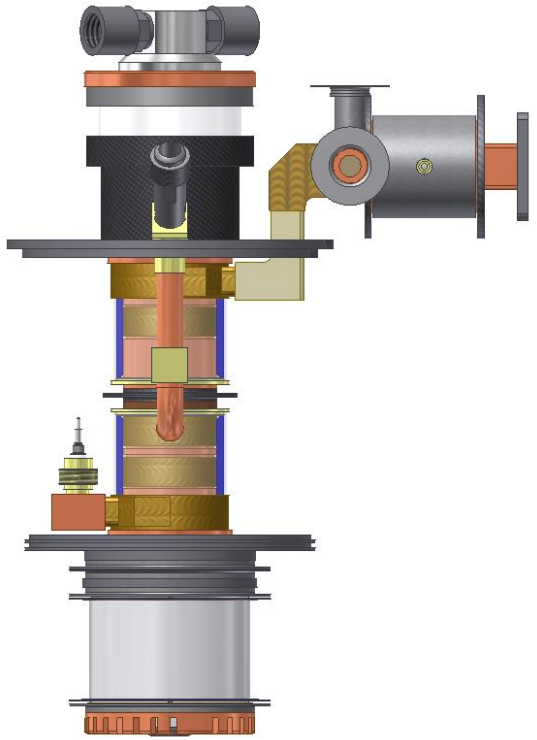
- Supply for medical accelerators
- Solenoid integrated with tube
- Oil cooling system integrated with tube
- Weight only 20kg totally

Layout size

oil cooling

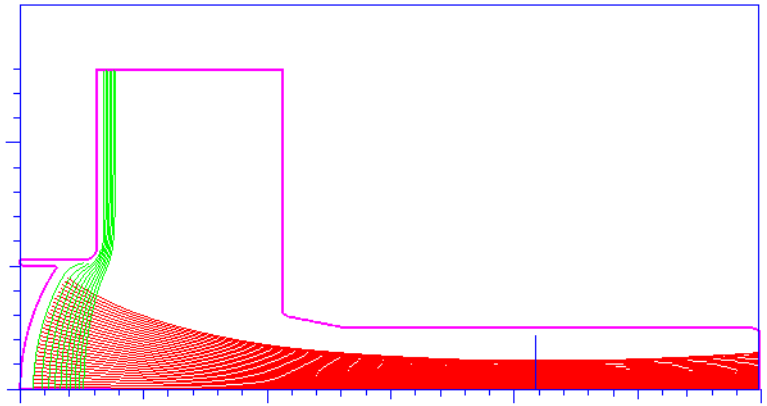
integrated design → 350mm

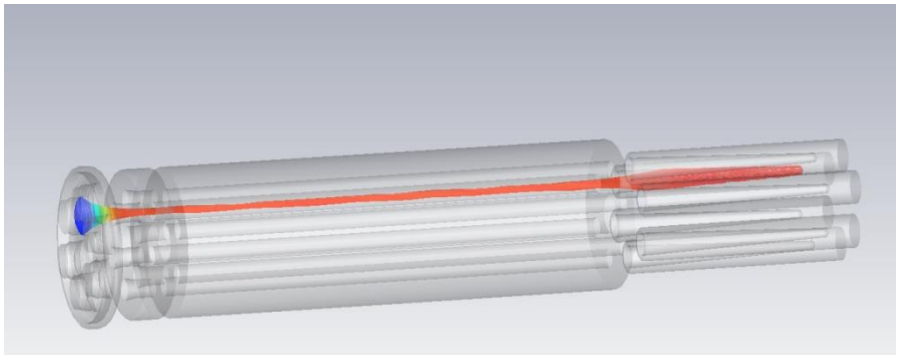




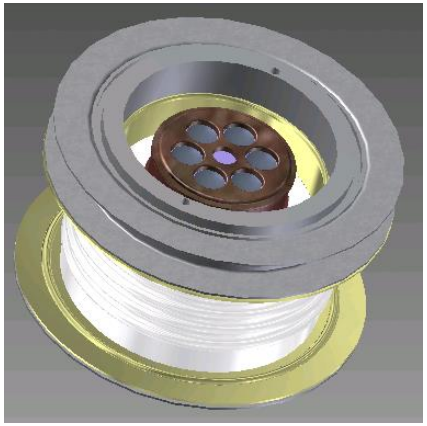
solenoid
design for validation

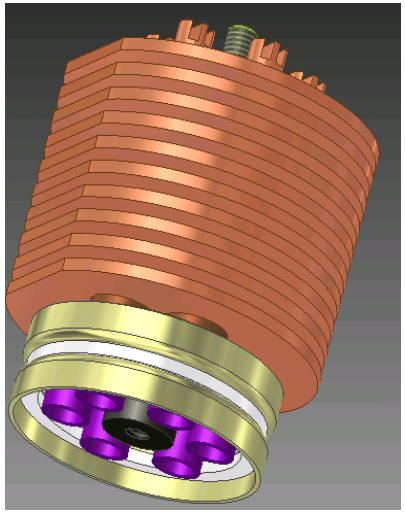
Design detail





6 beams with
coaxial cavity

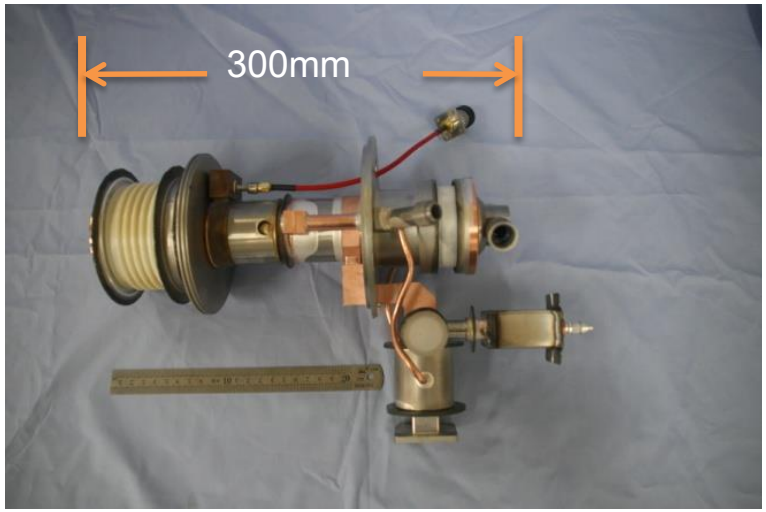




collector with
oil cooling

Current situation

- Tube with solenoid is under test while we are fixing the modulator.
- Finish fabrication and test of the integrated one by the end of this year.



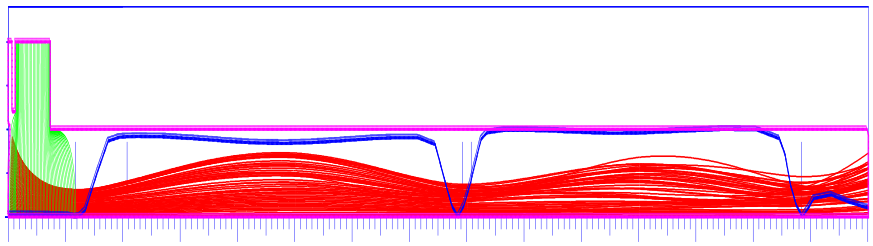
C-band MBK

Center frequency	5.712GHz	Beam voltage	50kV
Peak output power	3MW	Beam current	150A
Duty cycle	≥0.2%	Pulse width	10μs
Efficiency	≥40%	Focusing system	PRPM
Gain	> 45dB	Weight	35kg

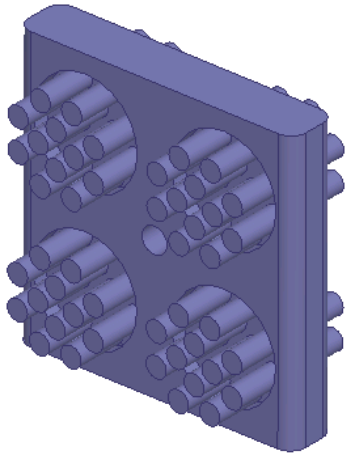
Tube parameters for specification

Features

- TM_{220} rectangular cavity design
- PRPM focusing system
- 35kg totally



Electron tracking with PRPM focusing

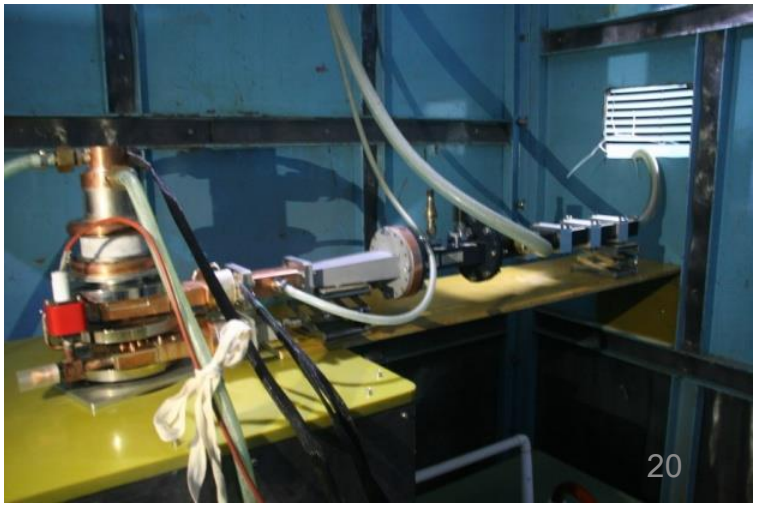


TM_{220} cavity

Test result

- A primary tube has been tested, output power of 2.7MW can be reached with the duty cycle of 0.2% under the voltage of 50kV.
- Electron transmission need to be improved with adjustment of pole piece.

Parameter	Measurement	Specification
Peak power	2.7MW	3MW
Duty cycle	0.2%	0.2%
Transmission	70%	90%
Efficiency	37%	40%



Summary

- S-band klystron with efficiency of 55% which still needs further test while we are fixing the marx modules.
- 7.5MW tube with higher efficiency under design and will be tested the next year.
- X-band MBK with integrated design tested this year.
- C-band MBK with 2.7MW and still needs adjustment.

Thanks