Communications & Power Industries

Extended Interaction Klystrons DNP – NMR

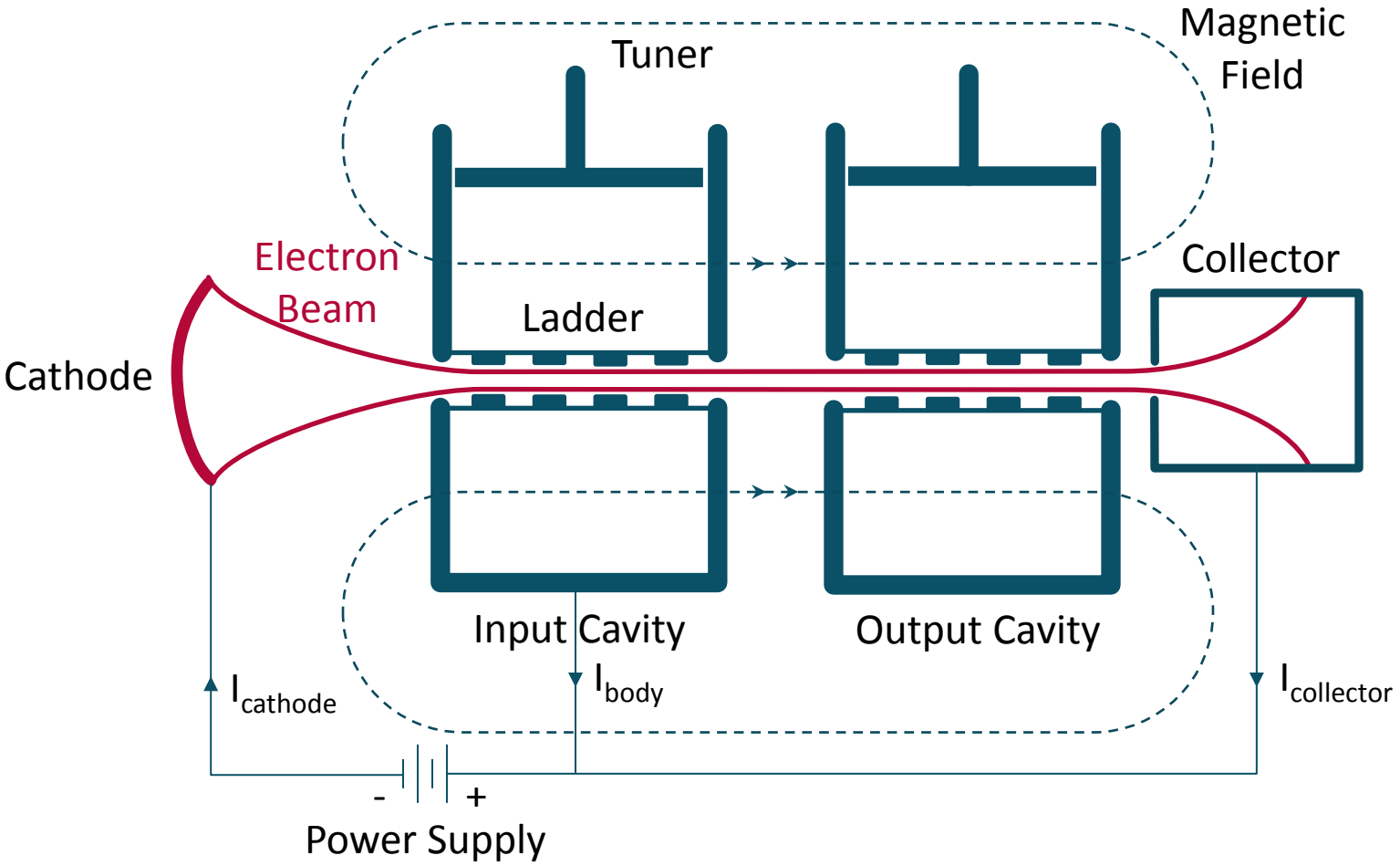
European COST Network on Hyperpolarization

Ross.MacHattie@cpii.com

Extended Interaction Klystrons

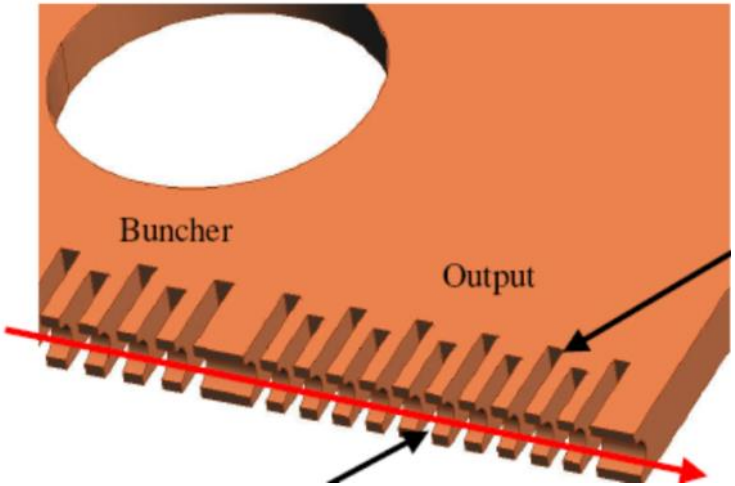
- EIK Technology
  - Based on Klystrons
    - Rugged
    - Reliable
  - Enhanced
    - Power
    - Bandwidth
    - Efficiency
  - GHz and THz frequencies
  - Moderate voltages
  - Compact
  - Minimal maintenance
- CPI Canada EIKs
  - Design & manufacturing
    - 40 years of experience
  - Applications
    - Radar
      - Airport
      - Space
      - Earth Observations
    - Communications
    - Instrumentation
      - DNP/ESR
  - Frequency range
    - 17 – 280 GHz proven
    - 0.7 THz modeled

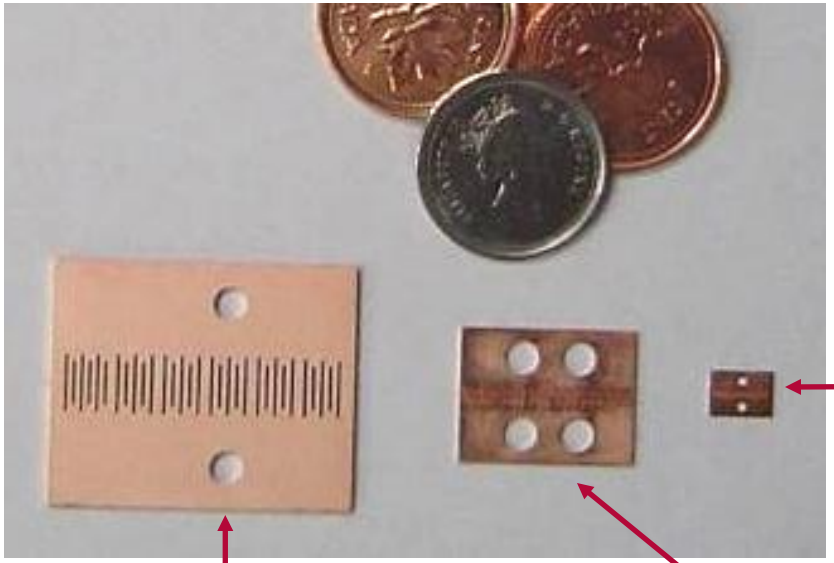
EIK Principle of Operation



Ladder Structure

- Ladder structures provide
  - High coupling impedance
  - Thermal stability



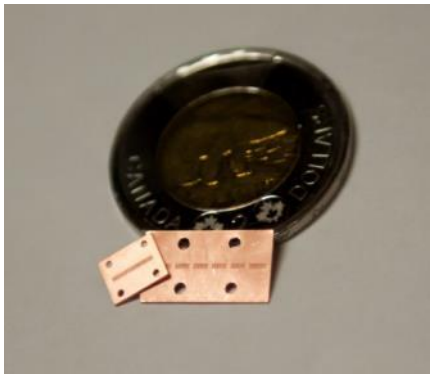


263 GHz
10 W pulsed
5 W CW

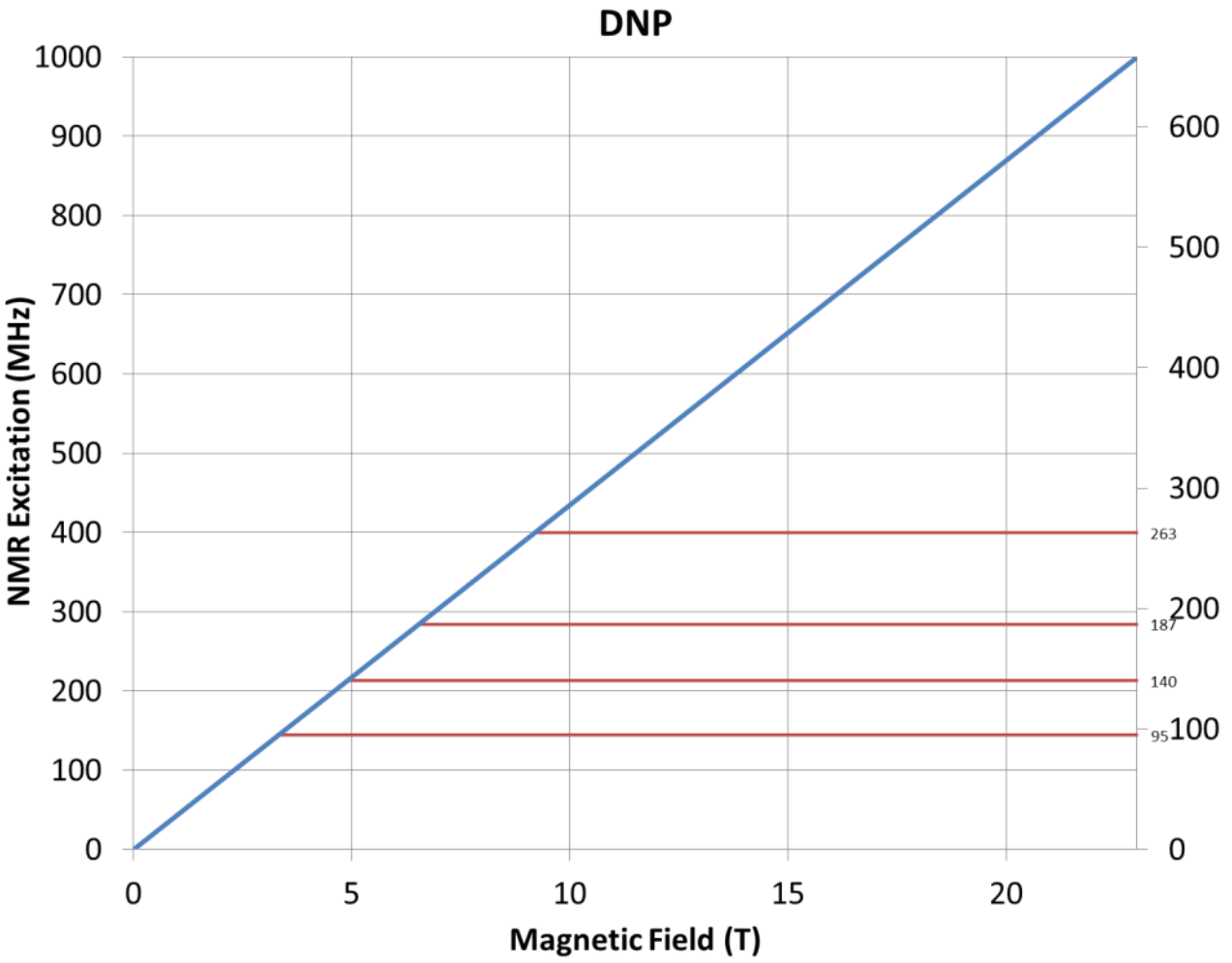
140 GHz
300 W pulsed
50 W average

30 GHz
3000 W pulsed
1200 W CW

95 GHz
2000 W pulsed
400 W average

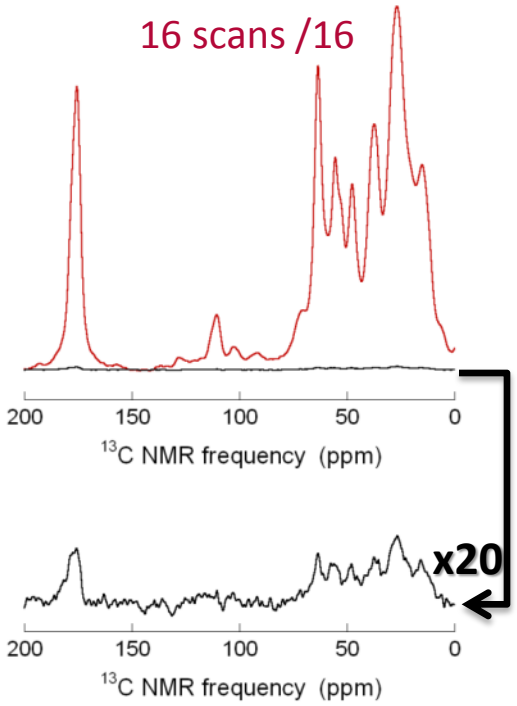


EIK/EIO DNP Frequencies



Signal Increase 110x*

with microwaves
16 scans /16

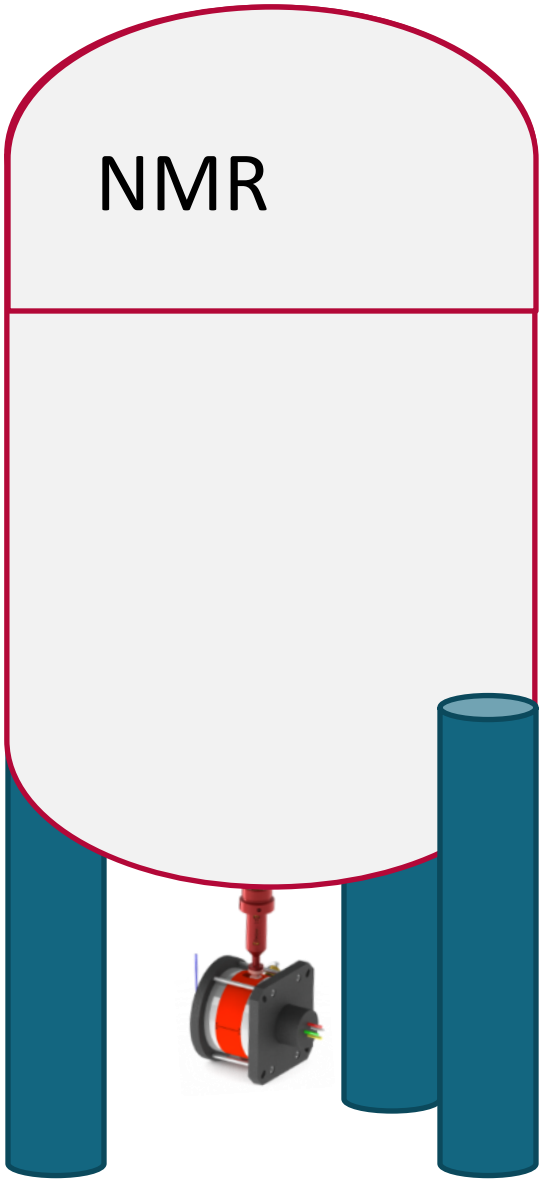


without microwaves
128 scans /128

*National Institutes of Health

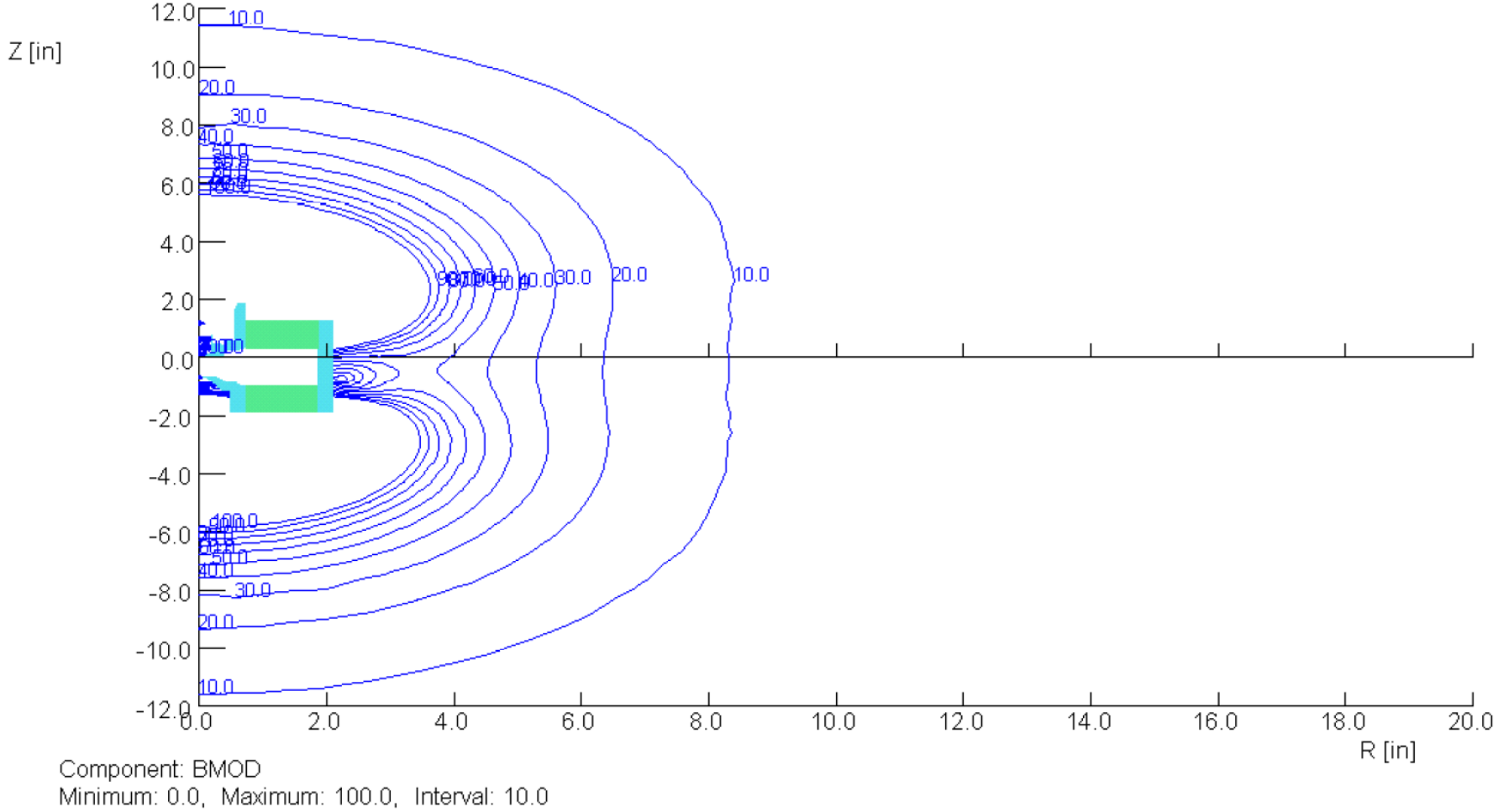
DNP Requirements

- Highly stable mmWave source
  - Short-term pulse-to-pulse amplitude stability
    - 0.02 dB RMS
      - Comparable to lower frequency EIKs
      - Predominantly driven by PS stability
- Wide bandwidth/tuning range
  - 1 GHz bandwidth (EIK)
  - 9 GHz tuning range (EIO)
- Compact
  - Close to NMR
  - Short waveguide run



Stray Magnetic Field Isoline Map

CPI 263 GHz EIK Magnet

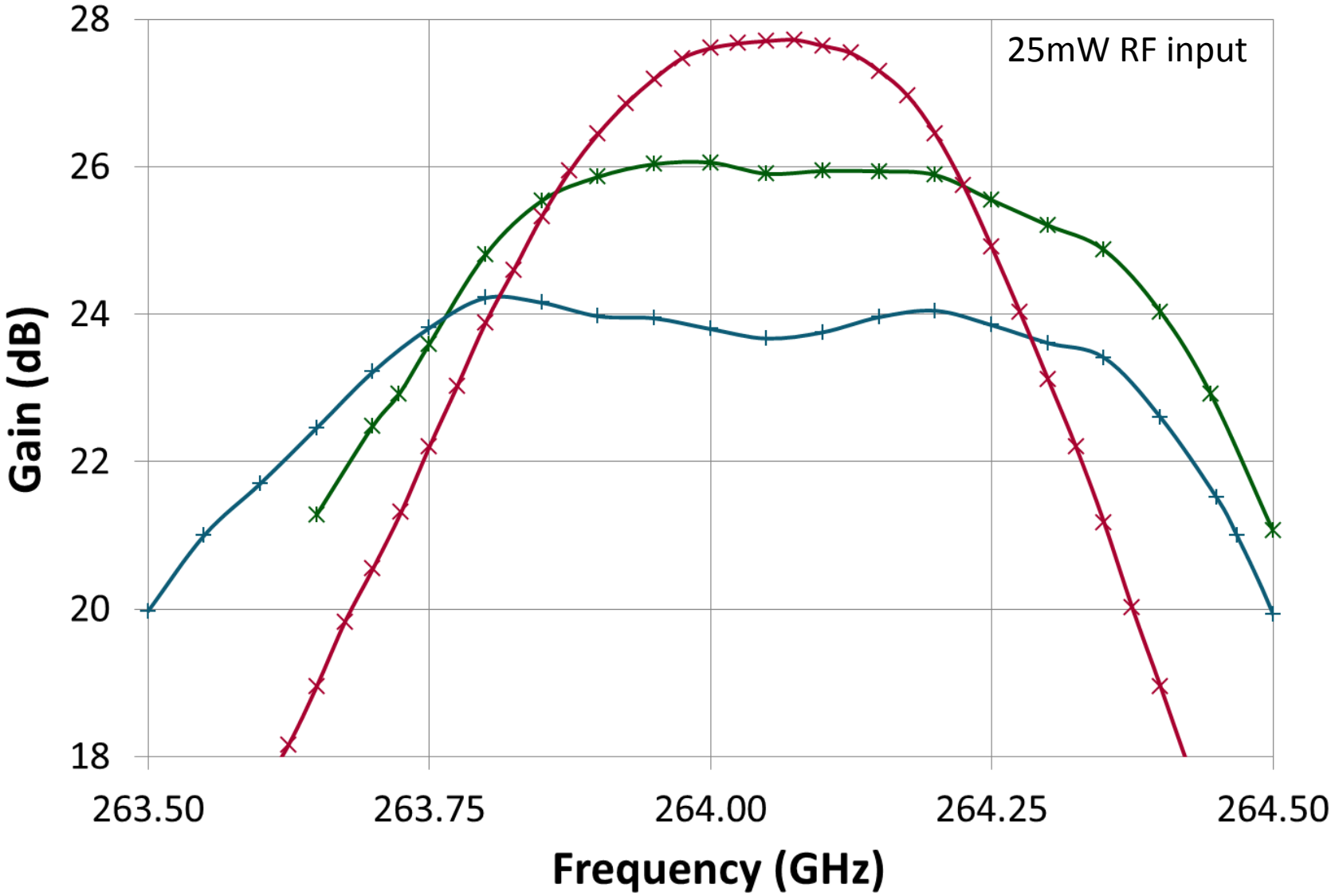


Contours of constant magnetic field (gauss)

264 GHz Pulsed EIK

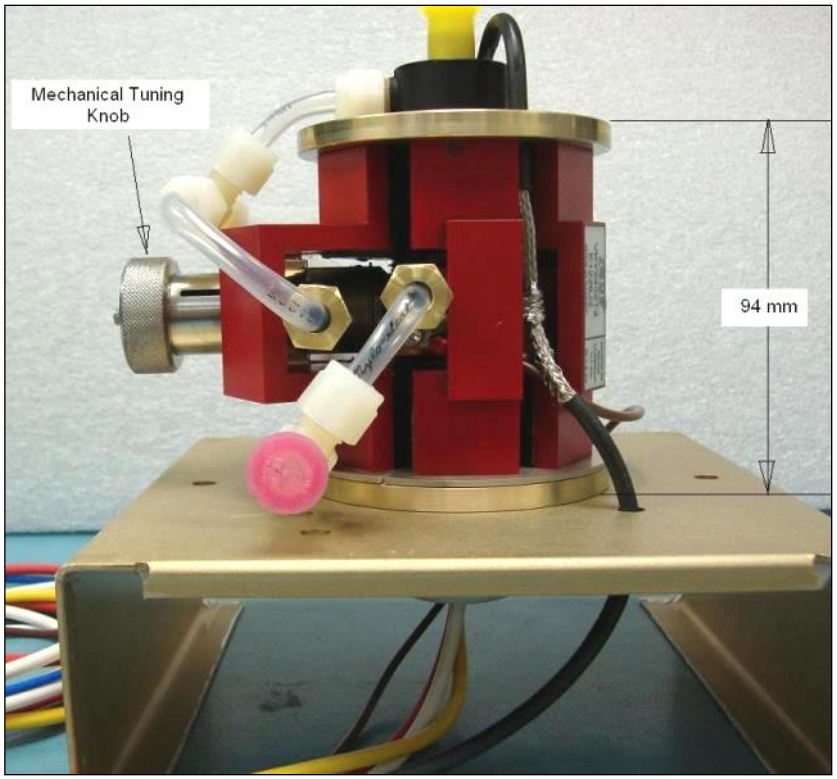
- Gun Optics
  - 18.5 kV
  - 250 mA
  - 18 µm x 15 mm tunnel

Pulsed EIK Gain Response



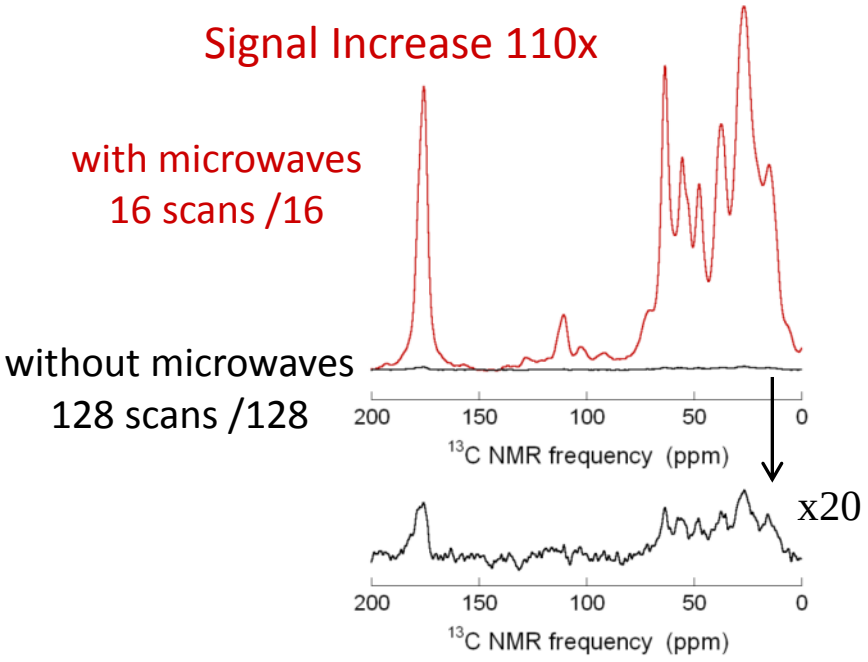
263 GHz CW Tunable EIO

- Developed for NMR experiments
- Cathode Current – 120 mA
- Cathode Voltage for Fundamental mode operation – 11.5 kV
- Cathode Voltage for High order mode operation – 12.3 kV
- Frequency separation between operating modes ~ 2 GHz
- Mechanical tuning range – 9 GHz
- Cathode Lifetime – 20,000 hours
- Liquid Cooling
- Weight < 3 kg

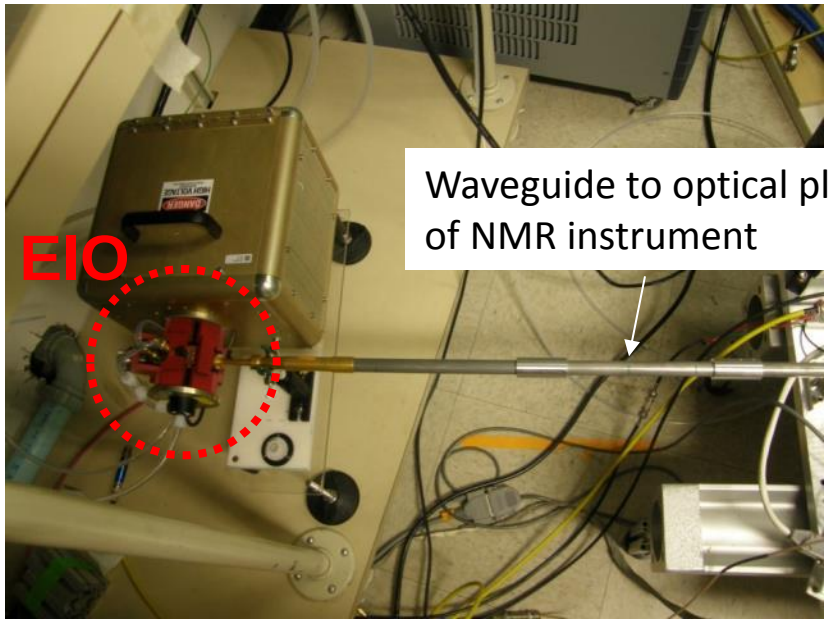


NMR Kidney Health Research

- 263 GHz EIO
  - USA National Institute of Health (NIH)
    - DNP enhancement of NMR spectra
    - Significant increase (110X) in NMR signal

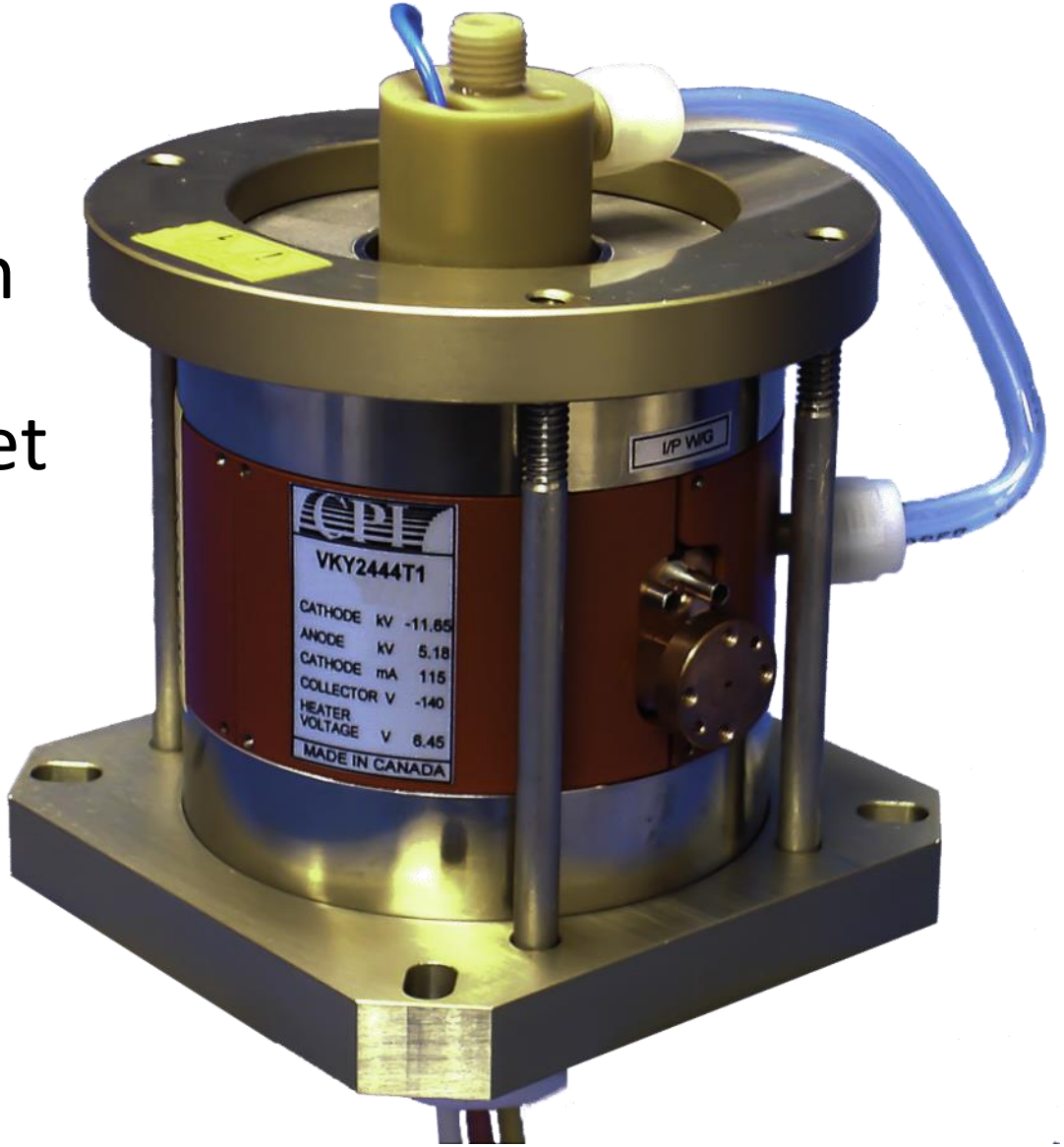


Data provided by NIH for CPI presentation at IVEC 2013

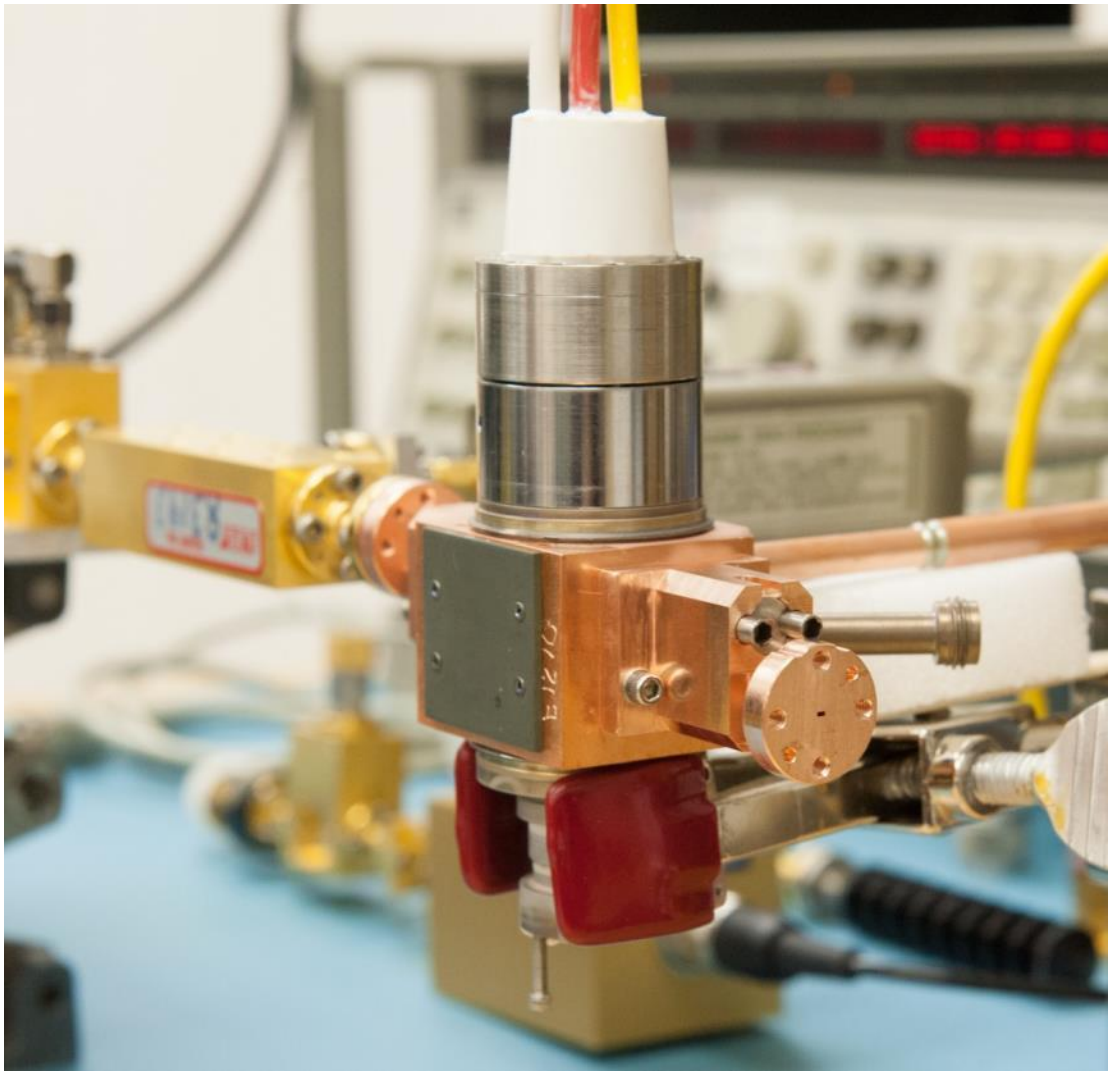


187 GHz CW EIK

- 5 W CW
- 400 MHz Bandwidth
- Single period magnet
- Water cooled
- Single stage depressed collector



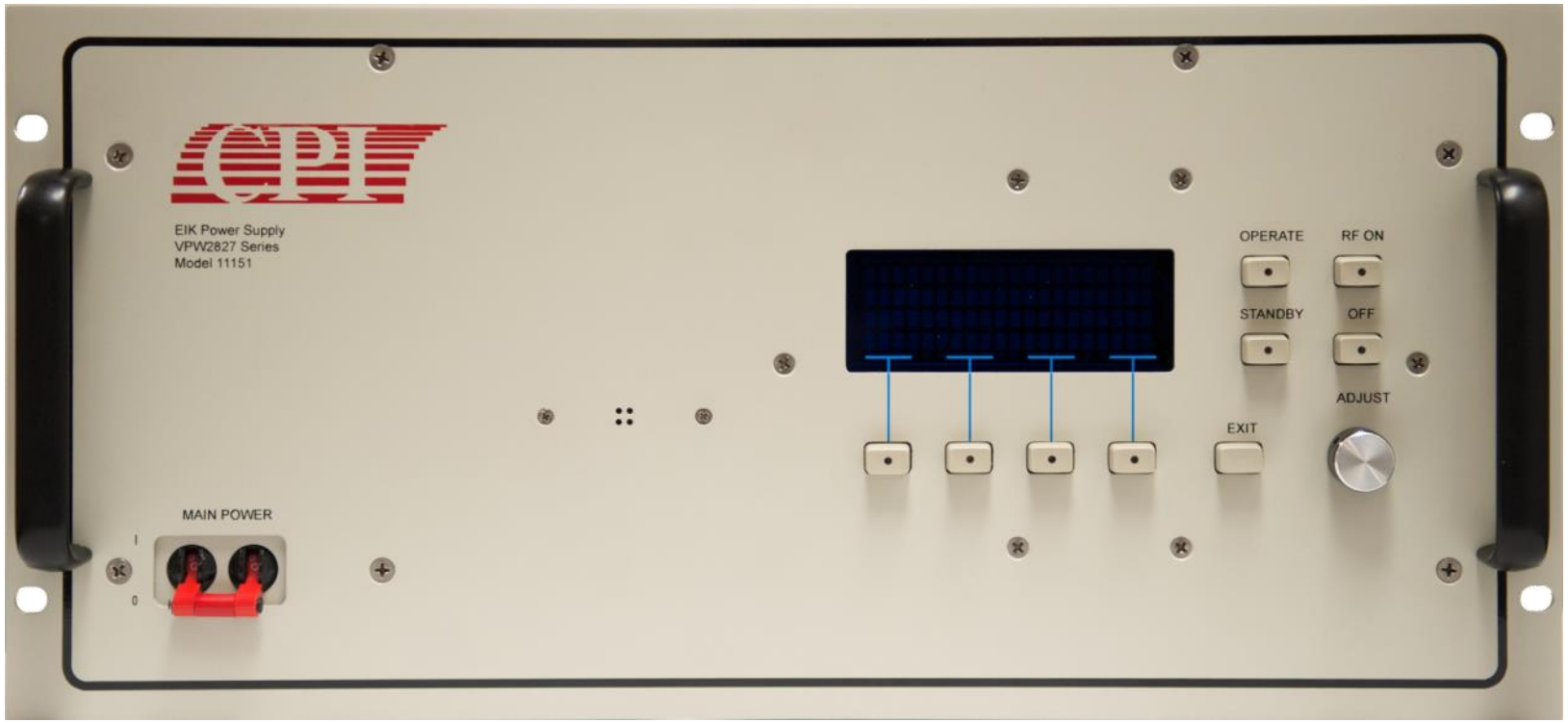
187 GHz EIK in Production



- Cold-testing
  - complete
- High-Pot testing
  - just finished
- Magnets
  - to be assembled
- Hot-testing
  - to follow

187 GHz EIK

- Six cavity EIK (fixed tuning)
- Turn-key Operation: Commercial Power Supply



Conclusions

- Proven DNP Solutions

Amplifier (EIK)	Power	Duty	Bandwidth
95 GHz	1 kW	10 %	1,000 MHz
95 GHz	100 W	100 %	200 MHz
187 GHz	5 W	100 %	400 MHz
263 GHz	10 W	1 %	800 MHz

Oscillator (EIO)	Power	Duty	Tuning Range
140 GHz	20 W	100 %	5,000 MHz
263 GHz	5 W	100 %	9,000 MHz