Extended Interaction Klystrons
DNP – NMR

European COST Network on Hyperpolarization

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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

Tuner

Electron Beam

Cathode

Ladder

Input Cavity

Output Cavity

Collector

Magnetic Field

Power Supply

$I_{\text{cathode}}$

$I_{\text{body}}$

$I_{\text{collector}}$

2014.06.27 2014 COST Hyperpolarization
Ladder Structure

- Ladder structures provide
  - High coupling impedance
  - Thermal stability

- 30 GHz
  - 3000 W pulsed
  - 1200 W CW

- 95 GHz
  - 2000 W pulsed
  - 400 W average

- 140 GHz
  - 300 W pulsed
  - 50 W average

- 263 GHz
  - 10 W pulsed
  - 5 W CW

- 2014 COST Hyperpolarization
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

Frequency (GHz)

Gain (dB)

25mW RF input
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 EI K

- 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

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<th>Amplifier (EIK)</th>
<th>Power</th>
<th>Duty</th>
<th>Bandwidth</th>
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