Efficient (and not so efficient) klystron work at Lancaster University

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CLIC MBK Study

- Collaboration with CERN and Thales (Erk Jensen, Igor Syratchev, Phillipe Thouvenin, Rodohple Marchesin).
- Efficiency as main target
- Evaluated configuration options, multiple beam klystron
- Targeted a conservative (plausible) design
- Targeted TESLA/ILC specification
- Theoretical efficiency: 80% (beyond state of the art)
Why many beams?

• Low permeance leads to higher efficiency.

\[
\text{permeance } K = \frac{I}{V^{3/2}}
\]

• Low current -> lower space charge forces -> better bunching -> higher efficiency

• 20 beams – trade off between beam voltage and complexity due to beams

\[I_b = 8.2A\]
\[V_b = 115V\]
Cavity Choices

1. Reentrant Cavity

2. Recessed Reentrant Cavity

3. & 4. Coaxial Cavity

5. Whispering Gallery
Cavity choice

- Comparison of multiple cavity types.
- Re-entrant & HOM cavities -> Low R/Q
- Recessed re-entrant and coax cavity -> high R/Q
Cavity HOMs

Can model coaxial cavity as a piece of ridged waveguide
Very good agreement even for HOMs

\[
\frac{\omega_0}{\omega_c} = \sqrt{1 + \frac{N^2}{R^2/\beta_c^2}} \quad \beta_c = \frac{\omega_c}{c}
\]

- Large diameter (35cm) at 15MW
- More power -> more beams -> larger still
  - Dipole mode gets closer for larger cavities
Interaction structure

• Optimised 6 cavity
• (single $2^{\text{nd}}$ harmonic)
• Low R/Q structure 70%
• High R/Q structure 20 beam structure up to 80%

Simulated efficiency of around 80% is possible for a 15MW tube
Automatic Klystron Optimisation

• Developed and published a new way to design klystron amplifiers:
  • ~14 Decisions (frequencies, drifts, Qe’s)
  • 3-4 objectives (efficiency, length, bandwidth, slowest electron)
    • Multi-objective optimiser
  • 5000-10,000 evaluations
  • Impractical without high throughput computing (CI HTCondor Pool)
    • Use spare clock cycles of desktop pcs
Multi Objective Optimisation

• In place we use non-dominated sorting (where a and b are solution vectors)

• Sort into groups where no one characteristic can be further optimised without detrimental effect on the other characteristics
Klystron Peculiarities

• We don’t want to know the gain, just whether it is in spec
• Target efficient “long” klystrons over short inefficient
Applied to B-Factory Klystron

- 71.9% efficient
  - more or less the same
- 19.8% shorter than published design
  - might be better, might not.
- 10,000 iterations
- Not much effort

![Graph showing Efficiency vs. Length comparison with Published design marked by an asterisk.]
The Future

• Secured funding to continuing efficient RF source work for CLIC
  • 2 years RA
  • PhD student

• Open 1.5D Klystron Code

• Benchmark Vorpal (the new magic?)

• Investigate new techniques for efficiency

• New collaborations.
InEfficient RF Sources Workshop
mm-Wave Upconverting Klystron

- Conventional klystron with a 3rd harmonic output cavity
- Input 1W at 31GHz
- Potential to output 200W @ 94GHz
  - 6 cavities
- Designed to be cheap to manufacture.
Operating Principal

• When beam is modulated with first harmonic the third harmonic exists anyway

• Just put in a 3\textsuperscript{rd} harmonic cavity
**mm-Wave Upconverting Klystron**

- First upconverter at these frequencies
- Has been built
- Hot test planned
- Collaboration with Strathclyde University
- Requires 9kW electron beam
  - 2% efficient
- 3 cavity proof of principal (0.2% efficient)
Announcements

• Bus Leaves the Cockcroft at 5:30
• Dinner Begins at 7pm in the hotels restaurant.