Higher Efficiency High Power RF Generation

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The limitation of synchrotron radiation losses to continuous 50 MW per beam is a basic design choice for the FCC-ee. Thus, the RF systems must provide a continuous total RF power of 100 MW, which is delivered through the cavities to the beam. To keep the overall power consumption at bay, CERN has started a focused R&D program towards high-power CW klystrons with very high efficiency. See e.g. https://ieeexplore.ieee.org/document/7194781 for some new ideas. Higher efficiency power conversion is of course relevant for all future accelerators and is – along with energy recovery – the only path towards "green" accelerators compatible with increasing demands to respect the environment. CERN has recently initiated the fabrication of a higher efficiency klystron industrial prototype, to be operated under realistic conditions in the LHC (400 MHz, 400 kW CW).

The lowest cost available sources of RF power are commercial magnetrons, which are mass-produced for industrial and food heating applications. These can be procured worldwide for less than $1/W including power supply, with efficiencies above 80%. For their use in accelerators however, they offer significant challenges, being oscillators rather than amplifiers and being inherently noisy sources. However by applying advanced control and feedback techniques the output power can be stabilized and locked to a reference source with greatly reduced noise, and the output power can be modulated continuously from full power to less than 40% while maintaining good efficiency. Maximum power available from existing commercial tubes is around 125 kW, so waveguide or cavity combiners are needed to create MW -class sources. While this is already sufficient for many industrial accelerator applications, further R&D is needed to determine if it can be acceptable for CW storage ring or LINAC operation.

Another approach towards higher efficiency, high power RF generation is the use of solid-state power amplifiers (SSPA). Solid-state RF technology has made tremendous progress over recent years. Since single solid-state devices do not reach the necessary power levels today, consequently an important part of R&D continues to be for low-loss power combiners, allowing combination of thousands of individual outputs. The development of high-power RF SSPAs based on GaN technology seems most promising today, and techniques to increase power conversion efficiency are already applied at lower power levels, e.g. for cellular communications. (Ref.: https://ieeexplore.ieee.org/document/8440054)

Areas of R&D:

- Higher efficiency klystron development involving modern concepts like "BAC", "COM", "CSM" and others. Application also to Inductive Output Tubes (IOTs),
- Investigate stabilization, phase control and combination of magnetron RF sources for possible accelerator use.
- Development of scalable power combiners to combine thousands of inputs (of kW level) in few stages to reach power levels necessary to operate large particle accelerators,
- Development, jointly with industry, GaN-based SSPA modules, applying techniques to increase efficiency at high power levels (Class F, multi-harmonic terminations …),
- Combination of the last previous two bullet points