GOBIERNO DE ESPAÑA | MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

CWRF 2014 — May 13-16, 2014 — Hotel NH - Trieste, Italy — Elettra Sincrotrone Trieste

AVAILABILITY IMPROVEMENTS FOR THE LIPAC RF POWER SYSTEM: TETRODES AND SOLID STATE SOLUTIONS

M. Weber, P. Mendez, D. Regidor, I. Kirpitchev, C.de la Morena, J. Molla, A. Ibarra

Introduction

The IFMIF/EVEDA Accelerator Prototype (LIPAc) is currently under construction in Rokkasho (Japan). LIPAc will generate a 9 MeV deuteron beam at 125 mA current with a 100% of duty cycle, and it will serve to validate the final IFMIF accelerator concept. The Reference Design for the Radiofrequency (RF) Power System, which is being integrated by CIEMAT (Spain) and its partner companies and institutes, consisted of 18 RF amplifier chains operating at 175 MHz: eight 200 kW chains for the radio-frequency quadrupole (RFQ); two 105kW chains for the re-buncher cavities of the Medium Energy Beam Transport (MEBT); and eight 105 kW chains for the superconducting half-wave resonator (HWR) cavities. It also comprised 13 high voltage power supplies (HVPS), which feed the final amplifiers, 18 coaxial transmission lines to reach the accelerator cavities, and the water cooling system primary circuit. Very high availability, high performance, and easy maintainability are the main objectives for this development. Dealing with such a challenging goals has required successive improvements in the reference design. The different proposals and developments are described in this poster

Availability at IFMIF

IFMIF(international Fusion Materials Irradiation Facility) will irradiate fusion structural materials under similar energy spectrum to the Fusion Neutron energy spectrum in order to test them under inner fusion reactor conditions. The data obtained from IFMIF are required for the building of the future DEMOnstration Fusion Reactor. Any delay in the IFMIF Program would directly delay the Fusion Program and the commercial application of Nuclear Fusion Energy. Achieving the required dpa on the materials pivots on two parameters: Deuteron current at the accelerator and irradiation time. Since IFMIF deuteron current is foreseen to be the maximum reasonably achievable (125 mA/accelerator) the only way to speed up the Program is by increasing the Availability.

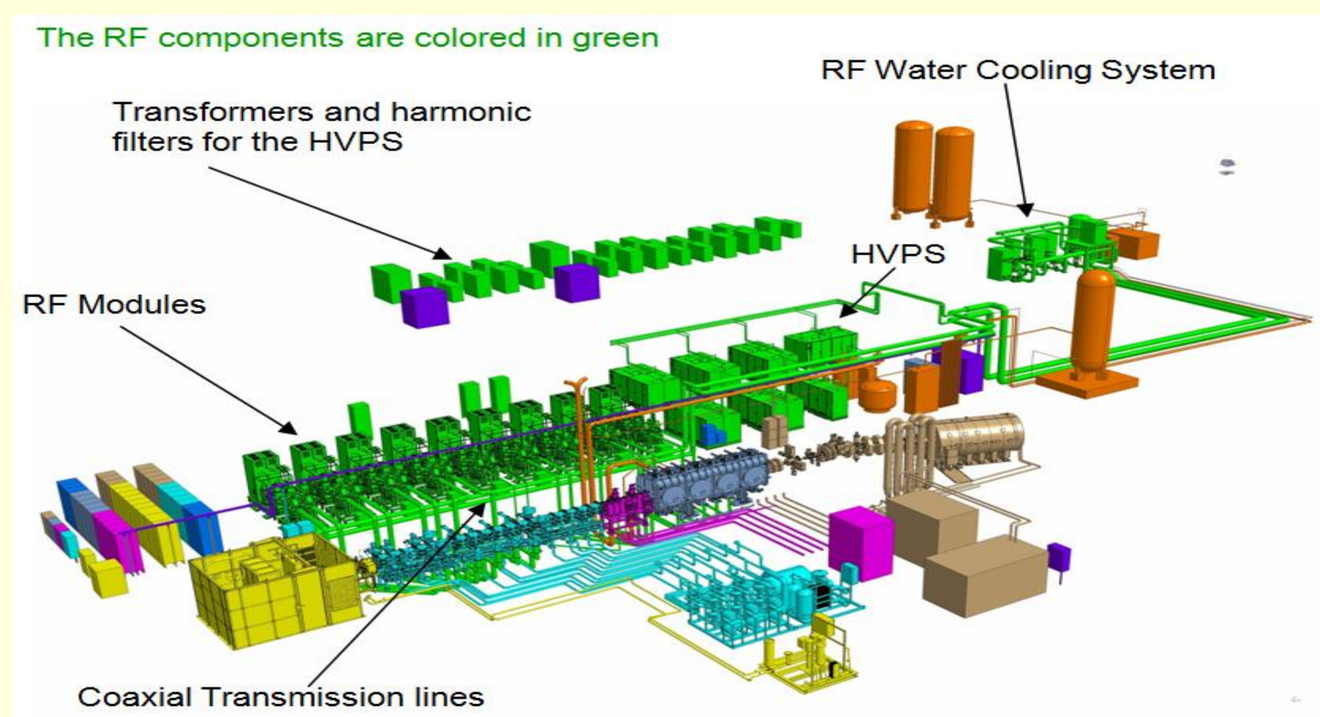
Since the RF Power System is the main active system of the accelerators sharing interfaces with most of the Accelerator Systems, its availability highly impacts on the IFMIF's overall availability. In order to increase RF Power System availability, the Reference Design has been improved by means of the following innovations:

1. **The Integrated RF Module and the Smart Spare Concept**
2. **The Ultra Available Solid State Power Amplifiers (SSPA)**
3. **The Fully Digital LLRF**
4. **The Matrix power combiner**

LIPAc RF System Reference Design

The Reference Design for the LIPAc RF RF Power system consists of :

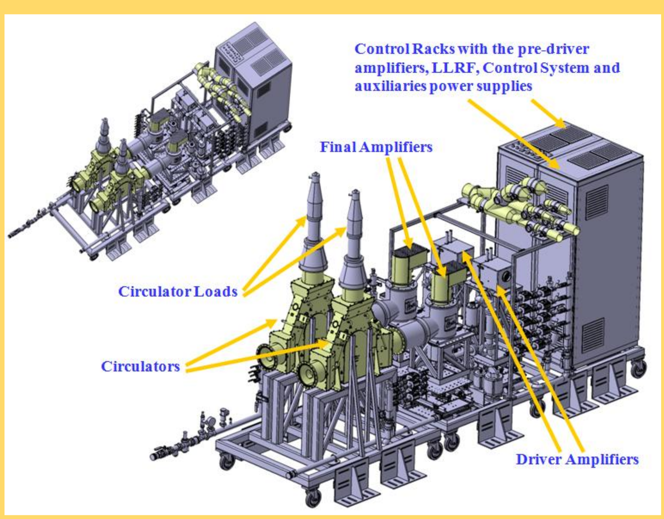
1. **Eight 200 kW RF chains for feeding the RFQ**
2. **Eight 105 kW RF chains for feeding the Super Conducting Linac**
3. **Two 105 kW RF chains for feeding the bunching cavities of the MEBT**
4. **Thirteen 400 kW, 13 KV DC Power Supplies (HVPS) for feeding the Anodes of the Final Amplifier Tetrodes**

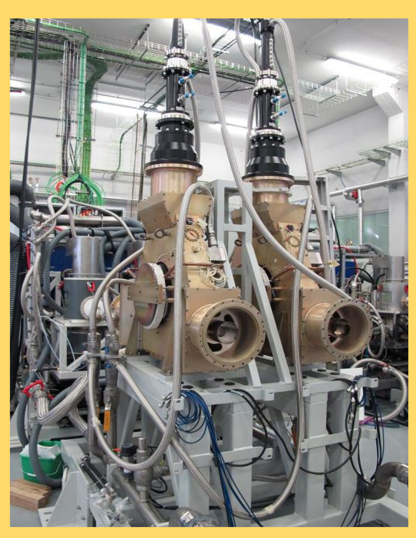


1. The Integrated RF Module & the Smart Spare Concept

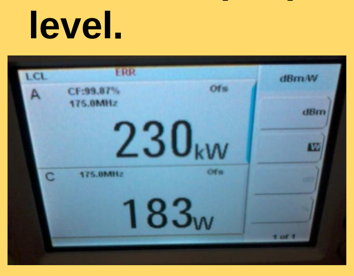
In most of the big science accelerators, RF power chains use to be located on the floor or supported by different structures often requiring complex disassembly works in case of substitution or deep maintenance. This characteristic leads to a longer time for repairing than the usual in the industry. This is not a very important issue in case of pulsed operated scientific accelerators, but IFMIF requires as much working time as possible in order to not delaying the Fusion Program. Due to the high number of RF power chains at IFMIF (104), their high power levels (200 kW) and the high number of components required by the tetrode technology, the Reference RF power system was destined to have an unacceptable availability from the IFMIF's point of view.

An innovative solution was proposed in order to improve the availability: The Integrated Module. This is a wheeled structure containing 2 complete RF chains. All the components of the 2 RF chains (except the HVPS) are on board of the wheeled platforms. Each platform (2 RF chains) can be removed and replaced by a spare one in only 3 hours, being the best way of limiting and minimizing the substitution time. That means that in the worst case, the accelerator will restart the operation in less than three hours after the worst fault happens in the RF power system. IFMIF Accelerators Facility's calculated availability increased several points by this concept. Of course, further availability has been achieved by a modular design at all the system and subsystem levels. This daring design was developed by CIEMAT and its partner company INDRA SISTEMAS.





Additionally, no bad consequence of this new design have been found on signal quality. The full power tests of the amplifier demonstrated its capabilities, exceeding the foreseen. The achieved gain after the fine tuning is 25.4dB showing a very high anode efficiency (73% at final amplifier). With 230kW CW RF output, the HVPS provides 11.6kV and 27A to the anode of the TH781. The output signal is a very clean sinus wave and the worst harmonic (3rd) is 30dB below the carrier level.



The SMART SPARE CONCEPT consists of a database containing all the parameters of each RF line (including circulator and couplers) that can be fast loaded on the Hot spare RF module in order to drastically speed up the setting of the spare for being installed in the failed RF line. That means that keeping ready only 2 Smart Spares for each IFMIF accelerators would be enough for fast repairing of any failure in less than 3 hours.

3. Fully Digital LLRF

Traditional LLRF designs for accelerators have been based on the use of analog IQ modulators/ demodulators for the RF signal generation and demodulation. Migration toward digital LLRF designs is the trend at the present moment. Recently several partially-digital LLRFs have been developed, where an intermediate frequency signal is digitally generated and the final up-conversion is analogically performed. One example is that developed by CIEMAT in collaboration with CELLS. Currently, CIEMAT is developing a new fully digital LLRF System for LIPAc, that means that both, signal modulation and demodulation are fully performed in the digital domain. This is a clear advantage in terms of flexibility, reliability, and fast response. Several companies, like SEVEN SOLUTIONS, have contributed with components and assessments.

4. Matrix Power Combiner

Achieving several hundreds of kW with SSPA requires several combination stages because the most powerful available transistor reaches only 1.2 kW. Each combination stage means from .15 to .25 dB of looses, leading to a poor efficiency at very high power levels. Before developing a very competitive VHF SSPA of several hundreds of kW, new combining structures have to be designed and tested.

CIEMAT is now testing a 200 kW 175 MHz Matrix Combiner with only one combination stage and high efficiency expected. CIEMAT will propose this system for being validated in the LIPAc accelerator as an alternative for the IFMIF RF System.

2. LIPAc & IFMIF Solid State Amplifiers

At the beginning of the IFMIF/EVEDA project, several reports and assessments were done to choose between the different technological alternatives for LIPAc and IFMIF RF chains. Although Solid State Power Amplifier (SSPA) technology had several advantages in terms of features, reliability, and availability, the technology was insufficiently developed to achieve these very high power requirements.

In 2012 after a successful design of the Integrated RF module (with tetrodes) the availability of the RF Power System increased several points but still remained the possibility of further increasing it by means of the solid State Technology.

The final aim was then targeted to a full Solid State RF Power system for IFMIF. That meant that several new designs had to be performed:

1. **Testing solid state concept in LIPAc**
2. **Developing a 200 kW solid state amplifier**
3. **Testing the 200 KW solid state amplifier in LIPAc**

The first point was leaded to a technology change proposal for the two RF chains of the MEBT. The improved design of the LIPAc MEBT reduced the required power from around 60 kW to 16 kW.

This was the perfect power for testing the solid state concept at the accelerator.

Two 16 kW RF power chains were developed by CIEMAT and its partner company Broad Telecom (BTESA).

The main characteristics of this new design are:

1. **High efficiency (allowing scalability up to 250 kW)**
2. **Degraded mode operation (working with several failed modules)**
3. **Basic modules hot swapping (allowing replacement of failed modules before general failure)**
4. **Non Stop Feeding: A new concept that avoid any beam stop due to RF System failure**
5. **Very fast LLRF system (allowing stable and fast response to module failures)**

Additionally, no HVPS is needed for these modules, so only 12 HVPS will be built for the whole system.

This work has been funded by the Spanish Government (MINECO) under project AIC-A-2011-0654 and the agreement published in BOE (BOE 16/01/2013, pp. 1988).