A.6: Design and development of 40 kW, 650 MHz solid-state RF amplifier

State-of-the-art high power solid-state amplifiers, operating at 505.8 MHz, have been developed and operating satisfactorily in round-the-clock mode in Indus-2. To cater to the need of future accelerator programs, an R&D programme has been taken up for the development of 650 MHz solid-state amplifiers (SSPA) to power low-beta and high-beta superconducting RF cavities. These amplifiers are also part of Indian Institutions Fermilab Collaboration (IIFC) program deliverable, proposed under XII Plan DAE mega science project. Under this activity, an initial prototype of 30 kW (average) solid-state amplifier was developed in 2015. With change in the requirement of RF power from 30 kW to 40 kW under IIFC, a compact 40 kW (average) solid-state amplifier has been developed at 650 MHz, occupying approximately same floor area as that of the 30 kW unit. The 40 kW SSPA has been designed using 500 W RF power amplifier modules, 48-port RF power dividers and combiners, and rigid coaxial line based directional couplers.

This 40 kW amplifier (Fig. A.6.1) makes use of two scalable and modular 20 kW amplifier units, power combined with the help of a 2-way power combiner. In each 20 kW unit, output RF powers from LDMOS based 500 W RF circuits is combined with the help of a 48-way radial combiner to get 20 kW of output power. For RF power sampling and monitoring, indigenous directional sensors and high power (20 kW and 75 kW) directional couplers were used in this amplifier. Each 20 kW unit, complete in all respect, is housed in a single customized euro rack. It is equipped with DC bias power supplies, electrical components, water cooling circuit and control/interlock hardware. These 20 kW units were tested successfully at full rated power with the help of a water-cooled dummy load before final combining.

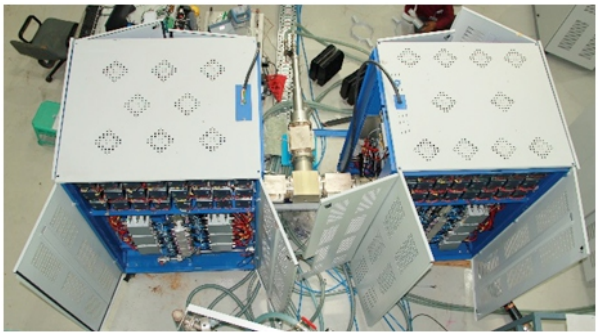

Fig. A.6.1: 650 MHz, 40 kW solid state RF amplifier

The enhancement in the output power of the 20 kW unit (compared to the 13 kW solid-state amplifier unit of Indus-2 RF system) was achieved with the help of newly designed RF components, including a compact 650 MHz 4X500 W amplifier module, a 48-port 20 kW power combiner and a 48-port power divider. The amplifier module encompasses four 500 W circuits with two circuits mounted on each side of a water cooled cold plate. Each circuit operates in class F operating mode with power gain of 20 dB and drain-conversion efficiency in excess of 60%. Compared to the Indus-2 RF system's power modules, its physical dimensions are nearly half, without compromising its RF performance. This 40 kW, 650 MHz amplifier makes use of 26 such modules. New 48-port power combiner, designed with its ports in two tier, saves the space and fabrication cost, as compared with earlier designed 16-port and 32-port combiners. It also minimizes the RF energy loss by incorporating more than twice of the peripheral combining ports in a single structure. The 48-port divider is nearly similar to the combiner, except that its input port is different in order to handle lower RF power.

The sampled forward and reflected RF signals from each 4X500 W module were rectified using the indigenously developed directional sensor with logarithmic RF power detector. This design, makes use of integrated RF and micro-controller based ADC and four RF detectors. The output of the sensor is communicated to an FPGA control and interlock unit. This design is economic and indigenous as compared to RF sensors, used in Indus-2 solid state amplifiers, implemented using imported detector boards and SMA coaxial cables. Further, present design is more immune to crosstalk at high RF power due to digital transmission of the forward/reflected power directly to the controller. In Indus-2, analog information was transmitted using SMA cables. An application-specific circuit board provides the interface with front-panel and enables the remote control of the complete amplifier. A graphical code, developed in-house using LabVIEW-RT software, is used for data acquisition and control/interlock. This 40 kW amplifier (Fig. A.6.1) was tested at full rated power with a water-cooled load at its output. A typical test result snapshot is shown in Fig. A.6.2.

Fig. A.6.2: Test result snapshot for 650 MHz, 40 kW solid state RF amplifier

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