ACCELERATOR PROGRAM

A.1 Solid state RF amplifier development

Solid-state RF amplifiers are finding increasing use in accelerator field as driver amplifiers. These amplifiers are also used to drive the super conducting cavity structures. Indus-2 RF system employs four modules of 64KW Klystron tube based power amplifiers. Four numbers of solid-state amplifiers operating at 505MHz have been developed to drive the klystron power amplifiers. Each of these solid-state amplifiers is capable of providing 10 Watt of RF power with a gain of 40dB. Additional four amplifiers have been developed as auxiliary amplifier for compensating line loss in RF system. Each amplifier consists of cascaded stages of 166C MOSFETs. Matching circuit of each stage encompasses transmission line transformer and micro strip line based network. Distributed negative feedback is employed to make amplifier stable for full range of VSWR. For reducing downtime, hot swappable redundant configuration has been used. For safety and precaution like over voltage, thermal overload etc. bias circuit has been designed using bias regulator. Hot swapping, gain control, transfer of amplifier status over serial bus and other supervisory functions are executed by an FPGA based card.

Fig. L.1.1 RF amplifier

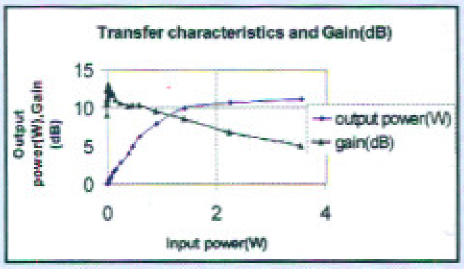

Fig.L.1.2 Gain and out put power curve

Complete amplifier has been housed in 19" form factor EMI/EMC sub rack (fig.L.1.1). Measured transfer characteristics for gain and power is shown in the fig. L.1.2. Development of SSA at 350 and 700MHz for use in Proton Accelerators has been taken up. Prototype amplifiers and combiners operating at these frequencies have been developed.

(Contributed by: PR Hannurkar; hannurka@cat.ernet.in)

A.2 Test set-up for measurement of conducted EMI

The high-frequency switching power conversion systems are known to be more efficient, lightweight and compact than their line frequency and linear counterparts. However, the former generates electromagnetic interference (EMI). The EMI, operates in two forms, radiated and conducted, and may disturb the normal functioning of other equipments in the vicinity. The conducted noise is usually several orders of magnitude higher than the radiated noise in the free space. The conducted noise, categorized as differential and common mode noise, is reduced by EMI filters. The metal cabinets normally reduce the radiated noise.

With increasing use of high-frequency switching power converters for accelerator and laser systems, it is imperative to limit the electromagnetic pollution to facilitate system integration. A set-up for the measurement of conducted EMI has been developed. The following normative documents containing provisions of concerned international standards are followed:

1. CISPR 11: 1997, Industrial, Scientific and Medical (ISM) radio frequency equipment – Electromagnetic disturbance characteristics – Limits and methods of measurements.
2. CISPR 16-1: 1997, Specifications for radio disturbance and immunity measuring apparatus and methods, Part – 1: Radio disturbance and immunity measuring apparatus.
3. CISPR 16-2: 1996, Specifications for radio disturbance and immunity measuring apparatus and methods, Part – 2: Methods of measurement of disturbance and immunity.

Fig.A.2.1 shows the photograph of the test set-up. The equipment under test (EUT), is placed on a 12 X 8 feet, 1.6mm thick ground plane fabricated with aluminum sheets on wooden insulating supports of height 10cm. The conducted noise is measured in terms of mains disturbance voltage across a 50Ω termination impedance of an artificial mains network (AMN) or line impedance stabilization network (LISN) through which the AC mains power to EUT is provided.

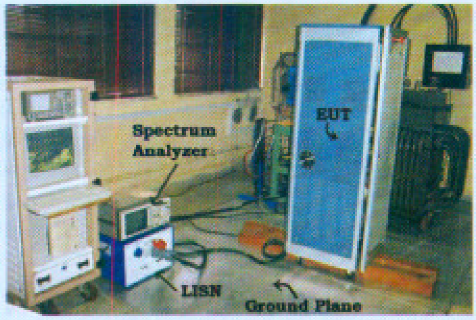

Fig.A.2.1 Photo of conducted EMI test set-up

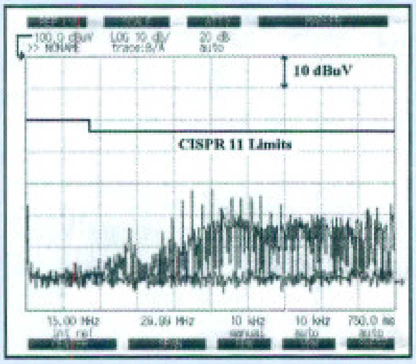

Fig.A.2.2 Measured conducted EMI spectrum

The LISN defines the line impedance to 50Ω as seen by the EUT for measurement frequency range of 150kHz to 30MHz. The power supplies are categorized as Group – 1, Class – A ISM equipment for which the limits for quasi-peak terminal disturbance voltage is 79dbμV for frequency band of 150kHz to 500kHz and 73dbμV for band of 500kHz to 30MHz. A 50μH / 50Ω, three-phase, four-wire LISN is installed at the setup for testing of EUTs powered from three-phase as well and single-phase AC mains. An attenuator inbuilt to LISN and additional transient pulse limiter are used for safe measurements on the spectrum analyzer. Fig. A.2.2 shows typical results obtained with the test set-up.

(Contributed by: Sunil Tiwari; sunil@cat.ernet.in)

A.3 Development of power supplies for Indus-2 quadrupole magnets

The specifications of the power supplies required for the quadrupole magnets type Q1, Q2, and Q3 are given in Table 1. The power supplies for Q1 and Q2 type are developed using transistor series pass scheme with twelve-pulse SCR rectifier as pre-regulator. Input three-phase supply is stepped down by a water-cooled delta/delta-star transformer, the secondary is rectified using a 12-pulse full bridge converter. The 600Hz ripple present in the DC output is attenuated with the help of a damped LC filter. The output is fed to a transistor bank, which controls the output current according to the set current. Q3 type power supplies are developed using high frequency resonant converter. Input three phase line is rectified using six-pulse SCR rectifier to get unregulated DC input. In resonant converter stage, an IGBT bridge converts input DC to high frequency square wave fed to a LCC network. The switching frequency of IGBT bridge is above the peak frequency of LCC network, this allows zero-voltage-switching of IGBTs and eliminates lossy snubbers. A switching frequency of 30 to 75kHz gives required variation in output current.

Power supplies have been tested on dummy load. The output current stability is found to be within specifications. Fig.A.3.1 shows typical long term stability measured on Q3 type magnet power supply at 150A output current. The maximum conversion efficiency of Q1 and Q2 type power supplies is 0.85 and that of Q3 type power supply is 0.92 as shown in fig. A.3.2. Output current sensing by DCCT and temperature controlled ambience for the front-end electronics of current feedback loop helps in achieving required output current stability. High frequency switching noise that is generated especially in Q3 magnet power supply can also degrade the stability and overall performance. Passive techniques for cancellation of common-mode (CM) noise reduce conducted electromagnetic interference (EMI) and consequently the requirement of additional EMI filters. Fig.A.3.3 shows the injected CM current before and after suggested passive noise cancellation techniques. Power supplies have been shifted to Indus-2 magnet power supply hall and pre-commissioning functional tests are in progress.

Table 1 Specifications of power supplies for quadrupole magnets type Q1, Q2 and Q3

Type	Q1	Q2	Q3
Maximum Output Voltage	82 V	113 V	92V
Maximum Output Current	170 A	170 A	170 A
Total Numbers	8	8	8
Output Current Stability	± 50ppm	± 50ppm	± 50ppm

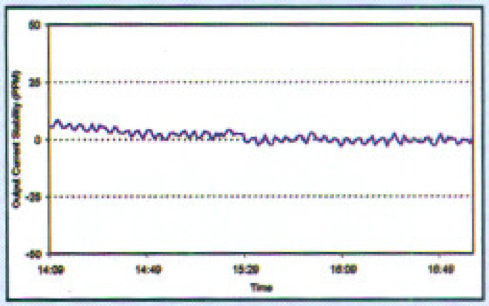

Fig.A.3.1 Stability of Indus-2 Q3 magnet power supply