Design and Development of High Power Pulsed Technologies and Systems for H^- and Proton Accelerators

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Abstract. For energizing the 3 MeV RFQ, under development at RRCAT, a 1MW pulsed RF system operating at 352.2 MHz is required. The characteristics of the pulsed RF delivered to RFQ are important for its correct operation. Keeping in view these requirements , in house design and development of crucial technologies like high voltage solid state pulse modulators, WR 2300 waveguide components, solid state high voltage switches, high voltage high power pulse transformers, advanced solid state Marx modulator, high power RF/Microwave test facilities etc has been initiated. A 1 MW pulsed test stand at 352.21MHz has been developed and tested using TH 2089 klystrons provided by CERN. A solid state bouncer modulator with 500 microsecs pulse duration, 25 Hz pulse repetition rate, giving output voltage upto 100kV for energizing klystron for pulsed RFQ has been designed, integrated and testing has been started. Design and prototype development of advanced solid state Marx modulator has also been carried out. The WR 2300 waveguide components have also been developed and tested at low power as well as 1MW pulsed power at the test stand. The WR 2300 waveguide transmission line with full height dual directional coupler, harmonic filter, three port junction circulator, full height to half height transition, half height waveguide sections, E and H bends, power dividers, flexible waveguides, phase shifter, 45 deg E plane bends, RF loads etc. was assembled and tested at 1MW pulsed power. Utilizing the experience gathered, design of WR 2300 waveguide transmission system for LEHIPA project of BARC was also done. Development of 1.3 GHz RF systems and cavity test set ups for characterizing the superconducting cavities is in advanced stage. A solid state bouncer compensated long pulse modulator operating at 100 kV, 20A with 800 µs pulse duration at 2Hz PRR, was successfully designed, developed and supplied to CERN for LINAC 4 proton accelerator project under DAE CERN collaboration in Novel Accelerator Technologies. In this paper, recent developments and test results of the high power pulsed systems and waveguide components are presented.

Keywords: klystrons, solid state modulators, RF/ Microwave amplifiers, waveguide, H- accelerator, proton accelerator, RFQ, superconducting cavity.
PACS: 41.20.-q, 84.40.Az, 84.30.Jc, 84.30.Le, 84.40.Dc, 84.40.Fe

SOLID STATE MODULATORS FOR 3MEV RFQ FOR LINAC 4 PROJECT AT CERN AND H- FRONT END AT RRCAT

In the solid state bouncer modulators designed at RRCAT, energy storage capacitors are discharged through primary of a 1:10 pulse transformer by a solid state series switch. The droop is compensated by an LC bouncer circuit (figure 1). For klystron arc protection, the series switch is opened and the crowbars are fired [2]. Table 1 lists the major specifications of the modulators for LINAC 4 and RRCAT projects. Fig. 2 gives photographs and results of modulators.

TABLE 1. Main specifications of solid-state bouncer modulators.

Parameter	Value (LINAC4 application)	Value (RRCAT application)	Unit
HV Pulse Amplitude max.	-110	-100	kV
Pulse width (70%-70% of pk)	800	600	µsec
Min. Flat Top available	600	500	µsec
Max. current during pulse	24	20	A
Pulse repetition rate	2	1-25	Hz
Acceptable voltage droop	≤ 1	≤ 1	%
Ripple on flat top (≥10kHz)	≤ 0.1	≤ 0.1	%
Rise time / Fall time	< 100	< 100	µsec
Energy limited in klystron arc	< 10	< 10	J

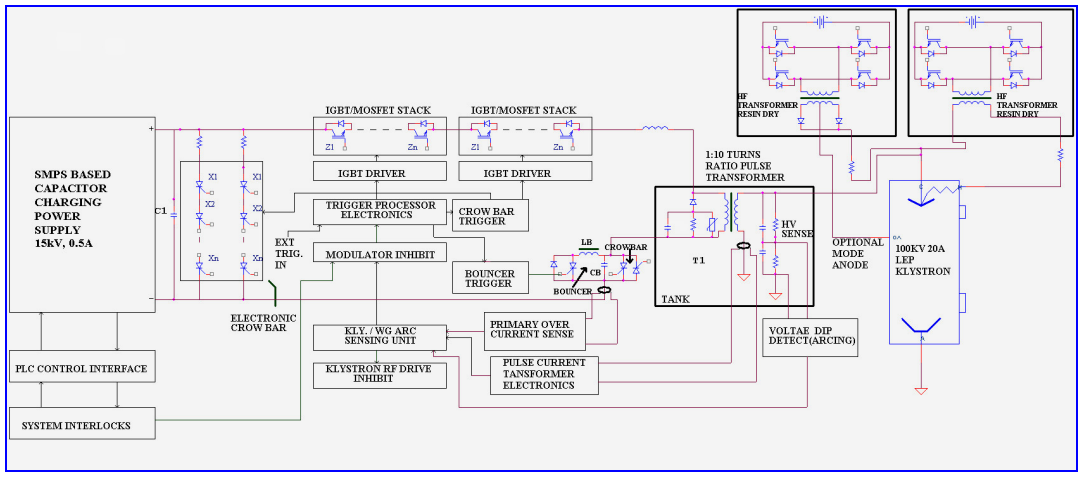
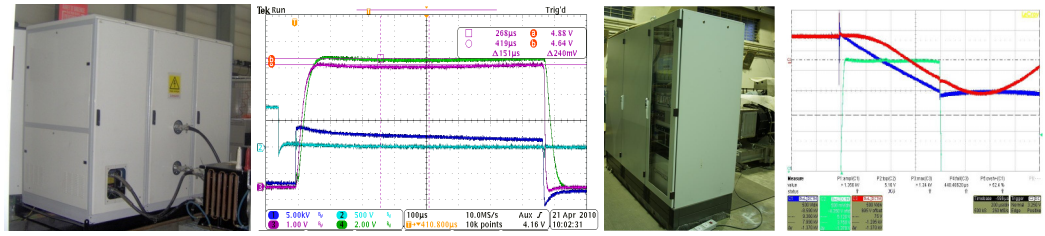


FIGURE 1. Schematic of solid state bouncer modulator topology

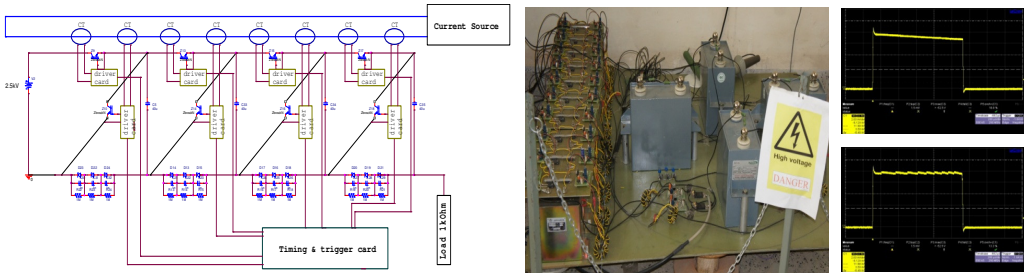


(a) (b) (c) (d)

FIGURE 2. (a) 110kV solid state bouncer modulator prototype delivered to CERN for LINAC 4 project. (b) 100kV, 800 microsecs ouput during acceptance test at CERN. (c) Integrated 25Hz modulator for RRCAT RFQ (d) Zoomed view of 10kV droop compensated pulse at the output of modulator.

Marx Type Modulator Prototype Development

An effort was made to design and develop solid state modulators similar to Marx type modulator construction (Fig 3). We have successfully designed and developed a 10kV, 20A marx module (fig 3b) and demonstrated generation of a 1msec long pulse of 10kV, with droop compensation(Fig 3 c). Construction of a 100kV 20A modulator for a 1MW 352.2 MHz Klystron is under progress at RRCAT.



(a) (b) (c)

FIGURE 3. (a) Schematic of solid state Marx cell modulator prototype, (b) 10kV Solid state Marx cell modulator prototype test assembly. (c) uppper trace shows 10kV output without droop compensation, lower trace is 10kV output with droop compensation generated from the Marx modulator prototype.

DEVELOPMENT OF WR2300 W/G COMPONENTS AND 1.3 MW 352.2 MHZ TEST STAND

Design and development of WR 2300 waveguide transmission line components was done keeping in view the requirements for H- and proton accelerators for Indian as well as International collaboration projects (CERN LINAC4) [1][2].

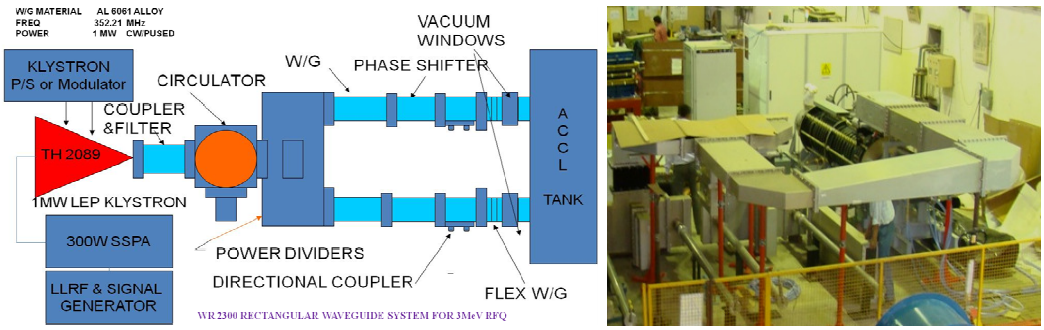
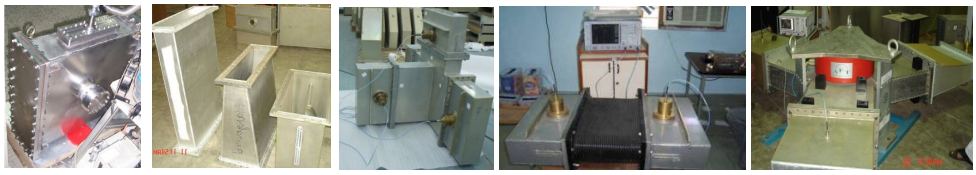


FIGURE 4. Left picture shows typical layout of 1MW klystron based 352.2 MHz RF system and on right is shown the 1.3 MW 352.2 MHz test stand designed and developed at RRCAT.

Figure 4 shows a typical layout with arrangement of waveguide components for RFQ. The power from klystron is delivered to the load (RFQ) by means of a WR 2300 waveguide transmission system consisting of dual directional coupler, harmonic filter, three port circulator, full height to half height transition, half height magic tee power divider feeding two inputs to the RFQ with flexible waveguide, directional coupler, phase shifter and vacuum RF window. Low power testing using vector network analyser with WR 2300 test set up and high power measurements in 1.3 MW pulsed test facility were done on all the waveguide components and found to satisfy the design characteristics. Figure 5(a) and (b) show the prototypes of WR 2300 Cu coated SS waveguide power coupler and Al 6061 waveguide components developed for LINAC 4 project of CERN. Figure 5 (c) and 5(d) show the half height magic tee power divider and other components for low energy high intensity proton accelerator project (LEHIPA) of BARC. Figure 5 (d) shows waveguide test set ups for testing the components and 5 (e) shows three port circulator tests.

TABLE 2. Specifications of the klystron based test stand.

Parameter	Value	Unit
HV Pulse Amplitude (-ve)	100	kV
Pulse width (70%-70% of pk)	800	µsec
Min. Flat Top available	600	µsec
Max. current during pulse	20	A
Pulsed output power maximum	1.3	MW
Operating frequency	352.2 ±0.8	MHz
Gain (typ.)	41	dB
Energy limited in klystron arc	< 20	J

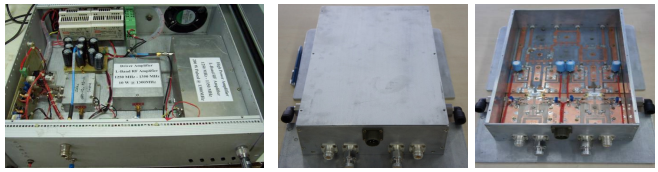


(a) (b) (c) (d) (e)

FIGURE 5. (a) Prototype SS Cu coated power coupler & (b) WR 2300 W/G components for LINAC 4 (c) magic tee, & (d) flexible waveguide under tests for LEHIPA. (e) 1MW circulator test set up.

Solid State Amplifiers for Test Stands

Design & development of solid state RF/Microwave amplifiers for pulsed/ CW operation at 352.2 MHz, 1.3 GHz were successfully accomplished. A 300W, 352.2 MHz solid state amplifier was developed and incorporated in the 1.3 MW test stand. 250W pulsed and 500W pulsed/CW solid state amplifiers have been successfully developed for use in the 1.3 GHz vertical test stand (VTS) for characterization of 1.3 GHz superconducting RF cavities being developed at RRCAT (figure 6).



(a) (b) (c)

FIGURE 6. (a) 250W pulsed 1.3 GHz amplifier, (b) & (c) 500W CW/pulsed solid state 1.3 GHz RF amplifiers.

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