FINAL LAY-OUT AND TEST RESULTS OF THE DISCONNECT SWITCH FOR ALS STORAGE RING RF SYSTEM POWER SUPPLY*

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Abstract

ALS is the 1.9GeV third generation synchrotron light source which has been operating since 1993 at Berkeley National Lab. The new RF system, which is now under construction will use two TH 2161B 300kW klystrons to power two single cell RF cavities. In the new design the existing conventional crow-bar klystron protection system will be replaced with the fast disconnect switch. The switch consist of a 24 high voltage IGBT's connected in series, equipped with static and dynamic balancing systems. The main advantage of using this new technology is faster action and virtually no stress for the components of the high voltage power supply. This paper will show the final lay-out and the test results of the production unit.

INTRODUCTION

Any electron tube based high power amplifier must be equipped with a fast acting system protecting this expensive device from damage caused by internal arcs or from working in unacceptable operational conditions. In most cases it is accomplished by shorting the electron tube feeding high voltage power supply (HVPS) using mercury containing ignitron(s). An alternative and safer way to achieve the same goal is to disconnect HVPS from the tube. This method has several substantial advantages over the crowbar circuits:

- Faster action. Typically less than 3us versus 5 to 10us for crowbars (8us in case of ALS crowbar).
- No stress on HVPS elements (transformer, choke and rectifier).
- HV can be turn back on within a microsecond after disconnect action which might save the circulating beam in the accelerator
- Lower power consumption (no ignitron current limiting resistors required).
- No danger of mercury contamination.

Switch could be built using vacuum tube(s) or stack of solid state devices (IGBT's or MOSFET's). Although the solid state devices are less expensive than vacuum tubes, they have lower forward voltage drop and longer lifetimes. In spite of the fact that there are several companies offering solid state switches/modulators we decided to build our own unit. The main reason for this decision was fast on-site service capability by our staff which is extremely important since ALS has to deliver light to thousands of users on the 24/7 basis.

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During our design/testing process we tried several different configurations of the switch. This paper presents the final (production) unit, which has been built and successfully tested up to 80% of nominal voltage in our test stand facility. The switch will be installed for final testing/operation in the ALS ring during January 2012 shut-down.

SOLID STATE DEVICE CHOICE

The new ALS RF system will use two THALES TH 2161B klystrons and will required up to 800kW DC power (16A at 50kV) from the HVPS. In order to keep the cost of the switch and the power consumption low we were looking for the IGBT device with the high voltage handling capabilities and the small dissipation factor. The IXYS IXEL40N400, 4kV, 40A IGBT with the dissipation factor (close to open voltage ratio) lower than 0.1% and the price below 100$ was the best choice. Switch production unit has 24 modules connected in series with total 72kV DC voltage and 30A DC current handling capabilities. This large excess voltage handling capability will give us a large redundancy factor and increase its operational reliability since the switch will be able to continue its service even with several faulty (shorted) modules.

SERIES CONNECTION OF THE IGBT'S

The main problem associated with series connection of the solid state devices is how to ensure that the voltage distribution across each unit is the same in the static and dynamic conditions. The static voltage balancing is easy to achieve by connecting in parallel with each IGBT device resistance low enough, that it will create the current flow significantly higher than the leakage current of the worst IGBT in the chain. The dynamic balance of the switch modules was achieved by connecting in parallel with each IGBT 10nf ceramic capacitor and by implementing delay chips in each IGBT drive chain.

Additionally, each module has been protected against sudden voltage transients by a string of the voltage suppressors. This will keep the IGBT conducting as long as the voltage across the transistor exceeds approximately 3kV. It limits the total switch voltage capability to approximately 72kV but makes it virtually indestructible by high voltage transients.

SINGLE MODULE DESCRIPTION

The single 3kV, 30A disconnect switch module is shown in Figure 1. Motorola MC33153 single gate driver is used to drive each IXYS IXEL40N400 IGBT. This

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device can source 1A and sink 2A and is equipped with the choice of desaturation or overcurrent protection circuits. Each module has two driver chips. The first is used strictly for turning ON and OFF IGBT and the second is used for switch internal overcurrent protection. It senses the voltage at the collector of the IGBT which is proportional to the current flowing in the IGBT. The R15 and C4 values determine the IGBT collector current value at which the comparator build in the MC33153 chip changes its status sending via fibre-optic channel error signal to the switch controller which in its term simultaneously sends an "OFF" command to all 24 modules. This switch internal overcurrent protection is acting within 30us which is fast enough to perform by itself without failure HVPS wire test (shorting HVPS using #30AWG wire). The same signal (from C4) is sent to the LM311 comparator (U6) which informs the PLC via separate fibre-optic channel about eventual failure of the IGBT in particular module. The PLC then can shut the switch off if too many modules are damaged (shorted) at the same time. The IGBT chip is mounted at the heat sink made out of extruded aluminium and the base surface area 300cm^2. The switch is cooled by forced air flowing along the heat sinks fins. Each IGBT module requires two DC power supplies (+20V and +5V) with the total power requirements up to 3W. Each source has to be insulated from the ground potential at the full switch voltage capability. The required power is generated by our audio system.

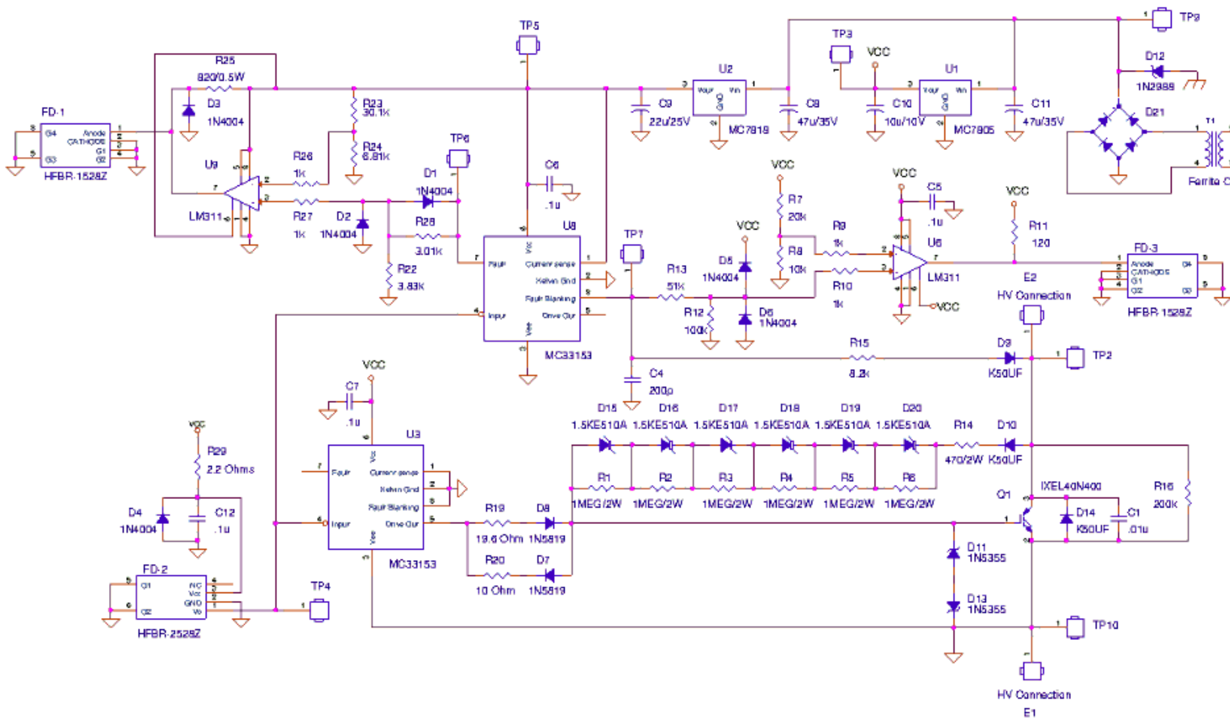

Figure 1: Disconnect switch single module schematic diagram.

AUDIO SYSTEM

The audio system includes ILC8038 waveform generator which creates sine-wave signal at 20 kHz and the commercial 900W audio amplifier. The output transformer has single turn primary winding made out of 100kV rating high voltage cable feeding 24 ferrite toroids with 17 secondary turns each. We loaded primary winding of the audio output transformer with several ferrite toroids to compensate for reactive (capacitive) component of the load. It prevents the PHONIC MAX 1600 audio amplifier from overheating. The switch audio system is shown in Figure 2.

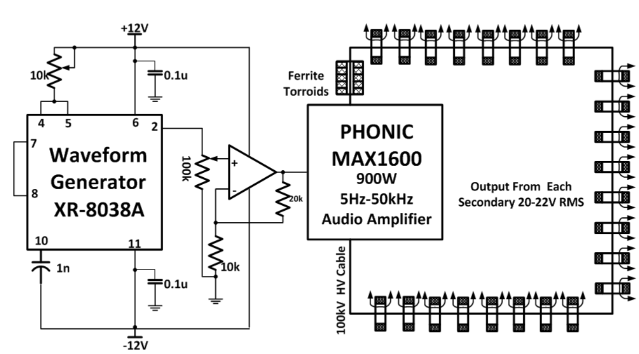

Figure 2: The switch audio system.

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PRODUCTION UNIT TESTS RESULTS

After successful testing proof of principle unit [1] (stack of three IGBT modules), we have built and tested the production unit up to the full capability of our test stand (40kV, 125mA power supply charging 1uF capacitor). The test stand block diagram is shown in Figure 3.

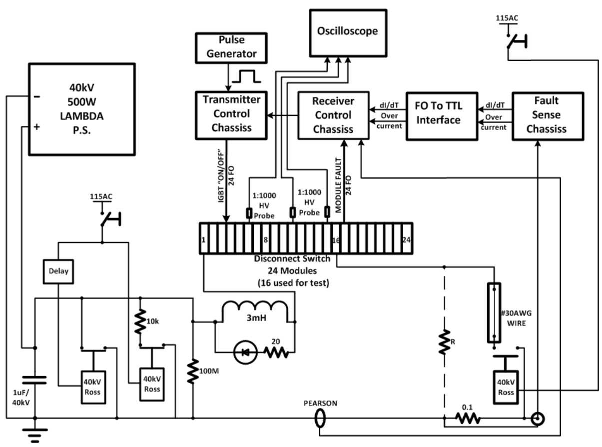

Figure 3: Test stand block diagram.

We performed numerous successful pulse and wire tests and some milestone results are shown in the oscilloscope pictures below.

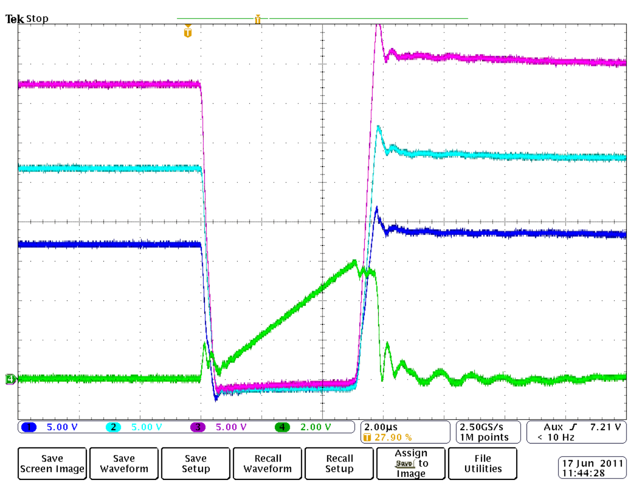

Figure 4: Pulse and wire tests.

Figure 4 shows the case when the controller is closing the switch (16 modules unit) on the shorted load (#30AWG wire). The switch opens back within 5us and the maximum current reaches 60A. Upper traces shows voltage at the modules: 7, 11 and 15. Lower trace show load current measured by Pearson coil (10A/V).

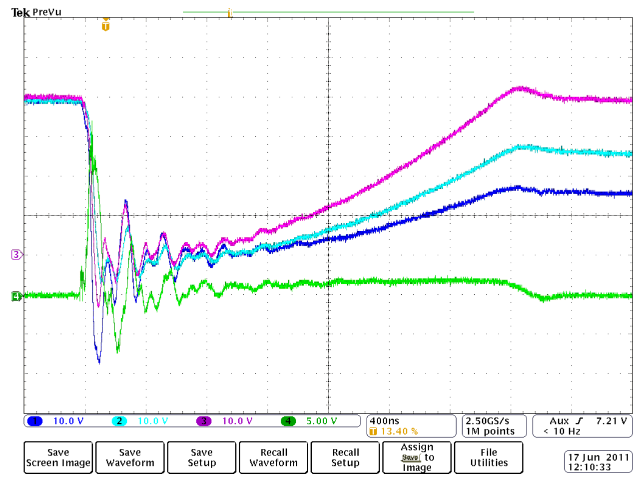

Figure 5: Shorting of closed switch.

Figure 5 shows the case when the closed switch is shorted with 30AWG wire. Switch opens in less than 3us. We performed the wire test described above many times without one single failure.

CONCLUSION

The ALS production unit of the fast disconnect switch has been designed, built and tested up to the full capability of our test stand with positive results. The switch will be installed for final testing/operation during January 2011 ALS shut-down.

REFERENCES

[1] S.Kwiatkowski, K. Baptiste, J.Julian; LBNL, Berkeley, CA94720, USA. "Fast Disconnect Switch for ALS Storage Ring RF System High Voltage Power Supply" PAC 2009, Vancouver TU6RFP084, http://www.JACoW.org.

[2] MOTOROLA "MC33153 Single IGBT Gate Driver Datasheet.

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