MODIFICATION IN LHCD DAC SYSTEM TO INCORPORATE MEASUREMENT OF RF POWER

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Abstract

The Lower Hybrid Current Drive (LHCD) system has four klystrons, each rated for 0.5 MW, CW power at 3.7 GHz, which are employed to launch the lower hybrid waves into plasma. VME and PXI based Data Acquisition and Control (DAC) system has already been implemented for the operation of LHCD System. VME based DAC system has been modified to incorporate measurement of RF Power signals.

The existing VME based DAC system has various instrumentation like DIO, AO, AI and timer cards integrated with VME RTOS program. The VGD4 acquisition card was integrated for the measurement of power from 96 signals of LHCD system. However because of random data acquisition problem, this card is replaced by IP330 analog input cards. IP330 analog cards have been included and integrated with existing system to measure 128 power measurement signals requirement with the subsystem. Carrier boards have been replaced with new version of device driver to integrate IP modules of AI, AO and timer card. Existing device driver program have been modified to add additional functionality for data acquisition and time synchronization. Adapter classes have been developed to integrate with RTOS application environment for low context switching and higher performance. NTFS has been used to handle long chunk of data during experimental shots. User interface is modified on Linux host machine to monitor and acquire for additional signals. The system has been validated during the SST-1 campaigns. Developed DAC software is modular, hierarchical and scalable in nature. To achieve the data storage with calibration and plotting, MDSplus has been integrated for data visualization and management of after shot analysis. In this paper, the design, implementation and results obtained with IP330 cards are reported and discussed.

1. INTRODUCTION

LHCD system [1] has been upgraded with four klystrons, which are employed to launch the lower hybrid waves into plasma [2]. LHCD DAC system has been modified to cater the requirement of measurement of RF power signals with required rate of acquisition. There are four layers of waveguide that delivers final output to tokamak. Each layer has 16 waveguide transmission lines comprising dual directional coupler for measurement of RF power. Hence each layer has 16 forward power measurement channel and 16 reflected power measurement channels making 32 channels in single layer. Thus it is required to have additional 128 AI (Analog Input) channels for power measurement. The existing VME based DAC system has various instrumentation like DIO (Digital Input/Output), AO (Analog Output) and timer/counter cards integrated with VME RTOS software using respective device drivers [2]. Acromag 9325 AI card has already been available with existing system which has capability of 32 channels single ended acquisition and monitoring. The detail description of signal requirement with instrumentation for existing LHCD DAC has been listed in Table 1. Additionally the existing AI card named VGD4 has been detected some random acquisition problem during validation so it has been replaced with Acromag IP330 AI boards. Each IP330 AI card can accommodate 32 channels only, so three different modules have been replaced in place of 92 channel VGD4 card. It is needed to modify and upgrade the VME instrumentation and RTOS software application in order to cater huge requirement of AI signals. The modified signal requirement with instrumentation has been listed in Table 2. Four different IP330 AI cards have been included and integrated with modified DAC system to measure 128 RF power signals [3]. Existing device driver programs have been modified to add additional functionality for data acquisition and time synchronization. Adapter classes have been developed to integrate with RTOS application environment for low context switching and higher performance. Network file sharing (NFS) is used to handle long chunk of data archival during experimental shots. All data from AI (32 + 128) channels is stored on PC by using NFS protocol. We have procured new carrier board with AI modules in order to fulfill new requirements of LHCD DAC. Modified VME instrumentation includes Acromag make AVME9668 carrier card [4] to add IP330 modules. TCL scripting language with C++ interface is modified to upgrade user interface to operate LHCD DAC remotely. TK toolkit and additional open source libraries have been used to modify user interface as per requirement of LHCD DAC.
### TABLE 1. EXISTING VME INSTRUMENTS LHCD DAC SYSTEM

<table>
<thead>
<tr>
<th>SIGNAL TYPE</th>
<th>VME CARD</th>
<th>Channels</th>
<th>Additional channels/cards Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor board</td>
<td>SBS-VG4 SBC</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Analog Input</td>
<td>AVME9325</td>
<td>32</td>
<td>128</td>
</tr>
<tr>
<td>Analog Output</td>
<td>Acromag IP220</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Digital Input</td>
<td>VMIVME2528</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>Digital Output</td>
<td>VMIVME2528</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>Counter/Timer card</td>
<td>Acromag IP480</td>
<td>6 (16bit)</td>
<td>0</td>
</tr>
<tr>
<td>Non intelligent Carrier board</td>
<td>AVME9660</td>
<td>NA</td>
<td>1</td>
</tr>
</tbody>
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### TABLE 2. MODIFIED VME INSTRUMENTS LHCD DAC SYSTEM

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<td>AVME9660</td>
<td>NA</td>
</tr>
<tr>
<td>Non intelligent Carrier board</td>
<td>AVME9668</td>
<td>NA</td>
</tr>
</tbody>
</table>

### 2. LHCD DAC SOFTWARE MODIFICATION

LHCD DAC software has to execute the task of data archiving, monitoring and control. In which RTOS server application takes care of fast action (<=1kHz) and client application is used for GUI (graphical user interface) for end user. The modified acquisition architecture of LHCD DAC system is shown in Fig. 1. The programming on the VME system includes card driver programming, system integration programming for operation and control. It also includes socket programming for GUI client in communication with VME server. Various monitoring and control threads are running on VME server with device driver application as per requirements of system in timer synchronization for failsafe operation. Linux operating system is used for client computer interface with RTOS server for reliable operation. High speed dedicated Ethernet communication is used for
communication with RTOS server and Linux client. User interface design is developed using TCL/TK toolkit and socket communication using C program. NFS is used for more reliable data acquisition.

To add more RF measurement signals, VME hardware needs non-intelligent carrier slave board to interface IP modules to VMEbus. AVME9668 6U carrier card is used, which can hold 4 IP modules. Tornado 2.0 is used for VME RTOS programming using VxWorks RTOS port on SBS VG4 processor board. Due to Motorola compiler PPC604 toolchain is used for compilation and make downloadable image for VME hardware [5]. Tornado environment provides board support package (BSP) libraries in C/C++ with networking tools for image building. These analog modules are configured for 32 single ended with 0V to +10V input voltage range, with straight binary data format, with interrupt and timers in disabled state. Individual card is initialized for each slot using jumper on carrier board to access each IP330 AI module respectively. We have selected single burst scan mode, and all channels single ended acquisition mode. Device driver program has been configured for scanning the channels and data is acquired by using value retrieved from its mailbox register. Initially, we tried using TaskDelay in archival of data, but that resulted into wrong data which is not advisable during interrupts in VxWorks. So we have used manual delay instead of TaskDelay [6]. Using all four AI modules RF power measurement has been integrated with DAC. Fig. 2. is snippet of user interface for monitoring of 64 channels power signals of two layers. The figure shows a passive screen before applying RF power.

![FIG. 2. Integration of two layers channels](image)

![Fig. 3. Existing user interface RF pulse screen](image)
Existing user interface was designed with TCL scripting language with CPP interface. It has CPP program for socket communication with VME server. Fig. 3. shows existing user interface RF pulse screen. After checking the status of each power supplies and based on current/voltage values RF pulse can be applied. Data from VME server is sent to client at regular interval of 100ms for monitoring. This data received from server is calibrated and updates GUI for monitoring on screen. Raw data is acquired via network which is received on client socket. This acquired data is calibrated and used for data plotting via shot analysis module. Further stored database files are converted to ASCII files.

Layout of existing user interface has been modified. Fig. 4. shows the upgraded user interface of RF pulse screen with additional control and monitoring. Here we have separated each power supplies status in according to operational requirements. Additional functionalities of current/voltage values with RHVPS [7] or HVPS options are available to select before applying RF power. RHVPS control has been added with Ion pump monitoring. Additionally, message board has been available on below part of screen for the actions given by user for make operation easier. Other tabs have been modified as per user requirements. Screen resolution is designed in such manner that it can adjust automatically with monitor screen. Few features have been newly introduced like: variable y-axis for every graph, mode select and copy acquired data to central storage directly and power monitoring of each layer. Data analysis and plotting of signals have been available for selected channels. Further, it shows calibrated and raw data in single graph with upper and lower limit for x and y axis selected by user. Finally calibrated data is acquired in tree based binary archival system which is discussed in next section.

3. MDSPLUS INTEGRATION FOR BINARY DATA ARCHIVAL

(Modal data system) MDSplus is a data management system used in many Nuclear Fusion experiments to handle data [8,9]. Various application programming interface (API) for data access are available with many languages, like C, C++, Fortran, Java, Python, MATLAB and IDL. Additionally set of visualization and analysis tools are available for data browsing and graph monitoring [10]. We have successfully installed and integrated MDSplus with LHCD DAC system. There are 160 AI channels required to acquire at the time of experiment for after shot analysis. The requirement of LHCD DAC system is successfully achieved and validated with data. We have used C++ API adapter classes for integration with LHCD DAC program.

The raw data has been stored by the Linux client is extracted from the data packet using Ethernet socket program from VME server. Acquired data is stored in binary hierarchical directory structure using MDSplus to achieve the data storage with calibration for plotting. MDSplus is used for data visualization and management for after shot analysis and a typical screen shot is shown in Fig. 5. Jscope which is java based tool has been used for visualization and analysis of the stored data in MDSplus tree. Here in the figure, one of the visualization screens has been shown to demonstrate the functionalities. Four different graphs have been shown for local shot.
number 5. First graph shows the Beam current and voltage of power supplies, second graph shows both klystron Anode currents. Third graph in the same figure shows filament power supplies voltage and current, fourth graph shows both klystron Anode voltages. MDSplus software has successfully deployed to achieve the target for calibration and smoothing of the curve while plotting.

FIG. 5. MDSPLUS analysis and visualization of data for LHCD DAC System

4. RECENT RESULTS AND MEASUREMENT WITH LATEST (21ST) SST-1 CAMPAIGN

In order to measure the forward as well as reflected power in each waveguide, RF detectors are installed on dual directional coupler. We have integrated first layer channels with LHCD DAC for measurement and analysis. Fig. 6. shows the result of four power measurement signals for first layer of LHCD system during SST1 (Steady State Superconducting Tokamak) testing campaign. In this shot, forward RF power of first layer is around 50kW measured at klystron output. Among all 16 forward channels, first four detector signals are shown in the graph which is averaged around 3.0kW. By applying mathematical formula and calculation, the summation of all channels forward RF powers calculated around 48kW with transmission loss. To achieve exact power measurement of all layers, gradually we will integrate the remaining layers with validation and final actual RF power will be measured and calculated.

FIG. 6. Acquisition of Layered power signals for LHCD System

5. SUMMARY

The modification of LHCD DAC has been successfully implemented with several quality checks and testing. Initially integration of 96 channels VGD4 AI card has been integrated. During the validation process after integration it has been detected that acquisition gives random problem in acquired data. After several test checks and verification it has been replaced by 4 AI IP330 modules which cater to 128 signals requirement. As the SBC was old and has limited memory in Motorola PowerPC controller we have implemented NFS for smooth acquisition of data over network. After testing in tokamak campaigns the final modified VME instrumentation and software application has been deployed.
6. CONCLUSION

In this paper, the modification in VME instrumentation and software up-degradation of LHCD DAC to accommodate additional channels for RF measurements discussed. The results obtained after successful deployment is also demonstrated which caters the need of LHCD system RF measurement. Data archival of 160 Analog input channels data have been successfully implemented with MDSplus tree based binary archival system which gives better performance in visualization and analysis of acquired data.

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REFERENCES