

THE RF-POWER-CONDITIONING-SYSTEM FOR THE FLASH RF MAIN COUPLERS

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Abstract

The main RF-Couplers for 1.3GHz TESLA-Type cavities in the FLASH linac need several preparation and processing steps. The RF processing is usually done on coupler test stands (2 couplers pairwise), on a single coupler together with a superconducting cavity in the horizontal cavity test stand, on the module test stand (up to 8 cavities) or finally in FLASH. In FLASH one or more modules are connected to one klystron and conditioned together. Therefore the software was forked several times and merged during the last FLASH shutdown into one version. This is flexible enough to handle all these different test setups, without additional programming for IO hardware or data handling. The system is based on LabView, DOOCS [1] and Linux operating system. The working principle is shown, including a possible outlook for the XFEL cavity production and operation.

HISTORY

The conditioning program design was started in September, 1995 to be used on the TTF (Tesla Test Facility) coupler test stand, which consists of two couplers. The storage data format was hard-coded and, after some months, needed the first upgrade into the ".c2dat" format, which was still based on a hard-coded structure. To be compatible with the old data on disk, all files were converted into the new format. At the next data format change, it was already clear that we cannot define a new file format for each new test setup and convert all existing files again and again. The idea of the "flex_data_struct" (.c3dat) format was born on 09.09.1997, since that time many different test setups have been used, up to 24 couplers in 3 coupler vacuum groups (accelerator modules) like in FLASH in 2007. This step was very successful, thus we use it also for pulsed cavity and motor tests. In the data format the configuration files "dat_source" is already included, in order to define which value names and types are measured, and the "net_alias" translation tables, which allows the use of the same channel names on different test stands with different real DOOCS addresses. The only upgrade was a "include" function which reduced the duplicated entries dramatically (it is much easier to maintain). With more test stands the config file for test stands was born, it contains the interlock channel names, test stand correlated cable calibration data (the only parameters which can be adjusted by the operator via the measurement program itself) and some device configurations, like the RF signal generator type, which can

also be a DSP (Digital Signal Processor) or FPGA (Field-Programmable Gate Array) system from the LLRF (Low Level Radio Frequency) group at DESY.

THE WORKING PRINCIPLE

Our RF (Radio Frequency) conditioning system is working in pulsed operation, starting with very short pulses (usually $20\mu\text{s}$) with a low replate (of usually 2Hz). The lowest limit is given by the powermeters, which permit RF pulses with a minimum pulselength of $2\mu\text{s}$ and a replate of minimum 1Hz. The general coupler conditioning procedure is simple: The program adjusts the driving power with short pulses, step by step to higher levels, and goes down again if any measured signal is reaching its limit. If the highest needed power level is reached, the level will be set to minimum and the procedure starts again with the next longer pulselength. The usual steps are $20\mu\text{s}$, $50\mu\text{s}$, $100\mu\text{s}$, $200\mu\text{s}$, $400\mu\text{s}$, $800\mu\text{s}$ and $1300\mu\text{s}$. For the most important sensor signals, there exists a hardware interlock, which will switch off the RF completely.

Overview

The measurement program is accessing only files and (one or more) GPIB (General Purpose Interface Bus = IEEE-488) buses to access the powermeters (and if available a RF signal generator). On our test stands, all RF signals (including the HOM (Higher Order Mode) couplers from cavities) are measured with powermeters. In the linac only some key values are measured with powermeters because of the very high number of channels. All other devices are used through the control system (DOOCS):

- Although the timing in Fig. 1 is shown only once, the clock decoder and server exist in any electronic crate individually and only some delay parameters are monitored by the program (usually the RF start trigger should be the same).
- The LLRF (Low Level RF) system, which adjusts the RF pulses in amplitude and phase, usually is used for conditioning in feed forward mode only. With help of this system, we are able to adjust every micro second of the RF pulse, so that also tickling (small pulses on the big pulse) or reducing the RF after the cavity filling time (if it is on resonance) is possible. (There is also a mode, which allows reduction of the slew rate, which we used for the RF gun coupler only.)

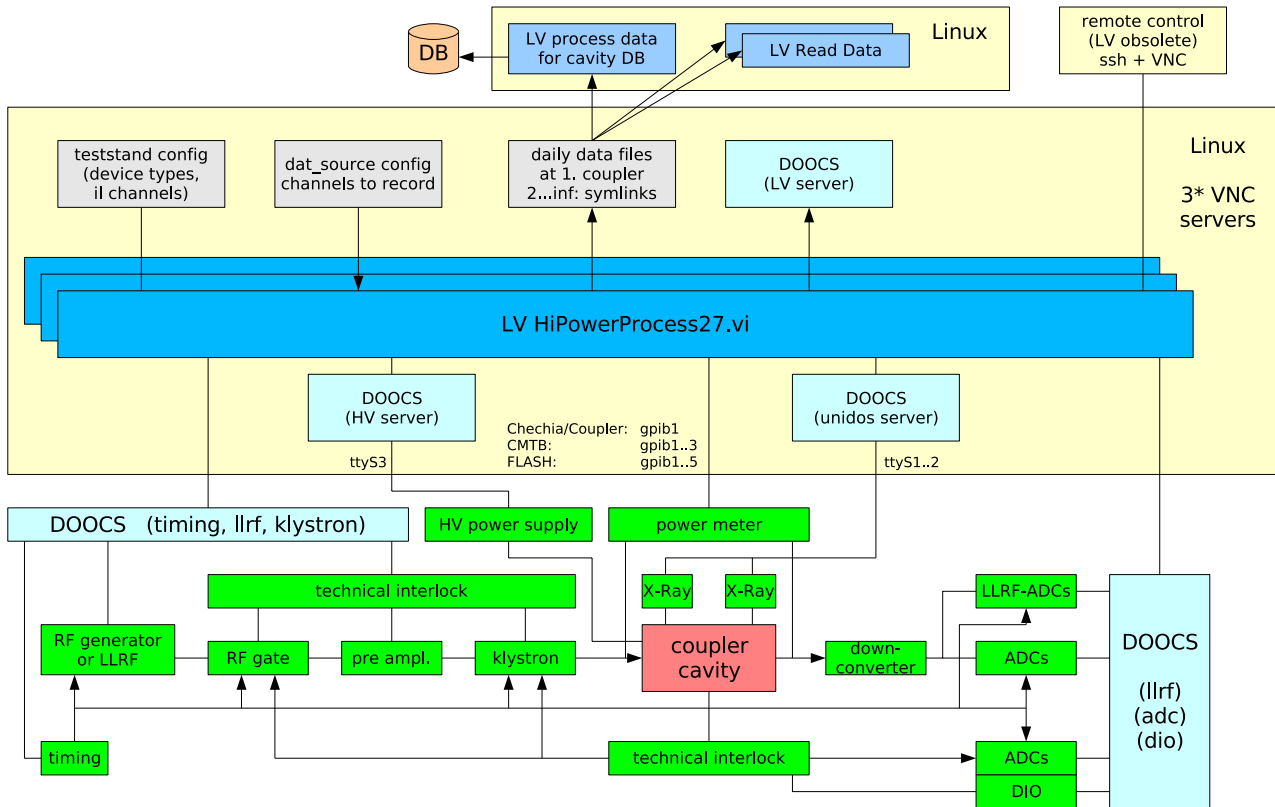


Figure 1: The general system overview, which is similar on FLASH or any of our pulsed RF test stands.

- The RF gate is controlled by the timing system and is used as additional security, in order to avoid longer RF pulses than expected. (For a RF power coupler it is dangerous to increase the pulse length abruptly.)
- The klystron unit persists of two parts looking from the point of view of the software: the technical interlock which stops the RF (by a RF gate and the preamplifier) and the modulator control, which contains its own interlock for the high voltage power supply. We need to know if there is anything which disables the RF, so that the program needs to go down with the power and tries to reset or restart the klystron afterwards.
- If there is a bias voltage supplied to the coupler, their values can be recorded. The adjustment of the high voltage is only done by the operator up to now.
- The technical interlock for the coupler and cavities is monitoring light and free electrons in the waveguide and coax of the coupler. In addition, the temperatures of the RF ceramic windows, the vacuum of couplers and cavities, the helium level and pressure and, if available, the bias high voltage will be checked by the hardware interlock. When an interlock event occurs, the first rising channel is indicated, too. The fast interlock signals (like free electrons (e-) and light) additionally are connected to fast ADCs, where the ADC

server will be configured from the measurement program to calculate the signal strength for each sensor and RF pulse. The highest value will be remembered until the moment when the program is asking for it and sets the maximum value back to zero again. With this method we do not miss any measured pulsed signal, even if it happens only once.

- All RF signals (except the RF from HOM couplers) are going through down converters and are measured by fast ADCs. The complete pulses usually are only stored for cavity on resonance performance measurements (flat top).
- The X-Rays are measured on the cavity and module test stand. In the FLASH linac this is done only sometimes (because the measurement will be disturbed if there are RF gun tests in parallel).

The measuring program is sending the data also to recorder servers (DOOCS), which allows everybody to look at the current power levels and the program state.

For the cavity and coupler test stands the program is running on GNU Linux OS (ubuntu) with a local GPIB. The conditioning of the RF-groups (Acc1; Acc2,3; Acc4,5,6) at FLASH is done from a screen less server (GNU Linux OS (debian)), which uses several GPIB-Ethernet adapters in the injector area and in the extension hall. All of them are able to run in parallel and can be managed via VNC

(Virtual Network Computing) from the office and also from home if needed.

Measurement Program

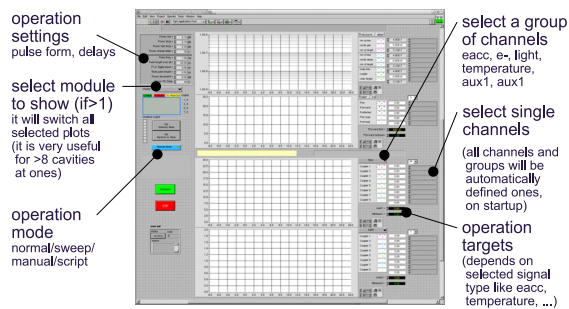


Figure 2: The measurement program.

The last version of the measurement program (Fig. 2) is internally divided in two parts:

- The hard working loop, which runs with an adjustable cycle time (usually 30s is fast enough; 4s is the fastest possible time, limited by the powermeter measurement (the number of channels does not matter)). It is requesting all configured values, checking their limitations (targets), adjusting the power or resetting an interlock and storing the data.
- The display management is used to show a short history (e.g. 3h) of the current values. For deeper analysis different reading programs can be used in parallel. The number of plots is dramatically reduced against previous versions, therefore the plotted data can be easily switched in groups and also the complete page can be switched if more than one module (8 cavities) is operated by this instance. Any channel can be selected by the operator to be shown in any plot. The plots or channels are not influencing the working loop, only the limitations (targets) of the signal groups which are shown in this area will be used for the conditioning.

The main steps of the measurement program are:

- Just after program start the operator can choose any known (configured) test stand and define which interlock alarm should not be automatically cleared (reset) by the program.
- The control loop is running independently from the current plots. The normal behaviour during a loop cycle:
 - Read settings and measure all defined values (1 cavity: >63 channels; at FLASH with 3 modules: >165 channels).
 - Check if there are new settings from a running script (see below).

- Depending on the current state (power up/down, interlock alarm, read error, fast power rising, manual control, ...) and on the currently measured values with their targets (= software limitations), decide what to do next (more / less power, wait, reset interlock, start or stop the klystron, ...) and define the new state.
- Store all data and control the hardware (LLRF, interlocks, klystron, ...).

SCRIPT CONTROL

One of the very nice and time reserving features is the script controlled operation mode. In this mode, the program will read a hand written text file, which contains one command per line, that is doing the same settings, like the operator can do on the front panel. The available commands in general:

- Set the program loop time, or data storage interval.
- Set the pulse length and shape.
- Define the power increment or decrement step size.
- Set the target (limit) value for a signal group (e.g. power, accelerating field Eacc, light, free electrons, temperature, pressures).
- Define the program mode (like normal, sweep).
- The wait command defines which target should be reached to go to the next script item (e.g. the maximum or minimum power or electrical field level, some running time).
- Finally there is also a command to stop the operation.

FLEXIBLE-DATA-STRUCTURE

As mentioned in the section "history", the designed "flex_data_struct" was a very useful step for various test setups, and enabled us to add channels during runtime. Here we would like to describe the principle in short.

There are two main data types. The "data_source" is a struct (in labview: cluster), which defines the used value names and their data types in arrays.

The second one "data" is a struct, which contains "one data point", which is a timestamp and two arrays (the indexes to the source names / types; and the binary of each value).

The "data_source" type (name: source) itself is the permanently existing name and data type (index=0), so that it can be reconstructed from the binary data. Each file contains many entries of type "data", which will contain the "data_source" in the first data point and in any further one, if updated.

If the data files are loaded, the changing of the "data_source" tables needs to be recognized, and the subsequent index list has to be updated for the merged "data_source" table in the memory.

The value naming structure uses tags, that define the reading source (g= GPIB, n= DOOCS, s= program settings, ...), the test stand (e.g. c= coupler), the signal group (e.g. pressure, power, light, ...) and a freely defined name. If there are more locations available, for example 8 couplers in one test setup, there is the position number appended. Values without this appended number are valid for all locations. Example: n;c;pressure;Pcoupler;1

The translation tables per test stand ("net_alias") will define the real DOOCS address and data type from these value names. So normally there is no programming needed to add or change the measured channels.

Further details about the data files and structure can be found in the web: <http://www-mhf.desy.de/public/tfadm/>

FURTHER DATA MANAGEMENT

The Data Reading Program

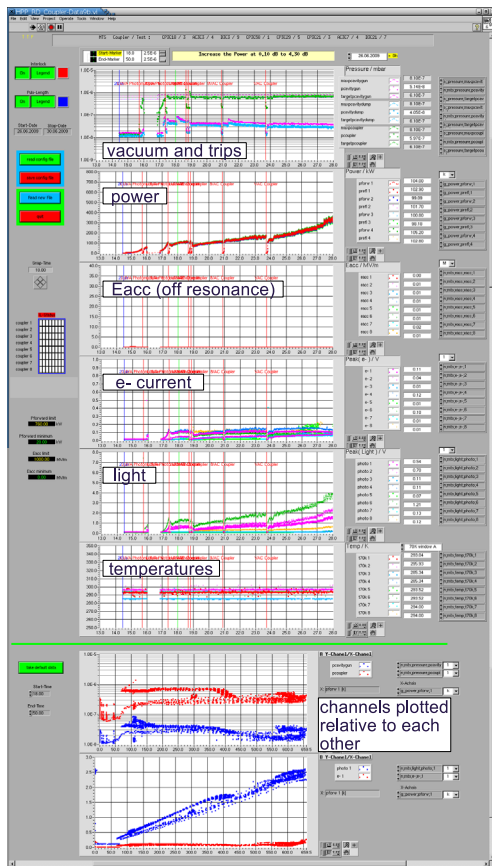


Figure 3: The data reading program.

When starting the data reading program (Fig. 3), one can select the coupler name, test number and the interesting time range (days), where the number of data points is shown in parallel. The data reading program will filter the

usually interesting channels and try to distribute them over the plots according to their type (like power, Eacc, ...). The operator can select manually any channel for each plot, and if this selection should be reused, the channel selections ("knob-config") can be stored on the file system and be reloaded afterwards.

Table View

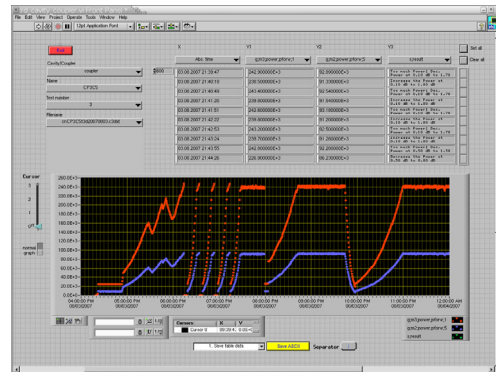


Figure 4: Read data to show it in a table view.

This more universal reading program (Fig. 4) permits to read only one file, but therefore any available channel can be selected for one of four columns (X and 3*Y). Additionally the shown table can be stored as CSV (Comma-Separated Values) ASCII file.

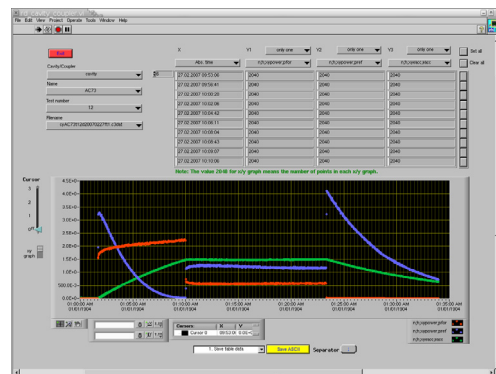


Figure 5: Example view for complete RF pulses.

The type of the channel can also be a string or if available, complete pulses (x/y plots), like for free electrons, electrical field or the RF power. Here (Fig. 5) is shown an example from the cavity measurement. (It is possible for coupler data, too)

Interlock Statistic

This tool (Fig. 6) lists all interlock events and shows how often each channel exceeds the limit. Including subsystems like klystron and high voltage modulator. Besides the first rising channel of each alarm is shown.

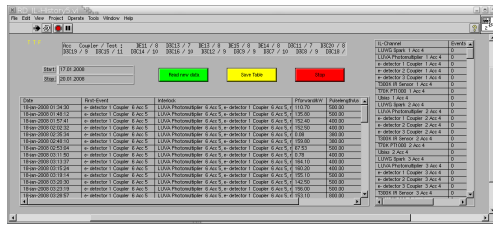


Figure 6: Get the interlock statistic for the RF test.

couplers) are extracted from these data after each RF test and are stored in the public cavity database.

REFERENCES

- [1] K. Rehlich et al, "DOOCS: an Object Oriented Control System as the integrating part for the TTF Linac", Proceedings ICALEPCS '97, Beijing, China. <http://doocs.desy.de/>
- [2] P.D. Gall et al, "A Database for Superconducting Cavities", Proceedings SRF 2007, Beijing, China.

Data Processing for the ORACLE Database



Figure 7: Data extraction for the ORACLE data base.

After each coupler test, the mainly interesting data will be extracted and transferred into the ORACLE data base [2] (Fig. 7). Therefore a program is searching for multipacting levels; this are power ranges where the free electrons are detected after conditioning. The start and stop power level for pressure jumping areas will be stored, too. This should help during normal operations to understand the behaviour of the couplers in the accelerator. For some statistics, the RF run time for each pulse length is also stored. In the same picture (Fig. 7), on the right side the public data view of the final data is shown.

OUTLOOK

Over the time, a flexible RF conditioning system was growing and is now able to work on all our 1.3GHz test stands with pulsed RF. It can be easily configured to work in the XFEL test hall (AMTF) as well. Due to problems with the current LabView versions, a control system (DOOCS) based structure will be developed in C++ and Java for the RF conditioning at the XFEL. The chosen data format (in arrays stored binaries, which where open for future data types) allows the use of universal reading programs working for other measurement programs (like cavity or tuner tests), too. The most common information (like operation times, power levels and multipacting ranges of