Upgrade of low-level radio-frequency box for resonant cavities characterization

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Enrico Munaron

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Contents

Abstract

During the year 2020 we upgraded the "Rf measuring system for cavity characterization" designed by S. Stark in 2004. The main purpose of this new LLRF box is to communicate with various operating systems and allow the control via EPICS and CSS GUI. In this document there's the descriptions of the hardware and firmware involved.

1 Introduction

The general structure of the measurement apparatus remain similar to the previous system, while the dedicated computer board was completely replaced with a microcontroller based board. This microcontroller based board allow the communication with the external EPICS IOC that run on linux pc. This board is based on RISC MCU and has an electrically isolated USB communication serial port.

2 RF circuit section

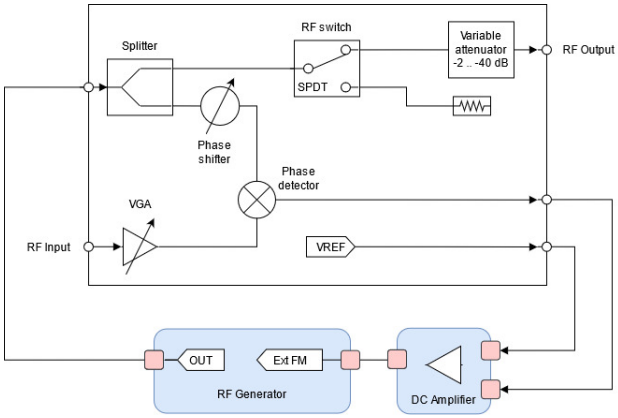

Figure 1: Simplified block diagram of LLRF box.

The LLRF box is a VCO-PLL system designed to track the cavity frequency, and is composed by few components:

- Variable gain amplifier (VGA).
- Phase detector
- Phase shifter
- An external RF Generator with FM modulation option.
- An external DC amplifier.
- RF switch
- Variable attenuator

In figure 1 the block diagram for the LLRF box RF path is shown. The signal coming from the resonator pickup (RF Input) is processed through a variable gain amplifier; the phase error is produced by comparing the VGA

output signal with a frequency reference coming from the output of the phase shifter by means of a phase detector, an AD8302; the amplitude error is obtained by comparison between the detected signal and a constant amplitude reference. The error signals are then amplified and feeds the FM modulation input of the RF Generator.

The RF Generator output is splitted in 2. Part of the signal goes directly into the RF Switch, the other part goes into the phase shifter.

The phase shifter is realized by means of a quadrature modulator controlled by a double channel DAC: in fact, it can be easily shown that if the modulation ports are driven by signals proportional respectively to $sin\alpha$ and $cos\alpha$ the resulting output is a signal whose amplitude is constant and the phase angle is α.

The RF switch is a PIN Diode SP2T switch used to turn ON/OFF the RF drive signal and is controlled by a digital I/O.

The RF drive signal level is adjusted by a variable attenuator, controlled by a DAC, then (RF Output) feeds the RF power amplifier connected at the cavity coupler.

3 MCU section

The MCU section is built around a PIC18, operating at 25 MHz. The section includes:

- 64kB Program memory ; 3.8kB Data memory ; 1kB EEPROM memory
- 1 USB to serial communication channel, 0.3 kV DC isolated.
- 2 SPI 16bit port expanders.

The following I/O channels have been added to control the RF section of the controller:

- 1 single channel DAC (12 bit + 1 control bit)
- 1 double channel DAC (10 bit + 3 control/clock bits)
- 1 VGA (4 bit + 1 control bit)
- 1 PIN Diode SP2T switch (1 control bit)

The function of each I/O channel will be explained in the followings subsection. The application program has been developed under MPLAB-IDE and XC8 Compiler; it is written entire in C.

3.1 USB Link

The communication to a host is ensured by serial port channel over USB at speed of 115.2 kbaud. The USB channel is electrically isolated from board power supply up to 0.3 kV DC, this ensure to avoid ground loops, equalizing currents and protect the host against over voltage.

3.2 Port expanders

Two MCP23S17 16bit I/O expander are present on the board to ensure enough GPIO for all I/O channels. Figure 2 show a map of control lines for each I/O channel.

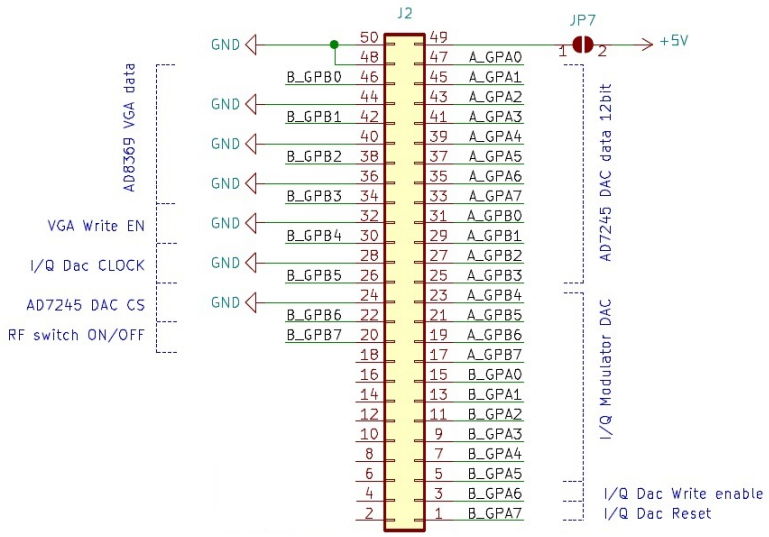

Figure 2: Map of all GPIO from Port Expanders.

3.3 Variable attenuator DAC

The Variable attenuator is a MACOM CG1 and is controlled by an AD7245A, a 12bit DAC with a parallel interface, that supply a voltage from 0 to 10 Vdc at the control pin of the attenuator.

Att.n @ 80 MHz (dB)	Att.n @ 160 MHz (dB)	Voltage DAC	Value DAC
2.9	3.0	7.15	2929
7.4	7.5	5.0	2048
8.6	8.8	4.5	1843
12.1	12.3	3.5	1434
15.7	15.8	2.9	1188
18.4	18.5	2.65	1085
23.2	23.2	2.4	938
34.1	33.7	2.15	881
46.5	42.4	2	819

Table 1: MACOM CG1 Attenuation table.

3.4 Phase shifter DAC

The control of the phase shifter is entrusted by a dual channel 10bit DAC, an AD9761 with a parallel interface. Both the I and Q DACs produce two complementary outputs that are fed into an AD8345 quadrature modulator.

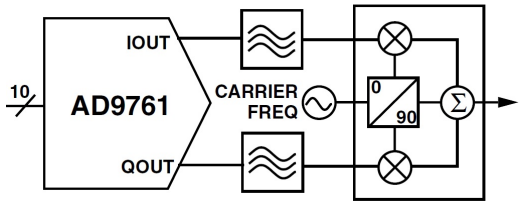

Figure 3: Implemented architecture for the phase shifter.

Phase angle α	V Qa	V Qb	V Ia	V Ib	Value DAC Q	Value DAC I
0	0,683	0,684	0,965	0,4	511	1023
45	0,89	0,476	0,935	0,43	872	872
90	0,975	0,391	0,758	0,607	1023	511
135	0,89	0,476	0,536	0,829	872	150
180	0,684	0,683	0,4	0,965	511	0
225	0,476	0,89	0,429	0,936	150	150
270	0,391	0,976	0,606	0,759	0	511
315	0,476	0,89	0,828	0,537	150	872
360	0,683	0,684	0,965	0,4	511	1023

Table 2: Phase shifter behaviour table.

3.5 Digitally controlled VGA

The variable gain amplifier is an AD8369. Digital control of the AD8369 is achieved using a parallel interface.

Gain (dB)	Digital value
-10	0
-1	3
14	8
23	11
35	15

Table 3: Variable gain amplifier behaviour table.

3.6 PIN Diode switch

The PIN diode SP2T switch is a CDS0912 controlled by a single bit.

4 Command section

For convenience the commands and the communication protocol are derived from G.Bassato Resonator controller. The following startup string is sent by the controller at power up.

```
    hello! here is the USB I/O CONTROLLER command interpreter ver. 1.0
>
```

4.1 Commands description

The commands accepted by the controller can be divided in two groups:

- 'Setting type', when a command is issued to set a parameter in the controller.
- 'Request type', when an information is requested from the controller.

These commands can be issued both in upper and lower case ; those belonging to the first group must contain, as terminator, the character '=' ; those belonging to the second group must use as terminator the character '?'. No spaces are allowed between the command string and the terminator character; in case of setting commands, one or more spaces are allowed between the terminator character and the parameter values.

4.1.1 Setting type

RFOUT=n set value to n = 0..1(Digital Value)

This command let to switch on/off the RF 0 = OFF, 1 = ON.

RFLVL=nnnn set value to nnnn = 0..4095(Decimal Value)

This command let to set the attenuation level (see table 1).

PKLVL=nn set value to nn = 0..15(Decimal Value)

This command let to set gain of the VGA (see table 3).

DACIQ=nnnn,nnnn set I and Q value to nnnn = 0..1023(Decimal Value)

This command let to set the phase shifter: must be loaded with the values I and Q or $sin\alpha$ and $cos\alpha$ to produce a phase shift of α ; I and Q are controlled individually (see table 2).

4.1.2 Request type

RFOUT?

Return the actual state of the RF 0 = OFF, 1 = ON.

RFLVL?

Return the actual value of the attenuation level (see table 1).

PKLVL?

Return the actual value of the VGA (see table 3).

DACIQ?

Return the latched I and Q values of the phase shifter (see table 2).

HELP

Return the complete command list.

INFO

Return hardware and firmware info.

Q

Return the actual value in hex (0 to F) of the 32 I/O's collected in nibble.

4.2 Communication protocol

With the only exception of the string issued at the startup, the communication between the board and the host computer is based on a simple protocol consisting of:

- a command issued by the host.
- a reply made of three strings issued by the controller. The meaning of these three strings is the following:
  1. the 'echo' string
  2. the string containing the requested information if the command was of 'request type' or the message 'done' if the message was of 'setting type'
  3. the prompt string '> '.

In case of syntax errors or errors in the parameter values (when a setting command is issued) the second string will contain an error message with an error code. The programmer must take care to read always three strings from the controller each time a command is issued by the host.

5 Schematics

The reference schematics can be found on following GitLab repository:
https://baltig.infn.it/bortolat/cavitymeasure/-/tree/enrico

List of Figures

List of Tables