DDS-BASED CONTROL LOOPS FOR THE RF SYSTEM AT INFN - LNS

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Abstract

In the last two years a new radio-frequency source generator has been working to synthesize the driving sinusoidal signals of the RF systems at LNS [1]. This device is based on Direct Digital Synthesis (DDS) technique. Every time you need a constant relation of phase between several RF signals, our DDS-based multiple frequencies generator produces these high frequency waveforms. The good results of this DDS synthesizer technique, make us feel confident that we can develop a new DDS control system for the various RF equipment. The AD9852/54 a commercial DDS microchip, will be the core of this new control system. The component allows, through digital ports, the manipulation of the frequency, amplitude and phase of the developed RF-carrier without any interruption to the latter. In this way we would have a complete DDS control system capable of stabilizing amplitude, phase and tuning ensuring the present stability of the analog control loops. The remaining operations, such as turning on/off and protection of the system will be performed at the same time. The prototype of this new DDS control, its technical performances and the experimental results will be presented in this paper.

DDS-BASED CONTROL RF SYSTEM

The DDS control system prototype will replace the present analog control system for the three resonators of the superconducting cyclotron [2]. Currently three different analog loops ensure the stabilization of the phase, amplitude and tuning of accelerating voltage on the electrodes (dees). They are three wide band analog loops able to operate in manual or automatic open/closed loop. The control system also includes several protection and turn on/off devices, plus the possibility to operate in remote mode for all the operative functions. These analog loops are described in the following schematic block diagrams. Figure 1 shows the amplitude loop.

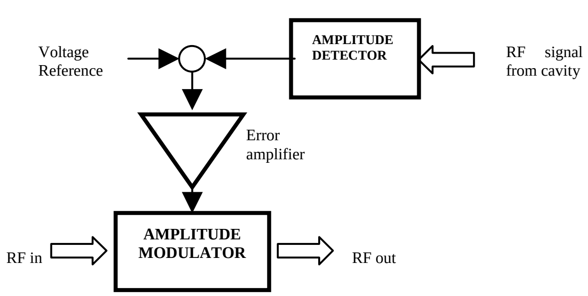

Figure1: Amplitude stabilization loop

The same principle of the previous amplitude loop is applied to the phase loop, as figure 2 below shows.

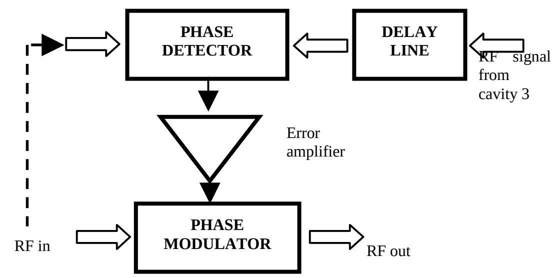

Figure2: Phase stabilization loop

Both of the above analog loop functions have been taken into consideration when developing the DDS-based control system shown in figure 3 below.

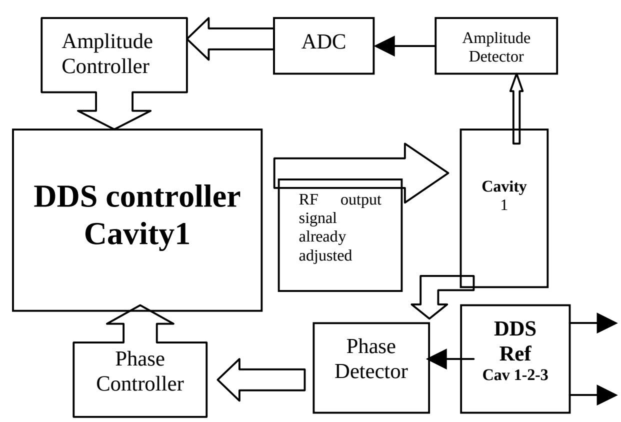

Figure 3: The block diagram of the new DDS control

The system consists of one DDS reference electronic board plus three other DDS controller boards. In schematic of figure 3 only the DDS control for the cavity 1 of the cyclotron is reported. The other two cavities are linked to the same DDS reference. The new system also includes the internal and external protections. The internal alarms include multipactoring, spark and reflected wave. In this case the system will try, after a while, to re-start the RF signal every time one of these alarms occurs. The external alarms, such amplifier failure, vacuum, cooling, radiation protection, switch off the system until the end of the problem. The turn on/off system has been designed on the same trapezoidal envelope of the old control system. Only the tuning system remains more or less similar to the old one. The DDS control prototype combines each function of a classic analog control system in a digital mode. One of the most important challenges is the relation between the operation speed of the analog and digital system. Until a few years ago there was no chance to replace an analog loop perfectly with a digital one, especially because for phase and amplitude loop the speed to maintain the requested stability is fundamental. Today, after the positive experience of the DDS-multiple frequencies generator, we would like to develop a new equipment, not only to realize a sinusoidal generator but a synthesizer able to detect a signal from a pick-up of the cavity, to adjust phase and amplitude, make a comparison with a reference value in order to stabilize the accelerating voltage on the dees. The characteristics of the core of the system, the AD9852/54 [3], described below, summarize the high performances of this microchip in the range of frequency of the cyclotrons.

- Generation of a sine wave output at frequencies up to 120 MHz
- Digitally tuned sine wave at a rate up to 100 million new frequencies per second
- Changing output frequencies without phase discontinuity
- Output frequency resolution, up to 48 bit
- Output frequency switching time, around 40ns
- Phase noise, related to the clock generator spectral purity
- 14 bits of digitally controlled phase modulation
- 12-bit digital multiplier permits programmable amplitude modulation
- Implementation complexity elements of proper RF design expertise, no longer required to implement a DDS solution
- Low cost

The matching between the above characteristics of the DDS and the main parameters of our RF system, make the control system possible with this new direct digital synthesis technique. Table 1 summarizes the main parameters of the RF system with their values and limits.

Table 1: Main parameters and specifications

Parameters	Value and limits
Max Accelerating Voltage	100 kVolts
Frequency range	15÷50 MHz
Open amplitude loop adjust	0÷100 kV
Closed amplitude loop adj.	±10% of the Vdee
Residual ampl. modulation	$<10^{-4}$ (40dBc)
Open phase loop adjust.	0÷360°
Residual phase modulation	±0.1°
Input/Output impedance	50Ω

For example a maximum residual phase modulation of 0.2° is ensured by 14 bits of digitally controlled phase modulation. The 20% of maximum variation voltage is possible with 12 bit of amplitude modulation under the 40dBc limit. The frequency range is under 120 MHz and also the 50Ω matching can be done easily.

If the core of the system can follow the characteristics of the rf cyclotron, the other devices around the AD9852/54 also ensure the same high speed performance. This is the reason why electronic components from the CPLD family have been chosen. The external Complex programmable logic devices, CPLD, have been used to realize the amplitude and phase controllers plus the phase detector. The CPLD devices are able to realize many complex high speed digital functions and operations. This helps us to come very close to performance of a classical analog real time loop control. The system is able to manage the dynamic performance of our DDS device, the AD9852.

Main characteristics of the DDS system

The list below summarizes the main characteristics of the digital phase and amplitude control system.

- The system is based on AD9852
- The front end between the cavity signals and the DDS is mainly based on the CPLD family
- A master DDS reference, CPU controlled, supplies the reference frequencies of 3 other DDS boards, one for each cyclotron cavity
- The pick-up signals from the cavities are compared with the phase reference. The system places each output sinusoids at 120° and after closes the phase loop
- The phase comparator increases or decreases a CPLD accumulator in order to drive the phase registers of the DDS
- The amplitude comparison between the detected signal from the cavity and the reference, changes the CPLD accumulator status, in order to drive the amplitude registers of the DDS

THE DDS PROTOTYPE

The new DDS control system prototype is ready. After the succesful phases of debugging, the first operative tests have been done. The system is very compact and all the electronic board devices are only placed in a 5 unit rack. A picture of the cabinet is shown in figure 4.

Figure 4: The DDS cabinet

The front panel shows an extremely easy to use architecture. It would be simple and at the same time intuitive for the operator. It hosts one main line switch, two green indication leds, eight N female coaxial connectors, three knob encoders and ¼ VGA colour display. The above first three connectors are the output sinusoidal signals of the DDS controllers. The last connector is the signal from the reference DDS board. The bottom output connectors are a copy of the ones above but are opposite in phase. The three black knobs are able to drive all the functions of the system. Each rotation of the knob moves a line on the screen of the LCD monitor. When the function appears on the screen, a light pressure on the same knob allows us to set or read the selected parameters. In this case we can increase or decrease the main parameters of the system, such as frequency, phases, amplitudes, delay, etc. The same simple layout of the front panel appears inside the cabinet. There are two main different blocks. The power supply and the DDS system. The DDS block consists of the reference DDS motherboard and three DDS controller boards. The the DDS block, inside the cabinet is shown in figure 5.

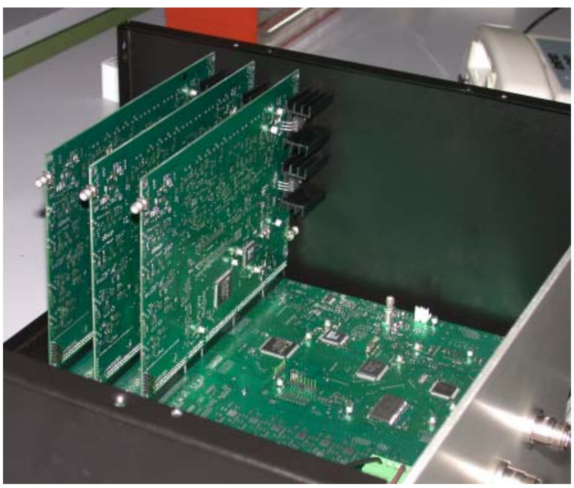

Figure 5: Internal view of the DDS cabinet

The open loop tests have been done and the results are satisfactory. The DDS equipment is able to synthesize three sinusoids in phase and out of phase. It is easy to change the initial phase and amplitude between the three sinusoids. The turn on-off procedure has also been tested together with the simulation of detected alarms. The system was also tested on the cavity 2 of the superconducting cyclotron at low power. Some closed loop tests have been done in phase and in amplitude. These preliminary tests have been done with the cavity in air. We used a 100 watt linear amplifier with the DDS cabinet as a driver and control system of one cavity. It was not possible to increase the power in the RF cavity, because the cyclotron was under maintanance. In this case the acceleration chamber of the cyclotron is not under vacuum and it is not possible to feed the proper rf power, in order to localize on the dees the high accelerating voltage. However case after these tests we are confident in the use of the DDS prototype as a complete RF source and control system in the near future.

CONCLUSION

At the moment the status of the entire system has taken a big step forward towards a complete multifrequency sinusoidal generator and a step back to becoming a full control system in order to guarantee the same performance of the present analog system. The present control system has been operating without major problems or interruptions since 1995. In May 2002 we introduced for the first time the new multifrequency DDS-based generator. At that time it was only an experimental test, but today it is used for the whole synthesis of the driver sinusoidal signals for the cyclotron, axial buncher, low and high energy choppers [4]. The present system has become in some parts quite obsolete. It sometimes gives us problems to find, still in production, old components to repairing the electronic boards. This is another reason for exploring the DDS alternative. As you can see from the previous pictures, the new system appears extremely compact and easy to use. To give an idea of the difference in size between the present system and the new one, see figure 6.

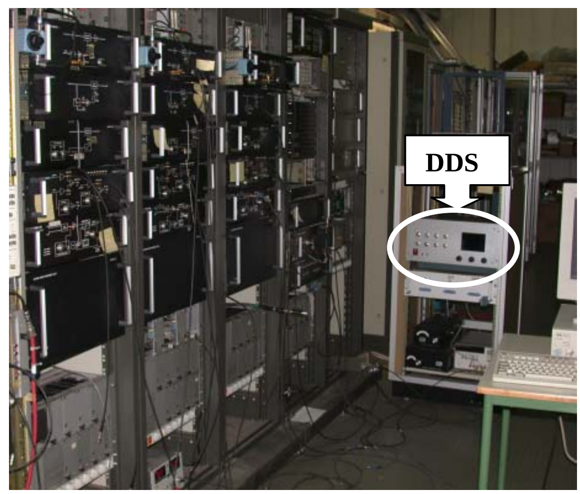

Figure 6: present and new dds control, comparison

It is clear that our final goal is to compress several cabinets into one 5 unit rack, including all the functions.

REFERENCES

[1] A. Caruso et al, “DDS-based multiple frequencies generator for the RF system at INFN-LNS “, NUKLEONIKA 2003; 48(Supplement 2):S69-S72.

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