How to optimize Quantum Physics experiments

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Questions & Answers

Q1: An AWG 9GSa/s generates waveform with 8-bit samples. Is that resolution enough to generate high-quality RF and uW signals?

A1: It is important to understand that quantization noise is equally distributed over the whole generation bandwidth. This means that an ideal 8-bit AWG running at 9GSa/s generates the same quantization noise spectral density than a 10-bit 650MSa/s AWG while offering 16 times more usable bandwidth. However, the 8-bit sample resolution spec is only valid when the generator is to generate a wideband signal from DC up to the maximum bandwidth. This is not the kind of RF signal being used in QC experiments, where BW is limited to a few tens or hundreds MHz. To generate such signals, Proteus use much lower sampling rate IQ baseband waveforms to feed the internal numerical IQ modulator and finally converted to and analog signal. As the modulator is located close to the DAC, just the lower sampling rate IQ sample pairs must be transferred and those are defined with 16 bits as well as the calculations made by the DUC. So, for RF/uW modulated carriers, the sample resolution is 16-bit and the DAC is 14-bit. At the end what matters is the SFDR specification in the vicinity of the modulated carriers and Proteus can generate RF modulated signals with SFDR better than 80 dBs in most frequency bands.

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Q2: In our experiments, we cannot make sure that everything will be properly terminated with the right 50 Ohm impedance. Does this mean that the signals applied will be distorted by reflections?

A2: If the impedance mismatch occurs at the end of the transmission path, the reflected waveform will go back to the generator, where it will be terminated by the 50 ohm output impedance of the generator. The residual reflected signal will be very small, if any at all.

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Q3: We have been using all kind of external mixers and IQ modulators in our experiments. What's your solution?

A3: If the signals to be generated go beyond 7.5GHz or the ones to be acquired go beyond 9GHz, external mixers or modulators/demodulators may be necessary to generate and acquire such signals. However, the ability to generate and capture signals in the microwave region, makes much easier and simpler to handle signals at higher frequencies. Additionally, IQ modulators, difficult to align and requiring two AWG channels per uW signal, may become unnecessary as modulation can be produced numerically at high IF frequencies.

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Q4: In our quantum computing experiments, we must spend a great deal of time aligning and calibrating all the components used in the control and readout of qubit states. What's your solution?

A4: The Proteus AWT has a few advantages for Quantum experiments:

- **A big reduction of the number of components required to set up a system.** In many cases, no external mixers or modulators/demodulators are required. When signal frequencies are higher than the ones supported directly, simple mixers can be used, and they are much easier to characterize and align than IQ modulators/demodulators.
- External mixers when combined with the Lucid multi-channel CW signal generator as the L.O. source, are simpler to align as all the signals are automatically phase-locked to the same reference, and differential phase can be set to any value.
- The built-in real-time DSP capability in the Proteus unit also allows for the application of real-time corrections tailored for each input and output channel.
- The calibration and correction tools available in the WDS environment automate the design process of correctors and both the output and input channels can be traced to references available in most laboratories, as maximally flat DSOs from multiple suppliers.

- The compact size and the integration density of the Proteus solution help to minimize the size of systems and interconnections, minimizing the loses and linear distortion.

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Q5: According to the presentation, several tools can be used to develop the IP for the internal FPGA. Does that mean that any available standard IP library can be used along with Proteus?

A5: Yes. Proteus incorporates a well-known FPGA platform from Xilinx and all the existing IP libraries can be applied as well as any compatible development tool. What Tabor supplies for these users are all the IP components to support the analog and digital inputs and outputs, the access to the DRAM memory, and high-speed communications through the PCIe backplane so users do not need to worry about timing issues or the details of the HW implementation. In particular, Quantum Computing IPs such as ARTIQ (or the more advanced and faster QDSP or APS2) can be deployed in the internal FPGA with ease.

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Q6: We are implementing QC systems with a few tens of qubits right now, but our plan is to keep growing that number in the future. Size and modularity are very important. What's your solution?

A6: The Proteus solutions are implemented in different platforms, all of them offering the highest channel count in the market in the smallest size. The Proteus PXI modules support up to 4 AWG channels in two slots, and two digitizer channels can be added using an additional slot. As an example, using the 21-slot Tabor optical PXIe chassis, a total of 40 2.5GSa/s AWG channels can be implemented in just one 19 inches chassis (4U height). Alternatively, up to 28 AWG 2.5GSa/s channels and 14 digitizer channels can be implemented in the same chassis. Or 14 9GSa/s AWG channels and 14 digitizer channels. In addition to Proteus, Lucid also supports high-density systems when multiple CW L.O. generators are required to feed external mixers and modulators/demodulators. Up to 16 channels can be supported in a single rackmount unit (3U height). The number of channels can be extended by synchronizing multiple chassis without the need for special or additional synchronization devices.

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Q7: AWGs are based in waveforms previously defined and calculated. In our application, it is not possible to define all the possible waveforms in advance as they have to be defined based in the results of the current feedback-forward cycle. How does your solution handle this kind of situations?

A7: Many QC applications can be supported by a limited series of waveforms, and just the timing and duration of the pulses must be adjusted in real-time during a quantum computation. In order to better support this kind of solutions, Proteus implements an innovative waveform memory handling, where all or the initial section of multiple waveforms can be stored in very fast static RAM implemented in the FPGA. This unique architecture combines the convenience of very large waveform memory offered by DRAM with the switching speed and deterministic timing (low trigger jitter) offered by static RAM. When this is not enough, the FPGA is fast enough to calculate waveforms in real-time according to the hardware (or SW) implemented in it or to apply differentiated processing to already-defined waveforms.