HYBRID QUANTUM COPROCESSORS

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Quantum computers are probabilistic and analog devices. A quantum computer operates under the control of a classical computer. A quantum computer is a quantum coprocessor (QC) in relation to a classical computer. The main component of QC is called qubit (QB). QB's behavior is described by the wave function $|\psi\rangle = \sum_{j=0}^{N-1} \lambda_i | j\rangle$, $p_j = \lambda_j^2$, $P = \sum_{j=0}^{N-1} \lambda_i^2 = 1$. Changes in the state of a QB are illustrated by the movement of the radius-vector *r* in a unit circle (Figure 1).

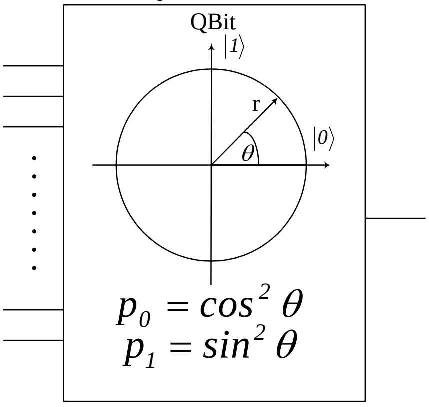

Figure 1. Digital qubit symbol

The state of a QB is determined by the angle θ. Its value can be changed, thus calculations can be performed with θ angle. The final position of the radius-vector determines the result of the calculation. But when measured, vector goes either to position $|0\rangle$ or to position $|0\rangle$ with probabilities p_0 and p_1, respectively (Figure 1). The sequence of actions on a qubit, which determines changes in its state, is described by an analog circuit, which consists of so-called quantum gates. If a quantum computer includes *N* qubits, then the result of its operation will be a multibit state $|\Psi\rangle = |\psi_0\psi_1 ... \psi_{N-1}\rangle$.

The DiVincenzo criteria [2] are conditions necessary for constructing a quantum computers. Not a single word about their physical nature is included in this criterion. So digital qubit (Figure 1) can be represented as a digital device whose operation is described by the same wave function as that of a true analog qubit. It has multiple inputs and one probabilistic output and it can be built in FPGA either as a finite state machine (FSM, Figure 2) or as a RISC-like pipeline of digital quantum gates. Thus, a digital quantum coprocessor (DQC) is also can be built in FPGA.

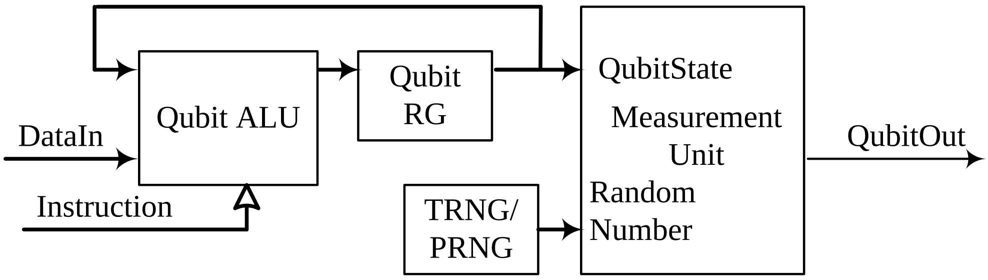

Figure 2. Digital qubit as FSM

To generate a probabilistic result, a digital qubit includes either true or pseudo-random number generator (either TRNG or PRNG) and a functional converter (FC) [1].

To determine the digital qubit output its angle θ final value have to compared with inverse converted random angle $D = arcsin\sqrt{A}$, where A is either true or pseudo-random number. TRNGs generally produce only a limited number of random bits per second and have significant restrictions for use as part FPGA. Therefore it is necessary to use either PRNGs in each qubit in so called fully digital heterogeneous DQC or use one common TRNG for all qubits in one FPGA of hybrid and homogeneous DQC [4], [5]. Such a coprocessor can be called hybrid because it consists of an analog TRNG and digital qubits.

The aim of the work is to test the possibility of creating a hybrid and homogeneous digital quantum coprocessor. For this, the possibility of constructing a coprocessor with one common PRNG for all qubits in one FPGA was first investigated (Figure 3).

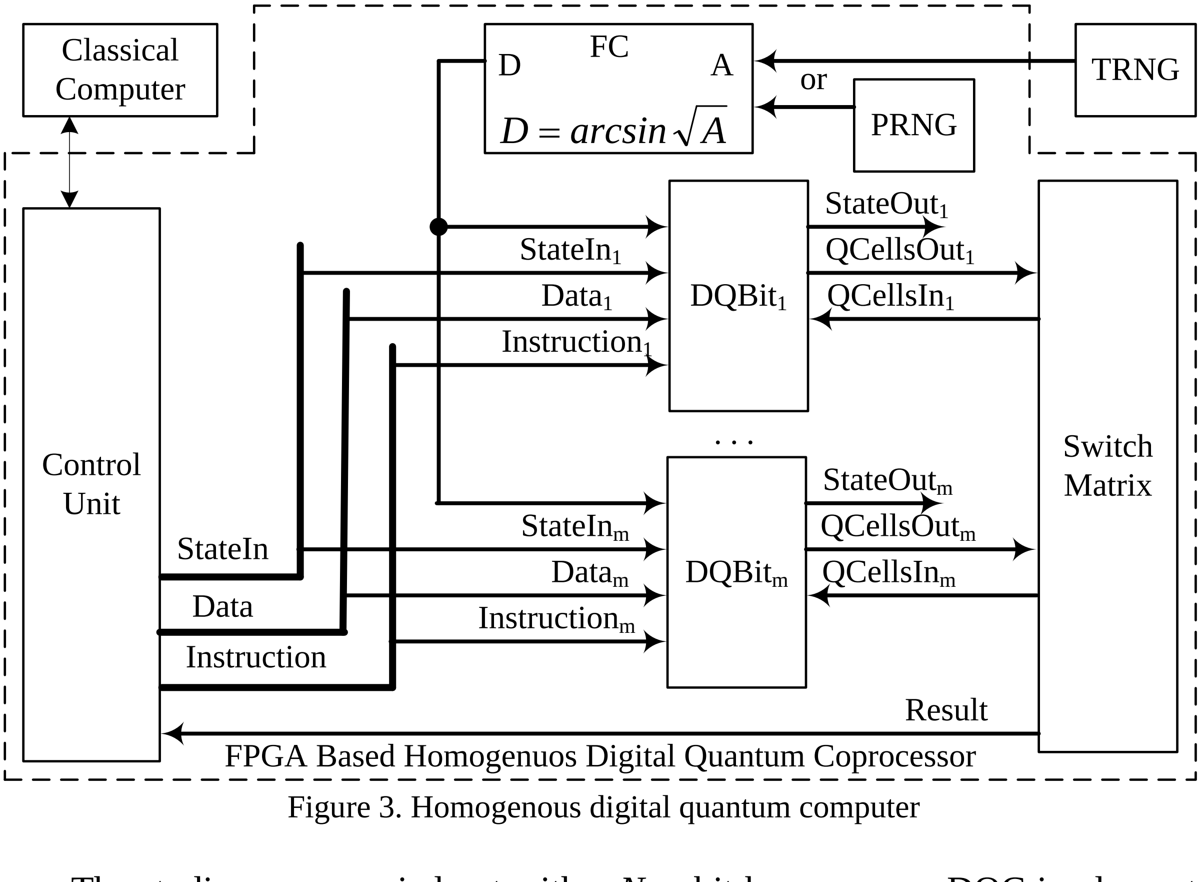

Figure 3. Homogenous digital quantum computer

The studies were carried out with a N-qubit homogenous DQC implemented on the FPGA (N = 32, 64, 128, 256, 512 and 1024). The probability P_N of getting the true result was checked by performing 4000 quantum Fourier transforms on the same input states spectrum of N qubits [3]. For the study, the spectra were selected, which consist of 2^{N-1} periods.

It was shown [3] that the homogeneous digital quantum coprocessor generally correctly determines the number of periods in the input signal (with probability more than 50 %), For a homogeneous version, the results are 7 times better than for heterogonous one.

Thus, the possibility of creating a hybrid quantum coprocessor has been shown. The analog element in such a coprocessor is TRNG. Also a true analog qubit can be used as a TRNG in conjunction with a digital quantum coprocessor. Together they form a hybrid quantum coprocessor. It is planned to test the operation of a hybrid quantum coprocessor with TRNG at the next stage of research.

References

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Анотація

Представлено структуру гібридного однорідного квантового співпроцесора, що складається з одного аналогового генератора істинно випадкових чисел (ГВЧ, яким може бути справжній кубіт) і набору цифрових кубіт.

Ключові слова: гібридний квантовий копроцесор, цифровий кубіт, ГВЧ.

Abstract

The structure of a hybrid homogeneous quantum coprocessor is presented, which consists of one analog generator of true random numbers (TRNG, which can be a true qubit) and a set of digital qubits. The probability of forming correct results with such a coprocessor exceeds 50%.

Keywords: hybrid quantum coprocessor, digital qubit, TRNG.