COMMENTS

Comment on "Quantum waveguide array generator for performing Fourier transforms: Alternate route to quantum computing" [Appl. Phys. Lett. 79, 2823 (2001)]

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In their letter[1] Akis and Ferry propose a quantum waveguide array approach for performing quantum Fourier transforms (QFTs). The waveguide produces 2^n waves at its output with controllable relative phases; n is the number of binary splits of the input wave. The interference pattern from these waves is recorded and implements a Fourier transform. The authors claim that their waveguide approach is "a more practical means" and an alternative to the "qubit paradigm that currently dominates the field of quantum computing" (double quotation marks are direct quotes from Ref. 1). The main result claimed by the authors is an implementation of the QFT that is as efficient as that obtained using the standard paradigm. In their conclusions they say, "... it is unclear whether the promised speedup in certain computations arises from the quantum nature of the systems or from the highly parallel analog processing that is provided by the array of qubits. We have argued that it is the latter that is important, and that equal speedup is available using analog processing arrays whose operation is based on general wave principles."

The arguments leading to this conclusion are unfortunately based on an incorrect assumption: that *interference* is sufficient to obtain a quantum speedup. The essence of the waveguide approach is quantum interference. Indeed, the authors claim: "Given that quantum mechanics is primarily a wave mechanics concept, these examples based on electromagnetic and acoustic waves suggest that there should be a more natural approach to quantum signal processing than that found in the existing quantum computing literature."

It is by now well appreciated that the exponential speedup offered by quantum computers in computing the QFT *is impossible without entanglement*.[2] Detailed discussions of this issue exist in the literature, e.g., Ref. 3. Most recently, Jozsa and Linden proved that for any quantum algorithm operating on pure states, the presence of multipartite entanglement, with a number of parties that increases unboundedly with input size, is necessary if the quantum algorithm is to provide an exponential speedup over classical computation (Theorem 1, Ref. 4). Entanglement is a property that depends on the existence of a *tensor product* Hilbert space. This implies that it is possible to *efficiently* (i.e., with resources that scale polynomially in the number of qubits) construct *local* (e.g., single-and two-qubit) operators, even though such operators are represented by exponentially large matrices. It is further understood that approaches to quantum computing that rely on interference alone, always incur some form of exponential overhead (in energy, resolution, or number of building blocks of the quantum circuit).[5,6]

The waveguide approach of Akis and Ferry is no different: by relying on interference, without entanglement, the authors have eliminated a key ingredient of the quantum speedup. Their proposed device is not equivalent to the standard qubit paradigm of quantum computing because it does not support a tensor–product Hilbert space. It is a multilevel quantum system, which has computational power equivalent to an experiment in classical wave mechanics. The exponential overhead they incur is in the size of their waveguide, as is immediately evident from Fig. 1(b) in their letter. Their waveguide has the shape of a binary tree; the distance between its nodes (the radiating elements) cannot be made arbitrarily small. Hence, the overall size of the device must grow exponentially. This can certainly not qualify as a valid quantum computer.

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1 R. Akis and D. K. Ferry, Appl. Phys. Lett. **79**, 2823 (2001).
2 Note that the exponential speedup of the QFT on a quantum computer is still unproven, i.e., a classical algorithm that is as fast as the quantum one may still be discovered, although this seems unlikely.
3 A. Ekert and R. Jozsa, Philos. Trans. R. Soc. London **356**, 1769 (1998).
4 R. Jozsa and N. Linden, eprint quant-ph/0201143.
5 D. A. Meyer, P. G. Kwiat, R. J. Hughes, P. H. Bucksbaum, J. Ahn, and T. C. Weinacht, Science **289**, 1431 (2000).
6 D. A. Meyer, Phys. Rev. Lett. **85**, 2014 (2000).

