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column

BEYOND DESIGN

Entanglement: The Holy Grail of High-Speed Design

by Barry Olney
IN-CIRCUIT DESIGN PTY LTD | AUSTRALIA

While high-speed SERDES serial communications seems to currently be at the cutting edge of technology, maybe it will shortly become an antiquated low-speed solution—even speed-of-light fiber optics may become obsolete. This month, we'll look at how quantum physics is transforming our world and how it could affect PCB design.

Differential signaling evolved due to the fact that high-speed, synchronous, parallel busses were getting increasingly wider—consuming more real estate—and faster until signal integrity issues forced a fundamental change in strategy. Multi-gigabit design is now the norm with up to 10 Gbps SERDES devices commonly available in FPGAs. Beyond the theoretical 12 Gbps limit, optical interconnects become the only solution. But are they?

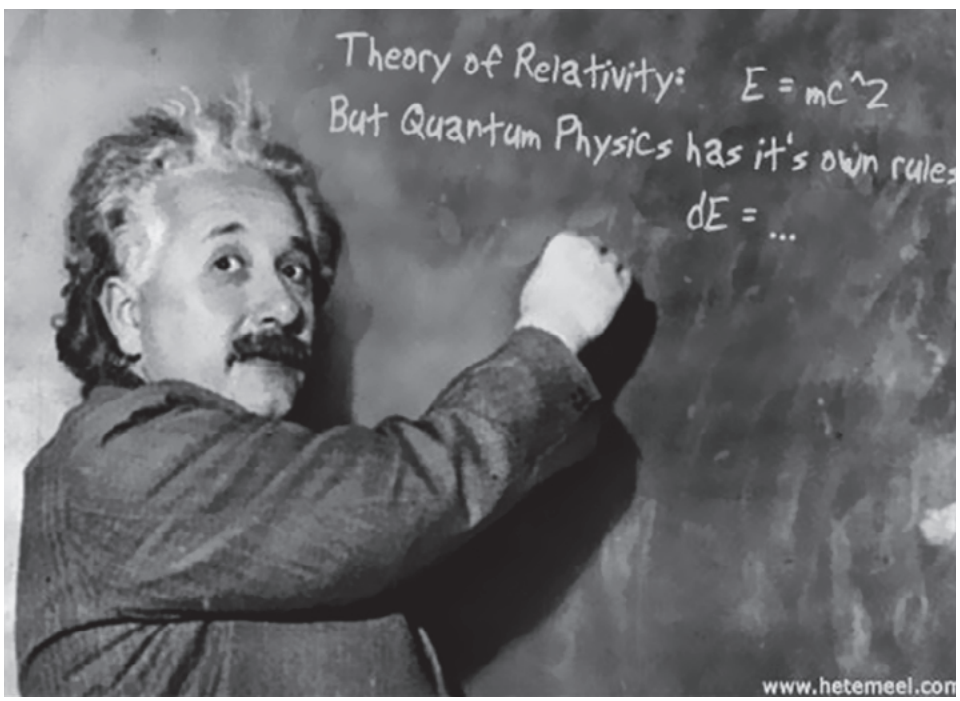

Figure 1: Albert Einstein and his Theory of Relativity.

Using quantum entanglement, devices may be able to transfer data at >10,000 times the speed of light over large distances and also possibly across time itself. Entanglement is a property in quantum physics that seemed so unbelievable and so lacking in detail that, 66 years ago, Einstein called it "spooky action at a distance."

Einstein said, "The behaviors of materials down at the level of atoms are often strange, but entanglement borders on our concepts of sorcery." Unfortunately, the Theory of Relativity does not describe the properties of quantum particles, and there still is a huge piece of the puzzle missing. Ideally, the laws of physics should apply equally to all matter in the universe.

If two electrons spinning in opposite directions are entangled, when one changes direction, the other immediately changes, whether the electrons are side by side, across the room or at opposite ends of the universe. Other particles, such as photons, atoms and molecules, can also become entangled, but taking advantage of the property requires more than a pair or handful.

Entanglement occurs when two particles are so intensely linked that they share the same existence. It arises naturally when two particles are created at the same point and instant in space. Entangled particles can become widely separated in space. But even so, the math implies that a measurement on one immediately influences the other, regardless of the distance between them.

Early this year, Chinese physicists have clocked the speed of seemingly instantaneous interaction between entangled quantum particles at least four orders of magnitude faster than the speed of light or 3 trillion meters per second. We say "at least" because the physicists do not rule out that this interaction is actually instantaneous.

In a classical, binary computer, the bits—the 1s and 0s—have a definite state. They are either 1 or 0. But qubits—quantum bits—can be in both states at the same time. They are in a state called superposition. In quantum mechanics, a physical system has no definite state until it is observed. With the qubit, more information can be stored because the information is in both of its possible states, whereas in the classical binary memory system, only one state can be stored. Different operations performed on different parts of the superposition, at the same time, effectively make a massively powerful parallel processor.

One qubit encodes 0 and 1 simultaneously. Two qubits store all four permutations 00, 01, 10 and 11. Similarly, three qubits store eight states, four qubits 16 states, and so on. The power increase is exponential: n qubits have the processing capacity of 2^n classic bits. So a 512-qubit processor is extremely powerful.

Looking at entanglement at the chip level, information about a qubit could possibly be sent from an IC at point A to another IC at point B or vice-versa, as illustrated in Figure 2. No PCB traces are required as the entangled pair interact through space faster than the speed of light. The information at point A contains a 0 and 1 simultaneously. In quantum teleportation, a pair of quanta in an entangled state is sent to both a sender and a receiver. IC A and B then share the entangled pair. So the sender takes one of the particles of the entangled pair, and the receiver takes the other—this is the only thing that needs to be physically transferred. Or possibly chip-sets could be supplied in matched, entangled pairs.

The sender can run a quantum algorithm measuring his part of the entangled pair as well as the qubit he wants to transport. The receiver acquires the information, and an algorithm is run to manipulate its part of the entangled pair in the same way. In the process, B re-creates the unknown qubit that A sent over—without receiving the qubit itself.

In fact, you do not need to transmit quantum states at all to exploit their power, as quantum teleportation protocols prove; it is sufficient to possess entangled quantum states and communicate using classical bits. So, the limiting factor here is how fast the serial data can be streamed into, or out of, the entangled particle at each end. This part of the process will still require the routing of high-speed serial busses.

If harnessed, entanglement could yield super high-speed communications, hack-proof encryptions and quantum computers so fast and powerful they would make today's supercomputers look like simple adding machines by comparison. Or imagine "quantum cash" chan-

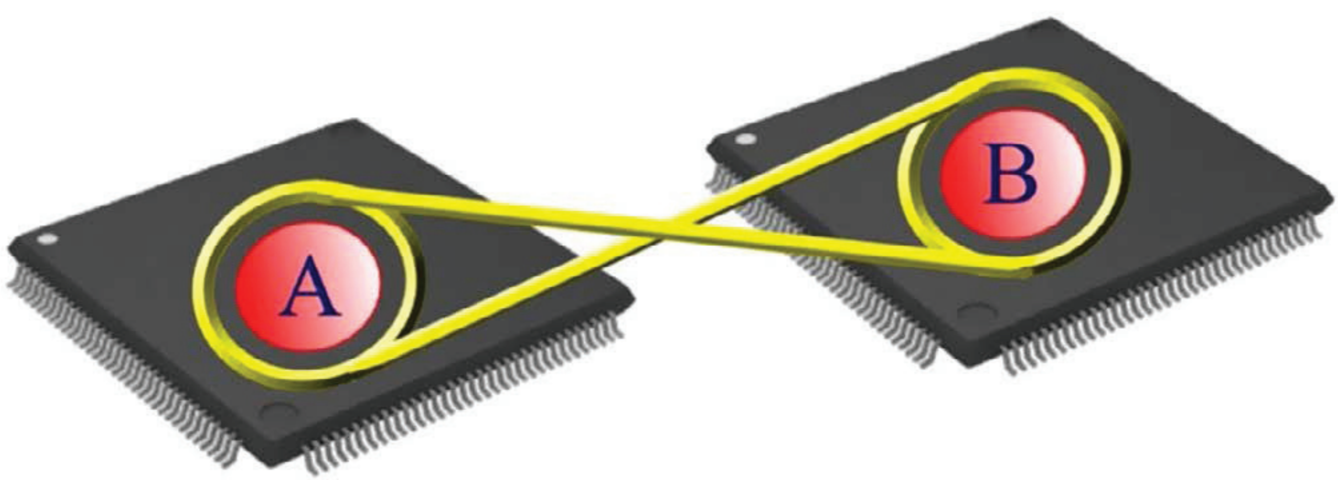

Figure 2: Data transfer via an entangled pair—no PCB traces required.

Figure 3: The first quantum network (courtesy www.extremetech.com).

neled through a financial system encrypted at the quantum level. The CIA is already using entanglement to securely encrypt communications. Entanglement may also provide a means for teleportation, as seen on Star Trek. This may all seem a bit far-fetched but let's look at practical implementations of entanglement.

In September 2012, a team of international researchers successfully teleported a quantum bit (qubit) over a record distance of 143 kilometers (89 miles), between the Canary Islands of La Palma and Tenerife. This distance is significant, as it is roughly the same distance to low Earth orbit (LEO) satellites—meaning it is now theoretically possible to build a satellite-based quantum communication network. Scientists entangled two photons in La Palma, and used a high-powered laser to fire one of the photons across the sea to a receiving station in Tenerife. Then, when the quantum state of one photon was altered, the quantum state of the second photon—despite being 89 miles away—was immediately altered, faster than the speed of light—without any measureable delay.

In the long term, a quantum network could form the backbone of an internet populated by quantum computers. In theory, each quantum processor/computer connected to the quantum network could be instantly linked to every other computer via an entangled pair of photons.

To set up another teleportation experiment, scientists from the Swiss Federal Institute of Technology (ETH), put three micron-size circuits on a chip measuring 300 mils (7.5 mm) square. Two of the circuits were the transmitters, while the other served as the receiver. The scientists cooled the chip to near absolute zero—at that temperature, the electrons in the circuits, which are the qubits, started behaving according to quantum mechanical rules (in this case, becoming entangled).

The team encoded information in the form of spin states, into the sending circuits' qubits, and measured them. At the same time, they measured the state of the qubits in the receiver. The sending and receiving qubits' states were correlated; the information had been teleported. Since the qubit did not go through the printed circuit board or even intervening space, one could infer that this is a way to communicate faster than light.

Researcher Dr. Arkady Fedorov of the University of Queensland, Australia's ARC Centre of Excellence for Engineered Quantum Systems, says the team has reined in the behavior of information on a quantum level.

"For the first time, the stunning process of quantum teleportation has now been used in a circuit to relay information from one corner of the sample [IC] to the other...this is a process by which quantum information can be transmitted from one place to another without sending a physical carrier of information," said Fedorov. "This quantum information allows us to do teleportation with impressive speed and accuracy above what has been achievable to date."

Figure 4 illustrates the test circuit which features the isolated quantum transmitter and receiver built into the same IC.

We may not have to wait too long for this new technology, as the first quantum computer has already been shipped: D-Wave Systems is a quantum computing company based in Burnaby, British Columbia. In May 2011, D-Wave Systems announced D-Wave One, labeled "the world's first commercially available quantum computer," operating on a 128-qubit chip-set using quantum annealing to solve optimization problems. In May 2013 it was announced that collaboration between NASA, Google and the Universities Space Research Association (USRA) launched a Quantum Artificial Intelligence Lab using a 512-qubit D-Wave Two that would be used for research into machine learning, among other fields of study.

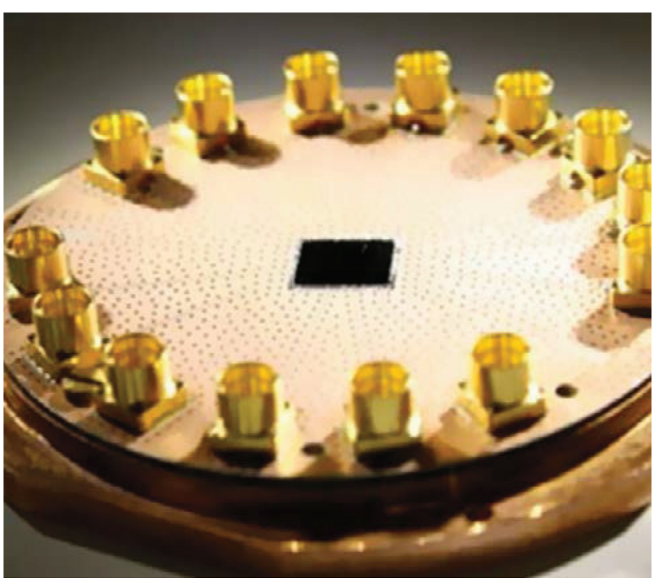

Figure 4: Test circuit for quantum teleportation (courtesy University of Queensland, Australia).

One of the major drawbacks of quantum computing is that the entangled particles must be kept at near absolute zero degrees Kelvin—the temperature of outer space vacuum—for the quantum effects to work. This may limit the mass market appeal. Also, they are highly energy intensive and obviously expensive to purchase and run. However, earlier this year, a group of Harvard scientists employed a custom-crafted industrial diamond to create quantum bits that were able to store information for nearly two seconds, and, incredibly, do it at room temperature. Two seconds may not sound like much, but when you are running at infinite speed and infinite bandwidth a lot of information could be transferred in a short time span.

Entanglement is not anywhere near the stage to "Beam me up, Scotty," but it is mind-blowing technology that shows huge potential. This technology may eliminate PCB routing altogether with the exception of the ICs and power and ground and peripheral circuitry. Maybe we will just put all the chips in a box, rattling around together, and they will just talk to each other instantaneously!

Points to Remember

• Entanglement occurs when two particles are so intensely linked that they share the same existence

• Particles, such as electrons, photons, atoms and molecules, can become entangled

• Entangled devices may be able to transfer data at >10,000 times the speed of light over large distances and also possibly across time itself

• More information can be stored with a qubit, than a classical bit, because the information is in both of its possible states

- The receiver end of an entangled pair can recreate an unknown qubit without receiving the qubit itself
- It is sufficient to possess entangled quantum states and communicate using classical bits
- Researchers have successfully teleported a qubit over a record distance of 143 kilometers instantaneously
- One of the major drawbacks of quantum computing is that the entangled particles must be kept at near absolute zero degrees Kelvin. However, a custom-crafted industrial diamond has been used to create qubits that were able to store information for nearly two seconds at room temperature
- The first quantum computer, a 512 qubit D-Wave Two, has already been shipped **PCBDESIGN**

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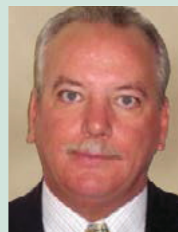

Barry Olney is managing director of In-Circuit Design Pty Ltd (ICD), Australia. ICD is a PCB design service bureau and specializing in board-level simulation. The company developed the ICD Stackup Planner and the ICD PDN Planner software. To read past columns or contact Olney, click here.

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video interview

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