Quantum Leap

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Quantum computers take advantage of quantum mechanics to speed up certain important types of computing problems by many orders of magnitude. Harnessing quantum effects requires reducing the temperature of the processor to near absolute zero and providing shielding that reduces stray magnetic fields to 50,000 times less than Earth's magnetic field. D-Wave uses ANSYS electromagnetic and thermal simulation tools to achieve these goals in less time and with less physical testing.

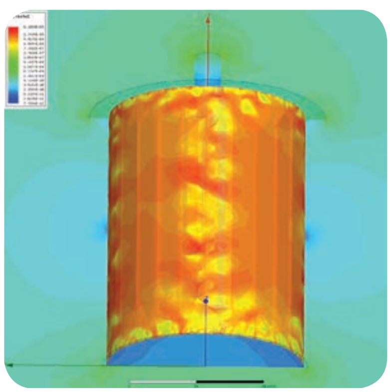
Market forecasts for the Internet of Things (IoT) predict that over a trillion sensors will soon be deployed around the world, collecting data. This data could be used to locate objects, understand and improve the performance of industrial assets, or support crucial research to prevent and cure diseases. For example, an Airbus 380-1000 series aircraft is expected to have more than 20,000 sensors generate more than 7.5 terabytes of data per day. By analyzing this data from hundreds of planes, airlines and their suppliers could improve the reliability and performance of the fleet.

> **"Engineers use *multiphysics simulation* employing ANSYS Maxwell and ANSYS Mechanical within the ANSYS Workbench environment."**

With the volume, velocity and variety of data rapidly increasing, quantum computing is a crucial technology for gleaning insights and driving outcomes. While conventional computers store information using bits representing 0s and 1s, in a quantum computer, the unit of information is called a qubit, which can be a 0 or a 1 or both at the same time. This enables quantum computers to consider and manipulate all combinations of bits simultaneously, making quantum computation extremely powerful. For example, the D-Wave 2X™ processor with 1,000 qubits can evaluate 21,000 possible solutions to a problem at the same time.

D-Wave quantum computers implement a quantum annealing algorithm that searches for the global minimum of a problem, and is designed to address a difficult class of computing problems, such as controlling risk in a financial portfolio, minimizing error in a voice recognition system, or reducing energy loss in an electrical grid. This type of problem can be thought of as trying to find the lowest point in a complex landscape consisting of many peaks and valleys. Every possible solution is mapped to coordinates on the landscape, and the altitude of the landscape is the energy or cost of the solution at that point. The aim is to find the lowest point or points on the map and read the coordinates, as this gives the lowest energy, or optimal solution to the problem. A classical computer is like a single traveler exploring the surface of a landscape one point at a time. A quantum computer performs in a way that is analogous to covering the entire landscape with a layer of water. The more water pooled in a particular valley, the higher the probability that the solution lies in that valley.

^ ANSYS Maxwell 2-D simulation identifies small amounts of leakage through shielding.



^ ANSYS Maxwell 3-D simulation of shielding shown in previous image

CHALLENGE OF CREATING ISOLATED ENVIRONMENT

For a quantum computer to function properly, the quantum processor must operate in an extremely cold and electromagnetically isolated environment. The D-Wave processor uses qubits based on the quantum unit of magnetic field, so eliminating all sources of magnetic fields is especially critical. Reducing the temperature of the quantum processor to near absolute zero is required to isolate it from its surroundings so that it can behave in a quantum manner. D-Wave quantum computers use a refrigerator and many layers of shielding to create an internal environment with a temperature close to absolute zero that is isolated from external magnetic fields, vibration and external RF signals of any kind. The D-Wave 2X processor operates at a temperature of 15 millikelvin, which is approximately 180 times colder than interstellar space. The quantum processor is adversely affected by stray magnetic fields, so extreme care must be taken to exclude them. The magnetic shielding subsystem achieves fields of less than 1 nanotesla across the processor in each axis. This is approximately 50,000 times less than the Earth's magnetic field.

The conditions required for optimal quantum computing performance are greater than those that have been required by previous generations of supercomputers, and they increase with each new product generation. Because of this, D-Wave continually pushes the state of the art in both low-temperature and electromagnetic

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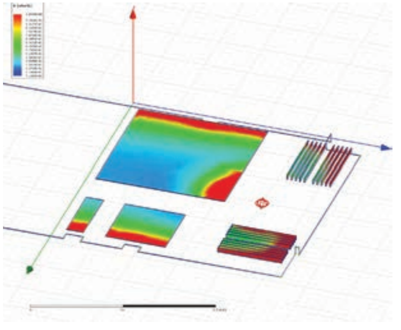
isolation technology. This task is complicated by the fact that changes in temperature change the properties of the shield, while the minute magnetic fields that penetrate the shielding produce heat that in turn further changes the properties of the shield. In the past, D-Wave used handbook calculations as a starting point in the design of magnetic shielding for quantum computers. The calculations are only accurate for very simple geometries, so engineers primarily relied on physical experiments to design shielding. These experiments were expensive and time-consuming because most of them needed to be performed in cryogenic conditions. Another limitation of the physical experiments is that only a few sensors fit inside the shielding, limiting the amount of information that can be obtained.

SIMULATION TOOLS EXCHANGE DATA SEAMLESSLY

D-Wave evaluated a number of different simulation tools that don’t communicate well with each other. Today, engineers use ANSYS Maxwell and ANSYS Mechanical within the ANSYS Workbench environment to automate the process of exchanging data between the two software packages for multiphysics simulations. D-Wave scientists employ Maxwell to model the operation of the company’s shields and the tiny residual magnetic fields to which the company’s chips are exposed. This information is passed to ANSYS Mechanical to simulate the effects of these fields on the shielding, chips and other components; to calculate the heat that is generated by the magnetic fields; and to determine the effect of the resulting temperature change on the properties of the materials being simulated. ANSYS Mechanical passes this information to Maxwell, which updates the electromagnetic simulation to take the materials’ property changes into account.

ANSYS Maxwell
ansys.com/maxwell



^ ANSYS Maxwell simulation of a magnetic impurity located on a D-Wave DW2X chip near the active area of the processor

OPTIMIZING THE MAGNETIC SHIELDING

In the design of a typical shield, D-Wave engineers evaluate the performance of the shielding with respect to distant magnetic fields, such as the Earth’s magnetic field, and fields nearby, which could be caused by very small amounts of magnetic material. Engineers often create their own materials by entering magnetic hysteresis curves, also known as B-H curves, obtained from physical testing data. Generating the mesh for electromagnetic simulation of the shielding is challenging because the difference in scale between the large features and the small features of the shield typically is five orders of magnitude. D-Wave scientists have had difficulty in the past obtaining convergence with other electromagnetic solvers. The Maxwell mesher automatically increases the density of the mesh in areas with high gradients while reducing density in areas with low gradients so convergence is easily achieved.

The Maxwell simulation identifies any weak points of the shield design, such as areas where it is penetrated by an external magnetic field. The simulation also shows the effects of the shielding on the external magnetic field. Based on the simulation results, D-Wave engineers typically change the shield design, for example by increasing its thickness in areas where penetration is seen. Engineers also try to minimize the mass of the shield because extra mass increases the cost and time required to cool the shield to cryogenic temperatures. They are frequently able to reduce the mass by removing material from areas of the shield where performance is better than necessary.

Simulation helps engineers and scientists diagnose proposed isolation technology designs and evaluate ideas for improvements without the need for expensive physical prototyping and testing. Simulation also provides more comprehensive measurement of shield leakage to simplify the process of developing compensating devices. ANSYS solutions help D-Wave optimize today’s quantum computers at a faster pace while providing insight that will make it possible to achieve huge leaps in performance in the next generation. And this next generation of computing is vital to enable organizations to glean value from the vast amounts of data generated by the IoT. Λ