Atomic clocks refined with AWG cards in PXIe format

Grosshansdorf, Germany – 16. September 2026. **Around the world, hundreds of atomic clocks are continuously compared to establish the International Atomic Time (TAI). In Germany, the Physikalisch-Technische Bundesanstalt (PTB) contributes with two of the world's leading caesium fountain clocks. Keeping these running, however, depends on sophisticated technology to cool down clouds of atoms with lasers to a few microkelvin and perform Ramsey spectroscopy. AWG cards by Spectrum Instrumentation play a key role in the latest setup of the atomic clocks. The caesium fountain clocks CSF1 and CSF2 steer the national reference time scale UTC (PTB) and constitute the basis for PTB's time services and the legal time for all of Germany, synchronizing everything from clocks and trains to air traffic, communications, broadcasting, computer systems, and much more.**

Caesium fountain clocks, such as those operated at PTB, rely on the quantum behaviour of caesium atoms. One second is defined as the duration of exactly 9,192,631,770 periods of the radiation corresponding to the transition between the two energy levels of the ground state of the caesium-133 atom. In a vacuum-chamber, an ultracold cloud of these atoms passes twice through a Ramsey microwave cavity before their final state is measured using laser-induced fluorescence spectroscopy.

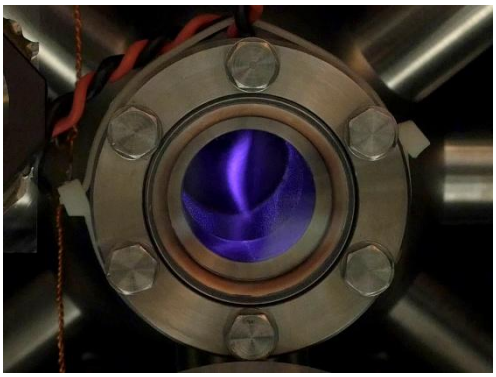
The two caesium fountain clocks at PTB provide the legal time for the entire Federal Republic of Germany. (Photo courtesy of PTB)

How to cool down the caesium atoms

Dr. Johannes Rahm, a member of PTB's Time and Frequency department, explains: "Before the measurement can take place, a cloud of ultracold atoms must be loaded. This is realized by means of a magneto-optical trap (CSF1) or an optical molasses (CSF2). In both cases, lasers in specific geometric alignment are detuned slightly below an optical transition of caesium-133. Due to the residual thermal motion, this laser light is Doppler-shifted to the transition frequency and by absorption of photons from the laser and conservation of momentum, the atoms in the cloud are slowed and therefore cooled down."

A working cycle of the caesium fountain clock

A small frequency difference between the lasers then pushes the cloud upward, like tossing a ball into the air. This creates the 'fountain' effect: the atoms pass through the Ramsey cavity once on the way up and again on the way down under gravity.



Infrared photo of the vacuum chamber showing the fluorescing cloud of caesium atoms. (Photo courtesy of Mareike Bernien)

After passing the Ramsey-cavity the second time, the transition probability is determined by means of fluorescence spectroscopy. During each passage of the Ramsey-cavity, a microwave pulse is applied. The frequency of this pulse is tuned so that the resulting transition probability is about 50%. With each fountain cycle, which consist of the loading phase, the launch phase, the Ramsey-interrogation, detection and ballistic flights in between the phases, the sign of the microwave frequency detuning is inversed, so that the left and the right side of the symmetrical transition probability structure is sampled. The true transition frequency is then given by the mean of the two steered frequencies set for the 50% transition probability. Once the measurement is complete, after about 1.2 seconds, the cycle starts again and continues 24 hours a day.

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Evolution of the clocks

The caesium fountain clock requires careful control of the lasers. This was originally implemented by using custom analog circuitry developed by an earlier generation of PTB engineers and scientists. Maintaining such a complex system for the long term becomes increasingly difficult. So, like the experiment itself, the supporting electronics must evolve, leading Dr. Rahm to explore how to replace its analog system with a digital alternative. His research led him to integrate AWG (Arbitrary Waveform Generator) cards in PXIe format from Spectrum Instrumentation. These cards generate the RF frequencies required to manipulate the laser frequencies for cooling, launching and detection of the atoms using acoustic-optical modulators.

Dr. Johannes Rahm inspecting the caesium fountain clocks, which run continuously 24 hours a day. (Photo courtesy of PTB)

Fast reaction of the Spectrum support

However, a challenge arose during implementation. Although the M4x.6622-x4 AWG cards met the accuracy extremely well, none of the possible signal generation modes matched the special requirements needed at PTB. For an efficient design of the caesium fountain clock cycle, each laser needs a specific set of waveforms at a specific time of the cycle. Dr. Rahm contacted the Spectrum Instrumentation support, which is handled by the design engineers directly. In just two days, the software engineers developed a new feature called “Sequence Restart Mode”. Dr. Rahm’s tests were successful, and the new mode works exactly as envisioned.

Spectrum M4x.6622 Arbitrary Waveform Generator card in PXIe format. (Photo by Spectrum)

Meanwhile, Spectrum Instrumentation released the Sequence Restart Mode as a free-of-charge upgrade for all AWGs in the 65xx and 66xx series. The new mode can be enabled easily by installing the latest drivers.

About Spectrum Instrumentation

Spectrum Instrumentation, founded in 1989, uses a unique modular concept to design and produce a wide range of more than 250 digitizers and generator products as PC-cards (PCIe and PXIe) and stand-alone Ethernet units (LXI). In over 35 years, Spectrum has gained customers all around the world, including many A-brand industry leaders and practically all prestigious universities. The company is headquartered near Hamburg, Germany, and is known for its 5-year warranty and outstanding support that comes directly from the design engineers. More information about Spectrum can be found at www.spectrum-instrumentation.com

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