Ultra-precision DC source for Superconducting Quantum Computer

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The Superconducting Quantum Computing (SQC) is one of the most promising quantum computing techniques. The SQC requires precise control and acquisition to operate the superconducting qubits. The ultra-precision DC source is used to provide a DC bias for the qubit to work at its operation point. With the development of the multi-qubit processor, to use the commercial precise DC source device is impossible for its large volume occupation. We present our ultra-precision DC source which is designed for SQC purpose in this paper. The DC source contains 12 channels in 1U 19 inch crate. The performances of our DC source strongly beat the commercial devices. The output rang is -7 V to +7 V with 20 mA maximum output current. The Vpp of the output noise is 3 uV, and the standard deviation is 0.497 uV. The temperature coefficient is less than 1.29 ppm/◦C in 14 V range. The primary results show that the total drift of the output within 48h at an A/C room temperature environment is 40 uV which equal to 2.9 ppm/48h. We are still trying to optimize the channel density and long-term drift and stability.

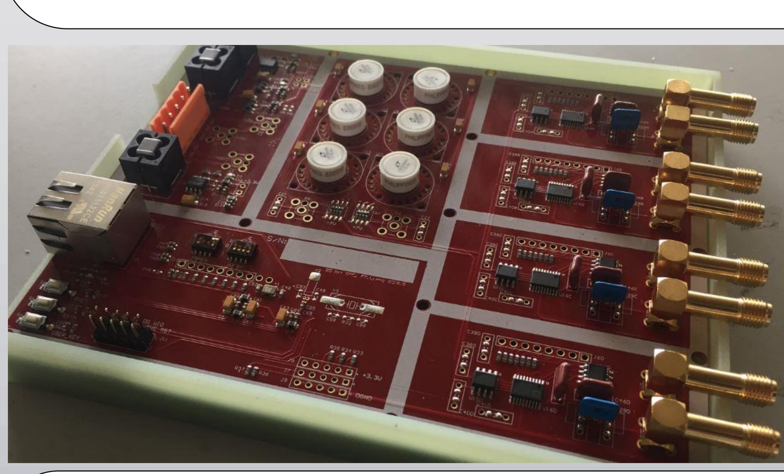
Circuit Design

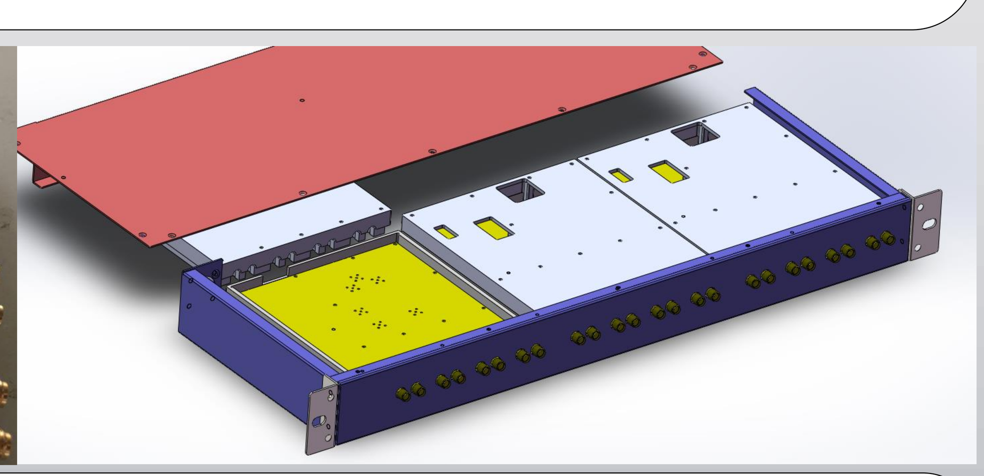
The 2 ppm precision requires at least 19 bits vertical resolution. The 2 ppm in 14 V range is 26.7 uV, and the output overall noise should slightly smaller than that. To simple the design and avoid unnecessary influence, we use one single DAC instead of two master-slave DAC scheme. There are not too many choices for DACs with more than 19 bits. We use AD5791 from Analog Devices, Inc., and strictly following the application note in our design.

The voltage reference is also very important for the design. To provides the precision and stability, only the LM399 and the LTZ1000 are the candidates. Still to simplify the design, we use LM399 for its sample setup components. We need a bipolar reference and to avoid the influence from the amplifier which is used in the polar convert, we use two references to provide the bipolar reference. The avoid the unstable and ”random jump” from the LM399 which we observed in the prototype design, we use three chips in parallel instead of one for one reference.

The ethernet is the best communication way for devices in SQC experiments. The DC source requires very low data bandwidth for LAN communication, and we choose an All-in-One ethernet solution, the W7500P from the WIZnet Co., Ltd. which integrates an ARM Cortex-M0, 128KB Flash and hardwired TCP/IP core & PHY for various embedded application platform.

In our prototype, we integrate four DAC channels, one group of reference and one ethernet into one unit, and three units together into one 1U 19 inch crate.





Mechanical Structure Design

For the prototype, we do not add temperature control in device. However, we use several ways to stabilize the work surroundings of the circuits.

First, thermal isolation and windshields are used for the voltage reference. A stabilizing heater is incorporated with the active Zener on a monolithic substrate which nearly eliminates changes in voltage with temperature in LM399. The protections we deployed can reduce the influence from the PCB and airflow.

Second, a plastic shield is used for the whole PCB. It provides the thermal isolation and windshield for components besides the voltage references. The foamed plastic is insert into the gap between PCB and the shield. The overall protection can smooth the temperature changes from the outside, and provides a self-balance thermal environments for temperature sensitive components on PCB. The above two ways make one DC source unit with a soft temperature change environment.

Finally, three units are covered with a metal case. The metal case reduces the RF noise from the outside. The design is compact, and each unit contains four DC channels in a 13.2 cm(W) x 15.9 cm(L) x 3.5 cm(H) plastic shield. Three units with 12 channels are packaged in a 1U 19 inch crate (43.8 cm(W) x 16.3 cm(L) x 4.4 cm(H)) .

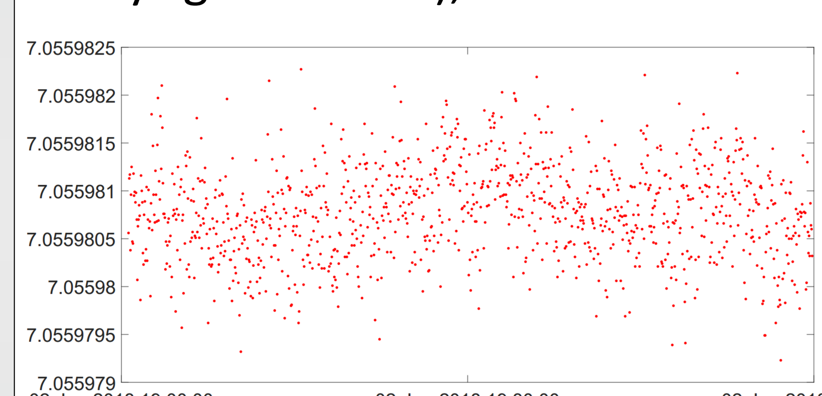
Results

Our DC source is design for specified application use, not for technique study, and all results are from all effects in full device.

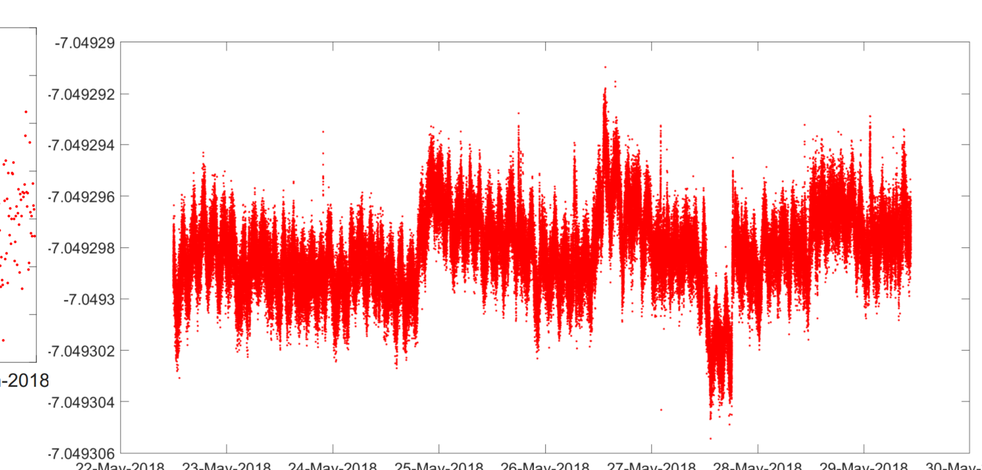
A. Output Noise

For precision DC source, low pass filter is usually deployed at the output, and the important noise is 0.1 Hz to 10 Hz. In our design, we do not apply filters at the output for that there are low pass filters in the low temperature chamber in SQC experiments. Even a passive RC filter can preform every well in low temperature chamber which has only 10 mK temperature variation.

The output noise from the direct output of the DC source is full bandwidth noise. We use the integral time in voltage meter as the lowpass filter. With 10 V range and 10 NPLC in 7 1⁄2 Digital Multimeter (DMM, Keysight 34470A), the resolution is 0.3 uV.



The Vpp is 3 uV which which equal to 0.21 ppm at 14 V range, and the standard deviation is 0.497 uV (0.004 ppm).



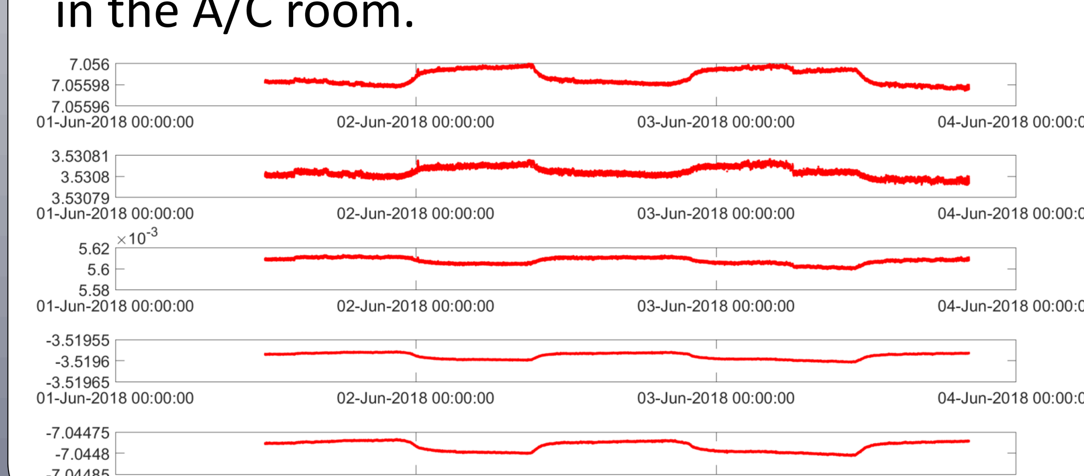
B. Temperature Coefficient

We did two kind of tests on temperature coefficient.

A) In a strict temperature controlled room, the room temperature is locked to 1 ◦C variation. The room temperature and output value at -7 V are shown in Fig. 4 a. The measured room temperature variation is 0.8 ◦C peak-to-peak. The Vpp of -7 V in the same time is 14.5 uV, which is equal to 18.1 uV/◦C, and 1.29 ppm/◦C. When we zoom in the time range into one hour, we can clearly see the temperature cycle is about 40 mins, and the voltage output variation follows the cycle. The temperature changes in this room are faster than we expect. The laboratory room temperature or even a regular A/C room temperature change is more smooth than that.

B) In an A/C room, the outputs in 48 h are shown in Fig. 4 b.

The worst overall drift Vpp is 40.6 uV at -7 V which is equal to 2.9 ppm/48h in the A/C room.



More results, analysis and improvement results please check on our paper or the device webpage.

http://dev.quans.tech/FTDA

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Conclusion

To satisfy the demands of the ultra-precision DC source on channel density, precision and stability in SQC measurements, we design our own ultra-precision DC source. The DC source contains 12 channels in 1U 19 inch crate. The performances beat the commercial devices, such as the 20 mA maximum output current in -7 V to +7 V output rang, the 0.497 uV standard deviation of the output noise, the 1.29 ppm/◦C of the temperature correlation. We are still trying to optimize the channel density and long-term drift and stability.