AnaPico Product Applications

Quantum Computing

(Related AnaPico Products: APMS-X, APVSG-X, APUASYN20-X)

On the internet, there are a lot of tutorial materials for a brief understanding of Quantum Computing (QC). (For those interested in more, we have a list of tutorials at the end of this document.)

We are not going to repeat an overview but rather start with the experimental / instrumentation systems that our target customers are building and figure out which AnaPico products are suitable and attractive as building blocks in the QC experimental systems.

QC Experimental Systems and the Key Technical Requirements for Instrumentation

QC technology today is still in its infancy phase. Scientists world-wide are building experimental systems allowing for the proof of concept and understanding of the fundamental mechanism. Most QC research teams are building systems involving a few QuBits today and planning to extend the systems to support dozens of QuBits.

A typical QC experimental system is shown below. From the hardware requirement perspective, there are the following major components:

- QuBits Fridge / Cryostat: a container with very low and stable temperature (close to 0 Kelvin) inside hosting the QuBits. There are today dozens of physical QuBit implementation methods / technologies such as TRANSMONS, TRAPPED IONs, etc. For more info, please start with: https://en.wikipedia.org/wiki/Quantum_computing.

- To control / manipulate the QuBits (changing the quantum states of QuBits, 0, 1, superposition) three different types of signals are needed:

    o (Shaped) pulse (baseband) signals modulated on RF / microwave frequency.

    o Intermediate Frequency (IF) signals modulated on (the same) RF / microwave frequency.

    o DC pulse signals for gating / switching function.

- To read-out the states of QuBits, the signals from QuBits Fridge are down converted to baseband and digital domain. Before sending the QuBits state info to the Control Board & Software (quantum algorithm), the digital signals are often pre-processed as much as possible and this way reduce the data processing load of the control board.

- The Control Board receives and further analyzes the detected QuBits status signals and gives instructions to the QuBits manipulation circuitries / instruments about the next step modulation schemes.
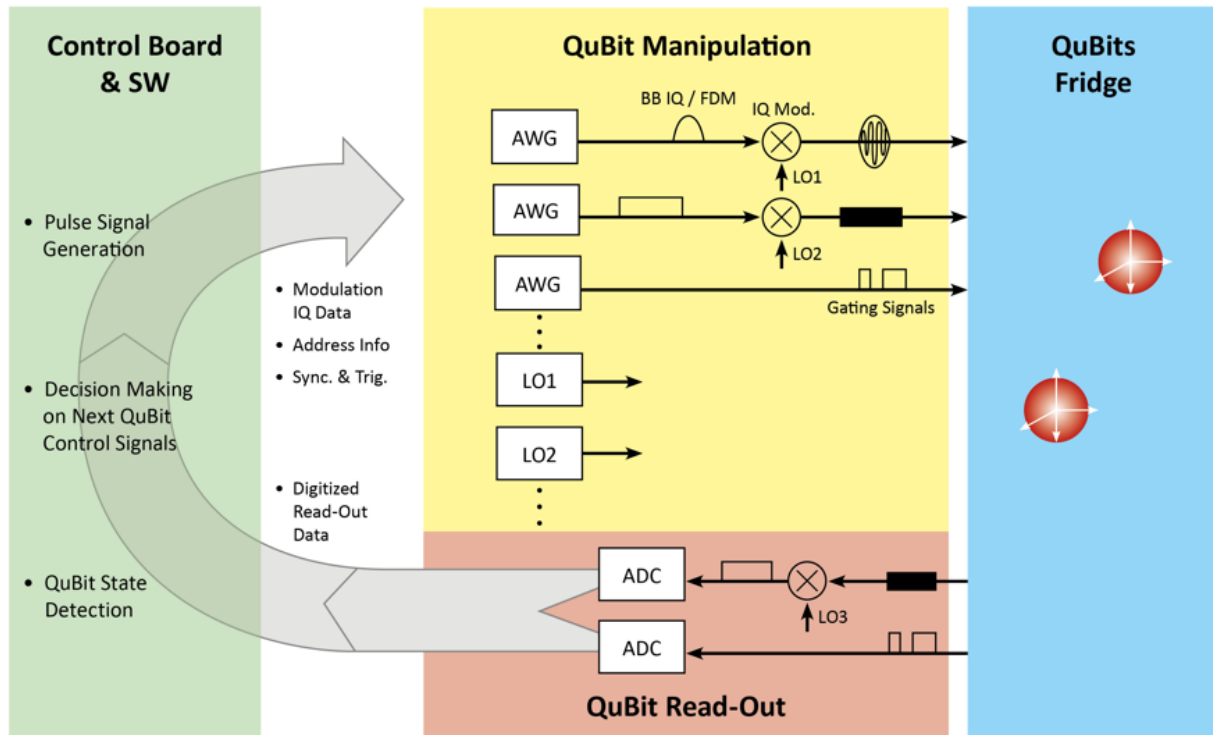
The QC experimental systems therefore work in such a closed loop mechanism: generation of modulation and control signals → application of modulated and control signals onto the QuBits inside the fridge → reading out the QuBits status continuously → analyzing the read-out signals and taking decision on what modulation and control signals should be applied next → and so on.

(Depending on the QuBit implementation methods, there are of course different ways of QuBit control and readout. In this document, we briefly describe the most relevant concept only that involves our test and measurement instruments.)

QC researchers building QC experimental systems will normally purchase all / most of the hardware equipment. It is obvious that AnaPico today can essentially contribute mainly to the QuBits manipulation part. The general technical requirements on the control signal generation are as follows:

- Low loop latency (from status read-out to application of control signals onto the QuBits) needs to be below 1 us. (The lifetime of the QuBits in the fridge is around 100 us.) This requirement is tough. The customer will therefore require each instrument / function block in the loop to be as fast operational as possible.

- The modulation pulse width should be close to / narrower than 10 ns. Due to the additional pulse shaping mechanism, the required sampling rate for the pulse generation should be therefore beyond 1 GS/s.

- The IF frequency is normally below 100 MHz.

- The local oscillation RF / MW frequency is mostly in the range of up to 12 / 20 GHz. From quantum-physical perspective: the higher the frequency, the bigger the QuBit state difference, but unfortunately also the more expensive the experimental systems. High spectral purity and low phase noise are needed for low-error-rate state detection. The phase coherence among the oscillation signals as well as the phase adjustment features are very valuable as this significantly helps to keep the loop latency low.

Having summarized the technical requirements above, the current state of research work, however, is that most of the research teams / experimental systems cannot support all the wished features and performance level yet, given the always limited budget available. Most of the experimental systems are still working in an open loop form. A lot of compromises are being made to start the experiments at all. QC Researchers and instrument suppliers are still working toward this set of requirements.

Suitable AnaPico Products for QC Experimental Systems

APMS-X and APUASYN20-X as Phase Coherent Oscillation Sources

In the recent few years, AnaPico's APMS series of multi-channel SGs have been chosen by dozens of QC teams in the world as the local oscillators in the QC experimental systems. The reasons for this success is as follows.


- Keysight's SGs (single-channel SGs, or with PXI platform) are too expensive especially when it comes to the multi-channel requirement. On the other side, the phase-coherence and the signal purity, etc. are not as good as with APMS-X.

- R&S has the similar situation. The only close to competitive product they have is the SGS100A. The list price level is way higher than APMS (30 to 60% higher). The heavy discount they sometimes apply is certainly appreciated by the QC customers but also concern-raising: what about when customers need to extend the system to support more QuBits?

- (SGS100A works up to 12.75 GHz. It has options for analog I/Q modulation, phase coherence, etc. But the additive price for the I/Q modulation capability is quite high. Most of the customers would therefore choose to go for external / separate I/Q mixers.)

- Several other QC instrument vendors (Zurich Instruments, Quantum Machines Israel) have products / building blocks for QC experimental systems, but no RF / MW oscillators. (Obviously, the development of RF / MW sources with the required features and performance level for QC applications is a technical challenge for many companies.)

- Another Israeli company TABOR ELECTRONCS has also introduced low-cost multi-channel SGs (LUCID series). Based on their specifications, the signal purity and mainly phase noise levels are not as good as the QC customers are expecting.)

- APMS-X are therefore attractive due to the following reasons:

  o Steadier and reasonable price level (at least for now).

  o Excellent phase-coherence, very low phase noise.

  o Phase adjustability of each channel.

  o High output power supporting a wide range of I/Q mixers.

  o 3 GHz based sync mechanism between the rack-mount modules ensuring the best-in-class phase coherence among the LO signal channels.

  o Compact size, low power consumption. (This is a big positive point for users having a bigger system in mind.)

  o Many customer references we can provide.

APMS series multi-channel SGs are so far the preferred local oscillators, especially for small- and medium-scaled QC systems. For customers building large-scaled systems with dozens of QuBits, in order to reduce the investment for the instrumentation part, they can also use our APUASYN20 series of multi-channel frequency synthesizers. APUASYN20-X is lower price than APMS-X, but with some performance levels lower than APMS-X (phase coherence, phase noise, etc.).

APVSG-X for QuBits Manipulation

Our new APVSG series of vector signal generators (multi-channel models also available) have the built-in functions AWG, LO, I/Q mixing, etc. that are all needed in the QC experimental systems. They are good for QC teams starting to build experimental systems at the onset, and not having many other instruments such as an AWG, I/Q Modulators, etc. The cost-effectiveness in combination with the nice features such as the operational agility, phase coherence and signal purity, etc. provide the QC customers the possibility to build their first / new QC experimental systems in a cost-efficient way.
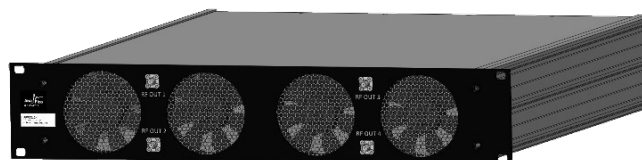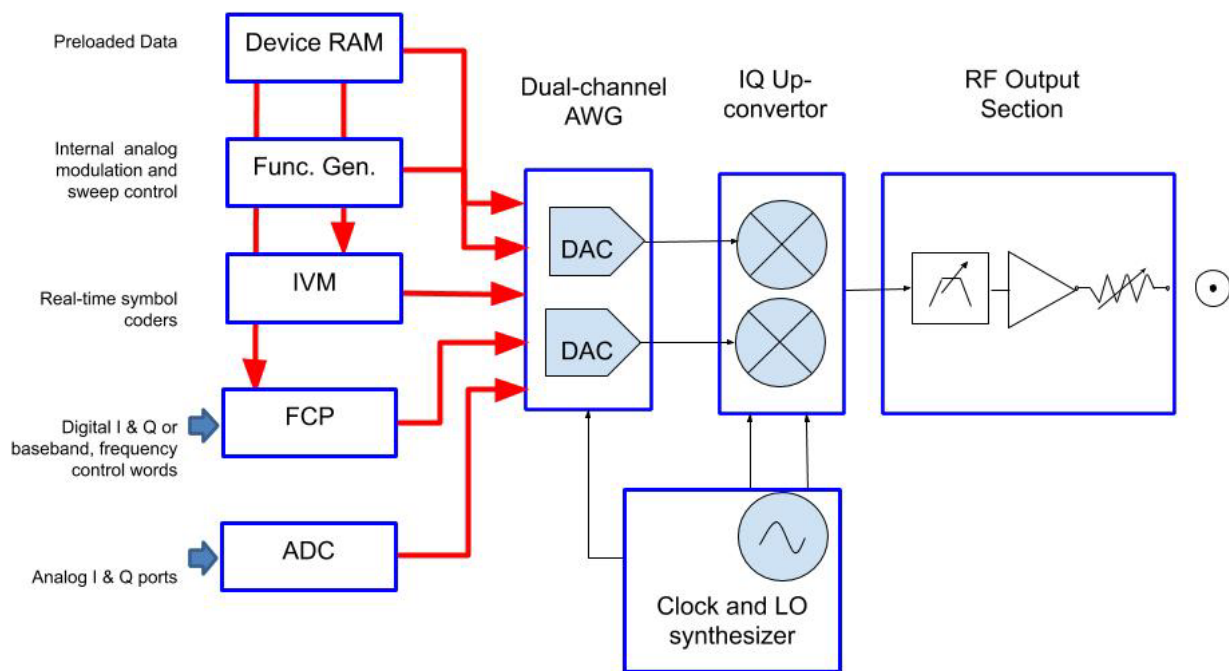
The APVSG features several operation / modulation modes among which two modes are potentially suitable for QC applications:

- Users can compile the needed I/Q data segments (base band shaped pulse signals) and pre-store them into the APVSG internal memory that has 512 MS size each with 32 bits (2x16 bits for I and Q). From today's perspective, the frequently used I/Q segments are below 100, each with <30 ns length. In operation, the Customer Board will instruct the APVSG with I/Q data segment address through the FCP, and APVSG will on-the-fly use the right segment and modulate the LO signal to generate the needed control signal. The operation from the address available to generation of the control signal will take only <200 ns time.

- The customer board will provide the I/Q data segment during the QC system operation and feed it through FCP to the APVSG engine. The rest is then like the process above.

Other modulation data compilation and input modes are either not applicable (MOD, IVM) or slow for closed loop operation (AIQ), and therefore not so relevant. (QC systems operating in open loop mechanism, as the link latency is not critical yet, may still use AIQ for analog I/Q signal input.)

APVSG for QuBit Manipulation

QuBit Readout (Customizable)
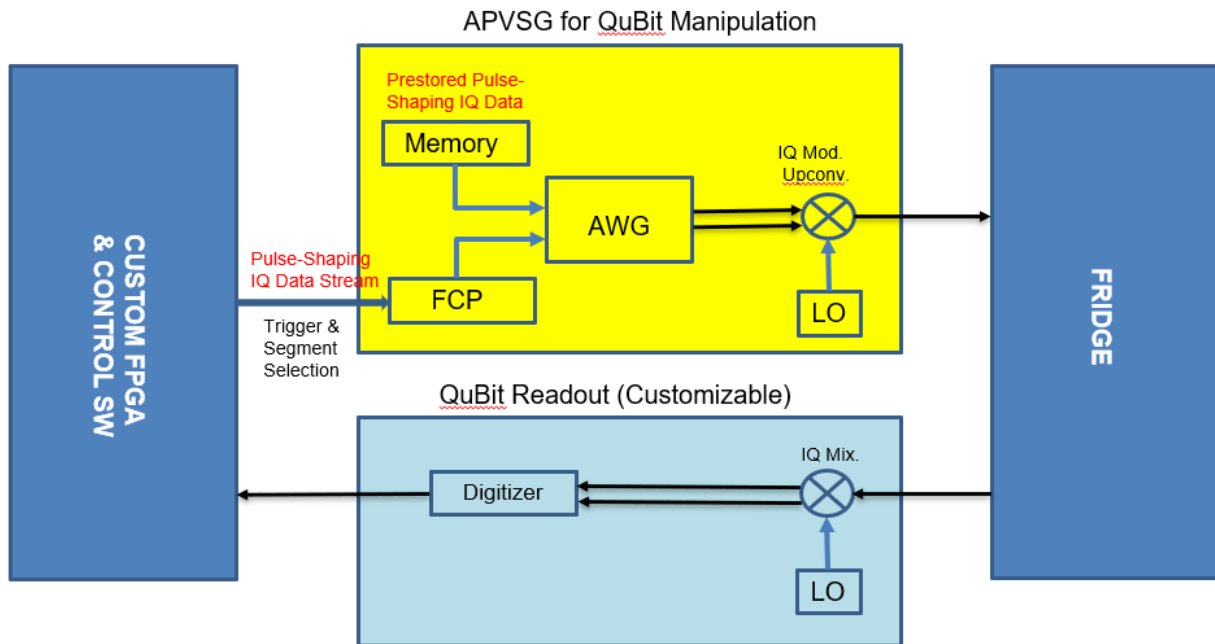
Our current APVSG generation features a digital modulation bandwidth of 400 MHz, a max sampling rate of 500 MS/s, a digital I/Q data streaming rate (at FCP) of up to 250 MS/s. For many initial QC experimental systems, this is sufficient. Other APVSG features contributing to the suitability for QC applications are very low phase noise, phase coherence in multi-channel version, individual phase adjustability, excellent signal purity (harmonics, nonharmonics, carrier leakage, image suppression), etc.

Our next generation APVSG will feature wider modulation bandwidth, higher sampling rate, etc. and thus meet the demanding QuBits manipulation requirements as well.

The Coexistence of Competition and Cooperation

As the QC research evolves, more and more T&M instrument vendors like AnaPico are entering this field. We mentioned several such companies above. So far, none of these companies is in the position to provide all building blocks that can flexibly meet all the diversified and detailed customer requirements. Most of the QC experimental systems we saw are therefore integrated systems consisting of building blocks from different vendors. Consequently, for AnaPico and our sales partners, competition and cooperation with other instrument vendors are existing.

We had cases whereby customers purchased multi-channel AWGs and readout circuitries from companies like Zurich Instruments or Quantum Machines and multi-channel phase coherent LOs from AnaPico (APMS-X, APUASYN20-X), and developed their own Quantum Algorithm supporting FPGA board. In other cases, for simplifying the system integration work and for quickly starting with, they purchased most of the materials from Keysight but the phase coherent LOs from us. This is an indication of the attractiveness of our APMS-X, APUASYN20-X for QC applications.

Thanks to the excellent cost/performance ratio of APVSG-X, the QC market sees the emerging of applying multi-channel VSGs for QuBit control. Many other VSGs in the market do not support the needed function / performance / price combination at the same time as we do. With the APVSG-X market launch, we are also changing the competition / cooperation landscape. Companies like Zurich Instruments and Quantum Machines, having always had us as complimentary partner before, are viewing us as potential competitor as well. The reason is obvious: we are also offering function blocks like AWG, I/Q mixing, overlapping with what they are also offering.

The coexistence of competition and cooperation is unavoidable for us. We are convinced that the QC experimental systems will more and more use multi-channel VSGs for higher system integrity and cost-effectiveness.

We are flexibly offering APMS-X, APUASYN20-X, and APVSG-X depending on customer preferences and therefore competing / cooperating with other companies.

Customer References

(Incomplete list due to NDA with AnaPico. All of them purchased our APMS for phase coherent local oscillation. Some of them also used our APUASYN20-X and APVSG-X.)

USA:

- IBM

- University of Massachusetts

- Google

- …

Europe:

- Oxford University, UK

- Oxford Quantum Circuits, UK

- Chalmers University, Sweden

- University of Vienna, Austria

- Karlsruhe Institute of Technology, Germany

- EPFL, Switzerland

- MiraEx, Switzerland

- …

Asia-Pacific:

- Qinghua University, China

- Beijing University, China

- Zhejiang University, China

- China Academy of Science

- University of Science and Technologies, China

- Institute of Microsystems, China Academy of Science

- Tokyo University of Science, Japan

- Nagoya University, Japan

- NTT, Japan

- AIST, Japan

- RIKEN, Japan

- NICT, Japan

- ETRI, Korea

- Sydney University of Technology, Australia

- …

Closing Remarks

This document is made for our world-wide sales and support forces to better understand the QC application requirements and why our multi-channel SGs are suitable for those mentioned functions. **It should not be shared directly with the end customers.**

On our distributor portal at www.anapico.com (for registered distributors), you can download the PPT doc "AnaPico Products for QC Applications" for your presentation and communications with the end users.

The QC research is a hot area. On the internet, one can easily find out which organizations and companies are involved and even who has received governmental funding, etc. Once you established the first contact with the QC teams in your area, we warmly encourage you to arrange online meetings with end users and AnaPico Sales. We will do our best to support our global sales partners to promote our products and services.

And finally, your feedback, critics, additions, corrections, etc. on this document are WELCOME!

Quantum Computing Tutorials

https://www.youtube.com/watch?v=0dXNmbiGPS4

https://www.youtube.com/watch?v=zOGNoDO7mcU

https://www.youtube.com/watch?v=SCRZVVSUCp0

https://www.youtube.com/watch?v=9AfG2nI0Hn4

https://www.edn.com/the-basics-of-quantum-computing-a-tutorial/

https://www.ibm.com/quantum-computing/

https://sites.google.com/ncsu.edu/qc-tutorial/

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