Microwaves for quantum computing

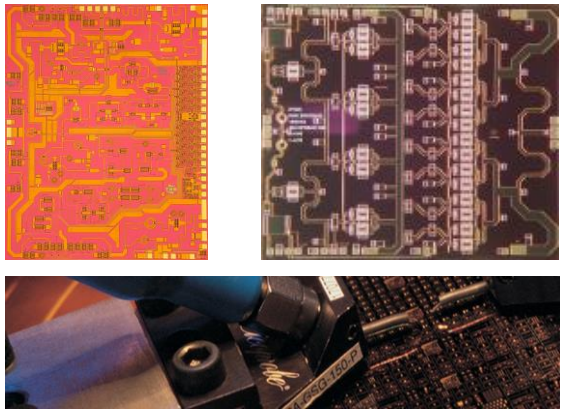
Duije Deurloo

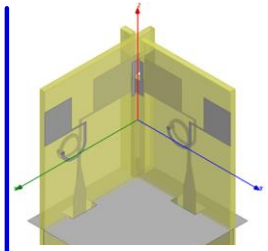
RF / Microwave designer

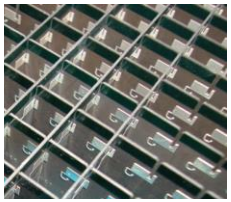
QuTech / TNO Radar Technology

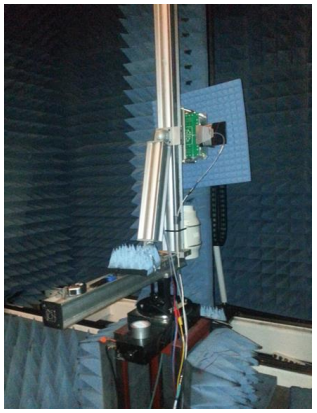
How I got involved in QuTech (RF-designer, TNO Radar Technology)

MMIC design



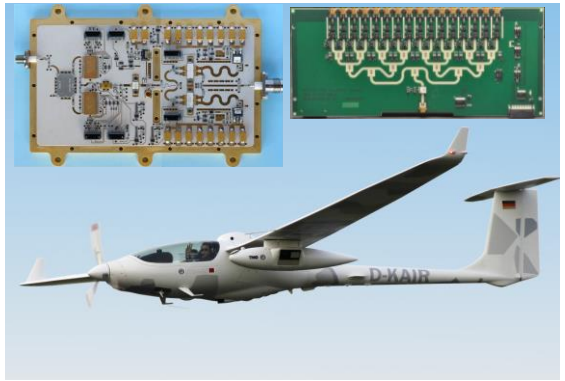






Antenna design

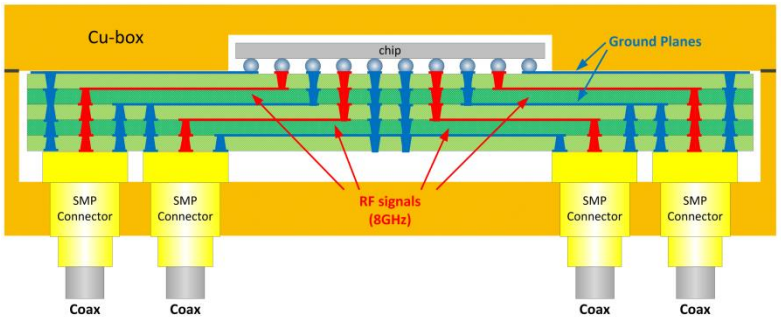
RF/MW modules
&
Systems

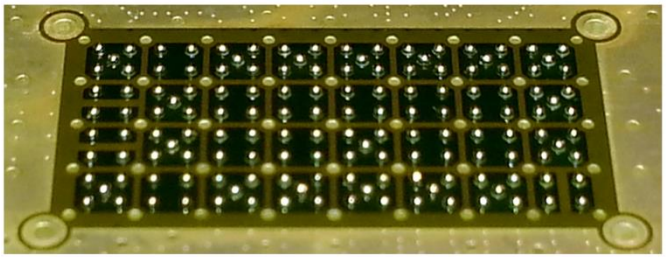


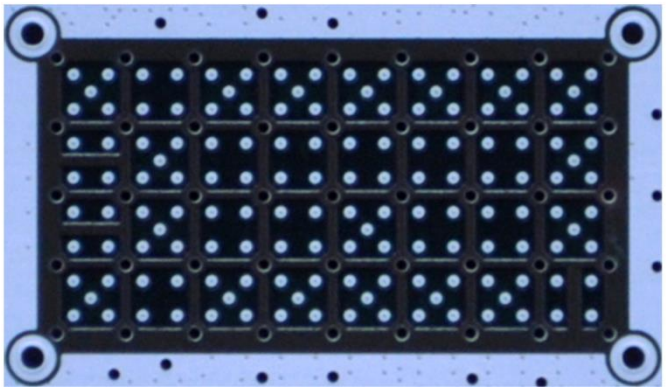
Radar Imaging
&
Simulation

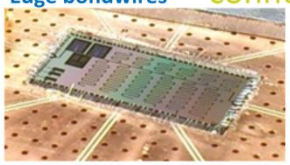
Duije Deurloo, RF and Microwave systems and modules designer

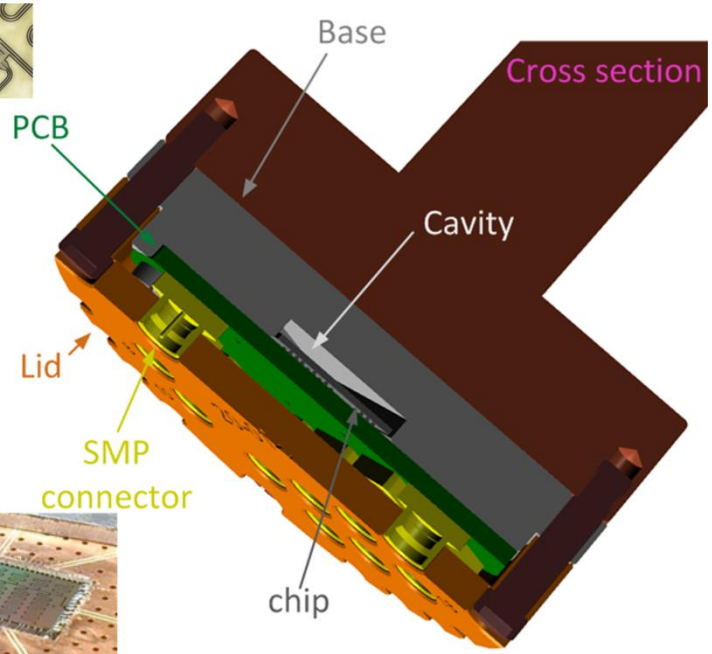
3D connectivity / microwave WSP/BGA (Q-socket)



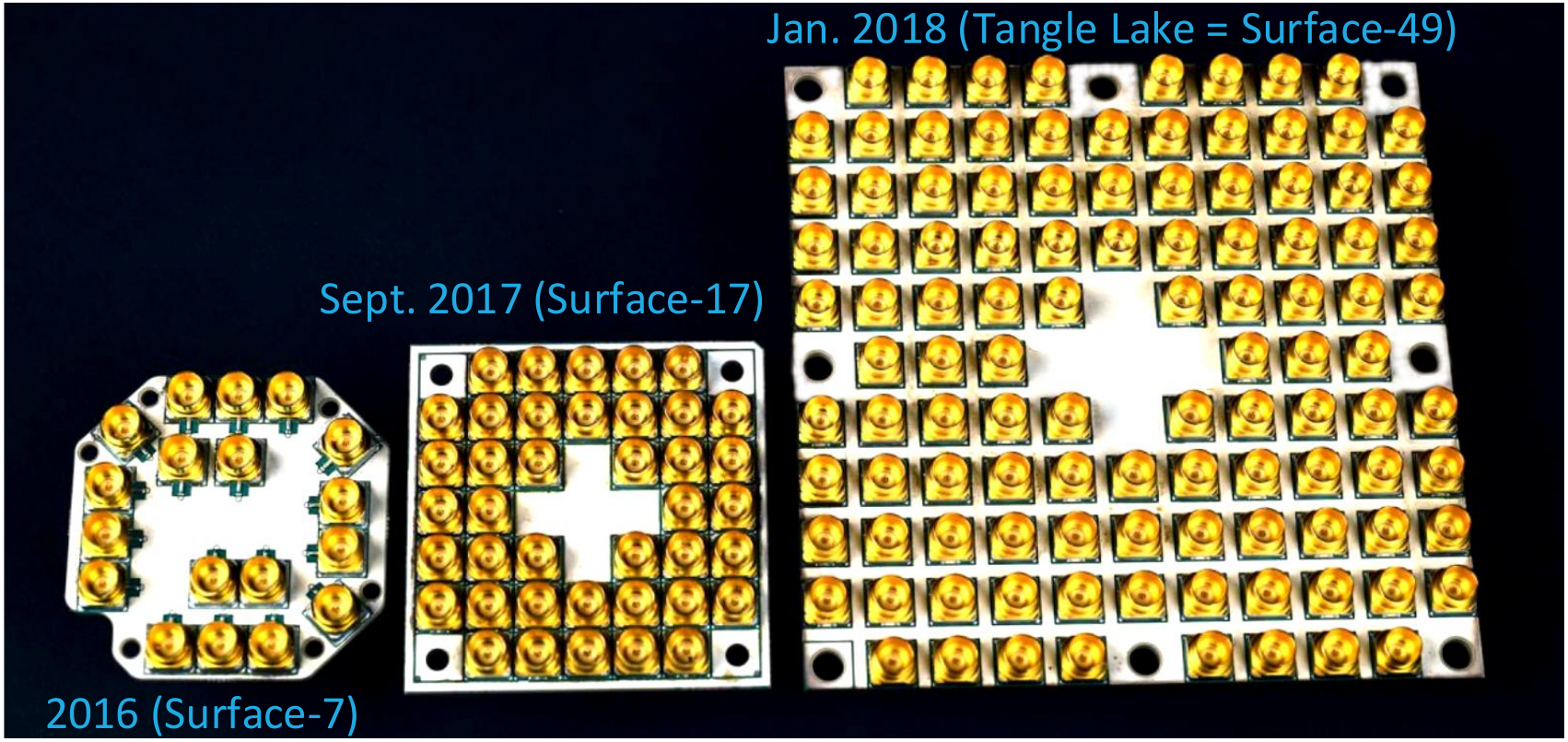








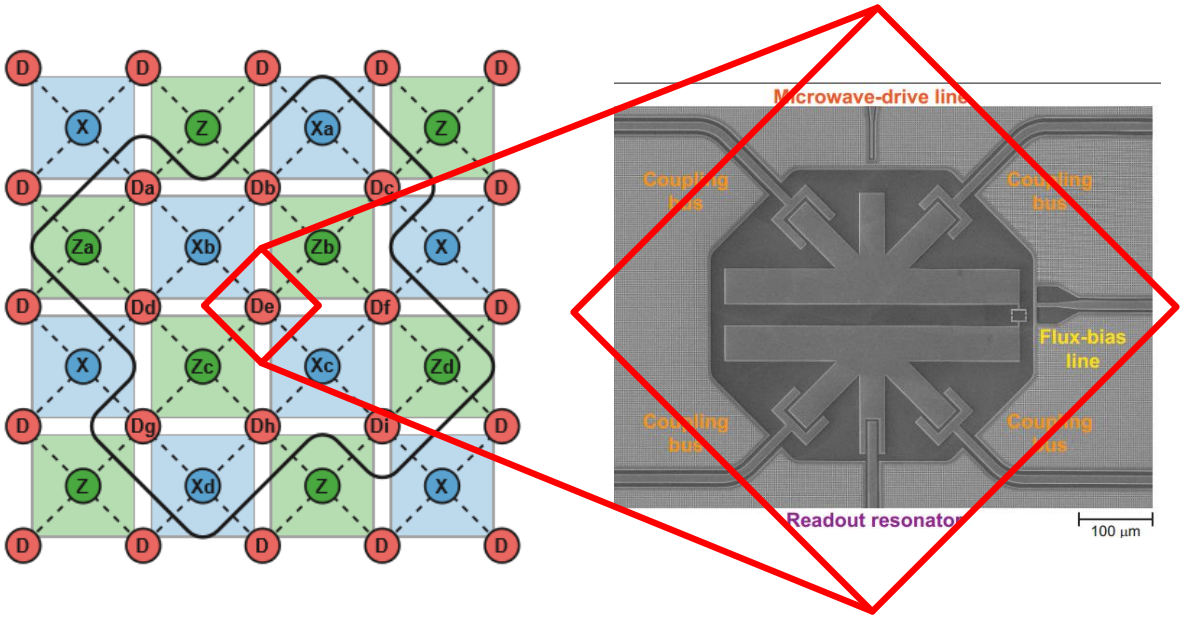
3 generations of sockets for quantum chips

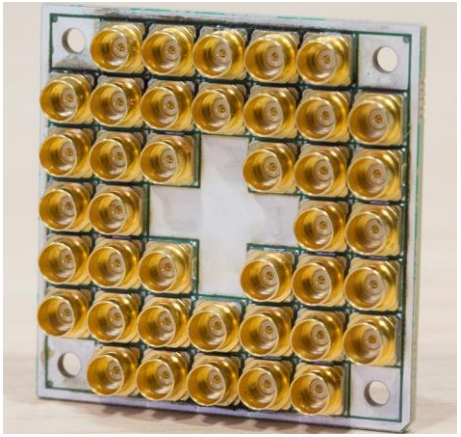


Q-processor on rear sides designs by QuTech, IC-foundry of Intel Corp.

Photo's above are from the Intel Newsroom website

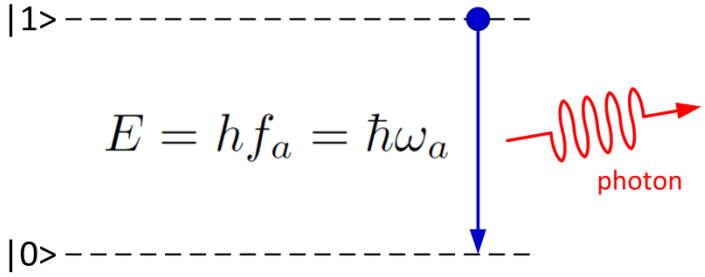
Introduction (2D lattice of qubits)





Introduction (Jaynes-Cummings Hamiltonian)

quantum 2 level system / atom / qubit



emit photon

absorb photon

$$H_{\mathrm{JC}} = \hbar\omega_{\mathrm{r}}(a^{\dagger}a + 1/2) + \hbar\frac{\omega_{\mathrm{a}}}{2}\sigma_{\mathrm{z}} + \hbar g(a^{\dagger}\sigma^{-} + a\sigma^{+})$$

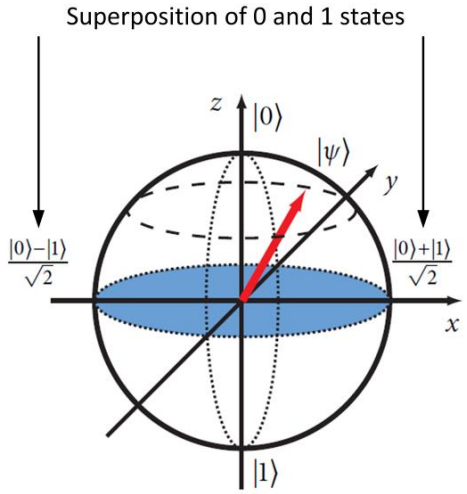
Energy of the EM field

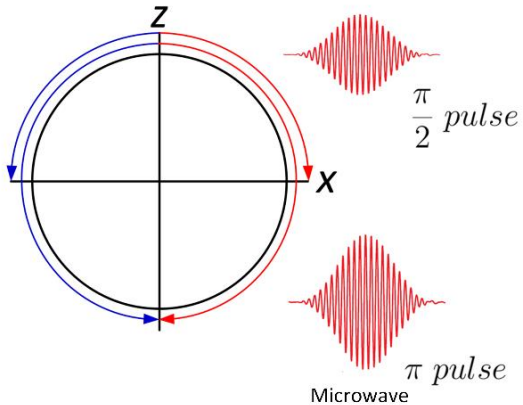
Energy of 'atom' transition

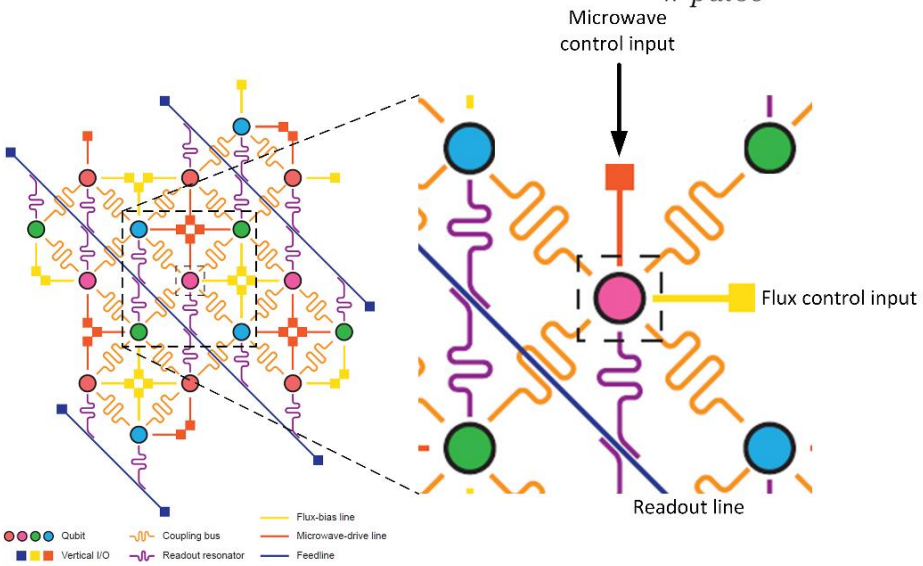
Interaction term

Source of Hamiltonian = Circuit Quantum Electrodynamics, Dissertation Thesis, David Isaac Schuster, 2007

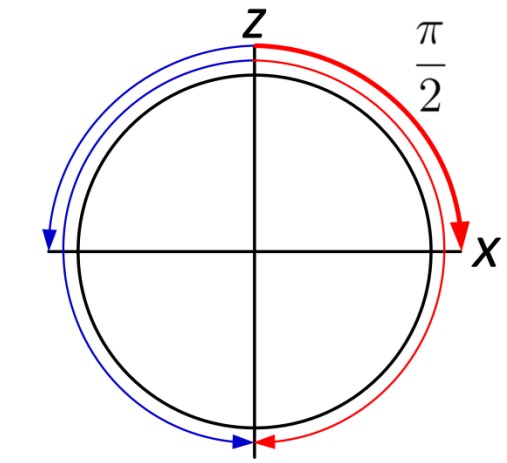
Introduction (Bloch sphere / qubit space)

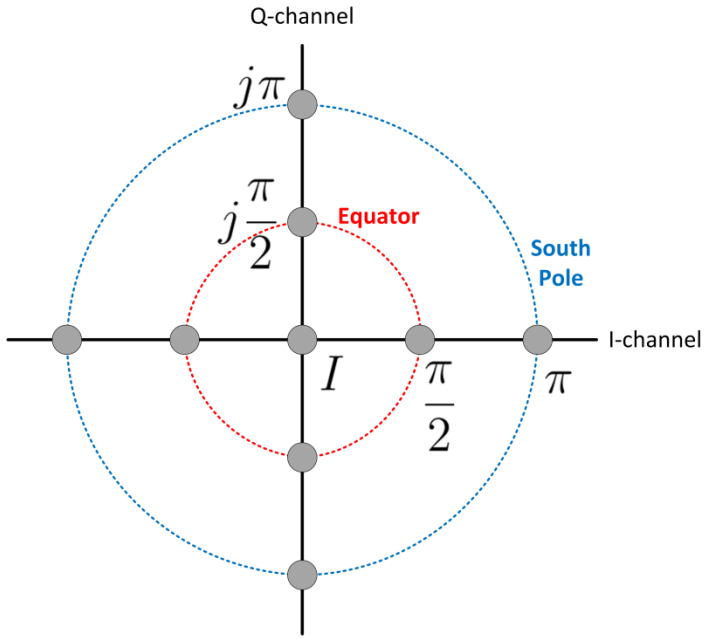




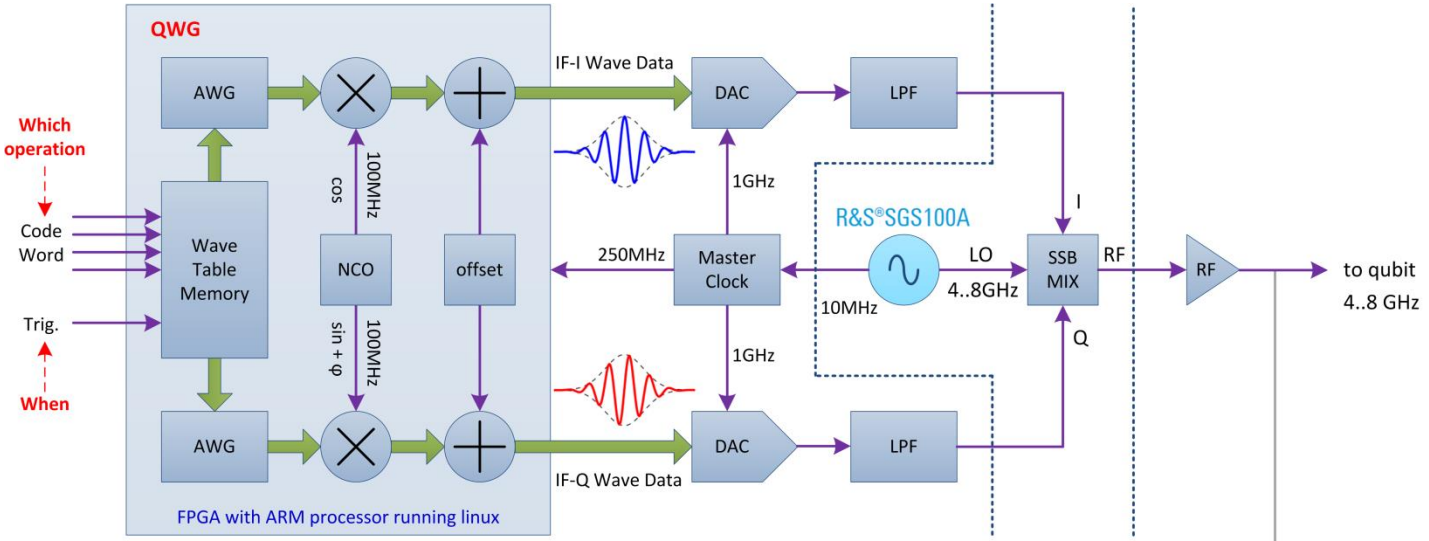


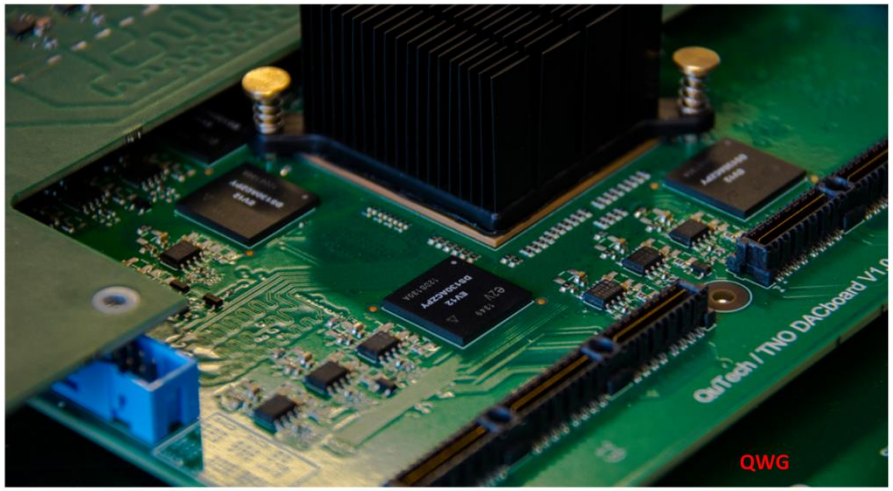
Introduction (Bloch sphere operations)

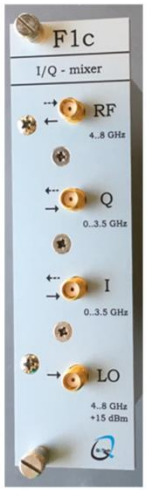


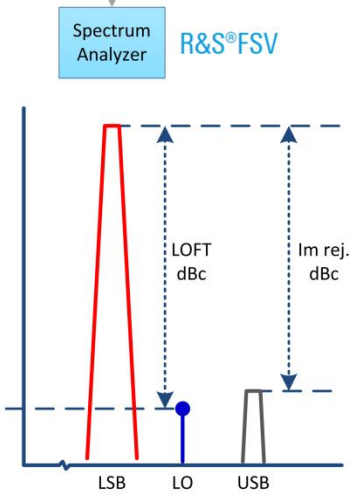


Code word triggered wave generation (QWG)

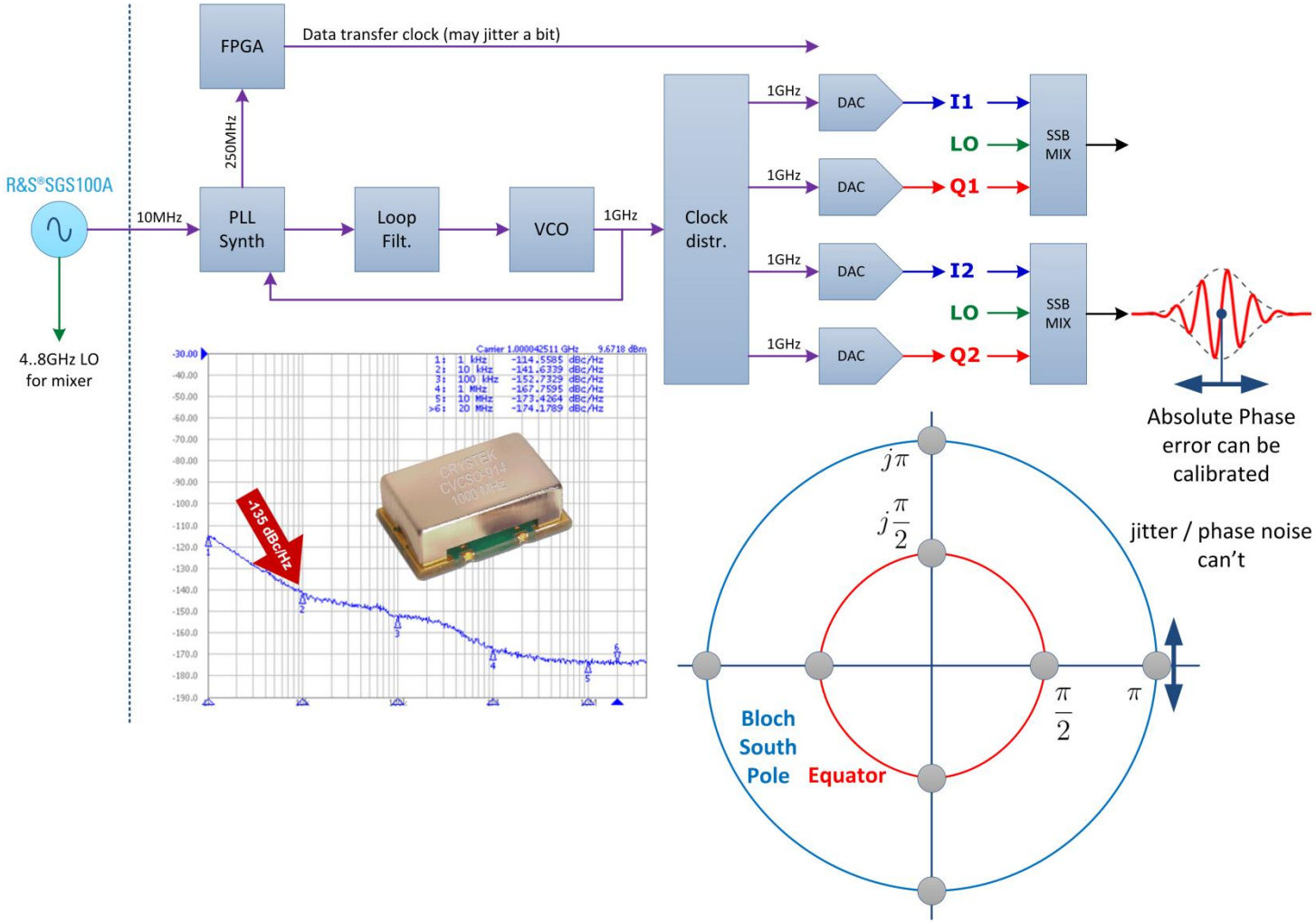






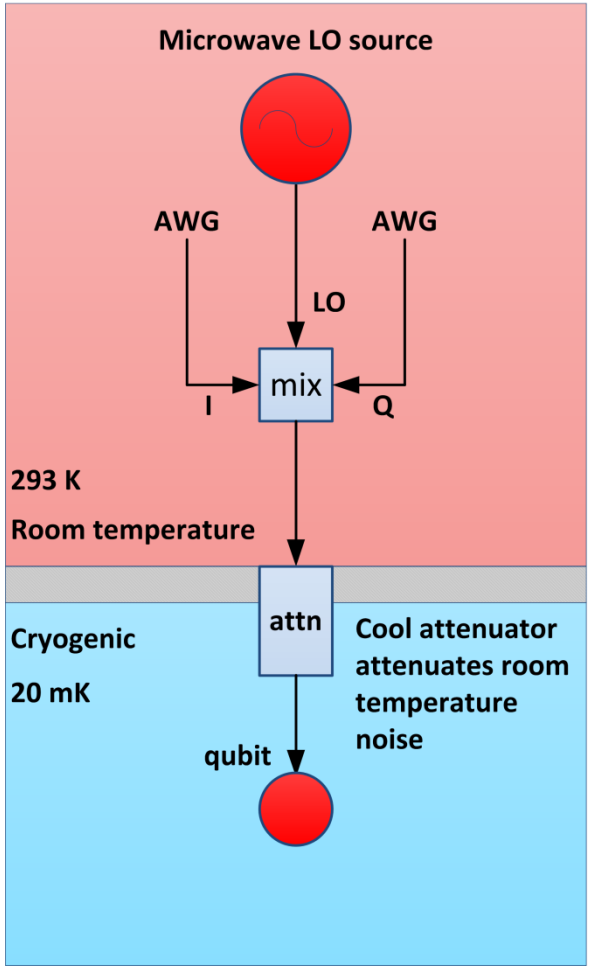


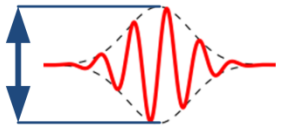
Wave generation clocks (phase noise)



Wave generation (thermal noise)

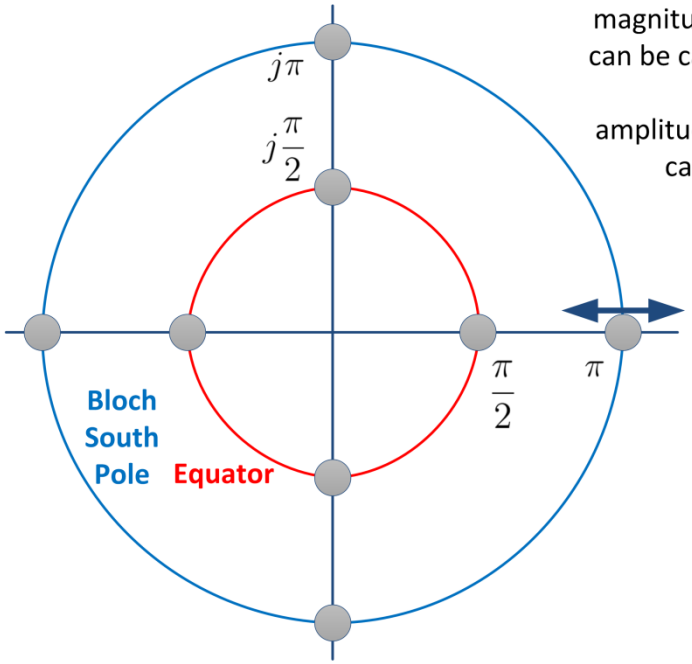
$$10\log(kT) + 30 = -174\,\mathrm{dBm/Hz}$$



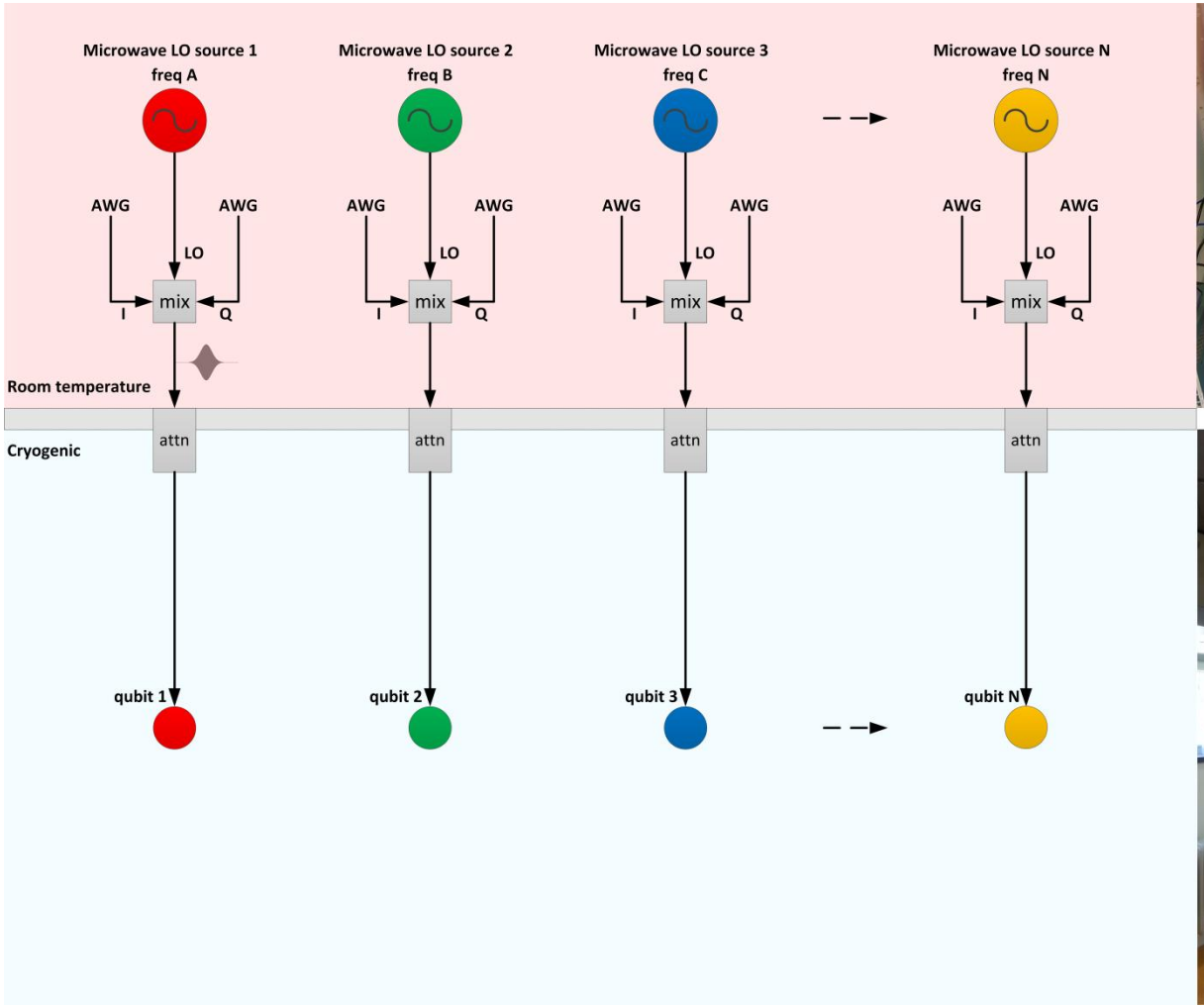


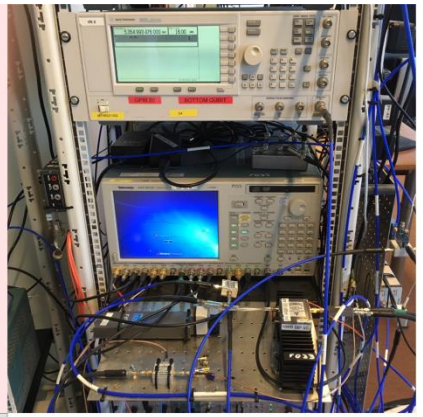
Absolute magnitude error can be calibrated

amplitude noise can't

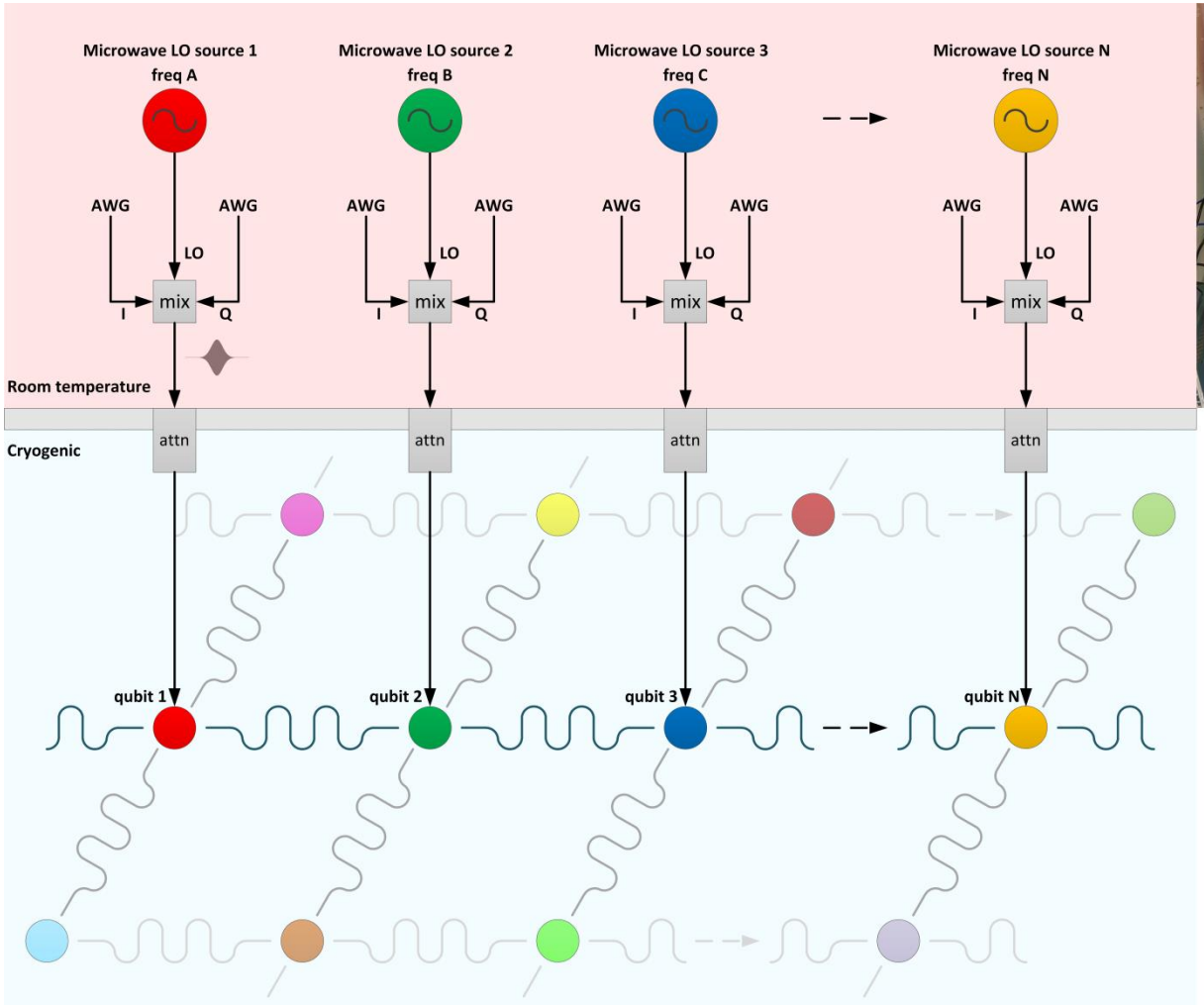


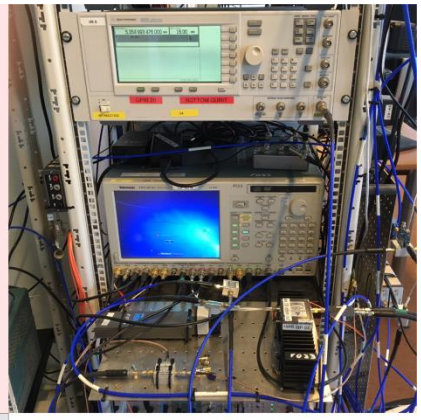
"Traditional" line array qubit control (individual)

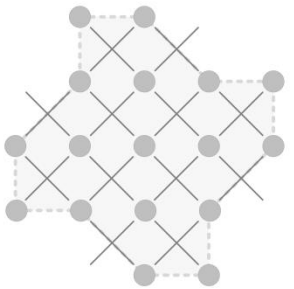




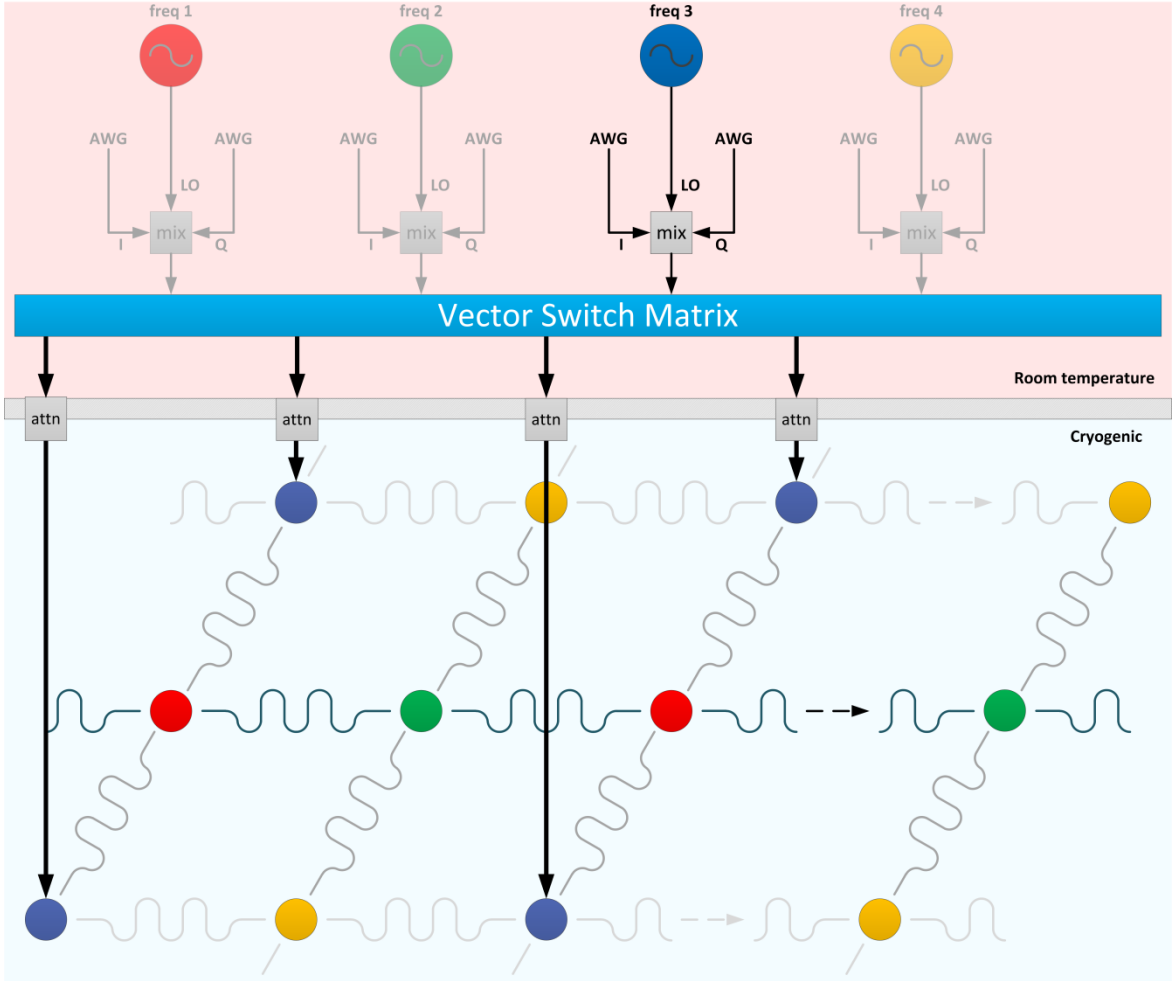
"Traditional" 2D plane qubit control (individual)

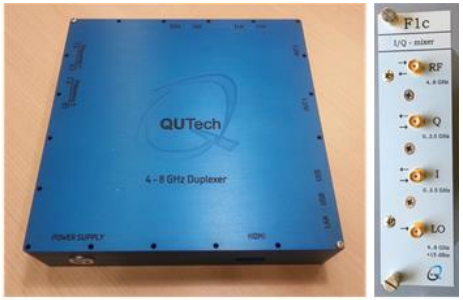






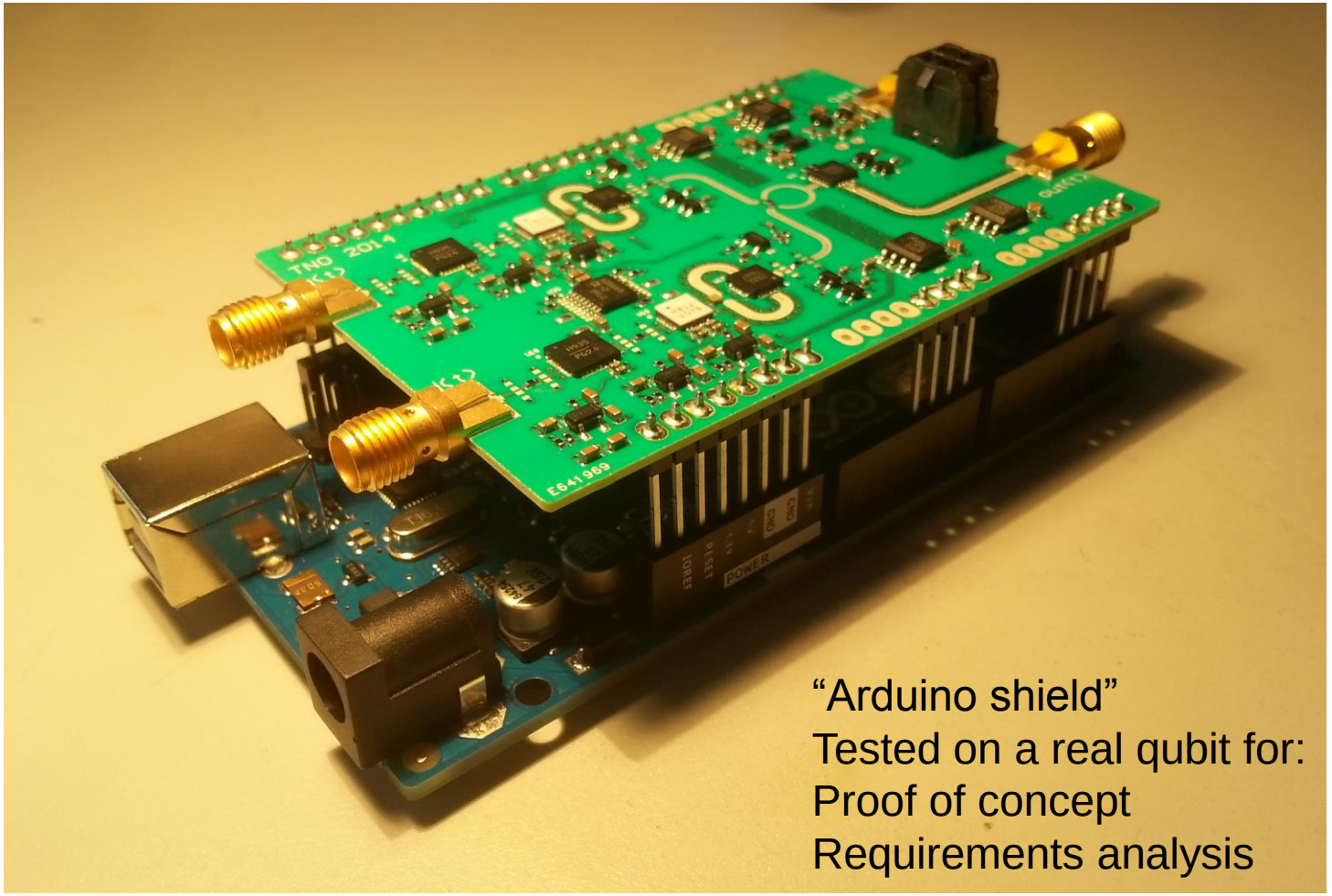
Repeated unit cell based 2D plane qubit control





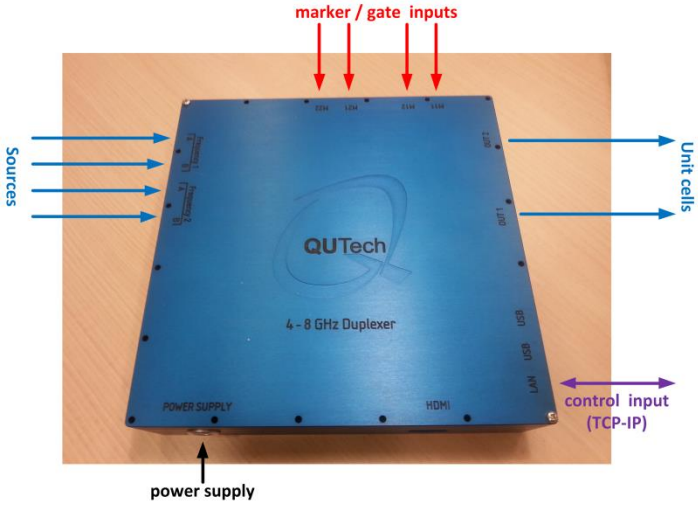
QuTech Patent: EU, US, JP + Paper: Independent, extensible control of same-frequency superconducting qubits by selective broadcasting, Asaad et. al. http://www.nature.com/articles/npjqi201629

The very first prototype (proof of concept)



"Arduino shield"
Tested on a real qubit for:
Proof of concept
Requirements analysis

The second prototype (patent and paper)



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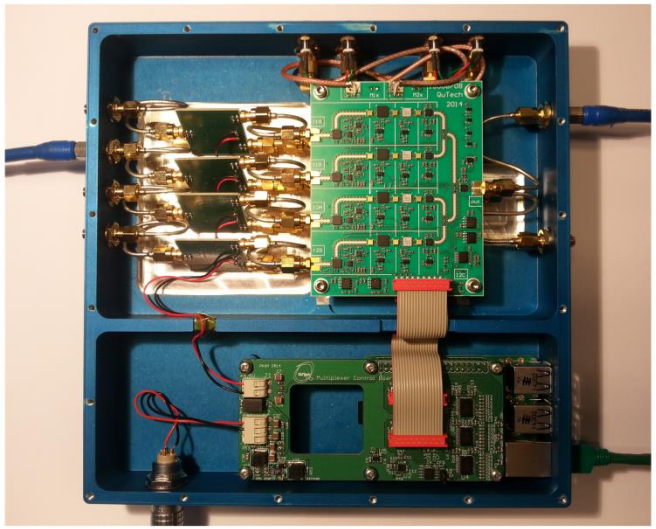
ARTICLE OPEN

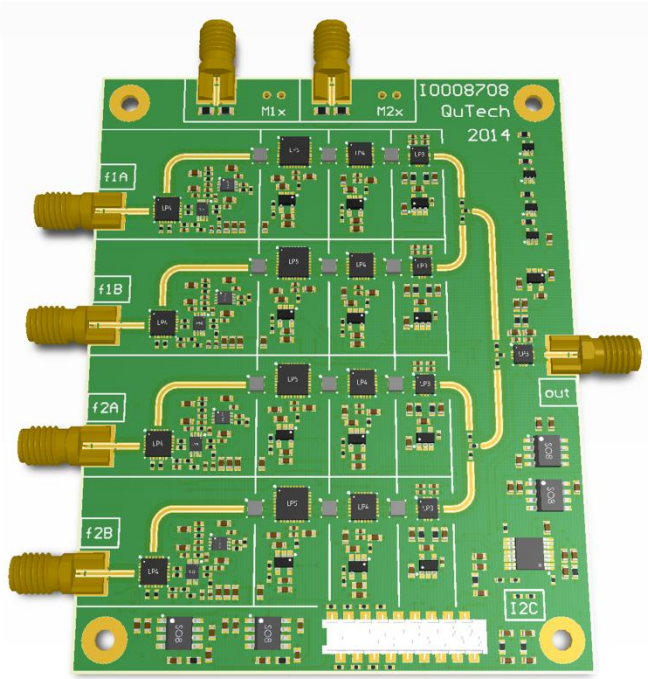
Independent, extensible control of same-frequency superconducting qubits by selective broadcasting

Serwan Asaad[1,2,4], Christian Dickel[1,2,4], Nathan K Langford[1,2], Stefano Poletto[1,2], Alessandro Bruno[1,2], Michiel Adriaan Rol[1,2], Duije Deurloo[1,3] and Leonardo DiCarlo[1,2]

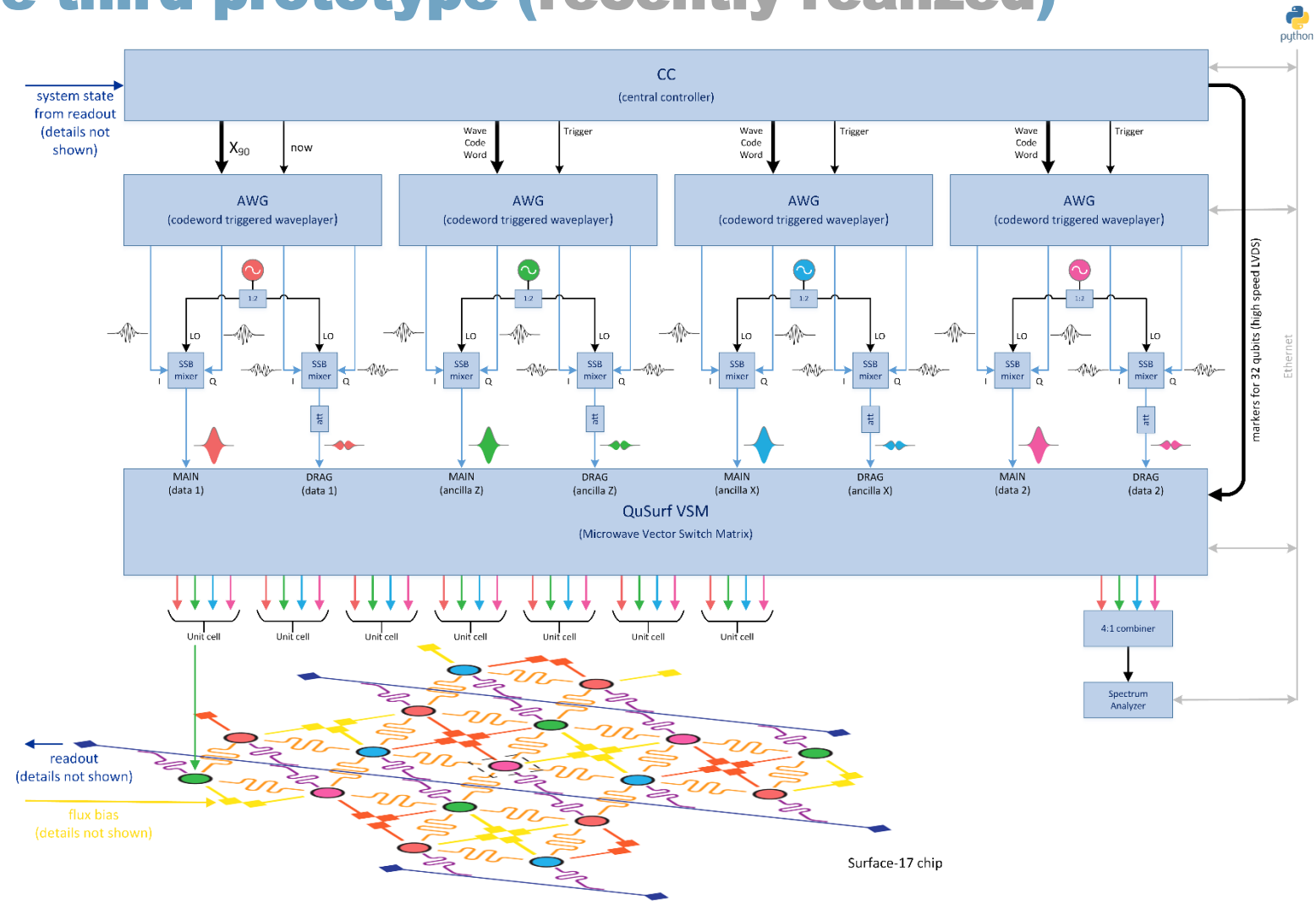
A critical ingredient for realising large-scale quantum information processors will be the ability to make economical use of qubit control hardware. We demonstrate an extensible strategy for reusing control hardware on same-frequency transmon qubits in a circuit QED chip with surface-code-compatible connectivity. A vector switch matrix enables selective broadcasting of input pulses to multiple transmons with individual tailoring of pulse quadratures for each, as required to minimise the effects of leakage on weakly anharmonic qubits. Using randomised benchmarking, we compare multiple broadcasting strategies that each pass the surface-code error threshold for single-qubit gates. In particular, we introduce a selective broadcasting control strategy using five pulse primitives, which allows independent, simultaneous Clifford gates on arbitrary numbers of qubits.

npj Quantum Information (2016) **2**, 16029; doi:10.1038/npjqi.2016.29; published online 23 August 2016

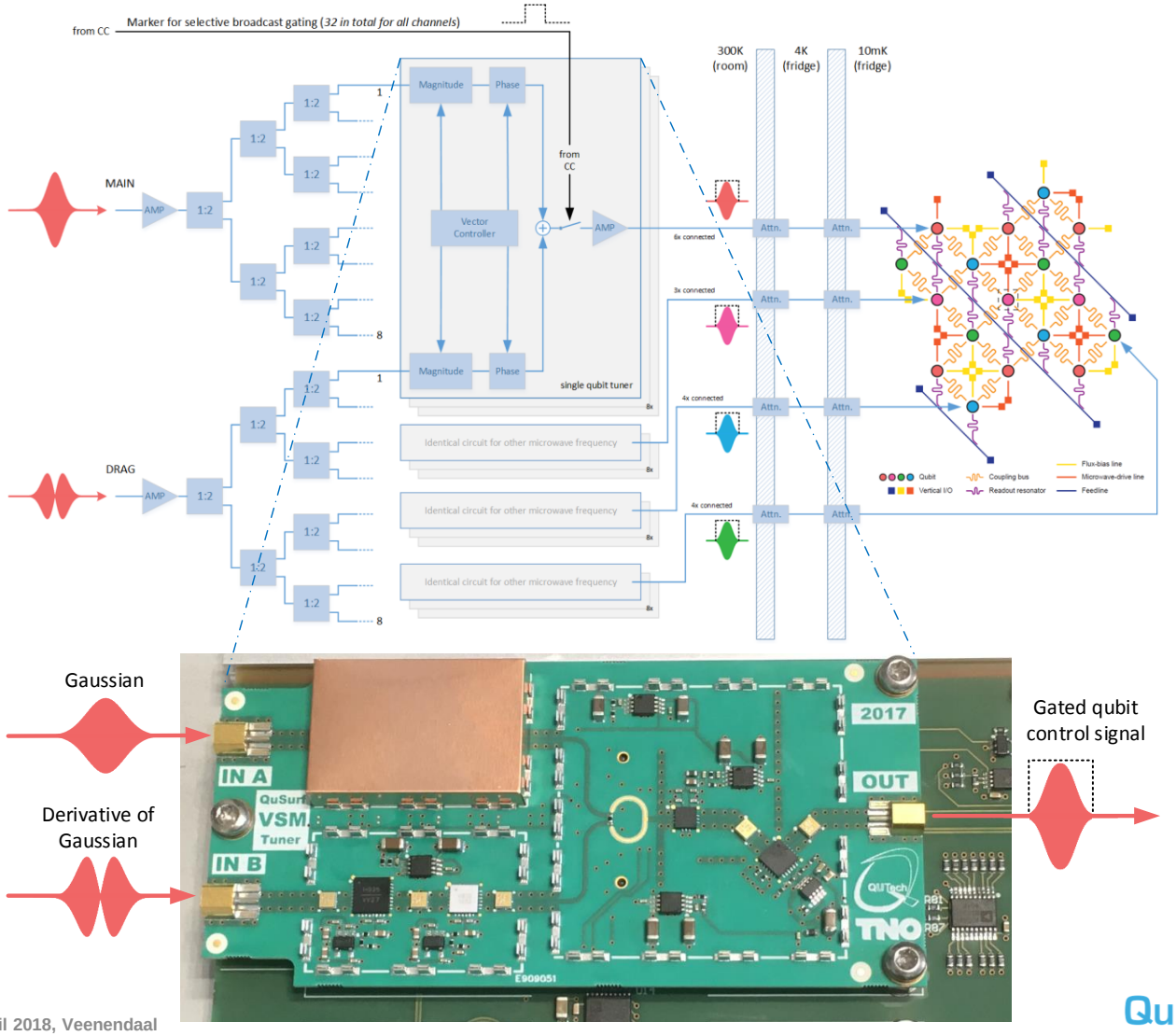




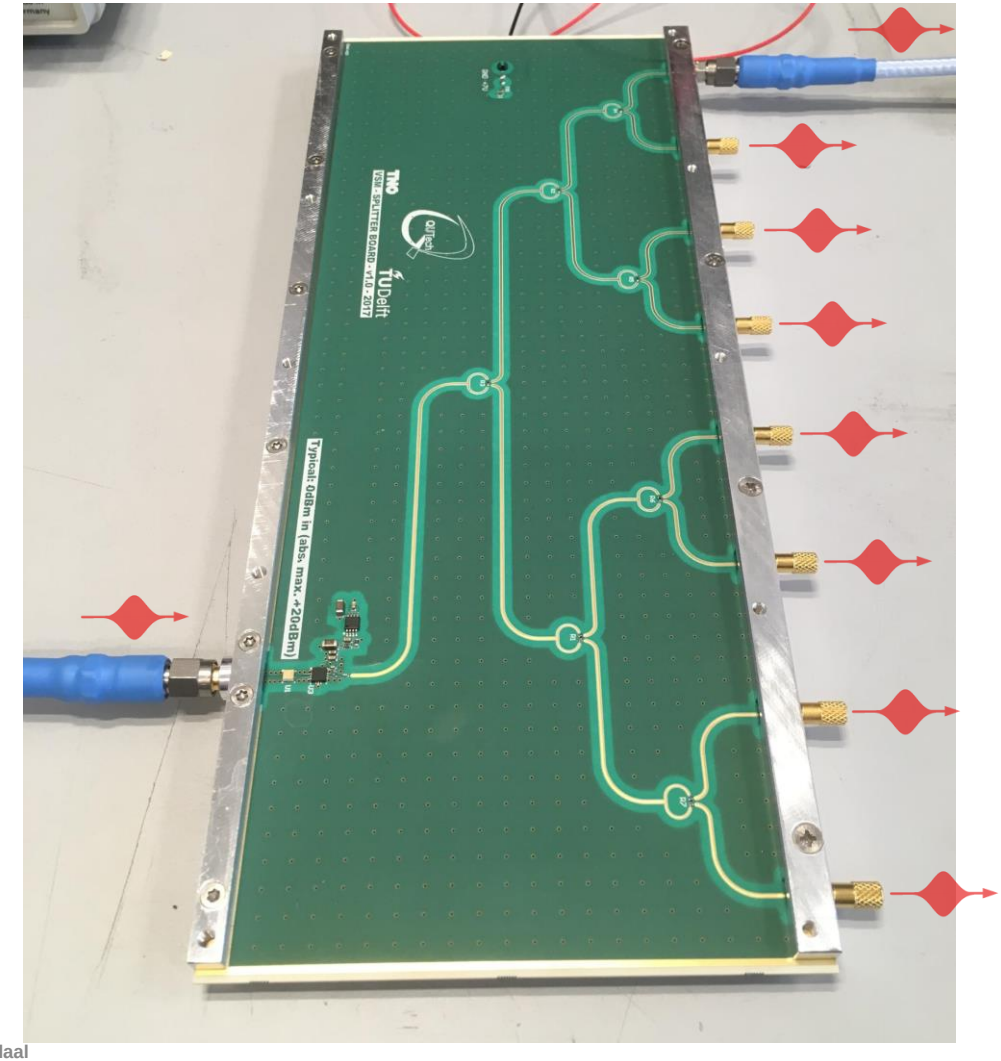
The third prototype (recently realized)



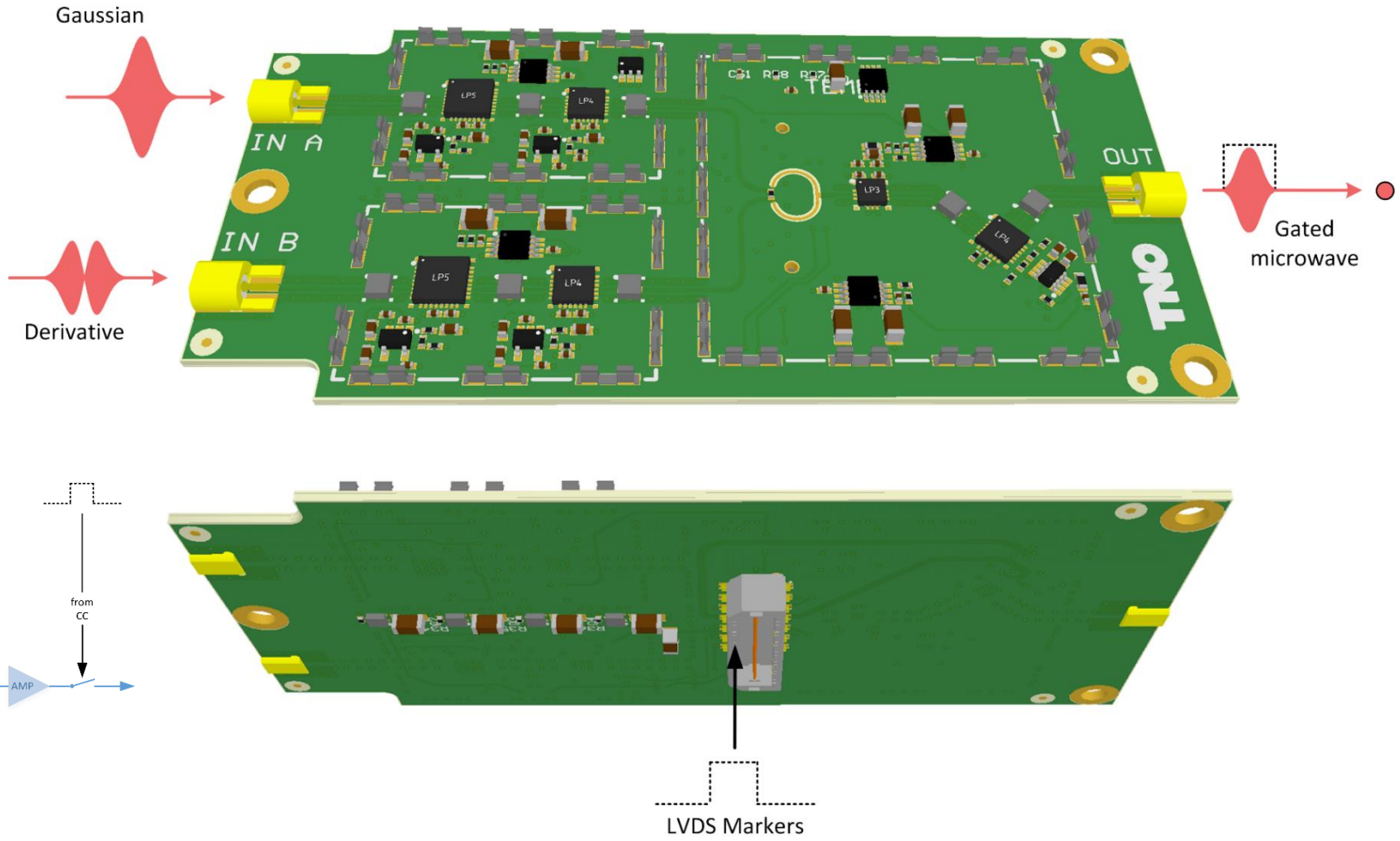
The third prototype (design phase)



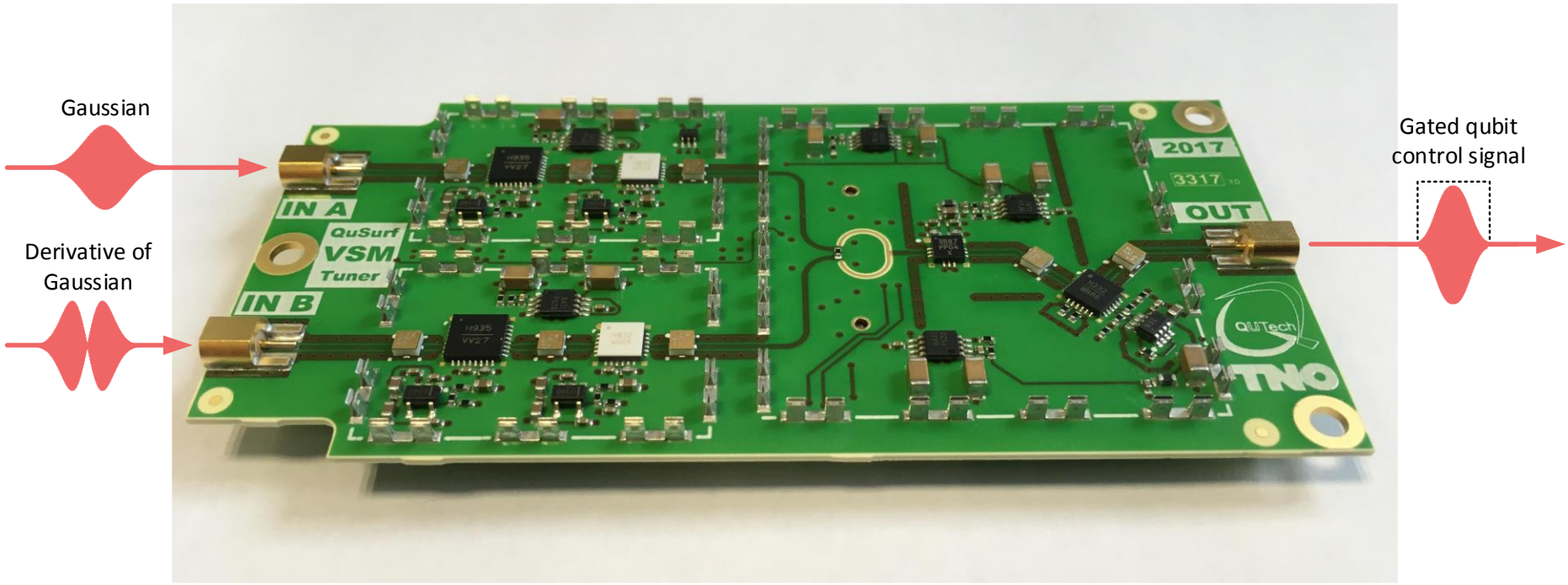
The third prototype (splitter board / make copies)



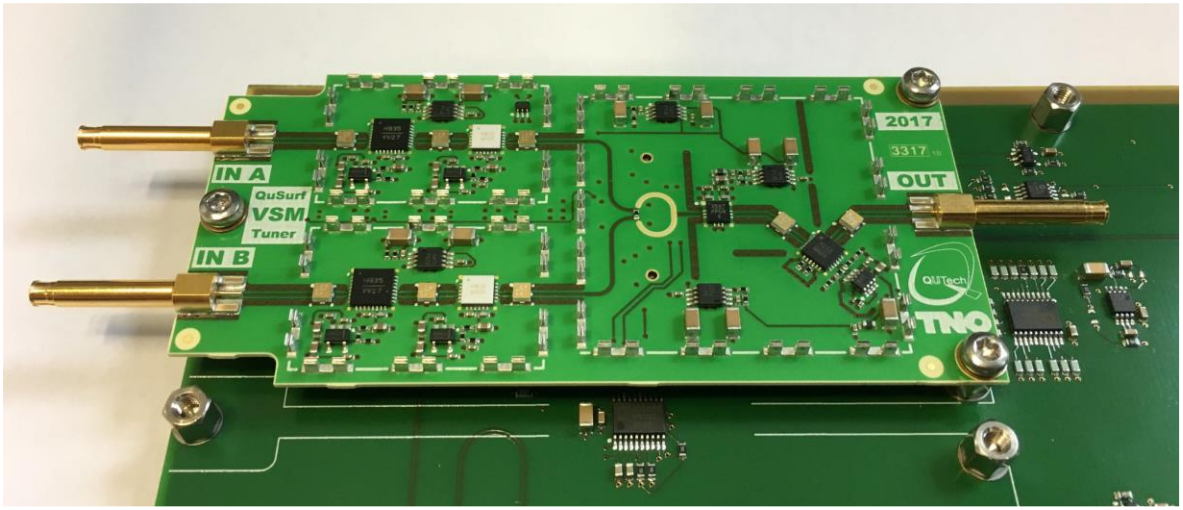
The third prototype (single qubit tuner design)

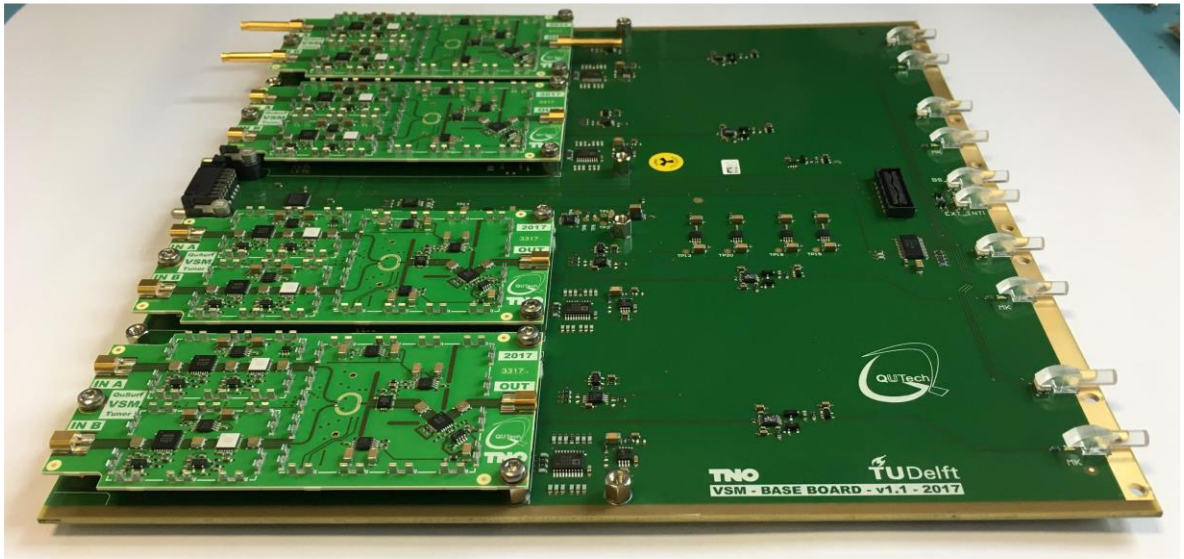


The third prototype (single qubit tuner produced)

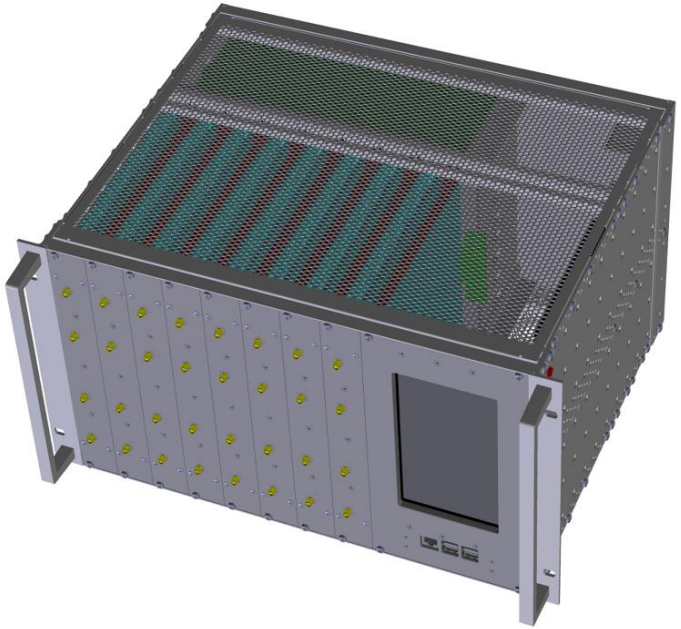


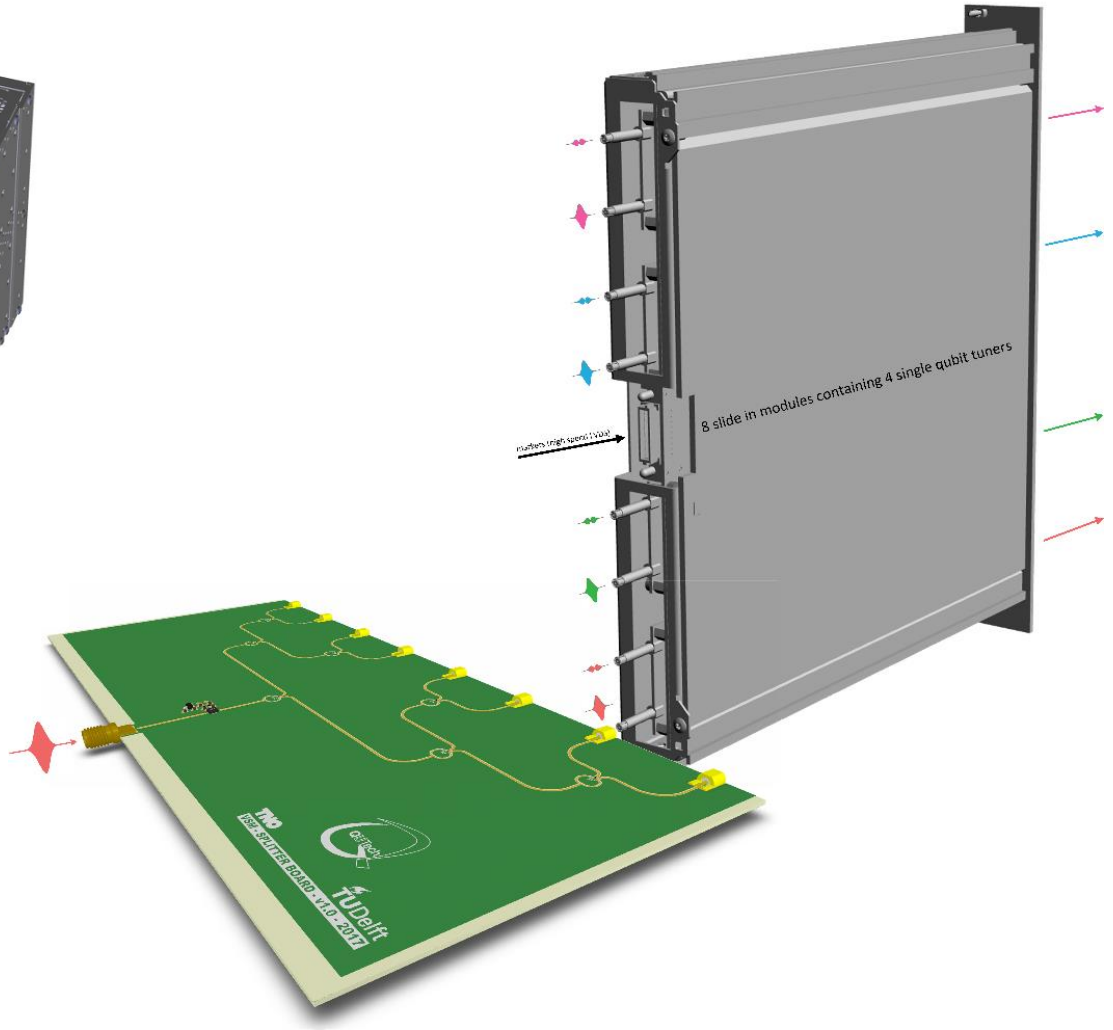
The third prototype (SQT on baseboard)



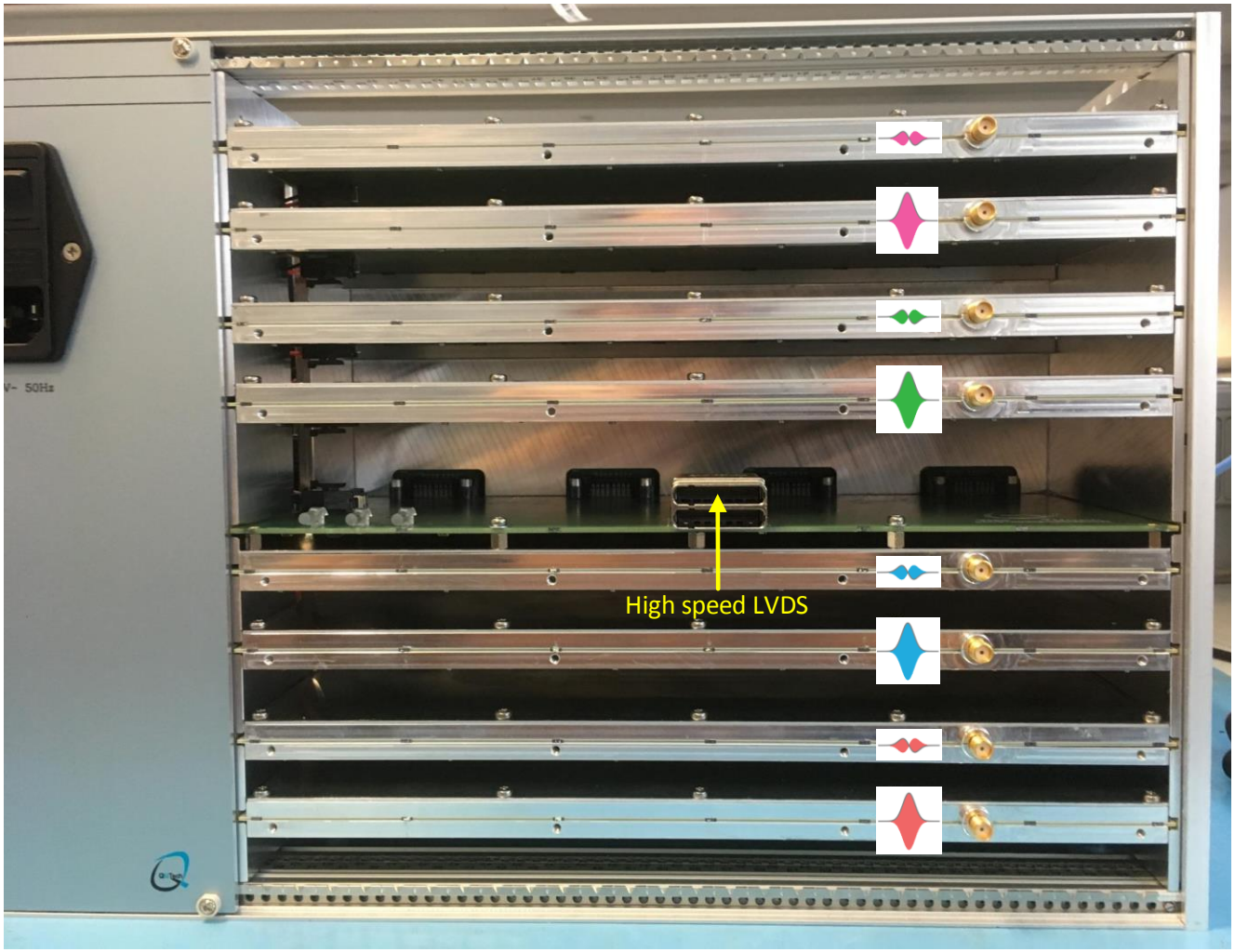


The third prototype (design phase)





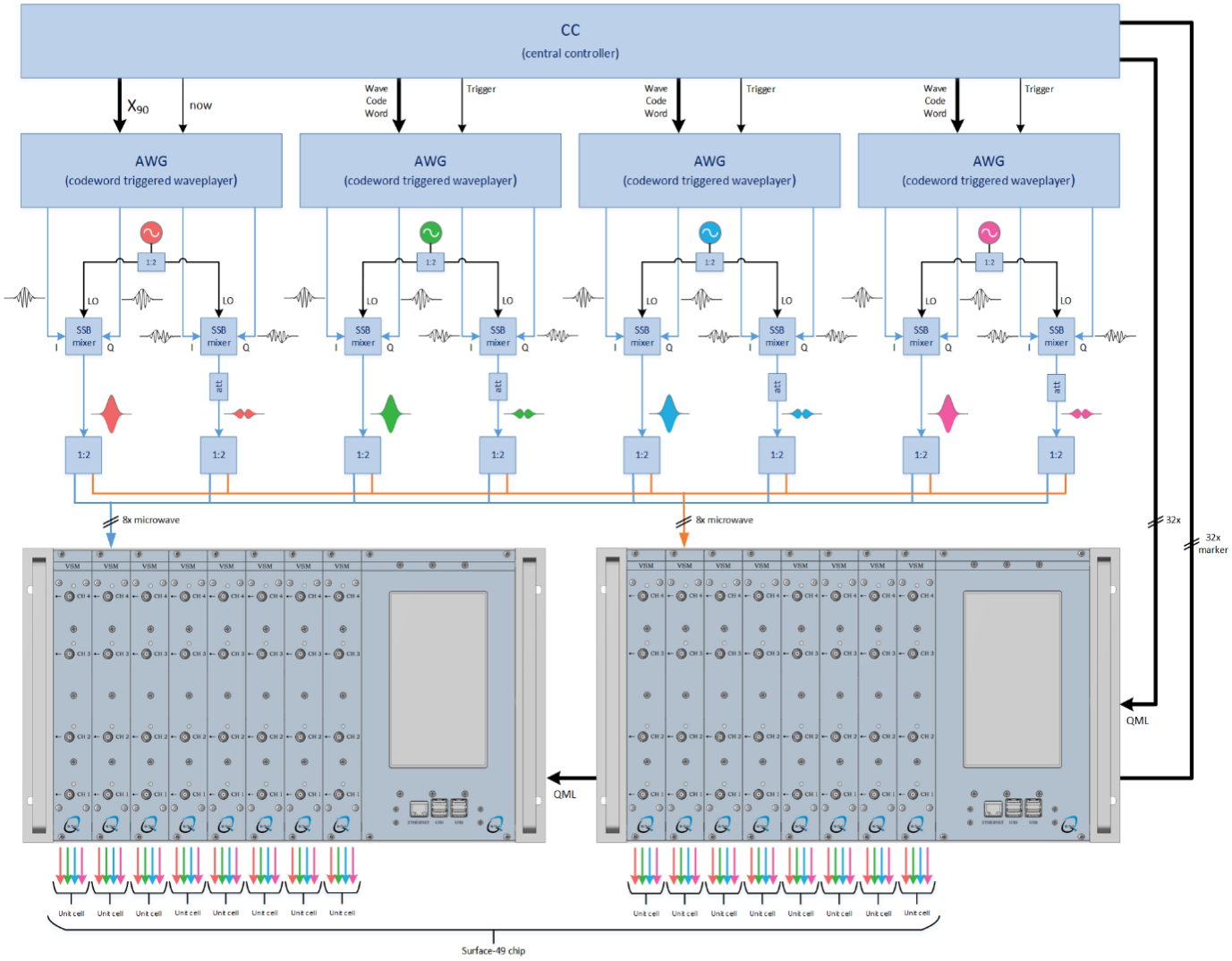
The third prototype (rear side splitter and marker boards)



The third prototype (the realized 19” rack)

The third prototype (demonstration @ QuTech)

The third prototype (extensibility, setup of today)



Thanks to:

Logical Qubits (LogiQ)

Office of the Director of National Intelligence
IARPA
BE THE FUTURE

TNO Team

TU Delft Team

Enthusiastic? → We are Hiring !

- RF / Microwave electronics designers
- Digital / FPGA (HW) / VHDL (FW) designers
- Embedded software (C/C++/Python) developers
- Fine mechanics engineers

The end