QUANTUM HARDWARE PLATFORMS

A BRIEF OVERVIEW

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Quantum hardware roadmaps are hard to directly compare

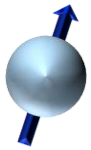
Platform	Player	2020	2021	2022	2023	2024	2025 to 2030
Superconducting	Google	**53Q**	100Q		10^3Q		10^4Q - 10^4Q - 1MQ
Superconducting	IBM	**65Q**	127Q	433Q	1121Q		path to 1MQ
Superconducting	Rigetti	**32Q**	4x32Q				
Trapped Ion	Honeywell	**H1**		H2	H3		H4 H5
Trapped Ion	IonQ	22AQ		29AQ		256AQ	1024AQ
Neutral Atom	ColdQuanta		100Q	300Q		1000Q	
Silicon	CEA Leti		6Q		100Q		
Silicon	SQC			10Q			100Q
Photonic	QuiX		12Qm	50Qm			
Photonic	PsiQ						1MQ
Photonic	Xanadu	X24	X40	X80	XD80		1MQ

Source: Fact Based Insight

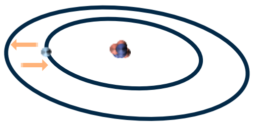
Qubits – a key building block for quantum hardware

Quantum systems ...

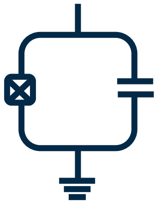
- □ Natural two-state systems
  - Electron spin up & spin down
  - Photon polarisation



- □ Systems with discrete states
  - Atoms or ions
  - "Artificial atoms" - e.g. defect-centres

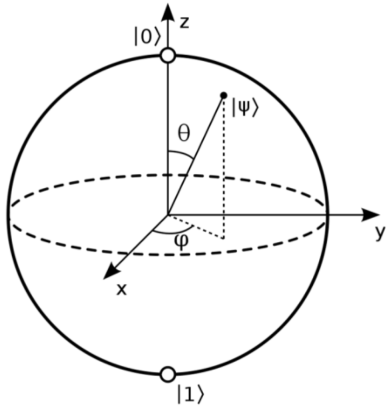


- □ Engineered quantum systems…
  - Current excitations in a superconducting circuit loop



A qubit

- □ $\Psi = \alpha|0\rangle + \beta|1\rangle$
  - α and β are complex numbers,
  - normalised $|\alpha|^2 + |\beta|^2 = 1$ i.e. probabilities sum to 100%



- □ Quantum gates drive Ψ around the sphere …so does noise
- □ Qubit plus a universal set of gates are sufficient for all quantum computing

Source: Fact Based Insight

FACT BASED INSIGHT

A simplified quantum stack

CONTROL LOGIC

Pulse & timing calibration
Optimal Control
Decoding

CONTROL PLANE

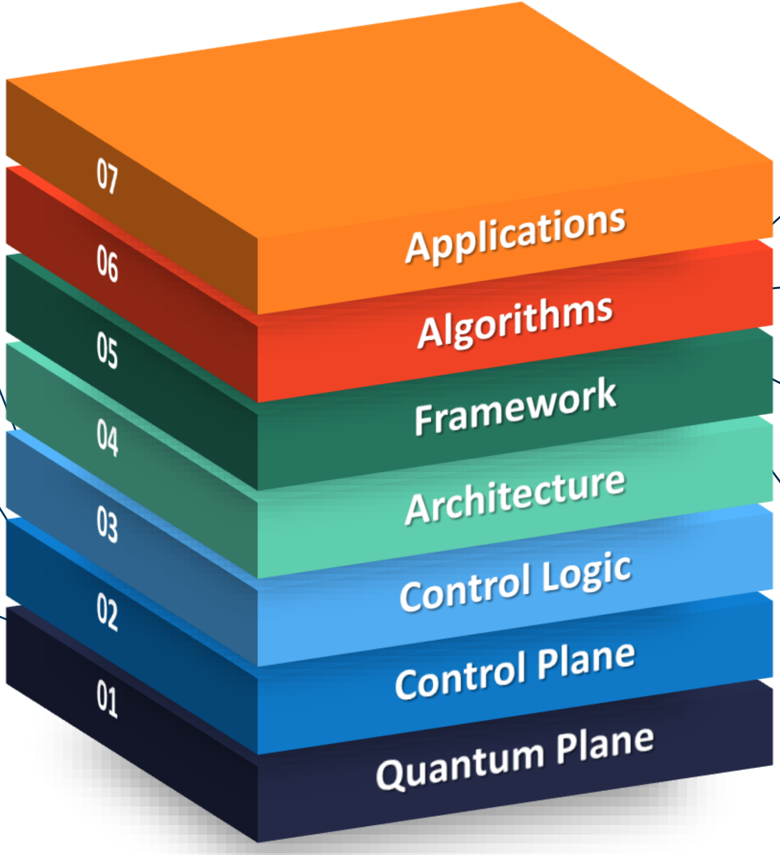
Crosstalk
Wiring/integration
Heat management

QUANTUM PLANE

Fidelity
Native gates
Connectivity
Interconnects

SIMULATOR

Verification & validation
Performance



APPLICATIONS

Development mgt.
Workflow mgt.

ALGORITHMS

Languages
Libraries

FRAMEWORK

Circuits
Optimising compilers

ARCHITECTURE

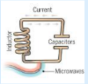
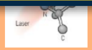
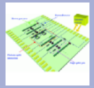
QPU kernel
Quantum error correction
Magic state factories
QRAM

Challenges of scaling-up the quantum hardware stack

	Challenge	Indicator/metric
ARCHITECTURE	• Quantum error correction	*Threshold; Cycle time* *Magic state factory footprint*
CONTROL LOGIC	• Calibration & optimal control • Heat management	Quantum volume 20mK vs 200mK vs 2K
CONTROL PLANE	• Control wiring/alignment • Cross talk	Integration strategy Simultaneous2Q gate fidelity
QUANTUM PLANE	• Modules size/interconnects • Connectivity	Interconnect speed *Error correction base cell*
	• Native gate set • High fidelity gates • State preparation & measurement • Long lifetime (T1 , T2)	Universal gate set 2Q gate fidelity (99%+, ideally 99.9%+) *Mid-circuit feedback* Lifetime/gate speed

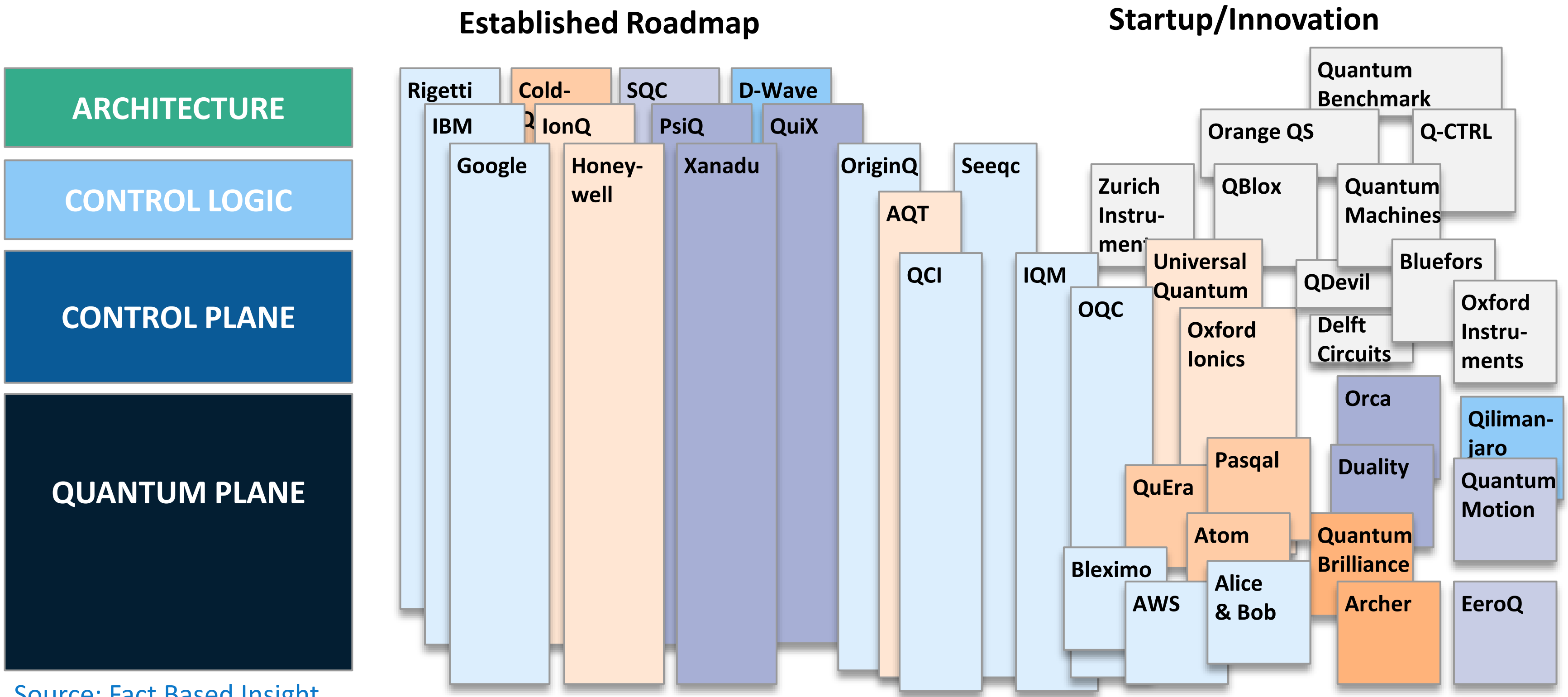
Source: Fact Based Insight

Old high level comparison of qubit technologies

ARCHITECTURE	Superconducting Circuits 	Trapped Ion 	Neutral Atom 	NV Diamond 	Silicon Spin 	Photonic 
			Sensing	Sensing		
	Building	Building	Large	Q Network	Chip	Room
Control Processor	Rack	Rack	Rack	Rack	*Integrated*	*Integrated*
	Cross talk?	Scaling?	?	?	?	?
Gate Control	Wire	Laser	Laser	Laser	Circuit	Electrical
	Fast gates	Long life	Long life	Long life	Fast gates	Fast Gates
Environment	Dilution	UHV	UHV	Ambient	Dilution	Ambient
				Deployable		Deployable
Connectivity	2D	All-to-all	2D/3D	Clusters	2D	Flexible
	Multi Q	Multi Q	Simulation		CMOS fab	CMOS fab
Substrate	Circuit	Trap	Trap	^{12}C	^{28}Si	Photonics
	99.4%	99.9%	97%	88%	98%	“98%”
Qubit	Current loop	Ion	Atom	NV defect	Electron	Photon

Source: Fact Based Insight

Established players plus thriving startups and innovation



Source: Fact Based Insight

Increasingly, variations of qubit technology are important

	Superconducting Circuits	Trapped Ion	Neutral Atom	NV Diamond	Silicon Spin	Photonic
Error Correction	*Surface code* *Colour code*	*Bacon-Shor cod* *Surface code*	*Surface code*		*Surface code*	*Beyond foliat* *GKP code*
Control Processor	*CryoCMOS* *SFQ*	Rack	Rack	*Mounted*	*Monolithic*	*Flipchip*
Gate Control	Freq. tuning M e Tunable couplers	Laser NF Microwave GF Microwave	Laser	Laser	CMOS fab STM fab	Electrical
Environment	20mK	UHV	UHV	Ambient	200mK?	2K (detector)
Connectivity	Square grid Hex grid	All-to-all Shuttling	2D+	Clusters	2D	Flexible
Substrate	Circuit	RF trap	MOT trap	^{12}C	^{28}Si	Photonics
Qubit	Tunable Fr Fixed Freq.	Hyperfine Optical	Hyperfine Optical	NV SiV	Qdot Donor	Single Photon Squeezed Light

Cat codes

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QV

99.85%

1K

1000Q?

99%

QS

Source: Fact Based Insight

Superconducting circuits – a challenge of fidelity and scaling

Notable variations	USP	Key Challenge	Notable Players	Leading device 2020	Announced For 2021
Tunable qubits 99.7%	Fast gates	Scaling-up	Google, OriginQ, QuTech, IQM, Seeqc,	53Q QS	100Q
Fixed-frequency 99.85%	Longer qubit lifetime	Integrating tunable couplers	IBM, OQC	27Q (QV 128) QV	128Q
Parametric gates 99%	Hybrid benefits	2Q gate fidelities	Rigetti, Bleximo,	32Q	4x32Q
Flux qubits	Rapid scale-up for quantum annealing	Demonstrating quantum advantage	D-Wave, Qilimanjaro	5000Q	

Source: Fact Based Insight

Trapped ions – very different approaches

Notable variations	USP	Key Challenge	Notable Players	Leading device 2020	Announced For 2021
Hyperfine qubits with laser gates	99.9% Highest fidelity	Scaling-up laser control system	IonQ, Honeywell	QV 10Q (QV 128)	? 32Q (QV 4millon)
Optical qubits with laser gates	99.6% Easier optical integration	Mitigating shorter qubit lifetime	AQT, NextGenQ	20Q	50Q
Hyperfine qubits with near-field microwave gates	99.7% High fidelity without lasers	Demonstrate multi-qubit device	Oxford Ionics	2Q	
Dressed states with global-field microwave gates	Very modular and scalable	2Q gate fidelities	Universal, NextGenQ	2Q	

Source: Fact Based Insight

	Superconducting Circuits	Trapped Ions	Neutral Atoms	NV Diamond	Silicon Spin	Photonic
Important Variants	Tunable, Fixed Freq., Parametric	Hyperfine, Optical, NF Microwave, GF Microwave	Hyperfine, Optical	Nitrogen Vacancy, Silicon Vacancy	Quantum Dots, Imp. Donor, STM-Fab. Door	MBQC, CVQC
Qubit T2 Lifetimes	Short 15-120μs	Long 0.2-50s	Long 0.2-50s	Long 10s	Mixed 1μs-0.5s	Short 150μs
2Q Gate Fidelity	High 99%-99.85%	High 99%-99.9%	Promising 97%	Interesting 99% (88%)	Promising 98%	Promising 98%
Gate Speeds	Fast 12-200ns	Mixed 1μs-3ms	Intermediate 1μs	Slow 100μs	Fast 0.8-80ns	Very Fast 1ns
Lifetime/ Speed	1250-100	1000000-500	1000000-100000	c.100000	10-50	c.150000
Environment	20mK	Ultra High Vacuum	Ultra High Vacuum	Ambient	20mK - 1K	1K - 10K (detectors)
Current Devices	65Q	20Q	51Q	10Q	2Q	12Q
Announced Devices for 2021	100Q 128Q	32Q 50Q	100Q	10Q	6Q	24Q 40Q-80Q
FTQC Footprint	Building	Building	Large	Network	Chip	Compact

Source: Fact Based Insight

1s = 1000ms = 1000,000μs = 1000,000,000ns

For more information and supporting references

- Factbasedinsight.com/quantum-hardware-outlook-2021
- Factbasedinsight.com/quantum-hardware-into-the-quantum-jungle

Source: Fact Based Insight