XBOX SERIES X SoC – A Next Generation Gaming Console

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Presenter Bio – Paul Paternoster

- Partner Hardware Engineer at Microsoft.
- He has worked on XBOX chips for the past 20 years and was the Microsoft SoC implementation lead for the XBOX One X and XBOX Series X SoCs.
- He has also worked on Kinect, Hololens and server projects while at Microsoft.
- Prior to joining Microsoft, Paul developed ASICs for Digital Equipment Corporation, Amdahl, 3DO , Cagent, Hot Rail and SanDisk.

Outline

- Context/Block diagram/feature description
- Chip statistics/comparison to previous generation
- Acoustic/Thermal/Power challenges and solutions with console tower form factor
- Power management HW features/optimization
- Compute flexibility for power/yield balancing

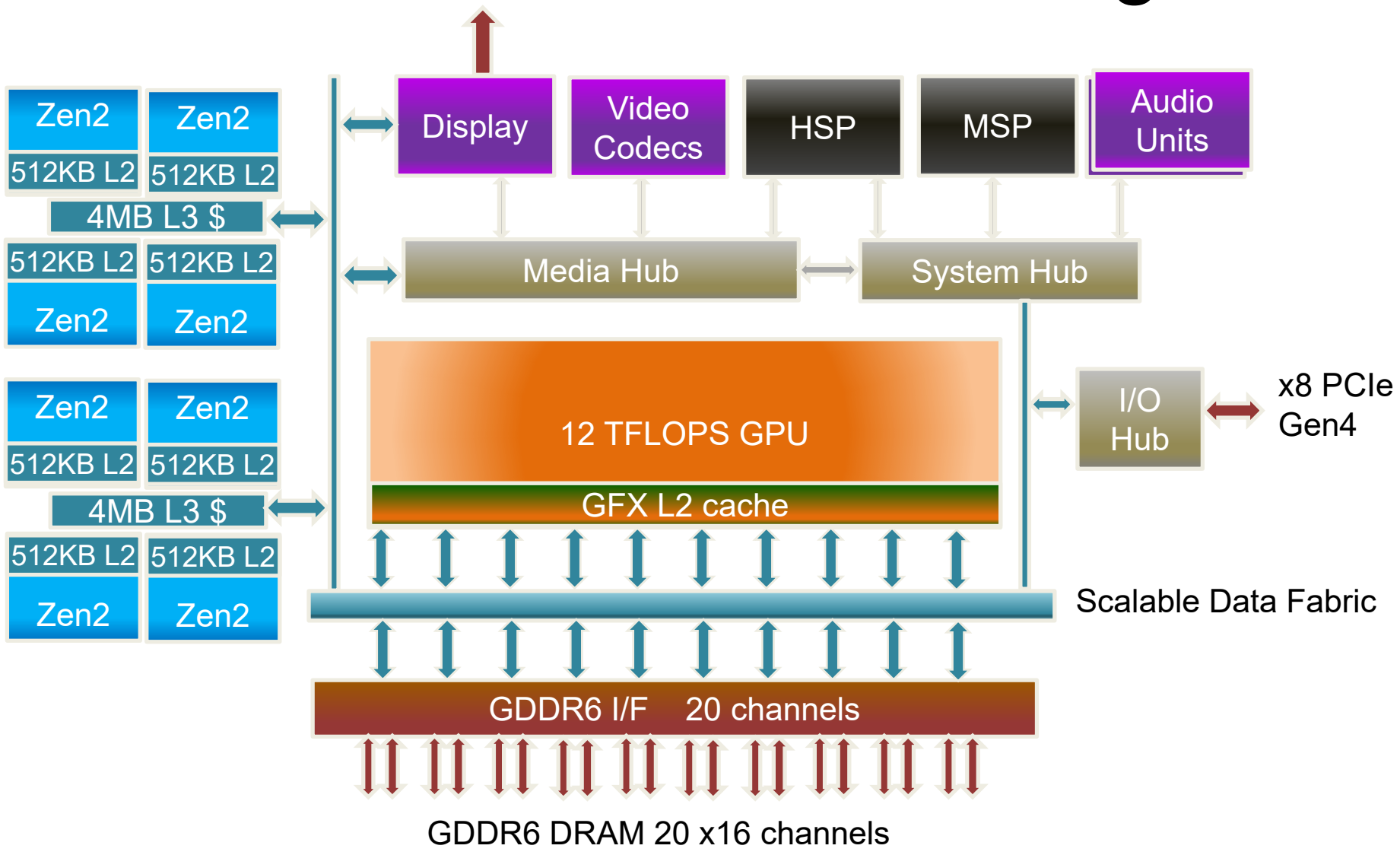
XBOX SERIES X Console Goals

- Most powerful next-gen console
  - True 4K & HDR Gaming
- Improved physics & visual fidelity for most immersive experience
  - Watch 4K Ultra HD Blu ray movies
- Best versions of your games
  - Backward compatibility provides thousands of titles
  - 40x faster game load time than previous generation

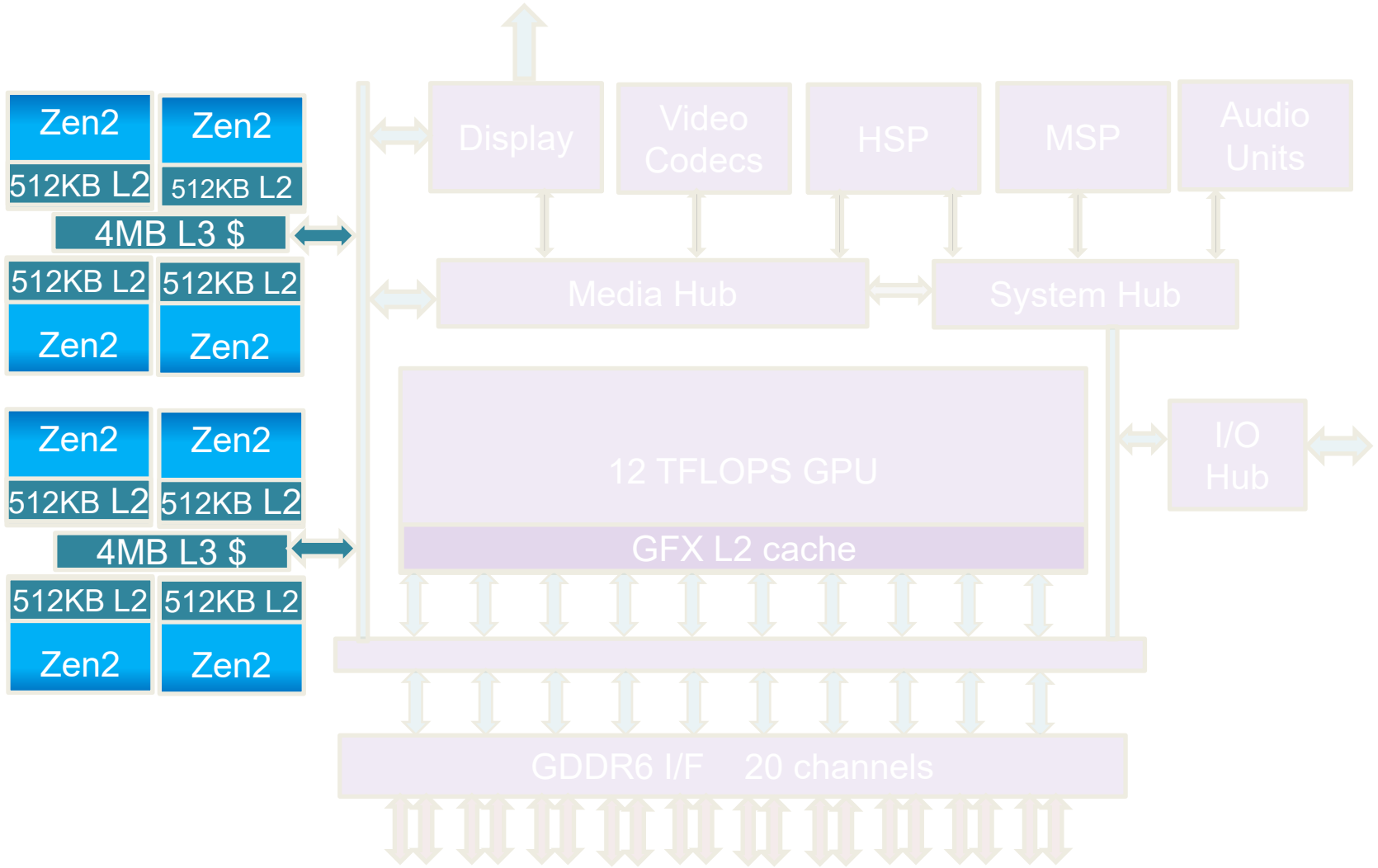
XBOX SERIES X Development

- Joint development between AMD and Microsoft
  - 3-4 years from concept to product
- Feature future proofing for several years after launch
  - 8K video support
  - Expansion Storage

XBOX SERIES X Block Diagram

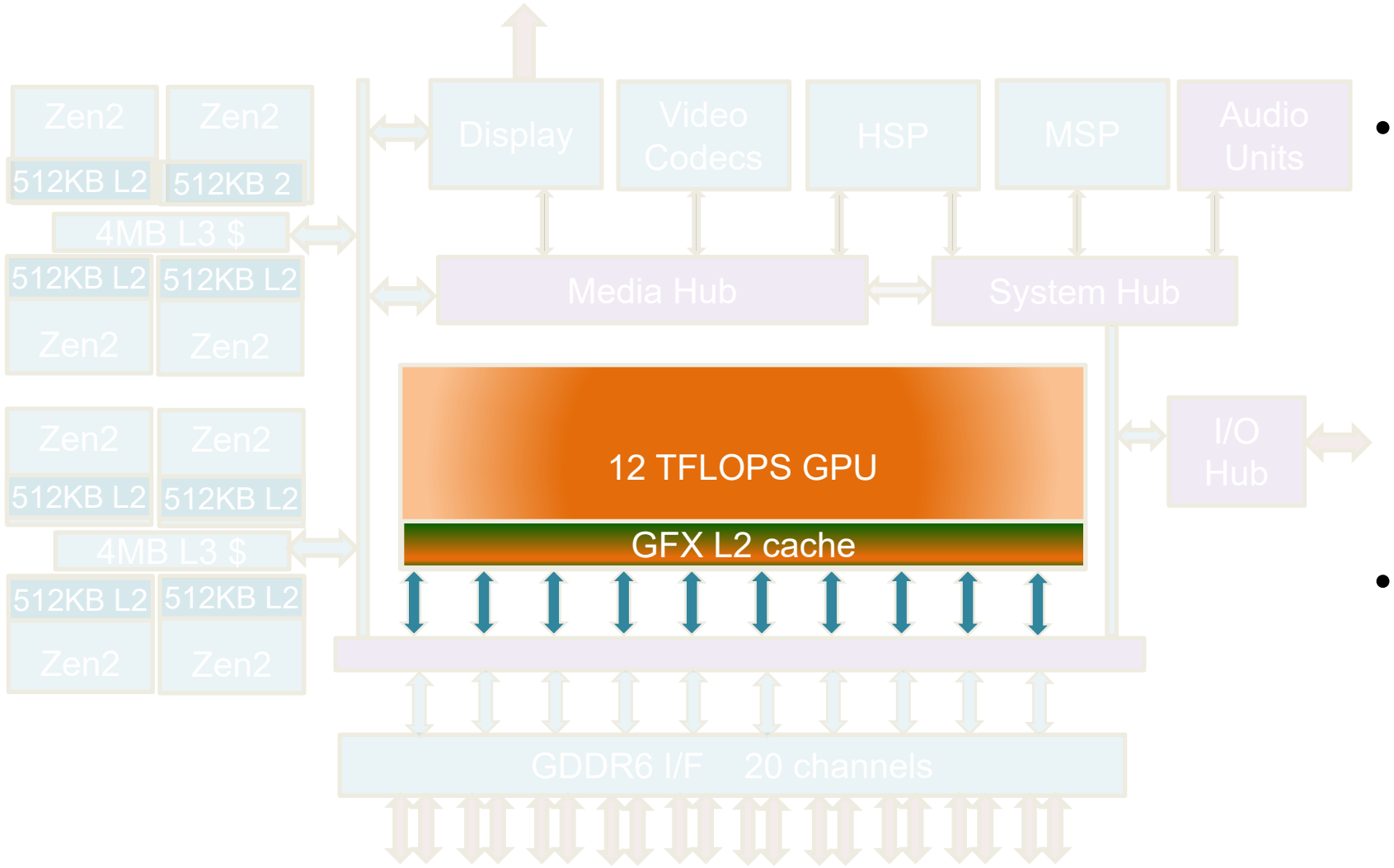


XBOX SERIES X CPU



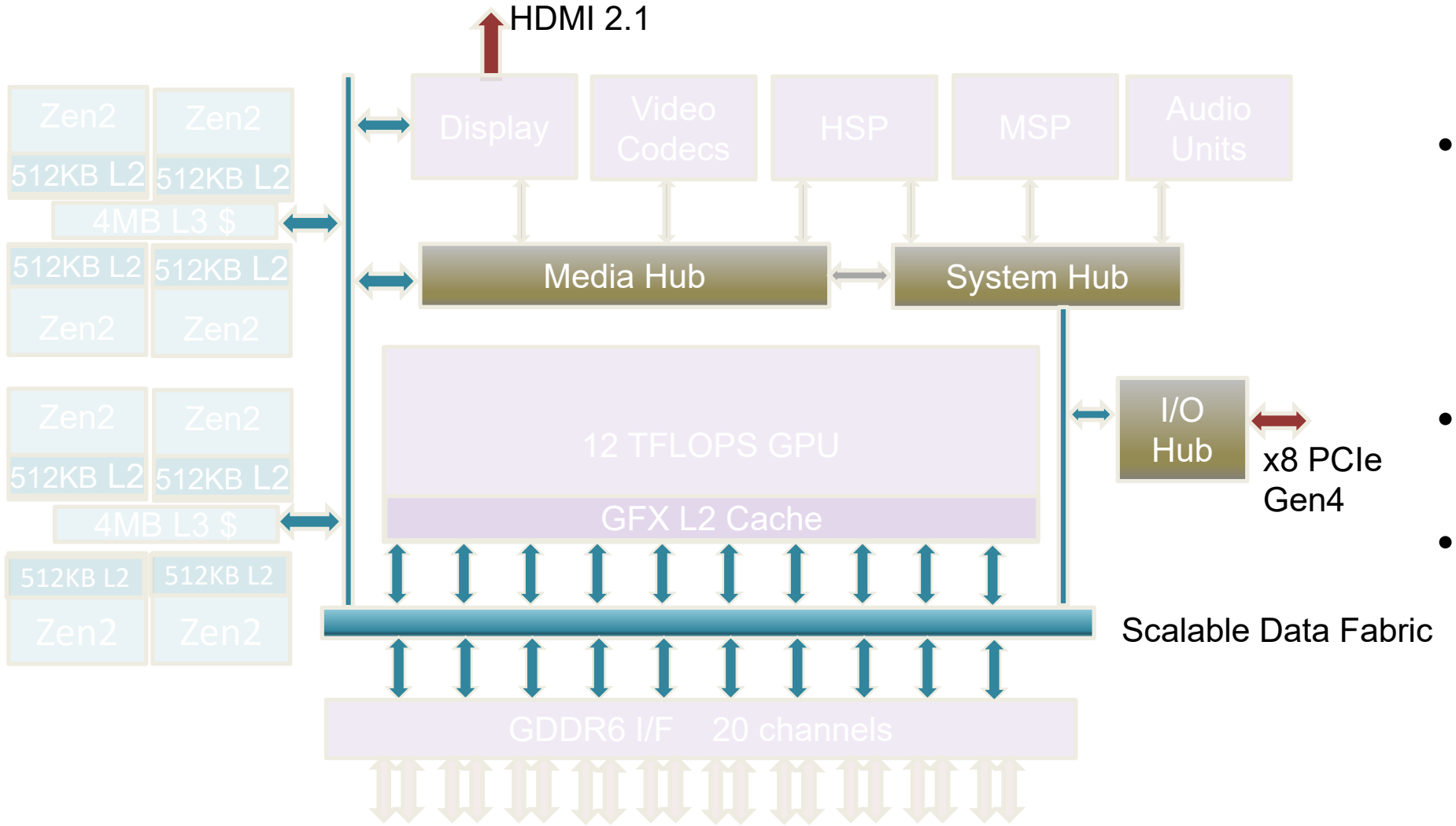
- 2 custom Zen2 core complexes (4 cores each)
  - 4 MB shared L3 per complex
  - 2 SIMD 256b FP pipes per core
  - 512KB L2 per core

XBOX SERIES X GPU



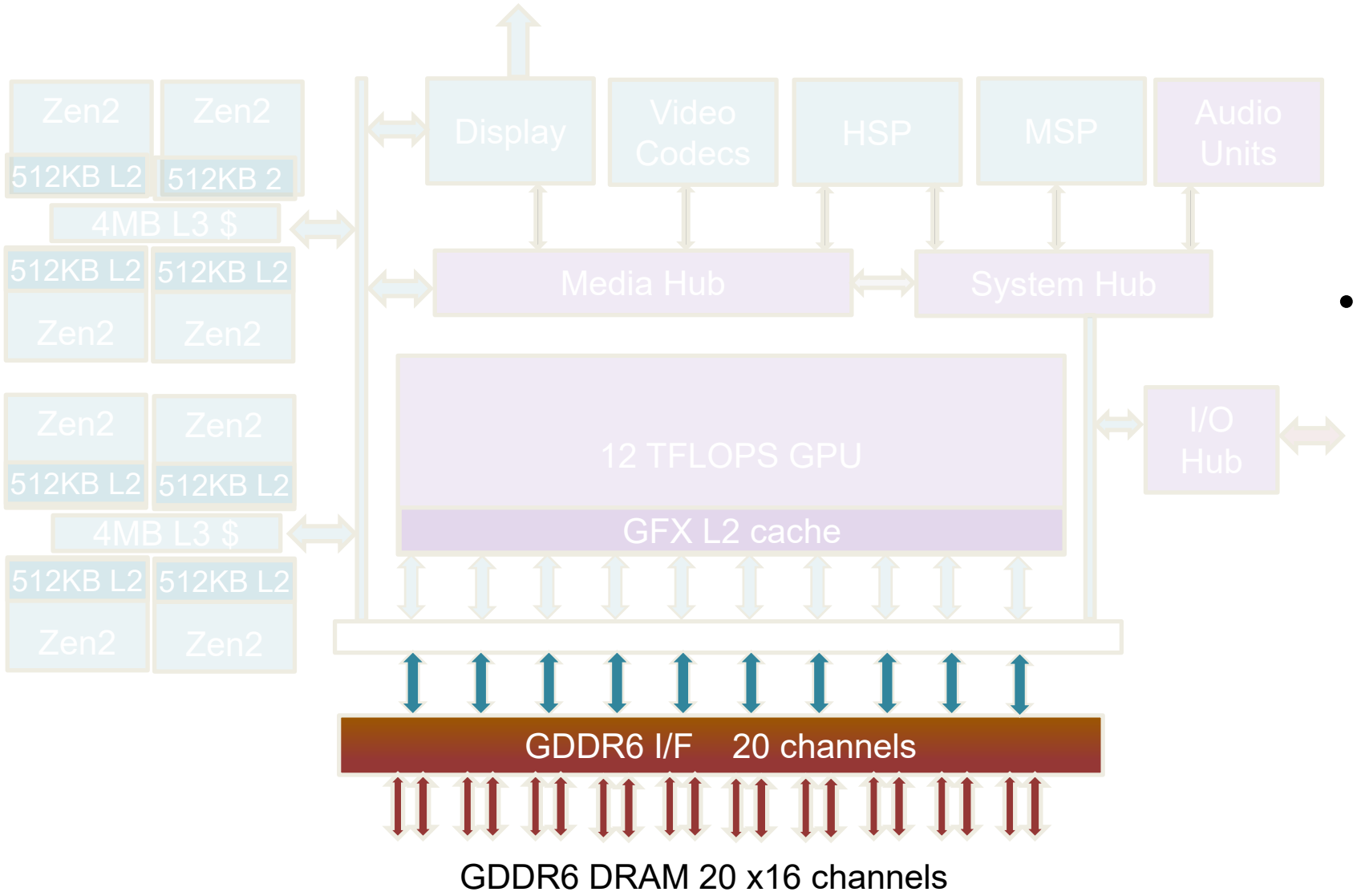
- Custom RDNA-based GPU with 12 TFLOPS peak performance
  - Variable rate shading
  - Ray tracing
  - Partially resident texture features
- 28 WGPs (work group processors)
  - 2 SEs (Shader Engines)
  - 2 SAs (Shader Assembly Blocks) per SE
  - 7 WGPs per SA

XBOX SERIES X Fabrics and IO



- Multiple fabric hubs
  - Media Hub
  - System Hub
  - I/O Hub
- Scalable Data Fabric
- I/O
  - PCIE Gen 4
  - HDMI 2.1 (10Gbps FRL)

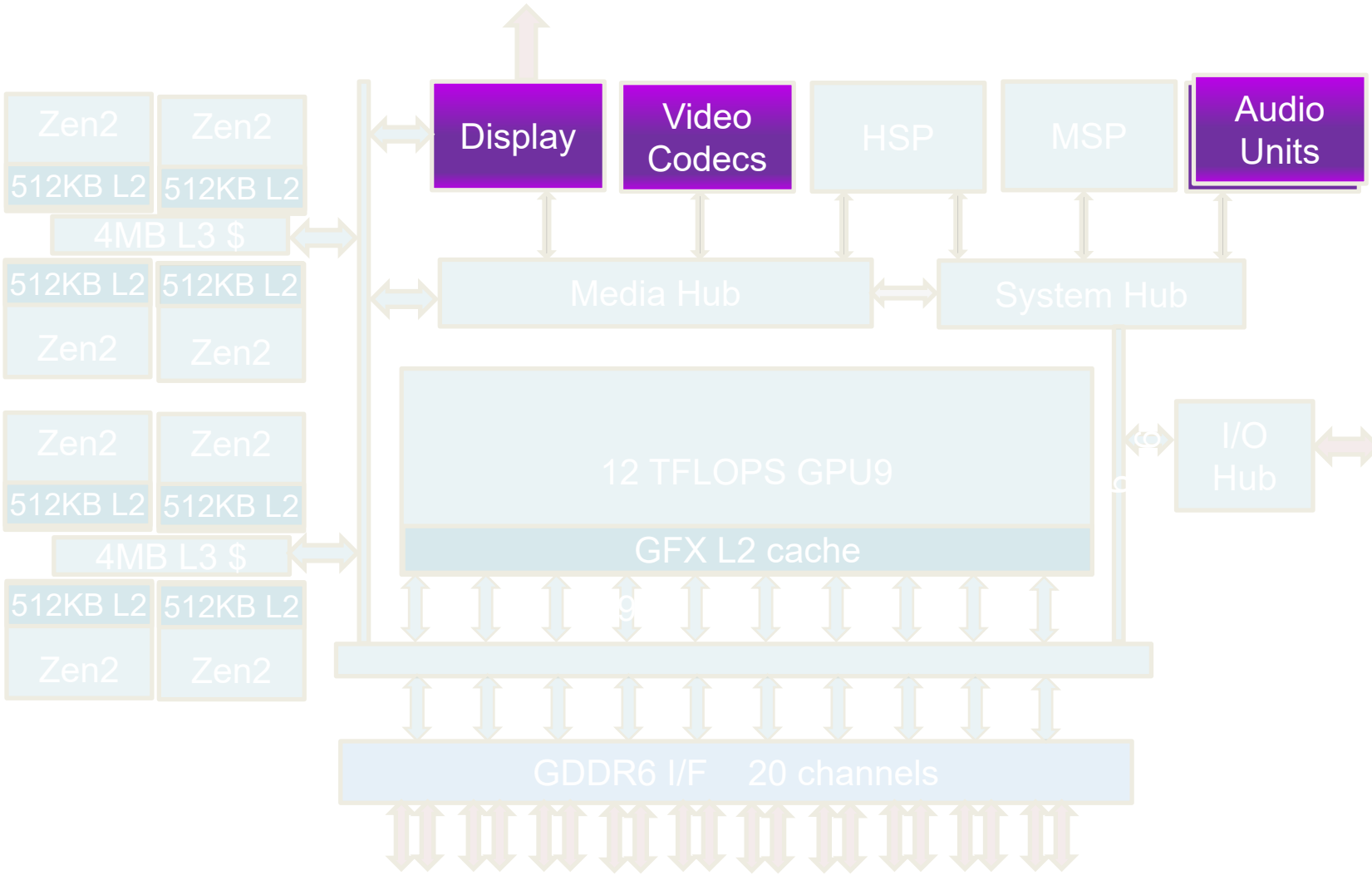
XBOX SERIES X Memory



GDDR6 DRAM 20 x16 channels

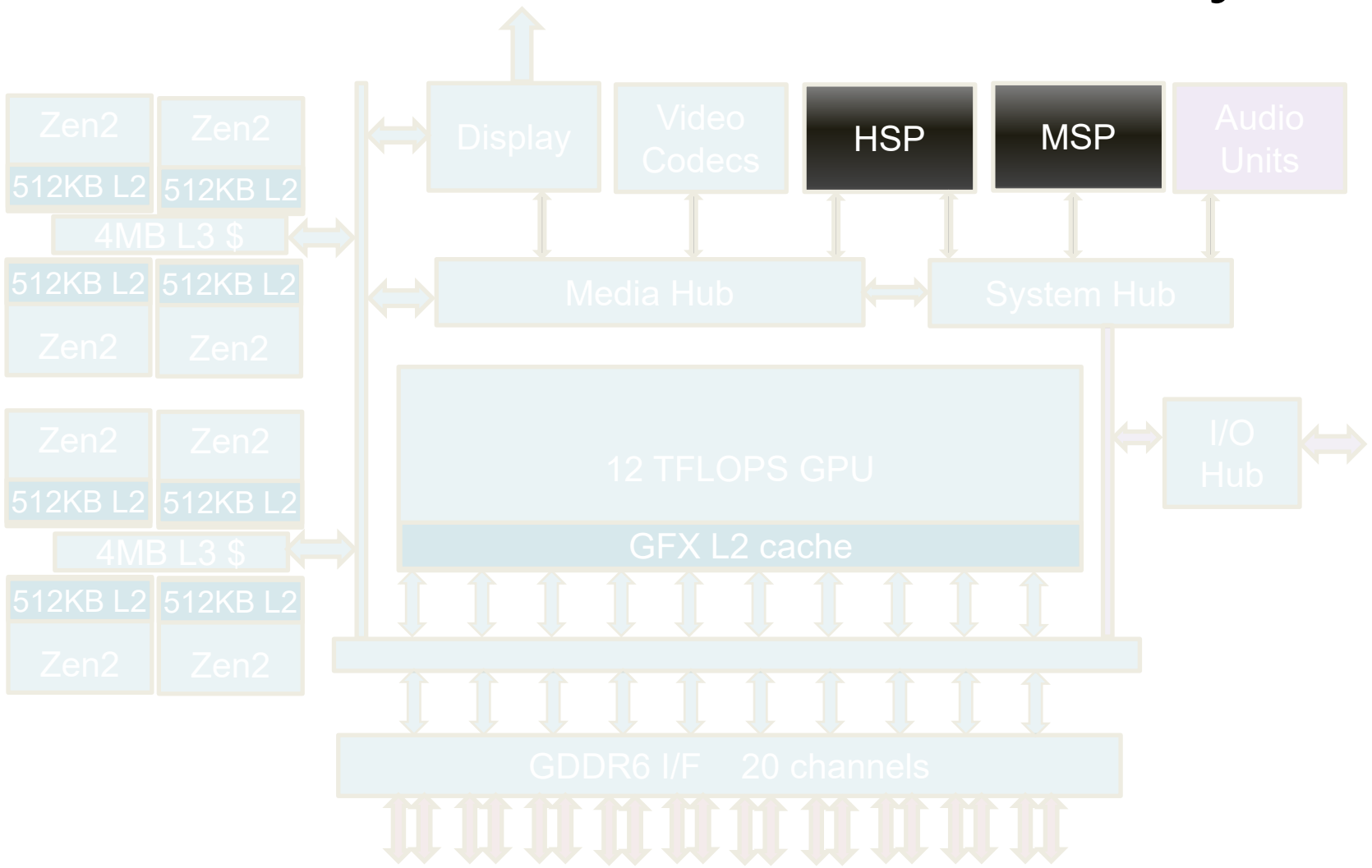
- 16 GB of GDDR6 memory
  - 10 GB high memory interleave – 560 GB/s B/W
  - 6 GB low memory interleave – 336 GB/s B/W

XBOX SERIES X Multimedia



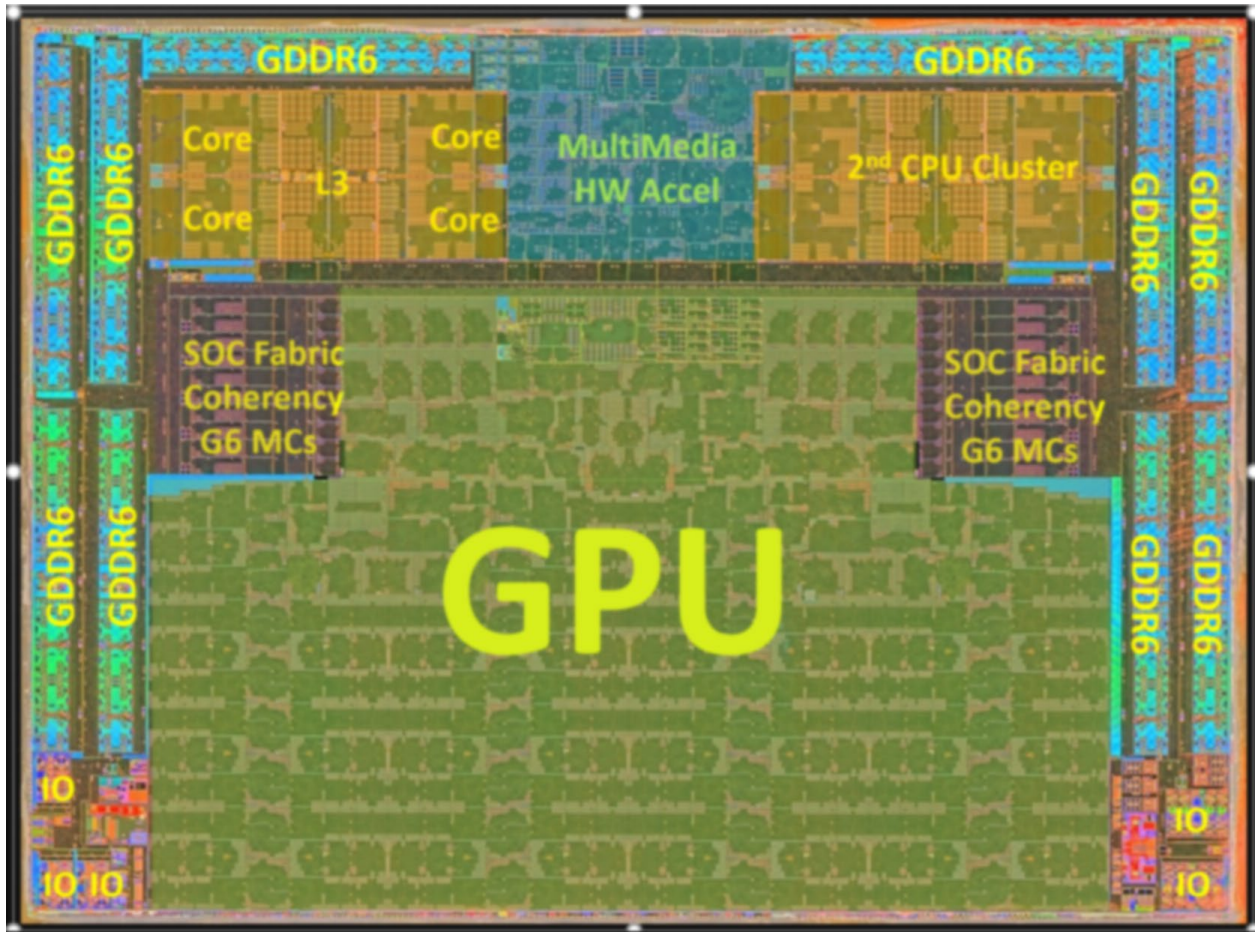
- 4 display plane support
- Video codecs
  - 4K/8K AVC
  - HEVC/VP9 HDR decode
  - AVC/HDR encode
- Audio processors (offloads CPU compute of > 3 x86 cores)
  - MOVAD- Opus/Vorbis decomp
  - CFPU2 for frequency domain processing
  - Logan IP for MEC, traditional game audio processing

XBOX SERIES X Security/Compression



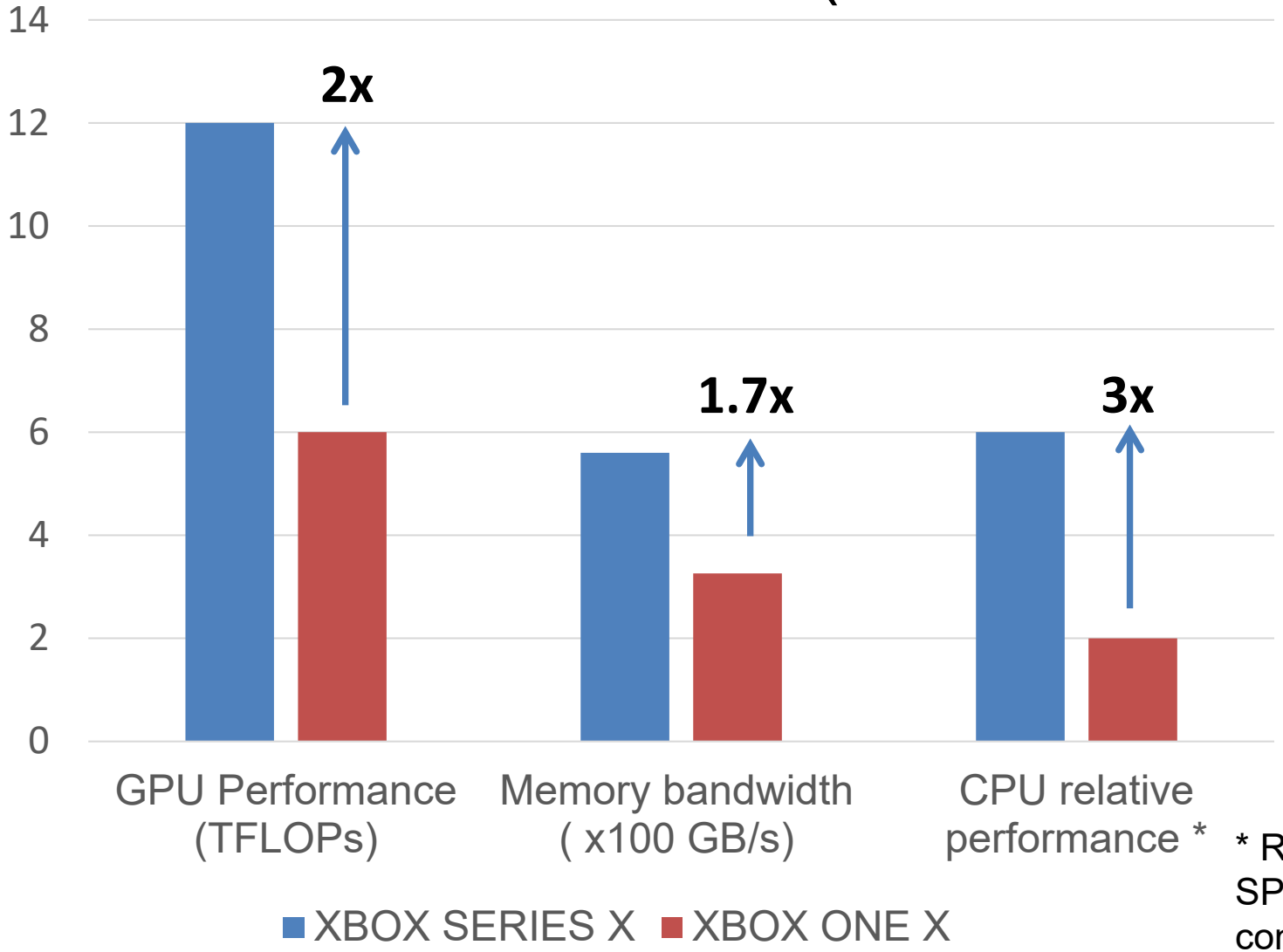
- HSP (Hardware Security Processor)
- MSP (Media Streaming Platform)
  - Compression support
    - LZ
    - Deflate
    - BC compression
  - Allows reduction in game footprint of 30-35% from previous generation
  - 40X faster load time (2 lanes PCIE Gen4 SSD)
  - Security support for AES

XBOX SERIES X SoC Die Photo & Comparison



Parameter	XBOX SERIES X	XBOX ONE X
Technology Node	TSMC 7nm	TSMC 16nm
Transistor Count	15.3B	6.6B
Area	360.4 mm^2	366.9 mm^2
Package type	12 layer (5-2-5)	12 layer (5-2-5)
Package size	52.5 mm x 52.5 mm	50 mm x 50 mm
Ball count	2963	2409
Ball pitch	0.80 mm (minimum)	0.80 mm (minimum)

XBOX SERIES X SoC vs. XBOX ONE X
(GPU/MEM/CPU)

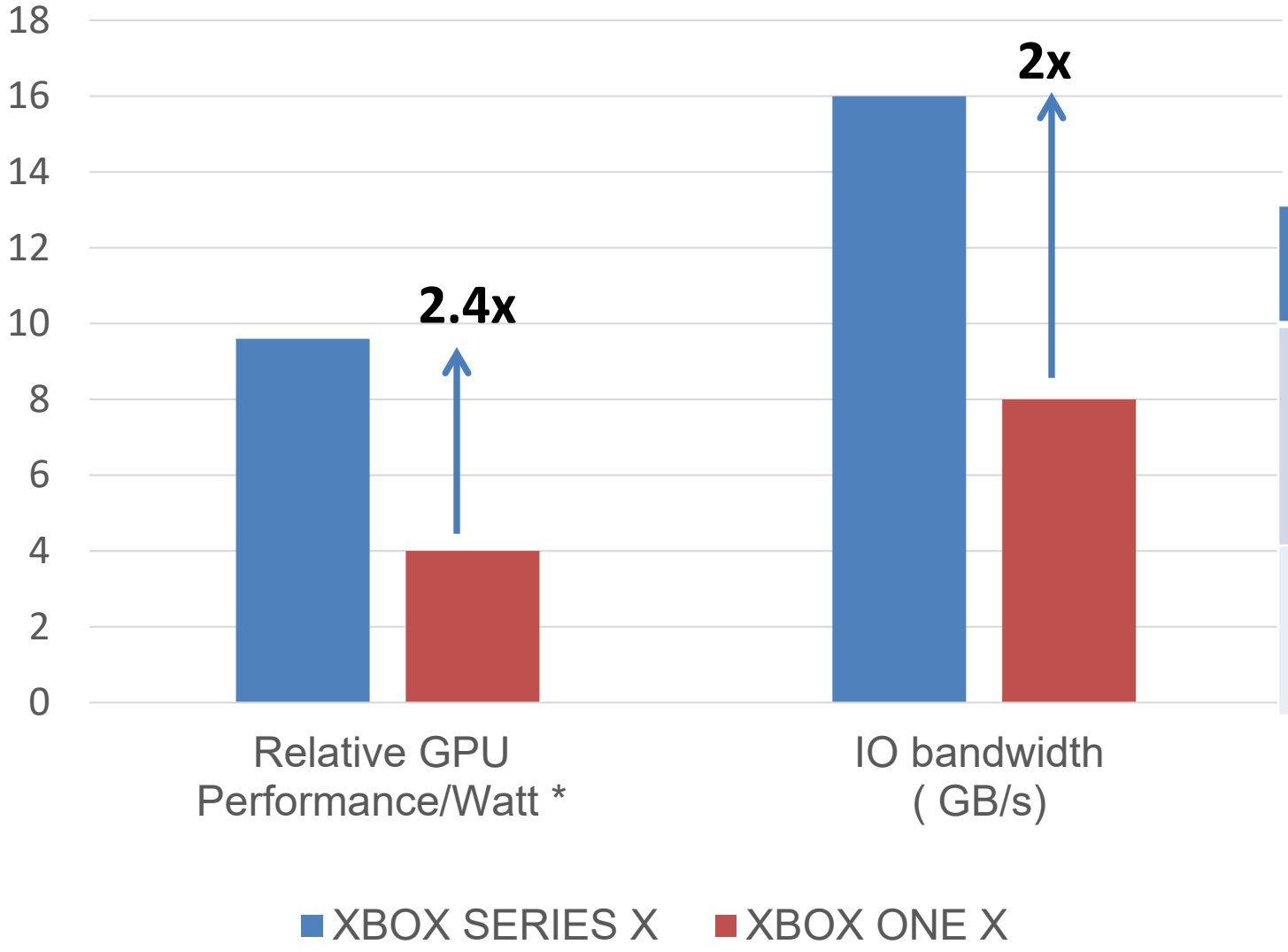


Parameter	XBOX SERIES X	XBOX ONE X
GPU performance	12 TFLOPS 52 CUs at 1825 MHz	6 TFLOPS 40 CUs at 1172 MHz
Memory bandwidth	560 GB/s 16 GB GDDR6 20 channels x16 (14 Gb/s)	326 GB/s 12 GB GDDR5 12 channels x32 (6.8 Gb/s)
CPU performance *	8 Hercules cores at 3.8 GHz	8 Jaguar cores at 2.3 GHz

* Relative CPU performance based on SPECint_rate_base2006 estimates using Open64 4.5.2.1-1 compiler, with testing done on preproduction systems

XBOX SERIES X SoC vs. XBOX ONE X

(Relative GPU power/W and IO)

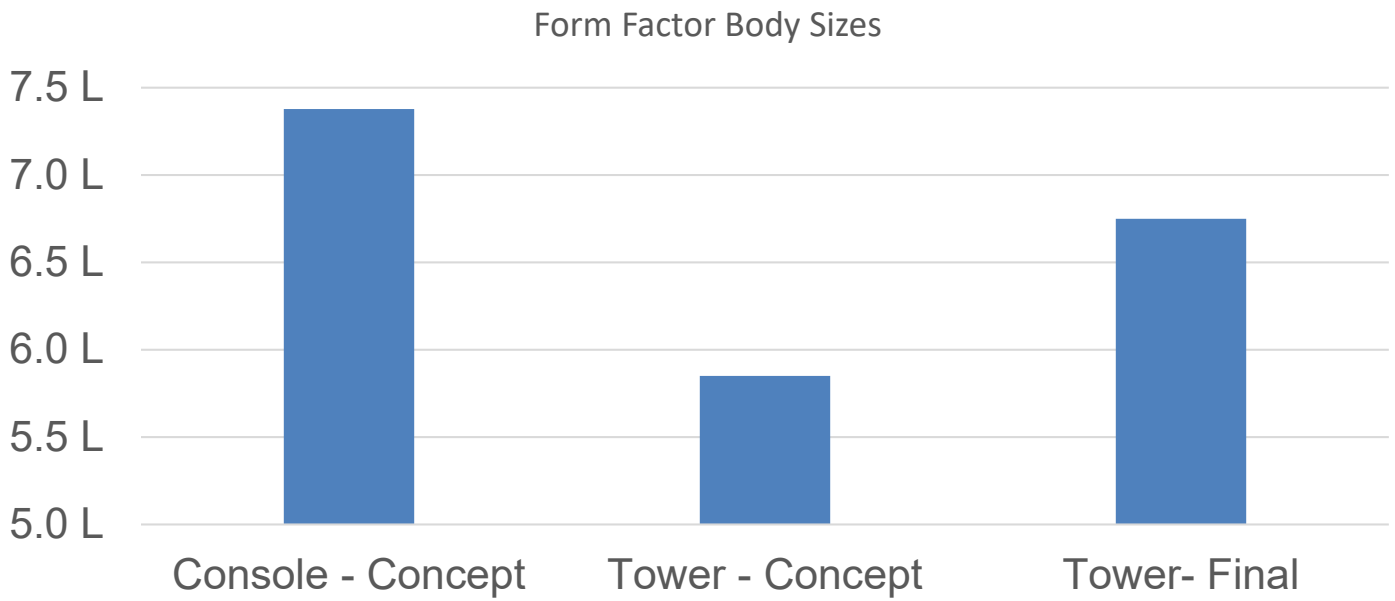


Parameter	XBOX SERIES X	XBOX ONE X
Relative GPU Performance per Watt *	2.4	1.0
PCIE bandwidth	16 GB/s 8 lanes Gen4	8 GB/s 8 lanes of Gen3

* Average across multiple popular Xbox gaming titles

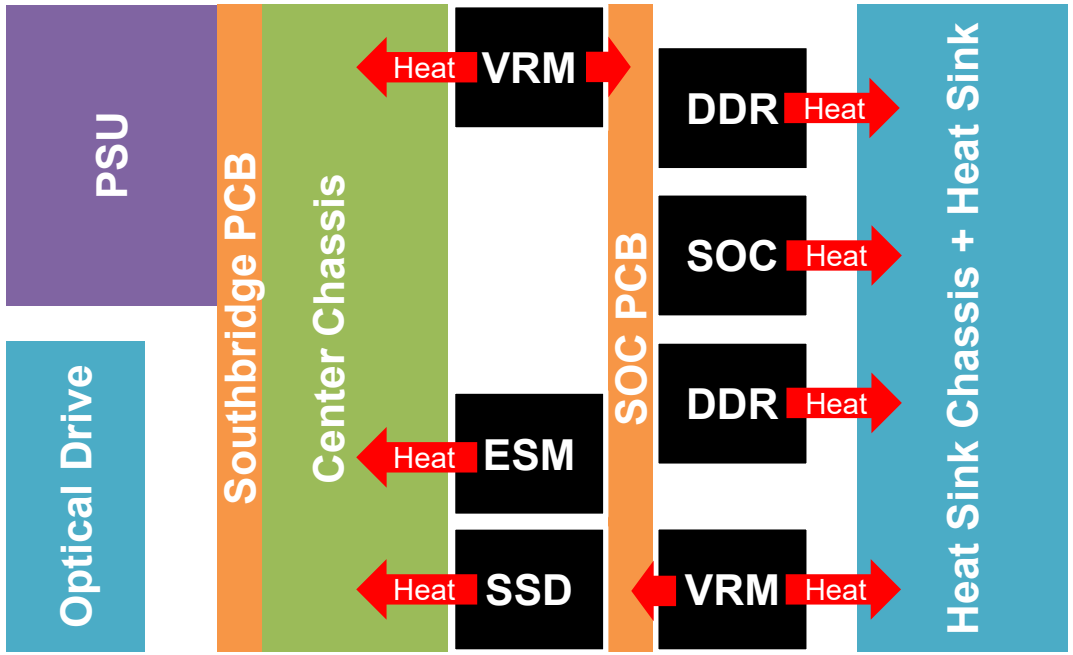
XBOX SERIES X Tower Form Factor

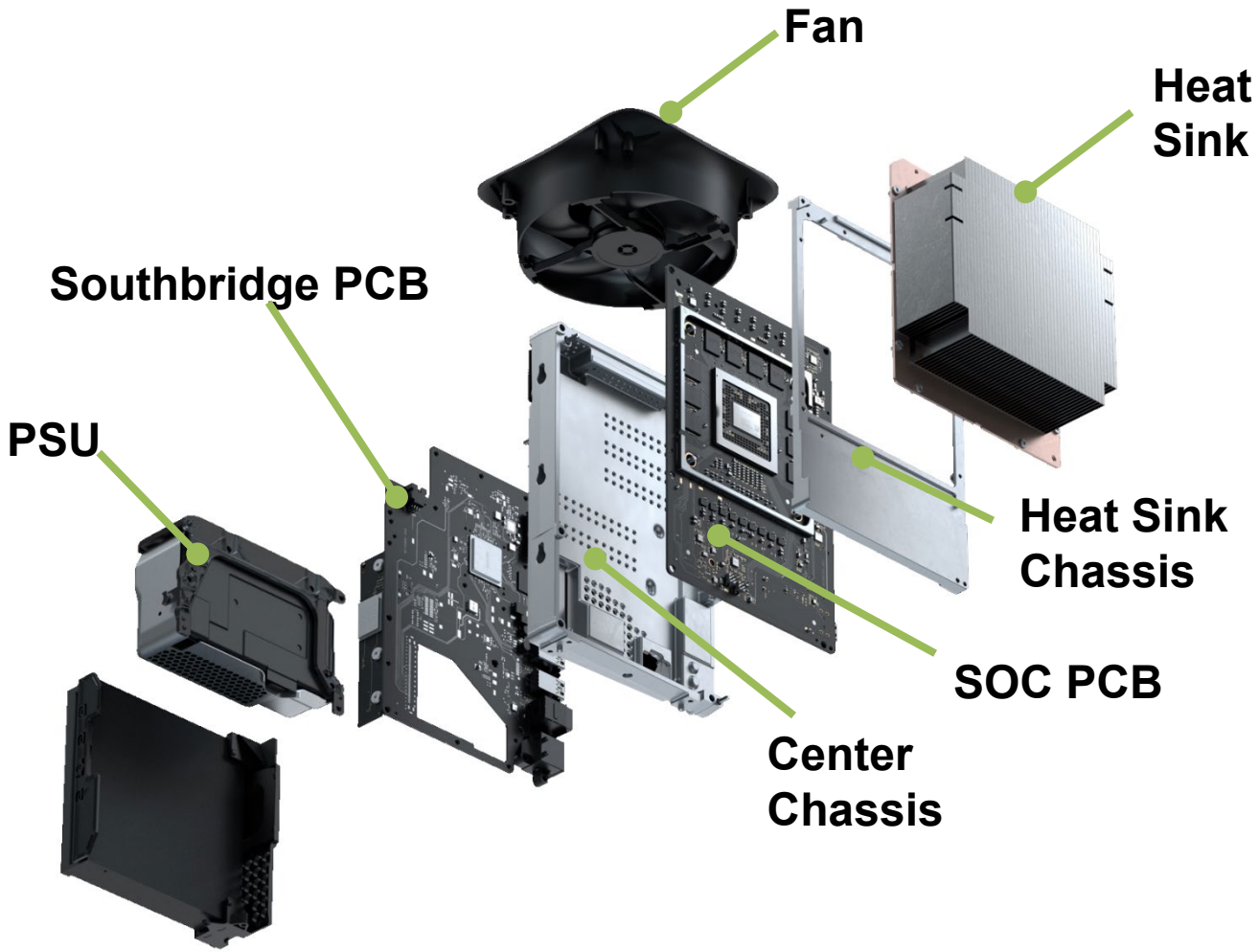
- Acoustic/Power/Thermal Challenges
  - Goal: 20% smaller than traditional console form factor
  - 15% TDP (thermal design power) increase from XBOX ONE X
  - Same acoustic dbA output spec. as XBOX ONE X
  - Stricter power compliance standards for multimedia playback



Calculated body volumes do not include feet.

XBOX SERIES X Tower Form Factor

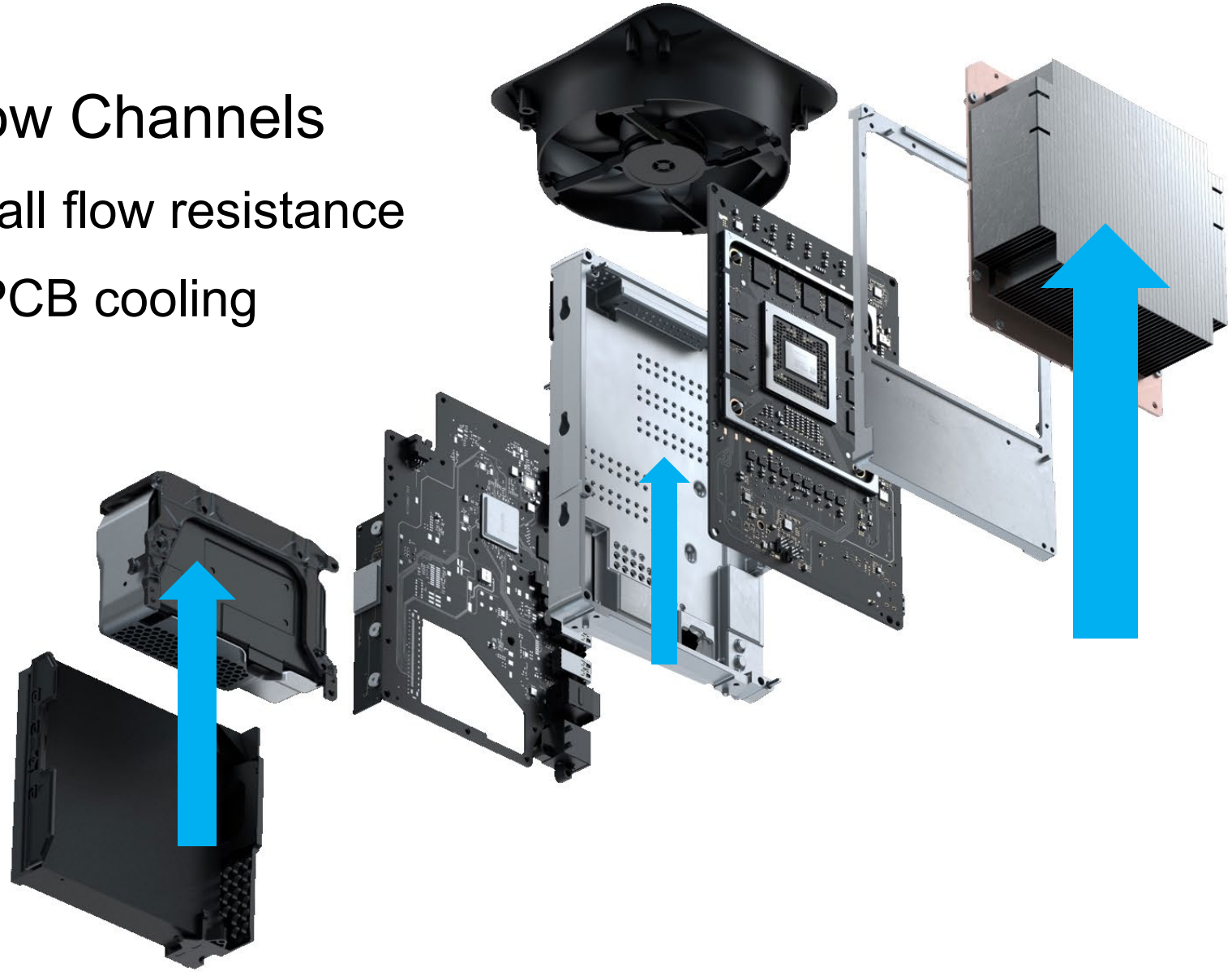


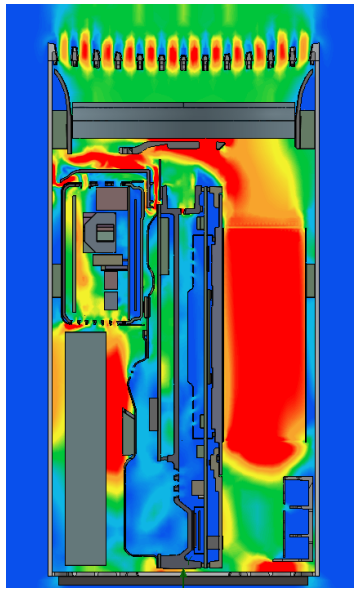


XBOX SERIES X Tower Form Factor

Parallel Airflow Channels

- Lowers overall flow resistance
- Maximizes PCB cooling





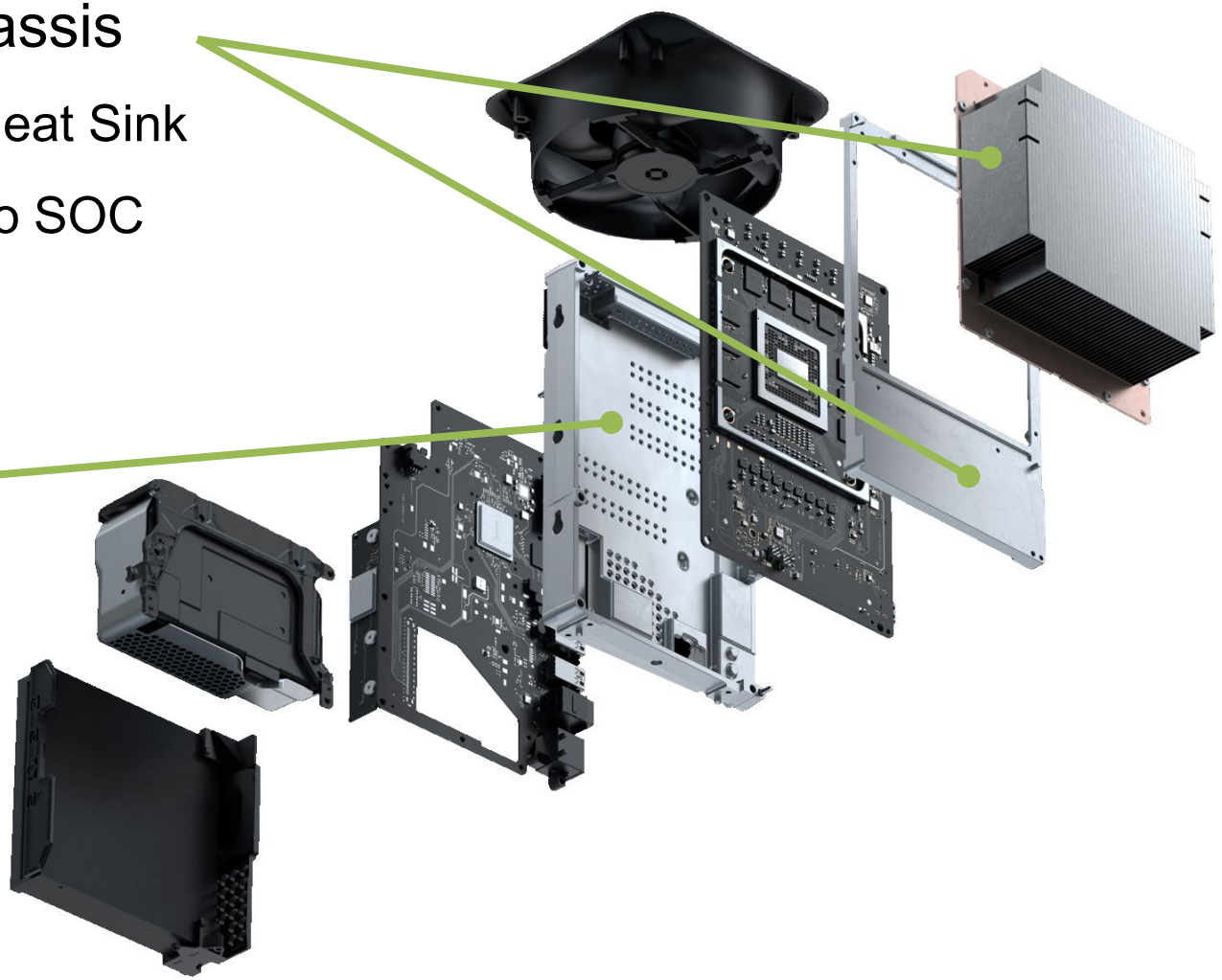
XBOX SERIES X Tower Form Factor

Vapor Chamber Heat Sink + Chassis

- 20% Improvement over HP Based Heat Sink
- Cools VRMs and DDRs in addition to SOC

Center Chassis

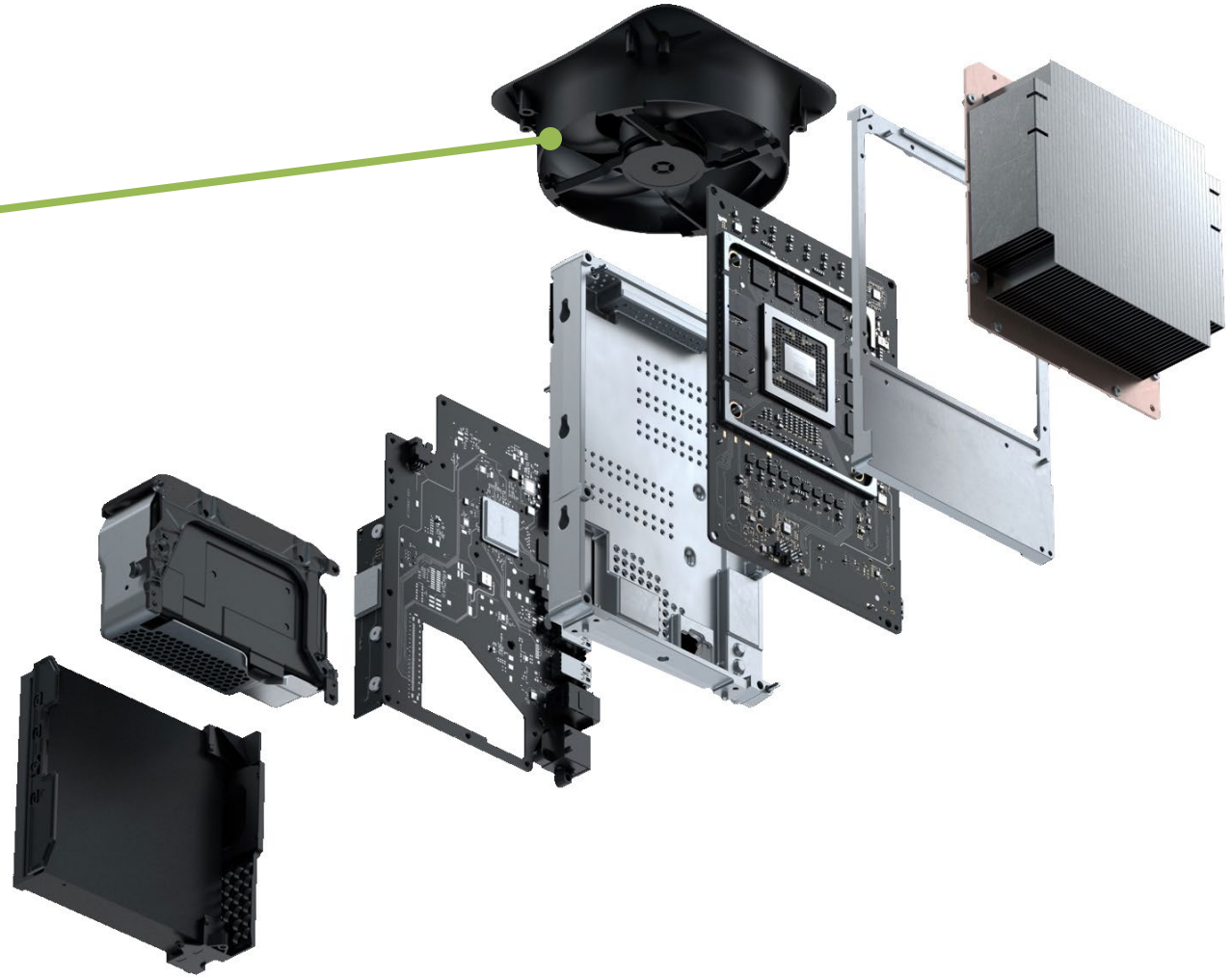
- Mechanical and EMI containment structure
- Cools VRMs, Storage Expansion Card, and SSD



XBOX SERIES X Tower Form Factor

Custom 130mm Axial Fan

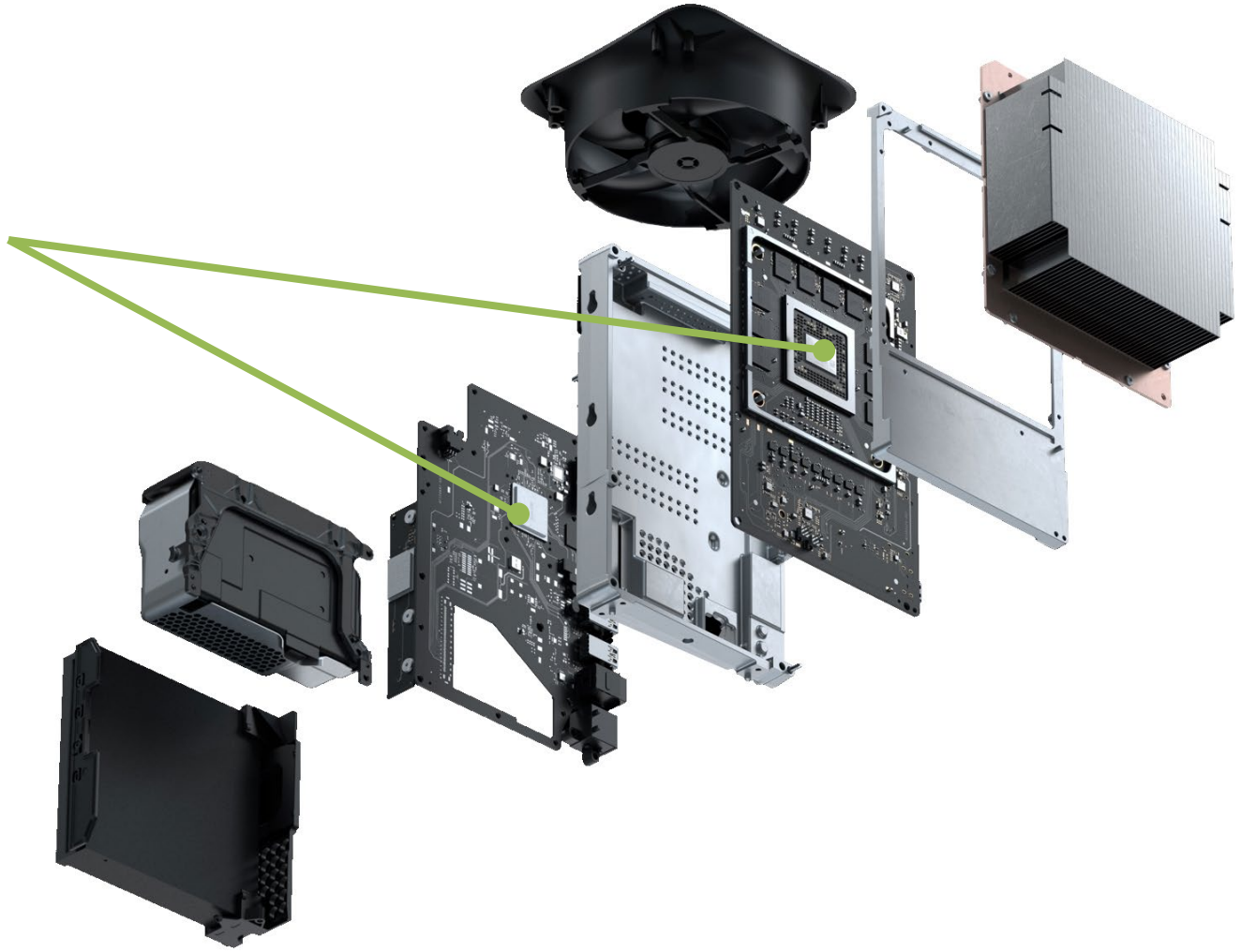
- 3-phase BLDC motor
- Optimized to reduce product acoustic noise levels with superior sound quality



XBOX SERIES X Tower Form Factor

Split Board Architecture

- Distributes heat load
- Enables a small product footprint

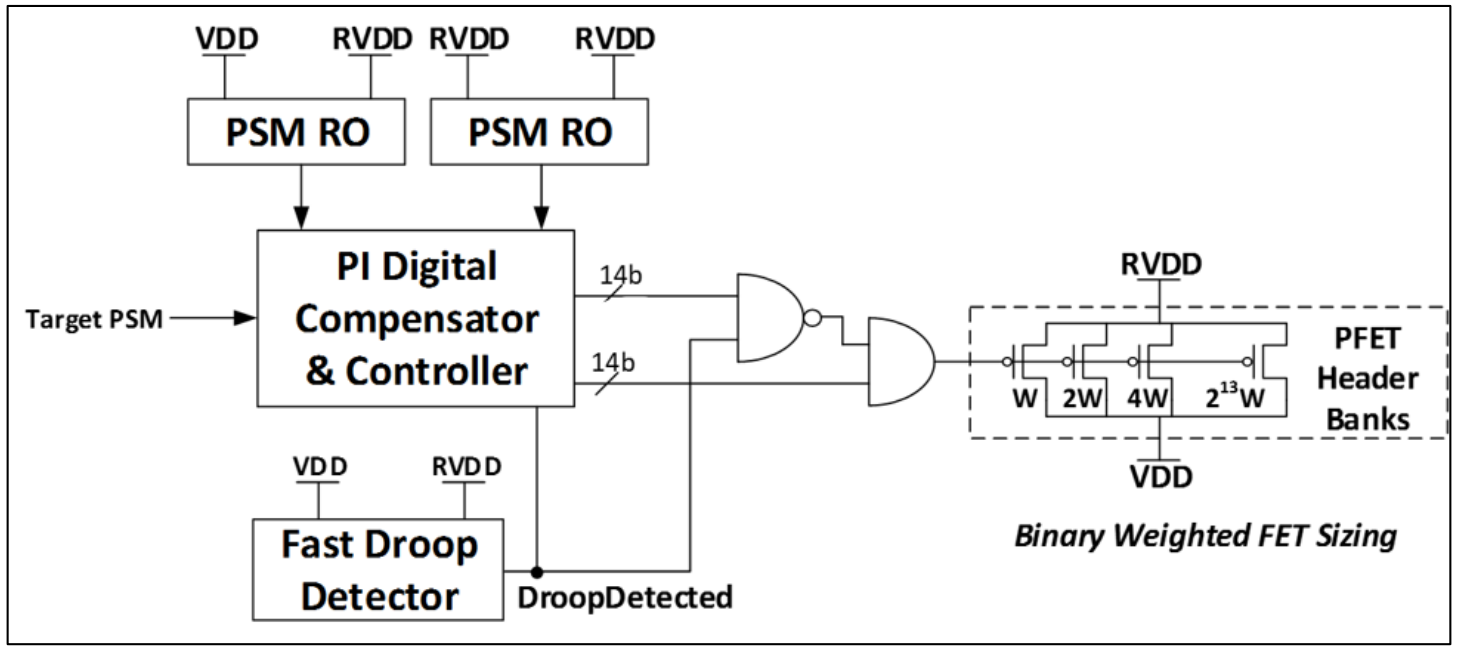


XBOX SERIES X SoC Power Mgmt. Feature List

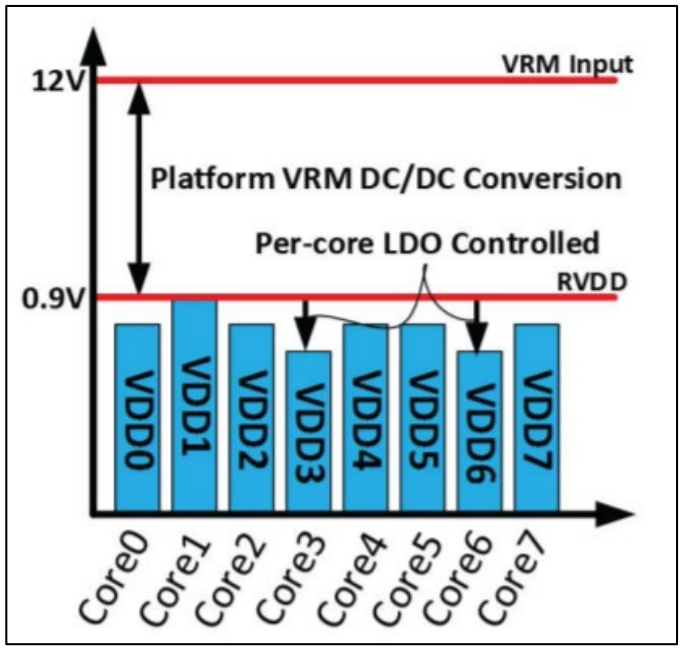
- Combined power savings of ~10% for these features
  - PSM (power supply monitor)
  - DLDO (digital low dropout regulator)
  - Fine Grained DVFS (dynamic voltage frequency scaling)
  - CLDO (chip low dropout regulator)
  - DC-BTC (direct current – boot time calibration)
- Combined power savings of ~10-15% for these features
  - Vmin search
  - Process re-centering
- Power states are used to define optimum VF points for specific operating modes

XBOX SERIES X SoC Power Management Features

- PSM (Power Supply Monitor)
  - On-chip voltage monitors to help reduce guard-bands for voltage setpoints
- DLDO (Digital Low Dropout Regulator)
  - Reduces power for CPU cores by providing a voltage-per-core



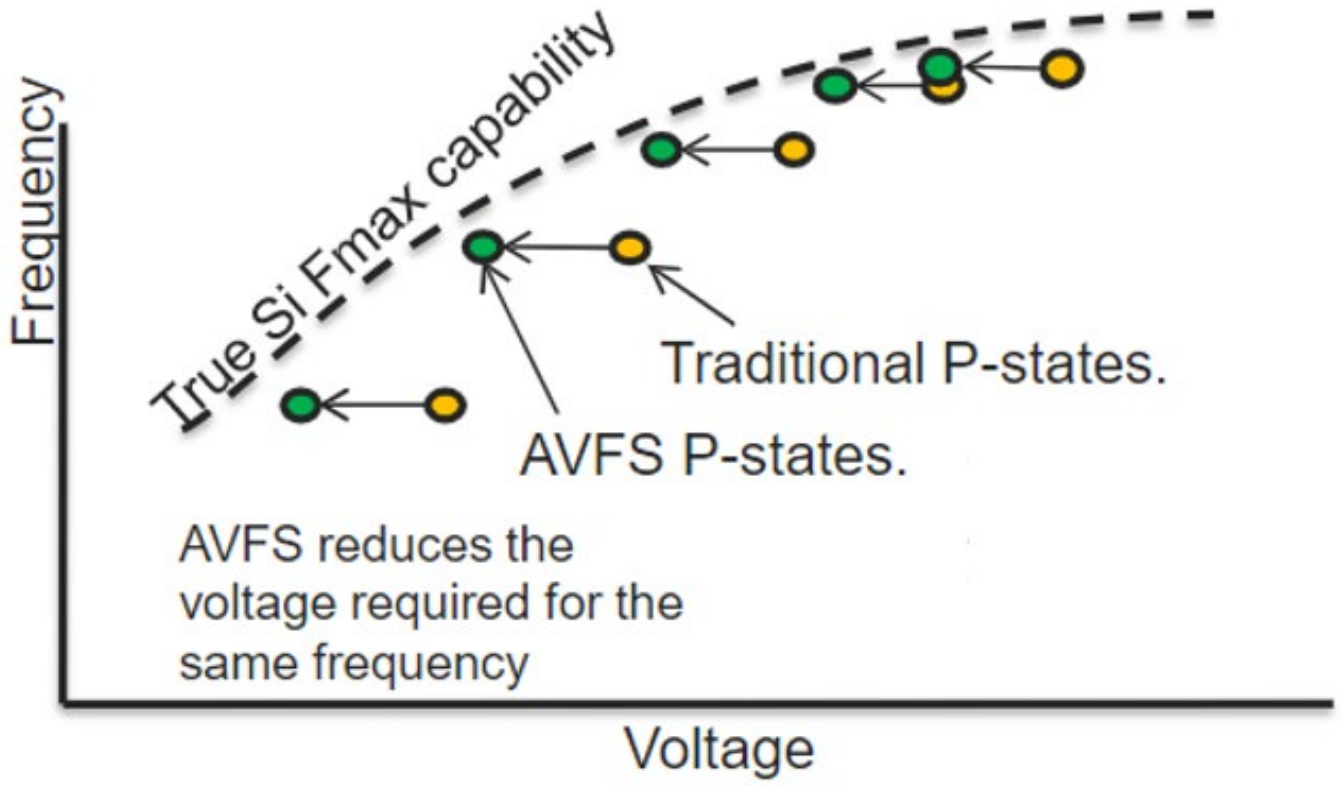
[Singh ISSCC 2017]



[Singh JSSC 2018]

XBOX SERIES X SoC Power Management Features

- Fine Grained DVFS (dynamic voltage frequency scaling)
  - VF curve optimization via per part monitoring

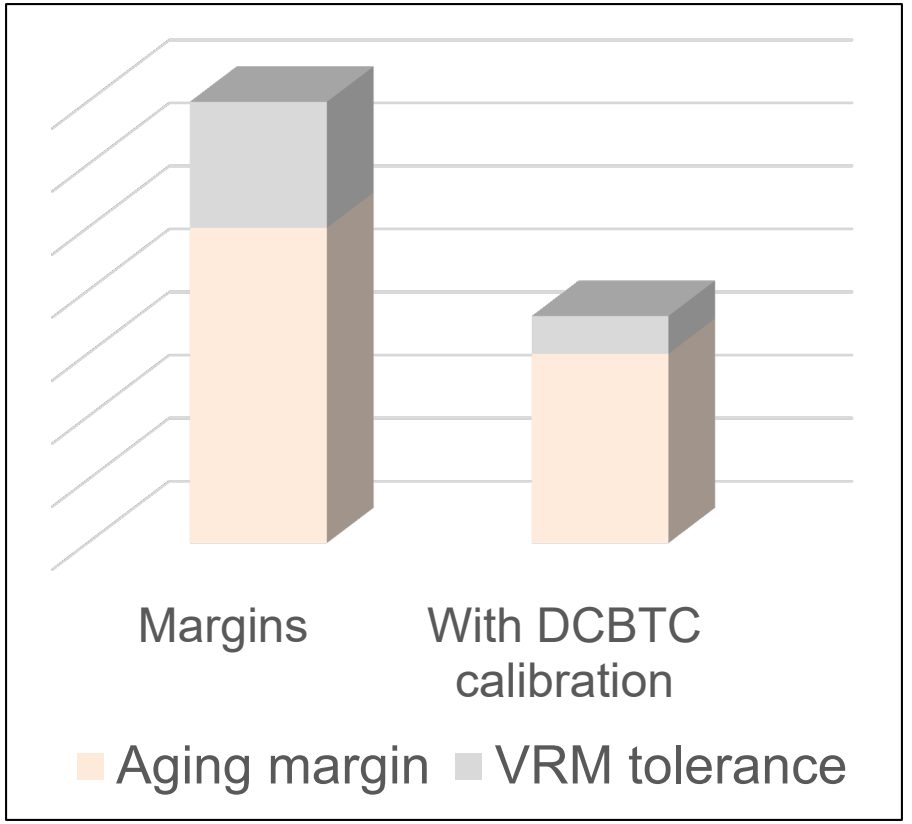


[Dasgupta ISSCC 2020]

XBOX SERIES X SoC Power Management Features

- CLDO (chip low dropout regulator)
  - Reduces power for CPU L2/L3 caches by providing a voltage-per-chip
  - Reacts to transients with low ripple noise
  - [Singh ISSCC 2020]

- DC-BTC (direct current – boot time calibration)
  - Reduces power by calibrating out effects of DC regulator voltage tolerance and aging effects of silicon

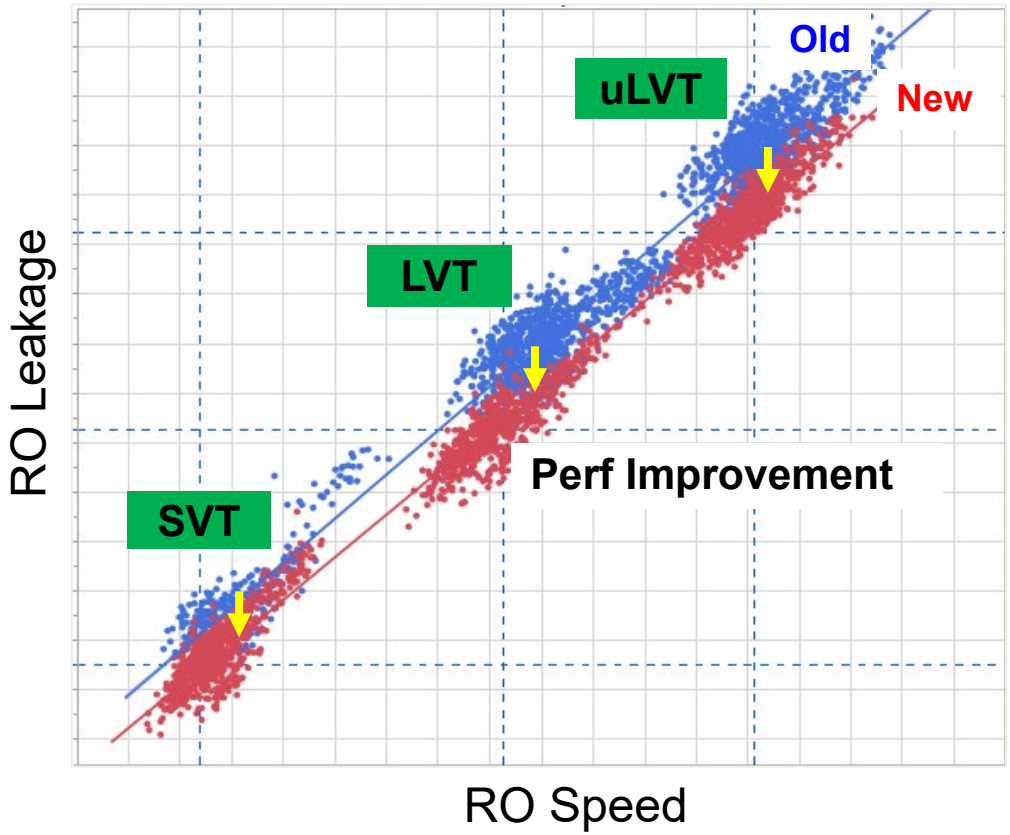


[Grenat ISSCC 2016]

Other XBOX Series X SoC Power Optimization Techniques

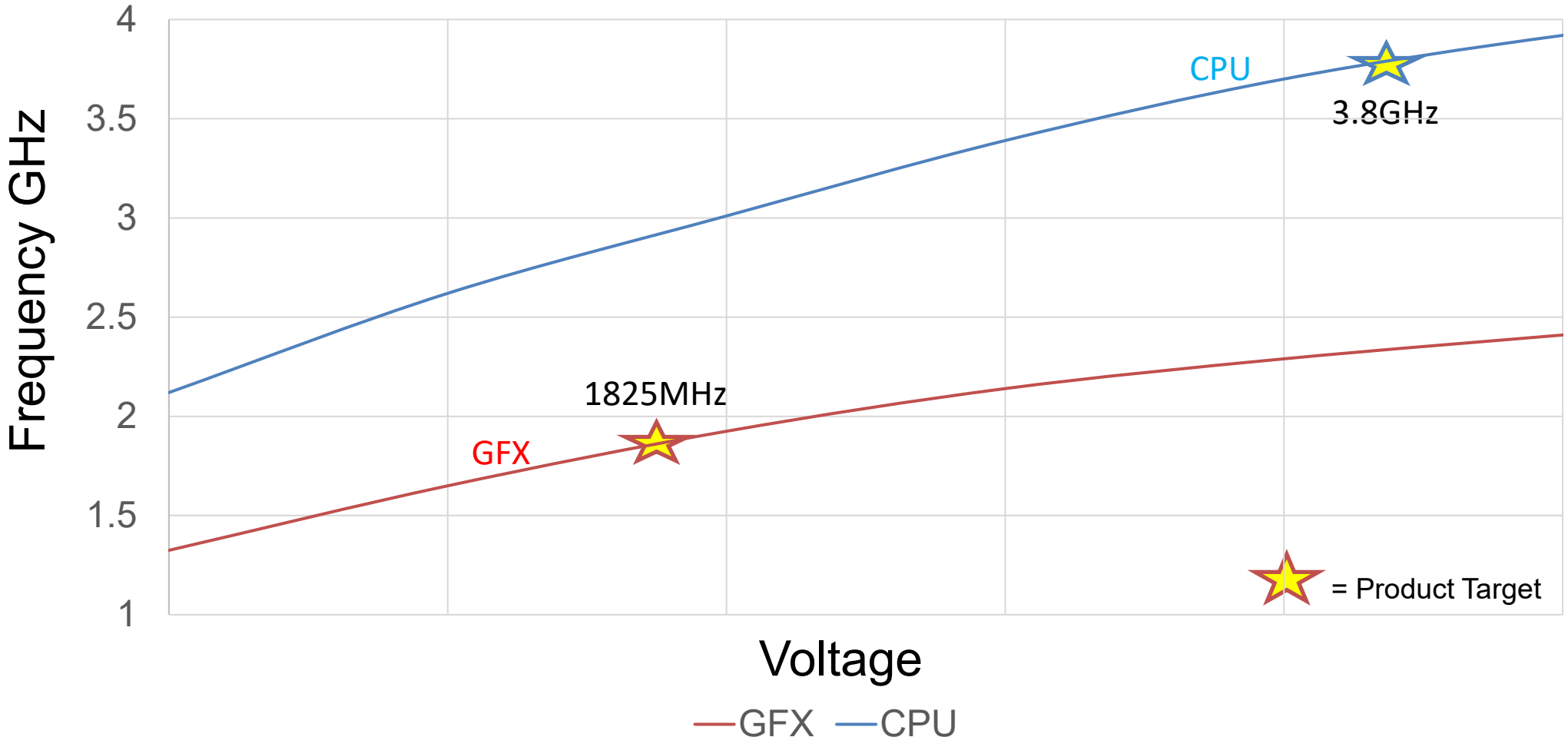
- Process re-centering
  - Adjust nominal process parameters (e.g. Vt, Idsat) to optimize for power and performance of a product
- Vmin search
  - Process of determining what the lowest voltage required is for running a stress app on a per-chip basis.
  - Set Vmin + guardband for setpoint

PROCESS BKM TARGETING OPTIMIZATION



RESULT: MAXIMIZE PRODUCT POWER PERF

XBOX SERIES X SoC Relative VF curve



XBOX SERIES X SoC Power States

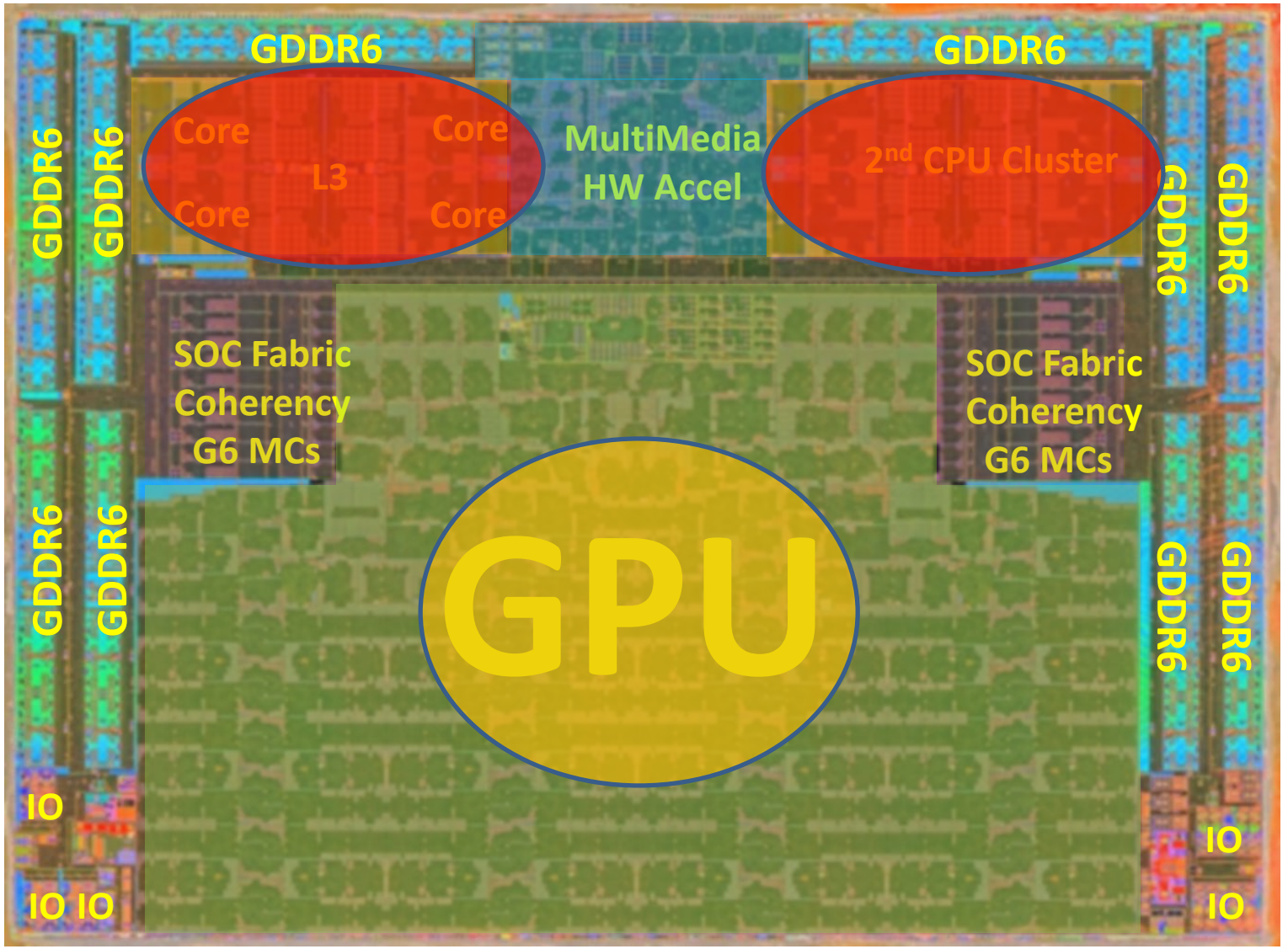
- Power state is defined as the voltage/frequency settings required to achieve a specific operating mode
- XBOX Series X has the following number of power states
  - 5 GPU pstates
  - 8 CPU pstates
  - 4 fabric pstates
  - 3 memory pstates
- Combinations of these pstates are defined for specific console operating modes

XBOX SERIES X SoC Operating Modes

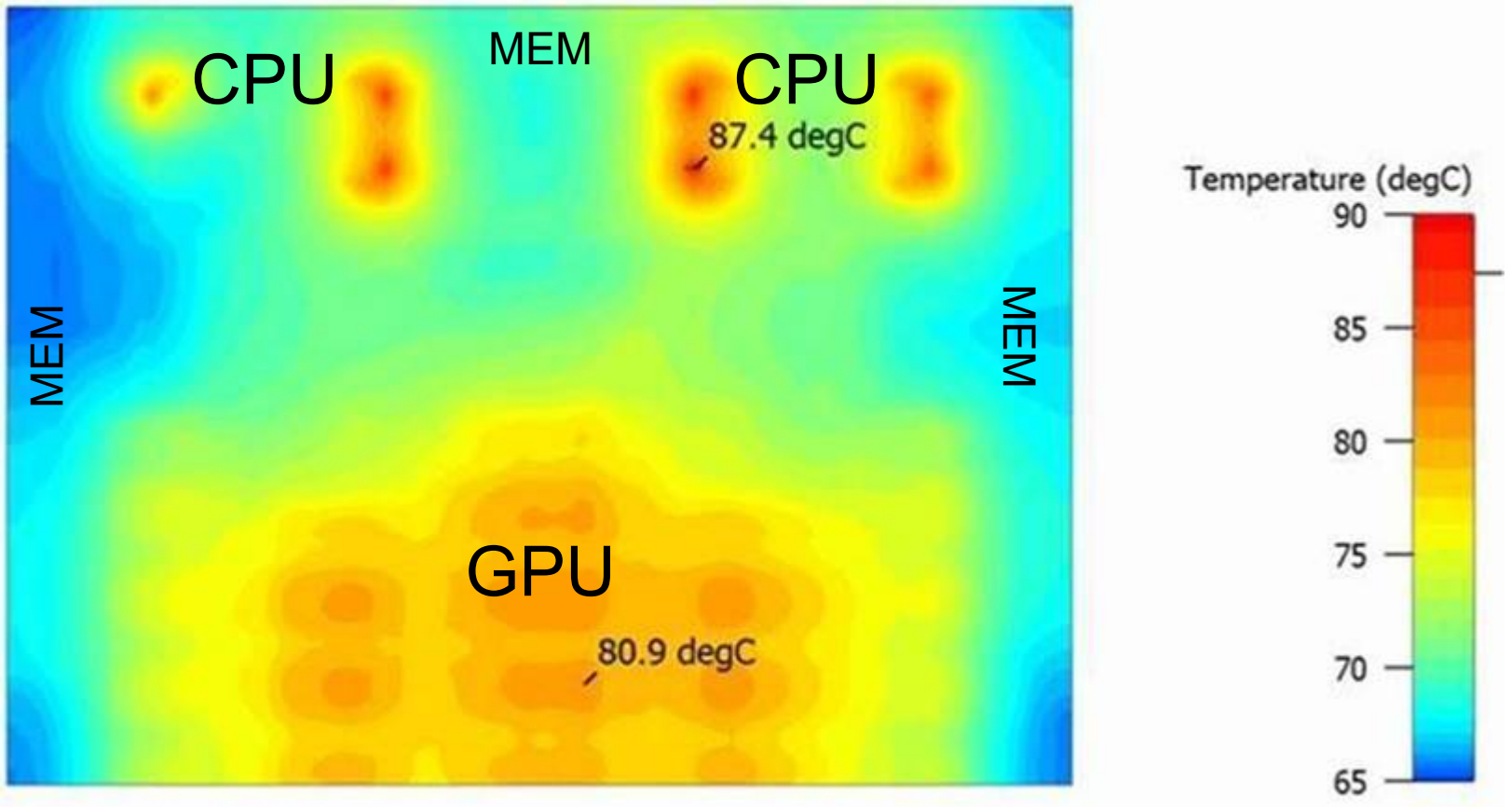
Operating mode	Relative % of game play power (SoC Only)	GPU pstate used	CPU pstate used	Fabric pstate used	Memory pstate used
Game play (up to 4Kp120)	100	P0 (max)	P0 (max) & P2 (non-SMT) P1 (SMT)	P0 (max)	P0 (max)
8Kp30 multimedia mode	27	P4 (min)	P3	P1	P1
4Kp60 multimedia mode	14	P4 (min)	P3	P2	P2
1080P multimedia mode	13	P4 (min)	P3	P2	P2
Background download	8	Off	P5	P2	P2
Connected standby	1.5	Off	P7 (min)	P3 (min)	P3 (min)
Regulatory standby	0 (SoC is powered off)	Off	Off	Off	Off

XBOX SERIES X SoC Power Density

- Acoustic specs drive the thermal constraints
- Traditionally XBOX SoC thermal control was driven by GPU Tj (junction temperature)
- XBOX SERIES X SoC did not follow that tradition.
- CPU Tj drives the thermal constraints in XBOX SERIES X
- Red (CPU) /orange (GPU) ovals denote high power/thermal density areas.

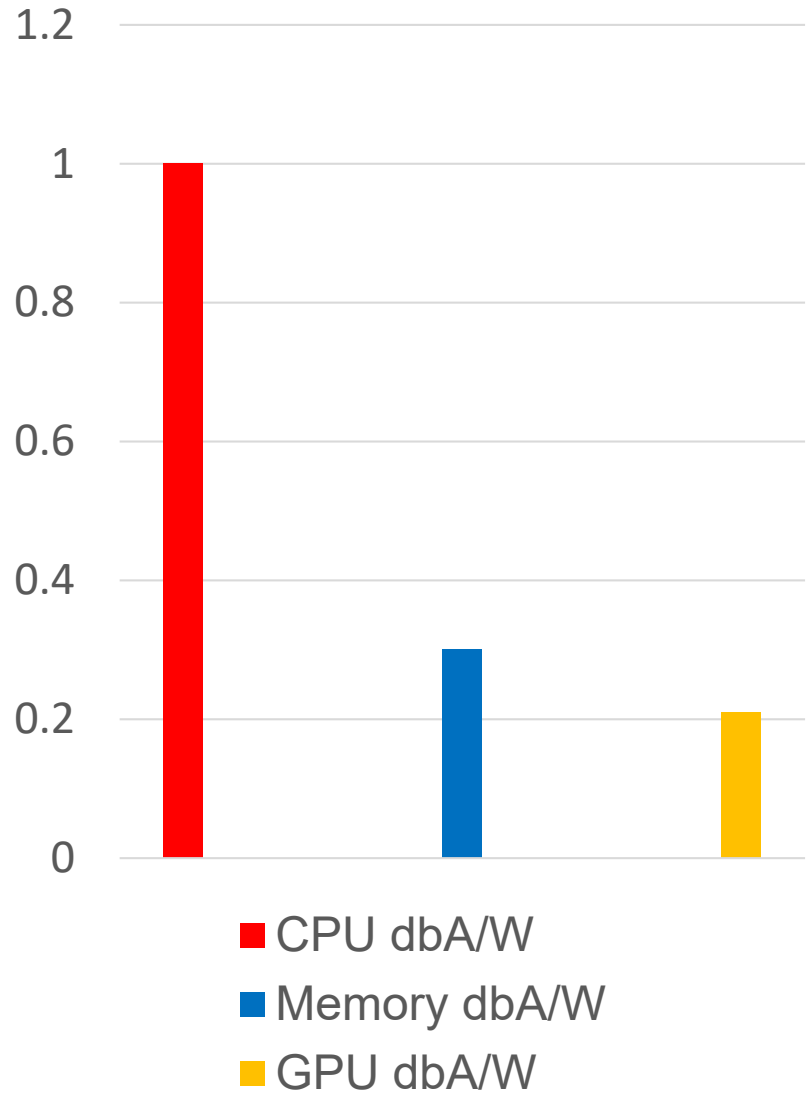


XBOX SERIES X SoC Thermal Density Map



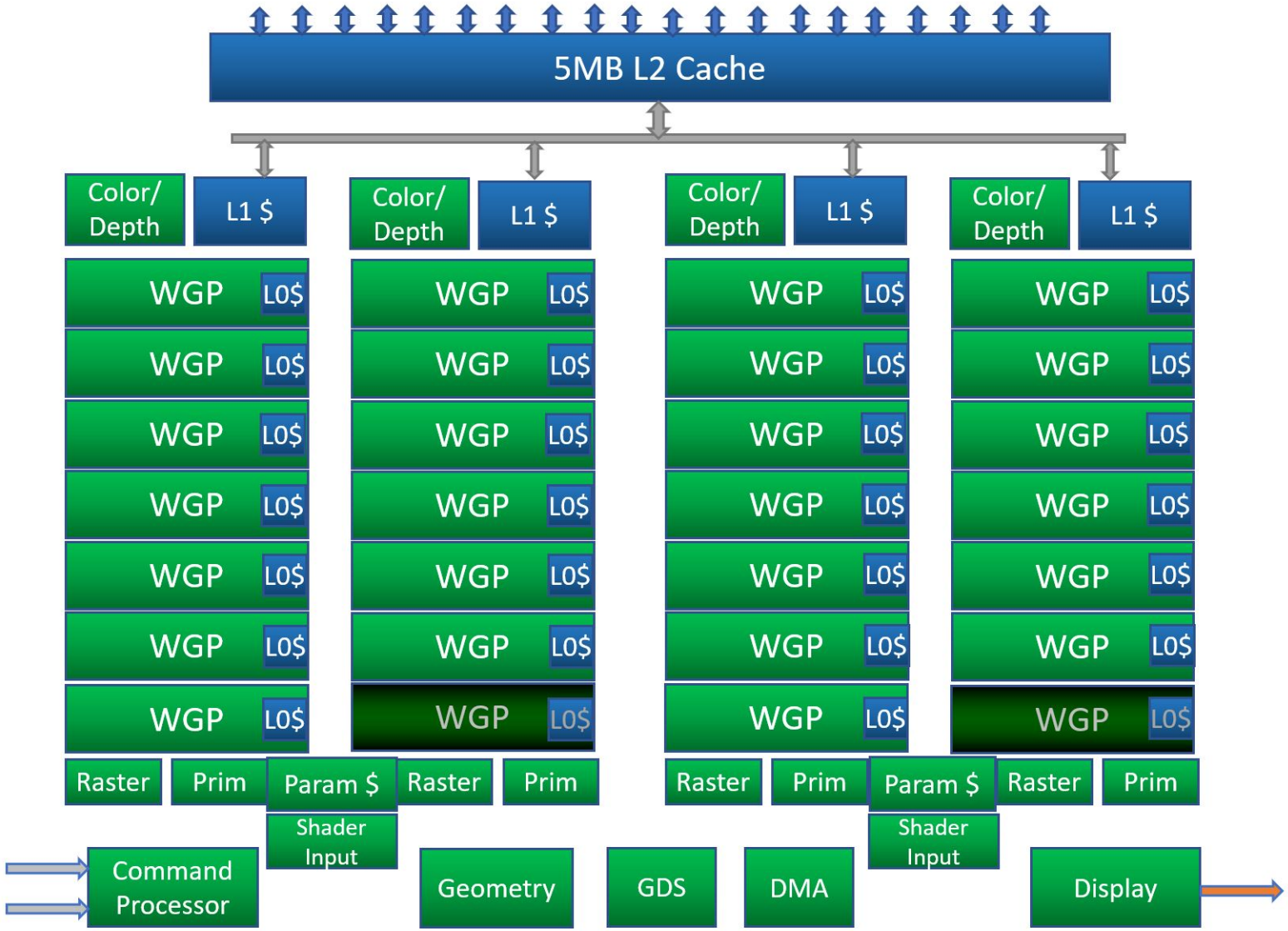
XBOX SERIES X SoC Thermal Density Disparity

- Wide disparity in relative acoustic impact per Watt of power for the different XBOX SERIES X SoC components
- To achieve acoustic goals – a tradeoff was made between thermal and CPU performance
- That frequency reduction reduces the worst-case CPU power such that acoustics can be maintained.

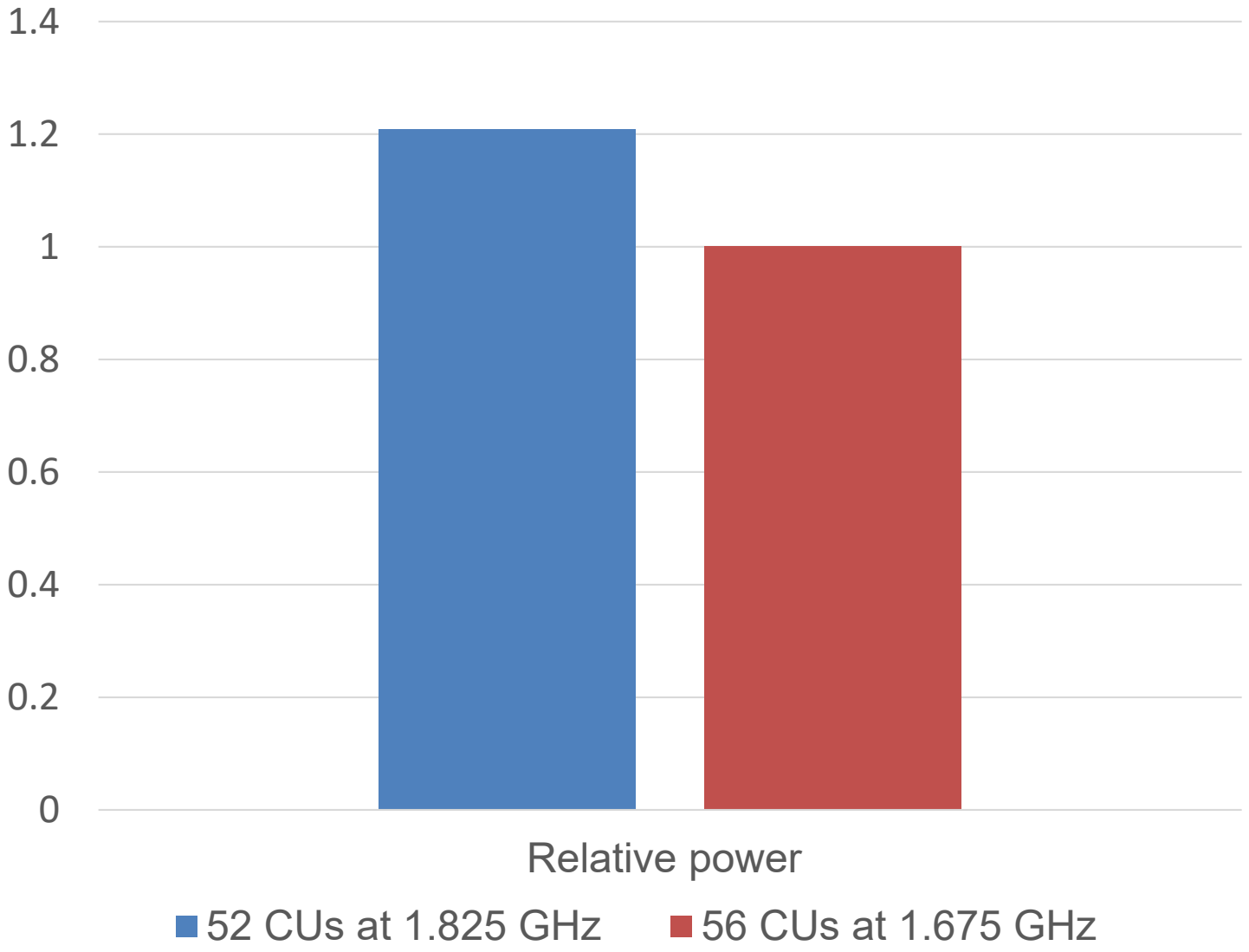


XBOX SERIES X SoC GPU compute flexibility

- Flexibility in configuring # of WGPs allows for tradeoffs of yield and power across multiple uses.
- XBOX cloud gaming can use >= 24 WGPs
- XBOX console gaming can use 26 or 28 WGPs



XBOX SERIES X SoC WGP Power Ratio



- 12 TFLOPS is achieved with either
  - 28 WGPs operating at 1.675 GHz
  - 26 WGPs operating at 1.825 GHz
  - 26 WGPs used for console operating point for optimized yield

Conclusions

- XBOX SERIES X SoC offers significant performance improvements over XBOX ONE X SoC
  - 2x GPU performance, 2.4x GPU performance/Watt, 3x CPU performance,
  - 1.7x memory bandwidth and 2x raw IO bandwidth performance

- XBOX SERIES X Console Tower Form Factor posed several challenges
  - Smaller than traditional console form factor
  - Modest 15% TDP increase allowed from XBOX ONE X
  - Same acoustic dbA output spec. as XBOX ONE X
  - Stricter power compliance standards for multimedia playback

- Power management features and compute flexibility enabled acoustic/thermal goals to be met
  - Features - PSM, DLDO, Fine Grained DFVS, CLDO, DC-BTC, Vmin search, process re-centering and power states
  - Flexibility - Configurable GPU WGP settings (24, 26, 28 WGPs)