Making immersive virtual reality possible in mobile

Qualcomm Technologies, Inc.
Agenda

1. Virtual reality will provide the ultimate level of immersion
2. Technologies and ecosystem are aligning for VR
3. VR has extreme requirements for visual quality, sound quality, and intuitive interactions
4. Qualcomm Technologies, Inc. (QTI) is uniquely positioned to support superior mobile VR experiences
Virtual reality will provide the ultimate level of immersion

Offering unprecedented experiences and unlimited possibilities
Immersive Experiences

Experiences worth having, remembering, and reliving

• Draw you in...
• Take you to another place...
• Keep you present in the moment...
Achieving full immersion
Simultaneously focusing on three key pillars:
- Visual quality
- Sound quality
- Intuitive interactions
VR will provide the ultimate level of immersion
Creating physical presence in real or imagined worlds

**Visuals**
So vibrant that they are eventually indistinguishable from the real world

**Sounds**
So accurate that they are true to life

**Interactions**
So intuitive that they become second nature
VR will be the new paradigm for how we interact with the world.
Offering unprecedented experiences and unlimited possibilities.

**Experiences in VR**

**Play**
- Immersive movies and shows
- Live concerts, sports, and other events
- Interactive gaming and entertainment

**Learn**
- Immersive education
- Training and demos
- 3D design and art

**Communicate**
- Social interactions
- Shared personal moments
- Empathetic storytelling
Play
Live sports experience
Communicate

Recital experience
Virtual reality is not augmented reality

Similar underlying technologies but distinct experiences

Virtual reality
Simulates physical presence in real or imagined worlds, and enables the user to interact in that world

Augmented reality
Superimposes content over the real world such that the content appears to a viewer to be part of the real-world scene
Technologies and ecosystem are aligning for VR

Mobile technologies are accelerating VR adoption
The time is right for VR
Technologies and ecosystem are now aligning

Ecosystem drivers

- Device availability
- Software infrastructure
- Content creation and deployment

Technology advancements

- Multimedia & AI technologies
- Display and sensor technologies
- Power and thermal efficiency
VR headsets are becoming available
Mobile VR headsets will drive mass adoption and provide the freedom to enjoy VR anywhere

Mobile VR headsets
Smartphone powered
• Smartphone plugs into or connects to the headset
• Mobile SoC powers VR experience

Standalone
• Dedicated headset optimized for VR
• Mobile SoC powers VR experience

Tethered VR headsets
PC or game console controlled
• Headset connects by wire to a PC or game console
• Desktop-class CPU and GPU power the VR experience

Continuum of VR experiences
The software infrastructure and tools are ready
A solid foundation exists and momentum is building

Tools and SDKs to generate, debug, and optimize content, such as:
- Google Cardboard SDK, Oculus Mobile SDK, Qualcomm® Snapdragon™ VR SDK
- 360° video processing tools

OS optimizations to better manage device resources
- Hardware, software, and peripherals

Optimized middleware
- Gaming engines like Unity and Unreal Engine
- Audio engines and libraries
- 360° video players

Optimized low-level drivers for VR requirements
- System-level latency reduction
- Peripheral tuning
- API acceleration

Software stack optimized for VR
Content is being generated and deployed
Content developers are experimenting with VR and see its potential as a new medium.

Content generation

Games and apps
- Finding the killer apps through experimentation
- A variety of compelling experiences already exist, from first person shooters to virtual chat rooms, education, and 3D sculpting

Video
- Cinematic VR, such as the life of a refugee or a concert
- Broadcast TV, such as the presidential debate, sports events, and comedy shows
- User generated content
- Premium streaming video providers, such as Netflix and Hulu

Content distribution

App stores
- App aggregation and distribution through stores, such as:
  - Google Play Store with Google Cardboard apps
  - Oculus Store and Oculus Share
  - HTC Viveport app store

Video distribution
- Upload and stream video from places, such as:
  - YouTube 360
  - 360 video on Facebook
Exponential technology advancements are making VR possible

**Multimedia technologies**
- Graphics processing
- Audio processing
- Video processing

**Display and sensor technologies**
- Displays with increased pixel density, power efficiency, and visual quality
- Smaller, lower power, and lower cost sensors without sacrificing accuracy

**Power and thermal efficiency**
- Architecture innovations, such as heterogeneous computing
- Optimized algorithms
- Integration efficiency, including better transistors
The mobile industry is accelerating VR adoption

**Scale**
Innovation at scale and cost advantage

**Rapid design cycles**
Fast adoption of cutting edge technologies

**Mass adoption**
Broad appeal for mainstream consumers
Immersive virtual reality has extreme requirements

Qualcomm® Snapdragon™ 845 processor is ideal for mobile VR
Immersive virtual reality has extreme requirements
Achieving full immersion at low power to enable a comfortable, sleek form factor

- Extreme pixel quantity and quality
  Screen is very close to the eyes

- Spherical view
  Look anywhere with a full 360° spherical view

- Stereoscopic display
  Humans see in 3D

- Visual quality

- Sound quality
  High resolution audio
  Up to human hearing capabilities
  3D audio
  Realistic 3D, positional, surround audio that is accurate to the real world

- Intuitive interactions
  Precise motion tracking
  Accurate on-device motion tracking

- Minimal latency
  Minimized system latency to remove perceptible lag

- Natural user interfaces
  Seamlessly interact with VR using natural movements, free from wires
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Natural user interfaces
Seamlessly interact with VR using natural movements, free from wires
Extreme pixel quantity and quality are required

The screen is very close to the eyes and a 360° spherical view is necessary

**Field of view (FOV)**
- For immersive VR, our entire FOV needs to be the virtual world
- Each human eye has ~145° horizontal FOV
- The fovea of the eye can see ~60 pixels per degree (PPD) but comprises less than 1% of the retinal size
- To look anywhere in the virtual world, VR needs to provide full 360° spherical view

**Screen-door effect**
- As the device is brought closer to your eyes, the screen takes up more of your FOV
- Biconvex lenses magnify the screen further and make the virtual world your entire FOV
- As the screen takes up more of your FOV, pixel density must increase
- Otherwise, you will see individual pixels - the screen door effect
Foveated rendering significantly reduces pixel processing

The human eye can only see high resolution where the fovea is focused

- Rather than rendering with high resolution throughout an image, just render high where the eye is fixated.
- The GPU renders a small rectangle at a high resolution and the rest of the FOV at a lower resolution.
- Foveated rendering will help minimize power, while improving performance and visual quality.
Lens correction for improved visual quality

Fixing lens distortion and chromatic aberration

**Lens distortion**

**Problem:** A wide-angle biconvex lens creates a pincushion distortion

**Solution:** Barrel warp compensates for pincushion distortion

- Rendered image
- Pincushion distortion
- Warped image
- Barrel-warped image
- Pincushion distortion
- Rendered image

**Chromatic aberration**

**Problem:** After passing through the lens, colors are focused at different positions in the focal plane.

**Solution:** Image processing compensates for chromatic aberration. The GPU parameters are determined through lens characterization.

- Rendered image
- Out of focus
- Chromatic correction
- In focus
- Corrected image
360° spherical view: Look anywhere
Generating and consuming 360° spherical video

VR headsets need to support multiple 360° spherical video formats

Generate video

- Simultaneously capture video with multiple cameras from different views to generate 360° spherical video. Stereoscopic video doubles the number of cameras
- Undistort, stitch together, and map the discrete images to an equirectangular or cube map format
- Encode video

Playback video

- Decode video
- Based on format, apply an equirectangular or cube map UV projection
- Determine pose and show appropriate view of 360° spherical video
Stereoscopic display to see the world in 3D
Binocular vision helps the brain determine depth

- Each eye rotates and focuses to see an object clearly, resulting in slightly different viewpoints.
- Based on the different viewpoints and by knowing the interpupillary distance, the brain determines depth.
- This stereoscopic effect makes the VR experience more immersive.
- For VR, we need to generate the appropriate view for each eye

Stereoscopic visuals

Interpupillary distance

Image shift

Need to generate left and right eye image appropriately
Accurate and efficient stereoscopy for realistic visuals

**Graphics**
- OpenGL ES multiview extension support
- A single draw call generates triangles for both eyes
- Driver and app overhead is reduced

**Video**
- For stereoscopic video, support of the multiview extension of HEVC codec
- Approximately 2X the decode work since there is a video stream per eye
- For monoscopic video, the same image is shown to both eyes, shifted for binocular disparity
Immersive virtual reality has extreme requirements

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- **Spherical view**
  Look anywhere with a full 360° spherical view

- **Stereoscopic display**
  Humans see in 3D

- **Minimal latency**
  Minimized system latency to remove perceptible lag

- **Natural user interfaces**
  Seamlessly interact with VR using natural movements, free from wires

- **Intuitive interactions**

- **Immersion**

- **Visual quality**

- **Sound quality**

  - **High resolution audio**
    Up to human hearing capabilities
  
  - **3D audio**
    Realistic 3D, positional, surround audio that is accurate to the real world

- **Precise motion tracking**
  Accurate on-device motion tracking
3D positional audio for realistic sound

Accurate 3D surround sound based on your head’s position relative to various sound sources

• Sound arrives to each ear at the accurate time and with the correct intensity
• HRTF (head related transfer function):
  o Takes into account typical human facial and body characteristics, like location, shape, and size of ears.
  o Is a function of frequency and three spatial variables.
• Sound appropriately adjusts dynamically as your head and the sound sources move
Reverberation for realistic sound
Sound reflections spread and interact with the environment appropriately

- Reverberation is a function of sound frequency, material absorption, room volume, and room surface area.
- Different rooms reflect and absorb sound differently, such as a hallway or cave versus an open space.
- Accurate reverberation makes the experience more immersive.
Qualcomm® Snapdragon™ 845 processor provides realistic sound quality for VR
Processing performance at low power and low latency

- **High fidelity audio**
  - 24-bit at 192 kHz
  - Real-time convolutional reverb
  - 18 ms playback

- **3D positional audio**
  - Support next-gen codecs, like MPEG-H 3D Audio and Dolby Atmos
  - HRTF support

- **Noise filtering**
  - Fluence™ noise filtering
  - Active noise cancellation

- **Qualcomm® Hexagon™ DSP**
  - High performance at low power
  - Low latency
  - CPU offload
  - Customer algorithms
Immersive virtual reality has extreme requirements
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    - Seamlessly interact with VR using natural movements, free from wires
Precise motion tracking of head movements

For accurate and intuitive interactions with the virtual world

3 degrees of freedom (3-DOF)
• “In which direction am I looking”
• Detect rotational movement
• Main benefit: look around the virtual world from a fixed point

6 degrees of freedom (6-DOF)
• “Where am I and in which direction am I looking”
• Detect rotational movement and translational movement
• Main benefit: move freely in the virtual world and look around corners
Achieving precise head motion tracking on the device
Visual inertial odometry (VIO) for rapid and accurate 6-DOF pose

Monocular camera data
Captured from tracking camera image sensor at ~30 fps

Accelerometer and gyroscope data
Sampled from external sensors at 800 / 1000 Hz

Snapdragon “VIO” subsystem

Camera feature processing

Inertial data processing

Hexagon DSP algorithms
- Camera and inertial sensor data fusion
- Continuous localization
- Accurate, high-rate “pose” generation & prediction

6-DOF position and orientation (aka “6-DOF pose”)
Minimizing motion to photon latency is crucial for immersion.

Lag prevents immersion and can cause discomfort.
An end-to-end approach is required to minimize latency
Many workloads must run efficiently for an immersive VR experience

Motion detection
Sensor sampling and fusion
Head pose generation

Visual processing
View generation
Render / decode

Display
Adjustment to latest pose (time warp)
Quality enhancement and display

“Motion” Total time (motion to photon latency) for steps must be less than 20 milliseconds

“Photon” (new pixels’ light emitted from the screen)
VR content requires an enhanced wireless connection
High bandwidth connectivity to share and consume VR content

Wireless connection

Higher bandwidth required

VR
360° spherical
Stereoscopic
Higher resolution
HDR

Non-VR
Fixed view
Monoscopic
Up to 4K
Great connectivity is the foundation of mobile experiences

The Qualcomm® Snapdragon™ 845 processor provides connectivity at high bandwidth and low latency.

Advanced 4G LTE
- Up to 1.2 Gbps downlink
- Up to 150 Mbps uplink
- Support for LAA

Advanced Wi-Fi
- 11ac MU-MIMO
- 11ad Wi-Fi
- Seamless access across bands

Advanced LTE/Wi-Fi convergence
- LTE + Wi-Fi aggregation
- Antenna sharing
- Advanced antenna design
Taking VR experiences to the next level with 5G
Continued 4G LTE advancements on the path to a more capable 5G platform

Enjoy VR experiences everywhere

At home, at work, at school, in the car, at the airport, ...

Share real-time, interactive experiences

Events, meetings, telepresence, ...

Extreme throughput
multi-gigabits per second

Ultra-low latency
down to 1ms latency

Uniform experience
with much more capacity

All while supporting new levels of cost and energy efficiency

Learn more about our vision for the future of mobile networks: www.qualcomm.com/5G
Power and thermal efficiency for VR tasks is essential

The VR headset needs to be comfortable to wear for extended periods

VR workloads
Compute intensive
Diverse characteristics

Constrained mobile wearable environment
Sleek, ultra-light
Long battery life
Thermal efficiency
A heterogeneous computing approach is needed for VR
Snapdragon 845 utilizes specialized engines across the SoC for efficient processing

Virtual reality
Computer vision, image processing, sensor processing, graphics, video processing, location, and cloud interaction

Entire SoC is used!

Qualcomm Spectra, Qualcomm Snapdragon, Qualcomm Adreno, Qualcomm Hexagon, and Qualcomm Kryo are products of Qualcomm Technologies, Inc.
Qualcomm® Snapdragon™ 845 processor is ideal for mobile VR

Designed to meet the VR processing demands within the thermal and power constraints

Smooth, 3D stereoscopic, foveated rendering, & support for the latest GPU APIs

Low power 360° 4K HEVC video decoding & display

Qualcomm® TruPalette™ display gamut mapping, color enhancement, etc.

Qualcomm Low-Power Picture Enhancement compression, variable refresh, etc.

Visual quality

Immersion

Intuitive interactions

Sound quality

Positional audio & 3D surround sound

Fluence™ noise filtering & active noise cancellation

Low level DSP access & tools for custom audio development

Integrated dual-camera ISP + DSP for low power 3D reconstruction & predictive 6-DOF motion tracking

Ultra-fast sensing for minimal motion to photon latency

Smooth, 3D stereoscopic, foveated rendering, & support for the latest GPU APIs

Low power 360° 4K HEVC video decoding & display

Qualcomm® TruPalette™ display gamut mapping, color enhancement, etc.

Qualcomm Low-Power Picture Enhancement compression, variable refresh, etc.

Qualcomm® Adreno™ Visual Processing | Qualcomm Spectra™ ISP | Qualcomm® Hexagon™ DSP

Qualcomm Artificial Intelligence Engine | Qualcomm Aqstic™ audio | Qualcomm Snapdragon VR SDK | Snapdragon tools
Qualcomm® Snapdragon™ VR SDK
Access to advanced VR features to optimize applications and simplify development

Benefits:
- Simplified development
- Optimized VR performance
- Power and thermal efficiency

DSP sensor fusion
Access to the latest and predictive head pose

Stereoscopic rendering
Generate left and right eye view

Asynchronous time warp
Warp image based on the latest head pose just prior to scan out

Single buffer rendering
Render directly to the display buffer for immediate display scan out

Chromatic aberration correction
Correct color distortion based on lens characteristics

Power & thermal management
Qualcomm® Symphony System Manager provides CPU, GPU, and DSP power, thermal, and performance management

Lens distortion correction
Barrel warp image based on lens characteristics

VR layering
Generate UI menus and text so that they render correctly in a virtual world

Qualcomm Symphony System Manager and Qualcomm Snapdragon are products of Qualcomm Technologies, Inc.
Offering superior VR development and optimization tools
Enabling content creation and tuned devices

**Content creation tools**
- Specialized solutions for VR development
  - Qualcomm® Snapdragon™ VR SDK
- Other relevant solutions
  - Qualcomm® Adreno™ SDK: Graphics/Compute SDK
  - Qualcomm® Hexagon™ SDK: DSP SDK
  - Qualcomm® Symphony System Manager SDK: Heterogeneous compute SDK
- Optimization and tuning
  - Snapdragon Profiler
- Optimal third-party middleware engines
  - Unity & Unreal Engine

**Device optimization tools**
- Calibration and tuning
  - Qualcomm® Display Color Management
  - Qualcomm® Audio Calibration Tool
- Analysis and debugging
  - Qualcomm® Commercial Analysis Toolkit
  - Qualcomm® eXtensible Diagnostic Monitor

**Other ecosystem enablement**
- Development devices
  - Commercial devices
- Customer support
  - Customer engineering support

Qualcomm Snapdragon, Qualcomm Adreno, Qualcomm Hexagon, Qualcomm Symphony System Manager, Qualcomm Display Color Management, Qualcomm Audio Calibration Tool, Qualcomm Commercial Analysis Toolkit, and Qualcomm eXtensible Diagnostic Monitor are products of Qualcomm Technologies, Inc.
QTI is uniquely positioned to support superior VR experiences

Custom designed SoCs and investments in the core VR technologies
Mobile VR evolution
Devices will become sleeker, lighter, and more fashionable

Google Cardboard
Slot-in
HMD
Sleek HMD
Imperceptible device?

Continued improvements in...
- Power efficiency
- Pixel density & quality
- Sound quality
- Intuitive interactions
- Cost efficiency
QTI is uniquely positioned to support superior VR experiences
Providing efficient, comprehensive solutions

**Immersive VR experiences**
- **Visual quality**
  - Consistent, accurate color
  - High resolution and frame rate
  - Stereoscopic and spherical display
- **Sound quality**
  - Positional audio
  - 3D surround sound
  - Noise filtering
- **Intuitive interactions**
  - Minimized system latency
  - Precise motion tracking
  - Intelligent, contextual interactions

**Within device constraints**
- Development time
- Sleek form factor
- Power and thermal efficiency
- Cost

**Commercialization**
- **Via Snapdragon™ solutions**
  - Efficient heterogeneous computing architecture
  - Custom designed processing engines
  - Comprehensive solutions across tiers
- **Via ecosystem enablement**
  - Snapdragon development platforms
  - App developer tools
  - Ecosystem collaboration
VR is here today

The mobile industry is accelerating VR adoption

Qualcomm® Snapdragon™ 845 processor is ideal for immersive mobile VR

Qualcomm Technologies will continue to drive VR technologies

Start developing  
https://developer.qualcomm.com

Learn more  
https://www.qualcomm.com/VR

Contact us  
https://developer.qualcomm.com/contact

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.
Thank you

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www.qualcomm.com & www.qualcomm.com/blog

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Resources

• **Websites**
  ◦ Virtual reality: https://www.qualcomm.com/VR
  ◦ Immersive experiences: https://www.qualcomm.com/Immersive
  ◦ Developers: https://developer.qualcomm.com
  ◦ Newsletter signup: http://www.qualcomm.com/mobile-computing-newsletter

• **Presentations**
  ◦ Immersive experiences: https://www.qualcomm.com/documents/immersive-experiences-presentation

• **Papers**

• **Videos**
  ◦ Immersive experiences video: https://www.qualcomm.com/videos/immersive-experiences