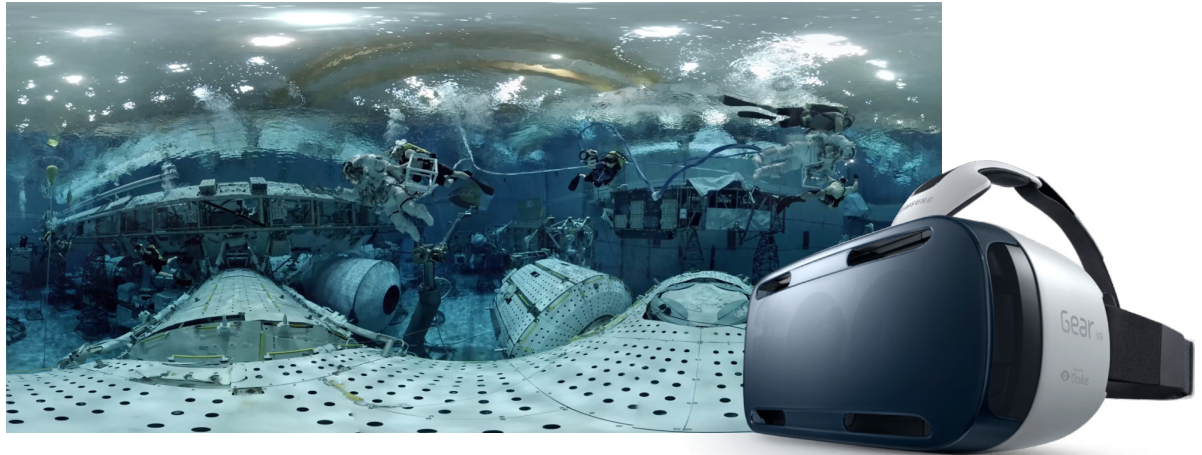


360° VR Video

SOLUTION BRIEF



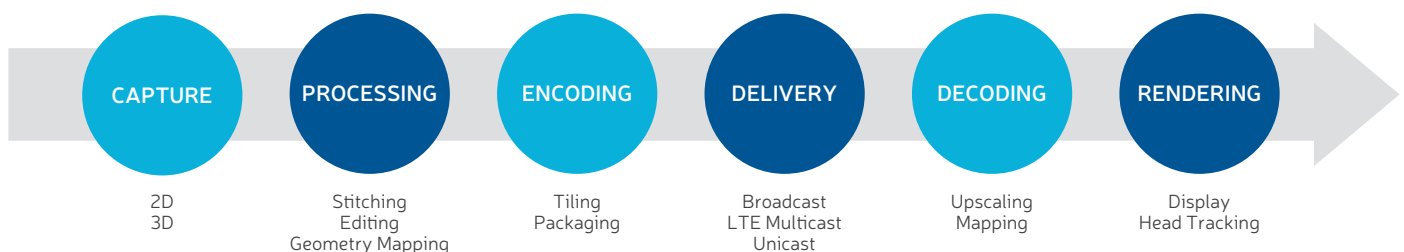
Virtual reality, sometimes referred to as immersive multimedia, is a computer-enhanced environment that can mimic physical presence in places both imagined and real. To create that sense of “being there,” VR possesses the ability to engage the complete gamut of human sensory perception: sight, sound, smell, touch and taste. Panoramic video, presented in either 180 degrees or fully immersive 360 degrees, is a key part of the experience.

VR video represents an entirely new way to consume content. Users gain the ability to step inside the video frame and control their viewing experiences — a revolutionary concept! The technology can provide the sensation of attending live concerts and sporting events or visiting foreign lands without leaving home. Gamers can play inside of fully realized alternate universes. Looking ahead, surgeons may one day travel into the human body to gain remarkable new perspectives on our anatomy and perform operations with unprecedented precision.

All of these things are possible with 360° VR video, and Harmonic, a recognized leader in the development of innovative video technology, stands at the forefront of the movement to make it happen.

The VR video production ecosystem contains many moving pieces and is still evolving. Its primary components include capture, processing, encoding, delivery, decoding and rendering. In general, 360° VR content is captured with multiple wide-angle HD cameras featuring overlapping fields of view. The content from each camera is stitched together to produce a single panoramic video. Different projection geometries are applied to the content before it is encoded and packaged for delivery, which may follow a broadcast, unicast or LTE multicast model. The content is decoded, upscaled and remapped on a consumer device, which could be a game console, STB, PC or smartphone, and is then rendered on a head-mounted device (HMD).

Steps in the VR Processing Chain



HIGHLIGHTS

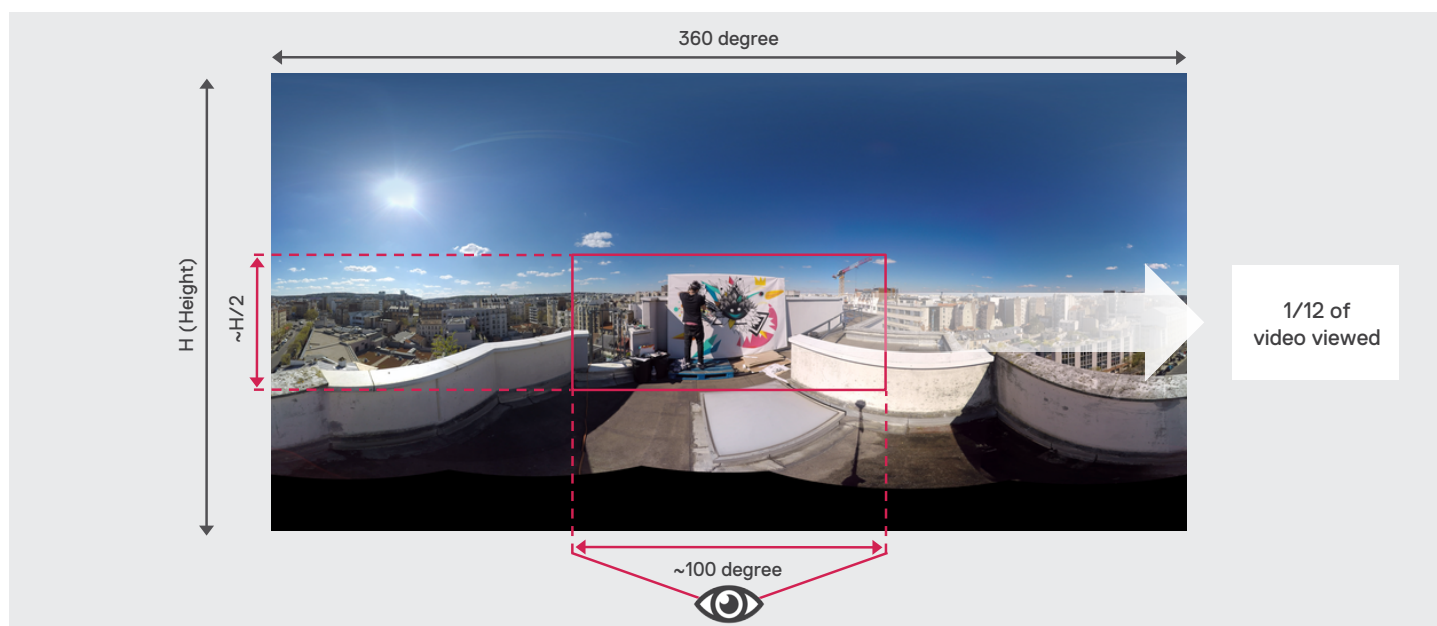
- Delivery of consistent, superior VR viewing experiences
- End-to-end ecosystem built with strategic partnerships
- Carrier-grade encoding and packaging
- ABR delivery of live, VOD and catch-up content
- Leveraging of Harmonic UHD and OTT processing expertise
- Technological leadership via active participation in standards development

VR Video Production Workflow

Raw VR content may be produced in 2D or 3D. The content can be made available via either a broadcast or unicast transmission, although unicast is a more natural approach, as VR viewing devices are IP-based and broadcast requires a dedicated infrastructure utilizing protocols such as LTE Broadcast or, for DTH, SAT>IP. In a typical live VR video workflow, the content is encoded in real time for distribution via a CDN in adaptive bitrate (ABR) format using the MPEG-DASH ISO BMFF or Apple® HLS protocols. The workflow for video-on-demand VR content is similar, except the content is transcoded as a file.

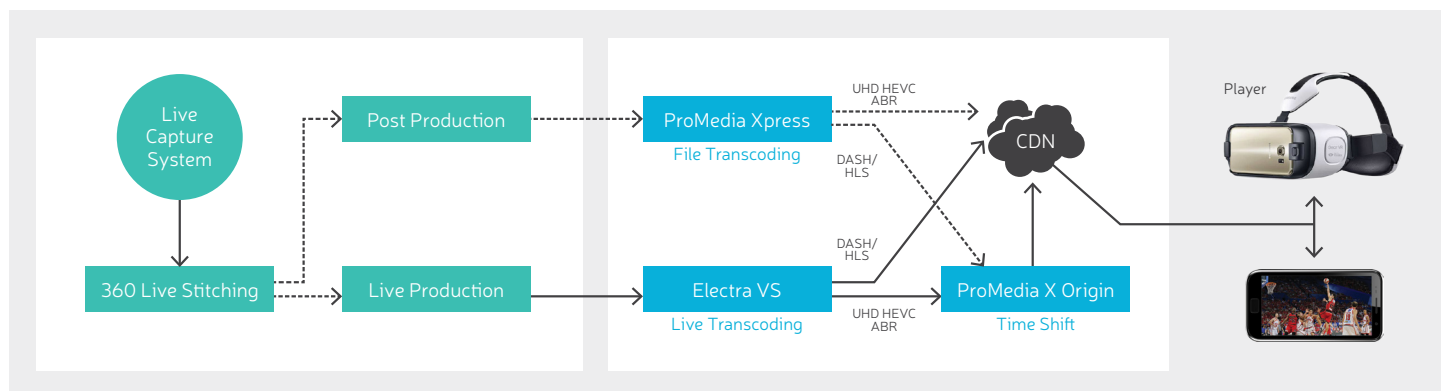
The current method for compressing VR video is to stitch the content prior to encoding. Today's stitching systems can combine multiple HD videos in real time, resulting in UHD-quality video up to 2160p60 8-bit resolution. The stitched video is then mapped into a geometry-based format, equirectangular being the standard projection technique used for 360° panoramic video. The viewing device selects decoded sections of the stream in real time, displaying the appropriate "Region of Interest" (ROI) based on the movements of the user.

This workflow is not the most efficient way to optimize bandwidth usage, but is currently the only way to deliver VR video over a broadcast network (to TV or to LTE broadcast phone). It does offer high quality of service (QoS), however. Unlike other unicast techniques (e.g., on-demand transcoding, tiling, pyramid encoding), delivery of 360° video is not network-dependent — another plus. On the downside, the perceived resolution is roughly 1/12 of the captured video when using an HMD. The need for better video quality is widely acknowledged, and continues to improve as more powerful compute platforms and compression efficiency come to market.



The region of interest in a 360° image on an HMD is 1/12 of the video resolution.

Harmonic VR Encoding



The Harmonic VR video workflow

Harmonic compression systems are part of a comprehensive solution for the preparation and delivery of real-time and on-demand VR video. Our systems work with leading stitching and geometry-mapping technologies to assure that the highest possible video quality is maintained throughout the production process.

For VOD content, the ProMedia® Xpress high-performance transcoder enables faster-than-real-time transcoding and packaging of content in HLS, MPEG-DASH and mp4 formats. For live applications, our Electra™ VS encoder can output multiple formats for UHD HEVC transmission, down to 1080p50 for single bitrates and 720p and 1080p for ABR streaming. The encoder can then package the content in Apple HLS and MPEG-DASH ISO BMFF format. Alternatively, the Electra X2 encoder can be used for resolutions up to 1080p for MPEG-4 AVC streaming.

Both ProMedia Xpress and Electra VS can send content to either our ProMedia X Origin multiscreen media server or directly to a CDN. ProMedia X Origin is an essential element in the solution. It's an HTTP streaming video server that ensures maximum interoperability with all target devices, and can package and host VR content in the HLS and MPEG-DASH protocols. ProMedia X Origin is optimized for use with the high-performance, highly scalable Harmonic MediaGrid storage system, which possesses the ability to support hundreds of hours' worth of VOD content. All ProMedia X Origin servers in the network have access to content stored on MediaGrid, no complex asset management required.

Harmonic VR Encoding Specifications

| ProMedia Xpress | | | | | |
|--------------------------------|----------------|--------------|---------------|---------------|----------------|
| Ingest Formats | Max Resolution | Codec | Output | Packaging | |
| | | | Multi Bitrate | | |
| | XAVC | 3840x2160x30 | AVC Main | Yes | HLS, MPEG-DASH |
| | AVC-Ultra | | | No | MP4 |
| | ProRes 422 | 3840x2160x60 | HEVC Main | Yes | HLS, MPEG-DASH |
| | DPX | | | No | MP4 |
| JPEG 2000 (MXF or MOV wrapped) | | | | | |
| MPEG-4 AVC | | | | | |
| Electra VS | | | | | |
| Ingest Formats | Max Resolution | Codec | Output | Packaging | |
| | | | Multi Bitrate | | |
| | SDI | 3840x2160x60 | HEVC Main | Yes | MPEG-DASH |
| IP (HEVC, TS) | No | | | MPEG-DASH, TS | |
| Electra X | | | | | |
| Ingest Formats | Max Resolution | Codec | Output | Packaging | |
| | | | Multi Bitrate | | |
| | SDI | 1920x1080x60 | AVC Main | Yes | HLS, MPEG-DASH |
| IP (AVC, TS) | No | | | MPEG-DASH, TS | |

VR Viewing Devices

One of the important considerations for VR production is the type of device to be targeted. For standard playback, content is viewed on a wireless device such as Samsung Gear VR or Google Cardboard, with a smartphone or STB functioning as the decoder. An HMD, either tethered or untethered, offers the most immersive experience.

HMDs for VR Video

| Device | Type | Resolution | Maximum Frame Rate | Codecs Supported |
|---|------------|------------|--------------------|------------------|
| Samsung Gear VR + Galaxy S6 & S7 | Untethered | 2560x1440 | 60 | HEVC |
| Google Daydream | Untethered | 2560x1440 | 60 | HEVC |
| Apple iPhone + HMD* | Untethered | 1920x1080 | 60 | AVC |
| Oculus Rift | Tethered | 2160x1200 | 90 | AVC, HEVC |
| HTC Vive | Tethered | 2160x1200 | 90 | AVC, HEVC |

* Apple has not made any public communication on its support of VR, but it is possible to connect an iPhone to a generic HMD (Hamido, Mattel, etc.). As the iPhone only natively supports AVC, the maximum resolution is 1080p60 in AVC.

As MPEG-4 AVC is the only format widely supported by all browsers, it is recommended that content creators encode up to 3840x2160x60 in AVC format when targeting web browsers. Because this bitrate is high, 1080p60 AVC offers an acceptable trade off in some cases. In terms of VR video platforms, Facebook 360 video can be watched on Chrome and Firefox browsers, in addition to the Facebook app, and YouTube VR360 video can be watched on Chrome, Opera, Firefox and Internet Explorer browsers, in addition to the YouTube app. For STB applications, the NVidia® Shield streaming media player is the first STB platform to support VR. Look for more VR support from STB manufacturers in 2017.




2D Support for VR Video

| Device | Type | Resolution | Maximum Frame Rate | Codecs Supported |
|----------------------|--------------|------------|--------------------|------------------|
| Web Browser | PC, Mobile | 3840x2160 | p60 | AVC |
| NVidia Shield | STB, Android | 3840x2160 | p60 | HEVC |

Content Delivery









For the best viewing experience single bitrate is recommended, especially if the content is to be delivered across a managed IP network. For OTT delivery ABR is preferred, although video quality might suffer. A CDN is used to deliver the ABR content to the VR device. Harmonic has developed strategic partnerships and performed interoperability testing with a number of leading CDN providers, and is ready to test other CDNs on a per-customer basis.

CDN Ecosystem Partners

| Company | Pull Mode (VOD) | Push Mode (Live) |
|---|-------------------------|------------------|
|  | MP4 MPEG-DASH HLS | MPEG-DASH HLS |
|  | MP4 MPEG-DASH HLS | MPEG-DASH HLS |
|  | MP4 MPEG-DASH HLS | MPEG-DASH HLS |

A Complete VR Video Ecosystem

Working with vendors you can trust is essential when deploying cutting-edge technologies such as VR. Harmonic possesses strategic partnerships with leading VR companies to offer the industry's most complete VR video ecosystem. With multiple completed trials and public demonstrations, Harmonic and its partners offer a one-stop shop for deploying your 360° VR video service.

| Category | Company | | |
|-----------------------------|---|--|---|
| VR Production |  | | |
| VR Camera |  |  |  |
| Live & File Video Stitching |  |  |  |
| Content Security & Player |  | | |

360° VR video offers the potential to revolutionize the ways people consume video. While the market continues to evolve, new business models will undoubtedly be developed to optimize — and monetize — the experience. Harmonic is ready to help you get there.



Harmonic is a founding member of the VR Industry Forum.

To learn more about VR, visit the organization's website: www.vr-if.org.