

Advanced Micro Devices

# Advanced Media Framework – h.264 Video Encoder

Programming Guide

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# 1 Introduction

## 1.1 Scope

This document provides a complete description of the AMD Advanced Media Framework (AMF) Video Encoder Component. This component exposes the AMD Video Compression Engine (VCE), which provides hardware accelerated H.264 video encoding functionality.

Figure 1 provides a system overview of the AMF Video Encoder Component.

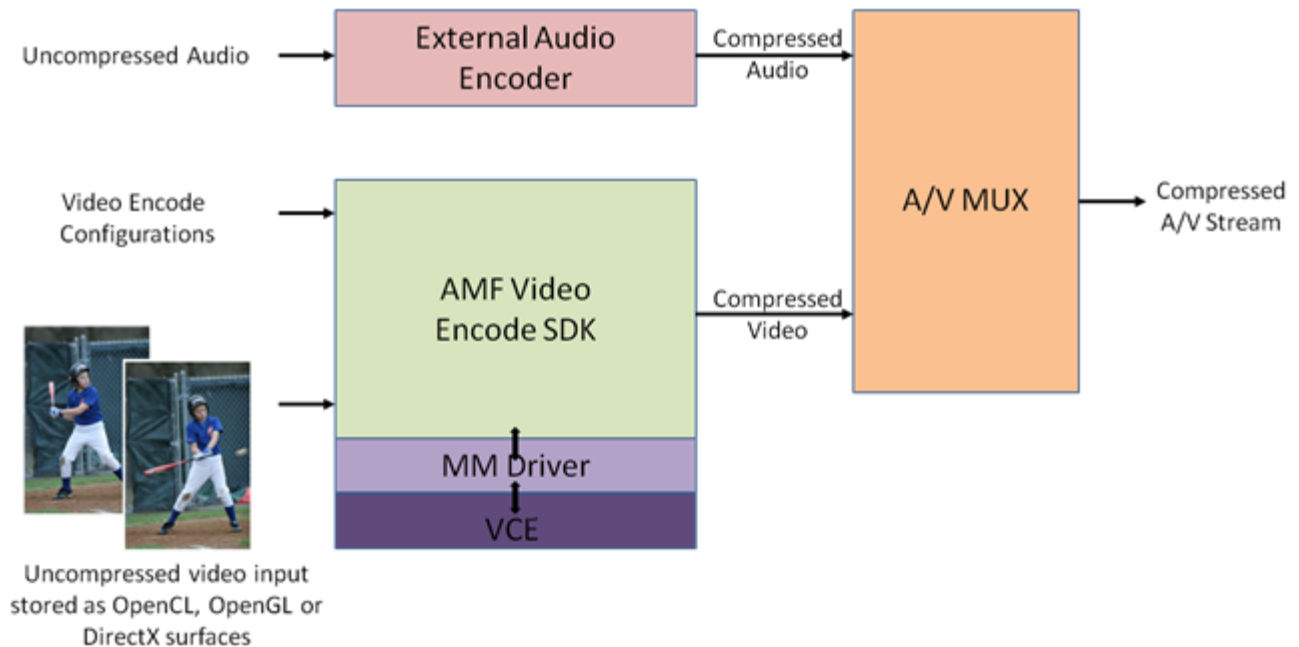


Figure 1 — System overview of the AMF Video Encode SDK

The AMF Video Encoder Component compresses RAW uncompressed video to an H.264 elementary bitstream.

The component does not provide a mechanism to handle audio compression, or stream multiplexing.

The component provides four different sets of pre-defined usages, which provide a convenient way for developers to configure the encoder to match the intended application use case. Advanced developers can also adjust encoding parameters to tailor the behavior to their specific application requirements.

## 1.2 Pre-defined Encoder Usages

The following table provides a brief overview of the encoding usage modes that have been defined:

Usage Mode	Intended use-cases	Comments
<b>Transcoding</b>	Transcoding, video editing	Favor compression efficiency and throughput over latency.
<b>Ultra-low latency</b>	Video game streaming	Optimize for extremely low latency use cases (e.g. cap the number of bits per frame), to enable high-interactivity applications.
<b>Low Latency</b>	Video collaboration, remote desktop	Optimize for low latency scenarios, but allow occasional bitrate overshoots to preserve quality.
<b>Webcam</b>	Video conferencing	Optimize for a low-latency video conferencing scenario, with scalable video coding (SVC) support.

## 2 AMF Video Encoder VCE-AVC Component

The AMF Video Encoder VCE-AVC component provides hardware accelerated AVC/SVC encoding using AMD's VCE.

To instantiate the AMF Video Encoder component, call the *AMFFactory::CreateComponent* method passing *AMFVideoEncoderVCE\_AVC* or *AMFVideoEncoderVCE\_SVC* component IDs defined in the *public/include/components/VideoEncoderVCE.h* header.

### 2.1 Input Submission and Output Retrieval

The AMF Video Encoder component accepts *AMFSurface* objects as input and produces *AMFBuffer* objects for output.

In the Transcoding mode the encoder needs to accept at least 3 input frames before any output is produced. In low latency modes output becomes available as soon as the first submitted frame is encoded.

### 2.2 Encode Parameters

Annex A provides the detailed description of encoding parameters (i.e., encoder properties) exposed by the Video Encoder VCE-AVC component for the following four usages:

- Transcoding mode,
- Ultra-low latency mode,
- Low Latency mode, and
- Webcam mode.

All properties are accessed using the *AMFPropertyStorage* interface of the Encoder object.

#### 2.2.1 Static Properties

Static properties (e.g., profile, level, usage) must be defined before the *Init()* function is called, and will apply until the end of the encoding session.

#### 2.2.2 Dynamic Properties

All dynamic properties have default values. Several properties can be changed subsequently and these changes will be flushed to encoder only before the next *Submit()* call.

#### 2.2.3 Frame Per-Submission Properties

Per submission properties are applied on a per frame basis. They can be set optionally to force a certain behavior (e.g., force frame type to IDR) by updating the properties of the *AMFSurface* object that is passed through the *AMFComponent::Submit()* call.

#### 2.2.4 SVC Properties

For define frame-rate SVC parameters per layer the next format must be used:

TL<Temporal\_Layer\_Number>.QL<Quality\_Layer\_Number>.<Parameter\_name>

For example, to configure "Target bitrate" for temporal layer 2 and quality layer 1 the next parameter name uses:

"TL2.QL0.TargetBitrate"

Remark: quality layers are not supported on VCE 1.0. "QL0" must be used for quality layers.

### 3 Sample Applications

The AMF Encoder Sample application show how to setup and use the AMF Video Encoder VCE-AVC Component to encode video frames that are loaded from disk or rendered by the DirectX 3D engine.

#### 3.1 List of Parameters

Sample applications support almost all visible encoder parameters (except PictureStructure, EndOfSequence, EndOfStream) and few additional parameters.

Additional parameters of VCEEncoderRaw application:

Category	Name	Values	Description
Miscellaneous parameters	ApplyTo	Frame number	Forces all subsequent configuration parameters to be applied to a specific frame
	Input	File name, relative or absolute path	Input file with frames (YUV420, NV12 or BGRA)
	Output	File name, relative or absolute path	Output H.264 file for encoded data
	DX9	Flag ( without any values )	Forces Direct3D 9 (default Direct3D 11)
	OpenCL	Flag ( without any values )	Forces OpenCL
	MTMode	Flag ( without any values )	Enables creating or reading from file of frames in separate thread.
	PerfStat	Flag ( without any values )	Enables showing a performance statistic

Additional parameters of VCEEncoderD3D application:

Category	Name	Values	Description
Miscellaneous parameters	Frames	Number of frames to be encoded	Number of frames to be encoded
	ApplyTo	Frame number	Forces all subsequent configuration parameters to be applied to a specific frame
	Output	File name, relative or absolute path	Output H.264 file for encoded data
	DX9	Flag ( without any values )	Use Direct3D 9 (default Direct3D 11) for rendering
	DX9EX	Flag ( without any values )	The same as DX9 but using Device9Ex instead Device9
	OpenGL	Flag ( without any values )	Use OpenGL for rendering
	Windowmode	Flag ( without any values )	Shows rendering window for D3D sample application



	MTMode	Flag ( without any values )	Enables creating or reading from file of frames in separate thread. Doesn't work for OpenGL.
	PerfStat	Flag ( without any values )	Enables showing a performance statistic

## 3.2 Command line example

### 3.2.1 Transcoding application (TranscodingHW.exe)

```
VCEEncoderRaw.exe -input input.h264 -output out.h264 -width 1280 -height 720 -usage transcoding -rateControlMethod cbr -targetBitrate 500000 -targetBitrate 100000
```

This command transcodes H264 elementary stream to H.264 video. Encoder is created with “Transcoding” usage.

### 3.2.2 D3D application (VCEEncoderD3D.exe)

```
VCEEncoderD3D.exe -output VideoSample_1024x768.h264 -width 1024 -height 768 -usage transcoding - rateControlMethod cbr -targetBitrate 500000 -frames 400
```

This command encodes 400 frames through D3D renderer and creates an output file with the encoded data. Encoder is created with “Transcoding” usage. Initial configuration sets bitrate to a value of 500kbts/sec.

## Annex A: Encoding & frame parameters description

**Table A-1.** The description of encoder's parameters.

Category	Name	Values	Description
Encoder static parameters	AMF_VIDEO_ENCODER_USAGE	0, 1, 2, 3 (Transcoding, UltraLowLatency, LowLatency, Webcam)	Selects the AMF usage (see Section 1.2)
	AMF_VIDEO_ENCODER_PROFILE	66, 77, 100 (Baseline, Main, High)	Selects the H.264 profile
	AMF_VIDEO_ENCODER_PROFILE_LEVEL	1, 1.1, 1.2, 1.3, 2, 2.1, 2.2, 3, 3.1, 3.2, 4, 4.1, 4.2	Selects the H.264 profile level
	AMF_VIDEO_ENCODER_MAX_LTR_FRAMES	0 ... 2	<p>The number of long-term references controlled by the user.</p> <p>Remarks:</p> <ul style="list-style-type: none"> <li>When == 0, the encoder may or may not use LTRs during encoding.</li> <li>When &gt;0, the user has control over all LTR.</li> <li>With user control of LTR, B-pictures and Intra-refresh features are not supported.</li> <li>The actual maximum number of LTRs allowed depends on H.264 Annex A Table A-1 Level limits, which defines dependencies between the H.264 Level number, encoding resolution, and DPB size. The DPB size limit impacts the maximum number of LTR allowed.</li> </ul>
	AMF_VIDEO_ENCODER_LOWLATENCY_MODE	True/False (On/Off); default is false	Enables low latency mode in the encoder and switches POC mode to 2
Encoder resolution parameters	AMF_VIDEO_ENCODER_FRAME_SIZE	Width: 64 – 4096 Height: 64 – 4096	Frame width and height in pixels, maximum values are hardware-specific, should be queried through <i>AMFCaps</i>

Category	Name	Values	Description
	AMF_VIDEO_ENCODER_ASPECT_RATIO	Default 1:1	Pixel aspect ratio
Encoder color conversion parameters	AMF_VIDEO_ENCODER_COLOR_BIT_DEPTH	8, 10, 16	Sets the number of bits in each pixel's color component in the encoder's output stream. Default is 8.
Encoder rate-control parameters	AMF_VIDEO_ENCODER_TARGET_BITRATE	10 000 - 100 000 000 bit/s	Sets the target bitrate
	AMF_VIDEO_ENCODER_PEAK_BITRATE	10 000 - 100 000 000 bit/s	Sets the peak bitrate
	AMF_VIDEO_ENCODER_RATE_CONTROL_METHOD	0, 1, 2, 3 (CQP, CBR, VBR, VBR_LAT)	<p>Selects the rate control method:</p> <ul style="list-style-type: none"> <li>• CQP – Constrained QP,</li> <li>• CBR - Constant Bitrate,</li> <li>• VBR - Peak Constrained VBR,</li> <li>• VBR_LAT - Latency Constrained VBR</li> </ul> <p>Remarks:</p> <ul style="list-style-type: none"> <li>• When SVC encoding is enabled, all Rate-control parameters (with some restrictions) can be configured differently for a particular SVC-layer. An SVC-layer is denoted by an index pair [SVC-Temporal Layer index][SVC-Quality Layer index]. E.g. The bitrate may be configured differently for SVC-layers [0][0] and [1][0].</li> <li>• We restrict all SVC layers to have the same Rate Control method. Some RC parameters are not enabled with SVC encoding (e.g. all parameters related to B-pictures).</li> </ul>
	AMF_VIDEO_ENCODER_RATE_CONTROL_SKIP_FRAME_ENABLE	True/False (On/Off)	Enables skip frame for rate control
	AMF_VIDEO_ENCODER_MIN_QP	0 – 51	Sets the minimum QP

Category	Name	Values	Description
	AMF_VIDEO_ENCODER_MAX_QP	0 – 51	Sets the maximum QP
	AMF_VIDEO_ENCODER_QP_I	0 – 51	Sets the constant QP for I-pictures.  Remarks: <ul style="list-style-type: none"> <li>Only available for CQP rate control method.</li> </ul>
	AMF_VIDEO_ENCODER_QP_P	0 – 51	Sets the constant QP for P-pictures.  Remarks: <ul style="list-style-type: none"> <li>Only available for CQP rate control method.</li> </ul>
	AMF_VIDEO_ENCODER_QP_B	0 – 51	Sets the constant QP for B-pictures.  Remarks: <ul style="list-style-type: none"> <li>Only available for CQP rate control method.</li> </ul>
	AMF_VIDEO_ENCODER_FRAMERATE	1*FrameRateDen ... 120*FrameRateDen	Frame rate numerator
	AMF_VIDEO_ENCODER_VBV_BUFFER_SIZE	1000 – 100 000 000	Sets the VBV buffer size in bits
	AMF_VIDEO_ENCODER_INITIAL_VBV_BUFFER_FULLNESS	0 - 64	Sets the initial VBV buffer fullness
	AMF_VIDEO_ENCODER_ENFORCE_HRD	True/False (On/Off)	Disables/enables constraints on QP variation within a picture to meet HRD requirement(s)
	AMF_VIDEO_ENCODER_ENABLE_VBAQ	True/False (On/Off)	Enables/disables VBAQ VBAQ stands for “Variance Based Adaptive Quantization”. The basic idea of VBAQ: Human visual system is typically less sensitive to artifacts in highly textured area. In VBAQ mode, we use pixel variance to indicate the complexity of spatial texture. This allows us to allocate more bits to smoother areas. Enabling such feature leads to improvements in subjective visual quality with some content.
	AMF_VIDEO_ENCODER_MAX_AU_SIZE	0 - 100 000 000 bits	Maximum AU size in bits

Category	Name	Values	Description
	AMF_VIDEO_ENCODER_B_PIC_DELTA_QP *	-10 ... 10	Selects the delta QP of non-reference B pictures with respect to I pictures
	AMF_VIDEO_ENCODER_REF_B_PIC_DELTA_QP *	-10 ... 10	Selects delta QP of reference B pictures with respect to I pictures
	AMF_VIDEO_ENCODER_RATE_CONTROL_PREANALYSIS_ENABLE	AMF_VIDEO_ENCODER_PREENCODE_DISABLED, AMF_VIDEO_ENCODER_PREENCODE_ENABLED, AMF_VIDEO_ENCODER_PREENCODE_ENABLED_DOWNSCALEFACTOR_2, AMF_VIDEO_ENCODER_PREENCODE_ENABLED_DOWNSCALEFACTOR_4	Enables or disables rate control pre-analysis, default is Disabled
	AMF_VIDEO_ENCODER_FILLER_DATA_ENABLE	True/False	Enables/disables filler data to maintain constant bit rate
Encoder picture-control parameters	AMF_VIDEO_ENCODER_HEADER_INSERTION_SPACING	0 ... 1000	Sets the headers insertion spacing
	AMF_VIDEO_ENCODER_IDR_PERIOD	0 ... 1000	Sets IDR period. IDRPeriod= 0 turns IDR off
	AMF_VIDEO_ENCODER_DE_BLOCKING_FILTER	True/False (On/Off)	Enable/disable the de-blocking filter
	AMF_VIDEO_ENCODER_INTRA_REFRESH_NUM_MBS_PER_SLOT	0 - #MBs per frame	Sets the number of intra-refresh macro-blocks per slot
	AMF_VIDEO_ENCODER_SLICES_PER_FRAME	1 - #MBs per frame	Sets the number of slices per frame
	AMF_VIDEO_ENCODER_B_PIC_PATTERN *	0, 1, 2, 3	Sets the number of consecutive B-pictures in a GOP. BPicturesPattern = 0 indicates that B-pictures are not used
	AMF_VIDEO_ENCODER_B_REFERENCE_ENABLE *	True/False (On/Off)	Enables or disables using B-pictures as references
	AMF_VIDEO_ENCODER_CABAC_ENABLE	AMF_VIDEO_ENCODER_UNDEFINED, AMF_VIDEO_ENCODER_CABAC, AMF_VIDEO_ENCODER_CALV	Encoder coding method, when Undefined is selected, the behavior is profile-specific: CALV for Baseline, CABAC for Main and High
	AMF_VIDEO_ENCODER_MAX_NUM_REFRAMES	0..16	Maximum number of reference frames
Encoder miscellaneous parameters	AMF_VIDEO_ENCODER_SCANTYPE	0, 1 (Progressive, Interlaced)	Selects progressive or interlaced scan
	AMF_VIDEO_ENCODER_QUALITY_PRESET	0, 1, 2 (Balanced, Speed, Quality)	Selects the quality preset
	AMF_VIDEO_ENCODER_FULL_RANGE_COLOR	True/False	True indicates that the YUV range is 0..255

Category	Name	Values	Description
	AMF_VIDEO_ENCODER_MAX_INSTANCES	1 or 2	Hardware-dependent, only some hardware supports 2 instances
	AMF_VIDEO_ENCODER_MULTI_INSTANCE_MODE	True or False	Enables or disables multi-instance mode, default - disabled
	AMF_VIDEO_ENCODER_CURRENT_QUEUE	0 or 1	Selects the encoder instance frames are being submitted to
Encoder motion estimation parameters	AMF_VIDEO_ENCODER_MOTION_HALF_PIXEL	True/False (On/Off)	Turns on/off half-pixel motion estimation
	AMF_VIDEO_ENCODER_MOTION_QUARTERPIXEL	True/False (On/Off)	Turns on/off quarter-pixel motion estimation
Encoder SVC parameters (only webcam usage)	AMF_VIDEO_ENCODER_NUM_TEMPORAL_ENHANCEMENT_LAYERS	0 ... MaxOfTemporalEnhancementLayers	<p>Change the number of temporal enhancement layers. The maximum number allowed is set by the corresponding create parameter.</p> <p>Remarks:</p> <ul style="list-style-type: none"> <li>Actual modification of the number of temporal enhancement layers will be delayed until the start of the next temporal GOP.</li> <li>B-pictures and Intra-refresh features are not supported with SVC.</li> </ul>

Category	Name	Values	Description
Encoder SVC per-layer parameters (only webcam usage)	TL<TL_Num>. QL<QL_Num>. <Parameter_name>	Parameter-specific values	<p>Configures SVC frame-rate parameter per SVC layer.</p> <ul style="list-style-type: none"> <li>• TL_Num — temporal layer number</li> <li>• QL_Num — quality layer number</li> <li>• Parameter_name — frame rate parameter name (look at frame-rate parameters on this table).</li> </ul> <p>Remarks:</p> <ul style="list-style-type: none"> <li>• Quality layers are not supported on VCE 1.0. “QLO” must be used for quality layers.</li> </ul>

\* this feature is not supported by VCE 1.0

**Table A-2.** The description of frame’s and encoded data parameters.

Category	Name	Values	Description
Frame per-submission parameters	AMF_VIDEO_ENCODER_INSERT_SPS	True/False (On/Off)	Inserts SPS
	AMF_VIDEO_ENCODER_INSERT_PPS	True/False (On/Off)	Inserts PPS
	AMF_VIDEO_ENCODER_INSERT_AUD	True/False (On/Off)	Inserts AUD
	AMF_VIDEO_ENCODER_PICTURE_STRUCTURE	0, 1, 2, 3 (None, Frame, TopField, BottomField)	Picture structure
	AMF_VIDEO_ENCODER_FORCE_PICTURE_TYPE	0, 1, 2, 3, 4, 5* (NONE, SKIP, IDR, I, P, B*)	Forces the picture type
	AMF_VIDEO_ENCODER_END_OF_SEQUENCE	True/False (On/Off)	End of sequence
	AMF_VIDEO_ENCODER_END_OF_STREAM	True/False (On/Off)	End of stream

Category	Name	Values	Description
	AMF_VIDEO_ENCODER_MARK_CURRENT_WITH_LTR_INDEX	-1 ... (MaxOfLTRFrames - 1)	<p>If != -1, the current picture is coded as a long-term reference with the given index.</p> <p>Remarks:</p> <ul style="list-style-type: none"><li>• When the user controls N LTRs (using the corresponding Create parameter), then the LTR Index the user can assign to a reference picture varies from 0 to N-1. By default, the encoder will “use up” available LTR Indices (i.e. assign them to references) even if the user does not request them to be used.</li><li>• When LTR is used with SVC encoding, only base temporal layer pictures can be coded as LTR. In this case, the request to mark the current picture as LTR would be delayed to the next base temporal layer picture if the current picture is in an enhancement layer. If the user submits multiple requests to mark current as LTR between base temporal layer pictures, then only the last request is applied.</li></ul>



Category	Name	Values	Description
	AMF_VIDEO_ENCODER_FORCE_LTR_REFERENCE_BITFIELD	Bitfield (MaxOfLTRFrames (max possible 16 bits))	Force LTR Reference allowed bitfield. If == 0, the current picture should predict from the default reference. If != 0, the current picture should predict from one of the LTRs allowed by the bitfield (bit# = LTR Index#).  Remarks: <ul style="list-style-type: none"> <li>E.g. if Bit#0 = 1, then the existing LTR with LTR Index = 0 may be used for reference. The bitfield may allow more than one LTR for reference, in which case the encoder is free to choose which one to use. This bitfield also disallows existing LTRs not enabled by it from current/future reference.</li> <li>E.g. if Bit#1 = 0, and there is an existing reference with LTR Index = 1, then this LTR Index will not be used for reference until it is replaced with a newer reference with the same LTR Index.</li> </ul>
Encoded data parameters	AMF_VIDEO_ENCODER_OUTPUT_DATA_TYPE	0, 1, 2, 3* (IDR, I, P, B*)	Type of encoded data
	AMF_VIDEO_ENCODER_OUTPUT_MARKED_LTR_INDEX	-1 ... (MaxOfLTRFrames - 1)	Marked as LTR Index. If != -1, then this picture was coded as a long-term reference with this LTR Index.
	AMF_VIDEO_ENCODER_OUTPUT_REFERENCED_LTR_INDEX_BITFIELD	Bitfield (MaxOfLTRFrames (max possible 16 bits))	Referenced LTR Index bitfield. If != 0, this picture was coded to reference long-term references. The enabled bits identify the LTR Indices of the referenced pictures (e.g. if Bit #0 = 1, then LTR Index 0 was used as a reference when coding this picture).

\* this feature is not supported by VCE 1.0

**Table A-3.** Default value of parameters.

Type	Name	Transcoding	Ultra low latency	Low latency	Webcam
Static Parameters (Set at creation time)	Profile	Main	Main	Main	Main
	AMF_VIDEO_ENCODER_PROFILE_LEVEL	4.2	4.2	4.2	4.2
Rate control	AMF_VIDEO_ENCODER_TARGET_BITRATE	20 mbps	20 mbps	20 mbps	20 mbps
	AMF_VIDEO_ENCODER_PEAK_BITRATE	30 mbps	20 mbps	30 mbps	30 mbps
	AMF_VIDEO_ENCODER_MIN_QP	18	22	22	22
	AMF_VIDEO_ENCODER_MAX_QP	46	48	48	48
	AMF_VIDEO_ENCODER_QP_I	22	22	22	22
	AMF_VIDEO_ENCODER_QP_P	22	22	22	22
	AMF_VIDEO_ENCODER_QP_B	22	22	22	22
	AMF_VIDEO_ENCODER_FRAMERATE	30 fps	30 fps	30 fps	30 fps
	AMF_VIDEO_ENCODER_VBV_BUFFER_SIZE	20 mbits	735 kbits	4 mbits	2 mbits
	AMF_VIDEO_ENCODER_INITIAL_VBV_BUFFER_FULLNESS	64	64	64	64
	AMF_VIDEO_ENCODER_ENFORCE_HRD	false	true	false	false
	AMF_VIDEO_ENCODER_MAX_AU_SIZE	0	0	0	0
	AMF_VIDEO_ENCODER_FILLER_DATA_ENABLE	false	false	false	false
	AMF_VIDEO_ENCODER_B_PIC_DELTA_QP*	+4	0	+4	+4
	AMF_VIDEO_ENCODER_REF_B_PIC_DELTA_QP*	+2	0	+2	+2
Picture Control	AMF_VIDEO_ENCODER_HEADER_INSERTION_SPACING**	0	0	0	0
	AMF_VIDEO_ENCODER_IDR_PERIOD	30	300	300	30
	AMF_VIDEO_ENCODER_DE_BLOCKING_FILTER	true	true	true	true
	AMF_VIDEO_ENCODER_INTRA_REFRESH_NUM_MBS_PER_SLOT*	0	255	255	0
	AMF_VIDEO_ENCODER_SLICES_PER_FRAME	1	1	1	1
	AMF_VIDEO_ENCODER_B_PIC_PATTERN*	3	0	0	0
	AMF_VIDEO_ENCODER_B_REFERENCE_ENABLE*	true	false	true	true
	AMF_VIDEO_ENCODER_SCANTYPE	0	0	0	0
	AMF_VIDEO_ENCODER_QUALITY_PRESET	Balanced	Speed	Speed	Speed
Motion estimation	AMF_VIDEO_ENCODER_MOTION_HALF_PIXEL	1	1	1	1
	AMF_VIDEO_ENCODER_MOTION_QUARTERPIXEL	1	1	1	1
SVC	AMF_VIDEO_ENCODER_NUM_TEMPORAL_ENHANCMENT_LAYERS	disable	disable	disable	0
Per-submission parameters	AMF_VIDEO_ENCODER_INSERT_SPS	0	0	0	0
	AMF_VIDEO_ENCODER_INSERT_PPS	0	0	0	0
	AMF_VIDEO_ENCODER_PICTURE_STRUCTURE	0	0	0	0
	AMF_VIDEO_ENCODER_FORCE_PICTURE_TYPE	0	0	0	0
	AMF_VIDEO_ENCODER_INSERT_AUD	false	false	false	false
	AMF_VIDEO_ENCODER_END_OF_SEQUENCE	false	false	false	false
	AMF_VIDEO_ENCODER_END_OF_STREAM	false	false	false	false
	AMF_VIDEO_ENCODER_MARK_CURRENT_WITH_LTR_INDEX	-1	-1	-1	-1
	AMF_VIDEO_ENCODER_FORCE_LTR_REFERENCE_BITFIELD	0x0	0x0	0x0	0x0

\* BPicturesDeltaQP, ReferenceBPicturesDeltaQP, IntraRefreshNumMBsPerSlot, BPicturesPattern and BReferenceEnable parameters are available only when:

- MaxOfReferenceFrames is greater than 1
- NumOfLTR is 0 (LTR is not used)

\*\* HeaderInsertionSpacing: Every IDR frame has SPS and PPS regardless of default value of HeaderInsertionSpacing per VCE logic.