- **What is the history and background of the auto cal feature?**
    - With the launch of our 2016 OLED products, we started receiving requests from professional content creators who were buying our OLED TVs for use as reference client monitors. They were happy with the product, but wanted to know if we had any tips for calibrating. This started an ongoing collaboration with a number of content partners to improve the accuracy of our displays, some of which was implemented in our 2017 consumer TVs, though without the automated feature.
    - During 2017, we started beta testing with our professional partners, the auto calibration in the form we introduced at CES 2018. At that time, we were the first, and probably still are the only CE company to offer hardware level access to the image processing functional blocks in our TVs, offering unparalleled flexibility and accuracy. At CES 2018 we were honoured to receive a 'Best of CES' award from AVS Forum for this feature.
    - After the success of our 2018 auto calibration feature, we started looking at how we could further improve functionality for 2019 products. We're pleased to announce three new features that build upon the 2018 functionality and address the cost 'barrier to entry', as well as providing flexibility in configuration and usability improvements.

      As in 2017 for our 2018 products, the feedback we received from beta testing with our content creation industry partners over the last year has directly influenced the new 2019 features, and we're very grateful to the partners we have worked with to achieve this.

- **What's new for 2019?**
    - For 2019, we're introducing 3 new features / changes over the 2018 auto calibration implementation.
        - Integrated Test Pattern Generator (iTPG) - Reduces the barrier to entry by at least $1,500
        - HDR10 Tone Curve Parameters - Provides the ability to set the HDR10 tone mapping to match the measured peak luminance of the display and adjust the roll-off point for 3 definable metadata points
        - Picture Mode Reset Behaviour - Allows individual picture modes to be reset to factory status after an auto calibration, removing the need to do a full factory reset loosing all calibrations for all picture modes as was the case in 2018

- **What are the capabilities of the iTPG, and how is it different from an HDMI TPG?**
    - The iTPG has the potential to result in increased accuracy over an external TPG for the following reasons:
        - It operates at 10-bit precision, with CalMAN able to make full use of this precision
        - It operates in RGB space, and is therefore not subject to the potential errors from RGB to YCbCr conversions such as rounding errors and / or incorrect matrix co-efficients

    - The iTPG operates in 10-bit Full Range RGB space, and has the following capabilities:
        - 3840 x 2160 native resolution
        - 10-bit precision RGB
        - Up to 10 different boxes can be defined at arbitrary sizes and positions (a typical 10% area patch is, for example, two boxes; 1 full screen black, and 1 10% area for the patch)
        - Up to 4 Gradient ramps running horizontally or vertically, with definable start RGB value, step size (in RGB value) and spacing (in pixels)

    - The iTPG is positioned in the video pipeline after the HDR processing, and after the Brightness and Contrast controls, but before all of the LUTs used for calibration.

    - Brightness and Contrast adjustments are a legacy function that is often misunderstood. In theory, these controls should never be used or needed with digital signals, and they should not normally be used when using the auto calibration feature because the functions they provide are more accurately served by making changes in the 1D LUT.

      The location of the iTPG means that any changes made to Brightness and Contrast will not have any effect on the iTPG patterns. Any changes from the default settings for Brightness and Contrast (50 and 85 in SDR; 50 and 100 in HDR respectively) will make an auto calibration using the iTPG invalid.

      Note: *Changes to the Brightness and Contrast from default will also cause a 1D auto calibration using an external TPG to fail, for related, though not identical reasons.*

    - The iTPG can be used for SDR, HDR and Dolby Vision calibration, but cannot be used to validate HDR and Dolby Vision calibration in PQ space because it is located after the HDR tone mapping, once the signal is in Gamma space.

        - It's important to understand that up-stream HDR processing is not something that gets calibrated, and is simply maths. LG would encourage journalists to test this (using a traditional external TPG to validate an iTPG HDR calibration), but if the iTPG calibration result is good, it is safe to assume that the HDR and Dolby Vision calibrations will also be good, even though they cannot be validated with the iTPG

    - As with an external TPG, it is necessary for the TV to be operating in SDR mode to perform an SDR calibration, HDR mode to perform an HDR calibration, and Dolby Vision mode to perform a Dolby Vision calibration. With an external TPG, this is achieved by setting the output mode of the TPG. With the iTPG however, there is no equivalent setting.

      It is therefore necessary to ensure that a video of SDR, HDR or Dolby Vision is playing as needed. This can be achieved using an external video source like a Blu-ray Player, but the easiest way is to play a video file using the USB file playback support of the TV. LG has therefore provided 3 test videos that simply play 1 hour of 15% stimulus full screen grey in SDR, HDR and Dolby Vision. These files can be downloaded here:
        - SDR - https://lgtca.box.com/v/SDR
        - HDR - https://lgtca.box.com/v/HDR
        - Dolby Vision - https://lgtca.box.com/v/DoVi

- **How do the HDR Tone Curve Parameters Work?**

    - LG has provided 7 parameters to adjust the HDR-10 tone mapping behaviour when Dynamic Tone Mapping is disabled:
        - Peak Luminance - Used to set the target output luminance range for tone mapping calculations; set to measured panel peak luminance to track PQ accurately
        - Tone Curve Metadata Point (x 3) - Used to define which content metadata peak luminance value you're defining the tone curve for
        - Roll-Off Point (x3) - Used to set the point at which the tone curve deviates from PQ, expressed as a percentage of the Peak Luminance value

    - With the 3 Metadata and Roll-Off Points, it is possible to accurately define tone curves for content with 3 specified metadata points (e.g. 1,000 nits peak content, 4,000 nits peak content, and 10,000 nits peak content); content with peak luminance metadata between these points will result in a tone curve that is interpolated between the three defined points.

    - If a PQ Hard Clip is desired regardless of metadata sent, such as for content creation purposes, or to use the display as a PQ reference, this can be easily achieved by setting all three Roll-Off Parameters to 100%.

- If content metadata signals a peak luminance lower than the Peak Luminance Tone Curve Parameter, a Peak Hard Clip tone curve will be used, tracking PQ up to the Peak Luminance Tone Curve Parameter and clipping content at higher luminance.

- LG TVs determine the PQ Luminance of content for static tone mapping as follows:
  - Use ST.2086 Mastering Display Peak
  - If MaxCLL is present *AND* lower than ST.2086 Mastering Display Peak, use MaxCLL
  - If ST.2086 Mastering Display Peak and MaxCLL are both signalled as zero (as defined for un-available), assume a peak luminance of 4,000 nits

- **How does CalMAN make use of the Tone Curve Parameters**

  - CalMAN features a new section in the DDC panel for entering the 7 parameters and an upload button to send the data to the TV. Workflows will be updated to walk users through this process

  - CalMAN has full information on the maths used by LG TVs to create tone curves based on the 7 parameters and can therefore use this to update the target EOTF in their software. If this is done, rather than checking the dE against PQ, which shows errors as tone mapping inevitably causes deviations from PQ, CalMAN will now only show errors as the display deviates from its intended, defined by Tone Curve Parameters EOTF.

- **Is it Possible to only change one of the 7 Tone Curve Parameters?**

  - No, all Parameters must be sent if any one of them is changed. Having said that, the default values for all 7 are known by CalMAN and it is possible to change only one of the values and then send the other 6 as the defaults.

  - For reference, the default values are:
    - Peak Luminance: 700 nits
    - Metadata Point 1: 1,000 nits
      - Roll-Off Point 1: 70%
    - Metadata Point 2: 4,000 nits
      - Roll-Off Point 2: 60%
    - Metadata Point 3: 10,000 nits
      - Roll-Off Point 3: 50%

- **Which picture modes can be calibrated?**

  Unchanged for 2019:

  - SDR
    - Cinema
    - ISF Expert Bright
    - ISF Expert Dark
    - Technicolor Expert
    - Game

  - HDR (HDR10/HLG)
    - HDR Cinema
    - HDR Game
    - HDR Technicolor Expert

  - Dolby Vision
    - Dolby Vision Cinema
    - Dolby Vision Cinema Home
    - Dolby Vision Game

- **What makes Hardware Level Auto Calibration different from competitor implementations?**

  - Although auto calibration is not a common feature on displays, auto calibration alone is not something new; many of our competitors have had auto calibration for some time. What sets this implementation apart from past versions is a number of significant features, but most importantly, direct hardware access to the functional blocks in the TV processor (3D LUT, 1D LUT and 3x3 Matrix).
    - This truly is revolutionary, because having direct access to these blocks allows for the best possible calibration, rather than being limited to a low number of adjustment points, or low precision or range of the controls.

  - Additional differentiating features include:
    - Secure, fast IP Communication (WiFi or Ethernet).
    - 33x33x33 3D LUT size.
    - The ability to calibrate multiple picture modes, including Game Modes.
    - HDR calibration in Gamma Space rather than PQ or HLG (Validation is done in PQ or HLG).

- **Why is calibrating HDR in Gamma Space beneficial?**

- Although not obvious, all consumer (and almost all professional) display panels produced today have a 2.2 Gamma native EOTF response. There are a number of reasons for this, including the actual non-linear characteristic of the display material (LCD, LED, OLED etc.), and of course history.

- As a result of the 2.2 Gamma native panel response, all TVs which support HDR video inputs, must convert the incoming signal from PQ or HLG into 2.2 Gamma. There are also no TVs produced today which can reproduce the full 10,000 nits of a PQ EOTF signal, so tone mapping must also be applied.

- The purpose of calibration is to correct for panel variability, and correct for panel behaviour that isn't as designed. Tone mapping and conversion to 2.2 Gamma are not calibration functions, they're simply maths, but the output of this maths assumes a perfect 2.2 Gamma panel with an accurate white point and a known peak luminance.

- When LG TVs are calibrated using the Autocal function, the upstream HDR maths is bypassed, and the 1D LUT and 3D LUT are created to achieve a result as close to the perfect 2.2 Gamma with accurate white point that the HDR processing is assuming.

- Calibrating HDR without bypassing this HDR processing maths is possible, but all of the adjustments are taking place in Gamma space, even though your input is PQ or HLG. If your panel peak luminance is higher or lower than the assumed peak luminance of the HDR processing maths, you may find yourself pushing the greyscale adjustments in odd directions to compensate, resulting in the potential for banding.

- **How big are the LUTs that CalMan has access to?**
  - The 1D LUT is a 10-bit LUT (1024 points) at 15-bit precision.
  - The 3D LUT is 33x33x33 in the Alpha 9 Gen 2 Chip (used on all OLED except for the B9 series).
  - The 3D LUT is 17x17x17 in the Alpha 7 Gen 2 Chip (used on all SK Series Super UHD LCD TVs and the B8 series OLED).

- **Why does CalMan only make adjustments for a small number of points if there is access to 1024 points in total?**
  - Obviously, measuring and adjusting 1024 points would take a long time, but we have found through testing that it is simply not necessary to make that many

adjustments. As long as the point that you are adjusting is exactly lined up with the point that you're measuring (which isn't always a given by the way), and the interpolation between points is sufficiently good, measuring additional points does not increase accuracy.

    - This can actually be seen when the autoCal process is running; often an patch is measured, and no adjustments are made at all because the interpolated LUT data at that point is already accurate.
    - Another way to look at this is that displays, including OLED and LCD will trend towards a certain neutral colour, rather than being, for example, too blue at 10% and then too Red at 20%. It's therefore understandable that if you adjust 10% and 20%, and you interpolate the adjustment at 15%, you'll already be very close; and in our testing, we optimised the spacing to take advantage of these trends. Multiple adjustment and measurement point options are given though, so you do get a choice.

- **If CalMan is only adjusting ~20 points for grayscale, how is this any advantage over a traditional 20 point grayscale adjustment?**

    - Traditional 20 point grayscale adjustment takes place at a 'UI' level, even though the eventual hardware that will implement the changes is a hardware 1D LUT just like we're using. At the UI level however, there are multiple settings that will take effect on the 1D LUT, such as:
        - White point setting
        - Gamma setting
        - 2 point white balance (RGB Gain / Offset)
        - 20 point white balance
        - Factory white balance settings in the service menu
        - Brightness & Contrast (indirectly)

    - All of these settings are merged in an algorithm that also interpolates values between settings and applies corrections for boosting contrast, lifting shadows etc. The interpolation algorithm for a traditional 20 point 5% spaced greyscale might be great, but there are so many other inputs that you may be fighting against that prevent you from, or make it take longer, to achieve a good result. An example of this might be that you want to target a white point of D65. The UI setting for D65 is too red, and the cooler white point is way too blue. You select the D65 setting because it's closest, and use the 2 point or 20 point to remove some red, but in this situation the factory calibration for the D65 UI setting had already added red to achieve the factory D65 white point. That setting is adding red and you're removing red; two UI settings fighting one another! With direct LUT access, all of the UI settings, including even the factory calibration settings are all bypassed, and the LUT data is directly manipulated.

- SpectraCal has worked hard through testing to optimize the number and distribution of the adjusted points, rather than simply adjusting at 5% intervals as is traditionally done.

- **What is a 1D LUT?**

  - A LUT, or 'Look Up Table' takes an input value, and outputs a different value from the data in the LUT. An example would like like this:

Input	Output
0	0
1	3
2	7
3	9
4	12
..	..

  - A 1D LUT can only make changes in a single dimension. For a TV, the 'dimensions' that the data is in are R, G and B, so what this means is that any Red input value can be mapped to any Red output value. A 1D LUT is typically very accurate, because there isn't much interpolation, if any, needed between points, but a 1D LUT does have limitations because it's only working in a single dimension - see 'What is a 3D LUT?' for more details.

  - There are typically 3 x 1D LUTs in a TV, one for each Red, Green and Blue.

  - 1D LUTs are typically used for grayscale / white point and gamma adjustment, and they're ideal for this because their limitations aren't relevant at this point in the video path.

- **What is a 3D LUT?**

  - A 3D LUT is similar to a 1D LUT in that it is a table with a list of input values and output values. It differs significantly in that it operates on three dimensions, typically R, G and B.

- Whereas a 1D LUT will look at only a single input value (single dimension), such as map Red input 3 to Red output 9 in the example above, a 3D LUT will look a an RGB triplet, effectively mapping any input colour to any output colour.

- 3D LUTs are far bigger than 1D LUTs, and it is extremely rare to see a 3D LUT implemented without any interpolation required. A full (no interpolation) 1D LUT for 10-bit RGB would be 3,072 points (3 x 1,024) A full 3D LUT for 10-bit RGB would be $1{,}024^3$ = 1.07 billion points! 3D LUTs are therefore implemented at smaller sizes and interpolation is used to re-map colours between these points.

- **What are the differences, from a calibration perspective, between the Alpha 9 Gen 2 Chip and the Alpha 7 Gen 2 Chip?**

  - The Alpha 9 Gen 2 features a 33x33x33 3D LUT, whereas the Alpha 7 Gen 2 has a 17x17x17 3D LUT. Functionally these operate in the same way, but a 33x33x33 3D LUT allows for less interpolation.

  - The Gen 2 versions of LG's TV SoCs are obviously based on the first generation of these SoCs, and the difference between the Alpha 9 Gen 2 and Alpha 7 Gen 2 with respect to LUT sizes is the same as between the Alpha 9 and Alpha 7 used in 2018 TVs

- **What are the impact to Game Modes?**

  New for 2019:

  - The HDR Gaming Interest Group (www.hgig.org) has created guidelines for displays, consoles and games to improve HDR Game Rendering. Using the HDR10 Tone Map parameters, it is possible to set the Game Mode HDR tone curve to accurately track PQ and hard clip at measured panel peak luminance. This will provide a best case implementation of the rendering guidelines of the HGIG.

  Unchanged for 2019:

  - This functionality will allow a vast improvement in colour accuracy for the low latency Game picture modes. Previously, the Game modes did not have user access to the detailed calibration controls that were available in the other modes (e.g. Cinema mode, or HDR Cinema.) Now there is no calibration difference between the low latency Game modes, and any other mode.

  - This calibration feature was based on feedback from game developers, and end users that made it clear that game video content should not be treated any different than movie or TV content. Some of the AAA game titles have development costs eclipsing big name movies, and game developers have made it clear that color accuracy is just as important to them as it is their movie counterparts. They want their creative intent to be preserved as much as Hollywood filmmakers do.

- **Will it be possible for 2018 TVs to be updated to support the new features launched in 2019?**
    - Almost certainly no for consumers. Development work for these features started on 2018 TVs, and some of our partners in content production have been using engineering firmware for 2018 TVs, and we will continue to support the partners that we worked with on this with their 2018 units, but it is not something that will be back ported and supported for consumers with 2018 models.

- **When will these feature be added to products?**

  Unchanged for 2019:

    - These features are not vaporware or even really pre-production. The software in our TVs to support these functions is already in the main development branch and only bug fixes will take place between now and the launch of these models. SpectraCal's software likewise is at a point where only bug fixes will take place between now and launch.

- **What other applications has the hardware level LUT access enabled besides calibration?**
    - LG TVs are now being used for colour science research in multiple research settings. Universities including RIT are conducting consumer studies with our OLED TVs, and Hollywood consultant colour scientists including Gary Demos are using our OLED TVs for developing new approaches to colour volume mapping and EOTFs.
    - Although the API for communicating with our TVs is not public, the API and additional tools are available to partners that we have a relationship with to enable access to additional features that CalMAN does not expose or make use of. Please reach out to Neil Robinson if you would be interested in getting access to this information.