RAW camera DPCM compression performance analysis

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ABSTRACT

The MIPI standard has adopted DPCM compression for RAW data images streamed from mobile cameras. This DPCM is line based and uses either a simple 1 or 2 pixel predictor. Due to its simplicity, the 1-pixel DPCM predictor has been almost exclusively used in the industry and is of interest of our investigation. The importance of evaluating image quality deterioration due to DPCM compression is further stressed by the fact that often DPCM compression/decompression is used repeatedly along the image processing pipeline to save memory buffers. In this paper, we analyze the DPCM compression performance as MTF degradation. Since it is well known that MIPI DPCM predictor is difference dependent and an edge is the most challenging structure, we use edges with varying level difference. The MTF is estimated by using a slanted edge according to I3A standard.[1] Slanted edges with different differentials can be generated by using Siemens star images that are binarized to two levels. The edge level differences are chosen such that they will produce the largest DPCM quantization error (edge difference falls between two quantization levels). DPCM compression introduces errors of different magnitudes and signs based on the pixel differences. As expected, those errors cause high pass or low pass degradation of the edge. In this study we passed edges with different level differences through 1-pixel DPCM compressor and computed the MTF responses. An eye diagram plot of the MTFs over a range of edge differences presents a useful methodology for evaluating the severity and consistency of a DPCM compression scheme. The latter becomes increasingly important as fixed or adaptive tone mapping is introduced later in the image processing pipeline.

Keywords: MIPI, DPCM, RAW, compression, MTF

1. INTRODUCTION

The MIPI standard has adopted DPCM compression for images streamed from mobile cameras.[2] This DPCM is line based and uses either a simple 1 or 2 pixel predictor. Here, we analyze the performance of the simple 1-pixel DPCM quantizer. This scheme uses one previous pixel to predict the present pixel, in combination with a M-N bit quantizer. If used on raw image data (e.g. with a GRBG Bayer pattern) we have $X_{pred}(n) = X_{decoded}(n-2)$. An example of a simple DPCM encoder and decoder[3] is shown in Fig. 1 .

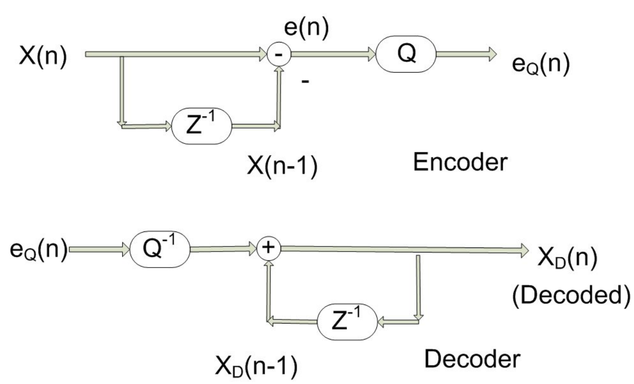

Figure 1. A simple DPCM encoder/ decoder block diagram.

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The quantizer is non-uniform and it implemented by encoding the range of the difference and the quantization value. In this manner, values within a given range are encoded similarly. As the range moves towards higher values, quantization levels remain the same while the quantization error increases. An example of quantization error as a function of pixel difference is shown in Fig. 2.

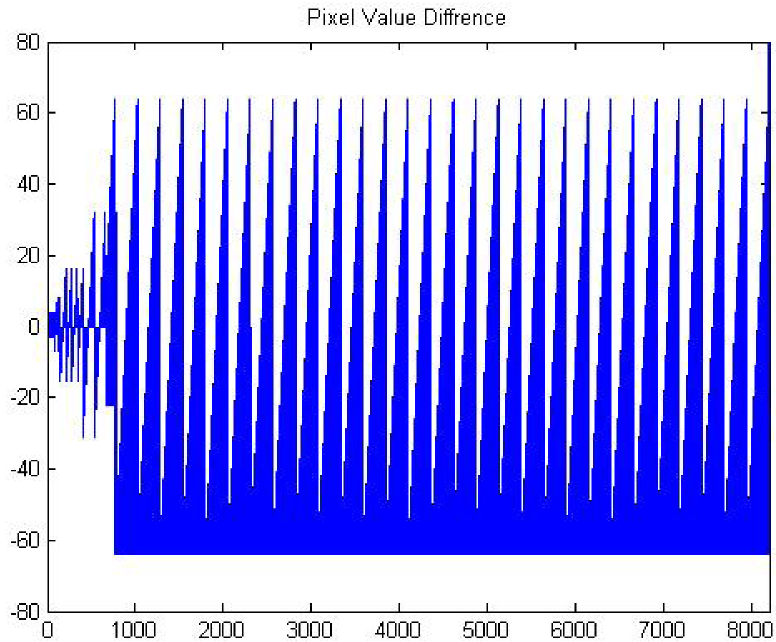

Figure 2. DPCM encoder error

As noted before, DPCM compression/decompression scheme can be used repeatedly along the image processing pipeline to reduce the data transfer rate and the size of the intermediate data storage buffer. As such, the deterioration in the worst case can be accumulative, especially if there is significant signal perturbation (processing) between DPCM decompression and compression. Also of importance is subsequent image post-processing that might later be introduced in the pipeline. Any adaptive noise reduction or edge enhancement algorithm would be affected by low pass or high pass edge deterioration. Furthermore, static tone mapping functions like gamma correction or adaptive processing, i.e, high dynamic range imaging, might potentially bring up darker levels thus making the DPCM deterioration more visible (see Fig. 3). In this figure, the leftmost image pair shows an edge image with and without DPCM compression. The other two image pairs show how gamma correction and tone mapping can exacerbate DPCM effects. As shown by the arrow, the effects of DPCM compression become more pronounced when the image is subject to tone mapping.

2. TESTING PROCEDURE

To test the performance of a certain DPCM scheme, one needs to be able to isolate and observe its effects independent of the other steps in the image processing chain. The presence of image demosaic algorithm will introduce artifacts similar to DPCM compression and thus needs to be considered carefully. Additionally, the compression artifacts will depend on the capabilities of the lens system which may vary considerably. In order to remove the influence of the above two factors, we have selected synthetic, gray scale images for DPCM testing. The decision is consistent with the fact that DPCM compression is not done across different color channels and allows for lens PSF to be introduced later.

To test the performance of a given DPCM scheme, the following procedure is used:

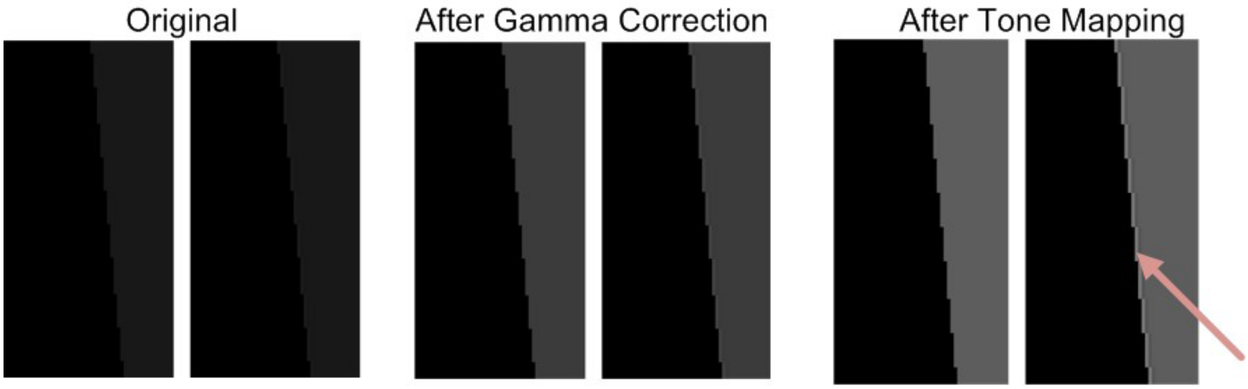

Figure 3. Effect of DPCM on other image processing steps: Left and right image pairs show original image on the left and processed image on the right.

- Siemens star images are generated and binarized to black and white (2 level) images *
- Black and white values (low and high levels) are then adjusted to produce a certain level difference (the lower level does not affect DPCM compression, thus it is selected to be zero).
- The level differences are selected based on the following.
  - They span the input range of the quantizer, i.e., 2^M levels.
  - They are just below and over (as bit granularity allows) the mid-point that is between any two adjacent quantization levels †
- Compress the image using the compression scheme under evaluation
- Select an edge with an appropriate slant and compute MTF using I3A standard
- Overlay the MTF for different edge differences to produce the eye diagram

The test procedure is as illustrated in Fig. 4.

3. RESULTS

In this section, we compare the slanted edge MTF response of a cropped region of a DPCM compressed Star image to that of the corresponding region in the original image. The MTF response is the frequency response of the derivative of the cropped edge image region. For an ideal edge whose derivative is the impulse function, the MTF is a horizontal line. For real image edges, the MTF is flat for a large section of the frequency range and has a slow roll-off. This MTF response is further affected by DPCM compression. For light to dark (intensity) transitions, we have plotted the MTF for transitions from 21 to 0 and 150 to 0. For dark to light transitions, we have plotted the MTF for 0 to 24 and 0 to 208. It is clear from Fig. 5 that the DPCM scheme introduces errors which results in a noticeable degradation of the MTF response curves. An interesting observation is that the degradation can either be high pass or low pass in nature. The amount of degradation is indicated by the deviation of the MTF of the DPCM compressed image (shown in blue) from the MTF of the original edge image (shown in red). Fig. 6 through Fig. 9 show the MTF response functions for DPCM compression of different level transitions (from low to high as well as high to low) as compared to the MTF response of the original image(in black) for the three M-N compression schemes considered (12-6 bit, 10-8 bit and 8-6 bit compression). Different amounts of MTF degradation are introduced by DPCM for different pixel intensity difference values.

*The usage of Siemens star is not critical but useful to evaluate the consistency of the methodology

†The level difference selection is not necessary (brute force approach could have produce similar results) but useful to reduce the amount of data to visualize/display.

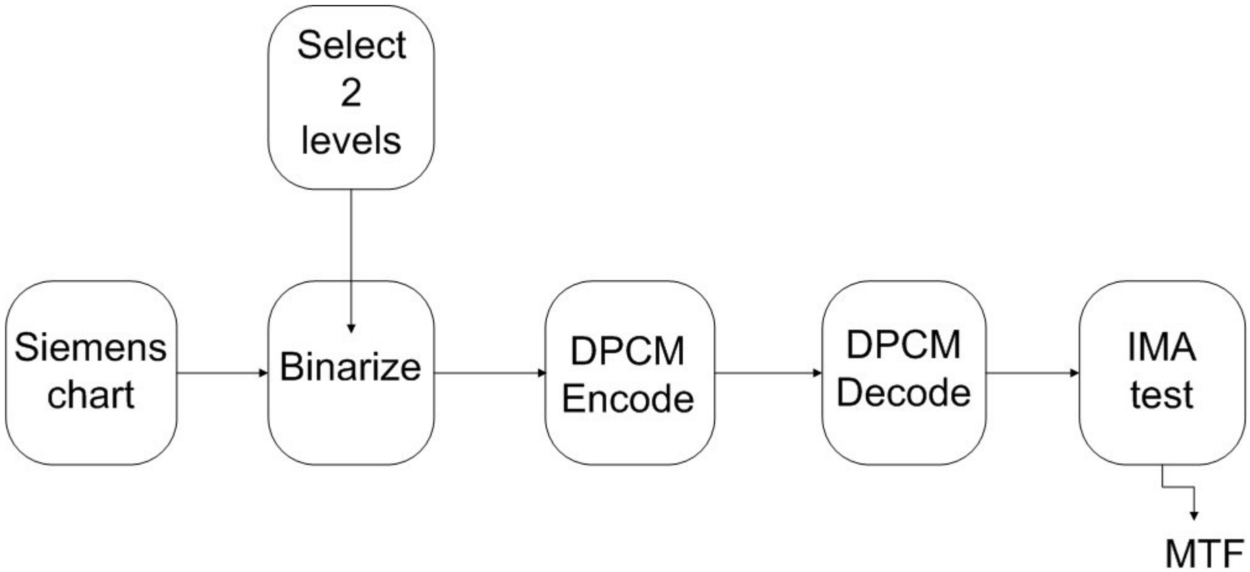

Figure 4. Illustration of the DPCM test procedure.

This composite curve represents the modulation transfer integrity function (MTIF). The MTIF gives a visual representation of the MTF degradation across all possible intensity difference levels. A smaller opening of the eye is indicative of better consistency in the degradation across edges of various pixel level transitions[4] and vice versa. Better consistency means that edges of different pixel level differences are affected the same way by the DPCM scheme. Also, the eye diagram is indicative of the severity of MTF degradation since it gives the deviation of the MTF from the ideal case.

4. CONCLUSIONS

As the demand for data bandwidth and storage during image processing is increasing, the MIPI compression standard is getting adopted as a means to reduce the amount of intermediate data. The use of DPCM is more advantageous when image processing is done on dedicated hardware and DPCM compression/decompression often is been used repeatedly between blocks. Based on the input and output bit width, there are different schemes for MIPI compression. Evaluation of the image deterioration due to DPCM compression is critical due to the fact that subsequent processing may exaggerate the artifacts. Selection of an appropriate DPCM scheme then is an important factor that affects the performance of the subsequent post processing and the final image quality. In this paper, we introduce a method for evaluating image quality deterioration that is based on measuring the MTF of a slanted edge. Evaluation of the DPCM compression as a function of the edge differential provides an insight into the MTF deterioration introduced and consistency of the compression. Eye diagram plots provide a means to visually assess the consistency (edges being affected in the same manner) and severity (deviation from the ideal curve) of the image deterioration introduced by DPCM compression.

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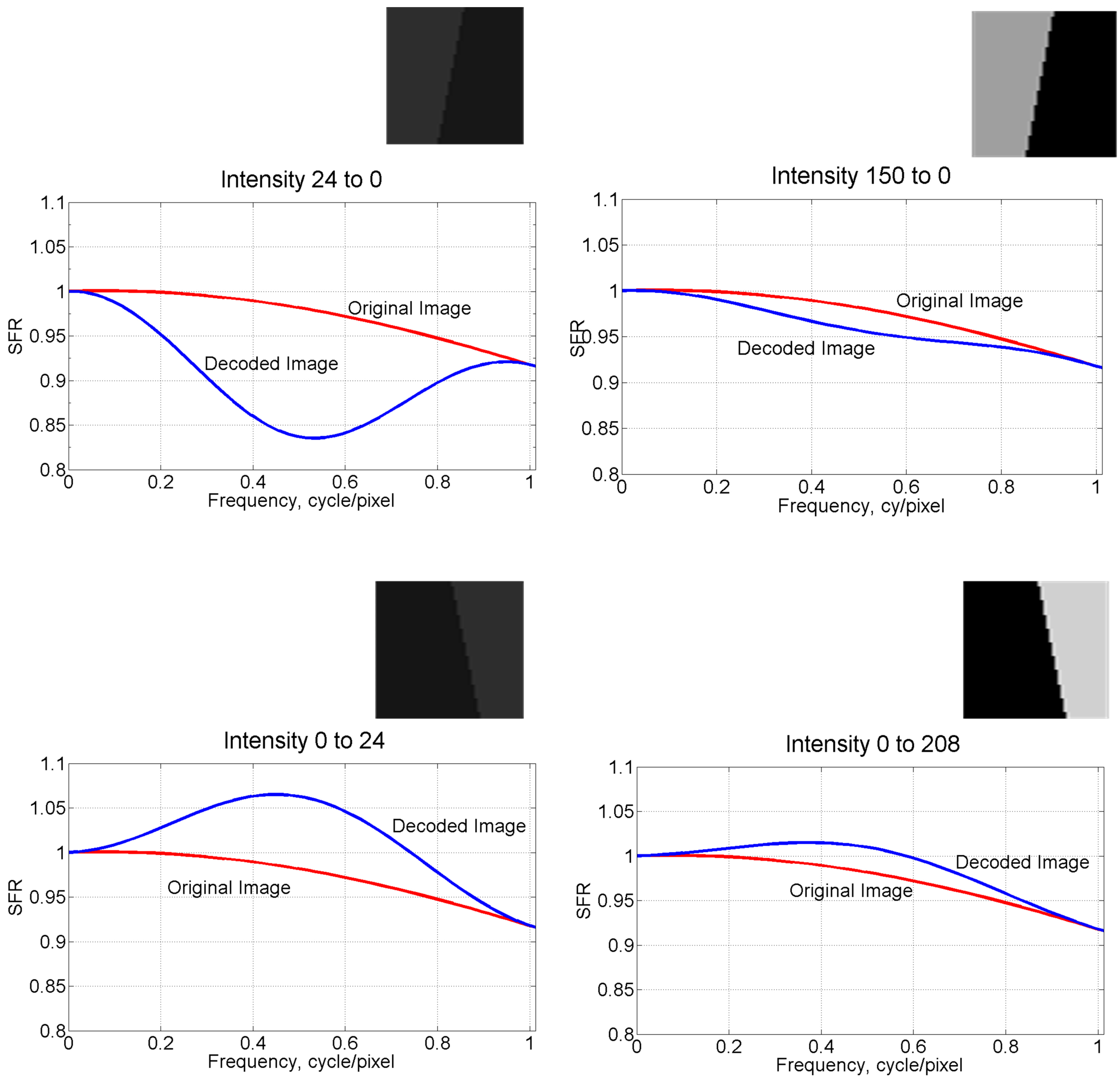

Figure 5. Comparison of the MTF responses for the slanted edges for different pixel value transitions. Notice that the MTF response is degraded by the DPCM scheme. The X axis has digital frequencies , MTF is plotted on the Y axis.

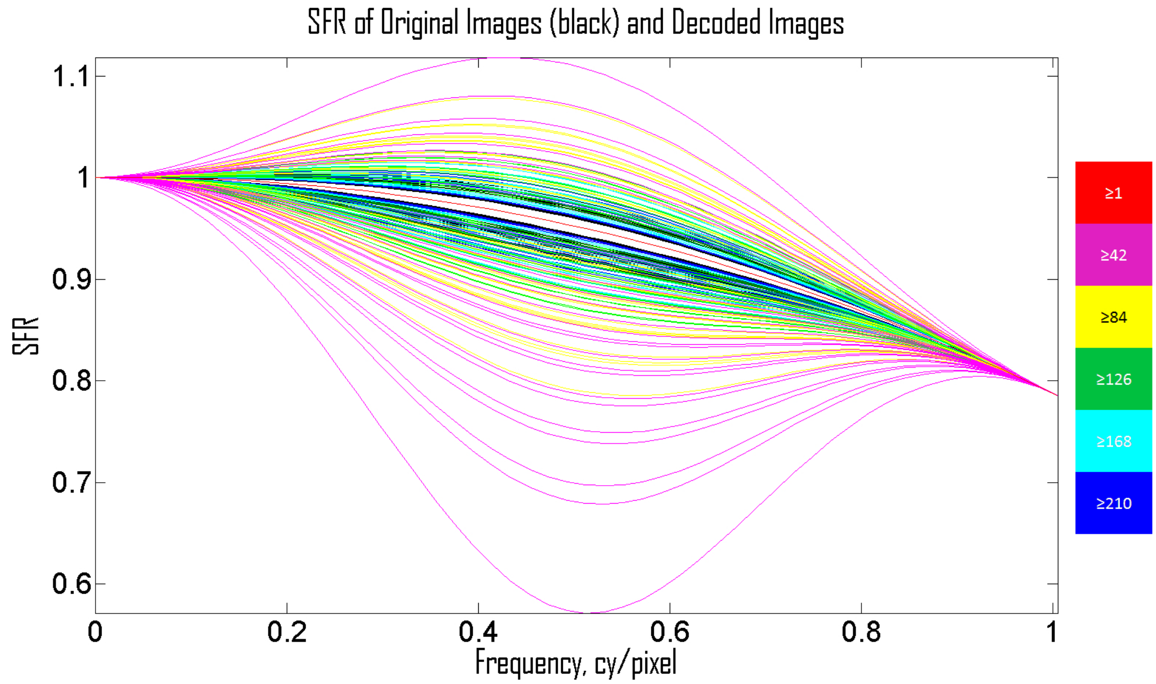

Figure 6. DPCM eye diagram. Transition from intensities 0-255 to 255 for the 8-6 bit compression scheme. Frequency response of the original image is shown in black.

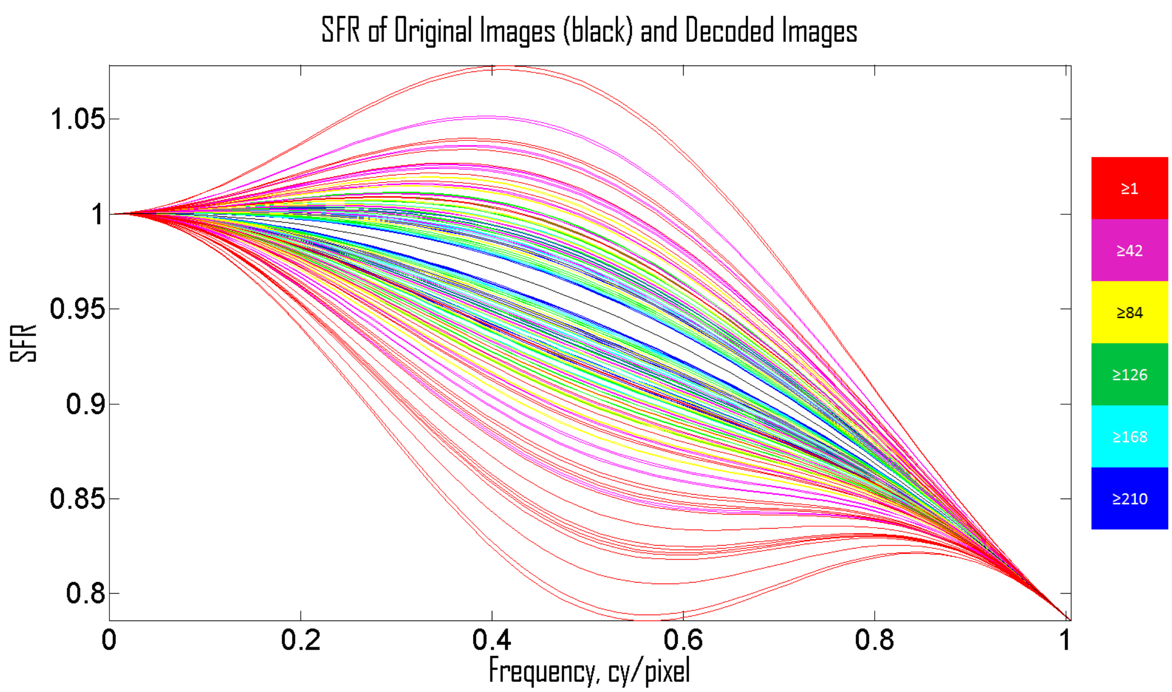

Figure 7. DPCM eye diagram. Transition from intensities 0-255 to 0 for the 8-6 bit compression scheme. Frequency response of the original image is shown in black.

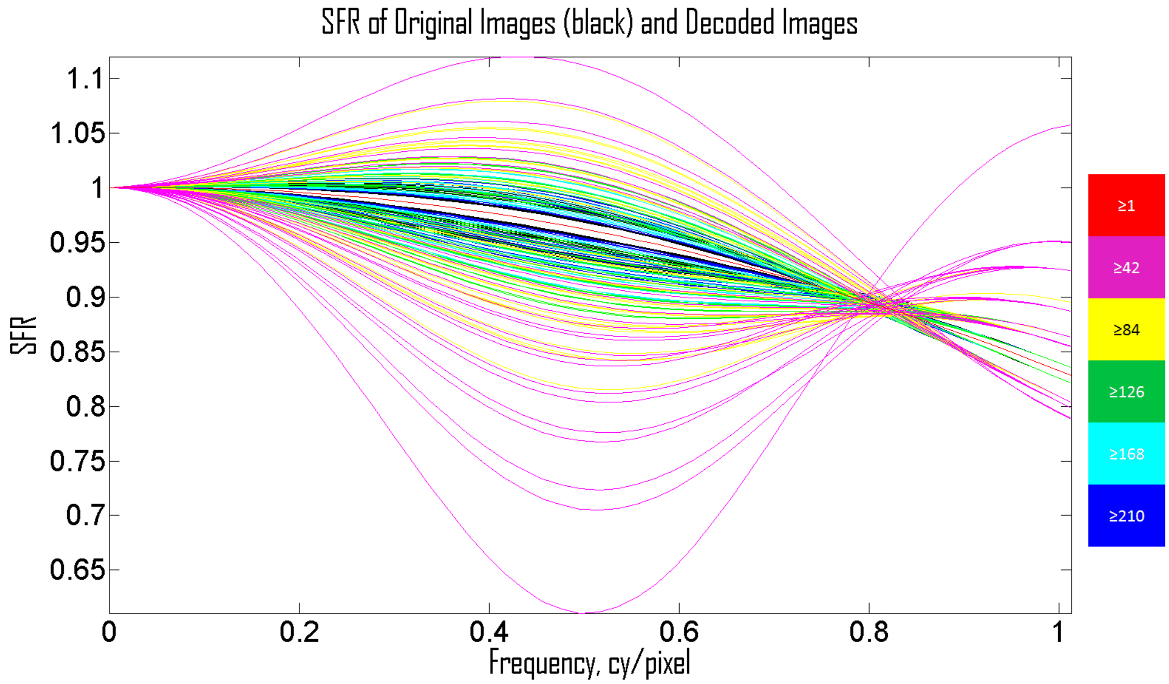

Figure 8. DPCM eye diagram. Transition from intensities 0-255 to 255 for the 10-8 bit compression scheme. Frequency response of the original image is shown in black.

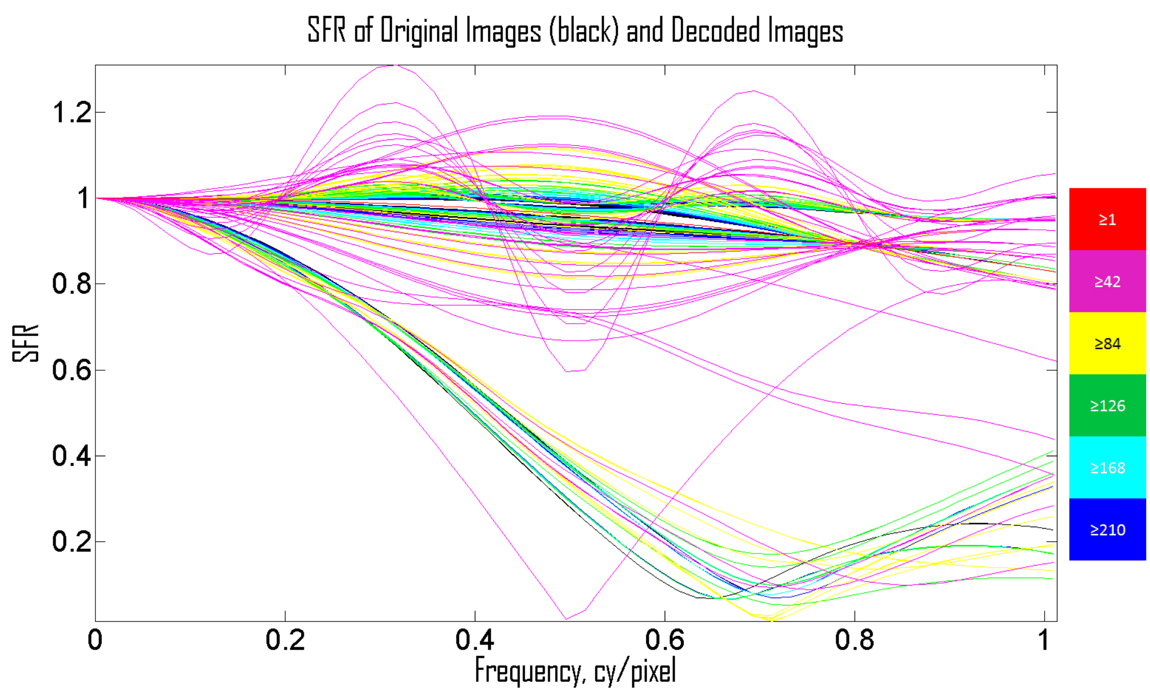

Figure 9. DPCM eye diagram. Transition from intensities 0-255 to 255 for the 12-6 bit compression scheme. Frequency response of the original image is shown in black.