Evaluating the quality of EDOF in camera phones

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Outline

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- Problem Description
- Evaluation methodology – test chart
- Evaluation methodology – proposed metrics
- Evaluation methodology – data processing
- Results
- Conclusions and remarks

Introduction

- Quality and reliability as well as cost are critical considerations when designing digital cameras
- Extended Depth Of Focus (EDOF) solutions might offer significant advantages over conventional technologies
- Different EDOF techniques have been well known and recently have entered camera phone market
- Conventional spatial frequency response (SFR) techniques might produce misleading or insufficient results when evaluating EDOF algorithms as those techniques assume different optical behavior
- In this paper we present a methodology to evaluate EDOF quality in a systematic fashion

Problem Description

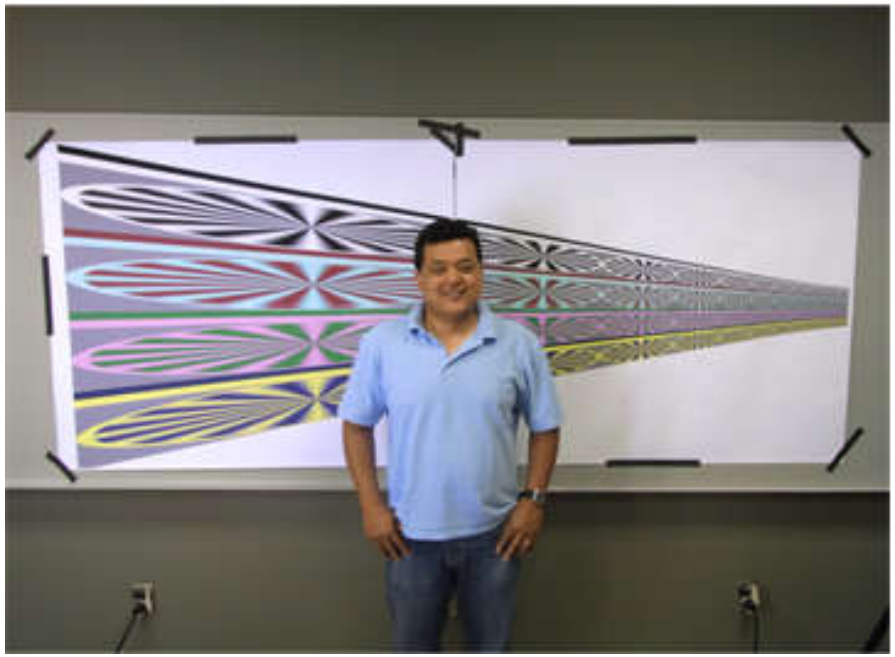
- EDOF implementations usually comprise of a combination of custom optics coupled with additional post-processing
- Critical elements of an EDOF evaluation for digital cameras are
  - focus quality variations over the whole range covered
  - consistent behavior over the whole color gamut
  - noise introduced during EDOF processing
  - artifacts introduced during EDOF processing
- Requirements for EDOF evaluation methodology
  - observe the above issues preferable in a single setting
  - offer comparison between EDOF and fixed/adjustable focus cameras
  - offer feedback for tuning of EDOF modules
  - evaluation is preferable on fully processed color images

Proposed test chart

- Test chart practicality is an important consideration – easy to deploy and with reasonable size
- Constructed as
  - 4 x12 grid of perspective compensated Siemens stars
  - every row has 12 stars that have the same properties.
- The 4 rows have the following properties
  - black and white stars
  - stars with no red component (the red plane is flat at a fixed offset)
  - stars with no green component (the green plane is flat at a fixed offset)
  - stars with no blue component (the blue plane is flat at a fixed offset)

Test chart

- Under certain assumptions the perspective is adjusted such as after capture all Siemens stars will appear as circles



Test Chart with perspective adjustment



Captured image of the test chart

Proposed metrics – frequency response

- **Frequency response at DC**
  - related to the dynamic range of the sensor
  - uses the horizontal stripes (dark and bright) above every star
- **Frequency response at frequencies up to Fs/2**
  - computed for every star and every color channel
  - normalized with respect to the DC
  - Includes a band around the true frequency to account for geometric distortion
- **Frequency response drop off (in case of post-processing/sharpening) – visual evaluation**
  - signifies roughly how much frequency was there to start with
  - edge enhancement block (if present) artificially boosts high frequencies
  - The inflection point of the frequency response can be used as a gauge for the frequency response before edge enhancement

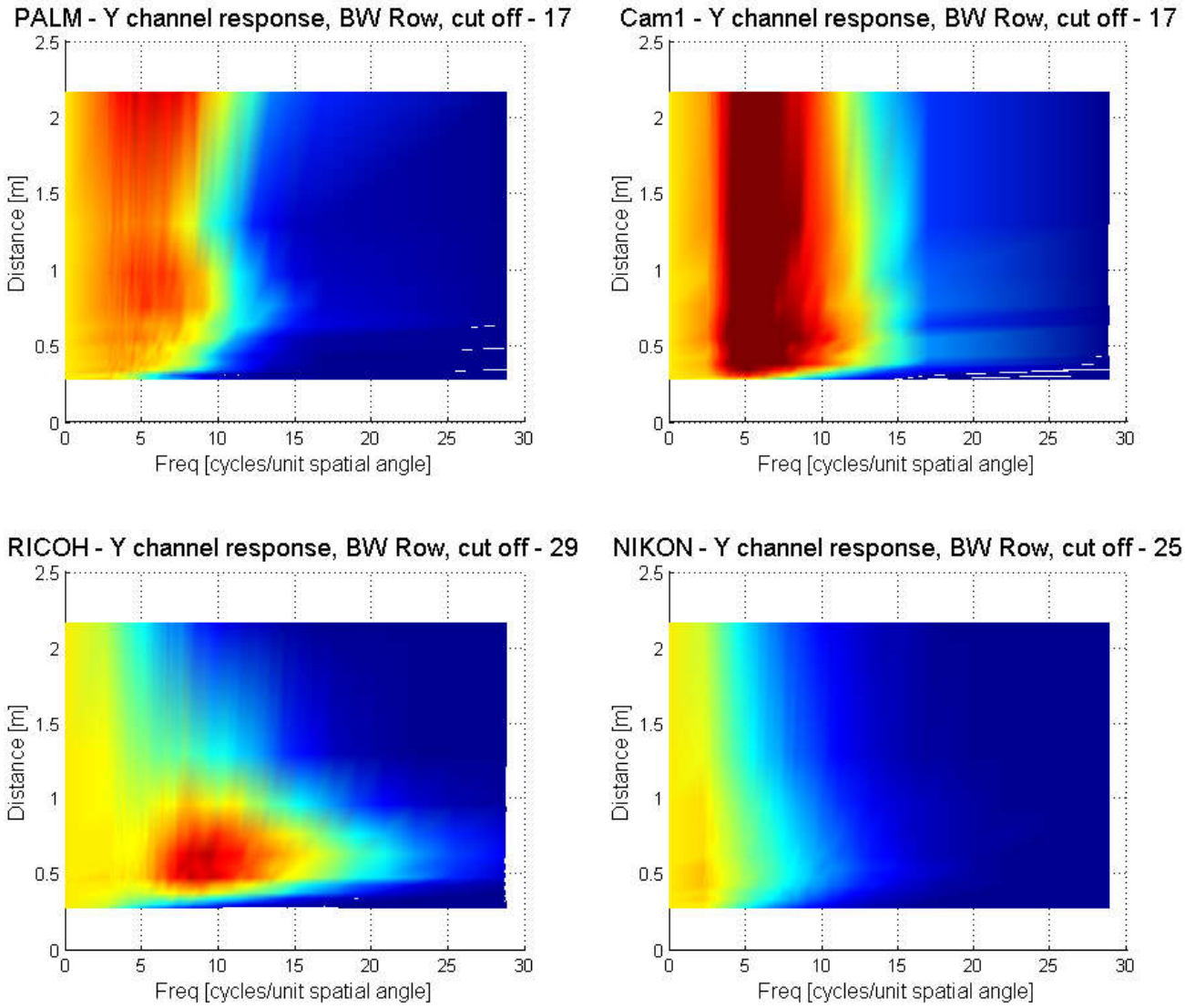
Proposed metrics – noise & artifacts

- To quantify uncorrelated noise and correlated noise (artifacts) the following metrics are used
  - Adjacent circle MSE
    - MSE between two concentric circles
    - ideally should be the noise if there were no artifacts present
    - bigger MSE can be interpreted as an indication that artifacts are present
  - Remaining noise in a circle
    - energy out of the band that is significantly above the noise level
    - represents how much energy was artificially introduced by an EDOF processing

Results – cameras under comparison

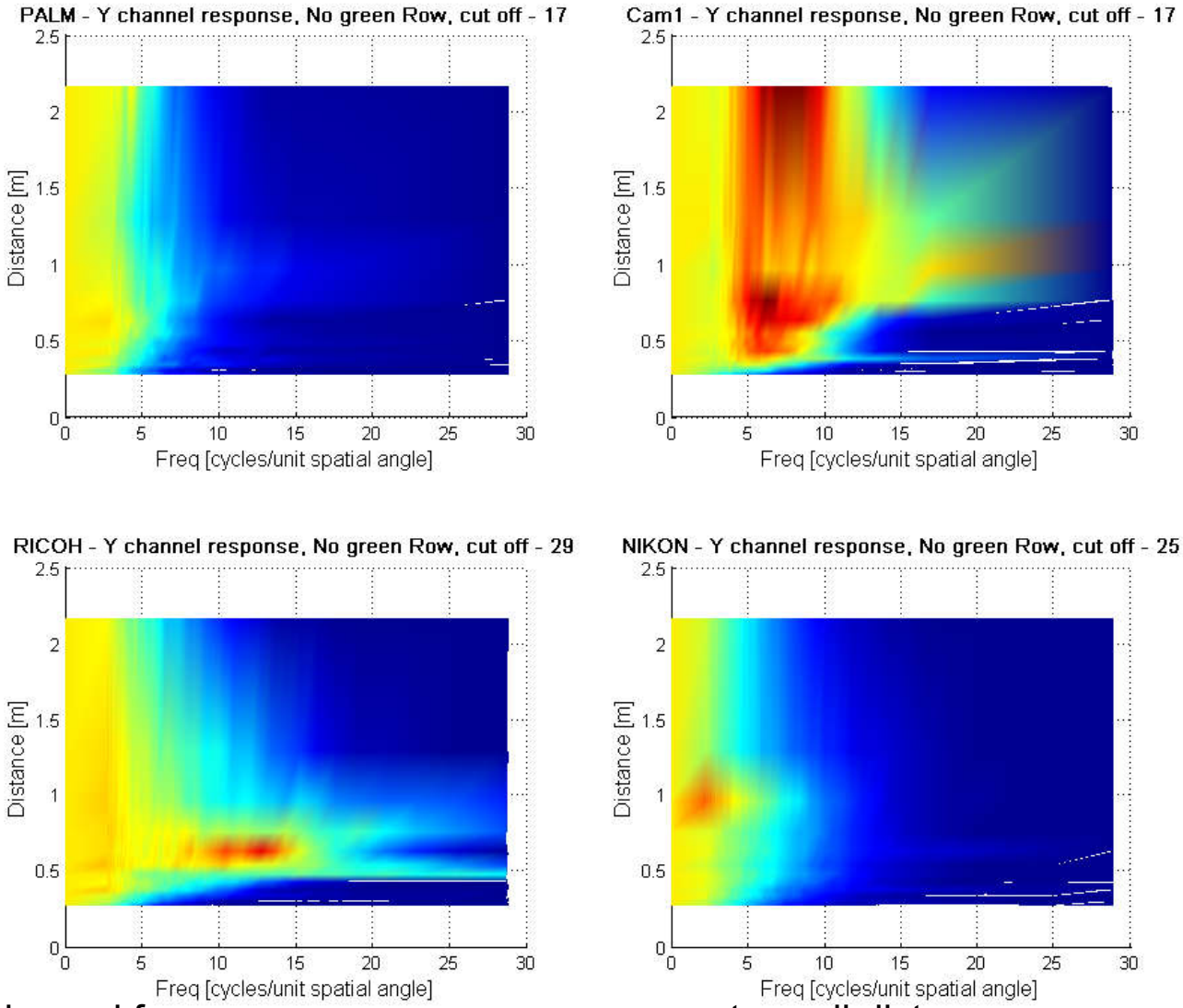
- Palm-pre (large depth of focus, small aperture)
  - Phone camera with EDOF turned on by default
  - algorithm decides which channel is the sharpest and uses it as a reference to bring “sharpness” to others
- Cam1 (large depth of focus, small aperture)
  - Phone camera with automatic focus placed around the middle of the chart
- Ricoh (medium depth of focus, medium aperture)
  - DSC camera with automatic focus placed around the middle of the chart
- Nikon (large depth of focus, large aperture)
  - DSLR camera with automatic focus placed around the middle of the chart
  - F-number adjusted for max range

Results



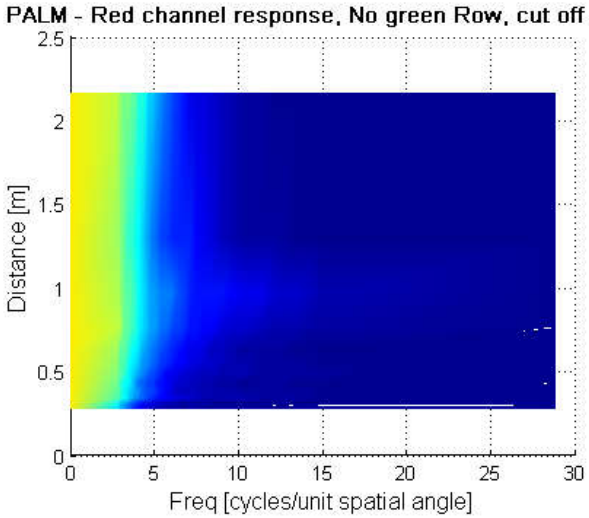
Y channel frequency response on B/W star - all distances

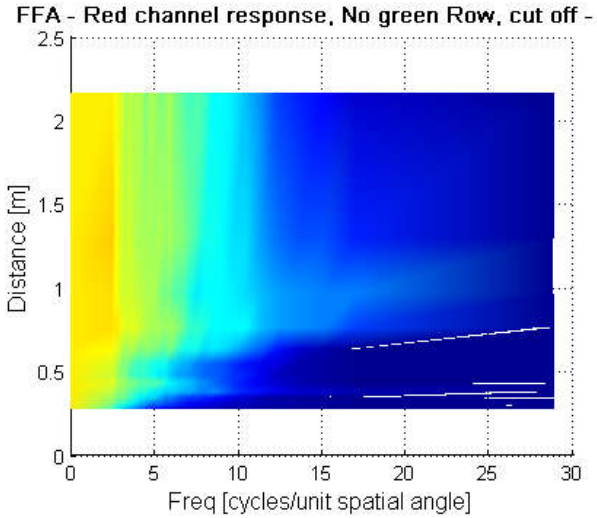
Results

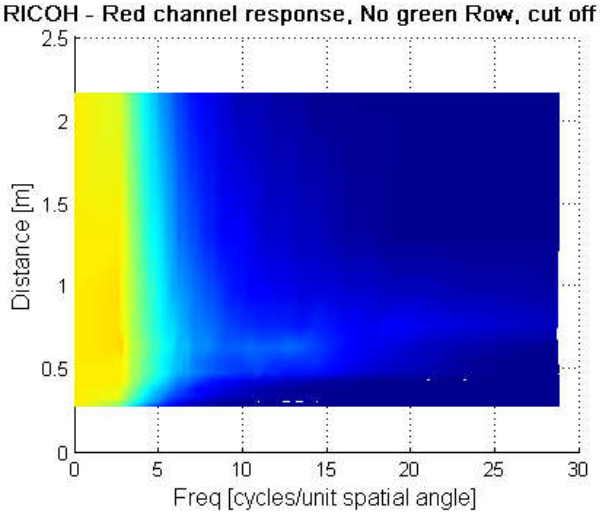


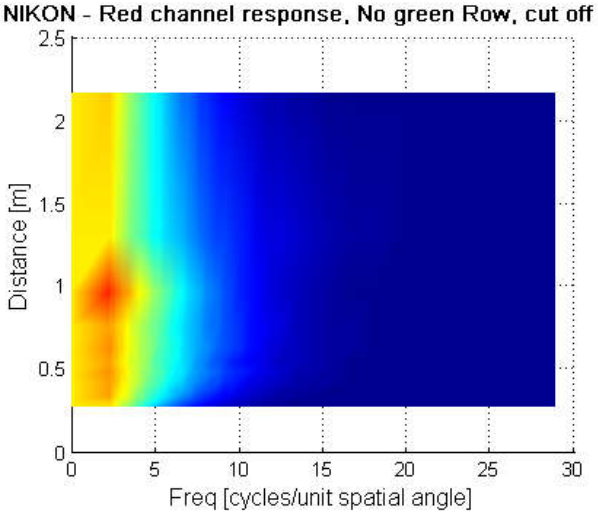
Y channel frequency response on no green star - all distances

Results



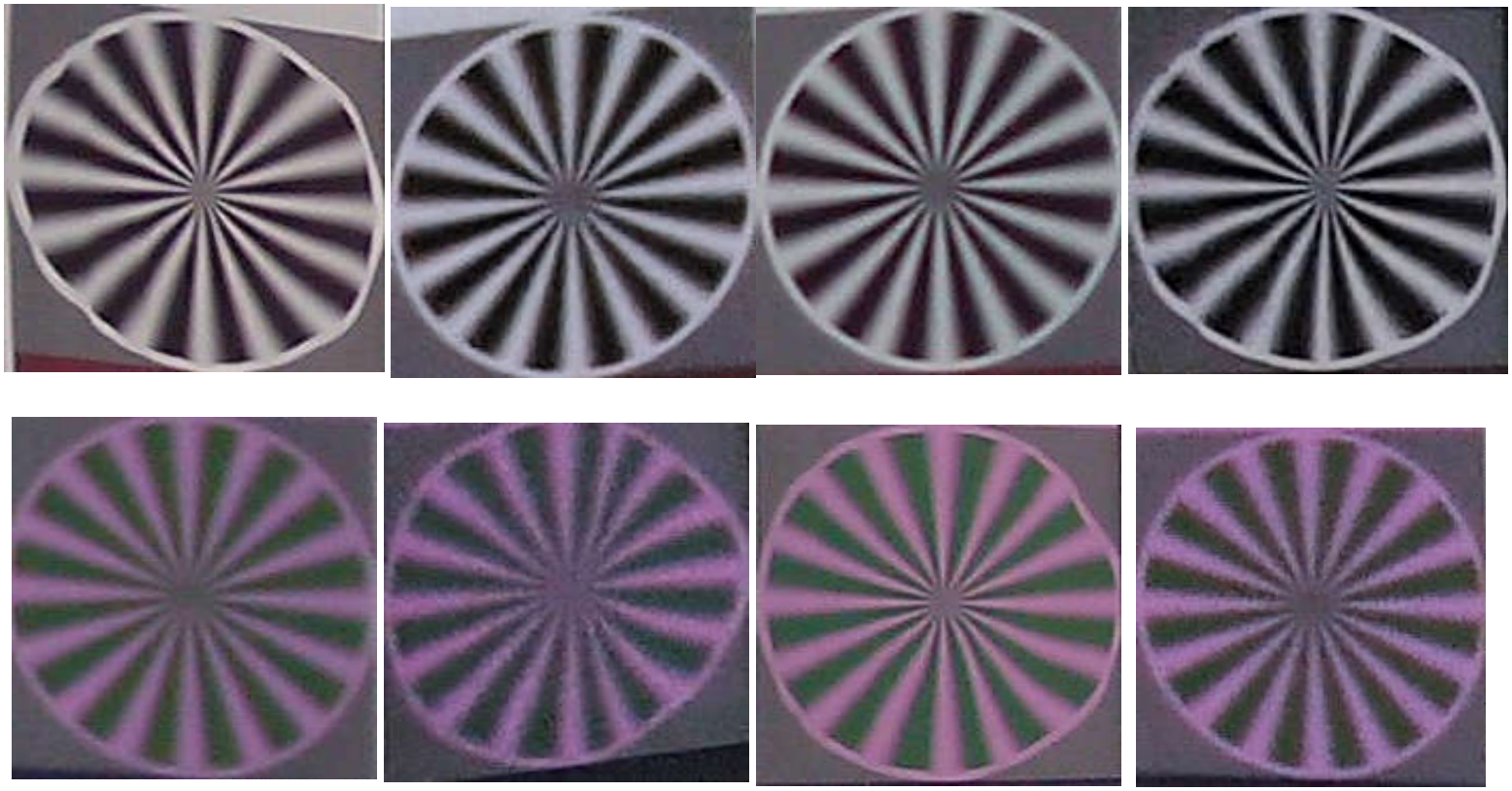






RED channel frequency response on no green star - all distances

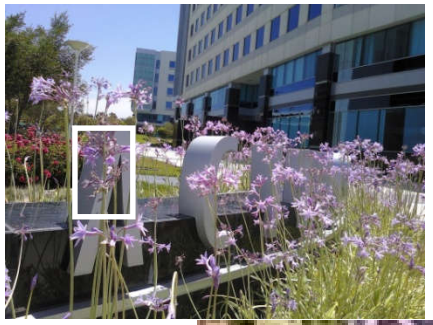
Results



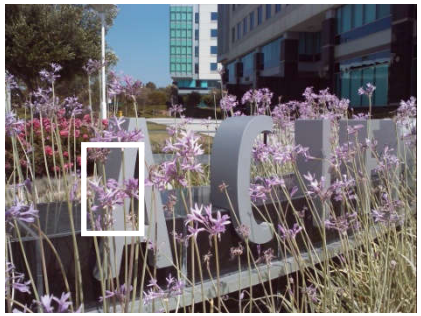
Close and Far on B/W stars (above) and no green stars (below)

first is Cam1 next PALM (left to right), left pair is close, right pair is far (both rows)

Palm-pre



Cam1



Natural Images





Palm-pre



Cam1



Natural Images





Palm-pre



Cam1



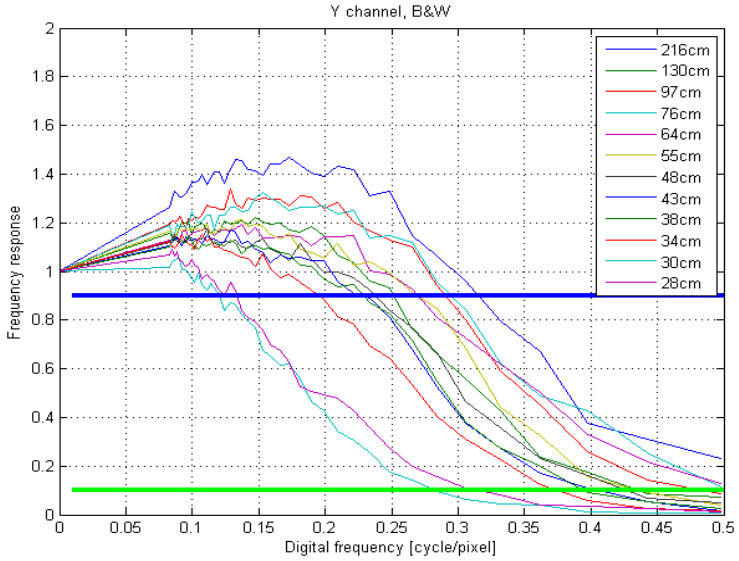
Natural Images



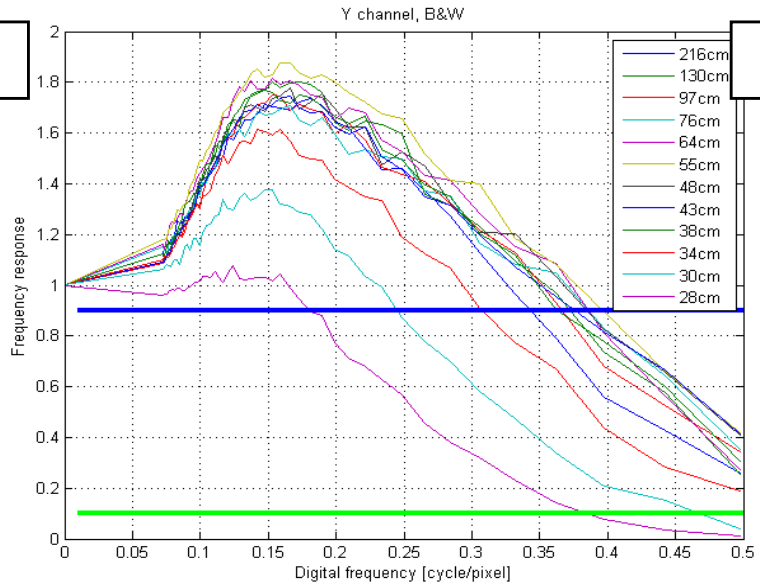


Results

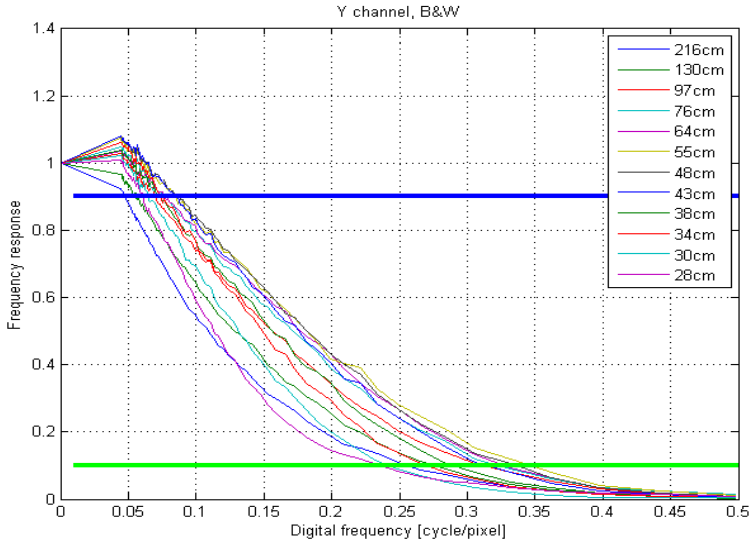
Palm-pre



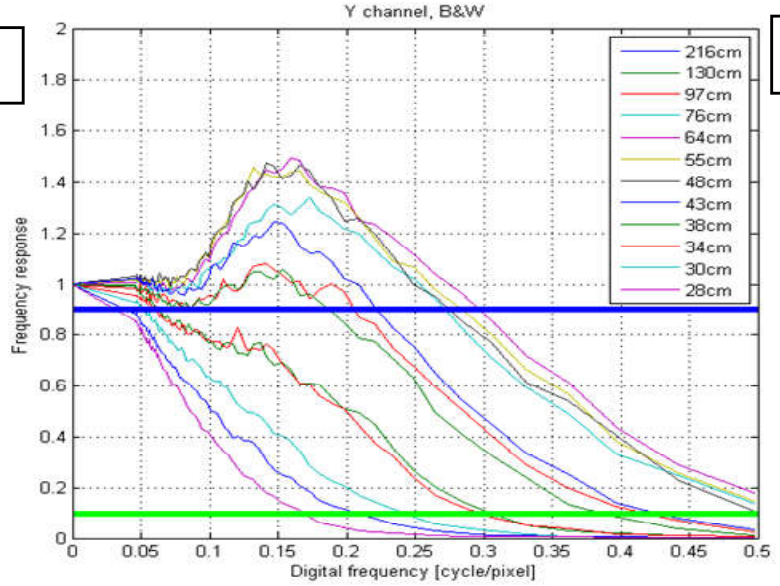
Cam1



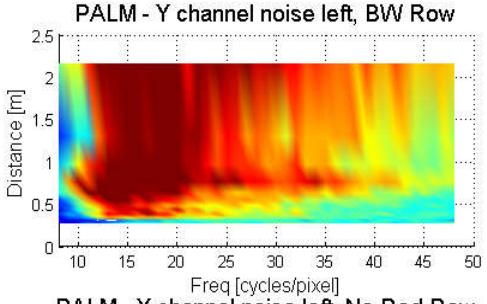
Nikon

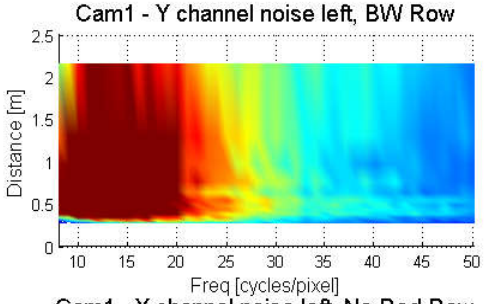


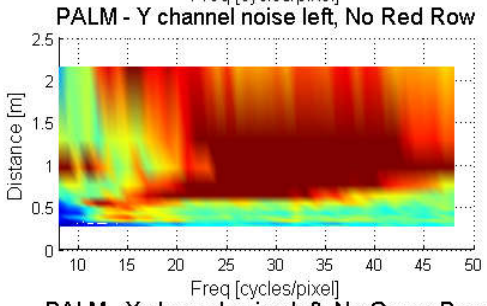
Ricoh

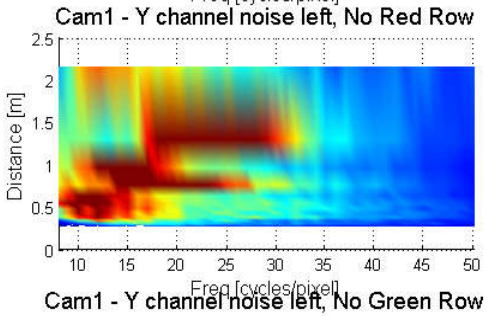


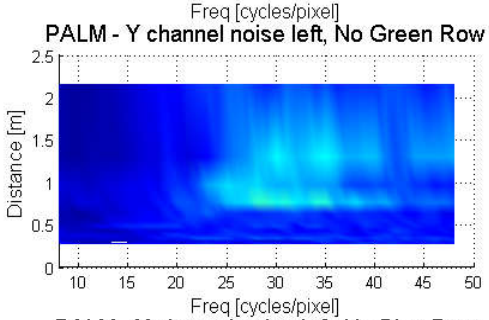
Noise results

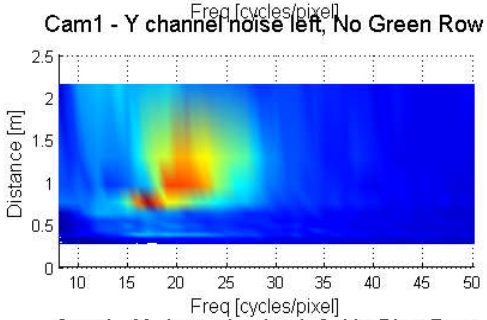


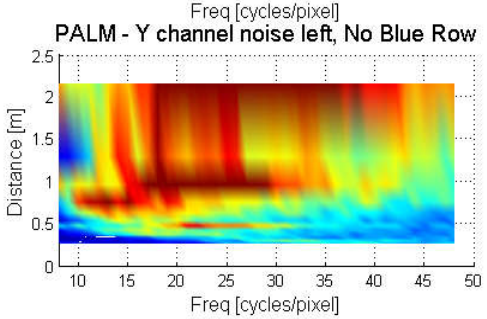


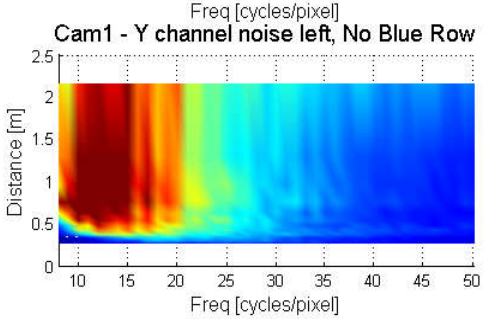










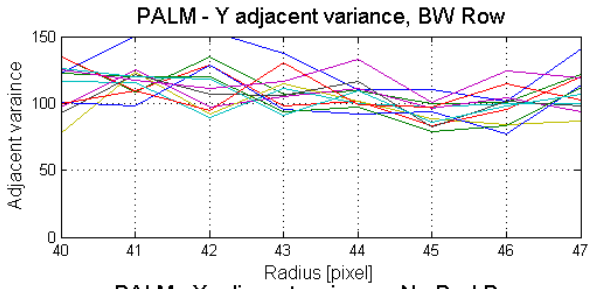


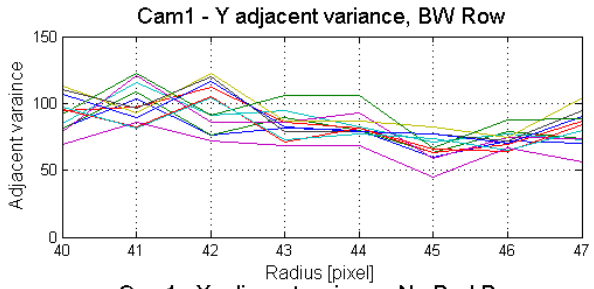
Noise measurements:

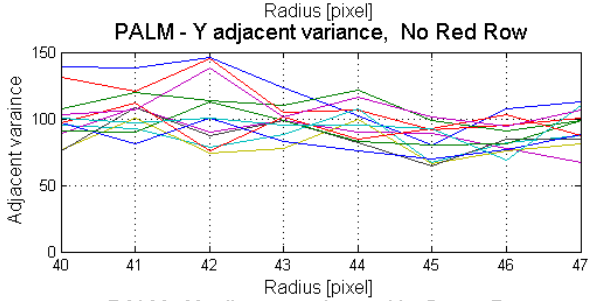
out-of-band energy, for each channel over the distance

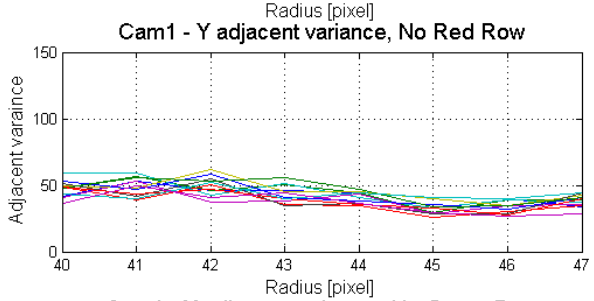
warmer color = more noise

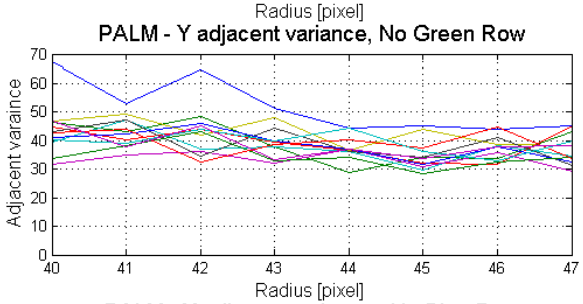
Noise results

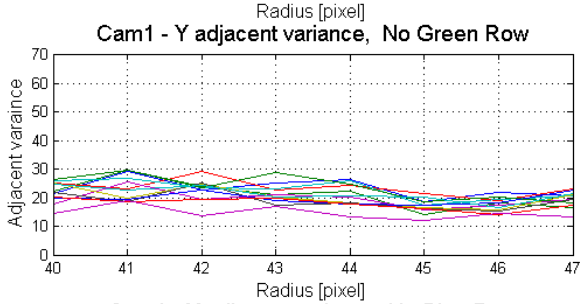


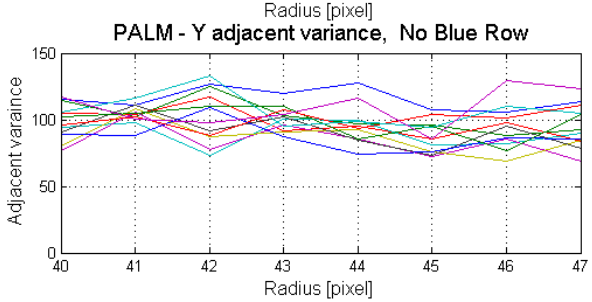


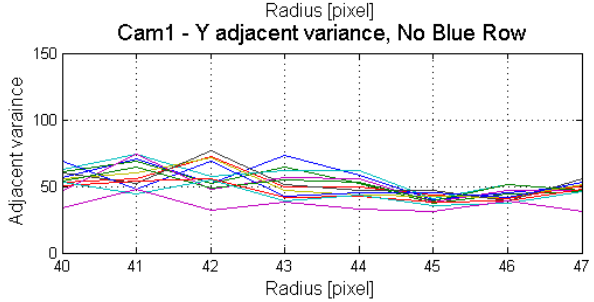












Noise measurements: Adjacent circle variance

higher number = more noise

Conclusions

- EDOF can extend the capabilities of the classical lens design
- Potential benefits and drawbacks of EDOF for camera phones should be analyzed systematically
- We apply the proposed metrics in 4 different camera with different capabilities to show how EDOF quality can be evaluated
- Our results indicate that the EDOF evaluated here does not show significant depth of focus increase for the range tested compared to the conventional focus module
- Artifacts associated with EDOF in this case are noticeable
- More research needs to be done on how to perceptually combine the metrics into a single EDOF quality indicator
- Standardizing a methodology to evaluate EDOF technologies similar to the one proposed here would be beneficial for identifying cases where this technology would be useful