Using Automatic Exposure Control in Digital Radiography

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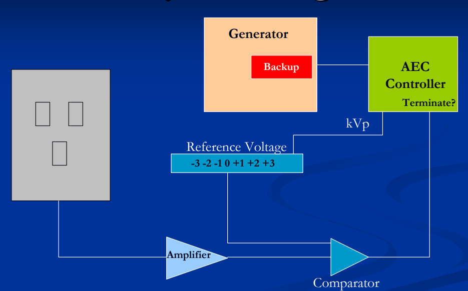
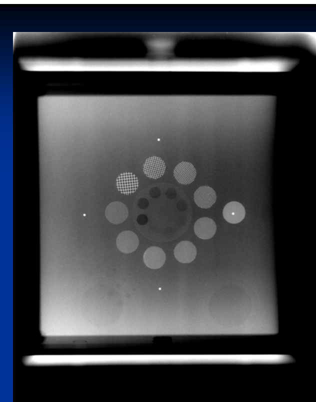
Automatic Exposure Control

- The purpose of AEC is to deliver consistent, reproducible exposures across a wide range of anatomical thicknesses, tube potentials, and users
- Detectors used in AEC systems include fluorescent screens with PMTs/photodiodes, ionization chambers, and possibly solid state detectors

AEC System Diagram



Loosely based on Bushberg, Seibert, Leidholdt, and Boone, The Essential Physics of Medical Imaging.



Fundamental AEC performance characteristics

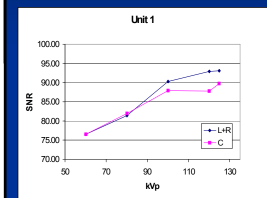
- Initial acceptance testing
  - Sensor selector/location
  - Density correction
  - Screen sensitivity adjustment
  - Sensitivity vs. speed setting
  - Reproducibility
  - AEC balance/field sensitivity matching
  - AEC sensitivity
  - Patient thickness tracking
  - kVp tracking
    - Beam quality correction curve
  - Backup timer
  - Cell mapping
  - Minimal exposure duration
  - Field size tracking*
- Ongoing QC testing
  - AEC sensitivity
  - Density correction
  - kVp tracking
  - Patient thickness tracking
  - Reproducibility
  - AEC balance
  - Backup timer
  - Minimum exposure duration
  - Field size tracking*

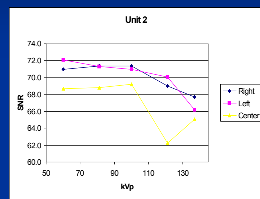
Remember this

- Test your system at the SID for which the grid is focused and your system calibrated
- AEC detectors themselves have an inherent energy dependence
- Slight variations do exist between cells and should be evaluated upon acceptance testing

True vignette: Siemens Sireskop system with reciprocating grid. AEC balance consistently failed when tested at an SID of 100 cm. Moving the tube to an SID of 115 cm resulted in passing test. Cause: Grid reciprocation delay was set to result in appropriately exposed images at an SID of 115 cm, where Siemens calibrates. We were able to adjust the delay to balance the AEC cells within 10% and provide acceptable image quality at 100 cm SID.

Inter-cell differences exist





Density control

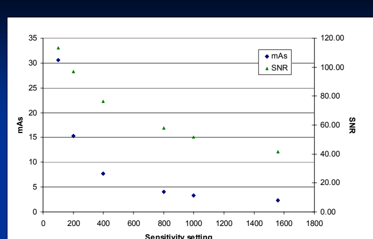
- Adjusts mAs upward or downward in increments of 25-30% per step
- Some newer DR systems do not incorporate this feature
- Published guidelines/recommendations
  - Tested for proper operation and similar step size (NCRP 99)
  - 0.15 to 0.30 OD per step (AAPM 74)
  - 4-step controller should adjust by 20-25% per step (AAPM 14)
- Fundamental differences from S/F: Absence of feature on some systems
  - Curious that some systems still include this feature

Air kerma vs. sensitivity selection

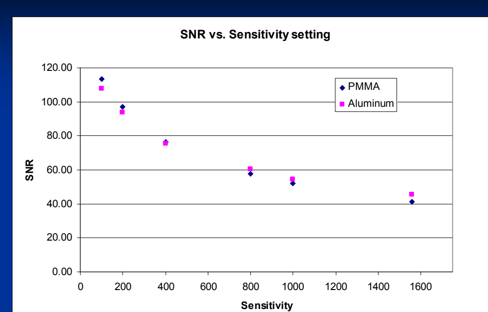
- Many DR systems feature selectable 'sensitivity' settings for imaging protocols
  - Refers to AEC, not digital detector
- These settings adjust the sensitivity of the AEC cells resulting in higher or lower image receptor exposures
  - Akin to using different speed screen/film combinations for different body regions – e.g. 200 speed for chest and 400 speed for general
- While no regulations or guidelines exist, it is prudent to verify that exposure varies logically and predictably with selection
  - Inversely proportional

Air kerma vs. sensitivity

- Fundamental differences from S/F: Similar to screen selector setting
- Philips DR system – Phil Rauch
  - Resolution of EI is not sufficient to identify changes in sensitivity setting



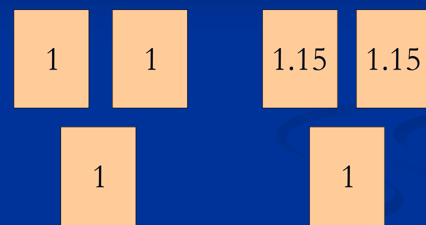
$$\text{mAs}_2 = \text{mAs}_1 \times \frac{S_1}{S_2}$$



AEC Balance

- Field sensitivity matching
- To achieve consistent exposures, AEC cells should be balanced
- Manufacturers of x-ray systems use several different schemes for AEC balancing
- Thus, a one-size-fits-all test will not be valid if you work with a variety of systems
- Fundamental difference from S/F: Some manufacturers have changed schemes

Common AEC balance schemes



AEC Balance

- Test AEC balance during acceptance testing to set a baseline standard for balance
- Ask your service engineer about the calibration/balancing procedure
  - Many manufacturers today use AEC systems that are not serviceable for balance – they can only be replaced
  - In this case you are stuck with manufacturer's balance scheme
  - Other manufacturers still have tunable AEC cells
    - Pots in generator
    - Software interface
    - Pots in detector housing
- Published guidelines/recommendations
  - ± 5% across all combinations (AAPM 14)

AEC Balance

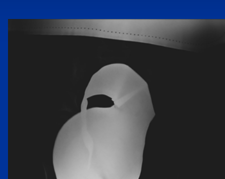
- Cells must also be matched when used in combinations
- AEC systems may terminate the exposure when the most sensitive cell reaches the required current level, or may average the signal between the cells being used
- Same criteria apply

	C	L	R	L+R	L+C	R+C	All
Unit 1	6.32	7.23	7.16	7.16	6.73	6.7	6.83
Unit 2	46.6	69.9	70.4	69.9	55.7	55.9	59.8
Unit 3	4.5	4.32	4.44	4.39	4.39	4.44	4.39

See also *'X-ray generator and automatic exposure control device acceptance testing'* by Raymond P. Rossi, M.S., in Specification, Acceptance Testing and Quality Control of Diagnostic X-ray Imaging Equipment, Proceedings of the 1991 AAPM Summer School

Backup timer

- In the case of a system malfunction or technical error, the exposure must be terminated after a certain period of time or delivered mAs
  - 600 mAs ≥ 51 kVp
  - 2,000 mAs < 51 kVp
  - 21CFR1020
- Many digital radiography systems have preset time limits based on kVp and mA settings, and some will terminate if no signal is detected



Reproducibility

- K_a delivered by the AEC system should be reproducible
- Published guidelines/recommendations
  - COV < 0.05 (AAPM 14)
  - ± 5% of average (NCRP 99)
- I'll leave it as an exercise to prove that these guidelines do not say the same thing

Minimum exposure duration

- Thin or less dense body parts can lead to very short exposure times for AEC-controlled radiography
  - E.g. chest imaging, small patients
- AEC systems should be capable of delivering appropriate exposures at these exposure times
- Published guidelines/recommendations
  - T_{min} < 1/60 sec or 5 mAs, whichever is greater (21CFR1020)

Minimum exposure duration - DR

- However, for DR systems, some of which require less exposure than film/screen systems, this limit is insufficient
  - Typical PA chest x-ray at 125 kVp and 320 mA: 3-4 ms
- Most measurement equipment is incapable of measuring these extremely short times
  - kVp divider
  - Spinning top
  - Oscilloscopes
- Acquire a series of images with a phantom that yields clinically relevant exposure times (3-10 msec)
  - Examine exposure time in DICOM header
  - Measure SNR in a uniform portion of the image
  - COV_{SNR} < 0.05
- Also, it is very important to find the minimum response time (MRT) of your AEC/generator and ensure that your AEC exposure times do not fall below this time

AEC sensitivity

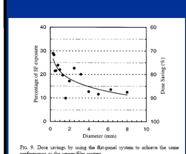
- Typically referenced to the center cell
- Manufacturer has calibrated the AEC system to the air kerma *they* believe their detector needs
- You may need to calibrate the AEC system to the air kerma *you and your radiologists know* the detector needs

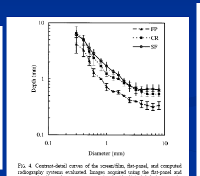
AEC Sensitivity

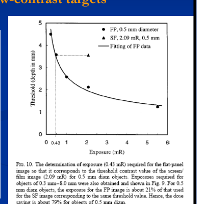
- AEC system must be calibrated to deliver the necessary but sufficient K_a to the image receptor
- Relatively simple task with screen/film imaging – achieve O.D. in linear portion of H+D curve (~ 1.4)
- Digital imaging is not contrast-limited, but noise limited
- How can you set up your AEC system to deliver the necessary amount of *noise* in an image?
- Fundamental difference from S/F: Wide range of K_a will yield usable images, must decide on acceptable noise level in images

Rong XJ, Shaw CC, Liu X, Lemacks MR, Thompson SK, *Comparison of an amorphous silicon/cesium iodide flat-panel digital chest radiography system with screen/film and computed radiography systems — A contrast-detail phantom study,* Med. Phys. **28**(11):2328-35, 2001.

Use of scored images of contrast-detail phantom (CDRAD) under clinical image processing conditions to attempt to determine detector exposure required to achieve similar detectability for small low-contrast targets



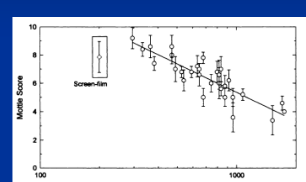




Conclusion: 0.43 mR required to achieve similar LCD for 0.5 mm object compared to 2.09 mR for the same screen-film image (21%)

Huda W, Slone RM, Belden CJ, Williams JL, Cumming WA, Palmer CK, *Mottle on computed radiographs of the chest in pediatric patients,* Med. Phys. **199**:242-252, 1996.

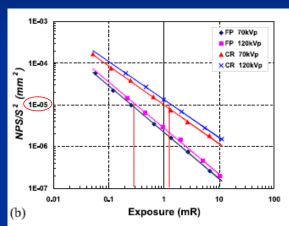
Use of a rating system based on degrees of mottle to determine what sensitivity number of a Fuji AC series would be needed to match the mottle in a 600-speed s/f system, then use the actual sensitivity numbers measured to compare CR to s/f.



Conclusion: To achieve comparable mottle to 600-speed s/f system a twofold increase in exposure is needed as compared to mean sensitivity number. An exposure consistent with a 200-speed s/f system would be needed to achieve negligible mottle.

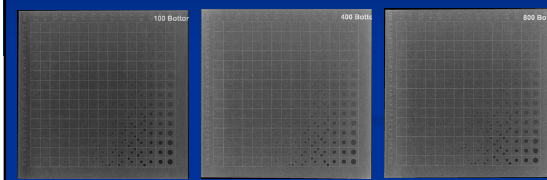
Liu X and Shaw, CC, *a-Si:H/CsI(Tl) flat-panel versus computed radiography for chest imaging applications: image quality metrics measurement,* Med. Phys. 31(1):98-110, 2004.

Compare indirect digital radiography and cassette-based digital radiography systems in terms of fundamental image quality metrics.



Conclusion: Indirect digital radiography detector has significantly higher DQE and lower NPS than cassette-based digital radiography detector. The magnitude of the differences is illustrated in the graphs from the manuscript.

Give radiologists a visual idea of what the impact of dose to the image receptor is on image quality – CDRAD phantom exposed under PMMA



Can also be done with other phantoms – ACR R/F phantom, anthropomorphic phantom, or even add noise to a patient image for comparison

Caveats

- Image processing has a large impact on noise (low-contrast detectability) and high-contrast resolution, and thus AEC sensitivity should be configured with this in mind.
- Also, pixel size has an impact on noise in images – this is especially important for digital receptors where pixel size is variable, such as PSP systems

I have a confession to make…

- I have been using a very simplistic method of calibrating our AEC systems for sensitivity (cassette-based)
- Eight inch PMMA phantom imaged using 80 kVp
- Processed with *Sensitivity*
- S number used as indicator of proper calibration
  - Properly calibrated reader
- DR – compare with acceptance testing data
- It ain't that easy

Methods for calibrating sensitivity

- Noise-based method
- K_a-based methods
  - Use a CR cassette with a cutout for a detector
  - Solid-state detector behind grid
  - Pre-detector K_a and primary transmission through grid*
- Use an exposure indicator (EI)

A word on exposure indicators

- Sometimes the relationship between EI and detector exposure is well understood or intuitive
  - Cassette-based digital radiography
- Sometimes the relationship between EI and detector exposure is not obvious/proprietary
- Exposure indicator must be verified
- Goldman AAPM Summer School

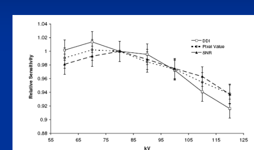


Figure 3. Comparison of the relative sensitivities of indicators that relate to image plate response for an Agfa CR system, normalized to the response at 80 kV. Error bars indicate an achievable tolerance of 3% in adjusting the AEC.

Doyle, P and Martin, CJ, Calibrating automatic exposure control devices for digital radiography, Phys. Med. Biol. **51**:5475-5485, 2006.

Noise-based AEC calibration

- For each kVp, an S number can be associated with the standard deviation of pixel values that produce the desired noise characteristics
  - STDEV is proportional to the square root of the x-ray fluence absorbed in the IP (after correcting for structured noise)
- Recommend use of an SNR-based threshold for choosing noise level
  - Example: $SNR_{threshold}$ of 5 → Signal difference of 50 can be seen with $\sigma = 10$
  - Still some determination to be done
- Setting up AEC in *Semi-automatic* EDR mode yields clinically valid results in *Automatic* EDR mode

Christodoulou, EG, Goodsitt, MG, Chan, H, and Hepburn, T, Phototimer setup for CR imaging, Med. Phys. 27:2652-2658, 2000.

K_a-based methods

- CR cassette with cutout
- S = 200/E, E = exposure (mR) for Fuji CR
- Cutout machined into IP cassette to accept 15 cm pancake ionization chamber
  - Introduces realistic scatter from cassette, overcomes cassette sensing

Doyle P, Gentle D, Martin CJ, Optimising automatic exopsure control in computed radiography and the impact on patient dose, Rad. Prot. Dosim. 114:236-39, 2005.

K_a-based methods

- Solid-state dosimeter with lead backing should be used to eliminate the effect of backscatter
- Not possible for all DR systems

http://www.rpi.edu/dept/radsafe/public_html/RADIATION%20DETECTORS_files/MOSFET.jpg

http://www.unfors.com/products.php?catid=168

Doyle P, and Martin CJ, Calibrating automatic exopsure control devices for digital radiography, Phys. Med. Biol. 51:5475-85, 2006.

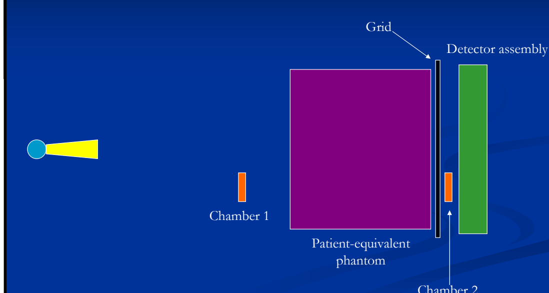
Pre-detector K_a

- Simple measurement to make
- Scatter avoidable
- Necessitates measurement of primary transmission of anti-scatter grid
- Some inaccuracy introduced due to beam hardening by grid which is not accounted for in this measurement

Measuring grid characteristics

- Anti-scatter grids are labeled with information such as:
  - Line rate
  - Grid ratio
  - Interspacer material
  - Focus distance
- They are not, however, labeled with other information
  - Contrast improvement factor
  - Primary attenuation
- Fetterly/Schueler poster SU-GG-I-153

180 cm focused grid measurement



Measuring the Bucky factor

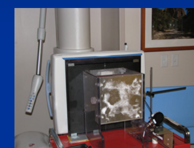
Rear chamber behind grid

Entire setup

A level grid is imperative

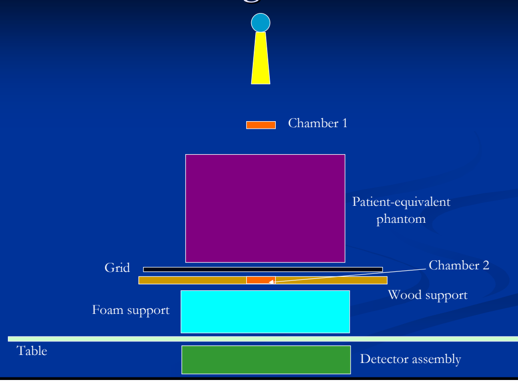
Measurement w/o grid

Typical exposure readings



Measuring for clinical grid

100 cm focused grid measurement

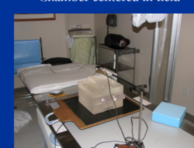


Table

Support for grid

Chamber centered in field

Centering and leveling of grid is imperative

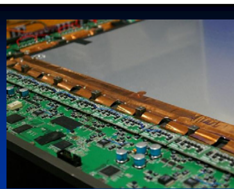


Complete setup

EI-based methods

- Once the EI has been verified to be accurate across the range of kVps and patient thicknesses used and seen clinically, it should be used to perform these tests
- EI verification involves some of the same skills and measurements discussed here
- More from Jeff Shepard coming up

You're not done yet…



http://www.instablogsimages.com/images/2007/11/23/digital-flat-panel-x-ray-detector_28.jpg

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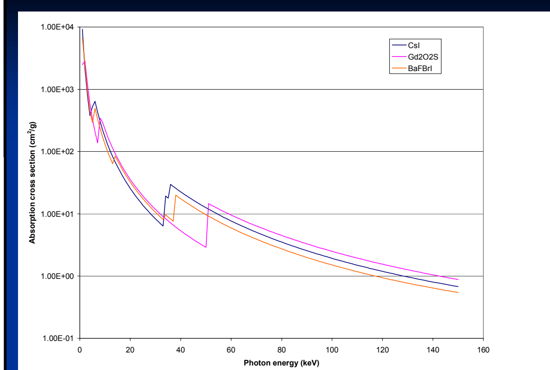
The Problem

- Many of our AEC systems have been calibrated for use with screen-film systems
- The energy response of gadolinium oxysulfide (Gd_2O_2S) screens is substantially different from that of image receptors used in digital radiography
- Thus, to properly expose digital radiographs, we must recalculate the kVp correction curve for our AEC systems to respond correctly considering the image receptor characteristics



The Solution

- Beam-quality dependent calibration curves for AEC systems used for digital radiography

- Doyle and Martin have calculated theoretical kVp correction curves for both CR and IDR detectors
- Also note that the addition of small amounts of Cu filtration does not significantly affect the calibration

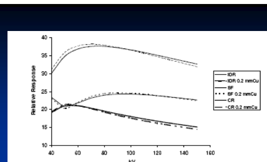


Figure 1. Variation of phosphor sensitivity with tube potential for a gadolinium oxysulphide (Gd_2O_2S) film-screen phosphor (0.20 mm thick), BaF(Br85%, I15%) CR phosphor (0.22 mm) and a CsI IDR phosphor (0.50 mm). Data are shown for x-ray beams filtered by 2.5 mm of aluminium, and by 2.5 mm of aluminium plus 0.2 mm of copper.

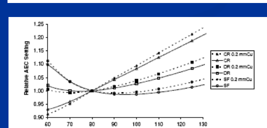
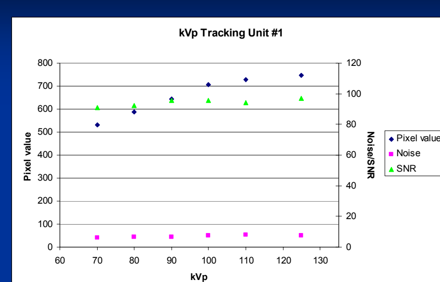
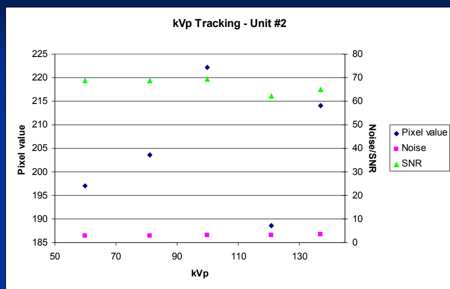


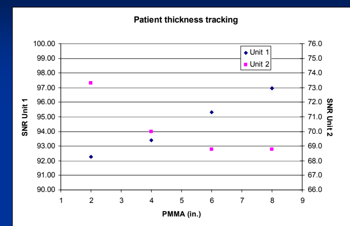
Figure 2. Theoretical evaluation of the variations in AEC setting for image receptor doses with a film-screen system, a CR system and an IDR system for x-ray beams with and without an additional 0.2 mm copper, normalized to the response at 80 kV.

Doyle, P and Martin, CJ, Calibrating automatic exposure control devices for digital radiography, Phys. Med. Biol. **51**:5475-5485, 2006.





Thickness tracking



Patient thickness tracking not only adjusts exposure time but also involves beam quality dependencies of detector absorption efficiencies and AEC sensitivity as well as scatter absorption by the AEC system and the contrast improvement factor of the grid.

Thickness tracking

- The overall variation I have seen when kVp tracking and thickness tracking are combined is 25-30% for one vendor (60 kVp) and 15% for another vendor
- When considering the combined impact of kVp and thickness variation, there is likely to be less variation for digital radiography systems (SNR) than in S/F (O.D.) due to the fact that the variation in Bucky factor over a range of kVp's no longer matters.
- Methods to attempt to improve on patient thickness tracking might include
  - Further tightening kVp correction curve
  - Calibrating with and using thin metal filters

What about phantoms?

- Simple, uniform phantoms are desired for AEC testing
- Also, consulting physicists probably don't want to lug around 65 lbs. of PMMA – and engineers certainly won't either
  - But, what about realistic patient scatter…

Phantoms for AEC calibration

- Moral of the story: PMMA, water, and aluminum, in the appropriate amounts, deliver similar transmitted spectra to the AEC system and digital receptor
  - So did 0.2 mm of Cu, but fluence was too high to achieve reasonable exposure times. 2 mm of Cu significantly altered the transmitted spectrum
- Introduction of scatter is a different situation

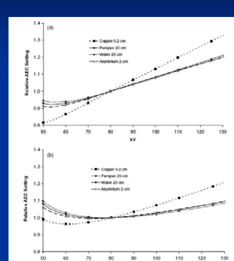


Figure 5. Calculated values for the relative AEC setting required for (a) a CR system and (b) an IDR system using four alternative phantom materials to simulate the x-ray beam transmitted through a patient.

Doyle, P and Martin, CJ, Calibrating automatic exposure control devices for digital radiography, Phys. Med. Biol. **51**:5475-5485, 2006.

Scatter and AEC calibration

- Scatter *does* influence absolute calibration of AEC sensitivity, however, but does not have a large impact on the kVp correction curve
- Many manufacturers do adjust the sensitivity of the AEC system based on the presence/absence of the anti-scatter grid

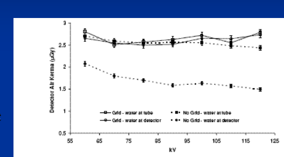


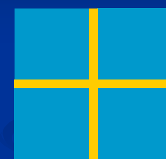
Figure 6. Plots of air kerma measured at the image detector for a CR system with the AEC set up to give a constant DAK across the range 60–120 kVp. Sets of results are shown for a 200 mm thick water phantom positioned at the image receptor and at the x-ray tube, with and without the grid in place in front of the dosimeter. Error bars indicate an experimental error of 3.3% in measuring DAK.

Future of Automatic Exposure Control in Radiography

- Fluoroscopy/angiography has already altered the way ADRC is performed
  - Monitoring signal value in a region of pixels
  - Detector is read many times per second
- These methods with TFT arrays do not work in radiography
  - Detector readout is destructive
- Fischer stereo unit – CCD array (Tony Siebert)
- CMOS (Tony Siebert)
  - Pixel architecture, with multiple transistors, allows for sampling without destroying the contained information

US Patent 5937027

- Thevenin B, Glasser F, Martin J-L, "Method and device for the taking of digital images with control and optimization of the exposure time of the object to X or g radiation."
  - Sobol W
- CCD array with two 'classes' of pixels
- Integrator/comparator
- Image corrected later



Other resources

- Goldman LW, Yester MV, Specifications, Performance Evaluations, and Quality Assurance of Radiographic and Fluoroscopic Systems in the Digital Era, 2004 Summer School Proceedings
  - Sobol WT, *Advances in and specifications for radiographic X-ray systems,* pg. 1-68
  - Goldman LW, *Speed values, AEC performance evaluation, and quality control with digital receptors,* pg. 271-297