

Assessing Television Camera Sensors For The Advanced HDTV Era

By Dave Bancroft

The exploding mass market in large high-resolution display screens for the consumer has placed big demands on broadcasters and content creators. Higher resolution video images are needed to fill these bigger and bigger screens. This has the greatest impact on camera imaging technology. Unlike Moore's Law for most integrated circuits, the quantum efficiency of camera image sensors does not increase each year, yet we must somehow maintain sensitivity and signal to noise ratio with smaller camera pixels (more squeezed into the same space). To make the challenge even greater, we are now making the pixels even smaller as we make the leap from interlace to super HDTV at sixty complete frames per second, in the new 1080p/60 format.

However, the design of broadcast cameras is not only a challenge in physics. Television production is a creative process, and technical tools such as cameras must support artists by fitting around creative working practices, not the other way round. For example, directors expect to adjust depth of field in the interpretation of a scene; in HDTV, this kind of creative control has become even more important to direct the attention of the consumer to the desired part of the big HDTV screen.

But where does television production technology come from? In recent years, there has been an increasing supply from consumer electronics camcorders; advances in miniaturization and manufacturing have resulted in amazing quality, tiny packages, and ever more economical prices – for the consumer. In particular, the convenience factor of the consumer camcorder increases when the optical format size shrinks; there are now 1/3-inch (and even smaller) sensors claiming "HD" capture.

Those considering such cameras should be aware that there is a catch, because once again physics gets in the way—although we have been able to maintain image resolution as we broadcasters reduced our format size first to 25 mm (1 inch), then to 2/3 inch—the greater demands of HDTV mean that resolution can be lost if we go smaller than this.

Perhaps at certain lens settings 1/3-inch format consumer camcorders may produce acceptable images, but what happens from one end of the zoom range to the other? What happens if the director wants to adjust the iris to control depth of field? The image will start to lose sharpness under many of these conditions, limiting the flexibility of the camera for creative purposes. It is important to realise that when this is happening it has nothing to do with how many pixels are in the camera sensor. The image will be soft coming out of the lens even before it reaches the sensor. Why?

It's a phenomenon of optics called diffraction limiting. Diffraction loss increases as the lens aperture is made smaller (bigger f-number); a smaller format sensor then has to magnify the lens image more for the same shot, magnifying the diffraction loss at the same time. Figure 1 shows graphically that diffraction limiting in the 1/3 inch format prevents its use for HDTV at most lens settings. Creative freedom then falls hostage to technology limitations.

In consumer equipment it may be acceptable to add artificial sharpening to try to compensate for the lost resolution. However, this might not work in a professional broadcast production as it may distort image reproduction.

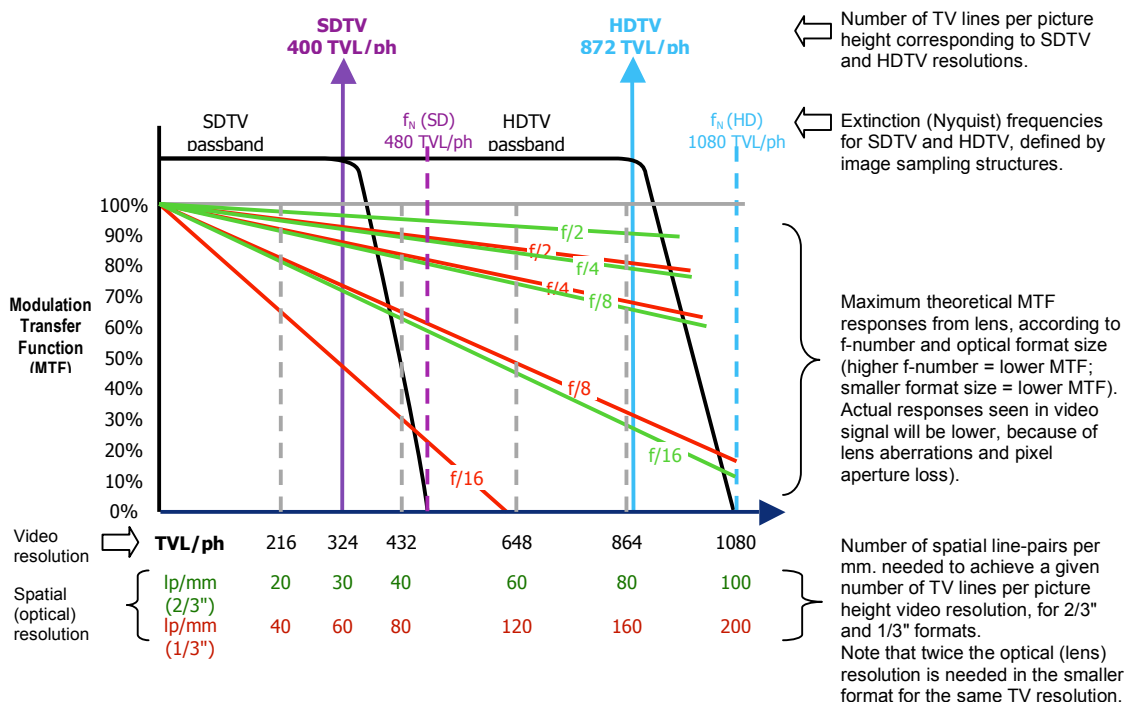


Figure 1. Graphs showing limitation of resolution due to diffraction, according to lens aperture, for 2/3 in. (green lines) and 1/3 in. (red lines) optical formats.

Attribution: Figure adapted from a diagram appearing in: "Special Report: Choosing a Lens for the New HDTV Studio," by Larry Thorpe and Gordon Tubbs, Canon July 2006.



The loss of natural image sharpness is not the only disadvantage of a very small format camera sensor; for the same number of pixels, e.g. 1920 x 1080, each pixel in the sensors will be smaller, which means it collects less light and produces fewer electrons to make the output signal. That means worse sensitivity and worse signal to noise ratio.

A further small format disadvantage is that the range of lens taking angles that are needed, especially for studio work, is limited. It is particularly difficult to get wide-angle lenses, because a much shorter focal length is needed for the same taking angle as the larger format.

Overall, the “sweet spot” for broadcasters in HDTV is still the 2/3-inch optical format size, because together with a convenient range of lens angles and good sensitivity it allows a useful range of lens iris settings between the two optical limits of diffraction limiting at small apertures and lens aberrations at large apertures. In comparison, a 1/3 inch format camera is still exhibiting diffraction even as the iris is opened up and it enters the zone of lens aberrations – in other words there is no operating point for the lens aperture at which it can perform well: 1/3 inch is just about sufficient for SDTV use, but definitely not for HDTV.

In summary, the optimum optical format for a broadcast camera is a blend of technical, creative and practical requirements:

- Technical: resolution, sensitivity, freedom from optical aberrations
- Creative: choice of lens taking angles, control of depth of field
- Practical: size, weight and cost of camera and lens; wide choice of lenses

The 2/3-inch format is the best compromise in meeting all of these requirements.

New Developments

Today's latest 2/3-inch format broadcast television cameras are very different from the past. For example, for a long time it was not possible to get sufficient image quality from CMOS sensors, because of the limitation of minimum feature size in silicon fabrication. That is no longer a problem, and the latest CMOS sensors are now able to compete with CCD. Now that bridge has been crossed, the benefits of CMOS such as reduced power consumption and greater integration of processing circuitry into the sensor chip are becoming available to broadcasters. For example, following the successful introduction of CMOS sensor technology in the Grass Valley Infinity camcorder, the new LDK 3000 camera launched at NAB 2009 applies the same sensor in a studio camera package. Future CMOS advances may include a much greater selection of video frame rates and resolutions from the same camera.

Conclusion

With the design objectives of broadcast cameras properly matched to the application, challenges such as advanced 1080p/60 HDTV can be met in terms of electrical performance specification, yet without excessive constraints in creative freedom. This is possible only when the equipment is optimized by a specialist supplier for the critical application of creative production for broadcasting. It might not be possible with equipment optimized for a less critical application such as the consumer camcorder. Optical image format size is the most critical parameter: ultra-small formats such as 1/3 inch are inadequate for HDTV.

Acknowledgment

Special thanks to Jan van Rooy of the Grass Valley camera group, located in Breda, Netherlands, for assistance in preparing this article.