The Image Resolution of 35mm Cinema Film in Theatrical Presentation

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The increasing use of electronic digital projection technology for the large-screen digital imaging (LSDI) of motion pictures and digital and HD video, has prompted interest in comparing the resolution achieved by LSDI displays with traditional 35mm motion picture film optical projected displays. In order to serve as a reference point for such comparisons, tests were made to determine the end-to-end resolution performance of 35mm cinema film from the 35mm negative to the final screen display. It is expected that the test results will be useful in determining for each LSDI application whether a resolution higher, lower, or equal to 35mm film optical projection is required. The paper summarizes the 35mm test procedures employed and the objective and subjective results obtained.

In the framework of the activity of ITU-R Study Group 6, intended to specify large-screen theatrical presentation of programs available in the form of digital imagery signals ("Large Screen Digital Imagery" or LSDI), tests were performed to determine the end-to-end resolution performance of 35mm cinema film from negative photography through to print projection in typical motion picture theaters today. This performance was considered to be an important reference point, because the vast majority of motion pictures are produced for distribution in the form of 35mm release prints, so that the main perceptual reference of performance for the 35mm cinema today is that which corresponds to theatrical projection of 35mm release prints. However, the study of this reference point did not imply the assumption that the performance of LSDI should necessarily be equivalent to that provided by theatrical exhibition of 35mm release prints of feature films. LSDI could be of higher quality than today's 35mm cinema film presentation, equal to it, or of lower quality depending on the application.

It is important to underline that the tests were not conceived as a research project intended to measure the ultimate resolution possible of the 35mm cinema film system nor to predict what could be achieved with developmental equipment, film stocks, processing, or projectors. Rather, these end-to-end 35mm cinema film resolution tests utilized existing state-of-the-art 35mm cinema film equipment, film stocks, processing, printing, and projection in actual day-to-day use for feature film production, post-production, processing, printing, and exhibition in theaters worldwide. Thus, the tests studied the practical 35mm cinema film resolution that is achieved in normal operation today.

To this end, qualified professionals and organizations that operate in the international cinema feature film industry were called upon to participate in the production of the 35mm test films, and their contribution is gratefully

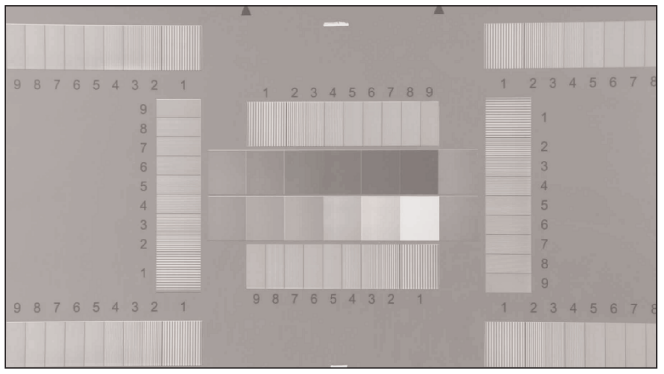

Figure 1. Resolution test chart used for the test.

acknowledged.

The tests were structured in two phases. During the first phase, the typical resolution obtained on theatrical presentation of a 35mm release print film was evaluated. During the second phase, the typical resolution obtained on theatrical projection of a 35mm answer-print film was evaluated.[1]

This paper summarizes the procedure used for the tests, gives some information on its implementation, and provides a summary of the objective and subjective results obtained.

Procedure Used for the Test

The test followed the procedure outlined below, which had been submitted for endorsement by an international group of experts.

• A resolution test pattern was photographed in the U.S. on a 35mm negative film stock typical of those used for the production of feature films. Film cameras and prime lenses typical of those used for feature films were used for the shooting, which was performed in the presence of an international panel of experts. A second shooting of the same resolution test pattern was made in France with the cooperation of the Association of French Cinematographers (AFC).

• The exposed negatives were developed using state-of-the-art facilities.

• The negatives were then edited to ease implementation of subjective assessment sessions.

• In the first phase of the test, interpositives (master positives), internegatives (duplicate negatives), and release prints were developed and printed in two laboratories as a control check, using state-of-the-art facilities and 35mm film stocks typical of those used for feature films. In the second phase, answer prints were struck from the original negative produced in the first phase.

• Objective measurements of the modulation transfer function (MTF) curve of the resolution test pattern were taken on the 35mm negatives, interpositives, internegatives, release prints, and answer prints.

• In the first phase of the test, the best of the 35mm release prints was projected in selected movie theaters after verification of the correct performance of the projectors, and an international panel of experts examined the projected images to assess the end-to-end resolution of the 35mm film chain. In the second phase, the answer print was projected in a Montreal theater for examination of the projected image.

Production of the 35mm Test Films

The Test Chart

The chart used for shooting contained multiple sine-wave test patterns and was specially made by Sine Patterns LLC of Pittsford, NY. It had an aspect ratio of 1.85:1 and measured 400mm x 740mm. The use of a sine-wave pattern was chosen over the more traditional square-wave pattern to permit accurate measurement of

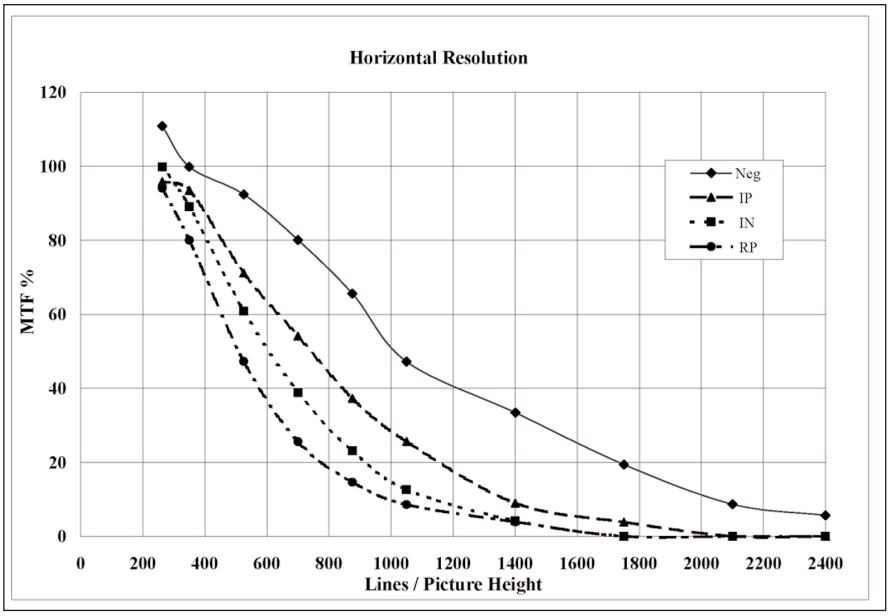

Figure 2. Horizontal MTF of 35mm negative, interpositive, internegative, and release print films.

the MTF of each stage of the film process, from the original negative, through the interpositive, the internegative, and the release print. These measurements then provided a true concatenation of the MTFs of the individual elements from the chart, imaging lens, and film. The low contrast range of the patterns ensured that the measurements would be performed on a relatively linear portion of the film-transfer curve.

Figure 1 shows the appearance of the test chart, which contains eight multiburst groups superimposed on a mid-gray background. Four groups are located toward the center of the test chart and four toward its edges. This was done to allow viewers to assess resolution in eight different areas of the projected image. Two of the groups toward the center of the test chart are oriented vertically. This was done to allow assessing of both vertical and horizontal resolution. Each multiburst group consists of nine sine-wave patterns, ranging from 0.375 cycles/mm to 3 cycles/mm.

When the 400mm height of the chart is imaged by a normal lens so as to fill the 11.33mm image height of the film Academy Aperture, the spatial frequencies exposed onto the negative range from 13.25 cycles/mm to 106 cycles/mm, equivalent to a resolution of 300, 400, 600, 800, 1000, 1200, 1600, 2000, and 2400 lines per picture height (L/PH) for the nine patterns. To provide additional data points for the test, the chart was also photographed such that 350mm of the chart height filled the Academy Aperture. This produces spatial frequencies ranging from 11.6 cycles/mm to 92.74 cycles/mm, equivalent to 262.5, 350, 525, 700, 875, 1050, 1400, 1750, and 2100 L/PH.

The depth of modulation of the multibursts on the test chart was measured, documented, and utilized as the reference for the film MTF measurements.

First Shooting

The first shooting of the negative film took place on Stage 2 of Panavision in Woodland Hills, CA, on June 27, 2001, under the supervision of cinematographer John Hora, ASC, in the presence of an international group of test monitors.

Two cameras (a Panavision Panaflex Millennium camera, serial number PFX-127M, and an Arriflex 435 S camera, serial number 435ES-140) were used to shoot the test chart. The Arriflex camera had been modified by Panavision to accept Panavision lenses.

Two prime lenses (a Panavision Primo-L lens and an anamorphic Panavision Primo Auto Panatar lens) were used to photograph the test chart. The two lenses were used on both cameras because they could be interchangeably mounted on both.

The illumination on the test chart was 200 fc. The lenses were set at a stop of T5.6. No filters were used on either lens when photographing the test chart. The performance of both cameras was measured and found to be within specifications. The axial MTF of both lenses was measured at the focusing distance and T-stop used during the shooting. The MTF of the Primo-L lens dropped to about 75% of its maximum value at a resolution of 50 cycles/mm, and the MTF of the Primo Auto Panatar lens dropped to about 68% of its maximum value at the same resolution.[2] Negative film stock type Kodak 5274 was used for the resolution test pattern photography.

The interpositive was struck on film stock type Kodak 5242 from the original negative. The internegative was struck on film stock type Kodak 2242 from the interpositive. The release prints for the first phase of the test were struck on film stock type Kodak Vision Color 2383 from the internegative using a high-speed printer. The answer prints for the second phase of the test were struck from the original negative on film stock type Kodak Vision Color 2383 using a wetgate printer.

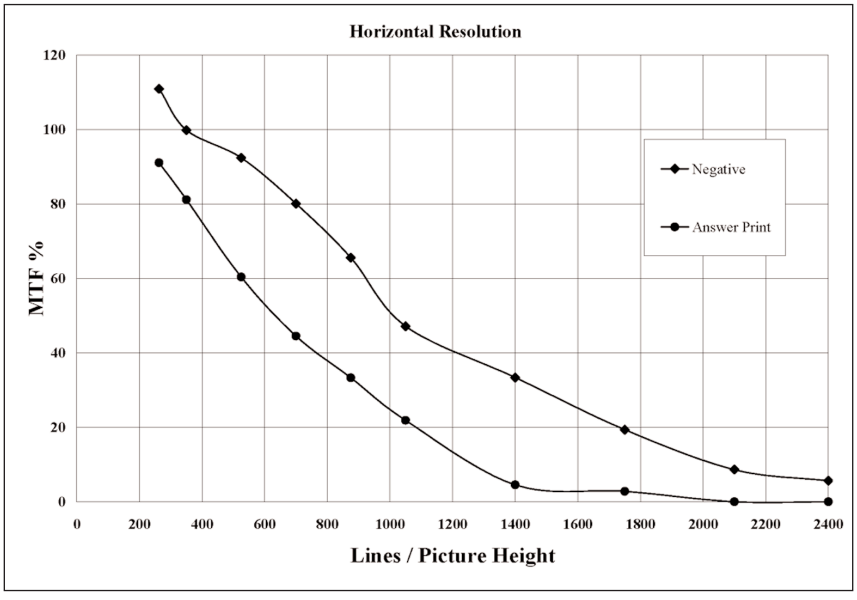

Figure 3. Horizontal MTF of 35mm negative and answer print films.

Second Shooting

The second shooting of the negative film took place at Technovision (32, rue Delizy, 93694 Pantin-Paris, France) from 10:00 a.m. to 1:00 p.m. on January 20, 2003, in the presence of an international group of test monitors in accordance with an approved test plan.

A film crew selected by the AFC did the shooting, which was supervised by Olivier Benoist (director of photography, France), Philippe Coroyer (director of photography, France), Jean-Noël Ferragut (director of photography, France), Magali Thirion (camera operator, France), and Jean-Marie Adam (lights and studio setup, CST, France). It was also supervised by test monitors Vittorio Baroncini (FUB, Italy), Matthieu Sintas (CST, France), and Paolo Zaccarian of Italy.

The camera used to photograph the test chart was an Arriflex III 35 (serial number 41212). The performance of the camera was measured before the shooting and found to be within specifications. A prime lens (Zeiss Planar 2/50, serial number 6784167) was used to photograph the test chart. The lens back focus was tested prior to the shooting. No filters were used on the lens when photographing the test chart.

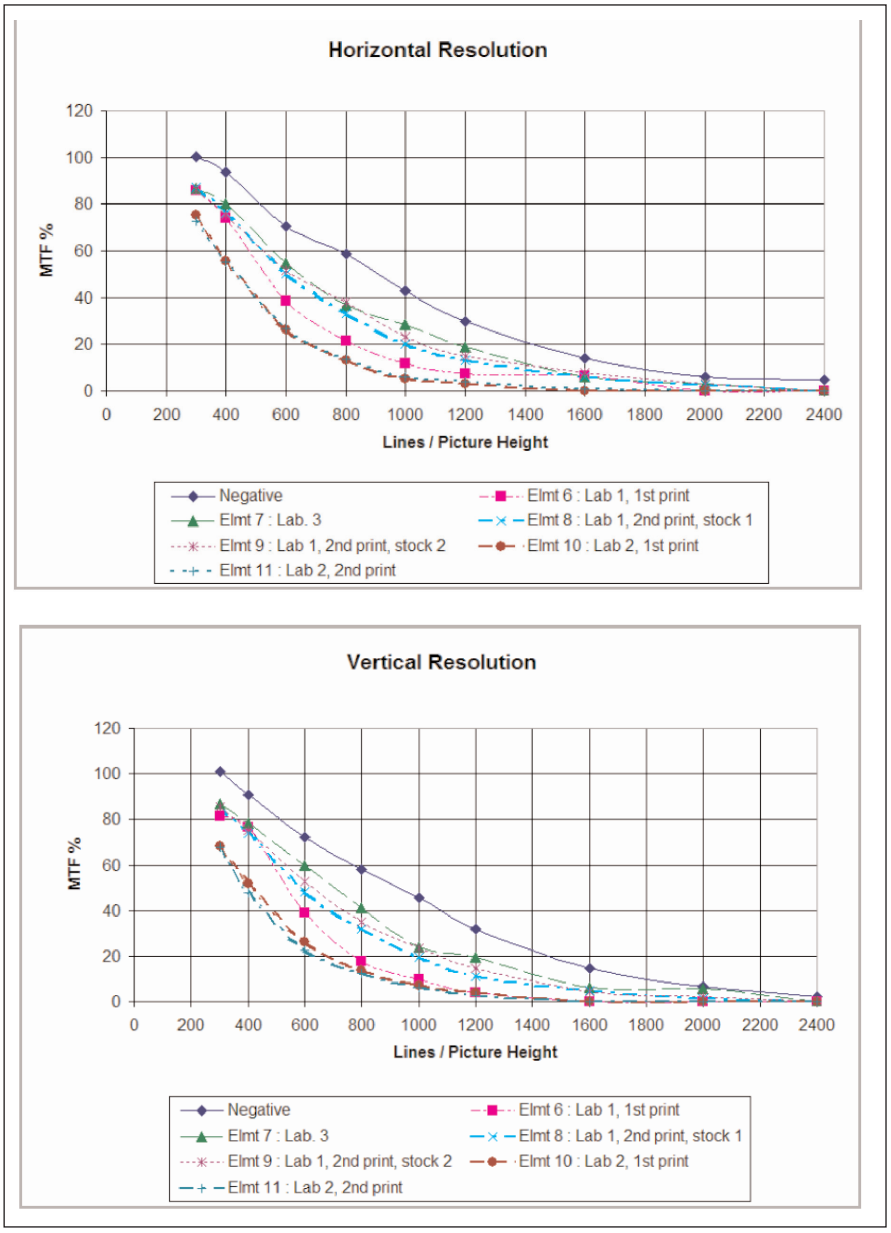

Figure 4. MTF variations from answer print to answer print.

Negative film stock Kodak type 5274 was used for the shooting. This film stock was indicated as the artificial light stock most widely used today to shoot feature films. The film used for the shooting was checked by means of sensitometric measurements before the shooting.

Objective MTF Film Measurements

MTF Variations Along the Film Production Chain

MTF resolution measurements of the test pattern were taken on the negatives, interpositives, internegatives, release prints, and answer prints. A proprietary microdensitometer of Sine Patterns LLC with a slit width of 1μ was used for the measurements. Results of the measurements on the negatives obtained from the two shootings were very close.

The results of the MTF horizontal response measurements for images photographed with the normal (spherical) lens for the first shooting are plotted on Figs. 2 and 3. Figure 2 applies to the first phase of the test (the release print resolution test). Figure 3 applies to the second phase of the test (the answer print resolution test). In both figures, the horizontal axis shows the spatial frequencies, expressed in lines per picture height (2 L/PH

A				D
600		E		632
	G	653	H	
	579	F	516	
B		684		C
674				642

Figure 5 (a). Release print resolution assessed in the Orlando movie theater.

A				D
800		E		750
	G	875	H	
	550	F	525	
B		825		C
875				825

Figure 5 (b). Release print resolution assessed in the Los Angeles movie theater.

A				D
733		E		667
	G	733	H	
	467	F	433	
B		700		C
667				667

Figure 5 (c). Release print resolution assessed in the New York movie theater.

A				D
720		E		700
	G	740	H	
	580	F	520	
B		720		C
680				740

Figure 5 (d). Release print resolution assessed in the Montreal movie theater.

A				D
700		E		700
	G	767	H	
	533	F	500	
B		733		C
700				600

Figure 5 (e). Release print resolution assessed in the Paris movie theater.

A				D
600		E		600
	G	640	H	
	560	F	480	
B		680		C
720				680

Figure 5 (f). Release print resolution assessed in the Milan movie theater.

A				D
840		E		770
	G	760	H	
	740	F	630	
B		680		C
860				805

Figure 6. Answer print resolution assessed in the Ville Saint-Laurent movie theater.

make up a cycle/PH). The vertical axis shows the modulation of the frequency bursts in the multiburst groups of the test pattern. The MTF response curves have been smoothed to eliminate minor variations in the data samples. The highest MTF response values among groups have been used on all the smoothed curves.

MTF Variations from Print-to-Print

Several answer prints were struck from a single negative obtained from the second shooting. The answer prints were struck in different laboratories, on different film stocks, and on different types of printers.

All the prints made by each laboratory were checked by that laboratory and found to be "good-for-delivery." The MTF response curve shown in Fig. 3 represents the response of the best answer print. However, a comparison of the MTF responses measured on the various answer prints shows a high variation of results. The choice of film stock had a small influence on this variation for answer prints developed at the same time in the same laboratory. This variation is shown in Fig. 4., presenting MTF response curves for both horizontal and vertical resolution.

For example, print numbers 10 and 11 were printed in the same laboratory on the same film stock. Print number 10 was struck on a dry printer, and print number 11 was struck on a wetgate printer. Prints 8 and 9 were printed in the same laboratory, but on different film stocks.

Subjective Assessments

Each subjective assessment session used at least seven expert assessors. All assessors were screened for normal visual acuity with or without corrective glasses. Subjective assessment sessions were held in movie theaters equipped with state-of-the-art projection facilities. The theaters were completely darkened during the test sessions.

Assessors were seated in central seats at a viewing distance of 1.5 times picture height from the screen. The choice of this short viewing distance was due to the need for the tests to produce highly discriminating results. Assessors were asked to score each one of the eight multiburst groups present on the projected image, identifying the highest spatial frequency burst in each multiburst group, where they were able to distinguish the bar structure. Each scoring sheet was labeled with the name of the assessor, the seat number, and the date and the time at which the test session was carried out.

Each formal subjective assessment session was followed by an informal "expert viewing" session, during which the experts had an opportunity to verify the opinions expressed during the formal test, to look at the test material as long as they wanted, to get as close to the screen as they liked, and to hold discussions among themselves to find a common agreement of the perceived quality. Formal subjective assessment sessions were held for the first phase of the test, according to the assessment procedure described in the previous section. The assessment sessions were held in a total of six movie theaters located in Orlando, FL; Los Angeles, CA; New York, NY; Montreal, Canada; Paris, France; and Milan, Italy.

The results of the test obtained in the six theaters are summarized in Figs. 5(a) to 5(f), separately for each theater and for release print shot with the normal (spherical) lens. For each theater, the tables show the average number of lines per picture height that the assessors detected in each one of the eight sections of the projected test chart where multiburst groups are present. The reported numbers are the mean values of the scores cast by the assessors. Their positions on the tables correspond to the positions, identified by letters from A to H, where the related multiburst groups are located.

A subjective assessment of the second phase of the test (answer print) was conducted at the Megaplex Spheretech 14 Theater, Ville Saint-Laurent, Canada. The results are shown in Fig. 6.

Conclusion

In the framework of the activity of ITU-R Study Group 6, related to LSDI, a test was performed in order to determine the end-to-end resolution provided by 35mm cinema film projection in typical motion picture theaters today. This can be considered to be one of the main perceptual performance references for the cinema today.

The test evaluated the typical resolution obtained on theatrical presentation of 35mm release prints and answer prints, which is achieved in normal operation, utilizing existing state-of-the-art 35mm cinema film equipment, film stocks, processing, printing, and projection in actual day-to-day use for feature films today.

A resolution test pattern was photographed on a 35mm negative film stock typical of those used for the production of feature films, and 35mm interpositive, internegative, release prints, and answer prints were struck from that negative in conformity with current cinema routines. Measurements of the MTF curve on the resolution test pattern were then taken on the 35mm negative, interpositive, internegative, release prints, and answer prints. The best 35mm release print was also projected in six selected movie theaters in various countries, and an international panel of experts assessed the resolution of the projected images, using a well-defined formal assessment procedure.

The MTF measurements performed on the films have shown that the MTF on the negative film drops to 10% of its peak value at about 2100 L/PH. It gradually continues to drop along the film chain from negative to interpositive

to internegative and to release print, and it reaches 10% of its peak value at about 1000 L/PH when measured on the release print. When measured on the answer print, it reaches 10% of its peak value at about 1400 L/PH.

The MTF measured on the 35mm answer print film quite closely matches the one measured on the 35mm interpositive film. This is not surprising, because a 35mm interpositive is a positive film printed from the original 35mm negative, as a 35mm answer print is. Obviously, it must be expected that the resolution measured on the 35mm release print (or on the answer print) will suffer some reduction when the print is projected in a movie theater, due to the passage of the image through the projector mechanism and lens.

Indeed, this was confirmed by the subjective assessment tests, which showed the following:

• There was a significant spread in the resolution performance of the six selected movie theaters where the assessment tests were performed.

• There was also some spread in the resolution performance of each selected movie theater, when measured at various points of the screen.

• The highest resolution that the expert assessors could discern in the highest performing movie theater was about 875 L/PH.

• The horizontal resolution averaged over the six multiburst groups measured on the screens of the six selected movie theaters was about 715 L/PH.

• A wide range of resolution values will be obtained, depending on the stocks, laboratory, type of printer, and so forth.

Notes

1. The process to produce a 35mm release print film is to strike a 35mm interpositive film of the original 35mm negative, then to strike a 35mm internegatives of the interpositive film, and finally to strike the required number of 35mm release prints from the internegative films. A release print is thus a third generation copy of the original negative. This approach is used in order to limit the wear-and-tear of the original camera negative, which could not be replaced if it were damaged. By contrast, the process to produce a 35mm answer print film is to strike it directly from the original 35mm camera negative. An answer print is thus a first-generation copy of the original negative. In order to limit the wear-and-tear of the original camera negative, answer prints are only made in very small numbers, to be used on some rare occasions, such as the presentation of a movie at a festival.
2. A spatial resolution of 50 cycles/mm corresponds to 1133 L/PH on release prints with an aspect ratio of 1.85:1.

THE AUTHORS

Vittorio Baroncini was born in Genoa, Italy, on January 23, 1948. He gained a Laurea in Physics at Rome University in 1974, discussing a thesis on digital filters. In 1986, he joined Fondazione Ugo Bordoni were he worked on digital TV design and later moved to the quality-assessment department. He is chairman of the Test Group of ISO/JEC-SC29WG11 (MPEG), chairman of the ITU-R WP 6Q, co-chairman of TG 6/9 (D-Cinema), and an active member of VQEG (Video Quality Expert Group).

Baroncini's main research activities are the study of new video test methodologies (D-Cinema, DTV, and multimedia services) and the objective quality-assessment of video related to the quality of services. He is the author of several technical papers presented at conferences and for journal publication, mainly related to video quality assessment issues.

Henry (Hank) Mahler is associate director, advanced technology, in the engineering department of CBS, in New York City. He is currently responsible for the evaluation, testing, development, and implementation of new broadcast television technology, equipment, and systems for the CBS Television network. Mahler has been with CBS since his graduation from Stevens Institute of Technology in 1960. Until 1986, he worked at CBS Laboratories R&D facility in Stamford, CT, where he was involved in pioneering work on HDTV, as well as the first slow-motion recorder, CBS Action Track, and field-sequential cameras for the Apollo moon missions.

Mahler is a Fellow of SMPTE, former chairman of the SMPTE Working Group on Television Applications, and has published the results of HDTV and film resolution tests in the *SMPTE Journal*, as well as tutorials on TV resolution.

Matthieu Sintas is the acquisition and creation department moderator of the Commission Supérieure Technique (CST), a center of audiovisual expertise for the French administration. During his career, he developed the French experimentation on digital cinema. He is a member of the Board of the EDCF (European Digital Cinema Forum) and writer of several technical articles.