locate faults to component level in an efficient and expeditious manner. The diagnostics to module level are essential; those to component level may be offered as an option. The preferred situation for machine repair to component level is a plug-in analyzer, optimally remote, which strikes a balance between the obligatory built-in first level diagnostics and the need to repair to component level.

An Engineering Guideline for the D-1 DTTR expressing this point of view has been proposed to the TRRT committee, but it is not likely to have a significant impact on manufacturers because first-generation machine design work has already been completed and machines will be delivered soon.

It is noted that the provision of onboard diagnostics and a rapidly maintainable design are concepts which must be addressed by the manufacturer in the earliest stages of design. Consequently, the point of view presented here cannot have significant influence on equipment already in production if the manufacturer chooses to ignore the need for efficient repairability of digital equipment by the client.

Digital equipment is a reality today, but an adequate level of diagnostics, documentation, and training is not. They will only become a reality when and if you, the user, speaks out loudly and clearly. Your statement will be heard only when you insist that diagnostic and technical support requirements be included with equipment.

Engineering Committee Report

SMPTE Study Group on 30-Frame Film Rate: Final Committee Report on the Feasibility of Motion-Picture Frame-Rate Modification to 30 Frames/sec

By Edmund M. DiGiulio

During a meeting of the Motion Picture Association of America (MPAA) on August 15, 1985, the suggestion was made by Allan Cooper, vice-president, technology evaluation and planning, MPAA, that perhaps it would be a good idea for the motion-picture industry to explore the possibility of changing the frame-rate standard for film production from 24 frames/sec to 30 frames/sec. Such a change would enable film production to be directly compatible with the proposed HDTV television standard as well as with existing NTSC television standards. It would also serve to enhance theatrical presentation.

This suggestion was carried to the Film Technology Committee of the SMPTE and to the (then) Engineering Vice-President of the Society, Richard Streeter. The SMPTE Engineering Director for Motion Pictures was encouraged to form a study group for this purpose.

The study group was charged to investigate and report on the effects of such a frame-rate change, and to determine as best it could the effects on the audience of how motion pictures produced and projected at 30 frames/sec would appear to the viewer. Would the higher frame rate lead to a perception of higher quality? They were also to investigate the effects on the projection system as to what changes would be required in existing projectors. If possible, they were to report on the effect on telecines, and on laboratory and production practices. The first plenary session of the study group was at the SMPTE Technical Conference in Los Angeles on October 31, 1985.

This first meeting included representatives from around the world and, as anticipated, the European delegates were quite skeptical and generally opposed to such a change. The European TV broadcasting standard, based on a 50-Hz mains frequency, is 25 frames or 50 fields/sec. Films shot in Europe, specifically intended for television release are, therefore, shot at 25 frames/sec, while theatrical films, which are always shot at 24 frames/sec, are shown on television in 50-Hz countries with no modification. The 4% discrepancy in frame rates is ignored. This makes for a convenient and compatible frame-rate situation in those countries, although a 60-min theatrical program runs for only 57 min and 36 sec on television.

In the U.S. and other 60-Hz countries, such as Japan, film production is generally at 24 frames/sec, whether for theatrical or television release. For television release, a frame-rate conversion from 24 to 30 frames/sec is required during the telecine transfer process. This generally involves the use of digital frame stores and is naturally more costly and complex than the existing telecine transfer process in 50-Hz countries.

The proposal for worldwide production standards for HDTV put forward by both the U.S. and Japanese delegations is based on a 60-Hz standard. Their position is that existing

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standards that provide 50 fields, i.e., 50 discrete images/sec, are unacceptable from the standpoint of excessive flicker perception, especially at elevated screen luminance.

The study group held three formal meetings. It was decided early on that the benefits of a motion-picture frame-rate change from 24 to 30 frames/sec for compatibility with HDTV standards, as well as with existing NTSC standards, were well known and obvious, and that we should concentrate our attention on the benefits and concomitant problems involved in theatrical presentation. Subcommittee action then proceeded to establish test criteria and to generate demonstration films.

Our recording secretary, John Mosely, supervised the installation of a "black box" in the projection booth of the main theater of the Academy of Motion Picture Arts and Sciences. The device is actually a frequency synthesizer capable of providing a variable frequency output from 0 to 75 Hz. At 75 Hz, a 60-Hz projector motor will run at 30 frames/sec. A serendipitous side benefit to the Academy is the ability to run these projectors at the variable frame rates required for showing some of the early silent films at their original filming speed.

Under the direction of Dick Barlow, Burbank Studios, we were able to produce films covering a variety of situations, shot by three cinematographers, and photographed at both 24 and 30 frames/sec. The demonstration reel was then presented before various groups in the motion-picture industry for comments, feedback, and general reaction. These presentations were made to the Theater Equipment Association (TEA), National Alliance of Theater Owners (NATO), and ShoWest, and as part of a special program at the SMPTE Technical Conference in New York organized by Ken Mason, Chairman of the Inter-Society Committee.

One of the most provocative demonstrations was at the National Film Theater in London, on August 31, 1986. This meeting, organized by David Samuelson, our most active international committee member, was extremely well attended on an unusually sunny afternoon in England. Audience reaction was, understandably, mixed. While the benefits and improvements in screen presentation at 30 frames/sec were readily apparent to this audience, they naturally expressed concern regarding the problems of telecine transfer from 30 to 25 frames/sec.

The most significant presentation of these films, from the standpoint of sophisticated professional feedback, occurred at a special January meeting of the Hollywood Section of the SMPTE. This meeting was held at the Academy Theater, on January 8, 1987, before an audience of 300 to 400 people. Questionnaires were handed out to test audience reaction and the results are discussed later in this report.

The use of 30 frames/sec for theatrical presentation is not new. In the mid-1950s, Mike Todd shot the first two Todd-AO films, *Oklahoma* and *Around the World in Eighty Days*, at 30 frames/sec for first-run release, as well as at 24 frames/sec for general release.

Experiments were conducted at that time by Dr. Brian O'Brian, American Optical Co., to determine the optimum frame rate to eliminate flicker and minimize the stroboscopic effects that are even more apparent in wide-screen presentations than with conventional Academy aspect ratio films. With the wider screen presentations, even in panning moves at a very slow rate, the displacement between discrete images flashed on the screen produces a disturbing strobe effect. Moreover, our peripheral vision, which is much more sensitive than our central vision, is brought into play in a wide-screen presentation so that flicker which might not be apparent in narrower displays becomes more disturbing.

Our perception of flicker, either by central or peripheral vision, is proportional to the number of images (i.e., flashes) per second being displayed, and their brightness. If, for example, one were to watch a European television set and the subject was a low-key dramatic scene, flicker would not be apparent, but watching a bright daylight scene on the same set would yield very perceptible flicker. The problem of flicker perception is more pronounced with television display than with theatrical presentation because television sets have screen luminances in excess of 40 fL, whereas a theatrical screen meeting American National Standard (ANSI)/SMPTE 196M, Screen Luminance and Viewing Conditions — Indoor Theater Projection, will have a screen luminance of 16 ± 2 fL. It is interesting to note that while we have bemoaned in the past the low screen luminance so often experienced in theaters, the fact is that significantly higher luminance levels could not be tolerated in theatrical presentation with existing standards, since 24 frames/sec yields 48 flashes/sec when using a standard 2-bladed shutter (actually a shutter with two openings), which is very close to perceptible flicker at 16 fL.

One must be careful when comparing image quality and characteristics between film and video. Information provided by Dr. Fred Kolb notes that the standard screen luminance of 16 fL for motion pictures is actually measured with no film in the projector gate and that even clear film reduces the screen luminance by half. On the other hand, "peak white" defines the actual luminance of the whitest white displayed on a television monitor. Our subjective perception of the brightness of film and video images will also be influenced by illumination of the viewing environment.

Kolb reports on the results of a study conducted several years ago at Eastman Kodak Co. to determine the threshold at which flicker becomes obvious to a general audience. Two projected images from still scenes were viewed side-by-side, one interrupted by a variable frequency shutter under control of the observer, which was open 50% of each cycle, and the other presented continuously at constant illumination at 50% of the peak brightness transmitted to the shuttered image so as to make the integrated brightness of the two images equal. The observer adjusted the frequency of the shuttered image until the perception of flicker just disappeared. The median values for the threshold of flicker perception for 99 observers were as follows:

Peak Luminance of the Image	Flicker Frequency
3 fL	48 Hz
5 fL	50 Hz
40 fL	60 Hz
500 fL	70 Hz

It is noted that the luminances reported above are those of the actual image in its brightest portion. As previously noted, the screen luminance measured as described in ANSI/SMPTE 196M would be approximately twice as great.

The work of Dr. Kolb confirmed that of Dr. O'Brian and other re-

searchers who had empirically determined that at 30 frames/sec, with 60 images/sec being flashed on the screen, we are beyond the threshold of flicker perception at any practical level of screen luminance. A convincing demonstration of this during our presentations of the test films was to show the projector running without film at elevated screen luminance (20 or more fL) at 20 and then 30 frames/sec. With no film in the projector to attenuate the light source, screen luminance was at its maximum level. There was a dramatic difference between the very obvious, and almost painful, flicker at 24 frames/sec and the absolutely pure white light at 30 frames/sec.

To get a critical professional evaluation of the various psychological phenomena involved in motion-picture viewing, a detailed questionnaire (Table 1) was prepared for the SMPTE members who attended our special demonstration meeting at the Academy Theater on January 8, 1987. Of those present, 131 returned the questionnaire. Of these, only 65 were filled out completely. To avoid skewing our results, only those 65 were used to provide our statistical evaluation.

To make our presentation as informative and effective as possible, we also included three other films that would give our audience a broader basis for comparison and evaluation. The first was an excerpt from *New Magic*, a film shot in the Showscan process, which involves filming in 65mm at 60 frames/sec and projection on 70mm at 60 frames/sec. In this case, however, our print was a reduction from the 65mm negative to a 35mm anamorphic print, with alternate frames being printed for a 30 frames/sec release. This is the way Showscan films would be shown in general-release theaters.

The second was a newly printed copy of the original film, *Oklahoma*, shot in 65mm, which, as previously noted, was the first film photographed at 30 frames/sec. The final film was one newly prepared by Dr. Richard Vetter, United Artists Communications, which was also photographed in 65mm at 30 frames/sec. The latter two films were projected in 70mm. This provided our audience with a wide variety of films to evaluate, with origination in both 35mm and 65mm, and projection in 35mm, 70mm, and print-down from 65mm to 35mm.

With regard to flicker, the test results show a significantly greater perception at 24 than at 30 frames/sec, with this perception being further increased at elevated screen luminances. (Please note that in all cases of "elevated" screen luminance during this test, the actual measured value was 24 fL.) With regard to strobe, a significant improvement from 24 to 30 frames/sec was also noted. Unlike the case of flicker, however, our audience did not perceive an increase in strobe with increased screen luminance. Interestingly, all three films from 65mm negatives scored extremely well in this category, which may relate to the increased resolution of these films.

One unanticipated additional benefit of filming at 30 frames/sec is the reduction in granularity apparent on the screen. Since grain is a random phenomenon and the picture content is repeatable and regular, it is reasonable to expect that by integrating 30 images/sec rather than 24, the random effect of granularity should be proportionately reduced. The improvement was observed to be even greater at elevated screen luminances.

The final factor to be considered was resolution and, here again, providing new picture information to the screen at 30 times/sec results in greater perceived resolution than

Table 1 — 30-Frame Study Group Sub-Committee Presentation: Results of Questionnaire for 65 Samples

1. **Blank Screen Flicker.** Please score degree of perceptible flicker you see at 24 and 30 frames/sec for both normal and elevated screen luminance. In all cases, score from 1–10, with 10 being best, i.e., least flicker, etc.

	Normal Luminance	Elevated Luminance
24 frames/sec	4.4	3.8
30 frames/sec	8.2	8.6

2. **35mm Projected Examples.** Please rank each of the factors below for each of the film samples you will see. Again, score from 1–10, with 10 being best, i.e., least flicker, least strobe, least granularity, and most resolution.

Film Sample	Frames/sec	Luminance	Flicker	Strobe	Granularity	Resolution
A. Shopping Mall	24	Normal	5.3	3.9	5.2	4.3
	30	Normal	8.2	7.3	7.1	7.3
	24	Elevated	4.4	3.6	4.8	8.0
	30	Elevated	8.0	7.6	7.0	7.6
B. Car Drive By	24	Normal	5.3	4.5	5.5	4.2
	30	Normal	8.1	7.2	5.4	7.3
	24	Elevated	4.8	4.2	5.3	5.8
	30	Elevated	8.0	7.5	7.0	7.6
C. TBS Back Lot	24	Normal	5.3	4.6	5.3	5.6
	30	Normal	8.0	7.6	5.2	5.6
	24	Elevated	4.8	4.7	5.2	5.6
	30	Elevated	8.1	7.7	7.0	7.7
D. New Magic	30	Elevated	8.9	8.9	9.0	8.7

3. **65mm Projected Examples.** Please score as in 2.

Film Sample	Frames/sec	Luminance	Flicker	Strobe	Granularity	Resolution
E. Oklahoma!	30	Elevated	8.8	8.8	8.5	8.3
F. Dr. Vetter UAC	30	Elevated	9.8	9.3	9.4	9.7

when such information is provided at 24 frames/sec. There was only a slightly higher perception of enhanced resolution at elevated screen luminance as compared with normal screen luminance. All three prints originating from 65mm negatives scored highest in this category.

It is interesting to note that the 35mm print-down from a 65mm negative scored so high. This can be explained by the fact that print stock has a much higher resolving power than negative film, typically 400 versus 100 line pairs/mm, so that all the additional resolution obtained in the original 65mm negative can be retained in a 35mm print-down.

In considering all of the technical problems that would be involved in a conversion to 30 frames/sec filming, the committee noted that in production, the only change would be an increase in camera speed to 30 frames/sec. All modern cameras are already capable of operating at that speed in crystal sync. There would, of course, be a slight increase in camera noise, which might present some problems for sync sound shooting. However, there have been significant improvements in sound level of 35mm sync sound cameras over the past several years, so that it would be fair to say that the sound level of such cameras operating at 30 frames/sec today would be no higher than those operating at 24 frames/sec five to ten years ago.

In the post-production area, editing tables and projectors would also have to be adapted to operate at 30 frames/sec.

The big change that proved the undoing of the 30 frames/sec concept in the 1950s was in the area of projection. Since it was not practical to expect theater owners to make major mechanical changeovers just to accommodate those few films that they would receive filmed at 30 frames/sec, Todd-AO used the expensive expedient of dual filming at 24 frames/sec for general distribution as well as as 30 frames/sec for special run houses. The Loews State Theater in New York City, where the Inter-Society Council presentation was held, had two motors that could be alternately cut in for operating at either 24 or 30 frames/sec. Fortunately, with modern technology, simpler solutions than dual projector motors or dual filming are available.

Today, the change in frame rate requires only a speed-up of the drive system of the projector. There are two major methods available to accomplish this. First, belt-driven projectors can have a pulley and belt change which boosts the speed from the same motor to the higher level.

Second, a reliable electronic frequency converter can be added to the input power system, so that the normal 60-cycle power is converted to 75-cycle power. If the motor horsepower is sufficient, it then reaches the 30-frame rate rather than the 24-frame rate. These two methods are the basic concepts of conversion and have been tested.

There are only two major projector types among the scores of brand names; first, those with pulley and belt drive, which are estimated to be about 95+% of all projectors in theaters. Second are the "direct drive" projectors, such as the SH-1000, which was made in the 1950s. The pulley and belt system can be converted with low-cost, easy-to-install parts to change to the 30-frame rate. The direct-drive systems must have either a different-speed motor to achieve the 30-frame rate, or the frequency converted to 75-cycle power so that the existing motor will drive at the higher frame rate.

Of American manufacture, the Simplex and Century account for about 70% of projectors in daily use. In addition, there are Ballantyne units, Christie units, Brenkert, Motiograph, RCA, and other older models. The Ballantyne was placed on the market in about 1971 and is belt-driven, and the Christie unit was placed on the market about 1978 and is also belt-driven. The Brenkert, RCA, and Motiograph units are older models, whose production stopped about 1955. Parts can be obtained for Simplex, Century, Christie, and Ballantyne. Parts for Brenkert, RCA, and Motiograph are much more difficult to obtain, as the manufacturing companies ceased production over 30 years ago. It is estimated that these older brand names account for only 10–15% of the entire theater business and nearly all are in much older theaters, which have been closing over the past few years.

Of the imported brands, the Cinemeccanica is the only one available in large numbers. It usually has a 3-phase synchronous motor drive, which can readily be converted by frequency converter systems. Some are belt-driven, which can have pulley and belt revisions. The Kinotone and Philips machines are in some use, and have either pulley and belt drives or synchronous drives subject to the frequency converter change. Tokiewa from Japan is available in small quantities and is a pulley-drive system. There are undoubtedly small quantities of AGA from Sweden, or Kalee from England, and similar devices which have not been investigated as yet. It is estimated that these account for less then ½% of those in use.

There are three major categories of change, and of course these costs are only estimates.

- The pulley and belt, which has a parts cost of less than $75 list, and is a 20 to 30-minute job for a serviceman. The cost of $100 should be a maximum at 1987 rates.
- The frequency converter installation. The frequency conversion unit to power the existing motor should be in the area of $900 or less, but it must be recognized that some motors will not have sufficient horsepower. In this case, the motor might change with the frequency converter installation. This could boost the cost to as much as $1100, which would give a better motor and synchronous operation for much more exact speed control (for better sound), and possible synchronous interlock with other projectors in the same area, which has become quite popular in the past five to ten years.
- The "electronic-automatic" system in which the typical automation control for the show-time is also tabbed for speed control change. This permits a typical film trailer of coming features at 24 frames/sec to be changed by tab on the film into a 30 frames/sec feature without operator intervention. The frequency converter already discussed is required, but it is controlled automatically rather than by the operator. It can reset back to 24-frame rate at the end of the show for the next run. Also, the light level can be changed by relay-control, so that the light and screen luminance can be increased by amperage change with the 30 frames/sec feature 20 to 50% brighter, assuming the proper xenon lamphouse is in place. Such automations can also change lenses at the same time. This automatic, tab-controlled equipment, with the frequency converter, is in the $2000 to $4000 range, depending on the existing equipment in the theater. Automatic

control systems would be appealing only if there were intermixes of features from one day to the next, in an industry which might not accept a complete standard conversion from one frame rate to another.

In summary, the conversion costs for a pulley-driven system is in the area of $100 or less, and seems quite simple. Added equipment, at higher cost, can be employed if the theater owner needs such flexibility, or unattended operation, or both.

As previously noted, the committee arranged for the installation of a frequency synthesizer at the Academy Theater. The device was commercially available, off-the-shelf, for less than $600. The device used in the Academy Theater generates a three-phase output from a single-phase input which, in this case, was compatible with the three-phase sync motors being used on the Academy projectors. As most general-distribution theaters throughout the country use single-phase motors, either induction or synchronous, a synthesizer with single-phase output would be required. Such devices do exist and are currently being tested by the committee. In any event, a worst-case scenario would require only the replacement of the single-phase motor by a three-phase synchronous motor at a cost of under $200, to work with the well-proven 3-phase frequency synthesizer device.

It is the committee's considered opinion that any easy, inexpensive conversion of theater projectors to 30 frames/sec is the only practical approach for general distribution. A subcommittee effort by Harry Whitmore to create a 24 frames/sec release print from a 30 frames/sec original negative clearly demonstrated the impracticality of this approach. Dropping every fifth frame in an optical printing process results in extremely objectionable motion discontinuity.

By far the most serious impediment to any large-scale conversion to 30 frames/sec as a film rate standard is the increased cost in film usage. Clearly, 30 frames/sec prints will be 25% longer than 24 frames/sec prints and thus more costly. The greater length will require more shipping reels and cases, and more changeovers in non-platter theaters. Extremely long films may exceed platter or large reel projector capacities.

However, at the same January 8 SMPTE presentation in the Academy Theater, Bengt Orhall, head of the largest film lab in Sweden, demonstrated a film shot by Rune Erikson, on a specially modified Panavision camera, that was produced using a 3-perforation pulldown as opposed to the conventional 4-perf pulldown. This is an idea that has been suggested by many film technicians for more than a decade. It is based on the fact that almost all theatrical presentations that are not anamorphic are presented in either the U.S. aspect ratio of 1.85:1 or the European standard of 1.66:1. In either case, the vertical cropping on the release print is such that either format could be presented on a 3-perf pulldown film, with the same projected area as on 4-perf pulldown film. Even the currently popular super 35 formats can be accommodated on a 3-perf pulldown format. When combined with 30 frames/sec, the 3-perf pulldown format results in a net saving of over 6% in print length.

In the case of 3-perf pulldown, however, projector modifications would not be as simple as the conversion to 30 frames/sec. The conversion would involve gear and sprocket changes which may be complicated and expensive, and which would be cumbersome to convert back and forth as required.

It is the committee's recommendation that a new committee be formed to investigate the technical and economic factors involved in a large-scale conversion to 30 frames/sec as a film production standard. Still to be analyzed is the exact impact on telecine transfer to 50 Hz countries from 30 frames/sec material. While most modern telecines will readily transport at 30 frames/sec, and telecines in 60-Hz countries already output their signals at the nominal 30-frame video rate, the conversion of 30 frames/sec film to a 25-frame video rate will certainly require additional signal processing, approximating the inverse of that required to convert 24 frames/sec film to 30-frame video. Copies of the test films have been sent to the Chairman of the New Technology Committee of the BKSTS, and it is anticipated that closer coordination with that body, as well as with the EBU, will help to resolve some of these questions.

It is clear that a change from 24 frames/sec to 30 frames/sec is not simply a matter of writing a new standard, even if there were no technical or economic considerations. We must have a dual standard, and in view of specialized production systems either in existence or proposed, we may well need a generalized standard which recognizes many frame rates. But the mere promulgation of a new standard doesn't make it happen. In the final analysis, it is the marketplace that will determine which technology is adopted and which is discarded. It is significant to note that in all of the presentations and demonstrations that have been made, it is the theater owners who have been most receptive and responsive to a possible change to 30 frames/sec as a filming standard. There is a growing awareness in this group that theater attendance increases as the quality of theatrical presentation is improved.

Statistical data shows that improvements in presentation increase box-office receipts. Dolby and THX sound systems and 70mm projection have clearly demonstrated their drawing power, and more and more theaters are being so equipped. Lucasfilms' Theater Alignment Program (TAP) indicated in their 1985 report that of some 200 to 300 first-run theaters they evaluated in 1984, only 38% met the ANSI/SMPTE 196M screen luminance standard, while by 1985 the percentage had increased to 71%.

In films made for television there is also interest in 30 frames/sec origination for the improved quality it can achieve. In fact, virtually all music videos are filmed in 16mm, 30 frames/sec for direct conversion from camera negative to video master tape. And in a combination of the two suggested improvements, the new TV show "Max Headroom" is filmed in 35mm, 3-perf at 30 frames/sec. In fairness, it should be noted that the 30 frames/sec motivation in this case derives mainly from the fact that filming of many TV monitors is involved, where 30 frames/sec conveniently eliminates the shutter bar problem.

Conclusion

In conclusion, it is safe to say that the improvements in theatrical presentation at 30 frames/sec have been clearly demonstrated. Work remains to be done on assessing the full economic impact of such a change. Hopefully, some far-sighted producer will step forward to shoot a feature film at 30 frames/sec to confirm that the improvements in quality far outweigh the costs.