(3) possibility of transmitting two high-quality sound channels (or several of lesser quality);

(4) one transmission link for picture and sound;

(5) considerable reduction of transmitter power, particularly in the case of satellite systems; and

(6) applicability to PAL, NTSC and SECAM color television systems by slight modifications.

In view of the theoretical and practical experience gained with integrated sound transmission systems, the use of the chosen method on transmission links appears to be possible in the very near future because no change of the equipment or the television standard will be required. A modification of the standard will be necessary when the method is extended to television systems including the home receiver. This would require a longer period with interim solutions for the simultaneous reception of integrated and nonintegrated sound signals.

Discussion

Robert J. Butler (NBC TV): I very much am in favor of integrating sound with the television picture. However, I question the quality when taking only two samples of the highest frequency of interest. Our studies indicate that the quality of signals that you can achieve by taking only two samples of the highest frequency would be objectionable. How does your experience bear on this?

Mr. Maegele: As outlined in the paper we have tested the system in the first method described and the results were very good. I must say that all the requirements were fulfilled in all respects on quality.

Mr. Butler: Were these subjective measurements that you made?

Mr. Maegele: These were objective measurements, some of them being automatic measurements.

Mr. Butler: Did you get any figure on distortion of signals as a result of low sampling rate?

Mr. Maegele: Yes I have some graphs with me which I can show you afterwards if you like. All the results were within the limits.

Charles W. Rhodes (Tektronix, Inc.): Would you comment on the rise time of these pulses and the energy outside of the video bandpass generated by these rather fast narrow pulses used? Have you tested the applicability over satellite channels with this bandwidth strictly limited?

Also, what is the means provided for field sync in the system so that no field frequency interruption in audio information arises?

Mr. Maegele: Yes, this is a real problem and we have noticed on tests via satellite link that we must somewhat reduce the amplitudes of the pulses; otherwise too much energy is lost outside the video bandwidth. The second problem is solved by inserting three additional pulses in the vertical blanking.

Andrew Kufluk (Ryerson Institute): In view of the fairly high level white going signals during the tail end of the vertical blanking, have you noticed any effect on the monitor or the receiver screen towards the left of the screen in the form of vertical bar pattern during retrace? I am thinking that the blanking period isn't always black and it does vary between white and black during the encoded time. Therefore, there is the possibility during the retrace time that the pattern will show as or at least the coding will show as a vertical pattern of stripes towards the lefthand of the screen as you look at the monitor or to the receiver. Has that been a factor or noticeable?

Mr. Maegele: Yes, this is a problem of clamping circuits. You must always have the same reference level in order to have a good relation between black and white. This is a problem of restoration of the standard blanking by clamping.

James D. Kirklin (Western Michigan University): My impression of what you are proposing is that for use on a network system once the program is received by a cable system or a local television station this blanking area would be restored to its normal state and the pictures seen on a home receiver would no longer contain this information. Therefore, this encoded information would not be a problem if you had poor blanking in the receiver. It wouldn't show on the retrace, would it?

Mr. Maegele: That is right.

The Development and Application of Metal Halide Lamps for Color Filming and Television

By ROBIN C. ALDWORTH

The development of high-pressure discharge lamps over the years has been aimed at improving color rendering, efficiency and life. The compact-source iodide (CSI) lamp was initially developed in 400-W and 1,000-W ratings for projector applications, but it was the new demands of outside broadcast color television in 1969 that led to the introduction of this lamp housed in a PAR-64 sealed-beam globe for floodlighting sports stadia from high corner towers. Sports areas with sidelighting were not so well suited to the use of the symmetrical beam CSI floodlights, so another metal halide lamp was introduced — this one with an unjacketed linear arc tube — in 750-W and 1,600-W ratings. For filming, the 1-kW lamp performs exceptionally well as a fill-in source with daylight. At 90 lm/W, it is five to six times more efficient than tungsten-halogen lamps used with blue filters to correct the daylight; four lamps are approximately equivalent to a 225-A brute arc. Control gear is being made simpler and more versatile, and the problem of "beat," which is already controllable in filming situations, is expected to be overcome completely with techniques now being developed.

Filament Lamp Development

Light source development over the years has had three main objectives — to improve efficiency, life and color rendering. For lighting units which are to provide a controlled beam, compact high-brightness sources are also necessary. Beyond pure lighting requirements, lamps also need to be robust, simple to replace and, of course, economical. It is evident that all these aims have influenced the development of filament lamps over the years. The color rendering of these lamps for filming has never been a problem because the spectral energy distribution is continuous; the film manufacturers were able to produce film stock to match it, but the early lamps were certainly neither robust nor compact. Over the years the introduction of single coil, coiled coil, bunched and low voltage filaments all added significant improvements, and recently the tungsten-halogen lamp in linear and compact forms has brought dramatic improvements in efficiency, lumen maintenance and life. The 10-kW studio lamp, giving 28 to 34 lm/W, with lives of 400 to 150 hours at around 3200 K, represents the culmination of 100 years of filament lamp development.

Discharge Lamp Development

Most discharge lamps, on the other hand, start with a distinct advantage in terms of efficiency—the amount of light they produce per watt of energy consumed. Plain mercury lamps operate at 50 lm/W with lives in excess of 7,000 h, but they are relatively large, low brightness sources and their color rendering is poor. Compact versions of mercury lamps have also been developed giving similar efficiencies, but attempts to improve color rendering by increasing current loading and adding substances such as cadmium and zinc to the arc tube filling have been of limited success.

Xenon lamps, in the familiar double-ended construction, can provide a very compact source which aids optical design and the color quality is very good. Lives of 1,000 h are common, but the efficiency is lower (30–35 lm/W and the lamp is expensive to make, fragile in operation and complicated to mount in lighting units. All of these lamps have found applications in specialized fields, but their various shortcomings have prevented their general acceptance in the spheres of film and television.

Compared with filament lamps, all discharge lamps have the disadvantage of requiring control gear. Nevertheless the film and television industries have from the beginning accepted grids and dc generators to run their carbon arcs, so a few items of control gear may not be regarded as an impossible burden if there are sufficient other benefits. Such benefits are now recognized as a practical possibility.

Presented on 12 November 1974 at the Society's 116th Technical Conference in Toronto by Robin C. Aldworth, Thorn Lighting Ltd., Thorn House, Upper St. Martin's Lane, London WC2H 9ED, England. (This paper, first received on 7 October 1974, was received in final form on 20 January 1975.)

Metal Halide Lamp Development

The principle of adding metal halides (particularly metal iodides) to a mercury arc discharge to improve the color rendering has been well known for many years. Lamps using small arc tubes with high current density were found to provide improved color rendering from a very compact and bright source. Furthermore, they maintained their brightness exceptionally well because the iodide cycle (by now a familiar feature of tungsten-halogen lamps) operates to clean up an arc tube which ordinarily would become blackened by tungsten evaporating from the electrodes.

The use of metal halide additives (there are approximately 40 to choose from) was obviously an attractive proposition, but first it was necessary to find the correct mixture of additives to give high efficiency with acceptable color rendering and good lumen maintenance throughout the life of the lamp. The possible combinations of 40 substances in different proportions are virtually infinite, and each substance has its own peculiar characteristics. Iodides of sodium, thallium and gallium, for example, produce discrete lines in the yellow, green and blue regions of the spectrum respectively, while the iodides of dysprosium, scandium and thorium produce a forest of lines throughout most of the visible spectrum. At the high loadings in compact source lamps, the discrete lines produced by the first group of iodides are reversed and throw out a continuum on both sides, which can improve the color quality. Under the same conditions, the dysprosium arc is constricted and tends to be unstable. The choice of additives also affects the lamp's electrical characteristic and the decay time of the emitted light over each half cycle of the supply. The importance of light decay time will be discussed later. When a combination is found which gives the correct spectral balance and the necessary electrical characteristics, the stability and lumen maintenance over the lamp's lifetime must still be checked — a time-consuming operation for which there are no shortcuts.

The compact-source-iodide (CSI) lamp, using a filling of sodium, thallium and gallium, was initially developed in a 400-W and later in a 1,000-W rating for projector, television and theater spotlight applications. An entirely new type of lamp construction was adopted which was a complete departure from the established compact discharge source with its double-ended construction. Figure 1 shows a 1,000-W CSI lamp, compared with the 1,000-W ME/D compact mercury lamp using the earlier construction methods. Due to the small volume of the arc tube, the discharge in the CSI lamp is "wall stabilized" rather than "electrode stabilized," as in the case of the double-ended lamps and carbon arcs. This reduces the possibility of arc "wander" and permits a steadier burning arc light source.

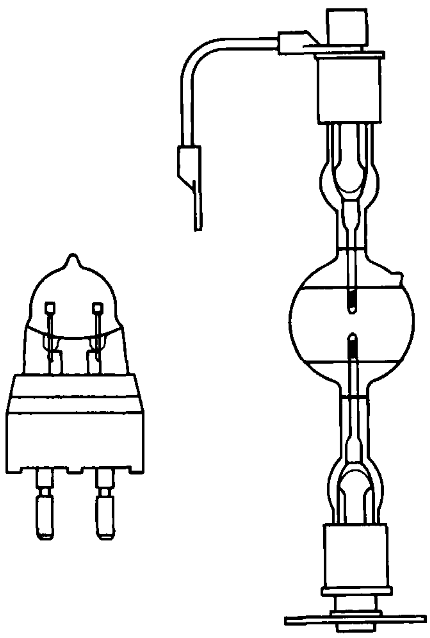

Fig. 1. Relative sizes of two 1,000-W compact source lamps. On the left is the bare CSI lamp with a pinch seal locating the two electrodes. Its medium bi-post G.22 base makes lamp mounting and replacement a simple matter compared with the compact mercury ME/D lamp, on the right, with the conventional double-ended construction.

The CSI lamps operate at 90 lm/W with excellent color rendering and have lives of 500 h for the 400-W size and 200 h for the 1,000-W size. The relatively short life of these lamps is primarily a consequence of the high operating temperatures in free air, which leads first to oxidation of the molybdenum foil used in the quartz pinch seal and ultimately to breakdown of the seal.

The next step in the development of this lamp came from the demands of a new lighting application which were certainly not foreseen in the early development stages.

Stadium Floodlighting for Color Television

Color television service was introduced in the UK in 1969. This soon involved a large outside broadcast commitment of sports coverage, and a large part of this was coverage of Association football (called "soccer" in the US) and Rugby football. Many of the games were midweek matches played after dark or Saturday afternoon matches which, in the winter months required the use of floodlighting. Football field floodlighting had gained in popularity since the first installations in 1949, so that 20 years later all major clubs had installations — most often four 100–120-ft (31–37-m) towers positioned at the corners of the pitch (playing field). These usually provided an average horizontal illumination of 10 fc (108 lm/m^2). The first estimates given by the color television engineers were that their cameras would require at least 100 fc (1080 lm/m^2) to cover the events in color.

Early market research revealed that most of the clubs which were prepared to consider upgrading their installations to permit color television coverage would accept a moderate increase in power consumption, but they were reluctant to purchase new heavy duty towers. The existing tower structures represented a large part of their original capital investment, and although the original floodlights were approaching the end of their useful life, the towers could be expected to be serviceable for another 20 years or more. Thus there was the fixed constraint of the amount of floodlighting equipment these towers would support and this depended on the front surface, or windage area, of the floodlights.

The overrun 1,500-W filament lamp floodlights used on most of the existing installations represented a windage load of 0.2 m^2 (2.15 ft^2) per kilowatt. Metal halide discharge lamps were four to five times more efficient than the overrun filament lamps which meant that the remainder of the ten-fold increase in horizontal illumination required for color television had to be achieved by using a greater number of 1-kW projectors with a maximum windage area of 0.075 m^2 (0.8 ft^2 — about 1 ft in diameter) if the safe windage load of the towers was not to be exceeded.

The CSI lamp was recognized as a natural choice to achieve the necessary beam control with reasonable system efficiency and control of glare for players, spectators and cameras. It was a very compact light source with a color quality suitable for color television, and it was already being used in follow spots and other projectors in television studios. However, the practical problems of designing a weatherproof floodlight of such small size in which the reflector maintained a reasonable efficiency over a 10 to 15 year life were considerable. There was also the question of lamp life: 200 h (the life achieved by the overrun filament lamps used in existing installations) represents about two seasons of floodlit football. Would the clubs accept a ten-fold increase in lamp replacement costs every two years on top of the capital cost of the upgraded installation?

Sealed-Beam Compact Source Iodide Lamp

The solution to all of these problems came in the idea of mounting the 1,000-W CSI "bubble" in a PAR-64 sealed-beam outer globe (Fig. 2) which could be filled with an inert gas to protect the quartz seal and the reflector. By this means, the optical performance of

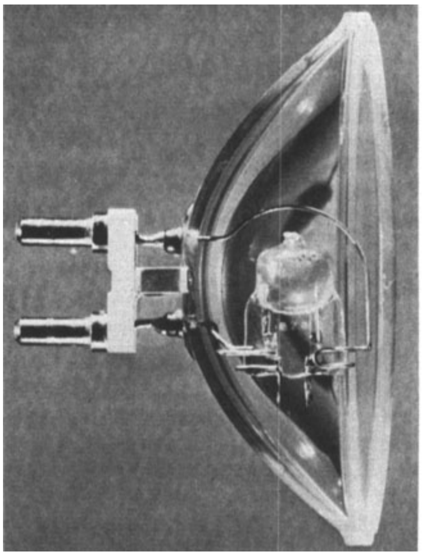

Fig. 2 Sectional view through a PAR-64 sealed-beam outer globe, showing the CSI arc tube accurately mounted at the focus of the reflector during manufacture to ensure consistent and highly efficient light control. The inert gas filling of the PAR globe increases the life of the arc tube and prevents deterioration of the reflector finish throughout life.

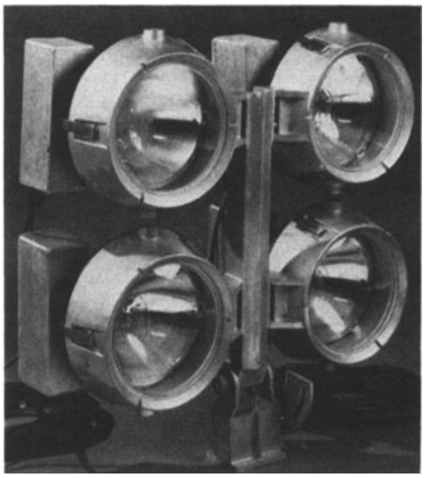

Fig. 3. Four 1-kW floodlights mounted on a cast aluminum bracket which makes the four beams accurately parallel. The group is then adjusted in elevation by pivoting on the bolt near the base of the bracket. The same bracket can be used to achieve two or three lamp groups, if required.

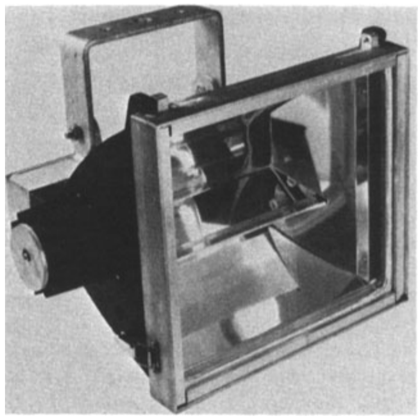

Fig. 4. The floodlight specially designed for the 1,600-W bare arc tube linear metal halide lamp (MBIL/H) provides both the necessary light control and the correct thermal environment to ensure the effective operation of the lamp. The internal reflector baffle, seen just above the lampholder position, provides a sharp runback above the peak beam intensity to reduce glare to spectators and lens flare to cameras.

the floodlight was maintained throughout the life of the lamp, the complete 8-in diameter reflector system being renewed at lamp replacement, with the average life increased to a nominal objective 1,000 h. There is a reasonable expectation that future developments will increase the lamp life to 2,000–3,000 h. By accurately placing the arc tube at the focus of the sealed-beam reflector, an initial peak beam candle power of 1.5×10^6 cd is achieved with a beam of 6° to one-half peak and 18° to one-tenth peak. This produces a beam factor of 0.43 compared with a typical value of 0.3 for floodlight reflectors with conventional jacketed metal halide lamps. By using the range of four standard PAR-64 front glass lenses in conjunction with the clear front glass on the lamp it is a simple matter to achieve wider beam angles — up to 68° at half peak and 100° at tenth peak (see Table I). By using a standard G.38 Mogul bipost cap on the lamp it is a simple operation to re-lamp the lighting unit. The lamp is extremely robust, and the quartz arc tube is not handled by the maintenance staff.

In the context of stadium floodlighting for color television, a 1-kW lamp rating seems rather low, and so it is, but higher ratings would rule out the use of standard PAR sealed-beam outer glasses, with all the benefits of long life, light control and lumen maintenance that this brings. In a practical stadium lighting installation, it is rarely necessary to have more than 24 separately aimed projectors on each tower in order to achieve the required uniformity of illumination. For this reason the 1-kW floodlights are mounted in four-way groups (Fig. 3) with all the beams parallel to achieve what is, in effect, a 4-kW floodlight. A side benefit of this arrangement is that it is possible to separately switch the lamps in each group so that the floodlighting system can be used at reduced illumination without losing uniformity of coverage.

The flexibility of this system makes it possible for the 1-kW CSI sealed-beam floodlight to meet all color television and filming requirements, as it does in the Olympic-standard stadium and Vellodrome complex at Aryamehr in Teheran using a total of 1,600 lamps. At the other end of the scale, small sports organizations can achieve 20 fc (215 lm/m^2) using as few as 50 lamps on inexpensive light-duty masts. Installations in Canada include the Varsity Arena in Toronto where Global Communications, Ltd. provides television coverage of the Toronto Maple Leaf hockey games.

Linear Metal Halide Lamps

Before moving on to the filming applications of the CSI lamp in both its bare arc tube and sealed beam versions, it is worth mentioning a parallel metal halide lamp development carried out at the same time, which is also widely used to floodlight large sports areas for color television outside broadcasts. The linear metal halide lamp (MBIL/H), unlike most conventional discharge lamps, consists of a bare tubular arc tube without the outer glass jacket which ordinarily serves to maintain a uniform temperature around the discharge tube and thus to ensure stable operation of the arc. The principle of the bare arc tube lamp on the other hand is such that it should operate in a specially designed floodlight which not only provides the required light control but also maintains the correct thermal environment for the lamp (Fig. 4). By dispensing with the large outer glass jacket, short focal length reflector systems can be designed around the lamp to achieve much smaller floodlights than those designed to house conventional jacketed lamps.

The lamp was first produced in the 750-W rating with a life of 5,000 h for general area floodlighting and street lighting applications. The first installation was in the famous Princes Street in Edinburgh. A 1,600-W rating followed, and the color quality achieved by the use of sodium and scandium filling, although not as good as the CSI lamp, was found to be entirely satisfactory for color television lighting.

Although the majority of sports stadia in the UK use the four corner tower system, a sizeable minority have adopted side lighting systems. Side lighting has been increasing in popularity as more clubs built covered stands on all four sides of the stadium; the roofs usually cast shadows onto the playing field if corner towers are used. There is also an important economic advantage for side lighting in that it produces the same illumination towards the camera for about half the electrical load of the tower system. The primary disadvantage is that of increased risk of glare to players and spectators and lens flare to cameras along the sidelines.

Careful optical design of the floodlights, using the 1,600-W linear lamp has resulted in a unit with a windage area of approximately 1 ft^2 (0.09 m^2) that produces a peak intensity of 250,000 cd with a sharp run back to one-tenth peak in 10° above the peak (to reduce glare and lens flare) and 60° below the peak.

In the horizontal plane the beam spread is 100°.

This lighting system is suited to large and small installations alike; 16 units will light a soccer field to 15 fc (161 lm/m^2) in the horizontal plane while over 200 units are used at Wembley Stadium to provide 100 fc (1,080 lm/m^2) towards the camera and 140 fc (1,510 lm/m^2) in the horizontal plane. Like compact-source-iodide systems, linear metal halide lamp installations have proved very satisfactory both for electronic and film cameras, even in the difficult transition period when events start in daylight and finish with the floodlighting as the sole source of illumination.

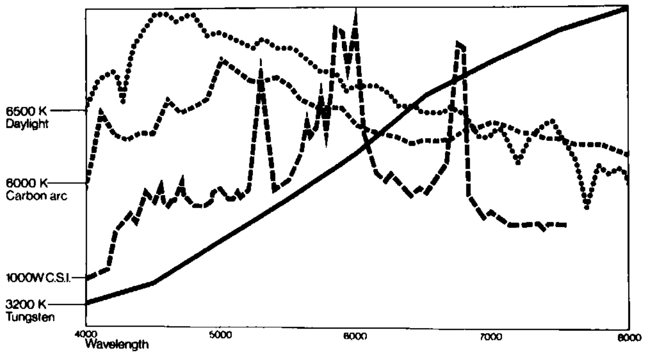

Fig. 5. Spectral energy distribution of the 1-kW CSI lamp compared with that of a tungsten filament lamp at 3200 K, a carbon arc at 6000 K and daylight at 6500 K. The large peaks cause such a departure from a blackbody curve that the concept of color temperature does not apply, even though good color rendering is possible.

CSI Lamps for Filming

Both lamps are now firmly established over a wide range of sports lighting applications, but it is the 1-kW CSI lamp, available in both bare lamp and PAR-64 versions, that has aroused particular interest for location and studio filming. The luminous efficiency is five to six times greater than a tungsten lamp used with a blue filter to correct to daylight, and a group of four lamps is approximately equivalent to a 225-A carbon arc (Table I).

The sealed beam version can be used in banks or arrays of two, four and six lamps about the way that tungsten-halogen PAR globes are used at present. A number of units specially designed for film and television applications are now becoming available. A range of spreader glasses permits various beam widths to be selected.

Where the beam angle must be changed smoothly the bare arc tube in conventional soft edged lanterns can be used. Both lamp types are of rugged construction and permit easy mounting and lamp replacement, and both run up rapidly to full light output in less than one minute.

Color Quality

Figure 5 shows the spectral energy distribution of the CSI lamp compared with that of tungsten filament lamps at 3200 K, carbon arcs at 6000 K and natural daylight at 6500 K. The color appearance of the CSI lamp is that of a warm phase of daylight, and the CIE color rendering index is 80 when compared with a reference source of 5500 K (photographic daylight). This has been chosen as the most appropriate reference within the CIE system for filming applications. Although the correlated color temperature of the lamp is approximately 4000 K, color temperature meter readings can range from 3500 K to 6000 K. (Strictly speaking, the concept of color temperature should be applied only to a continuous-spectrum source and not to the spectrum of lines and bands that make up the output of a discharge source.) Values of color temperature are quite meaningless as a guide to the color quality achieved on different film stocks or the selection of correction filters when using metal halide lamps and should therefore be disregarded.

When in doubt, a test film is advisable, but the following series of independent tests can be used as a guide. Tests using Type EF7242 film have given good results using an 85B filter on the camera, while Type 7254 film using an 85 filter on the camera showed that the lamp, with a quarter blue filter, can be mixed with daylight blue filtered filament lamps or carbon arcs with a WF green filter. Other tests using Types EF7242, 7252 and 7254 film have shown that the lamps performed exceptionally well as a fill-in source with daylight. In actual filming most cameramen use the lamp directly without filters. Sometimes a quarter blue or even a half blue is used, depending on the particular cameraman and the effect required. Either a full or half CT orange has been used to match filament lighting.

Control Gear

The control gear for these lamps can take a number of forms. The design depends upon the relative importance of cost, weight and size for different applications, but basically the gear consists of a current-limiting ballast which can be housed a considerable distance from the lamps, plus a high-frequency 9-kV ignitor which is most conveniently mounted within the lamp housing. Power factor correction, although not essential for the operation of the lamp, is strongly recommended where portable generators are used, because a large lagging power factor can upset the operation of voltage control devices.

Hot Restrike Circuits

In common with most high pressure discharge lamps, a hot lamp will not restrike with standard control gear and ignitors until the temperature of the lamp, and therefore the arc pressure, has been reduced. Depending upon operating conditions, the restrike time for CSI lamps will vary between 2 and 10 min unless a special hot restrike ignitor supplying a 25-kV pulse to the lamp pins is used. Due to the unique compact construction of the lamp (which is responsible for most of its major practical ad-

Table I. Illumination and light pattern vs. throw for various lamp and lens combinations. Values have been calculated in metric and British measurements are given below. *Somewhat different working distances have been used in the two sets of calculations so that a wider range of values can be illustrated.*

		Metric			British		
Lamp unit	Spreader lens	Throw (meters)	Illumination (lux)	Beam width (50% peak) (meters)	Throw (ft)	Illumination (fc)	Beam width (50% peak) (ft)
1 ×	OMW	3	15,500	1.3 × 3.5	15	620	6.4 × 17
1 ×	OME	3	7,000	3.8 × 3.8	15	280	19 × 19
1 ×	OMS	10	11,000	2.5 × 1.8	25	1,700	6.2 × 6.2
1 ×	OMP	10	4,300	2.6 × 4.3	25	690	6.6 × 10.6
4 ×	OMW	10	5,500	4.3 × 11.5	25	880	10.6 × 29
4 ×	OME	10	2,500	12.5 × 12.5	25	400	32 × 32
4 ×	OMS	20	11,000	5.0 × 5.0	100	440	25 × 25
4 ×	OMP	20	4,300	5.3 × 8.5	100	170	26 × 43
225A Brute (spot)		20	6,000	3.0 × 3.0	100	240	18 × 18
225A Brute (flood)		20	1,500	11.0 × 11.0	100	60	68 × 68

Key: OMS = narrow; OMP = medium; OMW = wide; OME = extra wide.

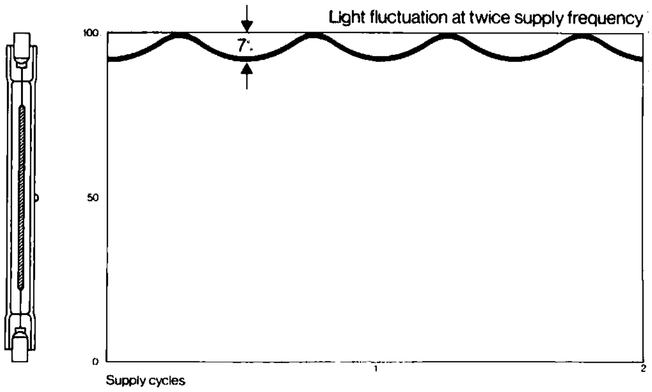

Fig. 6. Light fluctuation waveform for a 500-W tungsten-halogen lamp.

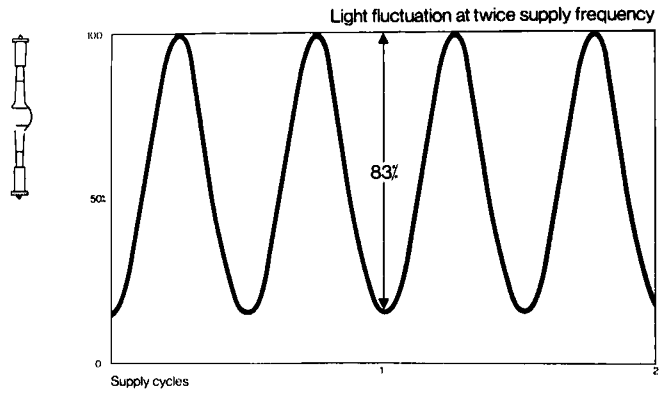

Fig. 7. Waveform for an electrode-stabilized compact source metal halide lamp, using dysprosium, holmium and thulium iodides.

vantages) using these high restrike voltages does present flashover problems. Nevertheless, hot restrike circuits can be used with lamps of modified construction, and if a demand exists for the hot restrike capability then it can be supplied.

Sports Stadia Hot Restrike Installations

Assuming that the public areas of a stadium are provided with an emergency lighting system, there seems to be little justification for the additional cost and complication of instant restrike facilities, except in the case of a few major international class stadia. It must also be realized that although lamp extinction can result from a momentary break in supply, a major electrical breakdown will also have the same effect and is just as likely to occur. To cover this eventuality, a second independent supply must be available on the site even when hot restrike equipment is used, if the lighting is to be reinstated only a few seconds after the failure.

The alternate method of connecting two lamps in parallel across single sets of control gear will also achieve either full or partial lighting within 30 s of the supply being reinstated. With this system, the lamp with the best starting characteristic in each pair will strike and run up to full output; if this lamp itself goes out, then the second ("cold") lamp will strike and run up in about 30 s. This solution is more economical than using special restrike circuits.

Due to the low windage area of compact source floodlights, even the duplication of units gives lower tower windage loads than where conventional floodlights with jacketed metal halide lamps are used.

Hot Restrike for Filming and Television

To be deliberately provocative for a moment: why do lamps have to be switched on and off so frequently? After all, if the usually restrictive concept of color temperature is found to have little or no relevance to metal halide lamps, perhaps some other aspects of accepted practice require rethinking as well.

Ignoring the case where portable handlamp equipment is used, there seem to be four main reasons for switching lamps:

(1) To enable the lighting cameramen to check the contribution of individual lamps in the overall lighting set-up. This can be done just as effectively, however, by waving a hand or a board in front of the lantern, or by using barndoor or mechanical shutters.

(2) To conserve life when the lighting is not being used, or when lanterns are to be repositioned in order to reduce the risk of vibration damage to the filament when it is hot. Discharge lamp life, however, is shortened by frequent switching, and if the off-time is sufficient to permit a significant saving, the lamp will have cooled down and will restrike with the standard circuits. Furthermore, the CSI PAR-64 lamp has a greater life than most filament studio lamps and is far less vulnerable to vibration damage when either hot or cold. Lanterns can be moved when the lamps are lit without affecting lamp life — which is certainly not the case with filament lamps.

(3) To reduce the heat load in the studio between shots and save power consumption. Using discharge lighting will reduce the lighting load at least to one quarter of that required for filament or arc lighting, and this is surely a significant saving.

(4) To reinstate lighting when it has been accidentally or prematurely killed. The "Sparks" may trip over a cable, or the Director may shout "Kill it!" — and a moment later change his mind. Such things happen, but it is open to question how much the industry is prepared to pay to cover these eventualities. At least with metal halide lamps, time is never required for a "re-trim." Obviously cases can always be made for a hot restrike facility, but considering the more expensive lamp, starter unit and the housing which must withstand the very high voltage pulses required, cases for which these costs can be justified are probably fewer than one would first believe. As indicated earlier, hot restrike lamps are now becoming available.

Beat Effect on Film

There is one more important characteristic of ac discharge lamps that has particular relevance to filming and this is the problem of "beat." The light output of any lamp operating on an ac supply fluctuates at twice the supply frequency; thus on a 60-Hz supply the time of one light cycle is 8.3 ms and on 50-Hz 10 ms. This is true for all types of lamp, but there is considerable variation in the percentage of light fluctuation (depth of the light variation) between the peak and trough of the light cycles of various lamps. Figure 6 shows the 7% fluctuation for a 500-W tungsten-halogen lamp; for the larger mass filaments used in higher rated studio lamps the fluctuation is less. With discharge lamps it is much greater: Fig. 7 shows an 83% fluctuation for an electrode stabilized compact-source metal halide lamp using dysprosium, holmium and thulium iodides, and Fig. 8 shows a value of 76% for a 1,600-W linear metal halide lamp. The light cycle fluctuation for a 1,000-W CSI lamp is shown in Fig. 9 to be 62%. Where CSI lamps are used to replace carbon arcs on outdoor locations to provide "fill" light, no beat problems have been experienced at normal frame speeds, but where they provide the sole source of light, beat can be a problem.

Using 1-kW CSI lamps in three-way groups, there are two different ways of reducing the depth of the light fluctuations. The first way — connecting each of the three lamps on a different phase — results in a light-cycle waveform with only a 4 to 5% fluctuation at a frequency of six times the supply frequency (Fig. 10).

Where a three-phase supply is not available, light fluctuations may yet be reduced by the second method: using special lead-lag circuits to operate groups of three lamps. This is achieved by connecting two lamps as a series pair with a combined capacitive and inductive ballast which results in a leading power

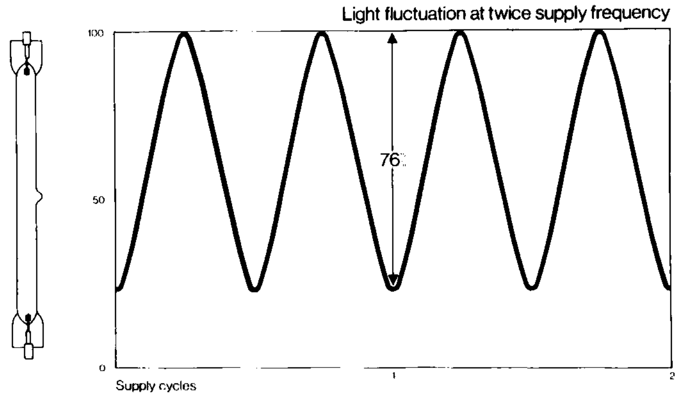

Fig. 8. **Waveform for a 1,600-W linear metal halide MBIL/H lamp.**

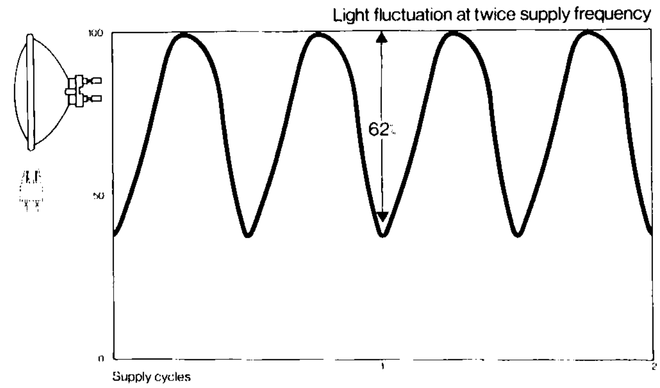

Fig. 9. Waveform for a 1,000-W CSI lamp.

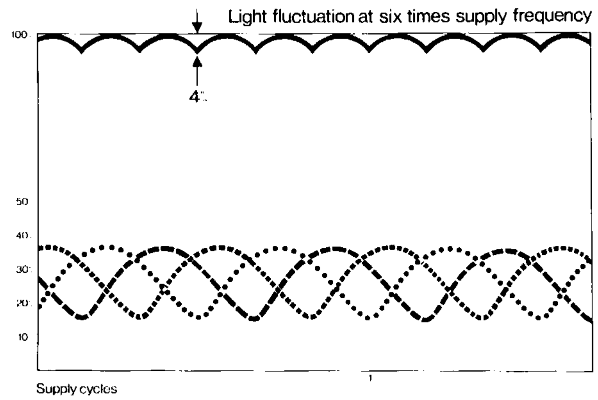

Fig. 10. Waveform for a group of three 1,000-W CSI lamps operating on three phases.

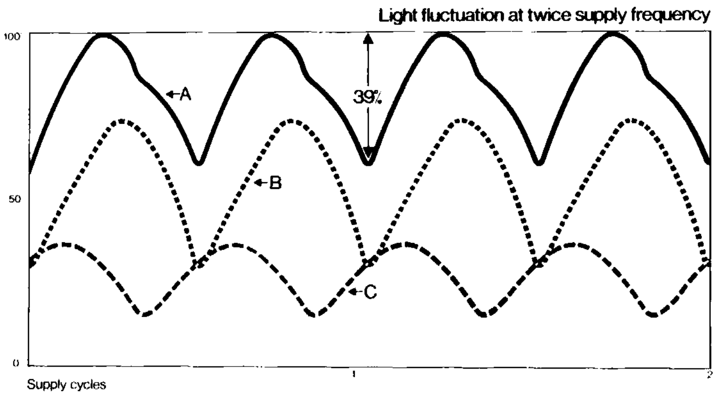

Fig. 11. Waveform for a group of three 1,000-W CSI lamps operating on lead/lag circuits. Curve A shows the combined effect of all three lamps, curve B the output of the two leading lamps and curve C the output of the single lagging lamp.

factor. The third lamp is connected to a standard ballast without power factor correction, to give a lagging power factor. Figure 11 shows that the light output of this combination still varies at twice the supply frequency, as for single-phase lamps, but the fluctuation is reduced to 39%. The group of three lamps operates at a power factor near unity, and the circuit has the advantage of reducing the control gear weight by approximately 30%, although a modified ignitor is required for the lamps operating as a series pair. Although the frequency of the light cycle is the same as the standard single-phase circuit, the improvement in fluctuation from 62% to 39% will reduce the likelihood of beat effects.

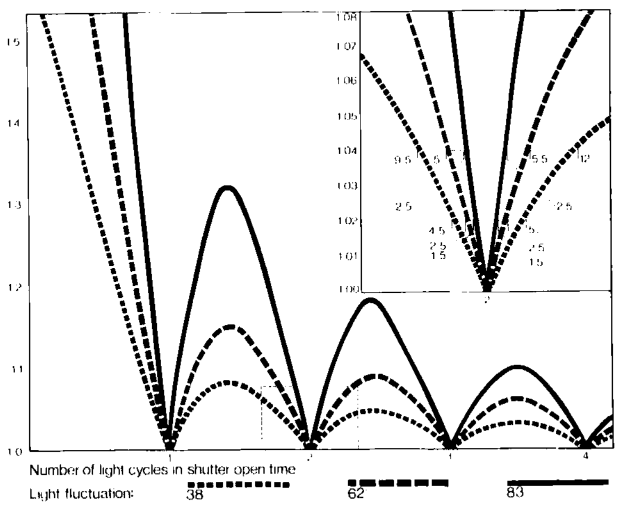

Fig. 12. Maximum/minimum ratios of exposure with increasing shutter open time for lamps with 83%, 62% and 39% light fluctuation. The insert shows an enlarged version of this curve around the point where shutter open time is equivalent to two light cycles. Note the increased tolerance in shutter open time that is possible with lamps giving a lower percentage of light fluctuation.

The variation in the exposure of successive frames is dependent upon the supply frequency, the percentage light cycle fluctuation of the lamp and the camera shutter open time; shutter open time is affected by both frame speed and the shutter angle.

Figure 12 shows the maximum variation in the exposure of successive frames vs. shutter open time for three values of lamp light cycle fluctuation. It can be seen that when the shutter open time corresponds exactly to the time of one or more complete light cycles the ratio of maximum exposure to minimum exposure equals one, providing consistent exposure. In practice plus or minus tolerances will apply to the camera speed, the supply frequency and the accuracy of the shutter angle setting. From the Fig. 12 insert it can be seen that to hold the exposure variation to 4%, these combined tolerances must be less than $\pm 2^1/_2$ if a lamp with light fluctuations of 83% is used, while they can be increased to $\pm 5\%$ if the light fluctuations are 62%.

The precise exposure variation which can be tolerated before projected flicker becomes noticeable is not known with certainty, nor is the combined tolerance of supply frequency and camera settings

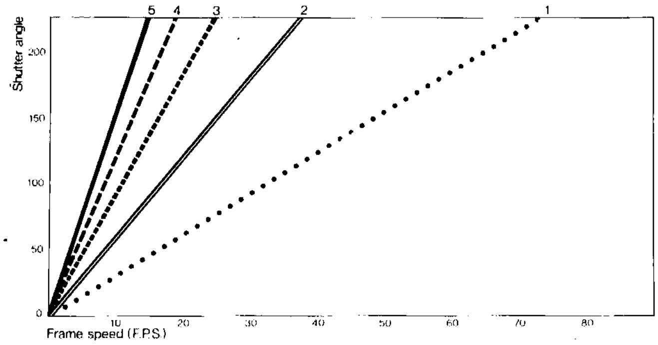

Fig. 13. Combinations of frame speeds and shutter angles which result in a shutter open time equivalent to 1–5 complete light cycles on a 60-Hz supply. (Shutter angle = 3*n* times the frame speed where *n* = 1,2,3,4,5, respectively. For 50-Hz supply, the constant 3 above becomes 3.6.)

which is normally achieved without special precautions. There is increasing evidence to suggest that the figure in both cases is about 4%. The third line corresponding to a light fluctuation of 39% using a three-way CSI lead lag group (Fig. 11) is included to show that good results could be obtained in this way.

As an alternative to setting the shutter open time to one or more complete light cycles, exposure variation will be nil if the camera and mains are synchronized and the camera speed is chosen to be an exact submultiple of double the mains frequency. Table II shows the frame speeds which can be used in this way on 60-Hz or 50-Hz supplies. At these frame speeds any shutter angle can be used.

Figure 13 shows combinations of frame speeds and shutter angles that give a shutter open time of one or more light cycles. These will also avoid flicker effects if the lamp used has a light fluctuation of less then 62% as described earlier.

From this theoretical data, it is possible to find certain combinations of camera settings which can give satisfactory results. Nevertheless, it is recommended that film tests be taken when there is any doubt about beat effects, because anomalies in practice (often due to camera faults) do occur.

When lamps are used in three-way groups from three-phase supplies, there may be a multiple shadow problem, depending upon the distance between the lamps in the group and the length of throw. Although surfaces lit equally by the group lamps are free from beat, shadow beat can occur and highlights in shiny surfaces might pulse. In practice good results are achieved if the three lamps are small enough to be mounted and used as one unit. Using lamps in groups is ideal for outdoor sports areas where a three-phase supply is normally available and the distance between the floodlights and playing area is great.

The future development of high-frequency single lamp circuits will overcome the problem of beat over the practical range of camera frame speeds used in cinematography for commercial purposes. Through the use of invertors to operate the lamps at around 2,000 Hz, the number of light cycles per frame will be increased. This improves the light cycle fluctuation and together with the increased number of light cycles occurring during each shutter opening will make beat effects imperceptible. These high-frequency circuits are still under development, but once perfected they will undoubtedly ensure that high-pressure metal halide discharge sources can play a full part in lighting for the film industry.

Conclusion

At present, the high-pressure metal halide discharge source constitutes an invaluable lighting tool on a par with established sources so long as the user is fully aware of certain limitations. Metal halide lamps have already been used successfully for such film and television applications as:

(1) Color television outside broadcasts for interior and exterior sporting events and other types of entertainment.

(2) Outdoor and indoor location filming where the portability and low power consumption are important advantages. They have been found to be particularly effective alternatives to carbon arcs.

(3) Television and film studios where the reduction of heating load is a great benefit.

(4) Slow-motion filming for commercial film productions and industrial applications where the high levels of illumination required cannot be economically achieved by other sources. With care, beat problems can now be minimized and, in the future, development of high, frequency equipment will eliminate this effect entirely.

Acknowledgments: The author wishes to express his thanks to colleagues and friends in Thorn Lighting Ltd., Lee Electric (Lighting) Ltd., Jack Frost Ltd., the BBC and the CBC, for their help and advice in the preparation and presentation of this paper.

Table II. Frame speeds which are likely to be most compatible on 50-Hz and 60-Hz supplies using battery-powered, crystal-synchronized cameras.

Number of light cycles	Frame speed (fps) 60-Hz	50-Hz
1	120	100
2	60	50
3	40	33.33
4	30	25
5	24	20
6	20	16.67
7	17.14	14.3
8	15	12.5
9	13.33	11.1
10	12	10

Discussion

Thomas M. Lemons (TLA-Lighting Consultants, Inc.): Your data on light output variations for various lamps should also note that this can vary by the exact ballast used. Though I agree with your data as being fairly accurate for standard reactor ballasts, my experience is that other wave shapes have been provided by ballasts for these lamps. This is especially true for ballasts developed for 120-V lines normally encountered in North America. The best judge of light wave shape is the ballast current crest factor which is limited to 1.6 to 1 for HMI lamps. Standard metal halide lamp ballasts used in the US and Canada have a current crest factor between 1.8 and 2.0 to 1 which would be much worse than your HMI data. Is there any current crest factor limit for CSI lamps? The filter correction of CSI and HMI lamps is important for balancing with both tungsten and daylight film. The HMI lamp tolerance is ±200 K for manufacturing and a 200-h life application and therefore color correction can be achieved with one basic filter. What is the manufacturing tolerance and color temperature change during life for the CSI lamps? Is this satisfactory to achieve color correction with one filter with all lamps throughout life or will filters have to be matched to preselected lamps and changed during life?

Mr. Aldworth: The reason for showing the variations in light waveform for various lamps in my paper was to illustrate the link between this characteristic and beat effects on film. The percentage of light fluctuation is fundamentally dependent upon the halide mix used in the lamp, and all my data was derived from circuits giving a crest factor not greater than 1.6. Had the crest factor been greater the fluctuation would undoubtedly have been increased, which would in turn have increased the problem of beat, but we have no experience of using lamps on circuits with higher values of crest factor and, therefore, we cannot state by how much the fluctuation would be increased. Conversely the effect would be reduced with crest factors nearer 1, but as my demonstration film showed, beat effects can also be avoided by running the lamp at higher frequencies which only achieves small improvements in the actual percentage of light fluctuation.

With regard to your query on filter correction, we do not believe that color temperature is a proper measure of the color rendering properties of discharge lamps. Our view is shared by the *American Cinematographer's Manual* (4th Ed.) which says, "Many of the newer types of improved mercury lights give excellent color rendering for the eye, and manufacturers often give an "effective" color temperature to the sources. This "kelvin" temperature has no meaning for the purposes of color photography." The lamp has been used extensibly for filmmaking, particularly in the UK, and a summary of our experience is given in the "Color Quality" section of the written paper.