1. SCOPE

Free TV Australia Operational Practice 31 is a guideline for the minimum lighting requirements for television coverage of events staged under artificial light. OP31 is a summary of international TV field lighting system specifications intended as a guideline for planning of installations to meet international standards and for upgrade of existing installations to cater for the stringent lighting demands for live TV production.

This Operational Practice is based on international practice. Adherence to this Practice will result in optimum lighting conditions for television broadcasting of sports events whilst providing good lighting for both competitors and the audience. The values given in this Operational Practice are intended to cover a wide range of events at both national and international level.

This Operational Practice has been developed by the Free TV Australia Project Group - Outside Broadcasts in the interests of maximising TV and Radio production potential and productivity at venues and the avoidance of costly omissions at planning and construction stages.

This Operational Practice recognises the wide usage of Super Slow Motion cameras, ("Super Slo-Mo" or SSM) High Definition (HD) cameras, the increasing use of Ultra Slow Motion cameras (USM) and a wide range of special effects cameras in general service in sports telecasts. For example, rugby football codes depend heavily on SSM cameras placed in the dead ball corners for replays and video referee deliberations. Whereas large arena sports such as cricket and AFL employ camera positions around the 360-degree field.

All cameras require full lighting level and even illumination. This is also a necessary requirement for players and spectators. Television lighting can also cater for non-televised events.

The wide general usage of HDTV slow motion cameras has led to revision of the minimum illumination for TV to the (non-major venue) professional level of $E_c \geq 1000$ lux. The international and professional major venue level remains at ≥1400 lux.

2. DEFINITIONS

- Cameras are referred to as either:
    - **Hard camera** - located in a fixed position for the event/discipline but may pan and tilt and may be a 'hand-held' camera mounted on a tripod (sticks).
    - **Main camera(s)** - those camera locations designated by the OB as being the principal cameras that cover 70% of the production.

      Note: a main camera can move e.g. the tracking camera in swimming is typically used as the principal camera covering the action.
    - **Secondary camera** - stationary or roving cameras other than designated main cameras.
    - **ERC** - ENG hand-held roving camera.

- **Super Slo Mo (SSM)** – camera systems up to 3 times speed
- **Ultra Super Slo Mo (USM)** – variable frame rate above 75 frames per second

- **Field of Play** (FOP) is the competition area as defined by the sport's governing body. For television purposes the FOP may extend beyond the defined area and is detailed in the associated specific OPs.

- **FOP-surround** is the area outside the competition space where competitors and officials may be present – often within a corral.

- **Run-off** is the area outside the FOP (and the FOP-surround, if defined) up to the spectator barrier – usually outside the corral.

- **Slow-motion replay zone** (SRZ) is an area of the FOP where replays are usually covered, usually in slow motion, and sometimes called 'the money shot'.

- **Mixed Zone** - an interview area at the venue where competitors, broadcasters and media mix to conduct post-event interviews. The lighting of the Mixed Zone refers to the area where the competitor/interviewer (talent) is likely to be positioned (**not** the space where the camera is located). Some Mixed Zones are located back-of-house.

- **Competitor entrance** and **exit** route is the route taken by competitors to and from the FOP, including medal ceremonies, which may differ from competition.

3. TECHNICAL CONSIDERATIONS

In order to enable a television camera operator to follow an object when high apparent speeds are involved, higher light levels are required. Where the action moves rapidly along the direction of view, the camera lens system must have a sufficiently large depth of field (i.e. range of distance within which objects stay in focus). This will necessitate a small lens aperture and consequently higher light levels are again needed to compensate.

The apparent size of an object is dependent upon the distance from the object to the camera (pick-up distance) and the actual size of the object. If a telephoto (zoom) lens is used to increase the apparent size, then a higher light level is needed because the longer the focal length of the zoom lens (i.e. the greater the magnifications) the smaller the aperture generally has to be. For example, the "ramp function" of a typical telephoto lens gives f/2 for wide angle pictures, decreasing to f/8 for narrow angle telephoto pictures. Extender lenses (in combination with zoom lenses) are also used with the same effect; smaller apertures at smaller picture angles or longer focal lengths.

For installations handling multi-purpose events it may be desirable to have a degree of operational flexibility:

- Choice of lighting levels available, e.g. low level for normal use and high level for television use.

- By switching, lighting of selected areas e.g. a tennis competition commencing with two or more courts, reducing to one court for the final.

Whilst developments in television camera design have led to a dramatic increase in camera sensitivity, this has been offset by the production of zoom lenses having a much wider range of focal lengths and the use of super and ultra slow motion cameras. Consequently, high levels of illuminance are required to produce the quality images that we have come to expect from a television broadcast.

3.1 Lens design

General lenses in current use are 75 x zoom with focal length of 1600 mm equivalent.

Lenses with 86x & 100x zoom with focal lengths of 1600 & 1860 mm respectively are now also in service. The trade-off with these more powerful zooms is F stop, and therefore overall camera system sensitivity. This applies for both HDTV and UHDTV (4k and 8k) camera systems.

3.2 Super Slo Mo (SSM) Cameras

At least 1800 lux minimum vertical illuminance toward (U)SSM camera positions is essential for satisfactory performance. The requirement is for those areas of the FOP typically covered by the (U)SSM cameras. See Clause 4.2 and Appendices.

Appendix A – AFL Slo Motion Replay Zone

Appendix B – Cricket Slo Motion Replay Zone

Appendix C – Rugby League Slo Motion Replay Zone

Appendix D – Rugby Union Slo Motion Replay Zone

Appendix E – Football (soccer) Slo Motion Replay Zone

Appendix F – Swimming Slo Motion Replay Zone

3.3 Ultra Slo Mo (USM) Cameras

3.3.1 USM cameras by their very nature require relatively higher illuminance levels for equitable image quality to the standard speed HD cameras.

3.3.2 Flicker is the main problem. See 4.7 Reduction of flicker.

4. ILLUMINATION

4.1 Vertical Illuminance

Illuminance on a vertical plane, commonly called vertical illuminance (E_v), is essential for viewing vertical objects. The side of a subject visible to an observer can be approximated by a vertical plane at right angles to the observer's line of view.

4.2 Camera Illuminance

In the case of TV coverage, to ensure a camera receives sufficient light to create a good quality image, it is necessary to specify (and measure) the illuminance perpendicular to each selected camera position. This is referred to as illuminance towards a camera or simply *camera illuminance* (E_c).

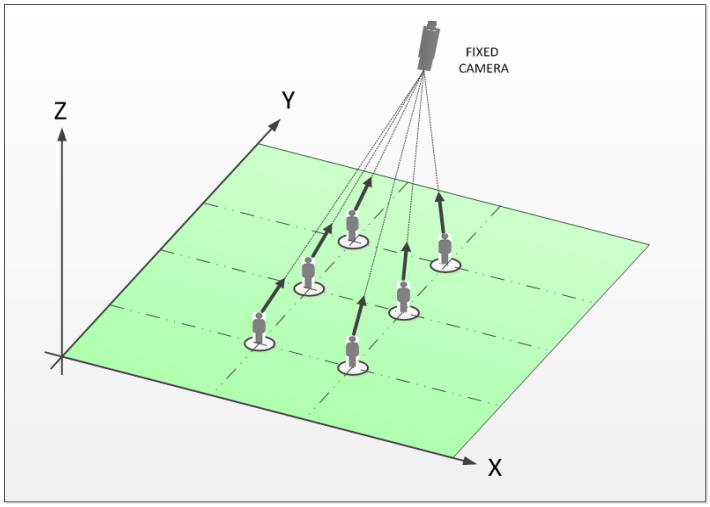


Figure 1 Camera illuminance – high angle camera view

The scene illuminance, and more particularly the camera illuminance, has a major influence on the quality of the final television picture. To guarantee an optimal view and identification of subjects from all directions, specified illuminances at a nominal height of 1.5 metres above the competition area are required. See Figure 1 and Figure 2 for details.

The orientation of the vertical plane at a grid point depends partly on the camera positions and partly on the layout of the competition area. For example, where the camera has an undefined position somewhere in an area bordering one of the competition area e.g. side-lines of a football pitch, the illuminance on vertical planes facing that side-line should fulfil the following requirements:

Minimum illuminance toward side-line, $E_{v\ min}$:	≥1000 lux
Low End Useable Level:	≥800 lux

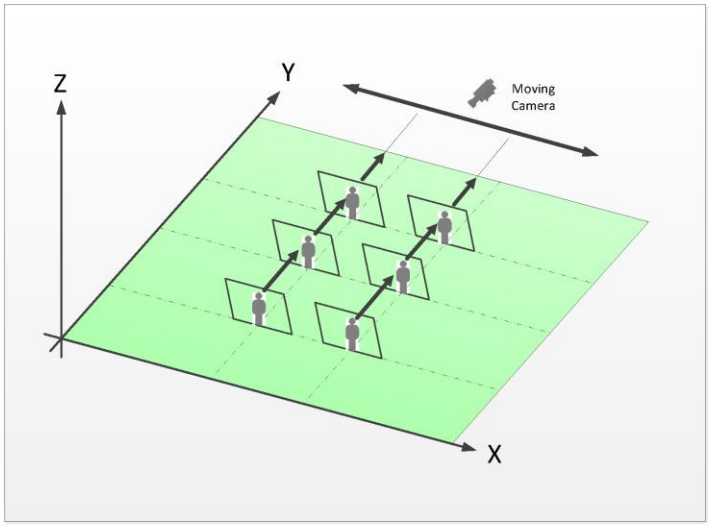


Figure 2 Vertical illuminance – roving camera view

Illuminance uniformity toward roving cameras i.e. orthogonal to side-line

$E_{v\ min}$: $E_{v\ max} \geq 0.6$; and

$E_{v\ min}$: $E_{v\ ave} \geq 0.7$

4.3 Minimum vertical illuminance and SSM replays: SRZ

Knowing the minimum to average uniformity meets the criteria in the previous clause does not reveal where the minimum occurs.

Television camera systems rely on having at least a minimum 'useable' illuminance level at critical parts of the FOP especially those areas where the highlight action slo-mo replay is likely to happen.

Typical examples are the goal area (hockey & football), the athletics finish line, the corner flag and try-line for rugby football codes, the balance beam of gymnastics, the touch pads at the swimming finish (the 'hero' shot) and the dives plummet etc.

4.3.1 SLOW-MOTION REPLAY ZONE (SRZ).

The SRZ is an area of the FOP where replays, commonly in slow motion, are usually covered.

Consequently, the lighting should be so designed/installed such that the minimum vertical illuminance does ***not*** fall in the SRZ – in fact preference would be for the maximum vertical illuminance to be within the SRZ.

The coverall definition is therefore:
The minimum vertical illuminance towards the main cameras shall not be within the areas where SSM replays of the action usually occur.

For sports where the replay can be anywhere, in principle, the maximum vertical illuminance toward camera #1 should be at the centre of the FOP.

The SRZs can be defined by sport.

Example 1: Rugby: television replay zones, both ends of the field (camera left and camera right):

- SRZ_{left}: an area bounded by the left goal line, the left 20m line and the touchlines.
- SRZ_{right}: an area bounded by the right goal line, the right 20m line and the touchlines.
- the maximum vertical illuminance shall be within the SRZ.
- SSM cameras: the specified minimum illuminance shall be within the associated SRZ e.g. left SSM and $SRZ_{left.}$

See the Appendices A-F for specific zones and sports.

4.4 Horizontal Illuminance (E_h)

The FOP surface acts a background to the competitors within a camera shot and establishes the overall look of the arena and is a major contribution to a satisfactory performance environment

Uniformity of horizontal illumination is important in avoiding dark spots in the overall viewing.

4.5 Modelling

The contrast between the lighting of the subjects (foreground) against the background creates a degree of three-dimensional modelling. To produce the modelling the ratio of average horizontal illuminance to average camera illuminance, $E_{h\ ave}/E_{c\ ave}$, should be in the range 0.5 to 2.0

4.6 Uniformity of Horizontal Illuminance

Good illuminance uniformity is important in order to avoid, on the one hand, adaptation problems for performers and audience, and, on the other hand, adjustment problems for cameras for different directions of view. If the uniformity is not good enough, there is a risk (especially with television cameras) that in the example of football, the ball and/or a player will not be clearly seen at certain positions on the performance area. The uniformity of the horizontal illuminance on the performance area surface shall be:

$E_{h\ min}$: $E_{h\ max} \geq 0.7$ and

$E_{h\ min}$: $E_{h\ ave} \geq 0.8$

Poor horizontal uniformity is particularly noticeable and unacceptable for HDTV broadcast.

4.7 Consideration for camera movement (panning)

It is important also that there is not too great a change in illuminance over a given distance. For example on large playing fields such as football a maximum gradient of illuminance of 20% change per 4 metres is recommended.

In lighting design terms this is known as the Uniformity Gradient (UG).

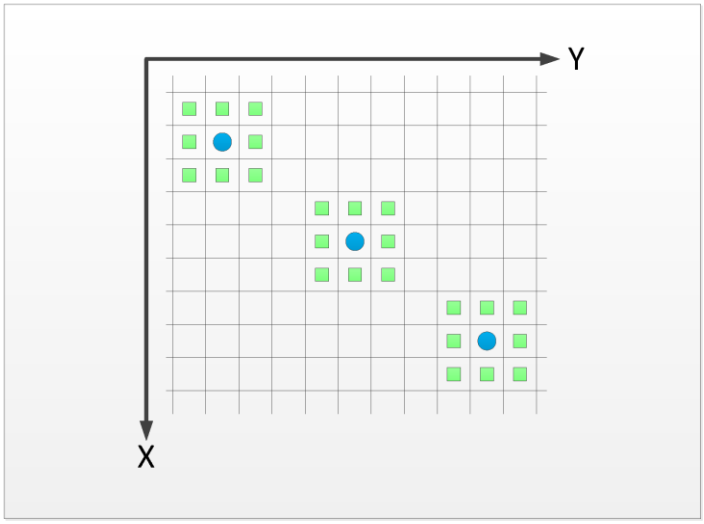


Figure 3 Uniformity Gradient

The UG is calculated/measured by comparing the illuminance of each grid point with the illuminance of the adjacent 8 grid points, see Figure 3.

The UG applies equally to horizontal illuminance (UG_h), vertical illuminance (UG_v) and camera illuminance (UG_c).

4.8 Reduction of Flicker

LED luminaires

Increasingly TV sports lighting is installed using LED sources which operate off electronic drivers. Nominally there should be no flicker. However, LED drivers, depending on the manufacturer, can operate at different frequencies. It is important to ensure the devices comply with the flicker factor (FF) limits specified below.

High intensity discharge (HID) lamp luminaires

Flicker can be practically eliminated, for both SSM and USM cameras, by the use of high frequency electronic control gear. It is important to ensure the e-ballasts comply with the flicker factor (FF) limits specified below.

For non-electronic ballasts, light flicker can be minimised by distribution to the three phases of the electrical mains circuit so that, when shooting with TV cameras whose field frequency differs from the mains frequency, interference will be as low as possible.

Therefore, when choosing and aligning the luminaires, it has to be ensured that each point on the playing surface is supplied with approximately equal levels of light produced over the three phases.

This is extremely important in cases where the mains frequency and the TV-field frequency are different (e.g. 50 Hz, 60 Hz).

Any HID lamp, operating on an alternating voltage will exhibit a fluctuating light output, because of the extinguishing and re-striking of the lamp every half cycle of the supply. When this effect is visible one speaks of the stroboscopic effect or "flicker".

For a large field-of-play (major stadiums) the above technique is reasonably successful but for smaller performance areas with fewer overlapping floodlight beams, the following design technique could be applied.

Low wattage floodlights are located in groups of three close together and aimed at the same point on the area in question; each lamp is fed from a different phase. The technique can also be applied to large stadiums to further reduce flicker for the SSM cameras.

Properly designed, the described design approach can be successful for SSM cameras. However the use of USM cameras will progressively show flicker at the higher speeds.

4.9 Flicker Factor

The technique for predicting flicker in sports lighting systems is the Flicker Factor.

Due to the increase use of SSM cameras and now USM cameras it is becoming necessary to specify specific flicker-free values. The parameter is defined as the Flicker Factor (FF):

$$FF = \frac{Ev.max - Ev.min}{Ev.max + Ev.min} \; x \; 100\%$$

where:

$E_{v.min}$ minimum camera illuminance ***in time*** at a point on the calculation grid

$E_{v.max}$ maximum camera illuminance ***in time*** at the corresponding point on the calculation grid.

The formula explained:

*E_v = the vertical illuminance (lux) towards the relevant camera at a point on the FOP, at a **point in time**. Mains frequency (50Hz) light travels in waves and there is a point in time when there is no light. This lack of light shows up in extremely fast shutter speed cameras (USM) and creates a flicker effect.*

The light from a luminaire on phase 1 of a 3-phase power supply will be zero 50 times per second. However, at that same point in time, another luminaire on phases 2 or 3 will still radiate light. The objective is to establish the maximum and minimum at a point in time at every [grid] point of the FOP.

Flicker factor (FF) should be ≤3% with camera speeds ≥400fps; and ≤10% with camera speeds ≤400fps.

Note 1: FF ≤1 % will not generate any flicker for SSM and USM cameras.

4.10 Colour Temperature

In the case of outdoor installation the colour temperature of the artificial lighting must be between 4000K and 6500K where floodlighting is used during the day and into dusk. This is to minimize apparent colour changes in the scene when daylight is replaced progressively by artificial lighting.

The preferred standard is 5600K – for both indoor and outdoor venues.

Within an installation the colour temperature must not deviate from the stated value by more than ±500K.

Indoor venues with fenestration, day competition.

Intrusive daylight can affect the picture quality in terms of changing colour temperatures and light levels. See Section 5.

4.11 Colour Rendering

The colour rendering properties of a light source can be indicated by the CIE general colour rendering index (R_a). The maximum value of the colour rendering index is 100, which indicates that there is no difference in colour reproduction between the source under test and a given reference illuminant having the same colour temperature.

Lighting installations intended for use with colour television should have a minimum colour rendering index (CRI) R_a in the order of 95 to ensure that visual differences between direct viewing and viewing on television are minimised.

Driven by the introduction of high efficiency LED lighting, the Television Lighting Consistency Index (TLCI) [1] is recommended by the EBU and has found worldwide acceptance. See https://tech.ebu.ch/tlci-2012

Note 2: The CIE CRI was not designed for television and only provides an approximate indication of the colour quality of the source suitable for broadcast. TLCI is significantly more reliable.

4.12 Light Level on Surrounding Audience Areas

For television broadcasts it is desirable that the areas bordering the performance areas should be illuminated to an average vertical illuminance level of 0.25 times the average vertical illuminance level on the performance area. This will ensure adequate contrast between the performance area and its background. This level

may be produced by existing stray light from the FOP lighting. Other stray or spill light should be avoided in the design of the installation.

4.13 Glare

It is essential that the lighting does not produce an unacceptable degree of glare to the competitors and the venue audience. In addition the photographic equivalent of glare, termed lens flare, must be minimal at all the camera positions.

The glare rating GR is given by:

$$GR = 27 + 24 \log (L_{vl}/L_{ve}, ^{0,9})$$

where L_{vl} is the veiling luminance produced by the luminaires and the L_{ve}, is the veiling luminance produced by the environment. A GR value of 50 is termed *"just admissible"* for the human eye. It is necessary to calculate GR over all the relevant areas in the installation and with the observer looking in the appropriate directions.

The GR should be in accordance with the values given in CIE 83 - *Guide for the Lighting of Sports Events for Colour Television and Film Systems*. The calculated GR value is dependent upon the reflectance of the playing surface. For a diffuse reflection value between 0.15 (e.g. dark surfaces) and 0.25 (e.g. grass) is usually a realistic value.

The glare assessment should be based on the standard competitor positions, at a height of 1.5 metres above the competition area, in the direction of its extremities.

The maximum GR value for the TV cameras is <40.

4.14 Obtrusive light

Outdoor sports lighting installations are a possible source of unwanted spill light referred to as obtrusive light. For information on the control of obtrusive light effects, refer to Australian Standard AS 4282 ‘Control of the obtrusive effects of outdoor lighting”.

5 SPECIAL REQUIREMENTS FOR INDOOR INSTALLATIONS

Cameras unavoidably positioned facing windows may encounter high levels of daylight from those windows. On such occasions excessive contrast should be eliminated by covering the offending windows with blinds, curtains or filter material either neutral or colour correcting.

Direct viewing by cameras of light sources and reflections from polished floors, water, or ice may create disturbing overexposures in cameras and flare effects in lenses.

6 NEW VENUE DEVELOPMENTS AND UPGRADE PROJECTS

Design criteria for development and upgrade projects at venues likely to host international and nationally significant events, should meet or exceed the qualitative criteria given in OP 31 and be constructed with a view to meeting future television standards as they evolve.

7 REFERENCES

[1] Television Lighting Consistency Index (TLCI) is recommended by the EBU. See https://tech.ebu.ch/tlci-2012

[2] CIE 083-1989 Guide for the Lighting of Sports Events for Colour Television and Film Systems (2nd edition). Note: at the time of publication of this OP the CIE guide is being revised and updated; check for the latest revision. Commission Internationale de l'éclairage http://www.cie.co.at

[3] Australian Standard AS 2560 series 'Sports Lighting'.

8 SUMMARY

Table 1 International and professional competition for major venues

$E_{c\ min}$ toward main cameras	≥1400 lux
Uniformities	$E_{c\ min}$: $E_{c\ max}$ ≥ 0.7; $E_{c\ min}$: $E_{c\ ave}$ ≥ 0.8 and UG ≤20% over 4m
$E_{v\ min}$ toward other directions	≥1000 lux
$E_{c\ min}$ toward USM cameras	≥1800 lux (within defined zones)
Modelling	0.5≤ [$E_{h\ ave}$/$E_{c\ ave}$] ≤2.0
Colour temperature, Tk	4000K≤ Tk ≤6500K; preferred 5600K
Colour rendering, TLCI	Q_a ≥ 85
or, CIE colour rendering index (CRI)	Minimum requirement R_a ≥ 85, preferred R_a ≥ 95
Glare rating, GR, for main cameras	GR_{max} ≤40
50 Hz mains flicker and flicker factor (FF)	Light source control to be HF electronic to suit FF ≤ 10% for ≤400fps FF ≤ 3% for >400fps For non-electronic control, minimise flicker by cross aiming and spreading floodlights equally over three phases.

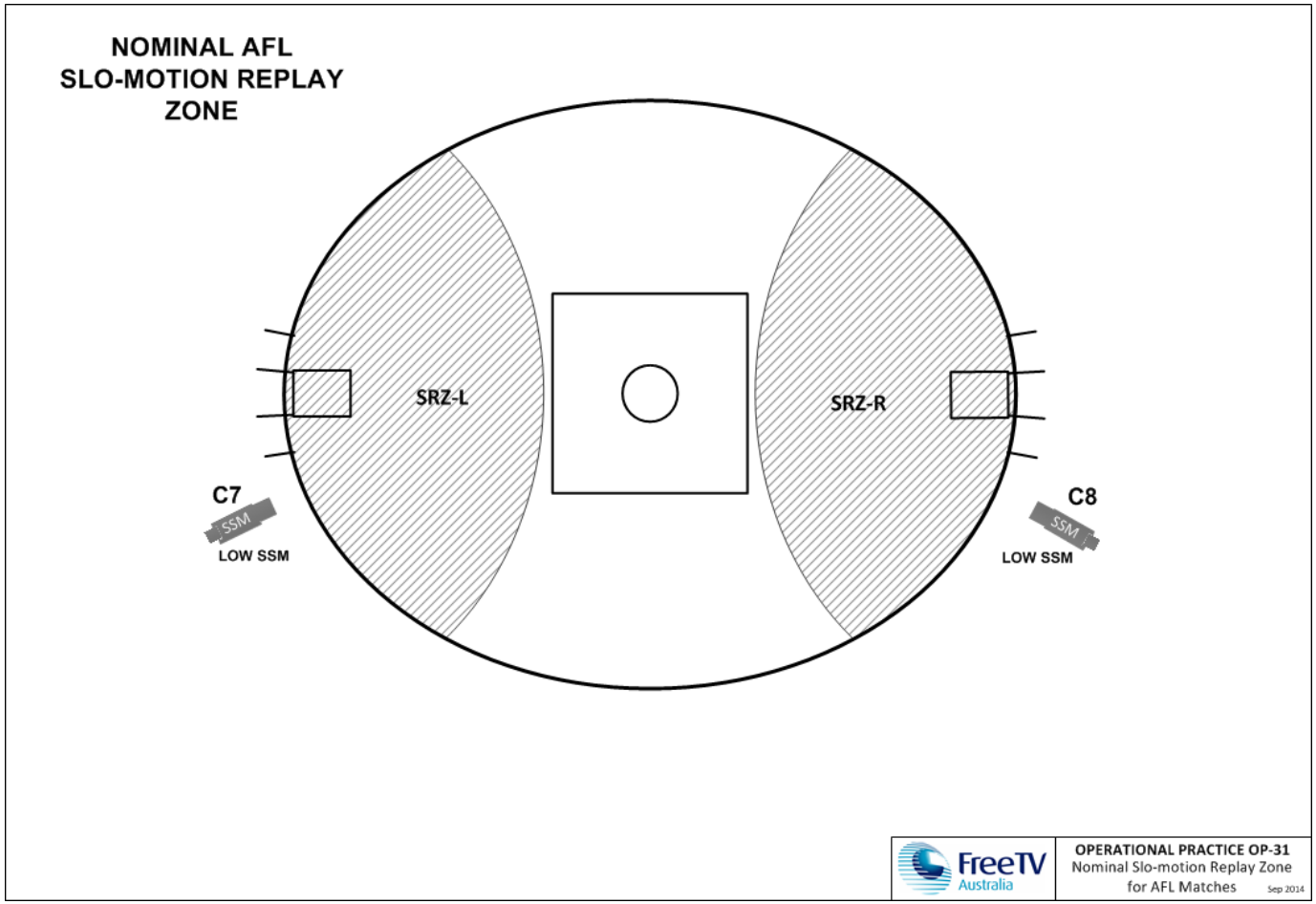
Table 2 Professional standard for other venues

$E_{c\ min}$ toward main cameras	≥1000 lux
Uniformities	$E_{c\ min} : E_{c\ max} \geq 0.7$; $E_{c\ min} : E_{c\ ave} \geq 0.8$ and UG ≤20% over 4m
$E_{v\ min}$ toward other directions	≥800 lux
Colour temperature, Tk	4000K≤ Tk ≤6500K, but within 500K at individual venues.
Colour rendering, TLCI	$Q_a \geq 85$
or, CIE colour rendering index (CRI)	Minimum requirement $R_a \geq 85$, preferred $R_a \geq 90$
Glare rating, GR, for main cameras	≤40
50 Hz mains flicker	Light source control to be electronic; or for non-electronic, minimise flicker by cross aiming and spreading luminaires equally over three phases.

Note 3: Whilst satisfactory picture quality can be achieved at the stated minimum lighting levels, restrictions are placed on full usage of zoom lenses and focusing becomes quite difficult for camera operators on BCU (big close up) camera angles. Super Slo-mo and Ultra Slo-mo cameras cannot perform satisfactorily below major venue professional standard lighting.

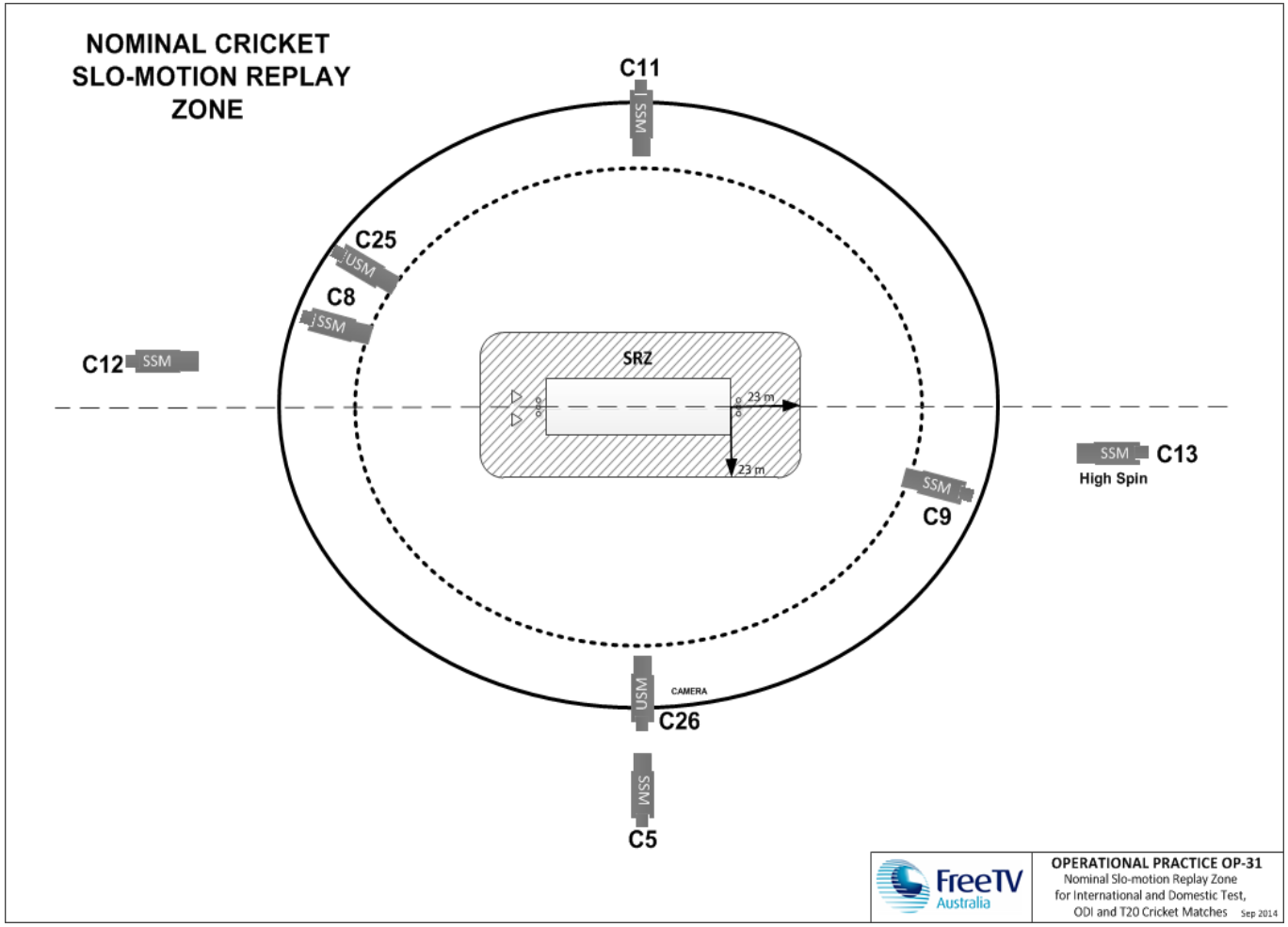
APPENDIX A

AFL Slo Mo Replay Zone



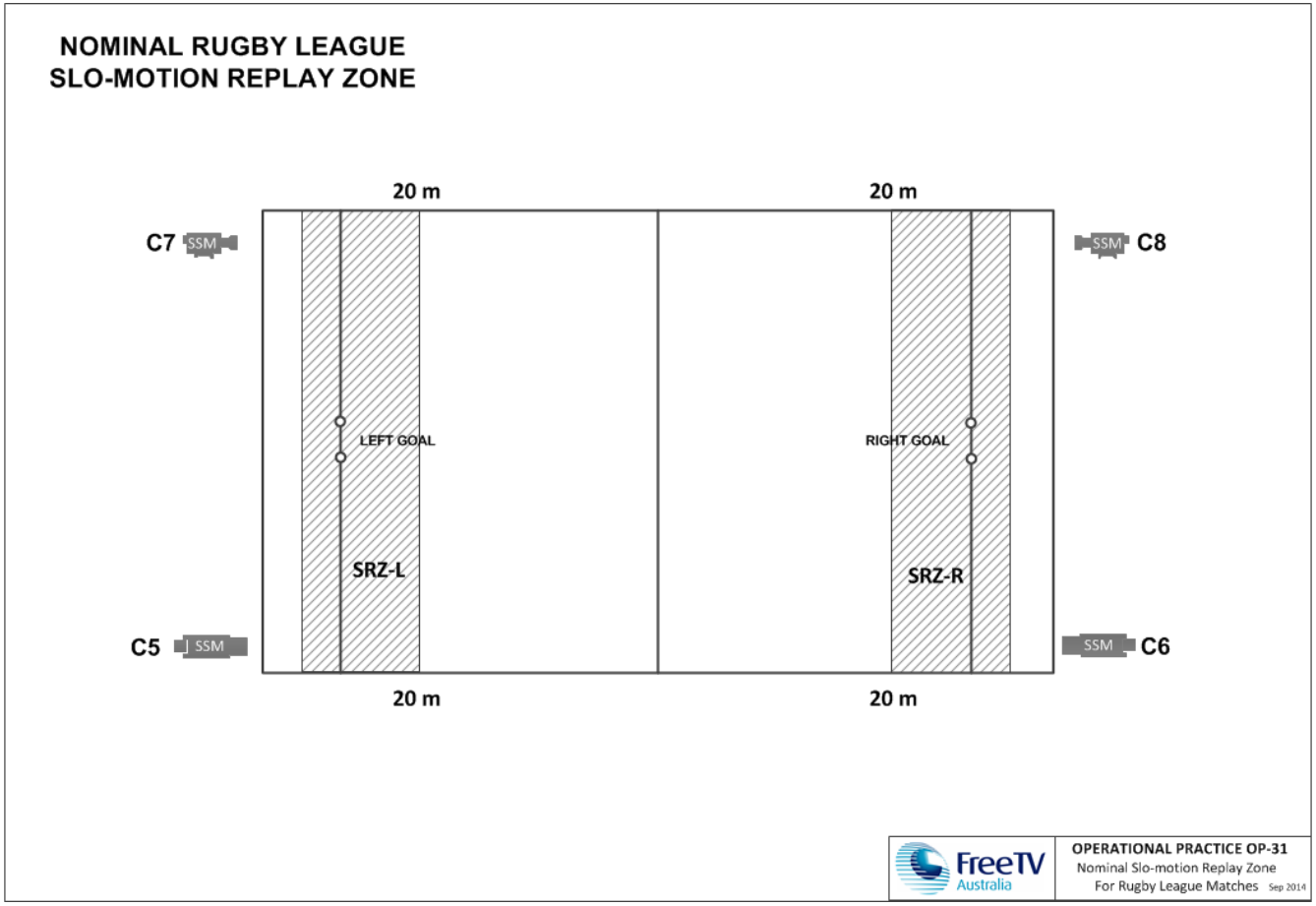
APPENDIX B

Cricket Slo Mo Replay Zone



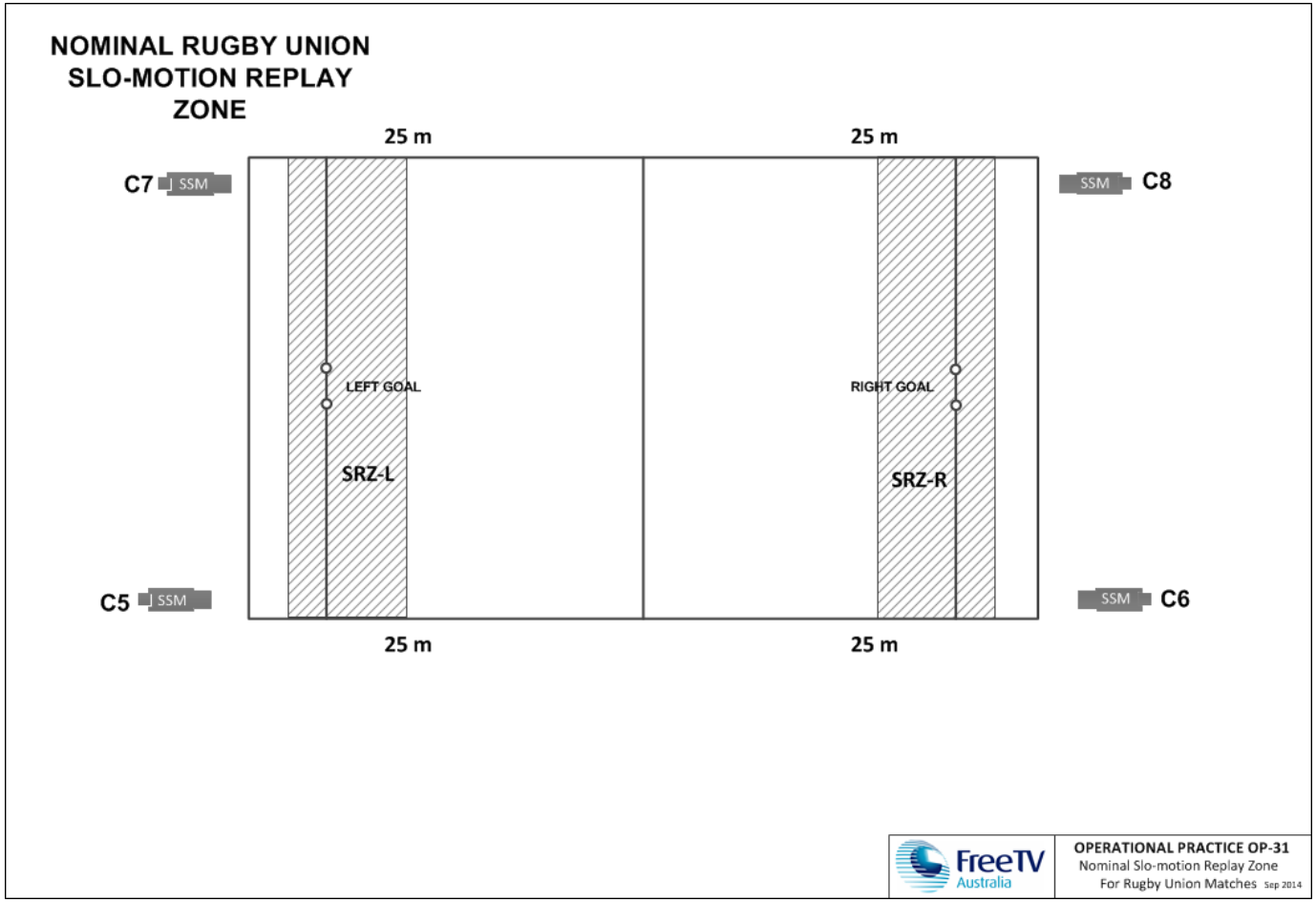
APPENDIX C

Rugby League Slo Mo Replay Zone



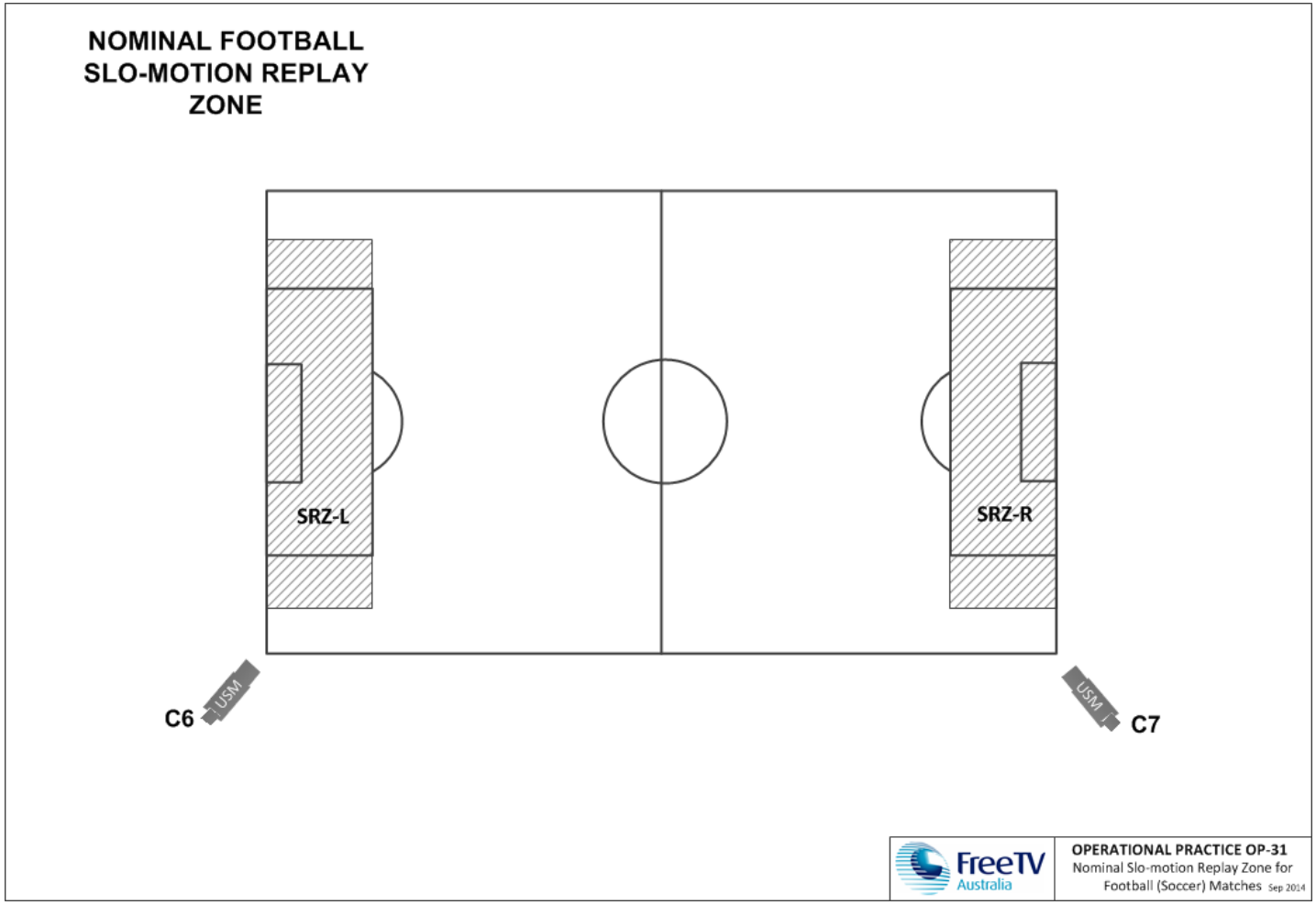
APPENDIX D

Rugby Union Slo Mo Replay Zone



APPENDIX E

Soccer Slo Mo Replay Zone



APPENDIX F

Swimming Slo Mo Replay Zone