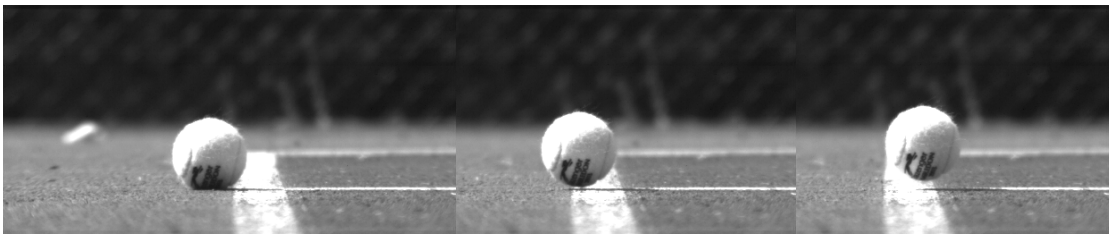
Automated Line-Calling Systems: ITF Evaluation



ITF Technical Centre

February 2005

Supported by

TABLE OF CONTENTS

ITF TECHNICAL CENTRE

AUTOMATED LINE-CALLING SYSTEMS – ITF EVALUATION

1. Introduction

Traditionally, tennis is adjudicated by humans. The decisions as to whether the ball bounced 'in' or 'out' have been made by Line Umpires and Chair Umpires. However, the human information-processing system has limited capacity and there are often occasions when there is uncertainty or dispute over a close call. This is because the impacts between balls and surfaces last for only about 0.005 seconds. The task of determining whether the ball is 'in' or 'out' is made more difficult by the high ball speed and different trajectories before and after the moment of impact.

The term 'automated line-calling system' refers to a generic class of tennis equipment designed to determine the location of impact between a ball and court surface, normally with respect to service lines and court boundaries.

Advances in technology have resulted in the development of several methods of automatically determining whether a ball is in or out. The International Tennis Federation (ITF), as the world governing body of tennis is the focal point for the collation, evaluation and dissemination of information relating to automated line-calling systems to relevant parties.

As major stakeholders in tennis, the ITF, ATP and WTA are collaborating on this project. These groups recognise that automated line-calling systems offer the potential for more accurate and consistent decision-making than humans, but that their suitability for purpose must be established. In addition to the technical and practical qualities of such systems (which can be established quantitatively), there are other non-technical issues to be considered. For example, the interaction between players and officials is a part of the game, but it is not within the remit of the process described in this document to consider the contribution made to the game by the presence of Line Umpires.

The aim of this document is to describe a process by which the accuracy, reliability, practicality and suitability of automated line-calling systems for use in officiating tennis matches can be established.

2. Theory of Ball/Surface Impact

The impact between a tennis ball and a court surface is complex. The contact area between a ball resting on a court surface is relatively small. If a ball is dropped vertically, the contact area tends to increase as the bottom of the ball deforms (i.e. it flattens out). The faster it is travelling in the vertical direction when it hits the surface (up to a point), the more it deforms and the bigger the contact area (see figure 1 for an extreme example). Thus, whether a ball touches a line may be determined by the speed at which it hits the ground, as a faster-moving ball has a greater area of contact with the court surface and so is more likely to touch a line. For the vast majority of impacts in tennis, the ball is moving horizontally as well as vertically, which adds an extra level of complexity. Due to the horizontal motion, not only does the ball bounce upwards off the court and have a contact area that is related to the

vertical speed at which it hits the surface, it slides and/or rolls along the ground, and thus the ball leaves the surface at a different position from that at which it first made contact. The amount of sliding changes from shot to shot, and depends on approach angle, speed, spin, and the court surface type, making it difficult to accurately infer an impact point.

Figure 1. The compression of a tennis ball during impact.

When humans are making line calls, there are often 'clues' to the impact location. For example, the ball disturbs the surface particles on a clay court, leaving a mark on the surface, while on grass, the presence or absence of chalk dust is sometimes used as evidence of the bounce location. Marks can also be seen on hard courts, but in all cases, such evidence may be misleading. For example, it is possible that clay particles not directly touched by the ball may be disturbed by those particles moving due to the ball impact, which will result in a larger mark than the true contact area. On a hard court, however, the threshold force required between the ball and surface to leave a mark may not be generated until sometime after initial contact, thus leaving a smaller mark than the true contact area.

3. General System Principles

To be acceptable, systems must be:

- Accurate – decisions as to whether a ball is in or out must be correct.
- Reliable – for the same ball impact conditions (speed, angle, spin), the system must make the same decision.
- Practical – systems must be easy to use by Chair Umpires and not interfere with other aspects of their role.
- Suitable – systems must operate over the full range of conditions experienced in tennis, while not exposing players to health and safety risks.

These items are sub-divided and described in more detail in Appendix 4. The process by which the extent to which a system meets these requirements is described in the following section.

4. Evaluation Process

A fundamental principle of the process is that it is manufacturer-driven. Thus, manufacturers are expected to lead the process in terms of submitting an application and arranging testing. The required forms can be found in appendices 1-3 of this document. The process can be summarised as follows (see also figure 2):

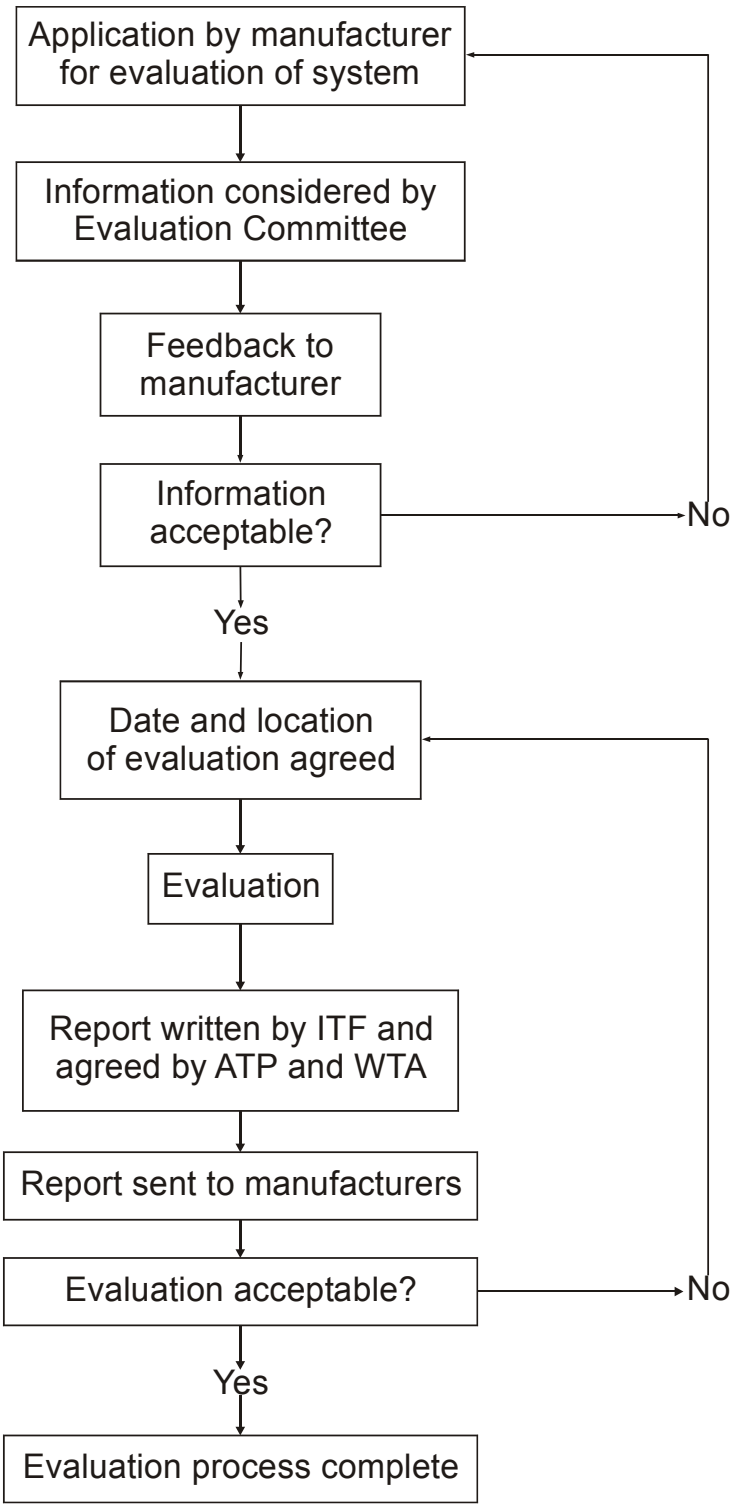


Figure 2. Flow diagram of evaluation process.

i. The manufacturer applies for evaluation of the system using forms ITF/ALCS/01, ITF/ALCS/02 and ITF/ALCS/03. Four videos (2 × PAL, 2 × NTSC) or CDs shall also be supplied. Each shall contain film of the system, showing all equipment, preferably in operation, and all visual devices (e.g. software output, and all information sent to Chair Umpire). A sound commentary is preferable. If sending CDs, video shall be saved as 'avi' files.

ii. Application forms and videos/CDs will be circulated to all members of the Evaluation Committee. Normally, feedback as to suitability of application for further evaluation will be provided within 4 weeks.

iii. Feedback will be provided if the application is not suitable for further evaluation. If the application is suitable, the manufacturer proposes a time and location for evaluation. Three days should be budgeted for the evaluation. Backup dates should be suggested in the case that the original dates are not suitable.

iv. Manufacturers informed of agreed testing date. Manufacturers to provide a minimum of 2 players for the duration of the evaluation.

v. Evaluation takes place in accordance with the protocol specified in form ITF/ALCS/04.

vi. Following the evaluation, a report is agreed by the ITF, ATP and WTA. This will normally be sent to manufacturers within 6 working weeks of the test date.

vii. The evaluation process is complete when the system performs sufficiently well that, in the Evaluation Committee's opinion, it could be used in 'live' play. If a system fails to perform sufficiently well, the manufacturer may apply for a further evaluation.

N.B. <u>All costs associated with evaluation of systems are to be met by manufacturers</u>.

This procedure is subject to ongoing review and may be amended as and when necessary and without prior notice. Periodic re-evaluation is under consideration, as technological advances will result in the hardware and/or software of systems being modified, the effects of which must be described and quantified where appropriate.

Only when a system has been through the evaluation process will it be considered for use at an event by the ITF, ATP and/or WTA. No system will be considered for use without evaluation. Full or part participation in evaluation does not guarantee that a system will be adopted in tournament play.

5. Conclusion

The process described in this paper is designed to facilitate the collection of information that describes the accuracy, reliability, practicality and suitability of automated line-calling systems and, therefore, to provide end users with sufficient information to aid the decision-making process with respect to the implementation of such systems. The process does not confer or imply official approval, and manufacturers may not use ITF, ATP or WTA logos in their advertising subsequent to a satisfactory evaluation. It should be noted that the decision as to if and when automated line-calling systems are incorporated into tennis tournaments is for their organisers to make.

APPENDIX 1 – APPLICATION FOR EVALUATION OF AUTOMATED LINE CALLING SYSTEM

Contact Details

Name of system: _____

Name of manufacturing company: _____

Name of contact person: _____

Address: _____

_____

_____

_____

Telephone: _____

Mobile: _____

Fax: _____

E-mail: _____

Have you previously made an application? Yes ☐ No ☐

If 'yes', when was the last application made: _____

Application Checklist

Completed forms ITF/ALCS/01, ITF/ALCS/02 ☐

4 videos (2 × PAL, 2 × NTSC) or 4 CDs ☐

Annotated diagram of equipment locations (ITF/ALCS/03)[1] ☐

Send application to:

ITF Technical Centre
Bank Lane
Roehampton
SW15 5XZ, UK
Tel: +44 (0)208 878 6464
Fax: +44 (0)208 392 4773
E-mail: technical@itftennis.com

[1] Other visual evidence (e.g. photographs) that amply demonstrate equipment locations is acceptable.

APPENDIX 2 – SYSTEM INFORMATION[1]

A2.1 General description

- System type (whole court [singles/doubles] or service-line only)

- Portability (dimensions, weight)

- Detection method (e.g. light beam, pixel recognition)

- Does the system require non-standard equipment? If so, please specify

[1] If you have previously made an application, please highlight the items that have changed since the last application, by adding the text "[**change**]" at the end of the relevant section(s)

- Cost (to buy outright and to rent) and technical support provided

- Is system claimed to work on all surfaces (if 'no', please specify surfaces for which system is not designed)

- Claimed major advantages of system (compared to other systems)

- How long does the system take to set up (please divide into installation time and calibration/verification, and state whether these can be done in parallel)?

- Minimum number of people required to operate system

A2.2 Hardware

- Type (manufacturer and model), number (minimum and optimum) and size of detection devices

- Location requirements of detection device(s)

- Number of PCs required and location(s) with respect to detection devices, court surface and operators

- Installation requirements (including power requirements, any modifications to court, connections between components)

- Are detection devices or hardware exposed to interference by spectators, officials etc.?

- Is a backup system available in case the main system fails (e.g. through power loss or hardware malfunction)?

- Number of access points to hardware during normal use (i.e. by spectators, officials etc.)

- Number of failure points (i.e. hardware locations where the normal system function may be disrupted)

A2.3 Software

- General description

- If camera-based, frame rate and shutter speed of camera

- If camera-based, please describe software algorithm used for reconstruction of ball trajectory

- If camera-based, how many images of a trajectory are needed to maximise tracking accuracy (specify pre- and post-impact separately)?

- Does system use post-bounce data to establish ball/surface contact locations? If 'yes', how many images?

- Information provided to Chair Umpire (including time delay between ball contact and signal to Chair Umpire)

- (How) does system deal with obstruction of ball by player(s)?

- (How) does system deal with the non-circularity of ball-surface contact area?

- (How) does system deal with sliding of ball during impact?

- (How) does system transfer data into other electronic systems (e.g. statistical databases and web-based 'live' scoring transmissions)?

A2.4 Performance (where known)[2]

- Accuracy (difference between true contact point and that recorded)

- Resolution (i.e. smallest determinable change in ball position)

- Reliability/precision (for a constant input, system makes the same decision)

- Performance established by manufacturer or independently?

- Range of temperature and humidity within which the system operates at maximum accuracy.

[2] Please note that any performance characteristics supplied above are not guaranteed to be accepted in lieu of testing. Where performance is not known, specify 'not known'.

- If performance has been established independently, provide contact details of testing body. **Please also supply copy of any test reports**

A2.5 Safety and security

- Does the system generate any emissions that are above ambient levels (such as electrical or magnetic fields)? If so, please specify type and intensity.

- Does the software contain security features to (a) prevent hacking, and (b) ensure that data are not manipulated, either accidentally or deliberately? If so, please describe.

Please indicate the preferred location of all equipment (including connecting wires) by drawing on, and labelling, the diagram on the following page.

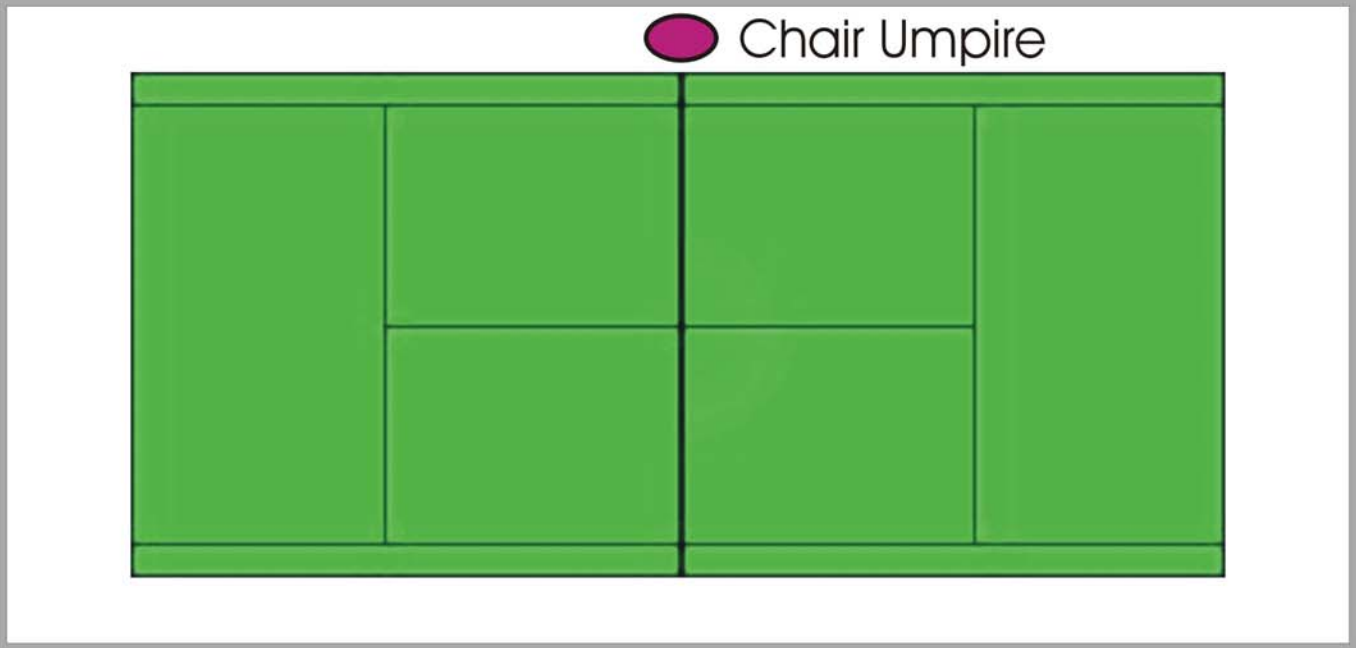
A2.6 Other information

- Please provide any further information that you feel is of relevance here

N.B. The system requirements will form part of the evaluation report in terms of how they influence performance.

N.B. Photographic information/evidence for any aspect of system information is welcomed.

Seating Area



APPENDIX 3 – AUTOMATED LINE-CALLING SYSTEM EVALUATION PROTOCOL

To accommodate the requirements for evaluation of automated line-calling systems, the on-court testing will be divided into 2 separate parts (see also sections 3.1.1-3.1.8 of this document):

A3.1 'Live' demonstration

There are several aspects of system performance that are evaluated in this aspect of evaluation. These are:

- Practicality of system for use by Chair Umpire[1]
- Reliability and suitability of system

To evaluate the system during 'live' play, the following testing is specified:

Stage 1 (familiarisation)

- System is installed on one court at a selected venue.
- One session of play (approximately 1 × 3-set match[2]), in which players may be instructed to modify playing styles (as necessary).

Stage 2 (shadowing)

- System is installed on one court at a selected event.
- System runs in parallel with on-court Line Umpires.
- On-court officials make line calls as normal during matches.
- System is monitored from courtside by independent observers.

Normally, stage 2 will take place following completion of the report of stage 1, to provide the manufacturer with the opportunity to make any modifications deemed necessary following stage 1.

It is recommended that demonstration (and laboratory testing) take place on a surface for which the system is primarily designed (where appropriate). Systems will be evaluated primarily on the surface on which they are evaluated. To save on cost, comments on the system's suitability for other surfaces will be estimated where necessary.

A3.2 'Laboratory' testing

The primary purpose of laboratory testing (which will take place on a separate day using the same system installation as for the tournament simulation if possible) is to evaluate the accuracy, precision and reliability of the system. The testing will be based on simulated impacts that are in a range possible during normal play. These will normally be a range of impact locations, speeds and angles.

---

[1] As applicable. If the system is being evaluated as an aid to officiating, then the requirements will be different from instances where the system is being evaluated to call all the lines as a replacement for on-court officials.

[2] The duration of play may vary according to the needs of the evaluation committee.

Balls will be projected at various points on and near to the service line, sidelines and baselines. To establish system accuracy, comparison will be made between the system 'decision' and one based on the analysis of high-speed video recordings (or the best available method) for each impact point.

If possible, a series of impacts at one speed/angle combination will be used to evaluate system precision (the ability to generate the same output for a constant input).

System evaluation will include three distinct levels:

- Reliability of tracking/decision-making (1): the percentage of times that the system successfully detects the ball.
- Reliability of tracking/decision-making (2): the percentage of correct in/out calls made by the system.
- Accuracy: the error in identifying the true impact location.

N.B. The minimum illuminance at court level for the 'laboratory' testing site is 1000 Lux (indoors) or 500 Lux (outdoors).

N.B. The evaluation committee may recommend/request further evaluation, based on the results of the tests specified in Appendix 3.

APPENDIX 4 – SYSTEM CHARACTERISTICS TO BE EVALUATED

To meet acceptable standards of the principles described in section 3, systems need to have the characteristics specified in sections A4.1-A4.8. **The extent to which these characteristics can be evaluated in this process will vary due to (e.g.) time and geographical constraints. It is strongly recommended, therefore, that end-users seek to establish that all characteristics are met in their own situation before implementing a system for 'live' use in tournament play.**

A4.1 General

The line-calling system must provide accurate and reliable line calls in an automatic manner.

The system must provide easy manual override, whenever so required.

The system must provide full performance in any combination of conditions that can be expected in a tennis match, without degradation of performance.

The line-calling system must be unobtrusive when installed in its operating environment. At a minimum, it must not adversely affect the players or the officials.

The system must not occupy so much space courtside as to interfere with the court layout, infrastructure or operation in comparison with currently accepted practice. It must not draw undue or excessive attention and must not detract from the enjoyment of spectators.

The system must not adversely affect activities related to television or other communication media.

The line-calling system must be a useful aid to the Chair Umpire. As such it should be controllable by the Chair Umpire, whether directly or remotely. The system must provide accurate and reliable information on line calls to the Chair Umpire.

Information must be provided in a time interval short enough so that no interference is caused with the smooth running of the match.

A4.2 Performance

The system must provide complete coverage of all court lines.

The system must be operational under natural-, artificial- and variable-light conditions that are suitable for play.

The system performance must be unaffected by rain or moisture on the court surface, or surface temperatures in the range of 0-70º Celsius.

The system must be operational under all weather conditions when play is required.

The system must provide full performance under all combinations of normal playing conditions, including different bounce locations, ball speed and trajectory angles.

The system will not be affected by the presence or movements of players, including stepping or standing on the lines.

The system performance will not be affected by any objects worn or carried by

players or officials.

The system should provide a visual image of the ball footprint relative to the lines on the court. The image quality and accuracy will be sufficient to visually reconfirm the system's (automated) decision. This image will be available to the Chair Umpire and, upon approval by the ITF, to others such as the spectators or television viewers as well. If possible (e.g. for camera-based systems), a visual image of the pre- and post-impact trajectory of the ball should be provided.

The system's visual replay must have the capability of displaying the system's accuracy to aid the Chair Umpire's ruling. The system's accuracy will be determined through independent testing.

A4.3 Court and Balls

If the court is modified in any way, the finished court must not be significantly different from a standard court in appearance and in all aspects which could affect play.

The court response to play must be the same whether or not the line-calling system is in operation.

Any modification to the standard ball must be such that it is applicable to all ball types in current use. Modified balls must be ITF Approved.

Balls must have the same bounce and play characteristics as an ITF Approved ball.

The sensing characteristics of the system/ball combination must not deteriorate over the ambient temperature range of 0-70º Celsius or by the appearance of moisture in the cloth cover.

A4.4 Line Coverage

There must be a sufficiently wide sensed zone either side of the line. The recommended minimum width of the sensed zone is ± 400 mm.

When used as a replacement for on-court Line Umpires, "out" calls must be automatic and provided to umpires (and, if so specified by the ITF, to players and spectators simultaneously) in a clear and unambiguous way with an audible signal. A number of choices of types and volumes of audible signals (including synthetic voice) must be available for use by the Chair Umpire or tournament management.

The time interval between ball bounce and the audible signal must not be significantly longer than that normally required for a Line Umpire's call.

A4.5 Accuracy and Consistency

The system must exhibit superior performance to that of tournament-quality human line umpires. Specifically:

- The success rate for a series of normally-distributed impacts within the sensed zone must be greater than that of human line umpires.
- The accuracy of decisions must be superior to the accuracy of human line umpires for impacts within 40 mm from the line.

The system should be capable of making the correct in/out decision if a ball legally crosses a line from outside to inside.

A4.6 Control/Replay Equipment

The line-calling system must include equipment to enable a Chair Umpire to control and/or monitor its status, and that of the match.

The control functions of any handset used by the Chair Umpire must be compatible with approved scoring handset systems and must have suitable interface characteristics.

When used as a replacement for on-court Line Umpires, the system status monitoring must be provided to the Chair Umpire in an unobtrusive manner, without affecting the officiating task.

When used as a replacement for on-court Line Umpires, the control equipment must have the capability to allow the use of special purpose software (e.g. for visual confirmation of all actions taken) and control requirements.

A4.7 Reliability and Maintenance

The system mean time between hardware/software breakdowns should be not less than 80 hours of operation.

All parts of the system should be modularized to facilitate failure repair.

The system should have multiple (at least double) redundancies built into the system design.

The system is recommended to constantly and automatically self-test. As a minimum, it should have a built-in capability for automatic self-test, which should be carried out at frequent intervals during standby conditions.

The system must have embedded test diagnostics.

The majority of failures of the system should be correctable easily by the Chair Umpire or a trained technician within 5 minutes.

For systems using impact-sensing elements under the court surface, a failure in one of those line elements must not affect the performance of the rest of the system.

The system must have a high level of discrimination capability against non-ball signals. This would include background rejection, and interference effects due to magnetic, optical, infrared or other sources.

There must be an acceptable level of protection against deliberate or inadvertent actions by spectators to either produce a false or incorrect signal (such as an audible “out” beep) or otherwise interfere with the system.

A4.8 Safety and Interference

The system must not present a risk to players due to collision with equipment, electric shock, etc.

Systems using energy sources such as electromagnetic radiation, infrared beams or

optical methods should not pose any risk to the players, officials or spectators.

The system must not have any significant adverse effects on other electrical equipment in the vicinity, such as TV cameras, data transmission lines, or microphones.

Systems must be capable of operating satisfactorily in the electromagnetic environments normally found at major tennis venues.