STADIUM SOUND SYSTEMS AND FIFA REGULATIONS

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1 ABSTRACT

Two events have initiated the construction of modern stadiums within the last 100 years, the inauguration of the modern Olympic Games first time in Athens in 1896 by Pierre de Coubertin and the foundation of the International Federation of Football Association FIFA in 1904. But it has taken 100 years to introduce concrete acoustic demands in the technical regulations and requirements of the FIFA. Still in the 3rd and even in the 4th editions of these regulations (valid until 2007 respectively 2011) only automatic level controls are mentioned, to make sure, that „all security relevant sound transmissions must be higher as the cheers of the present fans". In the 5th edition of 2011 first time concrete numbers for level values, intelligibility and needed absorption in stadiums are listed. For the World Cup 2018 in Russia these demands are extremely further enhanced. The paper describes this development, the used designs and speaker solutions and explains the difficulties to found satisfying solutions in huge stadiums by considering the actual FIFA regulations for sound systems.

2 MOTIVATION

Soccer games in stadiums and open sport fields are common since more than 100 years and the rules are changed and adapted for the soccer play constantly, recently to allow goal cameras to check the ball has or has not crossed the goal line. A constant development could be observed to improve the information for the audience before, during and after soccer games. This development was been influenced by technical possibilities but also by valid standards and regulations. Before the FIFA was founded in 1904 every country partly did use individual rules. Any hints or regulations to distribute verbal information for the visitors of a game have not been given. At that time corresponding sound systems have not been available. The actual contribution here shall describe the development of the stadiums in size and shape and the parallel improvement of sound systems to provide visitors with wanted and/or needed information. The available FIFA regulations are outlined.

3 STADIUM DESIGN BETWEEN 1900 AND 1930

3.1 Without any sound systems

Soccer world cup competitions started later in the 30ties, so only at that time during the Olympic Games international competitions took place, first time in London 1908 and 4 years later in Stockholm. How in 1908 the 66.000 visitors during the games did receive any information is not reported, we have to assume that large board displays did help with visual information, see fig. 1.

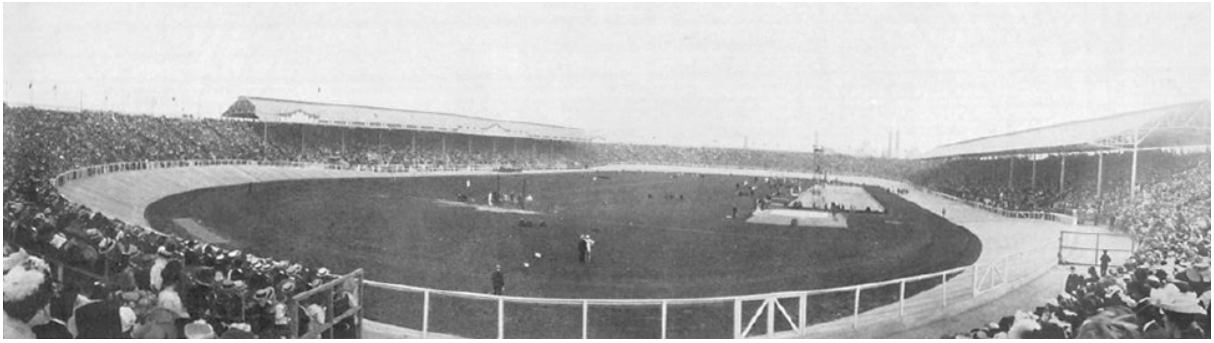


Fig. 1: Soccer game in the **White City Stadium** in 1908

In 1912 during the games in Stockholm the stadium was smaller (only 15.000 seats) and the transfer of visual information was because of the smaller dimensions simpler.

3.2 With first sound systems

After WWI first attempts have been made to cover larger areas with sound radiated by loudspeakers. Famous is a first sound system of Western electric in New York 1919 for around 10,000 people /1/. Here 112 telephone horns hanging on cable line have been used, see fig. 2.

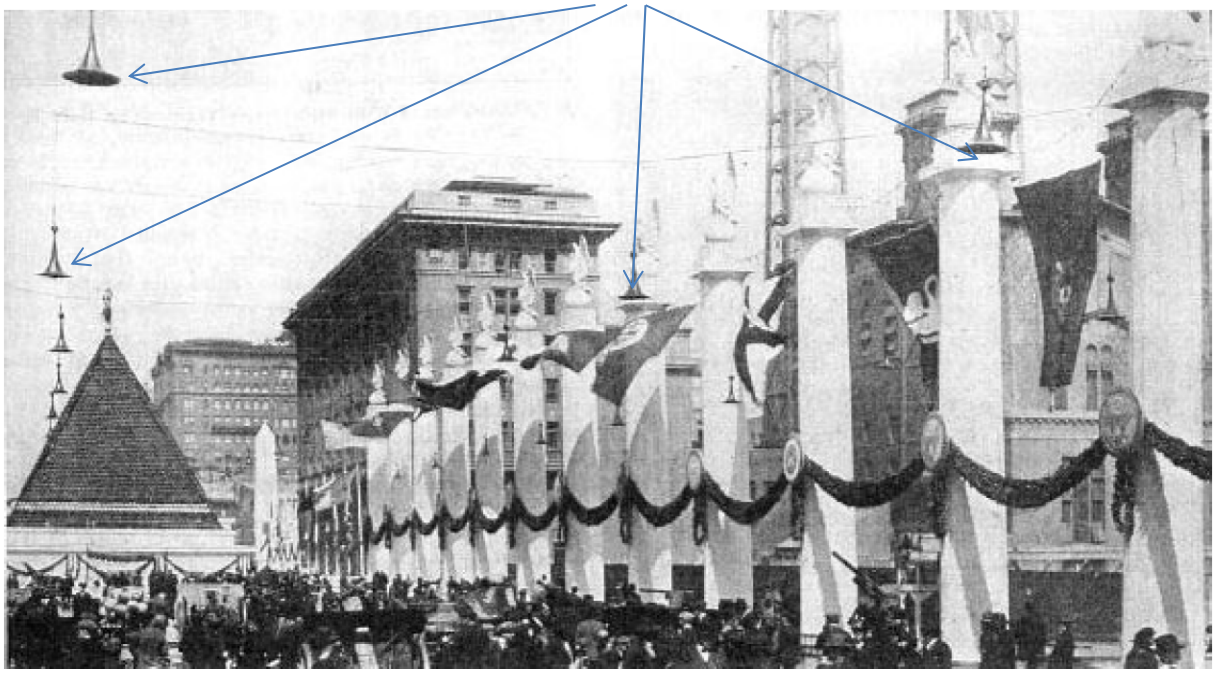


Fig. 2: Sound system “Victoria Liberty loan” 1919 NYC

Now in the international competitions during the Olympic Games in Antwerp (1920), Paris (1924) and Amsterdam (1928) Horn speaker did come in use more and more. Fig. 3 shows a sound system solution in the Main stadium 1928 in Amsterdam.

Fig. 3: Sound system in 1928 in Amsterdam

4 STADIUM DESIGN BETWEEN 1930 AND 1939

The First soccer world cup organized by the FIFA took place 1930 in Uruguay. We know from the literature that a simple sound coverage system with Horn speakers was installed on the partial stadium roof and the upper rim. Also playground speaker did come in use in the huge 93.000 seats Estadio Centenario, a principle roof solution of this time is shown in fig. 4.

A similar sound system solution has been used during the World Cup Games in Italy in 1934 in the 47.500 seats Stadio Nazionale PNF in Rome.

No any FIFA rules for a demanded sound system had been published at that time.

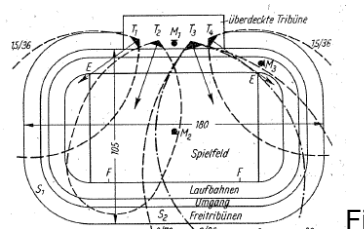


Fig. 4: Principle solution of a sound system of that time

Such a solution has been used until 50ties and 60ties in the last century and disappeared after full roof solutions are used more and more.

In the 100.000 seats Olympic stadium in 1932 in Los Angeles the Sound coverage of the bleachers has been done with Horn speakers on the pitch edge and on the upper stadium rim. A report about the quality of the sound coverage I could not found.

A more enhanced solution has been used during the world cup 1938 in the 60.000 seats Yves du Manoir Stade in Colombes close to Paris, compare fig. 5.

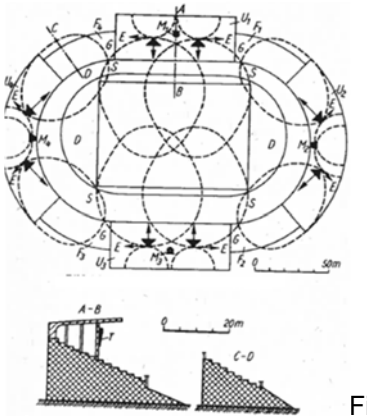
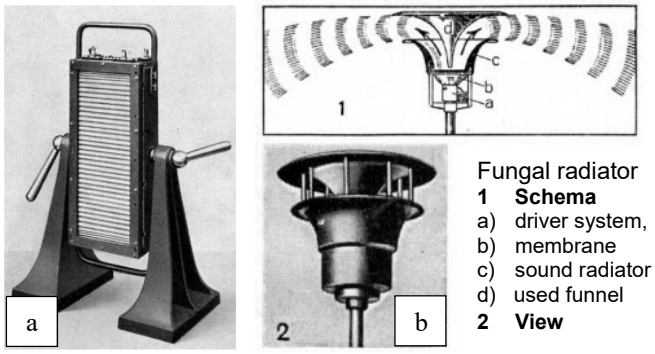


Fig. 5: Sound coverage by including more roof parts

In the 30ties new loudspeaker developments did start, in Germany this was initiated in the nazi time to cover mass meetings. Fig. 6 shows two such solutions /2/.



Fungal radiator
1 Schema
a) driver system,
b) membrane
c) sound radiator
d) used funnel
2 View

Fig. 6: New Loudspeaker developments
a) Large ribbon radiator
b) Fungal radiator

A special solution has been developed for the Olymic Games in Berlin 1936, see fig. 7.

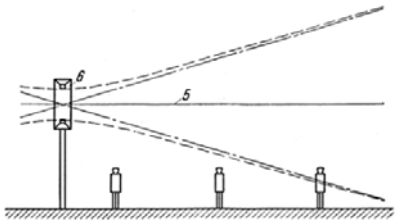


Fig. 7: Round or Canceling speaker

Two woofers have been used in a distance of around 1m and have been installed by radiating in the opposite direction. So any echoes in larger distances with other speakers could be avoided because the sound radiation was cancelled in the domain 5 in fig. 7.

The fig. 8 shows the arrangement of altogther 32 Round radiators in the 100.000 seats Olympic Stadium in Berlin 1936.

Fig. 8: Use of the round radiators in the Berlin Olympic Stadium in 1936

5 SOUND SYSTEMS BETWEEN 1950 AND 1990

These special radiators according fig. 7 are partially built until the end of the 50ties. But step by step the sound system design in stadia did return to central arranged speaker systems. A picture is shown in fig. 9a /3/. Sound coverage in smaller stadiums is schematically shown in fig. 9b.

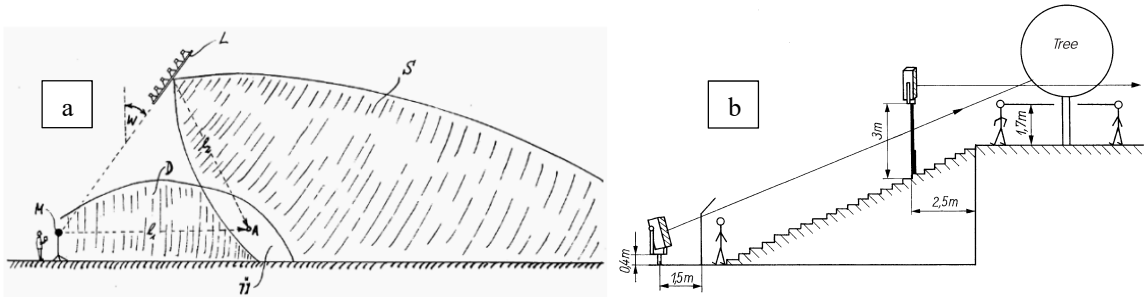


Fig. 9: Sound system design with normal sound columns

A plan of such a typical sound coverage is shown in fig. 10

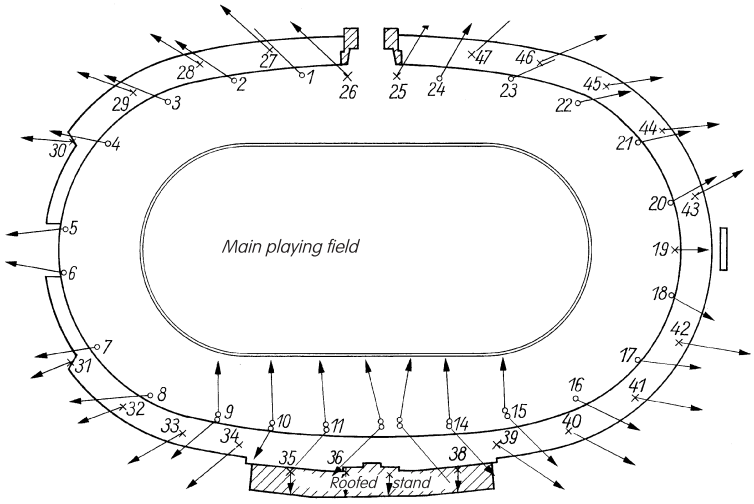


Fig. 10: Sound coverage from the pitch rim and from delayed positions

A challenge at that time was the solution of the sound system of the world cup Maracaña Stadium in Rio de Janeiro in 1950. The stadium had been used for around 200.000 visitors, i.e. the largest in the world.
So between 1950 and 1990 sound systems by using central or decentral arranged horns and sound columns dominated the selected solutions, compare figs. 4, 5, 9 and 10. No principal new design solution could be found.

6 SOUND SYSTEM DESIGN BETWEEN 1990 AND 2010

Since 1990 new sound arrays have been developed and one of the first ones was introduced by the company L'Acoustics /4/. But also point sources consisting of Horn speaker and woofers for the low end have been designed, compare fig. 11.

Fig.11: new sound systems, a and b point sources, c and d Line arrays

Such applications you have found for the world cup 1994 in the USA and 1998 in France. In the last case Nexo point radiators have been used in the 82.000 seats Stade de France, later substituted by the Nexo Geo S12 Array systems/5/.

The world cup 2002 did happen in Japan as well in South Korea. Beside the use of still point sources in the 72.000 seats International Stadium in Yokohama with the Nexo Alpha system in the 66.000 seats Seoul World Cup Stadium JBL Vertec line arrays VT4889 /6/ have been applied radiating to the stands from the pitch rims.

After the events in New York in September 2001 new regulations have been worked out for the world cup 2006 in Berlin and other German cities.

For all FIFA stadiums the new **FIFA-Regulations, 3rd edition** /7/ formulated as technical recommendations under item 7.2 Speaker system:

> **....the sound system must have an automatic level control, which makes sure, that in case of enhancing noise level „all security relevant sound transmissions must be higher as the cheers of the present fans".**

No any concrete level numbers for the maximum noise level or for the needed total sound level in the stands have been demanded.

In preparation of the design for a couple stadiums in Germany ADA did measure usual noise floor levels in existing stadiums. An example of these measurements is shown in fig. 12.

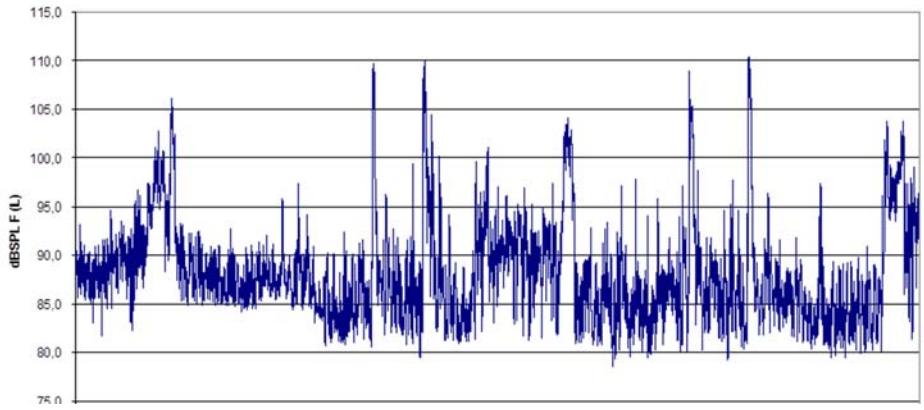


Fig. 12: Noise floor vs. time

In fig 12 the maximum peak level reaches 110 dBA, but this did happen in a short time (goals!). So for the calculation of the achieved Speech Transmission Index STI a noise floor level of 92dBA has been selected. The Assumptions for the games in Germany have been therefore:

- The max. noise level shall be 92dB(A) and
- The max. sound level must be minimum 102dB(A).
- Depending on sound system layout: shortly a max. sound pressure level of 105 dB(A)
- This signal distribution must cover the whole audience area of the stadium or arena or hall or only parts of it.
- Flat frequency response of the sound system between 70 Hz and 12000 Hz (+/- 5 dB) or better

  Other, but no FIFA demands for good acoustics have been the following:
- Reverberation time below the roof preferably below 3sec
- Tilted wall and window parts to deflect sound from the PA system
- Good sight lines promise good direct sound coverage (important if speaker are mounted at the pitch edge)
- No big building wall outside the stadium to avoid echoes

  Three principal Jobs for a stadium sound system may be found:
- **High quality sound coverage of the bleachers in halls and stadiums especially in emergency situations**
- Avoidance of high sound level radiation into the environment of halls and stadiums
- Prevention of impact of noise signals from outside into halls and stadiums

The first job will end in good speech intelligibility, i.e. STI values. So the Requirements to a Voice Alarm System in 2006 have been according to IEC 60849 /8/ at that time:

VA System announcements have to be intelligible and measureable by STI ≥ 0.50

In the renovated Olympic Stadium Berlin of 2006 all this demands have been considered:

Fig. 13: Berlin, Olympia Stadium before and after reconstruction 2004-2006

The 75.000seats stadium is equipped with 19 line arrays units with a total of 180 XLC by Electro-Voice /9/. Measurements have done only in the empty stadium and by using EASE an estimation of achieved satisfactory STI values in the occupied stadium could by obtained.

After the World Cup in Germany the FIFA did publish new regulation No. 4 /10/. Here an excerpt of it:

Public address system essentials (but no any concrete numbers have been given)

- communicating clearly with spectators inside and outside the stadium by means of a sufficiently powerful and reliable public address system.

Such a system should:

- have its control centre in a position with an unobstructed view of the whole stadium;
- be capable of addressing messages exclusively to individual sectors of the stadium, including banks of turnstiles, internal rooms, hospitality suites and blocks of seating;
- be capable of having its volume automatically increased to guarantee that messages will always be audible to spectators even when sudden increases in the crowd noise Level
- have an override which would permit the stadium controller to cut in to any separate sound in the event of an emergency;

The world cup 2010 did happen in South Africa and the above mentioned demands have had to be fulfilled.

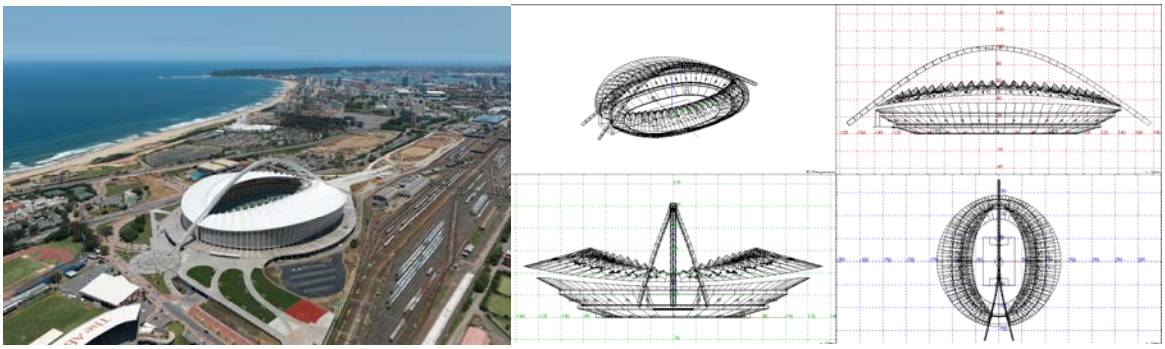


Fig. 14: Moses Mabhida Stadium, Durban, finished stadium and 3D model for acoustic simulation

The 68.000 seats stadium is covered by arrays with 118 VerTec VT4888 by JBL /11/. After the cup games the number of seats have been reduced by 10 … 15.000.

7 WORLD CUP 2014 IN BRASIL AND PREPARATIONS FOR 2018 IN RUSSIA

After the Games in South Africa and with the experience of the huge back ground noise in the South African stadiums (Vuvuzela sound!) **FIFA regulation no. 5** /12/ has been published.

All sound regulations from edition 4 are repeated but first time in FIFA history concrete target numbers are listed:

To ensure that adequate speech intelligibility for public address and emergency messages is achieved in the stadium spectator areas, the PA system should be designed to meet the following performance requirements and standards:

- The system is to achieve STI values (measured using the STI-PA method or calculated from the impulse response) of not less than STI 0.55 in the fixed spectator seating areas.
- The system shall provide maximum continuous sound levels of not less than 100 dBA and peak sound levels of at least 105 dBA, with deviations in overall direct sound levels across the spectator seating not exceeding +/-3.5 dBA.
- Frequency response as measured in the seating areas shall be at least 120Hz to 5000Hz +/-3 dB.

These rules have been used in the World cup stadiums in Brasil in 2014. In the updated 79.000 seats Maracanã Stadium in Rio de Janeiro 26 arrays with each 3 EVH boxes are installed. For the pitch coverage 8 Xi-2122MHA/42F /13/ are used, all speaker equipment was provided by Electro-Voice.

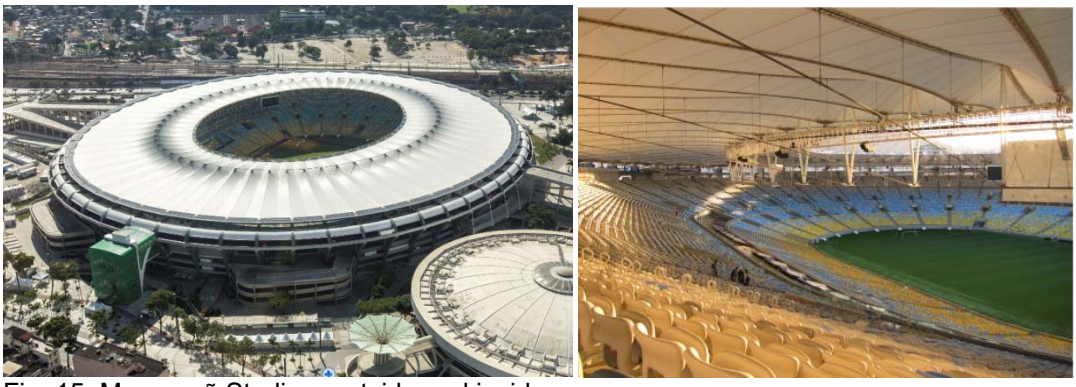


Fig. 15: Maracanã Stadium outside and inside

In preparation of the next World Cup 2018 in Russia new and partly stupid regulation under 50.20.20.20 in sound design has been published /14/. An excerpt of these regulations is shown in the following:

***Sound pressure level**, Value: dB SPL, weightings A and C*

- Excited football crowds can reach levels of 110 dB SPL A.
- The sound system shall be capable to overcome the crowd noise by at least 6 dB A
- The maximum SPL (sound pressure level) shall not exceed 125 dB SPL A.
- Frequency response as measured in the seating areas shall be at least 120Hz to 5000Hz, +/-3 dB.
- To provide adequate sonic quality for the reproduction of music, the system should be capable to reproduce between 40Hz and 120Hz + 6dB / - 3 dB and between 5000 Hz and 12 kHz within +/- 4dB.

Intelligibility, Value: STI (speech transmission index)

- STI PA (speech transmission index for PA systems) shall be used to verify the intelligibility of the system.
- An STI of > 0.55 for a full crowded Stadium shall be met inside the Stadium Bowl while it is recommended that for an occasion like the FIFA World Cup an STI of > 0.75 should be met to support entertainment purposes.

Comments to these regulations:
A maximal noise level of 110dBA is mentioned and the signal level shall exceed this level by 6dB. So this results in 116dBA. Crowd noise of 110dBA is certainly a short time noise in case of a goal. In this moment an announcement is not needed. Still more confusing is the fact that the level should not exceed 125dBA.
In this level range of > 100dB two consequences may or will happen:

a) It will happen hearing damage (at 125dBA this may end lethally in a single case and of course time depending). **Such levels should be prohibited.**
b) By the objectively caused masking properties of the auditory (not mentioned in the regulations!) the speech intelligibility decreases to 70% of the case with signal levels of 90dBA and below. As an example with a level of 90dB shall be achieved a STI value of 0.6, but with 116dBA this STI value is reduced to 0.42. **This means: more level does not help to improve intelligibility.**

To design a sound system under consideration of these not understandable regulations is quite difficult. On one side the demanded high noise floor will push the signal level to values of 116dB and more at the listener seats in the stadium to reduce the negative influence of noise on intelligibility. On the other side the high signal level causes high intelligibility losses because of the not negligible masking influence. Here a compromise has to find and the selection of sound systems to overcome these problems is limited. It leads in any case to higher numbers of sound devices and therefore to higher costs.
The author did make this experience in selecting the right devices in the design for the updated 81.000 seats Lushniki-Stadium in Moscow for the World Cup in 2018.

Fig. 16: Lushniki-Stadium in Moscow, SPL and STI calculations in EASE model

The final selection of the array devices is not done until now.

8 CONCLUSIONS

In the last 100 years the stadium construction was becoming more complex and sophisticated and the needed FIFA regulations cover now all fields of the stadium design. But only the last 20 years the sound design in stadiums is mentioned more specifically. The FIFA spoke now about crowd noise, maximum levels, automatic level control and head room for peak levels. Still in the 90ties the FIFA published only qualitative demands but now more and more quantitative numbers. Parallel we state a continuous increase of SPL and STI numbers in FIFA soccer stadiums.

With the Cup in Russia a new summit in the FIFA sound design regulations is achieved with unrealistic noise floors, maximum SPL values and STI values up to 0.75 and more. The praxis will show if this makes sense in the future.

9 LITERATURE

/1/ Electrical Review, May 31, 1919, pages 895-896

/2/ Sassnowski, Georg, Master work 09/2008, Technical University Berlin

/3/ Reprint of patent De 812258 of Siemens & Halske from May 1949

/4/ http://www.l-acoustics.com/

/5/ http://nexo-sa.com/en/systems/geos12/

/6/ http://www.jblpro.com/www/products/tour-sound/vertec-series/vt4889#.V9P25yzr270

/7/ http://www.fifa.com/mm/document/tournament/competition/51/53/98/safetyregulations_e.pdf

/8/ IEC 60849 at that time, not valid anymore, now ISO 7240-19

/9/ http://www.electrovoice.com/family.php?id=11

/10/ http://www.ksi.is/media/mannvirki/FIFA_Football_Stadiums.pdf

/11/ http://www.prosoundweb.com/article/crown_amplifiers_power_south_african_stadium/

/12/ https://de.scribd.com/doc/100501692/FIFA-Football-Stadiums-Technical-recommendation-and-requirements-5th-edition

/13/ http://www.electrovoice.com/family.php?id=117

/14/ http://www.fifa.com/mm/document/tournament/competition/02/59/22/68/regulationsfwc2018russia_short_e_v210415_neutral.pdf

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