A SCHEME FOR ARENA THEATRE LIGHTING GRID DESIGN IN TERMS OF GRID SPACING, WALKWAY SPACE, AND MASKING BY LOUVRES.

The Ohio State University, Ph.D., 1966
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A SCHEME FOR ARENA THEATRE LIGHTING GRID
DESIGN IN TERMS OF GRID SPACING,
WALKWAY SPACE, AND MASKING
BY LOUVRES

DISSERTATION
Presented in Partial Fulfillment of the Requirements
for the Degree Doctor of Philosophy in the
Graduate School of The Ohio State
University

By
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* * * * * * *

The Ohio State University
1966

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INTRODUCTION

The purpose of this dissertation is to contribute to theatre architecture by proposing a scheme of lighting grid design for arena theatre, based upon an objective examination of the desired functions of an arena theatre lighting grid. These functions are considered to be: to provide adequate instrument mounting capability, to provide adequate working conditions, and to provide masking for beam spill and light source.

The arena stage, in the brief space of thirty years as compared to the twenty-five hundred year history of theatre, has developed from an experimental and sometimes controversial place for the presentation of drama, to an accepted part of our contemporary theatre. A survey of recent theatre and architectural publications shows that over twenty new major theatres in the United States have been built or have been planned as arena theatres, or have included or have been planned to include arena theatre facilities. Despite this amount of building activity, the situation of arena theatre architecture today is much the same as it was in 1949 when Kelly Yeaton, speaking of

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1 Appendix A lists some of these theatres.
arena theatre in general, noted that "experience seems to be far in advance of published theory."\(^2\)

Ironically, one of the factors which contributed to the growth of arena staging may be responsible for the lack of research and published theory on arena architecture. The pioneers of arena theatre discovered that it provided a theatrical form for groups with limited capital for a physical plant. They could construct a theatre in almost any type of room of adequate size without the expense of constructing a conventional proscenium theatre. Many of the earliest arena theatres were located in basements, gymnasiums, hotel ballrooms, empty warehouses, remodeled houses, or any other imaginable place where suitable space was available. The technical problems of lighting were solved according to physical limitations of the available space and the capabilities of each producing organization.

Audiences and producers soon found that in addition to its economic advantages, this intimate though minimal theatre form was exciting and aesthetically satisfying. The popularity of arena theatre is reflected by the large number of arena stages included in many of the new educational and regional theatres recently finished or

\(^2\)Kelly Yeaton, "A Pool of Light," *Players Magazine*, XXV, No. 7 (April, 1949), 152.
now under construction in the United States. However, the
designs of these new arena theatres are frequently based
on a more practical adaptation of the owner's earlier and
limited facilities.

Thus the lack of research in arena architecture
may be partially attributed to the rapid growth of the
form, the tendency of builders to design the new facili-
ties in relation to their experience in a specific earlier
limited form, and the very diversity of the originals used
as models.

Therefore, this study, which proposes to investi-
gate one type of arena grid design according to function,
seems appropriate. The type of grid system selected for
investigation is gridded, permitting access to the instru-
ments from above the grid, and using louvres for masking.

The study is developed through five chapters and
an Introduction and Conclusion. Chapter I discusses cur-
rent types of arena theatre grid design by reporting on
six new theatres which represent six of the major ap-
proaches to arena theatre lighting grid structure. This
chapter contributes to the development of the study by
giving an overview of current practice and advancing the
history of one aspect of arena theatre architecture.

The theatres described were selected on the basis
of being representative of their particular grid style and
each was visited and examined by this writer. The six theatres and their grid types are:

3. Studio Theatre, Loeb Theatre, Harvard University, Boston, Massachusetts: gridded channel iron grid.

Interestingly, only one of these theatres is strictly four-sided, the Arena Stage. Four of the theatres, those at Macalester, Oberlin, Knox, and Harvard, are of the flexible type. The sixth theatre, Theatre St. Paul, is a three-sided arena. Even though these theatres are not all strictly arena theatres, their grid systems are appropriate for discussion here because the theatres can be used as arena theatres.

Only one of the six theatres has received any appreciable national publicity, Washington's Arena Stage. The room at the Loeb, despite its many interesting aspects, has largely been ignored as a result of the immense interest in the Loeb's main theatre.

The second chapter examines and defines criteria for determining grid dimensions. The project uses scaled graphic representations to investigate the problem. The
primary variables considered are the size and shape of the playing area, type of lighting instruments used, lighting angles desired, grid height, seating distance from the playing area, rise of the seating sections and the possibility of flying scenic units through the sections of the grid. The purpose of this chapter is to determine the effect of these variables on grid design.

The problem of access to the instruments via a walkway on the grid is discussed in Chapter III.

The investigation was conducted through a series of experiments using college students performing typical lighting activities on a grid mock-up that had a walkway which could be varied in width and a mounting pipe which could be varied in height. The results are based on a questionnaire completed by each student and personal observation by the experimenter. The purpose of the experiment was to investigate the practicality of various walkway widths and the interrelationship of the walkway width and the mounting pipe height.

Chapter IV investigates the practicality of using louvres for masking in arena theatre. The chapter discusses the reasons for and against masking in arena theatres and proposes that the use of louvres for masking is a method which has not yet been adequately explored. The investigation is initially developed through scaled
graphic representations and then further developed by an analysis of full scale mock-ups of the suggested solutions. Among the items covered in the chapter are the effects of grid height and spacing, stage and auditorium configuration, practical louvre dimensions, and mounting techniques.

The fifth chapter synthesizes the information from Chapters II, III, and IV to propose a type of arena lighting grid based on these findings. The proposed grid is offered as an addition to current practice, not necessarily as a replacement for any current techniques. The purpose of this chapter is to provide a cross check of the practicality of the theories of the earlier chapters and offer an example of their utilization. The Conclusion is a summary of the study.

A review of the previous writings and research on arena theatre lighting shows the majority of work to be devoted to reportage of current general or individual practice, coincident to the time of writing. Since most of these writings deal with the problems of adapting a particular limited facility for production rather than examining the potential of arena lighting in an unrestricted situation, they do not directly relate to this study and do not merit discussion here, although they are listed in the Bibliography.

Despite this general lack of prior theoretical writing, there are two works, an article "A Pool of Light"
by Kelly Yeaton, published in the April, 1949, issue of *Players Magazine*, and Joel Rubin's and Leland Watson's book *Theatre Lighting Practice*, which stand out as genuine contributions to arena theatre lighting.

Yeaton's early article is important because it is the first that encompasses the basic problems of arena theatre lighting design and the basic approaches to instrument placement. According to Yeaton the three problems or requirements for arena theatre lighting are:

"1. A separate lighting system for the stage and house."\(^3\)

The separate lighting systems are necessary to establish the difference between the stage and auditorium before and after the performance, between acts, and during scene changes. The lighting in effect replaces the curtain of the proscenium theatre.

"2. A lighting system to illuminate the actor on all sides."\(^4\) Although Yeaton was writing specifically about the four sided arena stage, this principle also applies to two and three sided arena stages if satisfactory illumination is to be attained.

"3. Lighting instruments so controlled that no glare or spill light will fall into the audience area."\(^5\)

Yeaton illustrates the problems of light spilling into the

\(^3\)Ibid.

\(^4\)Ibid.

\(^5\)Ibid.
audience as a result of audience proximity to the playing area and the multi-directions of lighting necessary for arena staging. He shows that a six foot separation between the stage and first row of seats is necessary if both stage and seats are on the same level and a standard forty-five degree vertical lighting angle is used. However, he also points out that if the first row of seats is elevated, the distance may be decreased.

In addition, Yeaton illustrates four methods of instrument placement as suitable for use. Two of these methods are now general practice. He designates them as the three color formula and the four instrument formula. Of these, the four instrument formula is the most satisfactory. It involves the use of four spotlights arranged around the lighting area at forty-five degrees, one hundred and thirty-five degrees, two hundred and twenty-five degrees, and three hundred and fifteen degrees. When using color media with the instruments, like colors should be placed in opposite instruments.

The three color formula utilizes three instruments placed around the lighting area at one hundred and twenty degrees, two hundred and forty degrees, and three hundred and sixty degrees. When color is used in this approach, Yeaton recommends that the lightest color be placed in
the furthest instrument and that darker colors be used in the nearer instruments.

At the time of this article, the primary types of instruments used for arena were PAR lamps in either commercial or homemade mountings. Consequently, parts of Yeaton's article are devoted to problems of lighting in conjunction with the use of these instruments. Even though today most arena lighting is accomplished with standard stage lighting instruments, the principles postulated in this article form the basis of arena lighting theory currently being used.

Rubin and Watson devote a chapter of their book, *Theatre Lighting Practice*, to arena stage lighting. The book is based, as the title indicates, on a survey of lighting practice and is not directly concerned with theoretical development. They discuss arena musical production, legitimate drama, and ice shows. In the discussion of musical production and legitimate drama they cover everything which is necessary for an understanding of conventional practice in arena theatre lighting.

The book does contain some information about light grid practice which is relevant to this study. Rubin and Watson suggest that the grids should be from fourteen to eighteen feet above the stage, and extend approximately

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six feet beyond the playing area. They admit the desirability of masking the instruments but indicate that masking is not absolutely necessary, particularly if it limits lighting technique or is inherently distracting. They describe three approaches to masking which they characterize as false ceilings which may or may not be an integral part of the light grid. The first consists of interchangeable opaque panels which may be removed or have holes cut in them to allow light passage. The second method is a permanent false ceiling which has permanently located portals for the lights. They point out that this system is restrictive and requires a thorough knowledge of the lighting requirements for the theatre before the structure is built. The third method is sometimes referred to as an egg crate grid or egg crate louvres. The louvres are rectangular sections, usually of plywood or aluminum, approximately one foot deep by two or three feet long and suspended beneath the light grid. The authors indicate that they feel this is the most practical solution to the masking problem.

In addition to the explanation of current practices, this book includes several examples of typical lighting plots and grid configurations which illustrate the practices, and would be most useful to anyone interested in the area. One of the more significant statements in the chapter states that arena "staging is among the
newer theatre forms and the principles of production are barely codified." In one small way this present study is aimed at trying to help solve that problem.

Two Master's theses, one by Bruce Griffeths at Yale University in 1951* and the other by Harry Rudenshiold at the University of Arizona in 1962, also deserve mention. Both are surveys of their contemporary practice and do not investigate new theories, but they do contain examples of lighting and grid design techniques from a wide variety of theatres in the United States.

Several terms are used in this study which may be understood to have a specialized definition for use here. Arena theatre or arena staging refers to a presentation in which the audience may be seated on four sides, three sides, or two sides of the stage. The term is not restrictive unless the text directly indicates a specific seating arrangement. The light grid, or simply grid, should be understood to refer to the general facility for mounting instruments in arena theatres, whether or not the system actually is constructed of gridded units. Masking refers to the shielding of light energy from the audience and not to the hiding or disguising of the lighting instruments themselves or the structural components of the grid. The beam source is the light within the instrument and at the

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lens of the instrument, but does not refer specifically to the lighting instrument. The beam direction is the path of the light beam in either the vertical or horizontal plane. Mounting flexibility refers to the ability to place individual instruments in a variety of locations on the grid in relation to the playing area.

Finally, the writer wishes to express his appreciation to the staffs and particularly the technical directors of the theatres mentioned in this study and many other theatres not mentioned which he visited while gathering background information. Without exception they were willing to take time from their own production commitments to discuss and show him their theatres. Without their willingness to discuss frankly the advantages and limitations of their own and other theatres in which they had worked and to allow a personal examination of their facilities, the work of this study would have been drastically limited, if not impossible.

For definitions of general technical terms the reader may refer to the Glossary in Appendix D.
CHAPTER I

A DESCRIPTION OF SEVERAL NEW ARENA THEATRES

This chapter surveys the various types of lighting grids used in new arena theatres in the United States. Since previous writings on arena theatre lighting have dealt almost exclusively with adapted theatre facilities, this chapter also adds to the history of the development of arena theatre architecture.

The six theatres described in this chapter represent six different, but effective, solutions to the arena theatre grid design problem. No theatre is meant to represent the best (or worst) example of a particular style, nor is any style meant to be presented as superior or inferior to any other style. Each method, as will be seen, has its own specific advantages and disadvantages.

During the course of investigation the writer was able to visit and personally inspect each described facility. He discussed the operational aspects with a member of the technical staff at four of the six theatres. At the two theatres where a member of the staff was not available (Oberlin and Harvard), he discussed the theatre's operation with students who were currently involved in production activities there.
The discussion of each theatre is organized to cover the following areas: the purpose or function of the theatre, the general physical characteristics of the theatre, the specific physical characteristics of the grid system, and an analysis of advantages and disadvantages of each approach as indicated by the theatres.

The purpose or function of the theatre is determined from the type of producing organization using the theatre, the type of personnel operating the theatre, the type and frequency of productions performed in the theatre, and the type of audience attending the productions.

The general physical characteristics of the theatre include the size and shape of the auditorium and playing area, seating capacity, finish of the auditorium, and general lighting details.

The discussion of the lighting grid covers an explanation of the grid type, the dimensions and features of the specific example, the method of access to the working area, the working area, and the electrical circuiting.

The discussion of the advantages and disadvantages of each type is based on the examined theatre, although some generalizations may be drawn for each type.
Studio Theatre in the Sophronia Brooks Hall and Auditorium at Oberlin College, Oberlin, Ohio

The Studio Theatre in the Sophronia Brooks Hall and Auditorium at Oberlin College in Oberlin, Ohio, is a multi-purpose room used for experimental productions. Oberlin College is a medium-sized (1965-66 enrollment, 2,644) liberal arts school. The room may be adapted for four-sided arena, three-sided arena, open staging and proscenium staging. The productions are directed either by the college theatre staff or by advanced theatre students. These productions are acted and crewed by students with varying degrees of supervision by the theatre faculty. The audience is composed primarily of students and people connected with the college.

The Studio Theatre room is forty-two feet long, thirty-five feet wide, and twelve feet high. The seating is temporary and may be arranged in any desired configuration within the confines of the room. The walls and floor are wood, stained in a natural finish. The grid design is the parallel pipe method. The lighting control board is located in a booth centered along one of the long walls and uses auto-transformer dimmers.

The grid consists of six two inch o.d. pipes running parallel to the forty-two foot walls which are suspended one foot below the ceiling and eleven feet above the floor. The grid is centered in the room and covers an
area fifteen feet by thirty feet. The four inside pipes are thirty feet long and the two outside pipes are twenty feet long. The pipes are separated laterally by three feet. There are thirty-eight grid circuits, spaced every five feet along the grid pipes. The four long pipes contain seven circuits each while the two short pipes have five circuits each. The grid module, or smallest geometric unit formed by the pipes and circuits, is three by five feet. None of the grid outlets are paired. In addition to the grid circuits, there are ten circuits in wall pockets. There are three pockets in each of the long walls and two pockets in each of the short walls. Access to the instruments is from beneath the grid by means of a small stepladder. No attempt is made to mask the instruments, which are five hundred watt, six inch Fresnels.

This type of grid system may be considered as a minimal approach since it is relatively inexpensive and simple to construct. The pipe sections may be suspended from the ceiling trusses and there are no cross joints to make between the pipes. Actually, since the cable enters at one end of the grid pipe, each pipe has only four or six circuits running within it. The lack of paired circuits in the grid also simplifies the wiring.

The lowness of the pipes means that the instruments may easily be moved or re-aimed from below. The closeness
of the pipes gives a reasonably wide variety of mounting positions within the limits of the grid. The length of the grid compared to the dimensions of the room gives good coverage longitudinally.

The virtues of simplicity also carry limitations. The lowness of the grid restricts the use of stage levels and places the lights extremely close to tall actors. The head of a six foot actor would be only four feet below the light source. This closeness limits the area covered by spotlight instruments for general illumination. A Fresnel at flood position could light only a maximum area of six feet. If the actor were placed on a one foot level the area would diminish to four and a half feet.

The fifteen foot width of the grid restricts the effectively lighted width of the playing area. If the pipes had been spaced further apart, this could have been avoided. The lack of masking and the low grid height, which places the actor in a direct line between the viewer and the beam source, must cause a definite spill and glare problem (although the students claimed that it was not "excessively" distracting).

Although the low grid height allows easy access to the instruments, floor obstructions can inhibit placing the ladder to work. For example, if the instruments are above the seating area, the seats must be moved to permit access,
or if the instrument needing adjustment is over the playing area, a scenic unit may have to be moved. This would be particularly inconvenient if an instrument needed relamping during a performance. Moreover, since most instruments are left mounted, most work with instruments would be aiming and coloring, much of which would have to be done with scenic elements in place.

The wiring in this theatre is simple and inexpensive, but restricts lighting technique. Since there are no paired outlets, if instruments are to be paired, either two separate circuits must be used or cables must be run from splits at the outlet. This problem is increased if a play or program is scheduled which requires double sets of lights.

The Oberlin system provides a grid that is inexpensive and easy to install. The low grid height provides easy access to the instruments from below providing the floor area is clear. The low height also limits the area covered by any one instrument. The simplicity of the cabling is offset by the necessity to use extra cables to reach some instruments or else limit the lighting capabilities of the facility. Thus the economy of installation is partially obtained at the later expense of time and inconvenience in using the theatre.
Studio Theatre in the Fine Arts Center of Knox College, Galesburg, Illinois

The Studio Theatre in the Fine Arts Center of Knox College at Galesburg, Illinois, is a multi-form room for experimental productions in a small (1965-66 enrollment, 1,223) liberal arts college. The college theatre has a two man staff which supervises student activity. The productions in this theatre may be faculty or student directed. The audience is drawn from the college and the college community.

The room is sixty feet long, forty feet wide, and twenty-five feet high. The walls are concrete block with moveable wood panels which are used for decor and acoustical effect. A curtain track is located along one of the sixty foot long walls. A six foot wide balcony, twelve feet above the floor, runs along the forty foot width and beyond the sixty foot length of the room. This balcony provides space for the dimmer bank, the light control console, sound equipment, and observation. The light control console is mounted on casters and may also be located on the floor of the room at the end opposite the balcony. The balcony has a railing which is suitable for instrument mounting. The grid is constructed of two inch o.d. pipe.

The grid covers an area approximately thirty-six by sixty feet and is seventeen feet above the stage floor. It is constructed from sections of two inch o.d. pipe which
are joined at intersections by four way pipe fittings to make four foot squares. There are, in effect, ten pipes running the length of the room and fifteen pipes running across the room. Access to the grid is from the balcony. Temporary walkways of two by twelve inch wood planking have been placed on the grid to provide access to the instruments. There are six walkways running the length of the grid and two which run laterally. The two center long walkways are twenty-four inches wide; the others are all twelve inches wide. In addition to having access from above, the grid can also be reached from below by means of a rolling scaffold.

There are forty grid circuits plus sixteen additional circuits located in wall pockets, eight along each long wall, and two circuits in floor pockets in the center of the room. The grid pipes are used as conduits for the cable. The grid circuits are located in the alternate lateral grid pipes. The outlets are offset by four feet in every other circuit pipe. The circuits are individual and have two receptacles at each outlet.

The standard lighting instruments used in this theatre are six inch, 500 watt Fresnels and ellipsoidal. They may be hung from the grid or "roostered." There is no masking provided and the technical director indicated that he did not contemplate devising any as he believes,
from his prior experience, that masking is either ineffective or too restrictive.

The most important assets of this grid example are the wide variety of mounting positions available and the ease of access to the instruments. An instrument may be mounted within two feet of the ideal location any place within the room. If an exact positioning is dictated for a special effect, an additional pipe can easily be placed across the four foot sections. The walkway system enables the technicians to work on the grid without drastically limiting the usable mounting space. In contrast to the grid at Oberlin, the grid at Knox is of sufficient height to allow platforms and tall scenic units to be used. In addition, there is enough space between the grid and the room ceiling to permit even the tallest workers to move about comfortably. The forty grid circuits, according to the writer's experience in arena staging, are sufficient to instrument the average production without resorting to extra cable runs and splits. In the event that a production requires heavier instrumentation, the dual receptacles provide facility for up to eighty instruments without extensive extra cabling.

The balcony at one end of the room gives the light and sound controllers a good view of the audience and playing area. Since the dimmer bank is also located there,
maintenance and troubleshooting may be expeditiously accomplished. Finally, since the grid extends over the entire area of the room, the only limitations to lighting angle and instrument placement are those imposed by the size and shape of the room.

There are some limitations in the design. According to the technical director the most serious problem is related to the circuiting layout. The circuits are evenly distributed over the grid. This affords available outlets for instrument placement any place on the grid, which is in keeping with the flexible concept of the theatre. However, in practice no production requires the entire grid and frequently there are multiple instrument mountings which require multiple cable run to the sections of greatest use.

The temporary walkways (perhaps incorrectly designated since the two by twelve planks are questionably portable) provide reasonable access to the mounting locations, but there are many areas not immediately accessible from the planks. The inherent problem in using the planks as access vehicles is that to provide complete access the planks would have to run adjacent to all the pipes of the grid, and this coverage would ultimately restrict the freedom of instrument location and beam angle.
The placement of the lighting console on the open balcony has an advantage and a disadvantage. Undoubtedly the communications problems during setup and rehearsal are minimized, and during a performance the operator has direct contact with the audience and the performers. On the other hand, the lack of a soundproof booth increases the probability of distracting noise from the control area through conversation, operational noises, and the inexcusable though inevitable "accidents."

Arena Stage, Washington, D. C.

The Arena Stage at Washington, D. C., is the most widely publicized theatre included in this study. It is a four-sided arena with a seating capacity of seven hundred and fifty-two. The theatre is used by a professional repertory company dedicated to presenting artistic and cultural drama. A cross section of the theatre room is shown in Figure 1.

The theatre room is one hundred and eight feet by one hundred and four feet. The stage is thirty feet by thirty-six feet, although the usable playing area is considered to be twenty-four feet by thirty feet. This reduction is caused by a three foot separation of the playing area from the seating to keep light spill off the
FIGURE 1

CROSS SECTION OF THE ARENA STAGE, WASHINGTON, D.C.
audience. The stage is trapped and has an eight foot high trap room beneath.

The primary seating consists of four tiered sections, each with eight rows. In addition, there are eleven boxes which ring the room above the tiered sections. The reason for the odd number of boxes is that the light and sound control booth occupies the space for the twelfth box. The seating in the boxes is not fixed and this accounts for the various published seating capacities for the auditorium. These figures range from seven hundred and thirty-two to eight hundred. The management considers seven hundred and seventy to be absolute maximum capacity.

The light grid is a rectangular light bridge which extends six feet beyond the stage on all sides. In addition, there are ceiling ports which are used for lighting the outside of the perimeter areas. There is a flying grid above the light bridge. This grid is thirty-seven feet above the stage. There are forty-eight sets of lines which can run to any of four pin rails. The pin rails are located one at each side of the control booth and two at the stage level.

The moveable bridge is forty-eight feet by forty-two feet and is normally suspended twenty-four feet above the stage. The instruments are mounted on pipes eighteen inches above the base of the grid. As mentioned earlier,
this grid is actually a rectangular light bridge with one longitudinal cross walk and two lateral cross walks. These cross walks divide the bridge into ten by twenty-one foot modules. The walkways are two feet wide and the mounting pipes extend a foot beyond the walkway on each side to give a four foot width at the mounting height.

The bridge is suspended by cables and can be varied in height or lowered to the floor by hand winches. According to the technical director, it normally takes half a day to lower the bridge to the stage floor, and half a day to raise it again. At some time in the near future an electric winch system is to be installed to operate both the bridge and fly system. Access to the bridge is either by an aluminum extension ladder or through a crawlway from the control booth. The technical staff considers the ladder as a temporary device to be used until the electric winch system permits easier raising and lowering of the bridge.

There are three hundred and forty-two circuits on the bridge and in the ceiling coves. The lighting instruments in use at the time of the writer's visit ranged from four hundred watt, conventional baby spots to eight inch ellipsoidal. This variety of instrumentation results from the need of an extensive number of instruments for repertory staging, forcing the organization to use
temporarily some of the instruments from their previous theatre.

There has been no attempt to mask the lighting instruments or the mounting area. The architects state that they and the owners believe that the equipment should be "considered a part of the frank theatricality of the arena staging form."

The light bridge concept used in this theatre provides a mounting platform which is convenient to work on and offers the possibility of double and triple mounting of instruments. The ceiling ports enable the use of lower lighting angles for the outer playing areas without necessitating the extension of the grid. In effect, the grid is extended beyond the confines of the room.

The large number of electrical circuits may seem extreme in comparison with the other theatres described here. However, this can be justified because the theatre performs in repertory and the additional circuits enable the lights for several shows with vastly different lighting plots to be hung at the same time and without necessitating readjusting the instruments between performances.

The major shortcoming of this grid design results from the large size of the grid module. The ten foot by

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twenty-one foot opening does give the possibility of flying large scenic units, but it also poses restrictions on mounting positions. This is particularly true in the placement of specials. In addition, the large modules may cause the instruments which light the general areas to be aimed at different vertical and horizontal angles.

An access problem to the ceiling ports limits their value. The working space at the ports is quite limited. Not only is the area small, but the ceiling is slanted and the technician must work in an unnatural physical position, like riveting in the tail of an airplane. A large person finds the conditions almost impossible. Consequently, there is a tendency to limit the amount of adjustment of the port instruments.

The visual impact of the light bridge in the auditorium is immense. The building is decorated in greys and pale umbers. The large, stark black bridge with its irregularities from the many projecting instruments acts as a focal point and draws the eye and attention of a spectator away from the pleasantness of the rest of the facility. Therefore, the writer's personal reaction is unfavorable to this attempt to justify this grid scheme as an admission of the theatricality of the theatre. Perhaps it would have been more effective if the theatre itself were more stark,
on the bridge somewhat more neutral, relative to the other room colors.

Studio Theatre in the Loeb Theatre at Harvard University

The Studio Theatre in the Loeb Theatre at Harvard University is every bit as interesting, though much less well-known than the main theatre. It is a room for theatre, suitable for arena, thrust, open, or proscenium staging. The theatre is used by students for experimental productions. The audience is drawn from the university community.

The room is thirty-five feet wide, forty-eight feet long, and twenty-four feet, six inches high. The light grid is a false ceiling, eighteen feet above the floor. The dimmer banks are located at one corner of the grid. A three foot wide balcony, located twelve feet above the floor and beyond the floor dimensions, extends around three sides of the room. The balcony has a pipe railing which is suitable for instrument mounting. The lighting and sound controls are located on this balcony.

Seating capacity is approximately one hundred. The seating arrangement is variable according to the placement of eight by twelve foot, collapsible bleacher sections. One of the more unique features of the theatre is the set of moveable panels suspended from the grid channels.
These panels may be moved about the room by sliding them in the slots of the channel iron. In this manner they can be used as a proscenium, wings, masking, backing, or other scenic devices. Their surface can be painted upon so they can be decorated appropriately according to their function.

The light grid is constructed of channel iron. The irons are gridded to form openings of twenty-four inches by twenty-four inches. The external dimensions of the grid are the same as the floor of the room, thirty-five by forty-eight feet.

Access to the instruments is from above the grid, which is reached by a ladder from the balcony. Travel from the floor to the balcony is accomplished either by an extension ladder within the room or by means of a hall and stairway in the building, but outside the room. There are five walkways which extend the length of the grid. The center walkway is four feet wide; the others are two feet wide. There are no cross walks. There is a four foot space between walkways; thus, any mounting position is within two feet of a walkway. The instruments are mounted in one of two ways. One method employs a unit resembling a saw horse made of two inch o.d. pipe which fits on top of the grid. The instruments are hung from the cross bar of the saw horse. The other method consists of placing a
two-by-four or pipe across the grid opening and then hang­ing the instrument below the grid. When the instruments are located above the grid, some masking is provided by the channel iron sections. When the instruments are hung below the grid, there is no masking.

All grid circuits are located along one side of the grid. At each circuit position there is a cable reel with a spring lock. The cable is unreeled to the desired location for use and retracted when not in use. There are only twenty-four grid circuits, a barely sufficient number. However, the balcony rail is also a primary mounting area, and the outlets there supplement the grid circuits.

This grid system offers good access to the instru­ments via the grid walkways. The walkways are quite wide and since the room ceiling is six feet above the grid, the working area is quite adequate. The cable reel method of circuiting allows a maximum flexibility and eliminates the problems and expense of running the circuiting within the grid. The two foot grid openings combined with six inch channel grid thickness provides some masking for instru­ments. The balcony around the room provides additional and low angle mounting facilities.

Although this grid would seem to provide a large number of mounting positions, this is not the case. Since the channel iron is not suitable for mounting instruments,
they must be mounted by additional means. The space required for the mounting hardware combined with the restriction of the two foot by two foot openings virtually limits the mounting to one instrument per opening, which means that double hanging is impractical. The walkways also cut down on the available space. One-third of the grid area is blocked by the walkways. Moreover, the double width walkway runs down the center of the grid and blocks what might be one of the most used hanging areas.

The reel cable method of circuiting is admirable for its flexibility and economy. However, problems may arise in use, from the tangling of cables by crisscrossing them. In addition, the cables may wear and the connectors work loose over a period of time which means that this system may require replacement and maintenance more frequently than a permanent system.

Theatre St. Paul, St. Paul Arts and Science Center, St. Paul, Minnesota

Theatre St. Paul, located in the St. Paul Arts and Science Center in St. Paul, Minnesota, is a three-sided arena theatre for a professional repertory group. It is part of a community center which also houses a natural history museum, an art gallery, and a small movie theatre. The theatre is meant to be self-sufficient and employs a professional technical staff, director, business staff,
and a nucleus of professional actors. The staff and actors are aided by a group of apprentices and volunteers. The audience is drawn from the Minneapolis-St. Paul urban area.

The theatre seats four hundred and ten. There are three hundred and fifty seats on the main level and sixty seats in the balcony which is on both sides of the control booth at the rear of the auditorium. The stage is raised eighteen inches above the floor level of the first row. The raised stage was an after-thought when it was discovered (during construction) that the auditorium rake was insufficient to allow acceptable sight lines. The stage is approximately twenty-five feet by fifty-five feet. There are wings at the extreme upstage area which allow for masked entrances. The light grid is a false ceiling constructed of steel I-beams twenty-five feet above the stage floor. The I-beams are one foot high and have three inch wide flanges. The beams are gridded into squares of thirty inches by thirty inches. Steel rods, spaced every five feet, suspend the grid four feet below the roof. Access to the grid is via a ladder located in a small room on the second floor of the building. The ladder may be raised out of the auditorium sight lines by means of a winch.
A set of pipes with flanges designed to fit the I-beam flanges are used for instrument mounting. The instruments can be either hung or "roostered" from the pipes. The theatre has a set of thirty inch square, one-fourth inch thick, masonite boards to place over the unused grid openings. These boards are intended to help acoustically and to facilitate movement on the grid by serving as a walkway around the instrument positions. The primary lighting instruments used in this theatre are six inch ellipsoidal and eight inch Fresnels.

This theatre is a good example of a situation where a series of seemingly minor flaws have been combined to make a reasonably good design idea almost unworkable. Consequently, this analysis, which may seem largely negative, should be understood as a criticism of the execution and not of the concept. If it seems that an inordinate amount of space is devoted to the mistakes in execution, it is because these mistakes point out the necessity for care and detail which must be employed in executing a design.

The problems start with the raised stage. As mentioned earlier, the stage level was raised to compensate for sight-line problems which resulted from insufficient rake to the auditorium floor. The raised stage solved the sight-line problem, but caused another—light spill into
the audience area. If the standard forty-five degree lighting angle is used, light spills onto the first four rows of seats. If the lights are adjusted to prevent the spill, the actors are inadequately lighted from the on-stage side through a band eight feet wide extending around the perimeter of the stage. Consequently, at least one-third of the stage is poorly lighted for any audience area.

The access ladder to the grid is the next trouble spot. The grid is about six feet higher than the level of the second floor. The ladder, which can be likened to a drawbridge, is normally stored at grid level to give a neat appearance to the auditorium. A high ratio winch system is necessary to move the heavy iron ladder. As a result of this high ratio, about five minutes of rapid cranking is necessary to raise or lower the ladder. The time and energy involved in this process discourages the staff from using the grid as much as might be desirable. Thus the strongest feature of a walk-around grid is negated by a fault in a relatively inexpensive item, the access ladder. At this point one might wonder which has priority, clean auditorium lines or easy access to the working areas. Of course if the theatre could afford an electric winch, the problem could be solved.

Next comes the problem of restricted movement on the grid itself. The four foot high clearance between the
grid and the ceiling makes erect travel impossible, but this would have been at least practical if the masonite board walkways had worked. Unfortunately, the flanges on the mounting pipes overlap the beams just enough so that the boards cannot lie flat on the squares adjacent to the instrument mounting locations. This means that the boards are not stable and will tip or slide when stepped on. Therefore, a worker must traverse the grid on the three inch wide beam tops. Now this is possible for a reasonably confident technician, but it would be so much easier if the ceiling were about two feet higher and the support rods were about a foot closer together to provide hand holds for balance.

The flanged pipes have worked well as a mounting device. However, the lighting designer prefers to hang a large number of his instruments from the pipes instead of "roostering" them. The difficulty of working below the grid floor level, especially with the lack of platform working space, prompted the lighting designer to do most of the hanging and aiming work from beneath the grid on an extended A-frame ladder. This large ladder is rather difficult to get into the theatre and there are the foreseeable problems of moving the ladder in the audience section to work on instruments hung over the auditorium. Overall, one can see that this general arrangement is far from satisfactory.
Despite all these problems there are some features of the system which have merit and perhaps in another theatre could be used without difficulty. For example, since the three inch I-beams can serve as a walking surface, though meager, a wider I-beam might prove satisfactory as the primary walkway. The masonite boards are unsatisfactory only because they do not fit. If more carefully planned, they could provide a useful, portable walkway and acoustical device. They are quite light and small enough to handle easily. Finally, the flanged pipes are an excellent mounting device. They are strong, stable and easily portable from location to location.

Macalester College Theatre, St. Paul, Minnesota

The Macalester College Theatre is a highly sophisticated, flexible theatre facility. It is designed to use machinery to change from standard proscenium to open stage, thrust, and arena configurations. Macalester is a small (1965-66 enrollment, 1,715), Protestant liberal arts college. The theatre department consists of a director and a technical director/designer. The plays presented by the college are primarily of the artistic or classic type. The audience is drawn primarily from the college students and people connected with the college.

The Macalester theatre is very similar to the main Loeb theatre and the proposed new Carnegie Tech theatre,
both of which were also designed by George Izenhour. This discussion of the theatre will dwell primarily on its configuration as an arena theatre. Seating capacity is three hundred. There are two hundred and ten permanent seats and ninety seats on moveable sections which swivel to the side of the auditorium. If a four-sided arena is desired, additional seats are added on risers placed on the main stage. The arena stage is twenty-five feet by twenty-five feet.

Access to the grid area is by a ladder from the observation booth. A soundproof observation gallery extends along the back wall of the auditorium and contains the lighting and sound controls. This area is not directly accessible from the auditorium and stage area. The beam lighting and/or grid system is comprised of square ceiling clouds.

The clouds alternate in height from twenty-four feet to twenty-five and one-half feet above the arena stage floor. They are separated horizontally by two feet. The clouds are six feet square and are each suspended from the roof by four one-quarter inch steel rods. They have an opaque, black bottom surface and a top (walking) surface of metal screen. A series of guy wires (not in the original specifications) anchors each cloud to inhibit sway as a worker moves from cloud to cloud. The clouds have
been placed to afford forty-five degree vertical angle lighting for the standard playing areas.

A two inch o.d. pipe, which serves as the mounting pipe, runs around the top of the cloud, four inches from the outside edge and two inches above the base of the cloud. Each cloud has four circuits, one per corner. These circuit outlets are paired with others on the grid and backstage. In addition to the clouds, there is a beam bridge located at grid height, immediately above the observation gallery. The first light pipe can also be dropped and used as a mounting area for the arena.

The cloud system is essentially a reverse use of space compared to the pipe grid method. What would be the open grid space is filled by the cloud and becomes a working area, while the walkways are removed to become gaps for beam travel. The clouds form a much larger working area than is possible using walkways. The alternation of cloud height provides a modicum of masking. The cloud system also has an aesthetic merit because it is not as stark as the grid and light bridge approaches. This design has been well-executed as evidenced by the fact that the mounting positions, the clouds, as mentioned earlier, have been placed in the correct location to give a forty-five degree vertical angle for the standard playing areas.

Nevertheless, in this as in other theatres, there are aspects which are open to qualification or modification.
First is the cloud concept itself. Granting that the open space in the pipe grids is normally used for instrument placement, there are times when a special can be rigged in that area, a feature not possible using the cloud system. Moreover, the dead space where an instrument cannot be hung in the other grid systems is rarely more than two feet, while in this system the dead space comes closer to eight feet.

A feature which may be even more important, considering that this is for a small educational theatre, is movement from cloud to cloud. To move from cloud to cloud a worker must traverse an eighteen inch increase or decrease in height and a two foot lateral distance. This may seem insignificant on the ground, but the psychological effect when twenty-five feet in the air is considerable. This problem is increased since the clouds sway slightly as a person moves from one to another and their surface is not rigid, but springs as a person walks on it. Finally, the mounting pipes present a hazard because of the possibility of tripping on them. Now these problems may or may not be important to an experienced or professional technician, but the writer suggests that one might be hesitant to introduce inexperienced students to theatre lighting by working under such conditions, especially if the student were one of the five foot tall, one hundred pound co-eds who are frequently tireless and efficient workers when trained.
The grid design schemes described in this chapter represent a variety of approaches to the same problem. Each design has its merits and its shortcomings. Some have been well-executed; others less well. Most important, no one grid system would necessarily be appropriate for all the theatres described. Nevertheless, they all offer a method of solution based on certain criteria essential in developing a grid design. These criteria will be discussed in the next chapter.
CHAPTER II

CRITERIA FOR BASIC LIGHTING GRID DESIGN

This chapter defines the relationship of external variable factors to the dimensions and spatial characteristics of an arena theatre lighting grid in order to propose a sequence of criteria which can be used during the grid design process. The basic physical characteristics of a lighting grid are its length, width, height, location of interior sections, type of construction material, and space allowance for movement upon the grid (optional). The last two items are not discussed in this chapter. The question of material is a mechanical engineering problem and is pertinent in the design problem primarily in terms of structural support and effect on details in instrument procurement. The question of space for movement upon the grid is a secondary aspect to be arranged after the other dimensions are determined. A method for determining the space necessary for efficient movement is developed in the next chapter.

The physical characteristics of the arena lighting grid should satisfactorily permit illumination of all potential acting areas from acceptable horizontal and vertical angles, and assure the elimination of direct spill into the audience area. This last requirement is
actually more dependent upon the spatial relationship of stage and seating than the grid characteristics. This relationship will also be explained in this chapter. Therefore, the primary design problem is to determine placement of instruments to ensure adequate visibility.

The instruments should be located to give a vertical beam angle of from thirty-five to forty-five degrees from the beam source to a point five feet, six inches above the stage at the center of the lighting area. The forty-five degree angle is, of course, the standard vertical lighting angle. In *Stage Lighting*, Frederick Bentham proposes that the beam lights in proscenium theatres might be lowered to thirty-five degrees to compensate for the diminishing use of footlights in modern lighting practice.¹ This principle could also be applied to the instruments which light the outer sides of the arena theatre's perimeter lighting areas where footlights are obviously impractical.

The four instrument or double McCandless method is most desirable for locating the instruments on the horizontal plane since this gives two instruments per audience side.² In this method the four audience sections are


assumed to be located at ninety, one hundred and eighty, two hundred and seventy, and three hundred and sixty degrees around the stage. The instruments are then located at forty-five, one hundred and thirty-five, two hundred and twenty-five, and three hundred and fifteen degrees around each stage area. This helps eliminate spill into the audience and gives a more plastic effect than if the lights were aimed in line with the seating.

The initial planning of the lateral, longitudinal, and internal section dimensions of the grid should be based on the area needed to place the instruments according to the light angle requirements. These dimensions can be plotted mechanically by either assuming a predetermined grid height, working from the center of the lighting area to find the horizontal plane distance or by starting with a plane distance and determining the necessary grid height.

Figure 2 illustrates the problem in which we have a predetermined grid height and wish to find the plane distance. In this example a grid height which places the instrument twenty-six feet above the stage floor is used. Point A is five feet, six inches above the floor and represents the actor's head when he is standing in the center of the area. Point B is the instrument level directly above point A and twenty feet above the stage. Point C is the intersection at instrument height of a line drawn from point A at a forty-five degree vertical angle to the
FIGURE 2

HORIZONTAL AND SLANT RANGE DISTANCE USING 35° AND 45° VERTICAL ANGLES
plane of the stage. Line BC is then the plane distance from the center of the lighting area to the instrument location at the mounting height. In this example the distance is fourteen feet, six inches. Point D represents the point of intersection of a line drawn at a thirty-five degree vertical angle from point A. Line BD is then the plane distance from the center of the lighting area to the instrument location. In this case the distance is twenty feet, nine inches.

This information can also be depicted visually as shown in Figure 3. The horizontal lines of the graph show the instrument height above the stage floor. The vertical lines depict the plane distance from the center of the lighting area to the instrument. Line one is drawn at a forty-five degree vertical angle from a point five feet, six inches above the center of the acting area. Line two is drawn at a thirty-five degree vertical angle from the same point.

We can see from the figure that if for some reason the maximum available space necessitated that an instrument could be no further than fifteen feet from the center of an area, an instrument aimed at forty-five degrees could be mounted no higher than twenty-one feet while an instrument aimed at a thirty-five degree angle would be limited to a mounting of no more than sixteen feet, three inches. On the other hand, if we had a grid height of twenty feet,
FIGURE 3

HORIZONTAL DISTANCE FROM CENTER OF AREA TO SOURCE AT VARIOUS HEIGHTS
then the instrument aimed at forty-five degrees would be fourteen feet from the center of the area and an instrument aimed at thirty-five degrees would be twenty feet, three inches from the center of the area.

If we take a typical stage area such as twenty by twenty-five feet and divide it into six lighting areas, such as shown in Figure 4, and plot the instrument positions using the previously described methods for a twenty-six foot high grid, we can see how the mounting positions will fall into a natural alignment. For purposes of illustration, the thirty-five degree vertical angle is used for instruments lighting the outer edges of the stage, while the forty-five degree vertical angle is used for those lighting the insides of the areas. In this example the grid covers an area of fifty by fifty-six feet. It could easily be constructed using six pipes, two pipes fifty feet long for the two end sides, and four pipes fifty-six feet long for the longitudinal sections. The two interior pipes divide the grid rectangle into thirds longitudinally. This placement would constitute the basic grid requirement for the theatre.

As can be seen in Figure 4, the grid extends over the audience area. This is a characteristic of all good lighting grids. Moreover, the amount of overhang increases with grid height and/or the use of the lower vertical angle.
FIGURE 4

A BASIC GRID PLAN
In addition to the center stage, the entrances are often used as playing areas. These entrances may be of several different types according to the theatre design. The amount or manner of their use may vary from theatre to theatre and production to production. The entrances may be the aisles for the seating sections or the theatre may have vomitoria as entrances which are separate from the seating aisles. Depending on the theatre or production the acting area may include: (1) only the center stage, (2) center stage and the spaces to the aisles or vomitoria, (3) center stage, connecting spaces and aisles and vomitoria.

The major problem in lighting these additional areas concerns spill into the seating sections. Spill is that portion of a light beam that illuminates an area or object other than the primary aiming area of the light. This problem is least present in cases where the additional area is an extension of the central stage toward the aisles or vomitoria. Usually the uses of a steeper vertical aiming angle (an admitted compromise) and ellipsoidal spotlights which can be framed to minimize audience spill are the most satisfactory solution. The problem is most severe when the aisles themselves are used. The simplest solution is to raise the house lights for the house section being used. This is not wholly satisfactory because the general illumination causes problems of attention focus, and the
light is not sufficiently intense. The actors are not effectively separated from the audience, and, therefore, are difficult to see. Obviously, if a standard four instrument per area method was used, shown in Figure 5, there would be excessive spill into the seating sections because of the proximity of the actor to the spectators. In addition, those spectators in the spill area would probably experience some physical discomfort and have difficulty looking directly at the performers because, to see, they would be looking directly at the spotlights. Thus the most satisfactory method would be to use pairs of instruments aimed up and down the aisle, as shown in Figure 6. They should be ellipsoidal spotlights which can be framed off the seats. Although this method sacrifices some visibility for those people at right angles to the aisles being used, the visibility for the majority of the audience is satisfactory.

In cases where the playing area extends from the stage to the vomitoria, it may be more practical to use three spotlights, as shown in Figure 7. The primary instrument is aimed from the atage in line with and directly at the entrance. The two side lights may have a plane angle of from ninety to one hundred and twenty degrees to the beam of the primary instrument, according to the relation of the seating to the area. Although the primary instrument should be at the standard vertical angle, the two
FIGURE 5

LIGHT SPILL INTO SEATING CAUSED BY USING FOUR INSTRUMENTS TO LIGHT AISLE
FIGURE 6

TWO INSTRUMENT METHOD TO LIGHT AISLES
FIGURE 7

THREE INSTRUMENT METHOD TO LIGHT CORNER ENTRANCE AREAS
side lights may be aimed at a steeper angle, if necessary, to limit audience spill.

Thus far we have shown how to determine the basic grid requirements according to the necessities of the basic lighting angles. There are, however, other variable factors which can affect location of the mounting positions. They are the size of the theatre room, the size of the playing areas, the spacing and configuration of the seating, the variety and number of lighting positions and angles desired, the type of lighting instruments to be used (particularly small-powered instruments which limit slant range distance), and although this is not common, the possibility of flying scenic units from above the lighting grid.

Ideally, the size and shape of the theatre room should be determined according to the needs of the stage, seating, and lighting. Unfortunately, this is rarely the case. Although the instances where the interiors of theatre buildings have been constrained to conform to an aesthetically imposed external architectural concept are decreasing, examples of this problem still occur. The new Cannon Hill Theatre in Birmingham, England, where the desire to keep a low building height imposed a low theatre
room ceiling and caused the grid walkways to become literally grid crawlways is a case in point.\textsuperscript{3}

More common reasons for restrictions of theatre room size are financial limitations or because of the incorporation of the theatre in a larger building complex with compromises to be made in terms of overall building space. This is particularly true since most of the new arena theatres are a part of an educational theatre building which also includes a major proscenium theatre.\textsuperscript{4} Therefore, initial space programming considerations may impose a height or lateral space limitation which prohibits placing the grid at the desired height or extending the grid beyond the playing area as far as desired.

Returning to the original premise that the size and shape of the theatre room should be determined by the needs of the playing and seating area, we should note that the choice of a small playing area and seating capacity could also limit the theatre room size to a smaller area than that required for the lighting grid. Therefore, if the desired lighting angles are to be attained without enlarging the room beyond the size necessary for the stage


\textsuperscript{4}Eleven of the eighteen new theatres listed in Appendix A are of this nature.
and seating, we need another type of mounting facility in addition to the grid.

One possible solution to this problem of limited lateral space is the use of wall ports. As shown in Figure 8, the plane distance from the center of the lighting area to the instrument decreases as the height of the instrument decreases. Thus the outer limits of the grid could be contained in the walls of the room, either at grid height or lower. The Arena Stage in Washington uses this method, and more recently, the Guthrie Theatre in Minneapolis has instituted modifications to improve lighting angles by putting ports above the balcony entrances.

The size and shape of the seating arrangement can also affect the lighting grid design. As pointed out above, a small or limited seating theatre could be accommodated without the necessary lateral space to allow a grid of desired lateral dimensions. The vertical rise of the seating rows could also affect grid height. This situation would be most noticeable in theatres with five or more rows per seating section, and will probably be more of a consideration in the future than now since some theatre architects are experimenting with a steeper rise of the seating to improve sight lines. As a result, the auditoriums of the future may have a rise of as much as twenty-four inches
WALL PORT USED TO COMPENSATE FOR LACK OF SUFFICIENT LATERAL GRID SPACE
At the present time, however, the rise from row to row ranges from six to sixteen inches. Assuming the maximum rise of sixteen inches, we find that a six foot tall spectator would have a head height of thirteen feet above the floor in a five row theatre and approximately seventeen feet above the floor in an eight row theatre. If we give a minimum of three feet clearance from the head of the standing spectator, we find that the minimum grid height for the five row theatre should be sixteen feet and the minimum height for the eight row theatre would be twenty feet. By projecting this rise we find that the five row theatre would require a nineteen foot high grid and that the eight row theatre would need a twenty-five foot high grid.

Concern occasionally arises about the problem of instruments located on that part of the grid which extends over the playing area having beam spill on the seating. As shown in Figure 9, this is a rather unlikely occurrence in a theatre where all the instruments are mounted on a grid. However, if some of the outer instruments are mounted in wall ports, their planned beam angle should be

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5 Curtis Greene, of Hammel and Greene Architects, Speech at NCTA Conference at St. Cloud State College, St. Cloud, Minnesota, on February 26, 1966.

6 Donald Mullin, "Lighting the Arena Stage," Tabs, XIII, No. 2 (June, 1965), 31.
FIGURE 9

BEAM PATH FROM INSTRUMENTS LOCATED OVER SEATING AREA
checked to see if a standing spectator might interrupt the beam angle. In general, the rise of the seating affects grid height primarily in terms of grid audience relationship rather than in lighting considerations.

It is appropriate to digress here to discuss an arena lighting problem, light spill into the seating sections from the stage lights, which actually is a seating and theatre design problem rather than a grid design problem. Although the means of avoiding auditorium spill, raising the seats above the stage level and removing them slightly from the edge of the playing area, has been generally accepted and published for some time,⁷ there are still occasions when it appears to have been either ignored or unknown.⁸ As shown in Figure 10, there is bound to be spill if the stage is higher than the first rows of seating. There will also be spill if the seats are at stage level and adjacent to the playing area, as shown in Figure 11. The spill can be virtually eliminated by leaving a four foot wide neutral area from the playing area to the first row of seats and raising the first row one foot above the height of the stage, as shown in Figure 12.

Although the method described earlier in the chapter establishes the basic grid requirements and

⁷Yeaton, pp. 152-53.
⁸Mullin, p. 31.
FIGURE 10

LIGHT SPILL INTO SEATING AREA WHEN STAGE IS ABOVE FIRST ROW SEAT LEVEL
FIGURE 11

LIGHT SPILL INTO SEATING AREA WHEN STAGE IS LEVEL WITH FIRST ROW OF SEATS
ELIMINATION OF LIGHT SPILL INTO SEATING AREA BY RAISING FIRST ROW OF SEATS ABOVE STAGE LEVEL

FIGURE 12
positions, they should be considered as the minimum necessities. In some lighting design situations we may desire to use additional non-standard areas, or special aiming angles. Therefore, the initial plan can be modified according to the size and arrangement of the lighting areas desired. The decision regarding the amount and type of flexibility desired will be a major determinant of the type of grid to be constructed. For example, the light bridge system at the Arena Stage is highly suitable for double hanging, but is limited for placement of instruments for special effects or angles. On the other hand, the Theatre St. Paul grid gives great flexibility in the placement of instruments but has definite limitations in terms of double hanging. One type of compromise has been achieved in the grid for the Lab Theatre at Knox College where the grid pipes are close enough together that an additional mounting pipe for specials can be rigged, if required, between the already existing grid pipes.

The type of lighting instruments to be used is closely related to grid design, since the various types of instruments have definite capabilities and limitations. Either the proper instruments must be acquired for the.

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9Mounting two or more lighting instruments in virtually the same physical location and aimed at the same area, usually with different color filters and used separately or together to achieve a change in lighting.
designed grid, or if an already owned stock of instruments is to be used, then the grid should be designed with them in mind. The Fresnel spotlight is most frequently used for general area illumination in arena theatres. Ellipsoidal spotlights are used for illuminating the entrance areas and for certain specials. With the development of the diffusion-edged shutters for ellipsoidal spotlights, their blending characteristics are much improved, and in the future these instruments may be used more frequently for general area illumination.

The considerations in selecting the right instrument for the grid or the right grid for the instrument are the beam spread for foot of throw distance and the effective candle power at the required distance. The beam spread for Fresnel spotlights is variable from one foot of spread for three feet of throw distance to one foot of beam spread for one foot of throw. Ellipsoidal spotlights have three types of lenses available, the narrow, medium, and wide beam lenses. The narrow beam lens gives one foot of spread for three feet of throw, the medium gives a two to one ratio, and the wide gives a one to one ratio. Therefore, the grid should be high enough to provide a slant range distance, from the beam source to the center of the lighting area, of at least twice the length of the diagonal of the lighting area.
The effective candlepower for throw distance can be found easily in the catalogues of the major lighting equipment manufacturers. According to their specifications a six inch Fresnel spotlight will provide twenty-five foot-candles of light at twenty-five feet. After that an eight inch instrument should be used.\textsuperscript{10} Five hundred watt ellipsoidal spotlights with from four and one-half to six inch lenses (the size varies according to manufacturer) should be adequate for all but the largest arenas. The recent development of quartz light instruments adds another aspect to the instrument, grid height, beam throw relationship. Although complete figures are not yet available, initial publicity seems to indicate that six inch Fresnels using the quartz light could be effective for beam throw length distances of up to thirty-five or forty feet.\textsuperscript{11}

Flown scenic units are not usually thought of in conjunction with arena staging; however, they can be an effective theatrical device. If a theatre is being designed with this machinery in mind, space must be left between the grid sections to allow passage of the scenic units. The minimum space would seem to be ten feet. That should allow adequate space for eight foot wide units with a foot of clearance on either side. Obviously if this is

\textsuperscript{10}Century Theatre Lighting Catalogue, 1960, pp. 42-43.

\textsuperscript{11}Kliegl Catalogue Q-8, 1965.
The degree of flexibility and variety of mounting positions for the lighting instruments are appreciably decreased.

The number of grid electrical circuits and the location of the outlets, although not a factor in determining the grid spatial characteristics, affect the ultimate use of the grid. No matter how well-arranged the grid units are, an inadequate number of grid circuits or poorly distributed outlets will limit lighting design flexibility. The problem of arena theatre electrical circuiting has to be investigated and is large enough to warrant a separate research problem. However, personal experience has shown that several general statements can be made pertaining to grid circuiting.

Ideally, there should be one circuit for each central and entrance area lighting instrument. These can be grouped on the dimmers to provide flexibility of area and color control. There should be an equal number of circuits in addition which would be available for special areas, special effects, and color toning to add flexibility to the lighting design, or permit separate designs for repertory staging. There should also be a number of "hot" circuits on the grid (a minimum of one per grid quadrant) which would be useful for the operation of power tools on the grid, checking equipment operation, and if absolutely necessary, non-dimming lighting circuits.
The number of circuits could be reduced, if necessary, by having a smaller number of extra circuits, by pairing the diagonally opposite instruments for each central lighting area on one circuit, and using only one circuit for each entrance area. This scheme still provides some area and color control. Only in the most extreme circumstances should only one circuit be used for all the instruments for a central lighting area since that arrangement severely limits lighting design flexibility.

The circuit outlets should be placed adjacent to the basic instrument locations. Although the outlets can be receptacles built into the mounting pipes, a better solution would utilize short (three to five feet long) cables coming from an electrical batten. Care must be taken to ensure that the batten is not in a position to interfere with possible mounting positions. This method eliminates the possibility of the receptacle on the mounting pipe interfering with a desired instrument location and provides better flexibility of mounting positions without resorting to the use of interconnecting cables. Interconnecting cables are undesirable because of the time needed to install and remove them, plus the hazard they present if used with a walkway system since workers might trip or stumble over them.

In this chapter we have seen how to plot mechanically the beam throw lines in the horizontal and vertical
planes to determine instrument locations for the standard lighting areas. These locations determine the form of the basic light grid. Frequently, however, other aspects of the building may affect or prohibit this initial arrangement. These factors may be the theatre room size and shape, the arrangement of the seating, the desirability of additional mounting positions in other locations, the types of instruments to be used, and the possibility of having a lighting grid which permits the use of a flying system. If any of these factors necessitate a modification of the initial plan, we have seen that the best solution is to vary the height of the grid and in certain cases mount the exterior instruments in wall ports at or below the grid height. In all cases the primary objective is the attainment of the proper vertical and horizontal beam angles for the instruments.
CHAPTER III

THE LIGHTING GRID WALKWAY

The lighting grid designer has a choice of grid schemes, one of which allows for working on the lighting instruments from above and the other which allows working only from below. There are advantages and disadvantages to either approach. The grid which permits access only from below may be a necessity because of architectural and acoustical considerations which restrict the height of the theatre room, and therefore limit the space above the grid if the space below is to be sufficient. This type of grid is generally simpler in construction, uses fewer materials, and is less expensive to construct than a grid which permits access from above because human access to the space above and support of human weight are not necessary. This grid type also makes possible, if desired, an almost infinite number of mounting locations since grid areas are not blocked by walkway space.

The disadvantages of this scheme lie in the working conditions it imposes. Let us now consider the processes involved in doing lighting work from beneath the grid:

1. The technician must procure a means of elevation, usually a stepladder, platform ladder,
A-frame ladder, or scaffolding. This unit must be brought to the desired location and then moved from spot to spot, a time and energy consuming process. The work, and sometimes the danger, is increased for want of sufficient space and satisfactory base for the ladder or scaffolding if the grid extends over the seating area. If the set is in place, the technician must frequently remove it and replace it to reach instruments over the playing area. Since most final aiming is done after the set is in position, the quality of the lighting job may suffer because of lack of time to shift the set or because the technician is unable to reach the instruments. In addition to the setting-up problems, access for adjustment or maintenance of the instruments, either over the stage or the audience, is impractical during a rehearsal or performance.

2. Secondly, the technician must carry the instrument up the ladder. Then he must raise it to the desired location and affix it to the grid.

3. Thirdly, the technician must work with his arms above shoulder height, an unnatural position. Anyone who has ever tried to win a dollar bill through the old parlor game of
holding it on the palm of his hand for one minute without wavering can understand the physical stress involved in working for extended periods with the arms above the shoulders.

4. Finally, in many instances the worker will find he either has limited vision of his work or is in an awkward physical position for aiming, or both, because he must still remain below the grid and he may encounter problems of leverage and sighting the direction of the beam.

Thus we can see that although a grid which provides access only from below may be more economical to construct and provides a better acoustical chamber, it has severe limitations for the worker.

A grid which provides access for working above grid level is initially more expensive because it requires a higher building and more materials and complex construction than the previously described system. Then too, the space consumed by walkways will limit space, and therefore flexibility. However, the writer believes that the working conditions it offers offset these liabilities. For instance, a good walkway system should provide easy and rapid access to all mounting positions on the grid. Since the technician is working on a constant level, the time and energy consumed in moving apparatus (ladders, platforms,
etc.) is eliminated. According to the design, the technician works either standing up, stooping, or sitting, positions which are less tiring and unnatural than working on a ladder with the arms over the head. Generally these positions give better leverage, control, and visibility than those from under the grid; moreover, since the worker is on a platform he is less likely to move into an awkward position than if he were on a ladder. Since access to the instruments is not dependent on use of the seating or playing area, it is possible to perform minor maintenance or adjustments during a rehearsal or performance. The lights also may be aimed or adjusted after the setting is in place without disturbing the setting or other work going on within the confines of the theatre.

If the selection of working access is less limited by financial or architectural considerations, the method of working from above grid level provides definite advantages. However, in any theatre the choice should be made to fit the needs of the user. Some of the measures of need are: (1) frequency of change in focus, color, and position; (2) time available for setup; (3) frequency of productions. One should admit though that a well-designed and executed grid with access from below may be far better than a poorly designed grid with access from above.

As demonstrated by several of the theatres described in Chapter I, there are nearly as many design
solutions for the method of access from grid level as there are arena theatres. One may choose a version of the lighting bridge similar to Washington's Arena Stage, the ceiling clouds of Macalester, the catwalks at Knox, or the St. Paul Arts and Science Center theatre's entire grid walkway principle. This diversity of walkway types suggests the lack of a standard clear-cut concept of the dimensional requirements for a satisfactory walkway. These requirements are defined and described in the following paragraphs.

The ideal grid walkway should provide sufficient headroom to allow erect movement on the grid; provide sufficient width to permit safe and confident movement from point to point; provide comfortably accessible mounting rails which frequently can also serve as guard rails; and cause minimum interference with potential mounting areas and mounting flexibility. Thus the lowest structural element of the ceiling (beam, duct, conduit, tie rod, etc.) above the walkway should be approximately seventy-eight inches above the walkway to guarantee sufficient headroom for all but the tallest workers, although a height as low as sixty-six inches may be possible if necessary. In relation to the fourth point, one can visualize that the less space used for the walkway, the less space will be removed from potential mounting use. Therefore, walkway width and
positioning of the mounting pipe become the significant criteria in design.

In an attempt to arrive scientifically at some basic dimensions to satisfy these criteria the writer constructed a grid walkway mock-up which had a variable width walkway and a variable height mounting pipe. The purpose of the experiment was to determine the minimum width of walkway and the optimum mounting pipe height for a walkway by observing a group of students performing standard lighting tasks on the mock-up and then gathering their evaluation by means of a subjective questionnaire.\(^1\)

The mock-up, constructed of lumber, was ten feet long, and five feet wide, and the walkway floor was ten feet above the room floor.\(^2\) The length was determined to be adequate to approximate the conditions of travel on a grid section. During their work the participants had to traverse the length of the unit and could not remain at the psychologically more secure ends of the walkway. The height was sufficient to approximate the psychological conditions of grid work while not causing any exceptionally difficult construction problems. Structurally the unit was stable and rigid. The walkway section was variable in three inch intervals from six inches wide to forty-two

\(^1\)Appendix B contains a sample questionnaire.

\(^2\)See Appendix C for photographs of the mock-up.
inches wide. The mounting pipe was variable in height in three inch stages from walkway level to thirty-six inches above the walkway. The distance of the pipe laterally from the walkway could vary from flush to twelve inches. Since it was unrealistic in terms of time and energy to expect any participant to go through the entire series of combinations, a pre-experiment test was made which showed the most meaningful combinations to be the following:

<table>
<thead>
<tr>
<th>WALKWAY WIDTH</th>
<th>PIPE HEIGHT</th>
<th>LATERAL PIPE DISTANCE</th>
</tr>
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<tbody>
<tr>
<td>18&quot;</td>
<td>30&quot;</td>
<td>0&quot;</td>
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<td>18&quot;</td>
<td>15&quot;</td>
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The participants were primarily speech and theatre students at Mankato State College, Mankato, Minnesota, although a few unwary bystanders were pressed into service. Participation was strictly voluntary and in an effort to obtain a representative cross section no qualifications of age, sex, size, physical ability, disability, or experience were imposed. This was done in the belief that the typical arena facility would and should be used by all types of people and that the experiment should contain a representative random group. Consequently, the group ranged in age
from seventeen to forty-five years old, was about one-third female, and had an experience range from absolutely no prior theatre experience to extensive undergraduate technical experience. The breakdown by sex is shown in Figure 13. Although the most preponderant physical limitation was poor eyesight, there was one case each of rheumatic heart, a stiff wrist, and one leg slightly over one inch longer than the other. In all, fifty-six people participated in the experiment.

The average length of time for an individual to complete the sequence was forty-five minutes. Some were able to finish in as short a time as half an hour while a few took nearly an hour. Generally the subjects were run through in pairs and the typical time period for this was two hours, including a five minute rest break during the experiment. The typical experiment followed this sequence. Volunteers were requested to participate in a technical theatre experiment which involved some climbing and light manual labor. The anticipated time required was stated as approximately one hour. Those interested were assigned a time to report to the experiment area. Upon arrival they were given a simple personal data form to fill out. This form recorded their age, sex, height, weight, physical limitations, and experience level. The experience level was rated as either: (A) no prior theatrical experience; (B) minimum experience—had been associated with
I - Total number of participants
II - Number of men
III - Number of women

FIGURE 13

NUMBER OF PARTICIPANTS ACCORDING TO SEX
theatrical productions but had no technical experience; (C) some experience—had done some theatrical lighting work; (D) experienced—capable of doing theatrical lighting tasks without direct supervision. Twenty-six participants (46.5 per cent) were in the A category, ten participants (18 per cent) were in the B category, sixteen participants (28.5 per cent) were in the C category, and four participants (7 per cent) were in the D category.

Figure 14 shows the breakdown by experience level.

Then they were told that they were participating in a project which was examining the size of walkway and mounting pipe height for arena theatre lighting grids.

The explanation was standardized and was given as follows:

This is an experiment to determine the walkway width and instrument mounting pipe height for arena theatre lighting grids. During the course of the experiment you will be asked to perform typical lighting tasks on this mock-up of a grid section. These tasks consist of mounting, aiming, and removing these two lighting instruments on the mock-up. These instruments are standard lighting instruments used in theatrical lighting: one is a 500 watt, six inch Fresnel, and the other is a six inch ellipsoidal spotlight. I will now demonstrate how to mount, aim, and remove them. (DEMONSTRATION)

You will work on three different walkway widths and at each width you will have three different pipe heights to use. At the end of the experiment you will be asked to answer four subjective questions pertaining to your evaluation of the various combinations so please try to make some sort of mental note at the end of each sequence. Also, remember that this is not a test to see how far you can go, so if at any time you encounter a combination on which you would rather not work, feel free to say so as this is one of the aspects in which we are interested. The first setting
FIGURE 14

EXPERIENCE LEVEL OF PARTICIPANTS

A - No experience
B - Minimum experience
C - Some experience
D - Experienced
you will work on is an eighteen inch wide walkway with the mounting pipe thirty inches above the walk.

Even though the participants were encouraged to discontinue the experiment at any time that they felt apprehensive about the spatial conditions, only eight of the fifty-eight failed to complete the entire sequence and all of these went as far as the twelve inch wide walkway and zero pipe height. Four of the eight attempted the nine inch width and thirty inch pipe height before stopping. Several requested and were permitted to work on the six inch wide walkway and indicated that they felt it was practical, although these results are not reported in the statistics since the purpose of the experiment was to determine a set of usable dimensions for a majority of users, and the small number able to use the six inch wide walkway was not significant to the study. After the experiment, the subjects were asked to answer the following four questions pertaining to their reaction to the various combinations:

1. Minimum walkway width at which you can work practically?
2. Minimum pipe height at which you can work practically?
3. Minimum combination of pipe height and walkway width at which you can work practically?
4. Combination of walkway width and pipe height at which you would prefer to work?

The results of the questionnaire are depicted in the following figures which show the reaction or evaluation
for the group as a whole, according to sex, and according to experience level.

The first space considered in the questionnaire was minimum walkway width. As shown in Figure 15, thirty-four of the fifty-eight participants (60.7 per cent) felt that they were able to work effectively on a nine inch wide walkway. Sixteen of the group (28.6 per cent) said that they needed at least a twelve inch wide walkway for effective movement. The remaining six people (10.7 per cent) were unable to work on a width of less than eighteen inches.

Figure 16 shows how these responses break down according to sex. All of the women were able to work on a width of twelve inches or less. Fourteen of the eighteen women (77.7 per cent) could use the nine inch walkway while the remaining four (22.3 per cent) stopped at the twelve inch width.

Six of the thirty-eight men (15.8 per cent) indicated that they needed a minimum eighteen inch wide walkway. Ten men (26.4 per cent) stopped at the twelve inch width, while twenty-two of the men (57.8 per cent) were able to use the nine inch walkway width.

An analysis of the responses to question one according to experience level, depicted in Figure 17, shows that of the twenty-six people in Group A (no experience) two (7.5 per cent) needed the eighteen inch width, six
FIGURE 15

RESPONSES TO QUESTION NUMBER ONE, MINIMUM WALKWAY WIDTH AT WHICH YOU CAN WORK PRACTICALLY
FIGURE 16

RESPONSES ACCORDING TO SEX TO QUESTION NUMBER ONE, MINIMUM PRACTICAL WALKWAY WIDTH
FIGURE 17

RESPONSES ACCORDING TO EXPERIENCE TO
QUESTION NUMBER ONE, MINIMUM
PRACTICAL WALKWAY WIDTH
(23 per cent) required a twelve inch width, and eighteen (69.5 per cent) were able to use the nine inch width. In Group B (minimum experience) none needed the eighteen inch width, two (20 per cent) required a twelve inch width, and eight (80 per cent) indicated the nine inch width. Group C (some experience) contained four people (25 per cent) who felt that they needed the eighteen inch width, four (25 per cent) who required a twelve inch width, and eight (50 per cent) who indicated the nine inch width. All four people (100 per cent) in Group D (experienced) selected the twelve inch wide walkway.

According to these results one could anticipate that with a walkway width of twelve inches, 90 per cent of the potential users would be able to move about freely and work efficiently regardless of their sex or prior experience.

In question two the participants were requested to record the minimum mounting pipe height at which they felt that they could work practically. As shown in Figure 18, eight (14 per cent) of the total group indicated that they felt that a thirty inch high pipe was necessary. Twenty-eight (50 per cent) indicated the fifteen inch high pipe, while the remaining twenty (36 per cent) said that they could work effectively with the pipe at the same height as the walkway.
FIGURE 18

TOTAL RESPONSE TO QUESTION NUMBER TWO, MINIMUM PRACTICAL PIPE HEIGHT
Once again sex or experience level did not seem to have a major effect on the choices. Figure 19 depicts the choices according to sex. Two women and six men desired a thirty inch high pipe. Eight women and twenty men chose the fifteen inch high pipe. Eight women and twelve men believed that the pipe at the walkway level was satisfactory.

Figure 20 shows the minimum selection height according to the experience levels. In Group A (no experience) four people (15 per cent) desired the thirty inch high pipe, fourteen (54 per cent) preferred the fifteen inch high position, and eight (31 per cent) were able to use the level position. Of the ten people in Group B (minimum experience), four (40 per cent) selected the fifteen inch height, and six (60 per cent) selected the level position. In Group C (some experience) four participants (25 per cent) chose the thirty inch height, eight (50 per cent) chose the fifteen inch height, and four (25 per cent) chose the level position. The four people in Group D (experienced) all indicated that they felt that the fifteen inch height was the most practical.¹

¹Personal experience and observation of the participants leads this writer to surmise that the participants with previous experience chose the fifteen and thirty inch pipe height on the basis of their experience in working in a variety of conditions, rather than their physical or psychological inability to use the lowest pipe height.
FIGURE 19

RESPONSES ACCORDING TO SEX TO QUESTION NUMBER TWO, MINIMUM PRACTICAL PIPE HEIGHT
FIGURE 20

RESPONSES ACCORDING TO EXPERIENCE TO QUESTION NUMBER TWO, MINIMUM PIPE HEIGHT
According to these results, one could expect that a mounting pipe height of fifteen inches would be practical for approximately 90 per cent of the potential users regardless of their sex or prior experience.

In question three the participants were asked to consider the walkway width and mounting pipe height in combination and indicate what they considered the minimum width and height combination at which they could work. As shown in Figure 21, twenty people (35 per cent) indicated a nine inch wide walkway with a pipe level with the walkway, fourteen (25 per cent) indicated a nine inch walkway with a fifteen inch high pipe, and two (3.5 per cent) indicated the nine inch walkway with a thirty inch pipe height. Sixteen of the participants selected a twelve inch wide walkway. Twelve (21.5 per cent) preferred a fifteen inch high pipe while two (3.5 per cent) indicated a level pipe, and two (3.5 per cent) indicated the thirty inch high pipe. Four people wanted an eighteen inch wide walkway, two (3.5 per cent) desiring a thirty inch high pipe and two (3.5 per cent) desiring a fifteen inch high pipe. As shown in Figures 22 and 23, the factors of sex and experience again do not seem to vary significantly. Approximately 90 per cent of the group stated that they believed that they could work effectively on a walkway that was at the maximum twelve inches wide with a pipe fifteen inches high.
TOTAL RESPONSES TO QUESTION NUMBER THREE,
MINIMUM COMBINATION OF WALKWAY WIDTH
AND PIPE HEIGHT
FIGURE 22

RESPONSES ACCORDING TO SEX TO QUESTION NUMBER THREE, MINIMUM COMBINATION OF WALKWAY WIDTH AND PIPE HEIGHT
FIGURE 23

RESPONSES ACCORDING TO EXPERIENCE TO QUESTION NUMBER THREE, MINIMUM COMBINATION OF WALKWAY WIDTH AND PIPE HEIGHT
For the final question the participants were asked to indicate what combination of walkway width and pipe height they thought was most practical. The results for the entire group are shown in Figure 24. The most preferred combination was the twelve inch wide walkway with a fifteen inch pipe height. Eighteen people (32 per cent) selected this configuration. Running a close second was the twelve inch wide walkway with the thirty inch high pipe, selected by fourteen (25 per cent) of the group. The rest of the combinations received about equal preference. Six people (10.5 per cent) wanted an eighteen inch walkway with a thirty inch pipe, four (6.5 per cent) chose the eighteen inch walkway with the fifteen inch high pipe, and four people (6.5 per cent) indicated the twelve inch wide walkway with a level pipe. Ten people preferred the nine inch walkway. Four (6.5 per cent) like the pipe level, four (6.5 per cent) liked the pipe at fifteen inches, and two (3.5 per cent) wanted it thirty inches high. The responses according to sex and level of experience, shown in Figures 25 and 26, again reflect the same proportions as the breakdown of the responses for the entire group.

As shown by the results of this experiment, a walkway grid system for an arena theatre which has a twelve inch wide walking surface and mounting pipes fifteen inches above the level of the walkway would be satisfactory for
FIGURE 24

TOTAL RESPONSES TO QUESTION NUMBER FOUR,
PREFERRED COMBINATION OF WALKWAY WIDTH AND PIPE HEIGHT
FIGURE 25

RESPONSES ACCORDING TO SEX TO QUESTION NUMBER FOUR, PREFERRED COMBINATION OF WALKWAY WIDTH AND PIPE HEIGHT
FIGURE 26

RESPONSES ACCORDING TO EXPERIENCE TO QUESTION NUMBER FOUR, PREFERRED COMBINATION OF WALKWAY WIDTH AND PIPE HEIGHT
almost any potential worker. If desirable, there is the possibility that either the walkway width could be decreased or the mounting pipe height lowered without drastically limiting the practicality of the arrangement. The minimum limits suggested by the survey are a nine inch wide walkway with the pipe at walkway level and three to six inches away from the walkway.
In this chapter the problems of lighting grid and instrument masking will be considered. The discussion will include the reasons for and against masking with particular attention to the problem of glare, and the use of louvres as a masking device.

Heretofore, masking has been used primarily to hide or disguise the grid, cabling, and instruments. Attempts to provide masking in some of the early arena theatres resulted in instrument aiming and/or placement restrictions or masking which was of limited effectiveness. These problems caused many designers and technicians to abandon direct attempts to mask in order to obtain fuller flexibility in lighting design. The Penthouse Theatre was one of the first planned arena theatres which incorporated a form of masking.¹ This consisted of a domed false ceiling with portholes cut for the instruments. With this system the lighting positions had to be planned carefully before construction of the building. Once completed, the design limited the use of additional instruments to specific

lighting design techniques. Another well-known theatre designed to use masking is the Ring Theatre at the University of Miami. This theatre utilizes the louvre or egg crate method. The grid is divided into four foot squares with suspended plywood panels four feet deep. This provides adequate masking, but the depth of the louvres severely inhibits beam angle range causing most instruments to be aimed nearly straight down.

More recently, some authorities have stated that grid masking is not necessary. Rubin and Watson point out that having lighting instruments in sight of the audience is not unusual or unacceptable since lighting instruments are frequently mounted on balconies, on "lighting trees" next to the proscenium, or on the walls of proscenium theatres. The architects of the Arena Stage in Washington go even further by proposing that the lighting grid and instruments are a part of the frank theatricality of the arena form and should not be masked.

2"Ring Around the Stage, University of Miami," Popular Mechanics, CXII, No. 6 (December, 1959), 106-107.


4Chicago Sunday Sun Times, December 10, 1961, sec. 3, p. 1. This attitude assumes, of course, that the whole structure was designed for theatricality.
Nevertheless, the lighting grid is the largest single architectural feature of an arena theatre, and as such can unnecessarily dominate the theatre unless it is made a balanced, unified part of the design, either through grid design techniques or through the use of masking. An examination of some of the newer theatres indicates that this problem may be resolving itself through some of the newer grid design approaches, such as the I-beam and masonite panel grid at Theatre St. Paul, the channel iron grid at the Loeb Studio Theatre, and the grid cloud system at the Macalester College Theatre. However, the problem of glare, which requires the use of masking, remains unsolved.

Glare is any brightness within the field of vision which causes discomfort, interference with vision, or eye fatigue. Glare effect cannot be measured easily since it is in some part a subjective reaction to a set of physical circumstances and the quality of the viewer's vision. Generally, the more defective the viewer's vision, the more acute the glare effect will be. Since over two out of every three Americans have a vision defect severe enough to require correction, the problem of glare merits consideration in terms of audience comfort.5 Extreme glare can

cause definite physical discomfort to members of the theatre audience, and even minimum glare will compete with the performance for the audience's attention.

Glare is usually caused by one or more of the following factors:

1. High brightness of source.
2. High contrast between source and background.
3. Location of source in field of view.
4. Total volume of light entering the eye.
5. Time of exposure to the source.6

The first two factors obviously exist in arena theatre since the lighting instruments are usually spot-lights varying in power from two hundred and fifty to as much as one thousand watts. This intensity is further emphasized since the space above the grid is dark during the performance, thus making the bright source more apparent. Even if the source is not aimed directly at the viewer, these bright spots can cause interference with vision or at least cause minor distraction according to the location in the viewer's field of vision.

The normal field of vision enables an individual to perceive objects up to sixty degrees above the direct line of sight. Experiments have shown that serious glare problems result if the source is thirty degrees or lower

above the line of sight\textsuperscript{7} and that glare problems can occur if the source is within a forty-five degree angle of the vertical line of sight.\textsuperscript{8} How this situation affects arena theatres is shown in Figures 27 and 28. In Figure 27 we have a hypothetical situation using a sixteen foot high source level and sources mounted fifteen, twenty, twenty-five, thirty, and thirty-five feet from the viewer. This is not an uncommon height for arena grids, and the distances cover a span commonly found under such circumstances. As can be seen in the figure, only the instrument located at fifteen foot plan distance from the viewer has an angle exceeding the critical thirty degrees. The others, in order of increasing distance, have angles of twenty-nine degrees, twenty-four degrees and seventeen degrees above the line of sight. The angles for this example were measured assuming a horizontal line of sight. Actually, the eyes of the first row patrons, looking at standing actors, are focused above the horizontal plane, thus decreasing the vertical angle between the beam source and the sight line.

In Figure 28 a higher source level of twenty-five feet above the stage is illustrated. This represents what


\textsuperscript{8}Kraehenbuehl, p. 56.
VERTICAL SIGHT LINE ANGLE TO LIGHT SOURCES 15 FEET HIGH

FIGURE 27
FIGURE 28

VERTICAL SIGHT LINE ANGLE TO LIGHT SOURCES 25 FEET HIGH
seems to be about the maximum grid height presently used in the newer arena theatres. The same horizontal distances from eye point to source are used in this example. With the increase of nine feet in source height, the angle increases significantly. All the instruments except the one at thirty-five foot distance are above the critical thirty degree angle, and the thirty-five foot distant source is at thirty degrees. The sources at fifteen foot and twenty foot distance are above the forty-five degree angle. The source at twenty-five feet has an angle of forty degrees, and the source at thirty feet has a thirty-four degree angle. From these figures it can be seen that grid height has a direct relation to source position in the line of vision, and that by raising the grid, the glare effect can be partially minimized.

The total volume of light entering the eye can also cause glare. However, excessive volume of light rarely occurs in arena theatre staging. Therefore, the problem of light volume is not a direct consideration in this investigation.

Finally, glare can have a cumulative effect depending upon the time of exposure to the source. A glare condition that may be tolerable for a short period of time, such as ten minutes, may eventually impinge on comfort and vision over a two hour performance time. This makes one wonder if occasionally the headaches or other forms of
discomfort some audience members experience after leaving the theatre might be as much a result of a threshold glare problem as the fault of the script, the performers, or an atmospheric (temperature or humidity) problem.

If a form of masking can be used which effectively limits glare without unduly restricting instrument placement and aiming, it would seem to be a worthwhile adjunct to the grid design. Masking schemes have usually been based on the use of some form of false ceiling, that is, a ceiling below the actual room ceiling. There have been three basic types. First is the solid false ceiling with permanent apertures or portholes through which the instruments can be aimed. An example of this type is in the previously mentioned Penthouse Theatre. As noted before, this system requires that all potential mounting positions be designated before the construction of the theatre. This method is successful in concealing mounting and mounting space, but because the instrument fronts must be mounted at or below the false ceiling, the method is unsuccessful in preventing glare.

A second approach uses a false ceiling with removable sections. These sections can be porthole-shaped, six to eight inches in diameter, or larger panels of the

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Another type of masking scheme could employ specially designed telescopic funnels for each instrument.
ceiling, for example, four foot by four foot squares. The Theatre St. Paul had planned to use this technique as mentioned in Chapter I, but perhaps a better example of this system is the Antioch College Theatre in Yellow Springs, Ohio. In this theatre the entire false ceiling of the theatre room, a former foundry, is covered by removable plywood sections four feet square. Depending upon the lighting design requirements, the appropriate panels are removed to permit instrument aiming. This method, like the one previously described, is primarily effective in masking the grid work and has little value for inhibiting glare.

The third masking scheme, which seems to have the most potential for reducing glare, is the louvre or egg crate grid. Here, too, there are problems in flexibility of aiming and instrument placement as opposed to complete masking. The use of too deep a louvre in proportion to the horizontal louvre module, as at the Ring Theatre, will impose unacceptable vertical beam angles for lighting. On the other hand, if the louvres are not deep enough, the masking will be incomplete. This, then, is the dilemma of the louvred grid, how to provide louvres deep enough to mask without imposing impractical restrictions on instrument aiming and placement.

The problem is solvable, but only through careful observance of certain design criteria and some minor
adjustments to the vertical aiming angles. The major factors involved in the design scheme are a maximum height for the light source, a minimum height for the light source, an acceptable louvre depth, the horizontal spacing of the louvre sections, and the size of the lighting areas. Each of these independent factors will affect and will be affected by the others, and each also determines certain requirements for the design.

As previously stated, in arriving at basic grid design criteria, the height of the grid can be influenced by the dimensions of the theatre room, the size of the lighting area, and the type of lighting instrument used. Now we must consider the effect of grid height as related to vertical sight lines. The vertical sight line angle is important because as the angle increases, the depth of the louvre needed to provide masking increases. This is depicted in the following series of figures which show the louvre depth necessary to provide masking for sources located at heights of fifteen, twenty, and twenty-five foot heights and at a horizontal plane distance in five foot increments of from fifteen to forty feet from the viewer. The horizontal distance from the source to the louvre is eight feet. This distance was arbitrarily selected as a typical or reasonable separation between louvres.

In Figure 29, which shows the twenty-five foot high source, we can see that the louvre depth necessary
FIGURE 29

MASKING DEPTH REQUIRED WITH LIGHT SOURCE 25 FEET HIGH AND LOUVRE 8 FEET FROM SOURCE
for masking the sources is extreme. A source twenty feet from the viewer needs a masking depth of eight feet, at thirty foot distance the depth is five feet, six inches, and at forty foot distance the depth is four feet. The four foot depth is barely usable but the five and one-half and eight foot depths are impractical since masking at this depth would cut off a portion of the spotlight beam. As shown in Figure 30, a light source with standard beam divergence (approximately one foot of spread for two feet of throw) has to be aimed at a steeper than forty-five degree vertical angle to clear the five foot, six inch masking depth, while the forty-five degree angled beam barely clears the four foot depth. Obviously, an eight foot depth would be completely impractical.

Figure 31 shows the masking depth necessary for a source located at a twenty foot elevation, using the same distances as above. By lowering the source height five feet, the required masking depth diminishes noticeably, but still not enough to be practical. The depth needed at twenty feet is six feet, at thirty feet the depth is three feet, ten inches, while at forty feet the depth is three feet. Since a majority of the instruments which would cause glare would probably be between twenty and thirty feet away from the first row seats, the necessary masking depth is still too much to be usable. As shown in Figure 30, a depth of four feet at an eight foot separation
FIGURE 30

INTERFERENCE WITH LIGHT BEAM FROM AN INSTRUMENT AIMED AT A 45° VERTICAL ANGLE BY A LOUVRE 8 FEET FROM THE SOURCE AND OVER 4 FEET DEEP
FIGURE 31

MASKING DEPTH REQUIRED WITH LIGHT SOURCE 25 FEET HIGH AND THE LOUVRE 8 FEET FROM SOURCE
is barely practical for a beam aimed at a forty-five degree vertical angle. If the modules were eight feet by eight feet, the distance from the source to a louvre in line with a sight line could be as much as twelve feet (the diagonal distance within the grid module), necessitating even deeper masking. On the other hand, if the maximum distance across the module were eight feet, then the module would have to be slightly less than six feet square. Again referring to Figure 30, we can see that a four foot depth with six feet of separation interrupts a forty-five degree vertical beam.

In Figure 32 we set up the problem using a fifteen foot high source and the same separation distances as used in the previous examples. The depth needed at twenty feet is four feet, still excessive, but it lessens to two feet, nine inches at thirty feet, and to two feet at forty feet distance. Thus we can see that the lowest reasonable beam source height should be used in designing a grid with louvre masking.

There are certain factors which restrict how low the source can be placed. First, an aesthetic limitation prevents us from using less than about twelve feet without restricting the vertical space of the stage area, making the playing area seem compressed. In addition, a height of less than twelve feet would restrict the height of levels and scenic units which could be used. Then too, we must
FIGURE 32

MASKING DEPTH REQUIRED WITH LIGHT SOURCE 15 FEET HIGH AND THE LOUvre 8 FEET FROM SOURCE
consider the rise of the seating. In a small theatre with only three rows, the bottom of the louvres would probably not be a factor. However, in large theatres, especially if the seating rise is a foot per row, grid and louvre height must be a consideration. For example, if we had a theatre with six rows, rising a foot for each row, and a fifteen foot high light source with a three foot louvre depth, there would be only a six foot distance from the floor of the sixth row to the bottom of the louvres. Therefore, to use louvres in a larger arena theatre, we must either use a higher source height, or lessen the seating rise. Finally, and most important, we must be concerned with the amount of beam spread possible with the lower light source heights. If we figure the spread according to the standard divergency of two feet of throw for one foot of beam spread, and place the center of the lighting area five feet, six inches above the floor, we find that a source at a fifteen foot height will have a beam width of approximately seven feet. This means that the lighting area would be approximately five to six feet square. If the source height were seventeen feet, the area could be from six to seven feet square. Therefore, the lowest practical source height is fifteen feet, to ensure an adequate-sized lighting area, while the maximum height should not exceed seventeen feet, to eliminate the
necessity of excessive masking depth caused by the vertical sight lines.

As shown earlier, the required depth of the masking is affected by the degree of vertical sight line. The depth is also directly related to the distance of the masking from the light source. To find the minimum practical depth for the masking we must consider both factors. The masking depth, of course, should be as small as possible to prevent interfering with aiming and placement of the lighting instrument. Figure 33 shows the masking depth required at one foot intervals from three to eight feet from the instrument where a source is fifteen feet high and twenty feet from the viewer. At three feet separation the masking depth is one and one-half feet, and increases one-half foot in depth for every additional foot of separation until at eight feet the depth is four feet. Figure 33 also shows the depths required for the same separations if the source is located at thirty and forty feet away from the viewing point. According to the figure, the three foot masking depth required for a six foot separation with source twenty feet in horizontal plane distance from the viewing point is also sufficient to provide masking at over eight feet of separation when the source is thirty and forty feet from the viewing point.

The six and eight foot dimensions are significant because the diagonal of a six foot square is slightly over
FIGURE 33

MASKING DEPTH REQUIRED WITH LIGHT SOURCE 15 FEET HIGH AND THE LOUVER 3 TO 8 FEET FROM SOURCE
eight feet long. Thus, if a three foot masking depth is practical, which is shown in Figure 34, we have determined a basic grid module of six feet by six feet which will allow masking and also permit flexibility of lighting instrument and aiming.

In Figure 34 we have a top and side view of the six foot by six foot module with a three foot masking depth. The side view shows that the top edge of a forty-five degree vertical beam, with standard divergence, aimed from the edge of the module will intersect the bottom of the masking one foot from the opposite side. Therefore, the angled beam needs five feet of horizontal distance to avoid interference from the masking. We see in the top view that an instrument can be aimed straight across the module from almost any position without interference from the masking (the exception being that if it is aimed parallel with the masking, there will be interference from the masking if the instrument is closer than fifteen inches to the parallel section), and that if the instrument is aimed across the module at a forty-five degree diagonal, it can move to within six inches of the center of a side before there is interference from the masking.\(^{10}\) If it is desirable to

\(^{10}\) Therefore, a grid with louvre masking should be oriented in line with the seating sections so that the grid diagonals will be aligned with the horizontal lighting angles, thus giving maximum aiming flexibility.
FIGURE 34

TOP AND SIDE VIEW OF LOUvre
MODULE 6 FEET WIDE AND 3
FEET DEEP SHOWING
LIGHT BEAM
CLEARANCE
mount the instrument in a position beyond the point of masking interference to obtain the necessary horizontal angle, the instrument may be moved to the adjacent side of the module on the horizontal aiming angle. Although this will make the vertical aiming angle somewhat steeper, it will still be less than sixty degrees and acceptable since the maximum deviation from the ideal mounting position will be less than five feet. This deviation from the ideal is within reasonable limits. Therefore, a masking depth of three feet in conjunction with a six foot square grid, masking module is practical in terms of both masking and lighting design flexibility.

We have now determined the basic criteria for the louvred grid. The grid should be high enough to permit a light source height of from fifteen to seventeen feet, the modules should be approximately six feet square, and the depth of the louvres from the source height should be approximately three feet. The next step is to determine a stage configuration which will conform to these criteria. This brings us to the effect of stage and lighting area size upon the grid design. The horizontal grid sections are determined by the size of the areas and the height of the light source. The difference of a foot in grid height or area size may make a difference of as much as two feet in spacing of the grid sections. This may not seem sizable, but when the tolerances for effective masking and
flexibility can be as little as three inches, these variances are critical. After much experimentation by trial and error, a stage based on six foot square lighting areas was found to be most practical. This may seem to be a case of putting the cart before the horse by first examining and determining the requirements of the grid and masking units and then designing a stage to fit them instead of starting with a playing area and fitting the louvred grid to it. The latter method was initially attempted; however, it readily became apparent that the complexities of devising a practical masking system dictated that the physical requirements of such a system needed to be explored and catalogued to determine if the system could be devised. In short, by starting with the stage, we found many things that would not work, and therefore turned to an investigation of what would or could work in hopes of then being able to fit them to a stage. This was accomplished and Figure 35 depicts the plan for an arena theatre stage and lighting grid which affords complete beam source masking for all members of the audience.

The stage is eighteen feet wide and twenty-four feet long. It is divided into twelve lighting areas of six by six feet. The front seating sections are raised a foot above the stage level and removed five feet from the edge of the playing area. This seating separation is important for the effectiveness of the masking. If the first row of
FIGURE 35

HORIZONTAL PLAN FOR LOUVRED GRID
seating is lower or nearer the playing area, the masking will be ineffective. The grid is fourteen feet, three inches above the stage level, giving a light source height of fifteen feet. The nine inch level was arrived at by measuring the distance from the mounting pipe to the center of the lens on a variety of lighting instruments "roost-ered" and aimed at a forty-five degree angle. The louvres are twenty-four inches deep, giving a masking depth of two feet, nine inches. The grid modules are five and six feet square.

The grid spacing was initially set up to give the ideal forty-five degree vertical and horizontal angles for a seventeen foot high light source. However, this did not provide complete masking for all seats in the first row. When the grid was lowered to give a fifteen foot high source, the resultant grid module shift was not satisfactory. Therefore, the grid was dropped to give the fifteen foot high light source, but retained the spacing for the seventeen foot high design. This shift alters the vertical beam angle slightly, from forty-five degrees to thirty-nine degrees if the beam is aimed directly at the center of the lighting area. However, one may take advantage of a physical peculiarity of a divergent beam aimed on an angle, and the even intensity of light given by a Fresnel spot-light, to use a vertical aiming angle of forty-two degrees. This effect is shown in Figure 36. If the center of the
FIGURE 36

EFFECT OF VERTICAL AIMING ANGLES OF 39°, 42°, and 45°
beam is aimed at the center of the area, five feet, six inches above the stage level, the vertical beam angle is thirty-nine degrees. Moreover, the upper part of the beam is about three feet above the far edge of the area. By aiming the beam four feet above the stage level, we make the beam more nearly conform to the lighting area.

The five foot square modules in the center sections running laterally and longitudinally do not present an instrument aiming problem since the decrease in separation from source to masking allowed the masking depth to be decreased from three feet to the two feet, nine inches which was used throughout.

A mock-up of a module section was constructed and set up to check the masking effectiveness for the various sight line angles, with the intention of taking photographs of the results. Fortunately, however, the masking was so effective that the instruments were completely concealed and photography would not have revealed them.

We did prove though that a louvred grid system which combines satisfactory masking techniques with adequate lighting design flexibility can be constructed. However, to be successful, it must adhere closely to the physical criteria outlined above. Though these criteria might be considered limiting in theatre design, they are certainly not limiting in theatre use.
CHAPTER V

A LIGHTING GRID DESIGN FOR ARENA THEATRE

In the preceding three chapters we have discussed three separate, but related, aspects of arena theatre lighting grid design. We have shown how to determine lighting instrument location and grid module to obtain ideal lighting angles for even illumination of the stage areas, suggested possible dimensions for walkways which would provide access from grid level to the instruments for aiming and maintenance, and demonstrated the practicality of a louvre masking system. In this chapter we will propose a sample grid system which contains all these features.

A well-designed and effective lighting grid is an integral part of the arena theatre room and the physical requirements for the grid should be considered as important as the stage and seating requirements when planning an arena theatre. This emphasis on lighting is explained by the fact that lighting as technical device is relatively more important in arena theatre than in conventional proscenium theatre since the use of conventional scenery is limited by the inherent sight lines and viewing angles present in the arena form. Moreover, the physical
characteristics of the stage, seating area, and grid, as will be shown, are interrelated. Therefore, to achieve the most satisfactory synthesis of auditorium, stage, and lighting, it is essential to include a consideration of lighting (i.e., the lighting grid) when determining the basic theatre configuration.

For this example of the proposed grid scheme we shall assume that there are no external limitations on the theatre room. The theatre shall be a medium-sized (200-400 seats), four-sided arena, and the lighting facilities shall include provision for illumination of the central and entrance playing areas, safe, convenient access to the instruments from grid level, and masking of glare by louvres. These are our design objectives. To achieve them we must determine which aspect or aspects are most limited in characteristics.

In this case the use of louvre masking acts as the initial space determinant since, as we found in Chapter IV, it requires a stage based on lighting areas of six foot increments. Therefore, we have a choice of the following proportions for the stage area: eighteen by eighteen feet, eighteen by twenty-four feet, eighteen by thirty feet, twenty-four by twenty-four feet, twenty-four by thirty feet, and thirty by thirty feet. A twenty-four by twenty-four foot stage area has been selected for this example. The dimensions of the entrance areas are related to the
arrangement of the seating areas so we will now proceed to complete the basic floor plan of the theatre room as shown in Figure 37.

To ensure satisfactory masking and elimination of spill, the first seating row should be removed five feet from the edge and elevated one foot above the level of the playing area. Each row is thirty-six inches deep, two inches more than the minimum thirty-four inches considered necessary for audience comfort.\(^1\) The first row of seating is seventeen feet from the center of the stage, not so far as to cause concern about lack of intimacy through distance. The short row depth is used to prevent increased distance from affecting the audience-performance intimacy for patrons in succeeding rows.

The seating areas are parallel to the side of the playing area, and the same length (twenty-four feet) as the stage sides. This gives good lateral sight lines, and also eliminates the problem of arranging a seating plan to go around the corners of the stage and room. Using this method, the space at the corner between the adjacent seating sections can be used as an entrance to the room and the stage.

FIGURE 37

FLOOR PLAN OF THEATRE ROOM
The seating capacity for the theatre is determined by the width of the seats and the number of rows in each seating section. In this example we have allowed twenty-four inches per seat\(^2\) plus four feet for aisle space, giving a capacity of ten seats per row, per section. The capacity for this theatre can be from eighty (two rows) to four hundred (ten rows) seats. For this proposal we have elected to use five rows with a total of two hundred seats.

Having determined the basic stage and seating arrangement, we can now establish the size and location of the entrance lighting-playing areas. The seven foot width between the adjacent seating sections sets an initial maximum width limitation. The length of the area out from the stage is limited by sight line considerations. Ideally, the area would extend only to a line drawn between the on-stage corners of the adjacent front seating rows, assuring adequate sight lines to the area for all spectators. However, this line is only four feet from the corner of the playing area, making the entrance area a bit too short to be practical. A reasonable compromise might be to extend the length two feet and use a lighting-playing area of the

\(^2\)Normally, theatre seats are from eighteen to twenty-two inches wide. This extra width gained by allowing twenty-four inches per seat provides two arm rests per patron. Using the narrower spacing the capacity can be increased to 12 (20") to 14 (18") per row.
same size, six by six feet, as is used on the central playing area.

The proximity of the entrance areas to the seating sections, only six inches at the nearest point, can result in beam spill problems in the seating sections. There are several ways to avoid this. The seating aisles should be placed at the ends of the rows, moving seated spectators from the most direct spill zones. The amount of spill can be minimized by aiming the instruments at a steeper than ideal angle (not to exceed sixty degrees) and aiming the two side instruments parallel to the seating sections as shown in Figure 38. Other less desirable solutions would be to remove those parts of the seating sections which fall in the spill area, make the entrance area narrower, use vertical beam angles of steeper than sixty degrees, move the fronts of the seating sections further from the playing area, or light the area with only two instruments, one aimed directly off-stage and the other aimed directly on-stage.

We have now determined the basic floor plan of the theatre room. As shown in Figure 37, the overall room is sixty-four by sixty-four feet. The stage area is twenty-four by twenty-four feet with an entrance area at each corner extending six feet beyond the corner of the square. The seating areas are parallel to and five feet from the playing area. Each section is twenty-four feet long and
FIGURE 38

LOCATION OF LIGHTING INSTRUMENTS FOR THE ENTRANCE AREAS
fifteen feet deep, consisting of five, three foot deep rows.

The lighting grid is, or should be, even more significant in determining the height of the theatre room. The grid must be at the correct height to provide the proper beam angles and beam spread for the desired lighting areas and the ceiling of the room should be high enough above the grid to allow erect travel by the technicians on the grid walkways, approximately six feet, six inches of clear space. Once again the use of the louvre masking provides the starting point for determining grid and room height.

As we found in Chapter IV, the best arrangement for satisfactory masking uses a source height of fifteen feet with the instruments placed according to modules derived from a seventeen foot source height. This combination provides a satisfactory vertical beam angle and a module-louvre dimension which allows flexibility in aiming and effective masking.

Using these dimensions and the techniques described in Chapter II, we can plot and determine the basic instrument positions and grid configuration. As shown in Figure 39, a source seventeen feet high and aimed at a forty-five degree angle to a point five feet, six inches above the stage floor has a horizontal distance of twelve feet from the source to the point. By dropping the source
FIGURE 39

ADJUSTMENT OF LIGHT SOURCE HEIGHT
height to fifteen feet while retaining the twelve foot horizontal separation, the vertical beam angle changes to forty degrees and the slant range distance is fifteen feet, three inches. These increments are sufficient to provide acceptable illumination for a six foot square lighting area.

The locations of the lighting instruments are determined, as shown in Figure 40, by extending diagonal lines on the horizontal plane at angles of forty-five, one hundred and thirty-five, two hundred and twenty-five, and three hundred and fifteen degrees from the base line through the center of the area. The point on these lines which is twelve feet from the center of the area represents the instrument position at the source height. The basic grid configuration is derived from the lateral and longitudinal lines which connect the instrument location points. This grid has external dimensions of thirty-five by thirty-five feet. The grid modules are six by six feet, six by five feet, and five by five feet as shown in Figure 40.

The lighting instruments for the entrance areas can be positioned using these modules, as shown in Figure 38. With the instruments in the positions shown, the vertical beam angle is fifty degrees. There is some light spill on the aisles of the seating sections, but it can be framed off the audience if ellipsoidal spotlights are used. The
FIGURE 40

BASIC INSTRUMENT LOCATIONS AND GRID MODULES
beam sources are masked from the audience by the grid louvres.

Thus far we have dealt with height strictly in terms of the source height. The other factors in grid height choice are the mounting pipe height, height of the walkway level and the masking depth. The mounting pipe height is dependent upon the method of instrument mounting, that is, whether the instruments are hung from or "roost-ered" above the pipe. The choice of mounting method in this case is based upon the physical characteristics of the walkway system.

The experiment in Chapter III showed that most of the participants preferred a twelve inch wide walkway with the mounting pipe three inches from the walkway and fifteen inches above the walkway level. The results also suggested an alternative dimension of nine inches for the walkway width, providing that there was a handrail or stabilizing device, and an alternate mounting pipe height level with the walkway. The next step is to lay out the pattern of the walkway system, according to the above dimensions, without dislocating the planned instrument locations, and providing access to all parts of the grid.

To start, we place a three foot wide walkway around the perimeter of the grid. Access to this walkway is via a three foot wide bridge from the side wall of the room to the grid at grid level. Ideally, this bridge would be
reached by a hall or staircase outside the theatre room, although a ladder on the wall of the theatre room could be substituted if necessary because of space or financial restrictions. The three foot width allows workers to pass each other and also serves as a transition area where novices can establish confidence before moving to the interior walkways. Next, we determine where walkways can be placed to extend the full length or width of the grid. Figure 41 shows that there are two natural paths which bisect the grid in perpendicular opposite directions. The space between the opposite instruments, outlining the paths, is twelve inches. This space is too narrow to permit the use of a twelve inch wide walkway with the mounting pipes three inches from it. However, the space is practical if we use a nine inch width and move the instrument positions on each side one and one-half inches. This shift is not enough to cause an undesirable shift in vertical beam angle or module size.

There is also space for two more full length walkways. Since the grid is symmetrical, the walkways can run either laterally or longitudinally along the outsides of the second and seventh pipes. These and the remaining walkways can be twelve inches wide and three inches from the pipes. 4

4. The varying of walkway sizes is done to make the walkways conform to the grid dimensions, rather than make...
FIGURE 41

THE GRID WALKWAY POSITIONS
Walkways cannot be placed along the third and sixth pipes because they would interfere with the locations of the entrance area instruments. Therefore, crosswalks are required along the second, third, sixth, and seventh lateral pipes running between the second and seventh longitudinal pipes.

The use of the nine inch wide center walkways necessitates having some form of handrail. A natural combination of uses would suggest using the mounting pipe as the handrail. Although the fifteen inch height arrived at in the walkway experiments seems a bit low, the participants indicated that it was practical. If the instruments were hung from the pipe, the height could be increased to thirty inches without affecting the masking characteristics of the grid, providing a more conventional rail height. The advantage of the fifteen inch pipe height is that instruments could be both hung from and "roostered" on it, providing a better use of space than the thirty inch high pipe from which the instruments could only be hung. For this reason we prefer the fifteen inch height.

Thus, with a beam source height of fifteen feet, the pipe would be sixteen feet, three inches above the floor of the walkways should be painted with colors which indicate the walkway width. This color-coding serves as a safety device for the technicians as they move from width to width.
stage level.\textsuperscript{5} The walkway, fifteen inches below the mounting pipe, would be fourteen feet, nine inches above the stage. The additional louvre depth below walkway level would be thirty inches to provide the necessary two feet, nine inches of masking depth necessary as computed in Chapter IV. This places the bottom of the grid twelve feet, three inches above the stage.

This grid requires a minimum of thirty-six circuits and seventy-six circuit outlets, not counting any extra circuits and outlets for specials. This provides thirty-two circuits for the sixty-four instruments lighting the sixteen basic areas, and four circuits for the twelve instruments used to light the four entrance areas. The two diagonally opposite instruments for each of the basic areas are paired, and the three instruments for each entrance area are paired on individual circuits. This arrangement gives some flexibility of area and color control, but has no provision for extra or special lighting instruments for flexibility of lighting design.

A better arrangement, and the one preferred for this example, would have one hundred and fifty-two grid circuits. This provides one circuit for each of the

\textsuperscript{5}The center of the light source from a standard six inch Fresnel spotlight aimed at forty-five degrees vertical angle and with the yoke vertical is twelve inches from the top of the mounting pipe.
seventy-six basic lighting instruments and an equal number of free circuits for special areas and color toning. This scheme gives better design flexibility since individual control is possible and circuits can be grouped on the dimmers according to the specific production requirements.

The electrical outlets should be located approximately six inches from the basic instrument locations. This slight separation is necessary to prevent the circuit outlets from physically interfering with the mounting of the instruments. For example, if the outlets were placed on the mounting pipes, the space taken by the outlet would prevent an instrument from being mounted at that specific point. However, if the outlets were on cables attached to the sides (not the floor) of the walkways, they would still be easily accessible but not interfere with instrument mounting locations.

These cables must be long enough to reach instruments mounted in their module area without the need for cable extensions. In this sample grid, the cables at the larger modules should be approximately four feet long while the cables for the smaller modules could be three feet long. If the cables were allowed to hang down when not in use, they would present a sloppy and distracting appearance. To solve this problem, some device such as a small chain with a snap hook could be fastened to the free end of the cable to attach the cable to the mounting pipe. Another solution
could be to use trays along the sides of the walkways in which the cable could be laid. This second method also has the advantage of providing a place for any longer cable runs that might occasionally be needed, eliminating the need to place the cable on the walkways or tie it to the pipe.

Having determined the vertical dimensions of the lighting grid, we can now return to their effect on the vertical dimensions of the theatre room and seating sections. With a walkway height of fourteen feet, nine inches, the ceiling of the room, including any beams or structural supports, should be no lower than twenty-one feet, nine inches to provide the six foot, six inch clearance necessary for unimpeded erect movement on the grid.

The elevation of the succeeding seating rows, using the five row depth, can be one foot per row, the same as for the first row. This makes the elevation of the fifth row five feet. A six foot tall patron standing on the last row would have a clearance of one foot, nine inches below the lowest grid structure. However, if more rows were desired, the elevation of the succeeding rows after the first row should be decreased to six inches per row. The head of a six foot tall patron standing on the tenth row of a section using a six inch rise would be one foot, three inches below the lowest grid unit.
The total grid system outlined above demonstrates the interrelationship of the lighting grid to the overall theatre design. As planned, this grid system provides for illumination of the playing areas, flexibility in lighting design, convenient access to the lighting instruments, and masking of glare from the beam sources. There are other variations of the scheme which could work as effectively if the basic principles of spatial relationship were observed. A compromise of these criteria for the relationship of grid, seating, and stage would undoubtedly result in a compromised usability of the theatre facility.
CONCLUSION

Arena theatre lighting grid design is still in a phase of experimentation and development because of the relative newness of the theatrical form, the wide diversity of the initial theatres which serve as guides to builders of new theatres, and the development of new construction techniques and materials. Nevertheless, there are certain standard requirements and functions common to all lighting grid schemes which can be categorized and controlled.

An arena theatre lighting grid should provide a mounting platform for the lighting instruments which ensures illumination using standard lighting angles for all normal playing areas; maximum flexibility of mounting positions for special lighting design requirements; convenient access to the lighting instruments for aiming and maintenance; and masking of glare from the beam sources. If these goals are to be achieved, the lighting grid must be considered as one of the primary elements in programming the space requirements of an arena theatre building. If the spatial needs of the grid system are compromised in planning the theatre, the usefulness of the theatre may be diminished. The basic grid configuration for a specific
theatre can be determined easily by mechanically plotting the instrument locations for the lighting areas. Factors which should be considered in this determination are the size of the stage, the size of the lighting area desired, the types of lighting instruments to be used, and the vertical and horizontal room space available.

The lighting grid has both lateral and vertical space requirements which are interrelated. As the grid height increases, the lateral space covered by the grid will increase. If the grid height necessitates a lateral grid space larger than the size of the theatre room, the perimeter lighting instruments can be placed in wall ports, which will be lower than the height of the lighting grid.

The maximum height of the lighting grid is limited by available room height, lateral room area (large enough to contain the necessary grid area plus the wall ports if necessary), and the type of lighting instruments to be used. If the basic lighting instruments for the theatre are to be 500 watt Fresnel and ellipsoidal spotlights, the maximum grid height should be no more than twenty feet or else the slant range distance of the beam throw will be too long to ensure adequate light intensity. The grid can be higher if larger and higher powered instruments are used. The minimum grid height should be no less than twelve feet. If the grid is lower, there will be inadequate slant range distance to allow beam spread to provide reasonably-sized
lighting area. In addition, a lower height will restrict the use of staging platforms and vertical scenic units.

Access to the lighting instruments should be via a grid walkway system. All potential mounting locations should be accessible from the walkway. The walkway dimensions should be kept to a minimum to avoid interfering with or prohibiting the use of any potential instrument mounting positions, yet be large enough to allow comfortable movement by the technicians. A twelve inch wide walkway using the mounting pipe as a hand or stabilizing rail seems to be best. In addition, there should be at least six feet, six inches of clear space above the walkways to allow erect travel.

Louvre masking is the most effective way to prevent glare; however, the dimensional tolerances involved in the design of a louvre masking system are critical and must be observed if the masking is to be effective without limiting design flexibility. An alternative to masking is to have a grid height of over twenty-five feet which places the beam sources above the normal field of vision and minimizes glare effect.

This study dealt specifically with the problems of instrument location, walkway dimensions, and louvre masking for arena theatre lighting grid design. There are other aspects of the design problem which merit further research. New construction techniques and construction materials for
the grid which might affect grid design should be investigated. Grid (and theatre) circuiting, mentioned briefly in the text, should be analyzed to determine circuit load requirements, numbers of circuits required, number of outlets required, and optimum location of outlets. The use of special funnels attached to the instruments for beam source masking, and the development of camouflage techniques in theatres where louvre masking is not possible also offer areas for further research.

The sample grid proposed in this dissertation demonstrates one scheme by which the desirable characteristics of a lighting grid may be obtained. The example is not meant to represent the only satisfactory solution to the grid design problem, since theatres are rarely identical in terms of production requirements and funds for construction. Each theatre, and therefore each lighting grid, should be planned to meet the needs of the specific user. However, the procedures and criteria used in the design of the sample grid are common to all grid design, and can provide a guide for basic grid design regardless of the ultimate implementation in construction technique.
APPENDIXES
APPENDIX A

SOME NEW ARENA THEATRES

Alley Theatre, Houston, Texas

Arena Stage, Washington, D. C.

Arena Theatre, Benjamin Harris Fine Arts Center, Brigham Young University, Provo, Utah

Benedicta Arts Center, St. Joseph, Minnesota

Camden County Fair, Camden, New Jersey

Center Theatre, University of California, Santa Barbara, California

Experimental Theatre, Communications Building Group, Southern Illinois University, Carbondale, Illinois

Experimental Theatre, University of Texas, Austin, Texas

Hopkins Center, Dartmouth College, New Hampshire

Lab Theatre, Knox College, Galesburg, Illinois

Loeb Theatre, Harvard University, Boston, Massachusetts

Loretto Hilton Center, Webster College, Webster Groves, Missouri

Macalester College Theatre, Macalester College, St. Paul, Minnesota

Multiform Theatre, University of California, Berkeley, California

Pavilion Theatre, Pennsylvania State University, State College, Pennsylvania

Studio Theatre, John F. Kennedy Center for the Performing Arts, Washington, D. C.

Studio Theatre, Oberlin College, Oberlin, Ohio
Studio Theatre, Pioneer Memorial Theatre, Salt Lake City, Utah

Tenthouse Theatre, Highland Park, Illinois

Valley Music Theatre, Los Angeles, California
APPENDIX B

QUESTIONNAIRE FOR PARTICIPANTS IN GRID WALKWAY EXPERIMENT

PERSONAL STATISTICS:

1. Sex______  3. Height______
2. Age_______  4. Weight_______
5. Do you have any physical limitations?

6. Experience level:
   a. ____none                          c. ____some (have done some work in stage lighting)
   b. ____minimum (have been associated with theatre activities but have no appreciable technical experience)
   d. ____experienced (capable of doing stage lighting without direct supervision)

EVALUATION:

1. Minimum walkway width at which you can work practically?

2. Minimum pipe height at which you can work practically?

3. Minimum combination of walkway width and pipe height at which you can work practically?

4. Combination of walkway width and pipe height at which you would prefer to work?

5. Comments:
FIGURE 42
WALKWAY TEST MACHINE SHOWING WALKWAY WIDTHS
FIGURE 43

STUDENT MOUNTING A SIX INCH FRESNEL SPOTLIGHT. WALKWAY WIDTH, TWELVE INCHES; MOUNTING PIPE HEIGHT, FIFTEEN INCHES
FIGURE 44

STUDENT MOUNTING A SIX INCH ELLIPSOIDAL SPOTLIGHT. WALKWAY WIDTH, TWELVE INCHES; MOUNTING PIPE HEIGHT, 0 INCHES
FIGURE 45

STUDENT MOUNTING A SIX INCH FRESNEL SPOTLIGHT. WALKWAY WIDTH, TWELVE INCHES; MOUNTING PIPE HEIGHT, THIRTY INCHES
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baby Spots</td>
<td>250 to 500 watt conventional spotlights.</td>
</tr>
<tr>
<td>Beam Direction</td>
<td>The path of the light beam in either the vertical or horizontal plane.</td>
</tr>
<tr>
<td>Beam Source</td>
<td>The point of light production within the lighting instrument, or at the lens of the instrument.</td>
</tr>
<tr>
<td>Beam Spill</td>
<td>That part of the light beam which illuminates other than the direct aiming area.</td>
</tr>
<tr>
<td>Beam Spread</td>
<td>The divergence of opposite sides of the light beam as it extends from the instrument.</td>
</tr>
<tr>
<td>Beam Throw Distance</td>
<td>The direct linear distance from the light source to the center of the lighting area.</td>
</tr>
<tr>
<td>Candle Power</td>
<td>A measure of light intensity based on the International candle which is related to a black surface at a temperature of 2024 degrees K.</td>
</tr>
<tr>
<td>Ceiling Clouds</td>
<td>Independent units suspended from the roof and forming a false ceiling, normally used to improve acoustics or conceal lighting instrument locations.</td>
</tr>
<tr>
<td>Conduit</td>
<td>Pipe containing electrical cables.</td>
</tr>
<tr>
<td>Dimmer</td>
<td>An apparatus which controls the flow of electricity and thus controls the brightness of a light.</td>
</tr>
<tr>
<td>Dimmer Bank</td>
<td>A unit containing a group of dimmers.</td>
</tr>
</tbody>
</table>
Double Hanging. The mounting of two or more lighting instruments at approximately the same place to illuminate the same area together or separately, usually to achieve changes in colors.

Elipsoidal Spotlight. A spotlight distinguished by its elipsoidal reflector.

Floor Pocket. A recess in the floor containing electrical outlets.

Fresnel Spotlight. A spotlight using a lens distinguished by concentric rings on the front of the lens and a diffused surface on the back of the lens.

Grid. A grid or open floor of iron above the stage.

Grid Module. The smallest geometric unit of the grid by the pipes and/or circuits.

I-Beam. A steel structural beam which, when seen in cross section, resembles the capital letter I.

Lamp. A light producing unit consisting of a filament, bulb, and base.

Lamping (Relamping). The act of placing the lamp in the lighting instrument.

Light Bridge. A catwalk above the stage with provision for mounting lighting instruments.

Lighting Control Console. The unit which operates the dimmers, either directly or indirectly, thus controlling lighting intensity.

Lighting Grid. The general facility for mounting lighting instruments in arena theatre.

Lighting Tree. A vertical pipe with horizontal arms used for mounting lighting instruments.
Louvres. Two-dimensional sheets used for masking, usually made of plywood or sheet metal, one to three feet deep and two to six feet long.

Masking. The shielding of the light beam source from the audience's view.

O.D. Outside diameter width of pipe.

PAR Lamp A lamp with a built-in parabolic aluminized reflector.

Ports (Ceiling, Wall). Openings in the wall or ceiling to permit the use of lighting instruments mounted behind these surfaces.

Rooster. The method of mounting lighting instruments above the mounting pipe instead of hanging them beneath it.
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