1948

Design of a radio broadcasting station

John William Hamman

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DESIGN OF A RADIO BROADCASTING STATION

BY

JOHN W. HALLMANN

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, ELECTRICAL ENGINEERING MAJOR

Rolla, Missouri

1948

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Approved by

[Signature]

Professor of Electrical Engineering
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John W. Hammann

Rolla, Missouri
July 12, 1948
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INTRODUCTION

In the design of any piece of equipment, before any work whatsoever is done, a reason for developing the object must be apparent to all concerned. Any expenditure of time, labor and money must be properly justified before action can be taken. In the case of this paper, then, the reason for designing a broadcast radio station for the Missouri School of Mines & Metallurgy at Rolla, Missouri is twofold: First, to provide an additional instrument whereby instruction may be given to students interested in the study of radio; second, to supply the residents of Rolla and vicinity with entertainment and instruction in keeping with the high ideals of the School.

At present, the Rolla radio receivers are provided programs principally from KTTR, in Rolla. Other stations, however, are received with more or less consistency varying with the time of day, the season of the year and the quality of the receiver. St. Louis radio stations are heard, as are also the high powered transmitters from Ft. Worth, Texas, Dallas, Texas, Shreveport, La., Louisville, Ky., New Orleans, La., and Nashville, Tenn. There can be little doubt however of a radio audience in the vicinity of Rolla alone of at least several thousand students and residents. The idea of this thesis fits in nicely with the aim of the
Federal Communication Commission, which is to provide adequate radio coverage for all the populated areas of the United States.

In the way of instruction facilities for the students, the station would provide many new features. Naturally, students interested in radio broadcasting and communications engineering in general would receive benefits from visits to the station. The transmitter could be manned by students (properly licensed, of course). This would stimulate interest in securing government radio licenses and in competing for the tasks available. It is desirable, although certainly not necessary, for anyone specializing in electrical engineering with a communications option\(^{(1)}\) to be licensed as

\(^{(1)}\) A course of study available at the Missouri School of Mines.

a first class radiotelephone operator or a first class radiotelegraph operator. Likewise, having an opportunity to actually work with commercial radio equipment is something to be prized by anyone seeking education along that line. It gives the student a chance to become familiar with apparatus first hand instead of receiving only a reading acquaintance.

The radio station need not benefit the electrical engineering department only; a program manager would be
required, probably from any department; also, news announcers, program announcers, sports announcing and guest speakers; talent shows from all branches of the student body; programs by the Glee Club and Dramatic Club; lectures by the Dean and professors; and discussions and political speeches by the office seekers in the area. A program of general education in engineering for all ages might be established. All in all, many people would benefit from the radio station, particularly the School.

It is not the purpose of this thesis to draw up a complete set of plans and specifications for a radio broadcast station, since such an undertaking would require a great deal of time and expense; but only to work out the more important details and show what could be done if funds were available for the purpose.

Therefore, it will be assumed that a transmitting station is to be built of 250 watts radiated energy, and that a frequency has been assigned of 1250 kc; further, that an antenna height of 190 ft. has been granted. Such a combination should give a consistent coverage of roughly thirty-five miles in all directions from Rolla. Detailed calculations of field strength are shown in the chapter on the Antenna. A program of three hours a day, six days per week is anticipated.
A REVIEW OF LITERATURE

There have been many books published concerning the various phases of radio broadcasting dealing with waves from 50,000 cycles per second up to hundreds of megacycles. These publications cover subjects such as wave theory, fundamental radio circuits, advanced circuits, receiver design, transmitter design, oscillators, studio acoustics, mathematics as applied to radio waves, short wave amateur operations, experimental radio, radio direction finding, RADAR and SONAR, just to mention a few. Then there are innumerable magazine publications, devoting either wholly or in part to information concerning radio. Many informed writers have discussed the pros and cons of radio broadcasting before technical meetings. Their works have been published in volumes of "Procedures". So, there is certainly no shortage of information on the general subject of Radio.

However, obtaining information about the design of a radio broadcasting station requires some digging in libraries and some consulting with the proper people, since relatively few books are written about that particular subject. Since all radio stations must be licensed, a likely source of technical information would be the Federal Communications Commission. The Commission has published a considerable number of booklets such as the

The above texts furnish an excellent source of information concerning the subject of radio station design, and the one titled "Standards of Good Engineering Practice Concerning Broadcasting Stations" is by far the most important. The FCC here lists and explains the necessary qualifications required of a station seeking a license. It also lists a good deal of general technical information which is available from no other source. Another possible valuable reference, which was not available to the writer, however, is a publication called "National Association of Broadcasters' Engineering Handbook".

Mr. Nilson and Mr. Hornung have written an excellent work entitled "Practical Radio Communication". It is helpful in the present instance in that it covers many phases of commercial radio broadcasting. However, it also discloses facts concerning amateur radio, marine radio, aviation radio, spark transmitters, receiver design, fundamentals of electricity, etc., that are of no interest here.
Henney's "Radio Engineering Handbook" and Terman's "Radio Engineering" are certainly useful to anyone interested in the technical aspects of radio and were of estimable value in this case. The "Radio Amateurs Handbook" was referred to, although it is primarily useful to radio amateurs. "Elements of Radio" by Marcus & Horton proved an excellent text.

A few words should be said concerning Mr. G. E. Sterling's "The Radio Manual". This book was written for the benefit of radio operators, engineers and technicians, and is a compilation of information concerning many different types of broadcasting and receiving equipment. Throughout his book, Mr. Sterling has introduced various items by manufacturer's name and type number, giving a complete description of the operation. Circuit diagrams have, in many cases, been included. Also references to FCC's "Rules and Regulations" are made. In the back of the book is a complete list of the "Rules and Regulations". By means of this book, a ready reference to commercial equipment is obtained. Although the data may be slightly out of date, this is no serious handicap where theory only is desired. Mr. Sterling, in 1938, was the Assistant Chief, Field Section, Engineering Department, Federal Communications Commission and also a member of the Institute of Radio Engineers.

For periodicals, reference was made to "Radio", "Com-
munications", and various publications of the Portland Cement Association and National Concrete Masonry Association. The trade publications provided many ideas concerning the building design and construction. For architectural design, many good books are available at the School library. Another source of information, not too important, was the advertisements of radio equipment manufacturers and the descriptive catalogues showing what their products will or will not do. An example of these would be Western Electric's "2A Frequency Monitor" (unnumbered publication). It describes in pictures and words a frequency monitor for checking the broadcast transmitter frequency. The information contained therein is available from no other source. There are many such pamphlets available from manufacturers.
Location of Transmitter and Antenna

The location of the antenna is probably the most important geographical consideration of the whole radio station. It must be, at best, a compromise; because three considerations must always be kept in mind when locating an antenna and each must be satisfied before construction can proceed. These three considerations are:

1. Location of transmitter antenna so as to properly serve the desired area.
2. The purchase, rent, or lease of the desired ground for erecting the antenna.
3. The distance from the transmitter to the antenna.

Two of the considerations may be eliminated at once: No ground is to be purchased for this work and also the transmitter and antenna will be close together. The most important consideration, then, is the first. If the broadcast does not properly reach the radio sets which are to be provided with radio service, then the location is unsatisfactory and should not be used. It is difficult, of course, to select a piece of ground which is satisfactory from a technical view point with-
Field strength tests are made by means of a special calibrated receiver which is moved from place to place in the area being tested, readings being taken of field strength at each location. The readings are in microvolts (or millivolts) per meter which is a measure of the field intensity at that particular spot. By making a plot on a map of the various recorded data, points of the same field intensity may be joined by a line. A series of such lines of equal field intensity would then give a field intensity contour map. (Similar in appearance to the contours on an ordinary map.) The contours would be separated a greater distance at certain points than at others, due to the fact that the radio waves passed over the distance with less attenuation. Less attenuation occurs where ground conductivity is good. Hence where contours are close together, the particular area crossed has poor ground conductivity and would indicate (other things being equal) a less desirable location for an antenna.

require equipment which is not available and which is also beyond the scope of this thesis. Field strength tests are not so important in determining the location of a low power transmitter such as is contemplated. If a location were being selected for a radio station like KMOX, for example, then field strength tests would be all important.

A further subject to be considered is the matter of city zoning. Station KXLW in St. Louis erected a broadcast antenna at Olivette in St. Louis county and used this radiator for several months. According to the newspapers, it then came to light that there were zoning laws concerning the types of construction permitted in various
areas. As a result, KXLW was faced with the possibility of having to move the antenna.

Working on the basis that the broadcast station will have a power of 250 watts, will be on the air during the daytime only for three hours, and is to cover Rolla, Waynesville, St. James and Cuba, the following locations were selected. Each location will be studied in detail and its advantages and disadvantages cited.

"The ideal location of a broadcast transmitter is in a low area of marshy or 'crawfishy' soil or area which is damp the maximum percentage of the time and from which a clear view over the entire center of population may be had, and the tall buildings in the business section of the city would cast a shadow across the minimum residential area. The type and condition of the soil or earth immediately around a site is very important. Important, to an extent, is the soil or earth between the site and the principal area to be served. Sandy soil is considered the worst type, with glacial deposits and mineral ore areas next. Alluvial, marshy areas and salt water bogs have been found to have the least absorption of the signal. One is fortunate to have available such an area and, if not
available, the next best condition must be selected."

(3) Federal Communications Commission, Standards of Good Engineering Practice Concerning Standard Broadcast Stations (550-1500 KC), p. 33, (1939), revised to June 1, 1944.

It can be seen from the above quoted paragraph that conditions around Rolla, Missouri are not conducive to good radio transmission and reception.

When a radio wave leaves an antenna, it radiates as a ground wave and also as a sky wave. The ground wave moves out from the antenna along the ground (see Chap. 6) whereas the sky wave is radiated up to the ionized layers and part of it may be reflected back to the earth. The ground wave is fairly constant in that it is not seriously affected by temperature, time of day, cosmic ray bombardment, etc. The sky wave, on the other hand, is seriously affected by the factors outlined and therefore the location at which the wave is reflected back to the ground varies considerably. Therefore, the range expected from a given broadcast transmitter for consistent reception depends on the ground wave only.

Another way to visualize this situation is to observe the listener's own use of the radio receiver. Certainly with modern radio sets the user can tune in stations on the broadcast band which are located five hundred or a thousand miles away. For a few minutes, or perhaps several hours, the programs come in clearly and
with sufficient loudness for easy listening. However, at another time of day or during another part of the year, the same stations do not come in at all or are so weak and garbled as to be unintelligible. This is due to the shifting of the sky wave. Hence for twenty-four hours a day, year round reception, the ground wave of a closer station must be relied on. To prevent distortion, the receiver must also be close enough to the transmitter so that the sky wave passes completely overhead, causing no interference with the ground wave. The ground wave is attenuated as it travels along the earth's surface. Therefore, the farther one is away from the transmitting antenna the weaker the ground wave becomes. Also, at higher frequencies the attenuation is greater. The attenuation also varies with the type of terrain. Notice the table on the next page.
Values of inductivity and conductivity recommended to be used for various types of country in the absence of surveys over the particular area involved.

<table>
<thead>
<tr>
<th>Type of Terrain</th>
<th>Inductivity</th>
<th>Conductivity</th>
<th>Absorption Factor at 50 miles</th>
<th>1000 KC(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea water, minimum attenuation.</td>
<td></td>
<td>$4.64 \times 10^{-11}$</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Pastoral, low hills, rich soil, typical of Dallas, Tex., Lincoln, Nebr., &amp; Wolf Point, Mont., areas.</td>
<td>20</td>
<td>$3 \times 10^{-13}$</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Pastoral, low hills, rich soil, typical of Ohio and Illinois.</td>
<td>14</td>
<td>$10^{-13}$</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Flat country, marshy, densely wooded, typical of Louisiana near Mississippi River.</td>
<td>12</td>
<td>$7.5 \times 10^{-14}$</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Pastoral, medium hills, &amp; forestation, typical of Maryland, Penna., New York, exclusive of mountainous territory and sea coasts.</td>
<td>13</td>
<td>$6 \times 10^{-14}$</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Pastoral, medium hills, forestation, heavy clay soil, typical of central Virginia.</td>
<td>13</td>
<td>$4 \times 10^{-14}$</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Rocky soil, steep hills, typical of New England.</td>
<td>14</td>
<td>$2 \times 10^{-14}$</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>Sandy, dry, flat, typical of coastal country.</td>
<td>10</td>
<td>$2 \times 10^{-14}$</td>
<td>0.024</td>
<td></td>
</tr>
<tr>
<td>City, industrial areas, average attenuation.</td>
<td>5</td>
<td>$10^{-14}$</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>City, industrial areas, maximum attenuation.</td>
<td>3</td>
<td>$10^{-15}$</td>
<td>0.003</td>
<td></td>
</tr>
</tbody>
</table>


(5) This figure is stated for comparison purposes in order to indicate at a glance which values of conductivity and inductivity represent the higher absorption. This figure is the ratio between field intensity obtained with the soil constants given and with no absorption.
It can be seen from this chart that soil conductivity conditions around Rolla are far from ideal and the ground wave will be attenuated rapidly. The characteristics of central Missouri in the foothills of the Ozarks would probably fit under the heading of "Pastoral, medium hills, and forestation, heavy clay soil, typical of central Virginia". Referring to Table A, this terrain would give a ground conductivity of $4 \times 10^{-14}$. This figure will be used later in determining the approximate range of the radio station.

Another factor which must be kept in mind concerns Table B. From this table, and using a value of 250 watts power in a city of between 5,000 and 10,000, the approximate radius of blanket area is 0.3-0.5 miles. Also, the location of the station must be 1-3 miles from the center of city. A maximum percentage of total population in blanket area is 1%.

Numerous other considerations must be kept in mind. Relative position of the antenna with respect to airports and airways. (The FCC recommends using a distance of three miles as a guide.) Hazards to aviation must be considered. Space to erect the antenna and ground must be available. Closeness of power lines, substations, telephone systems, intervening hills, altitude (with respect to area being served) all have their effect. If this station is built, it would be recommended strongly
Table B (6)

Federal Communications Commission, Standards of Good Engineering Practice Concerning Standard Broadcast Stations (550-1600 KC), p. 31, (1939)

General guide to be used in determining the approximate site of broadcast transmitters.

<table>
<thead>
<tr>
<th>Power of Station</th>
<th>Population of City or Metropolitan Area (7)</th>
<th>Approx. Rad. of Blanket Area 250 mv/m (8)</th>
<th>Site-dist. from ctr. of City (Business or Geographical)</th>
<th>Max. Percentage of Total Population in Blanket Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Watts</td>
<td>5,000-50,000</td>
<td>0.15</td>
<td>1/2-1</td>
<td>1</td>
</tr>
<tr>
<td>100 Watts</td>
<td>50,000 or more</td>
<td>0.15</td>
<td>(9)</td>
<td></td>
</tr>
<tr>
<td>250-500 Watts</td>
<td>5,000 - 150,000</td>
<td>0.3-0.5</td>
<td>1-3</td>
<td>1</td>
</tr>
<tr>
<td>250-500 Watts</td>
<td>150,000 or more</td>
<td>0.3-0.5</td>
<td>(9)</td>
<td></td>
</tr>
<tr>
<td>1 Kilo-watt</td>
<td>5,000 to 200,000</td>
<td>0.6-0.9</td>
<td>2-5</td>
<td>1</td>
</tr>
<tr>
<td>1 Kilo-watt</td>
<td>200,000 or more</td>
<td>0.6-0.9</td>
<td>(9)</td>
<td></td>
</tr>
<tr>
<td>5-10 Kw.</td>
<td>All</td>
<td>1.5-2.5</td>
<td>5-10</td>
<td>1</td>
</tr>
<tr>
<td>25-50 Kw.</td>
<td>All</td>
<td>3.0-4.5</td>
<td>10-15</td>
<td>1</td>
</tr>
</tbody>
</table>

(7) The total population is the population of the city sought to be served except in those instances when the station is to be located in an area classified by the Department of Commerce, Bureau of Census, as a metropolitan area, in which case the population of the metropolitan area shall apply. Provided, however, that when the power of the station is such that all the metropolitan area cannot be served, the population that will actually be served shall determine. The population figures are those determined by the latest official census and where greater population is claimed, the burden of proof is on the applicant.

(8) These radii are only approximate and the actual blanket area (area within the 250 mv/m contour) may be materially different depending on the antenna employed and other factors.

(9) In these instances it is usually necessary to locate the station within the city in order to render satisfactory service throughout the city. Such sites shall be in or near the center of the business district and under no circumstances will a site in the residential area be approved.
that a field intensity survey be made over the area before any ground is purchased or leased.

In deciding on a location for the radio station, it is wise to make two or three selections so that if one location is not for sale or lease, another may be used. This condition might easily arise—in fact, all locations may be absolutely unobtainable in which case it would be necessary to start over and make new selections. Even though a suitable location is available, it may be that the person taking care of the financial end of the business would not see fit to pay the prices asked. So it is well to have at least two or three locations available.

Four possible locations for the transmitter and antenna were selected in the Rolla area. These are shown on Plate 1. Their various advantages and disadvantages will be discussed and a selection made to determine which of the four positions would be most desirable. No attempt was made to ascertain whether or not the areas were obtainable from the owners.

**POSITION ONE** (See Plates 1, 2, & 3)

This location is shown on Plate 1 in its geographical section in Missouri. Plate 2 shows the topographical location, and Plate 3 shows the spot in relationship to the city of Rolla. To go to position one, proceed east on Arkansas Avenue for one-half mile until the end
ROAD MAP OF ROLLA AND VICINITY

Scale 1"=20mi.

PLATE NO. 1
of the street is reached. The possible location of the radio station and antenna is seventy-five yards east. The ground is a large field, going downhill to the east and towards a small stream (the Burgher Branch of the Little Dry Fork) which would serve to keep the ground damp in the vicinity and thus provide better ground conductivity.

A survey of the ground contour from Plate 2 shows that the base of the antenna would be at an elevation of 1060 ft. above sea level. The city of Rolla has an elevation which varies for different sections of the city between 1100 and 1160 ft. (BM1119). As a result of this condition, the ground wave from the transmitter would have to travel uphill and also parts of the town would be in radio shadow due to low intervening hills. This would probably not cause an objectionable decrease in field strength in view of the short distance from Rolla to the radio station (a matter of less than a mile).

**POSITION TWO (See Plates 1, 2, & 3)**

To get to position two, proceed due east on 10th St. across the St. Louis and San Francisco Railroad tracks until a point .9 mile east of the railroad is reached. From this location, (the REA substation is located here) proceed west 100 yds. and north 50 yds. This is the proposed location of the radio station. Its geographical section is ideal as far as the ground conductivity and
The topographic maps of the United States

The United States Geological Survey is engaged in making a series of topographic maps of the entire United States. This work has been in progress since 1883, and its results consist of published maps of more than 600,000 square miles, covering the entire country, exclusive of Alaska.

The topographic map is published in the form of maps on a scale of about 150 miles to an inch. The basic five-inch square map has been divided into 24 pages of about 150 square miles each, the size of each page being about 10 inches by 15 inches. Each of these pages is divided into 4 quadrangles, each containing about 37 square miles. The quadrangles are bounded by lines of latitude and longitude, and each page is numbered for easy reference.

The topographic map shows the surface features of the United States, including roads, railroads, rivers, lakes, streams, and other bodies of water. It also shows the general relief of the land, indicating the heights and depths of the various features. The map is intended to be used by engineers, surveyors, and other professionals who need detailed information about the topography of the United States.

The topographic map is a valuable tool for various applications, including urban planning, real estate development, and natural resource management. It provides a detailed view of the surface features of the United States, allowing professionals to make informed decisions based on accurate and up-to-date information.

In conclusion, the topographic map of the United States is an essential tool for various applications and provides valuable information about the surface features of the country. It is an important resource for professionals and individuals who need detailed information about the topography of the United States.
elevation are concerned, since there is a stream nearby which would serve to keep the ground moist. Also, this spot is the base of a broad, gently sloping valley which runs generally from northwest to southeast. There is not too much wooded area present, which is advantageous because wooded areas absorb the radiated signal. In addition, the necessary power and telephone service are available. The location is easily accessible by automobile.

The disadvantage of this position is the nearness to the electric switching station of the "Show-Me" Power Co. This would cause some absorption of energy. The many power and telephone lines running nearby might also absorb a prohibitive amount of power.

POSITION THREE (See Plates, 1, 2, & 3)

Another possibility in the same valley with positions 1 and 2 is found by proceeding southeast from Rolla on Salem Road. Follow Salem Road until highway 72 (Rolla and Salem Road) is reached. At this point, turn left towards Salem; go one-half miles to dirt road coming in from the left. Here, turn left onto dirt road and proceed .4 miles east (almost to the end of the road).

It will be noticed that this dirt road runs along the edge of a broad valley (the same valley as mentioned in positions 1 and 2) and a clear view for miles may be
obtained to the north, east and northwest across the valley. There is comparatively little of this area which is wooded, and a stream flows in the bottom of the valley. Position three has all the advantages of position two with the addition of the fact that there is no substation and power wiring nearby. There is, however, the necessary pole line to bring electric power to the station. Also, there are telephone lines in the vicinity.

The main objection to this place is the fact that it is on a dirt road, and a few days of rain would make the position more or less inaccessible.

POSITION FOUR (See Plates 1, 2, & 3)

This position is recommended as being the most suitable of the four possibilities for the location of a radio station. It has all the advantages of the other locations and not such serious disadvantages. It is not near a power substation, and is certainly accessible in all weather, since it is located on a concrete road running right into Rolla.

The position is reached by proceeding south from Rolla on U. S. highway 63. After passing the intersection of highway 72 and 63, go south along U. S. highway 63 for one and four-tenths miles (see Plates 1, 2, & 3). At this distance, a huge level area may be seen to the left of the road, and also the markings of a small stream.
One hundred feet to the left of the road at this point is the suggested location of the radio station. This spot is not in the same valley as the previous locations (see Plate 2) but is in another broad valley to the south of Rolla. The valley runs generally east and west and is watered by the Deible Branch of the Little Dry Fork Creek. This stream will serve to keep the ground moist and will thus increase the ground conductivity.

An examination of the contoured map of this area shows that there is a slight rise between the two points so that the city of Rolla would be in somewhat of a radio shadow. The extent of this shadow is shown on Plates 4, 5, 6, 7, and 8. The area, however, is generally not wooded and slopes are gentle in all directions for the better part of a mile. These facts point this area out as a good possible location. Power is available in the form of an REA distribution circuit, and telephone lines are in the vicinity.

The elevation of the site for the transmitter and antenna is 1096 ft. In order to show the possible affects of ground contour on the reception of signals in Rolla, Plates 4, 5, 6, 7 and 8 were drawn. These curves show the radio shadows which would result at five different locations in the city of Rolla. The points were selected roughly as the center of town, northwest corner,
GROUND CONTOUR FROM ANTENNA TO SOUTHWEST CORNER OF ROLLA

GROUND CONTOUR FROM ANTENNA TO SOUTHEAST CORNER OF ROLLA

GROUND CONTOUR FROM ANTENNA TO NORTHWEST CORNER OF ROLLA

GROUND CONTOUR FROM ANTENNA TO NORTHEAST CORNER OF ROLLA

GROUND CONTOUR FROM ANTENNA TO CENTER PORTION OF ROLLA
northeast corner, southwest corner and the southeast corner. In order to understand the curves, assume that a straight line were drawn from the transmitter antenna to each one of the points mentioned above. Along any one of these lines, assume that a vertical plane was passed through both ends of the line and down into the earth. The curve, then, would represent the intersection of the earth's surface with the vertical plane.

Radio shadow, then, would be shown by drawing a straight line on the plate from the top of the antenna (190 feet above the ground) toward the point in question. If the line intersects any hills before reaching the receiver, then the receiver is in radio shadow. It is well to investigate radio shadow because it cuts down on signal strength. While it is not nearly so important to amplitude modulated broadcast stations as it is to frequency modulated stations, it is well to keep shadow in mind since it does affect the field intensity and the station coverage. At the short distance the transmitter is from Rolla, it is not contemplated that the shadow will decrease the ground wave below a minimum of 5 to 10 millivolts per meter(10) over the most distant residential

sections.

Let us consider also the other factors concerning the proposed location. The FCC specifies, as shown in Table B (page 15), that the 250 watt station has an approximate radius of blanket area of 250 mv/m of .3 to .5 mile. If a circle is drawn around the suggested location with a map radius of .5 mile, then the blanket area is shown within. (Represented as a yellow circle on Plate 2.) Specifications also allow a maximum of one percent of the population in the blanket area. A visit to the transmitter location will prove in a short time that less than one percent of the population of Rolla is concentrated in the area. Standing at the spot, it is possible to see well over one-half mile in any direction except southwest. To the southwest the ground falls away rapidly down to Wolf Creek. This area is heavily wooded. In any other direction the ground is open, with only a few scattered farm houses on large farms visible. The population of Rolla at the present time (August 1947) is approximately 12000. This is an estimate made by the city clerk, but it is certainly more accurate than the 1940 census since so many people have moved to Rolla since then. One percent of this is 120, and there can be little doubt that less than this many people live in the blanket area. (See Plate 9.)
PHOTOGRAPHS OF SELECTED AREA

The above pictures were taken at the proposed site of the broadcasting station. They provide a 360° panoramic view of the terrain.

PLATE NO. 9
Concerning danger to aircraft caused by the transmitting antenna, it should be mentioned that the nearest airport is located on the opposite side of Rolla and at a distance greater than four miles away. The antenna would be considerably higher than the surrounding objects and it would be wise to contact the Civil Aeronautics Administration in regard to their attitude concerning the location of the antenna. The FCC always refers each request for a station license to the CAA and, therefore, time could be saved by contacting the CAA first. Necessary aircraft warning lights must be mounted on the antenna and it must also be properly painted.

As a matter of interest, construction was begun in August 1947 on a commercial radio station, KTTR. This station is located in the same broad valley east of Rolla as positions one, two and three. (See Plate 2.) The motto of the station is "Keep Tuned To Rolla" and the licensed power is 250 watts. To go to the transmitter location, drive southeast on Salem Road to Soest Road. Turn left on Soest Road and proceed nine-tenths of a mile. The radio station is on the left side of the road, in a large field, and about one-hundred yards from a creek bed.

While all the facts outlined above have their effect
on the antenna location, a quotation\(^{(11)}\) to illustrate

\[\text{(11) Federal Communications Commission, Standards of Good Engineering Practice Concerning Standard Broadcast Stations (550-1600 KC), p. 35.}\]

their importance is given: "When making the final selection of a site, the need for a field intensity survey to establish the exact conditions cannot be stressed too strongly. The selection of a proper site for a broadcast station is an important engineering problem and can only be done properly by experienced radio engineers."
Main Building and Associated Equipment

The location of the transmitter having been decided upon, it next would be in order to determine the type and construction of building to house the transmitter and associated equipment. It would be advantageous to have the studio located on the Missouri School of Mines campus and the transmitter located at the place selected outside of Rolla. However, this method would mean considerable more expense since there is little space on the MSM campus which could be used for a radio studio. Furthermore, a communication line would have to be established between the campus and the transmitter, and this would be expensive. For the present, it is deemed best to locate studios and transmitter at one place. A disadvantage of the common location is the fact that water and sewage facilities are not readily available at the spot selected for the station. Power is available since the Missouri Power and Light Co. has power lines within three hundred feet of the site. There are telephone lines along the highway so that necessary telephone connections and remote pickup could be utilized. It is essential to have good telephone connections so that programs in various parts of Rolla or the Missouri School of Mines may be presented.

As an illustration of remote pickup, suppose that
Dean Wilson of the School of Mines were making an address in Parker Hall and that it was desired to broadcast this speech so that a larger audience could be reached. By means of a portable amplifier, microphone, monitoring set and cable, this speech could be fed into the telephone lines and so to the studio. Such a scheme could also be used to broadcast from Norwood Hall, The Long Hotel, Pennant Hotel, football stadium and the gymnasium. However, the telephone wire hookup is not always the answer to problems which arise; for instance, suppose the School were running a golf match on the golf course. In order to present this to the public over the air, it can be easily seen that telephone connections (in the immediate vicinity of the golfers) would be out of the question. A method of handling this situation has been worked out by broadcasters somewhat similar to the following: The announcer walks around the golf course with the players, carrying a portable microphone to which is attached a cord forty or fifty feet long. This cord terminates at a small high-frequency transmitter which is mounted in a tractor. The tractor follows along as the game progresses. The low-power transmitter takes the sound received by the microphone and transmits it by means of high-frequency electromagnetic waves to a receiver which is mounted at some convenient location near a telephone line. The receiver takes the signal, converts it to audi-
...o-frequencies and sends it over the telephone line to the studio where it is broadcasted on the standard broadcast band. The receiver is also used for monitoring purposes; that is, an engineer listening in can tell whether the microphone is too far away from the person doing the talking, or too close, or whether too much extraneous noise is being admitted to the circuit, etc. Knowing these things, the monitoring engineer has a separate small high-frequency broadcasting set nearby so that he can send instructions to the announcer at the site of the game. The announcer, of course, must have a receiver mounted on his tractor to pick up the instructions. To prevent interference with the program being broadcast, the announcer may wear a pair of headphones so that only he may hear the instructions. It should be mentioned at this point that the method just illustrated has many ramifications, and a large radio station would have many pieces of equipment to take care of all the possible needs which might appear.

Getting back to our Missouri School of Mines station, no such elaborate equipment as outlined above is contemplated for the initial layout. However, it is quite possible that as time progresses, funds become more available and a need exists, such changes could be made.

In the present design, various factors must be considered, such as, space, noise level, reverberation in
the studios, heating, ventilation, storage, test and checking. Each one of these must be considered in the light of funds available, how good a program it is intended to put on the air (that is, the fidelity of the sounds) and the type of program. If costs are cut so far that programs do not sound properly, audience passive disinterest or even active opposition may result. An example follows: Suppose it is desired to broadcast an octette of mixed voices from a small studio, not properly sound-engineered. The program might resemble the same octette singing in a cave, with reverberations and echoes from the sound being reflected back and forth from the walls. On the other hand, the same program might sound muffled and lifeless over the radio if the studio were too heavily sound-insulated such that there was no reverberation. A proper amount of reverberation is required in order to provide true fidelity for the listeners. An interesting sidelight on this matter is explained by Tyler (12) and will be investigated later.


In laying out the necessary plans for the building, numerous factors must be kept in mind, such as, cost, acoustic qualities, accessibility, maintenance, convenience, and personnel. Certainly in most cases the cost
is the most important factor, and in this design it is desired to keep the cost at a minimum and still give the proper satisfactory station operation as required by law and also as expected of an engineering school in Missouri. In order to obtain the necessary standards there is a certain minimum cost below which it is not possible to go. For instance, theoretically it would be possible to establish a broadcast station in the attic of the gymnasium. However, due to building vibration during basketball games, and when crowds are entering or leaving the building, the location would be extremely objectionable. Again, the gymnasium would be bad from the viewpoint of noise. It would be difficult indeed to sound-insulate a radio station located in the attic when a basketball game was in progress and the crowd cheers! (Such cheers have been heard three blocks away.)

Therefore, a separate building is almost a necessity considering only the acoustics and vibration factors. Another possibility presents itself, although it hinges on many uncertainties concerning the future. At the present time (April, 1948) the University of Missouri has asked the State for an appropriation of $500,000 to build a new mechanical and electrical engineering building on the Missouri School of Mines campus.
opposite Parker Hall. It would be entirely possible to request that a certain amount of space in this building be allocated to radio studios. (The transmitter itself would still be at the location previously selected.) Then, programs might be picked up directly from the campus in these studios and transmitted at audio frequencies by wire to the radio station. Broadcast would then take place on radio frequencies. Such an arrangement would fit in nicely with the contemplated design since the transmitter building would still be needed and the studios located in the transmitter building would still be available. The studios could be used on occasion of quick program changeovers from one studio to another and also as test studios for setting up special acoustical devices. The making of background sounds for dramatic programs requires time and experimentation in advance. The studios could be set aside for days or weeks at a time to permit sound engineers to manufacture, experiment with and make test runs on sound-producing mechanisms. Also, these same engineers could use the space to make recordings of sounds to be used at a later date. The sounds would have to be made in a location where proper equipment is at hand and also where proper acoustics are available.

Regardless of whether or not space for additional studios is available in the proposed engineering build-
ing, the transmitter and adjoining studios will still be required. The general layout of the building, then, would be as shown on Plate No. 10. This building would house the broadcast transmitter, studio equipment, turntables, office equipment, record racks, furnace, and workshop furnishings. Since the building is located several miles from Rolla, utilities are not immediately available. Power and light are present, as are the telephone facilities, but no water nor sewage disposal arrangements are at hand.

The building is to be made primarily of concrete masonry blocks, since these are available in Rolla in quantity and are not too costly. The exterior will be painted with a suitable white concrete paint. The blocks make a satisfactory substance for the walls in that the appearance is pleasing, they are fireproof, absorb a certain amount of noise, and furnish good heat insulating qualities. The sound-absorbing qualities of the concrete blocks are especially advantageous, since in the building will be housed certain noise-producing devices such as the oil burner furnace and the ventilating fan. Both these units will generate noise and as a result precautions must be exercised to see that the noise and vibration does not reach any of the microphones or the transmitting or monitoring equipment.
BUILDING FOR TRANSMITTER AND STUDIOS

To Antenna

Parking Lot

To Deep Well Pump

Plan

44-0

Control Room 16 x 22

Workshop 4 x 8

Office 10 x 10

Hallway 6 x 16

Reception Room 14 x 10

Studio B 12 x 16

Studio A 10 x 12

4 x 6

Furnace

Office

Reception Room

MSMR

Front Elevation
Scale 1/2"=1'

PLATE NO. 10
For the ventilating air ducts which will carry heated air throughout the building in winter, a sound baffle will have to be installed to prevent sound waves traveling from the fans to the studios and so to the microphones. The hot air ducts must be lined with fireproof sound absorbing material. The fan should also be mounted on cushioned supports, to minimize the vibration being transmitted to the floors and walls. The same should be done to the oil burner moving parts. A proper vibration-absorbing mounting will aid greatly to cut down unwanted noise. Haydite concrete blocks should be used for all interior walls (i.e. between studios, between office and transmitter room, to line the interior walls, etc.) This brick has good sound-absorbing qualities which make it fine for sound-proofing but on the other hand it also tends to absorb moisture. So in this case, it would be better to use a different, more weather-resisting block for the external walls.

In order to provide the necessary running water, the use of a well and installation of a deep-well pump is anticipated. Running water is almost a necessity in a radio station and since no water utility is available (the nearest would be Rolla, and it impractical to consider laying water pipe all the way to Rolla) it will have to be provided for. A "Crane-Line" jet pump and water system is designed to do this job. The combin-
ation is known as the SJC-4 and consists of a pump, electric motor drive, and a storage tank. A probable depth from pump to draw-down water level is 80 ft. A 245 gal. per hour demand is expected. These requirements call for a double pipe jet pump, complete with 1/2 HP, 220 V, 60 cycle capacitor motor, weather protected, and 42 gallon storage tank. The equipment comes complete with an automatic pressure switch so that when the pressure in the tank drops below 20# per square inch, the motor starts. It continues to run until a pressure of 40# per square inch is available within the tank. A wide differential in starting and stopping pressures permits the pump to do a lot of work at infrequent intervals, rather than a little work at frequent intervals. The advantage of this scheme is that the motor starts a fewer number of times per day. A large percentage of the motor wear occurs during starting which requires a relatively large amount of power. As a result, frequent starting means shorter life and larger electric bills. Hence fewer starts per day gives an advantage.

The well size required for the pump is 4" diameter and a double pipe for the operation of the jet is needed. A 1½" suction pipe, a 1" pressure pipe and a 1" discharge pipe will also be required. The jet type pump is operated on the principle of forcing a jet of water down in-
to the well below the draw-down water level. This jet lifts the water up the well pipe to a point which is within suction distance of a centrifugal pump. Thus the pump actually circulates a portion of the water through the double pipe assembly and a portion of this water is drawn off to the storage tank. No priming is required, since priming is automatically maintained.

The equipment, of course, must be ready to operate in all kinds of weather. A suitable installation would consist of a small pump house located approximately fifty feet south of the radio station. The house would consist merely of a frame covering for a pit. The pit would be ten feet deep and five feet square, walled with brick or concrete. The covering need only be a foot or two above the ground level and would be provided only to keep out snow, ice and rain and to keep people from falling into the pit. A padlock would also be provided. In the bottom of the pit would be placed the pump and storage tank. Such an installation would prevent freezing in winter time and would permit all-weather operation. A ladder would be placed permanently in the pit to permit inspection of the machinery. Pipes would be placed under-ground from the pump to the house, thus making the whole installation safe for year-round temperature changes. Keeping the pump away from the building will further minimize studio noise.
Next to be considered is the septic tank and its associated parts. Drainage from the house sewer system is led through underground soil pipe to the septic tank. A good location for the tank is seventy-five feet east of the building. This places the tank well over one hundred feet down grade from the pump so that no contamination of the water supply should result. The tank will be placed entirely underground and is of three hundred gallon capacity. Since it requires cleaning only every five or ten years, it may be completely covered. If cleaning is required, the cover may be exposed and fasteners removed.

Operation of the sewage system may be understood by reference to Plate No. 11. Drainage from the building is led to the tank through a pipe and admitted to the tank in such a way that the surface of the liquid is disturbed as little as possible. Bacteria form here on the surface and digest the material in the tank. The outflow is also taken from beneath the surface for the same reason. No chemicals whatsoever are required. The tank overflow is taken to a settling basin which merely consists of a concrete tank. Overflow from the settling basin is taken through perforated fibre pipe, as shown on Plate No. 12, and distributed throughout the soil. Liquids flow through the pipes, seep through the joints and perforations, and are absorbed by the soil. The pipes must be laid on a proper down grade so that correct flow will re-
sult. Pipes should also be laid on a bed of gravel so that liquid flow from the pipes to the ground will be less impeded. Soil from clogging the perforations will also be prevented.

The fibre pipe is made in eight foot lengths and should be laid twelve to eighteen inches below the ground surface. Approximately 250 feet of four inch pipe should be placed underground to provide sufficient drainage capacity. The various pipes should be placed so that if they are parallel, there is at least six feet between them. See Plate No. 12.

Pump, furnace fan, and lighting connections should be made to one distribution transformer supplied by the power company; the transmitter should have its own separate transformer. This method will tend to minimize line disturbances (and so the voltage regulation) when either of the motors starts up.

The layout of the interior of the transmitter building is important. (See Plate No. 10) In making the initial sketch, it was decided to keep the cost down and yet provide the minimum essentials necessary for the problem at hand. Two studios are shown, although the station could be operated at reduced efficiency with but one. If only one is used, however, there would be no opportunity to prepare a program in another studio while
one studio is being used for broadcasting. With two studios, it is far easier to handle a program changeover. An example of this is as follows: Suppose it was desired to broadcast a male sextette from 4 to 4:15 in the afternoon and then change over to a soap box opera from 4:15 to 4:30 P.M. The first listed program requires six singers with possibly a seventh man as announcer. The second program may require four people to take part in the play. With two studios, it would be a simple matter to have each group assigned to one studio into which they could come a few minutes before actual broadcast time and prepare positions, make last minute corrections, etc. With only one studio it would be necessary, at 4:15, to hastily get the sextette out of the studio and the soap box opera group into the studio, all without interrupting the continuous flow of entertainment over the air. Such a rapid changeover would be conducive to mistakes and poor arrangement of personnel around the microphone. Participants must be properly located with respect to the microphone in order to get best program efficiency.

There is another factor to be considered and this is the matter of auditioning. The radio station operators frequently wish to find out what a program is going to sound like before actually sending it out over the air. Therefore, at certain times during the day the studio which is not being used could be pressed into service for
auditioning purposes.

In the arrangement shown on Plate No. 10, a microphone is placed on the desk in front of the operator in the transmitter room. Then this microphone may be used by the operator on duty for news broadcasts, and program announcements in case the two studios are in use. This plan gives almost the equivalent of three studios.

For auditioning, the operator would merely feed the output of the studio microphone into a speech amplifier and then to the auditioning loudspeaker located in the office. This is done by means of a switch mounted on the operator's console. Whoever is checking the audition can hear the program almost as it would sound if broadcasted and picked up by a listener's receiver. Also, at a future date and if funds were available, a recorder could be purchased and set up in the station and used for the purpose of recording programs in advance of their times of broadcast by means of the auditioning studio. For larger stations with the bigger programs, a sound studio (i.e. a studio devoted only to the production of special sound effects) is used and also storage space is available for the necessary sound-making machines. These rooms could be eliminated in the case of this Missouri School of Mines transmitter, however.

The reception room is simply provided for the personnel required on the radio programs. Plate No. 13 shows
Diamond Pattern on Cast Concrete Floor Smooth Finish
a suggested floor design for the interior concrete floors. The reception room need have only a few pieces of furniture, a rug, and would be equipped with a loudspeaker so that any program being transmitted would be heard. The reception room is right outside of the office so that contact could be made immediately upon arrival and programs checked. Persons could then be given directions as to which studio to use, proper positions around the microphone and other last minute instructions.

The foundation details are shown on Plate No. 14 and it can readily be seen that the foundation is simple in line with keeping costs down. The foundation consists of a cast concrete base to act as a supporting member on all four sides of the building upon which the concrete blocks may be placed. This foundation must provide the necessary footing to support the weight of the structure and to prevent undue settling. It also has the additional purpose of keeping moisture out of the space under the floor. By placing drain tiles around the exterior of the foundation, as shown in the plate, water will be kept from seeping under the building in the volume occupied by the cinders. Failure to provide the drain tiles will almost surely result in water collecting under the building.

To provide a pleasing but inexpensive floor for the building, concrete is again used. This time it is a one-inch layer over the rough sub-floor, smoothly finished and
BUILDING FOUNDATION

7\(\frac{5}{8}\)" x 7\(\frac{5}{8}\)" x 15\(\frac{5}{8}\)"
Concrete Block

3\(\frac{5}{8}\)" x 7\(\frac{5}{8}\)" x 15\(\frac{5}{8}\)"
Haydite Block

Concrete

Cinders

6" Drain
Tile

Scale 1"=1'

PLATE NO.14
with grooves cut into it in a geometrical pattern. This is shown on Plate 13. In the two studios rugs would be placed on the floors. The transmitter room would have rubber strip mats placed on the floor in locations where most walking occurs. Mats would also be placed on the floor around the transmitter for safety reasons. The office floor and reception room floor would need no rugs whatsoever.

A few other necessities, in addition to those already mentioned, would be required inside the building. These would include the necessary light, heat, and water fittings, chairs, desk, piano, clothes rack, table, pictures (decorative) and necessary equipment for the workshop.

The exterior of the building will be of concrete blocks, painted with white paint manufactured for the purpose. The National Concrete Masonry Association and also the Portland Cement Association both publish numerous brochures illustrating what can be done with concrete blocks. Some attractive designs may be worked out for the exterior appearance of the building. The design selected for the Missouri School of Mines station is called "Random Ashlar." It is merely an arrangement of concrete blocks which is attractive to the eye. See Plate No. 15.

Probably the most important room in the entire building is the transmitter room. In this spot would be the transmitter itself, a monitor for checking the transmitter
frequency, a cathode ray oscilloscope for investigating wave shapes, two turntables, a console and record rack. Since the programs delivered over the air would undoubtedly be mostly recorded, it is imperative that proper space be provided for record storage. This storage space should be located in such a position that the operator, seated between the two turntables, could swing around and reach the racks with a minimum amount of effort on his part. This matter is important because the operator will probably have to make many trips to the racks each day.

The workshop might be considered as a separate room, but in the case of this Missouri School of Mines radio station, it would be better to consider the workshop as a part of the transmitter room. Any repairs which need be made on the transmitter, monitor, console or speech amplifiers, could be made in a minimum of time and with minimum effort by removing the apparatus to the workshop. The workshop need not necessarily have walls around it, since it could merely be a corner of the transmitter room; however, walls are included in this design because again there may be noises in the workshop which should be kept away from the transmitter and microphones. At this point it would be well to mention that before any repairs or changes are made to the transmitter, it would be imperative to study the F.C.C. rules and regula-
ensions concerning such matters as very definite restrictions are imposed.

Returning to the operator seated on a swivel chair before the console, it can easily be seen that he must be able to see what is going on in either or both studios. Therefore, the operator is provided with a large double plate glass window immediately in front of him above the console. Looking through this window and across the hall he can see through the window of each studio and is able to watch what is going on. He can also give the necessary signals. This layout permits the use of only one window per studio, one door per studio, and still gives the operator complete control over the program personnel with a minimum amount of effort. It is highly desirable to keep down the number and size of windows and doors in the studios. Such devices are difficult to sound-insulate. Windows are more so than doors. Sound waves striking glass are reflected back and cause reverberation and in this way tend to distort the program.

The human ear is accustomed to expect a certain amount of reverberation, depending on the physical location of the sound source. If the expected amount of reverberation is not present, whether large or small, the sound is distorted. As an example, consider a person calling to another person removed some distance inside a tunnel. The ear would expect and get a certain sound,
"flavored" by that sound's passage through the tunnel. If the same two people exchanged sounds outdoors, the ear would receive, and expect to receive, a different signal than that in the previous case. Neither case, however, would sound distorted. In other words, distortion may be considered as a "variation" from what the ear expects to hear.

To illustrate further, a sound heard out-of-doors in an open area (no trees, buildings, etc.) would be heard only once by a listener. If objects such as walls were properly placed in the area, the listener could hear the sound twice; that is, once when the original sound came to his ears and once when it was reflected back. Likewise, more walls properly placed in the area might produce two or even more echoes. This phenomena is quite apparent in mountainous country and is caused by sound waves traveling between and being reflected by the mountains. Consider now the case where the sound is reflected back in such a manner that there is very little elapsed time between the original sound and the echo. In this case, no echo as such would be distinguishable; however, the original sound would certainly sound differently to the ear than if there was no sound reflection present. This time delay between the original sound and the echo is the cause of reverberation effects. It should not be called distortion unless the effect is incorrect for the situation
in hand; then it would definitely be distortion.

The dictionary lists "reverberate" as "To send back, as sound; re-echo: v.i. to be driven back, or reflected, as sound or light." So the time of the return of the echo and the number of returns distinctly affects the sound, and when an ear hears a sound with definite time of reverberation and number of echos, then it immediately connects that sound with a certain physical location.

A practical use is made of this principle in "manufactured" sounds. Suppose in a soap box opera the script calls for someone to speak from the interior of a tunnel. This phenomena may be reproduced artifically by means of the equipment shown on Plate No. 16. Starting at the top of the sheet, the sound source (someone speaking) is fed into a microphone. From here it is amplified in the speech amplifier and then the energy takes two parallel paths - one through wires to the mixer and the other through the loudspeaker, sound chamber, microphone and then to the mixer. The mixer combines the two signals and feeds them on to the transmitter. It can be seen that the sound going through the air passage and traveling at roughly one thousand feet per second is going to arrive at the mixer considerably out of phase with that sound going through the wires and moving at a rate of approximately 186,000 miles per second. Hence by using this apparatus an echo effect is produced by having the "echo" arrive at
CREATING AN ARTIFICIAL ECHO

Sound Source

Microphone

Speech Amplifier

Loud Speaker
Sound Chamber
Microphone

Mixer

Output

PLATE NO. 16
the mixer slightly out of phase and lagging the energy transmitted through the wires only. Thus the output of the mixer will sound as it is supposed to; i.e. like someone speaking from the interior of a tunnel.

Returning to the studio design, then, it can be seen that some slight reverberation is desirable in the studio. The walls should not absorb all the sound energy since the ear knows from experience that words spoken indoors do sound "indoors-ish." Therefore, unless some special sound effects are needed, the program should sound as if it were coming from a studio. To achieve this end, the studio should be lined with celotex on the walls and ceiling and the floor should be carpeted. The inside of the building walls are already lined with Haydite brick and the combination would absorb a large enough percentage of the sound waves to give good studio acoustical qualities. One relatively small double-glass window and a door would be sufficient for the purposes desired.

In large broadcasting studios the sound engineers go to a great deal of expense and trouble in order to get the sounds exactly as they want them. For instance, there is one studio from which chain programs are broadcast. The studio consists of a stage from which the program originates, and seats for an audience in front of the stage. Naturally, the people present in the audience will absorb a great deal more of the sound waves produced than would the empty chairs. Therefore, in order to properly correct
for a small audience in attendance, "acousti-vanes" are mounted in the walls to the rear of the audience. See Plate No. 17. These vanes are large, slightly curved surfaces, several feet wide and reaching from the floor to the ceiling. They are pivoted about a vertical axis at the center of the vane. By means of a motor and control mechanism, the vanes may be made parallel to the wall, in which case the wall is completely concealed and sound waves striking the vanes will be reflected. Or, the vanes may be turned perpendicular to the wall, so that sound waves pass by the vanes and strike special sound-absorbing materials purposely placed against the wall. In this fashion, by properly rotating the vanes, the proper amount of sound reflection may be obtained to compensate for a small audience. That is, a small audience would require the vanes to be almost completely open whereas a large audience would require that the vanes be almost entirely closed. Sound engineers would make the proper setting. In this same studio, no two walls are erected parallel to each other. This is done so as to minimize possibilities of unwanted echo.

Concerning the external layout of the area, a driveway leading up from highway 66 leads to the main entrance. A parking lot would be located immediately north of the station and the dimensions of the lot would be approximately 50 ft. by 70 ft. The driveway and parking lot would
"ACOUSTI - VANE" PRINCIPLE

Vanes may be rotated about axis. All rotate at same time and same amount.

Wall

Sound-absorbing substance

View Looking Down On Studio

PLATE NO.17
be cindered (cinder obtained from the School power plant) and also other areas would be sodded. Shrubbery and trees would improve the appearance greatly but are not immediately required and could be added as funds become available.
TRANSMITTER AND ASSOCIATED EQUIPMENT

There are many manufacturers who make the necessary broadcasting equipment for radio stations. However, it is necessary to choose certain types of equipment and the choice is made as given below. Of course, the prime factor is that the equipment be built according to the high standards of the Federal Communications Commission, as otherwise no license to broadcast would be issued. It is entirely possible for an individual to build up a complete transmitter himself, starting with the necessary tubes, condensers, wires, etc., but this is not the method used today. It is far better to purchase the equipment already assembled and built according to FCC specifications than it is to try to assemble a transmitter and then get the assembly approved. Approval takes time and any changes required may become expensive.

A transmitter adapted to the use desired is the Western Electric 451A-1 which is marketed by the Graybar Electric Co. This transmitter is approximately 30" wide, 28" deep and 76" high and the shipping weight is approximately 1300 pounds. A block diagram is shown on plate No. 18. Reference to this drawing shows that the transmitter has high-level modulation and consists of a crystal controlled oscillator with three stages of radio frequency amplification. The two intermediate stages, or buffer stages, are introduced in order to separate the oscillator
TRANSMITTER BLOCK DIAGRAM


Feedback and Monitoring Rectifier

1st A.F. Amp.

2nd A.F. Amp. and Modulator

Speech Input

Ant.

PLATE NO. 18
as far as possible from the antenna loading, which is considered good practice since it results in less frequency variation under load. The audio amplifier and modulator stages are also shown.

The tubes required for the transmitting equipment are shown below:

Table C
VACUUM TUBE LIST (13)

(13) Western Electric Radio Transmitting Equipment; Publication number WECO-T 1752 C.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>247 A</td>
<td>Oscillator</td>
</tr>
<tr>
<td>1</td>
<td>350 B</td>
<td>First R.F. Amplifier</td>
</tr>
<tr>
<td>1</td>
<td>312 A</td>
<td>Second R.F. Amplifier</td>
</tr>
<tr>
<td>6</td>
<td>242 C</td>
<td>Third R.F. Amplifier</td>
</tr>
<tr>
<td>1</td>
<td>350 B</td>
<td>First A.F. Amplifier</td>
</tr>
<tr>
<td>2</td>
<td>350 B</td>
<td>Second A.F. Amplifier</td>
</tr>
<tr>
<td>1</td>
<td>351 A</td>
<td>Feedback and Monitoring Rectifier</td>
</tr>
<tr>
<td>1</td>
<td>301 A</td>
<td>Grid Bias Rectifier</td>
</tr>
<tr>
<td>2</td>
<td>249 B</td>
<td>Plate and Screen Supply Rectifiers</td>
</tr>
</tbody>
</table>
The schematic diagram of the transmitting equipment is displayed on Plate No. 19.

To determine the Western Electric code number of the tubes shown on the schematic diagram, see Table D.

The final stage of radio frequency amplification consists of six type 242-C tubes working together. (The tube types are Western Electric designation and do not correspond to other commercial types of tubes.) The circuit shows them in two sets of three tubes each. The three tubes of each set are connected in parallel and the two sets are connected in push-pull. The parallel arrangement permits a greater output than that from one tube; in fact, the power output varies directly as the number of tubes in parallel. The push-pull circuit also provides an increased output. In addition, it suppresses all the even harmonic frequencies thus eliminating some of the objectionable harmonics. In other words, the six tubes placed in parallel would provide the necessary output, but by adding the push-pull arrangement, a suppression of some unwanted frequencies is also obtained. A disadvantage, however, of the push-pull circuit is that twice the grid voltage of one tube is required. This is not the case with parallel operation.

Characteristics of the radio tubes used in this transmitting equipment may be seen by turning to Table E. This table shows the 242-C tube as having an output rating of
SCHEMATIC DIAGRAM

250 WATT RADIO TRANSMITTING EQUIPMENT WE 451A-1

Reproduced From Western Electric Radio Transmitting Equipment Undated Publication No. WECO-T 1752C Page 6

PLATE NO. 19
<table>
<thead>
<tr>
<th>Designation</th>
<th>Western Electric Code Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>V 1</td>
<td>247A</td>
</tr>
<tr>
<td>V 1 A</td>
<td>350B</td>
</tr>
<tr>
<td>V 2 A</td>
<td>312A</td>
</tr>
<tr>
<td>V 3.1 A</td>
<td>242C</td>
</tr>
<tr>
<td>V 3.2 A</td>
<td>242C</td>
</tr>
<tr>
<td>V 3.3 A</td>
<td>242C</td>
</tr>
<tr>
<td>V 4.1 A</td>
<td>242C</td>
</tr>
<tr>
<td>V 4.2 A</td>
<td>242C</td>
</tr>
<tr>
<td>V 4.3 A</td>
<td>242C</td>
</tr>
<tr>
<td>V 5 A</td>
<td>351A</td>
</tr>
<tr>
<td>V 6 A</td>
<td>350B</td>
</tr>
<tr>
<td>V 7.1 A</td>
<td>350B</td>
</tr>
<tr>
<td>V 7.2 A</td>
<td>350B</td>
</tr>
<tr>
<td>*V 8 A</td>
<td>274A</td>
</tr>
<tr>
<td>*V 9 A</td>
<td>249B</td>
</tr>
<tr>
<td>*V 10 A</td>
<td>249B</td>
</tr>
</tbody>
</table>

*Rectifier tubes (not shown on wiring diagram)
## Table X

### Tube Data

| Code | Name | Type | Volts | dIUp. | Voltage | Plate Current | Control Voltage | Screen Grid Current | Plate Current | Amplification Factor | Plate Power | Ceramic Plate Resistance | Transconductance | Trans-Cooling | Class of Operation | Average Characteristics - Class of Operation | Max. Plate Power | Max. Peak Plate Current | Max. Peak Plate Voltage |
|------|------|------|-------|-------|----------|---------------|-----------------|-------------------|-----------------|----------------|------------------|-------------|------------------------|-------------------|--------------|---------------------|------------------------------------------------|-----------------|------------------------|---------------------|
| 245C | Triode | T-F  | 10.0  | 3.15  | 1250     | 0.180         | -90             | 5                 | 50              | 100           | 1250             | 0.068      | 11.3                  | 3,500             | 1000         | A                   | Class A Amplifier | 2900          | 1800                  | 1000                |
| 247A | Triode | H    | 1.0   | 1.6   | 135      | 0.0032       | -4.5             | 5                 | 0.037           | 135           | 0.0034          | 15.2       | 16,000                | 940               | 7500         | B                   | Class B Amplifier | 1900          | 1000                  | 1000                |
| 1448B| Rectifier | O-F  | 2.5   | 7.5   | 1250     | 0.0025       | -50              | 5                 | 23              | 650           | 0.042           | 15.3       | 20,500                | 650               | 1000        | C                   | Class C Amplifier | 2900          | 1600                  | 1000                |
| 1414A| Rectifier | O-F  | 5.0   | 3.0   | 1250     | 0.0025       | -50              | *                 | 23              | 650           | 0.042           | 15.3       | 20,500                | 650               | 1000        | C                   | Class C Amplifier | 2900          | 1600                  | 1000                |
| 1410A| Pentode | T-F  | 10.0  | 2.5   | 1250     | 0.0025       | -50              | *                 | 23              | 650           | 0.042           | 15.3       | 20,500                | 650               | 1000        | D                   | Class D Amplifier | 2900          | 1600                  | 1000                |
| 2508 | Tetrode | V    | 6.3   | 1.6   | 400      | 0.0085       | -50              | *                 | 23              | 650           | 0.042           | 15.3       | 20,500                | 650               | 1000        | E                   | Class E Amplifier | 2900          | 1600                  | 1000                |
| 355A | Rectifier | H    | 6.3   | 1.0   | 1250     | 0.0025       | -50              | *                 | 23              | 650           | 0.042           | 15.3       | 20,500                | 650               | 1000        | F                   | Class F Amplifier | 2900          | 1600                  | 1000                |

From: "Western Electric Vacuum Tubes. General Bulletin. Tabular Characteristic Data and Arrangement of Terminal Connections. Issue 1, February 1, 1941."

**Key to Designations**
- **H** = Heater Type Cathode
- **Rf** = Full wave
- **Hg** = Mercury
- **SGM** = Suppressor Grid Modulated
- **T** = Thoriated Tungsten
- **V** = High Vacuum
- **O** = Oxide Coated

*Approx. to 2,000 (approx.)
50 watts. A rough check on the output obtainable from the six tubes in parallel would be $6 \times 50 = 300$ watts output. But the transmitter is only rated at 250 watts output, showing a conservative rating.

Another advantage of the transmitter circuit shown can be seen by tracing the output circuit of the final R.F. amplifier to determine the destination of the flow of energy. It can be seen that most of the R.F. energy flows to the antenna; however, a portion of it is brought back and fed into tube V5A (a type 351-A full wave rectifier tube) which acts as a feedback and monitoring rectifier. From the Radio Amateur's Handbook (15), the explanation of this circuit is given.


given. A negative feedback condition is established such that part of the amplified energy is fed back to the grid circuit of the modulator out of phase with the original grid excitation voltage. This results in a condition known as degeneration and causes less amplification through the stages concerned. But at the same time it also results in a more uniform amplification of a wide band of frequencies, and also minimizes any distortion which may be added by the amplification stages. An explanation of the degeneration principle can best be understood by examining first the
"regeneration" idea. In this case, a voltage from the plate circuit is fed back to the grid circuit in phase with the grid voltage. Thus any frequency which is amplified by the stage will be further amplified by the feeding back of energy from the plate to the grid circuit. This means that if the stage happens to amplify any one particular frequency more than another, the situation will be aggravated. In other words, regeneration results in a sharper resonance curve (or more selectivity). Conversely, a degeneration causes a flatter resonance curve and less distortion.

because any frequency which may be amplified by the stage more than another will be fed back into the grid circuit with a larger out-of-phase voltage tending to reduce discrimination of frequencies. Frey (16) also lists some other advantages and disadvantages of degeneration.

An audio input level of +20db (referred to one milliwatt) is required for 100% modulation at a single audio frequency. The audio input impedance is 600 ohms.

In the transmitter circuit shown (see Plate No. 19) the V5A tube is a rectifier tube with two plates. Therefore, the small amount of energy returned to the tube from the antenna coupling circuit is fed into two circuits; one circuit is the speech input circuit (for degenerative feedback) and the other is the monitor circuit. It is important

for operating personnel to know whether or not the sta-
tion is actually on the air. One almost-sure way of
determining this is to take some of the r-f energy, feed
it back to a monitoring receiver and listen. If the trans-
mitter is actually broadcasting, the sound should be heard
in the monitor. However, if any of the stages between the
microphone and the antenna are not functioning, the matter
would be instantly recognizable since no sound would come
from the monitor. No assurance, however, is forthcoming
that the r-f energy is actually getting from the antenna
coupling circuit to the antenna (although the possibilities
of trouble here are remote). There will also be a monitor
of the frequency-monitoring type in which it is desired to
make certain that the transmitter is operating on the correct
frequency.

In accordance with the Federal Communications
Commission Rules and Regulations, the operating power is
permitted to vary between 5% above authorized power to
10% below for short periods. From the above it can be seen
that the power output must be held within limits. This is
accomplished by proper transmitter design, incorporating
tubes which are applied conservatively within their ratings
and by using condensers, resistors, capacitors, trans-
formers, inductances and connections which are large enough
to prevent serious changes in power output due to tempera-
ture rise of the parts under operation.
Another serious consideration affecting the power output of the transmitter is the matter of station power supply. The geographical location selected for the transmitter places it within the service area of REA with headquarters at Licking, Missouri. A common difficulty with rural power transmission lines is the variation of line voltage at different times during the day when widely separated power loads are added to or taken from the power line. Upon construction of the broadcasting station, information should be passed on to the power company engineers so that provision could be made to furnish as constant a voltage as possible under the conditions. This would entail, on the part of the public utility, installation of power transformers and electric service wiring of relatively large size. It would be advantageous, from the school's viewpoint, for the power company to supply one transformer for the transmitter and associated equipment and another transformer for the pump, furnace, and lighting. However, this would be a matter for the public utility engineers to decide. The transmitter specified is supplied complete with its own voltage regulator, capable of correcting the input voltage over the range from 205 to 244 volts. This regulator, however, is manually operated and so would be of little use where rapid voltage variations are encountered. An automatic voltage regulator could be purchased and installed but the advantages so obtained would not be worth the expense required. There
would be little profit in holding the transmitter output too constant. As long as it is within F.C.C. specifications it will be satisfactory.

It would be advisable to consult with the telephone company to make certain that they would be able to supply the necessary telephone lines, leased wires, etc. They would, in all probability, also have something to say concerning the matter of interference to their lines due to the proximity of the radio transmitter antenna. No serious objections, however, are anticipated on this score.

The requirements of the F.C.C. are such that both a modulation monitor and a frequency deviation monitor are required at the transmitter. For a modulation monitor, a General Radio Type 1931-A would be used. It consists essentially of a radio receiver circuit, but the output at audio frequencies is fed into a visible monitoring arrangement which will indicate the percentage of modulation of the transmitter carrier wave. Naturally the percentage of modulation changes with the strength of the audible sound fed into the microphone. Therefore, the percentage of modulation is usually changing continuously and a means must be provided for the radio operator to adjust the microphone input so that the modulation percentage over a period of time is correct. To provide the visible indication, the output of the monitor receiver circuit is applied through the proper circuit to a neon bulb. Since
the neon bulb glows only after the applied potential has exceeded a fixed value, the proper circuit constants may be arranged in such a way that the bulb will flash at any desired percentage of modulation. For instance, suppose it is desired that the bulb flash at eighty-five percent modulation. Then, when the audio signal from the monitor receiver is strong enough to flash the bulb, an indication results. The monitor is also equipped with the equivalent of a vacuum-tube voltmeter. This combination indicates on a meter the percent of modulation at any instant of time. Since the modulation percentage is continually changing, the meter needle is continually in motion. No accurate readings would, therefore, be possible if it were not for the fact that the meter needle is fixed to move rapidly in the "increase" direction and slowly in the "decrease" direction. Then the eye has a chance to read the meter between upward movements of the needle. Arrangements are also made to read either positive or negative modulation peaks. A relay is also provided so that in case of overmodulation an audible alarm may be sounded or other indication used to call the attention of the staff to the condition.

The process of modulation of a radio frequency wave is not necessarily a symmetrical one. Due to faults in the transmitter, or also due to an inherent capacity of certain peoples voices, the positive modulation peaks may
not be the same height as the negative peaks. For this reason, the modulation monitor is equipped with a throw-over switch so that either positive or negative peaks may be monitored. The input of the modulation monitor must be coupled electromagnetically to the output of the transmitter. For further information on this subject, see Sterling, The Radio Amateur's Handbook (17), or


Wilson and Hornung (19).


Another method of checking the modulation (and an accurate one) is by means of a cathode-ray oscillograph. Radio-frequency energy from the transmitter may be applied to the cathode-ray oscilloscope and the resulting wave pattern is visible on the screen. Any modulation of the carrier wave is immediately seen on the screen and the percentage of modulation may be determined by measurements of the wave height. The advantage of this method is the elimination of distortion and losses between the transmitter and indicating instrument due to receiver-circuit design. The cathode-ray oscillograph makes the radio
frequency voltage variations themselves visible on the screen. Hence the advisability of having a cathode-ray oscillograph available in the building for the use of the radio engineers. There are also many other uses for this device.

To insure that the transmitter does not deviate more than the plus-or-minus twenty cycles per second allotted by the F.C.C. from the correct frequency, a frequency monitor is required. This will be a General Radio Type 1181-A frequency deviation monitor. Its function is to indicate whether or not the transmitter is actually on its assigned frequency and if not, how far the frequency is from being correct. Regulations require that both an audible and a visual indication be given. As a result the monitor has a meter for visual indication and has connections for plugging in a headset to give audible indication. The meter reads directly in cycles per second deviation both above and below the assigned frequency.

Essentially, the circuit consists of an accurate, temperature-controlled crystal generating a frequency which is caused to beat against the output of the transmitter. Any resulting beat note will give an indication on the meter and a sound in the earphones (if beat note is within the audible range). It is essential that great care be utilized in the installation, handling, and calibration of the frequency monitor since it will be used as a station
standard for setting the frequency of the broadcast transmitter.

Occasionally a check on the calibration of the frequency deviation should be made and a simple procedure for this is given below. There is a company in Kansas City which will make an accurate check of a transmitter frequency by picking up the radiated signal when the transmitter is on the air. They will then notify the interested persons of the exact frequency of the transmitter. (This may be done by telephone, if desired). At that time, the frequency deviation monitor should indicate the correct deviation (if any) for that frequency. If the indicated deviation is incorrect, an adjustment on the frequency deviation monitor is provided so that calibration may be improved.

The monitor receives its radio frequency energy from the transmitter by means of a short piece of wire extended as an aerial. For use close to the transmitter, this is probably all that will be required.

Sometimes it is desirable to make a test on the operation of the modulator and transmitter circuits in the following manner. Programs from the studios, or elsewhere, are fed into the Speech Input Equipment (described later) and, after proper control and amplification, are passed on to the transmitting equipment. From the speech input equipment, a connection is made to loud speakers so that the
program may be heard by station personnel. Also, some of the output energy of the transmitter is returned, rectified through tube V5A of the transmitting equipment and this audio frequency energy may then be used to operate a loudspeaker. Hence by comparing the sound from the loudspeaker coupled to the speech input equipment to the sound from the loudspeaker coupled to the transmitter, an accurate test may be made of the operation of the modulator and transmitter stages.

A Western Electric 23C speech input equipment would be used for controlling the flow of power from the incoming program lines and microphones to the transmitter. By referring to Plate No. 20, it can be seen that a total of four program lines, eight microphones (or equivalent low-level output turntables), control room microphone and monitoring facilities may be connected to the speech input equipment. The power required is 105 to 125 v. AC and also 12 v. DC for operating the relays and pilot light. The DC is not ordinarily available from the electric power utility so the DC would have to be supplied from a rectifier. A Western Electric KS-7593 rectifier will serve the purpose.

By means of the speech input equipment, the outputs from any four microphones (or less) may be mixed together in the mixer along with the program supplied over one input program line. An amplifier then builds the power up
to the point where it is sufficient to excite the modulator circuit of the transmitter. (Later on in this discussion, a comparison of input and output impedances of the various elements will be made and also computations of power levels from the microphone or program line to the transmitter). The speech input equipment has a gain of 96 db for microphone circuits and 64 db for program line circuits. The microphone impedances may be either 30 or 250 ohms and the program line impedance 600 ohms.

Controls on the operating panel permit adjustment of the gain from each input circuit independently. Pre-amplifiers are provided only for the microphone circuits, however, since the power level provided by the program lines needs no pre-amplifying. The master gain control permits the mixed signals to be adjusted to the required power level. The speech input equipment provides the amount of flexibility of circuit connection needed in this radio station. Any one of the microphones (or a maximum of four of them) may be connected to either of the outgoing lines. At the same time a monitoring amplifier provides the necessary gain to feed some of the program energy to three (or less) loudspeakers for immediate monitoring. Monitoring may be carried on prior to placing the program on the air or while it is being placed on the air.

"Cuing" is even more important in radio broadcasting
than it is in stage plays. As an example, suppose a program were to be broadcast from Parker Hall at 7:00 P.M. It is to follow a civic discussion from the studio which is on the air from 6:45 to 7:00 P.M. An operator on duty at Parker Hall has to know precisely when to cue in his program. This is accomplished by means of a cuing line which is simply another telephone line over which the civic discussion is sent to the Parker Hall operator. This man can then hear when the preceding program is over and so receives the necessary information so that he can connect in his own program. He can also listen to his own broadcast, if it is desirable.

The same ideas may be used for cuing programs originating right in the studios. A performer about to begin his broadcast may listen to the program preceding his over a loudspeaker mounted in the studio. In this way he can hear the termination of the other broadcast and be prepared to start his own. An electrical interlock automatically disconnects the studio loudspeaker immediately upon energizing the studio microphones. If this were not provided, the program being sent out over the air would be fed back into the microphone in which it originated causing a tremendous howl. This condition must be carefully avoided. The condition can sometimes be noticed in public address systems where the microphone is too close to the loudspeakers.
During auditioning, it may be necessary for the studio operator to give instructions to a group in one of the studios. This "talkback" feature is available by merely pressing a switch on the speech input equipment. The switch connects the control room microphone to the loudspeaker in the studio. This circuit is independent from the transmitter.

A volume indicator meter is provided on the panel so that the operator may see the amount of energy being passed to the transmitter.

It should be brought to mind that all programs will not originate in the studios. As a result, provision must be made to take care of remote pickups. This entails renting or leasing the necessary telephone lines and, in addition, having available a remote speech input equipment. This will be used by the remote operator to control as well as amplify the sound coming over his microphones to a point where it is strong enough to be sent out over the telephone wires. A type 22D Western Electric portable speech input equipment will be satisfactory. Monitoring on the spot by either headsets or loudspeaker is provided. The set operates from an impedance of 30 ohms and should feed into 150 or 600 ohms. It also provides 92 db gain. Either batteries may be used as a power supply or 110 v., 60 cycle AC if available.

A large percentage of the programs broadcast over the
air will be recordings. Hence the need is apparent for two Western Electric Type G 2 Deluxe Turntables. Two are required since it is necessary for the operator to be setting up machine No. 2 while No. 1 is playing. These turntables will fit in nicely with the speech input equipment since they may be fed in and amplified the same as any program over the microphones. Provisions are also available for fading in or out and also mixing the recorded programs with announcements over the control room microphone.

With the turntables must go a fairly complete set of recordings and also a place to keep them. File cabinets are available for this purpose. The records should include both popular, semi-popular, chamber music, dinner music, string quartets and classical numbers. It would be convenient also to have a record cutter available in the studio so that transcriptions could be made of programs and then broadcasted at some time in the future. No such equipment is contemplated however, for the present installation.

There will be three Western Electric Type 633-A microphones and also three Western Electric Type 639-A microphones required complete with the necessary stands, cable and attachments. The first type is somewhat directional in nature, while this feature may be accentuated by means of a separate baffle attachment. The
second type of microphone has a much flatter frequency response curve from 40 to 12,000 cycles per second and also has controlled directivity. By means of a switch on the microphone itself, the directivity pattern may be adjusted to any one of six patterns. This permits great flexibility of installation. Of course, this microphone costs more also.

The type 639-B microphone is made to be used with amplifiers having input impedances from 25 to 50 ohms. The type 633-A has an output impedance of 20±2 ohms.

Three Western Electric type 755-A loudspeakers will be required. One of these will be mounted in the control room, another in studio A and the third in the reception room. This will permit the necessary monitoring. Speakers may be switched on or off at will by the control room operator.

A check on impedance matching from the microphones to the transmitter yields the following results:

Microphone to speech input equipment -
20 ohms into 30 ohms. Satisfactory.

Microphone to portable speech input equipment -
20 ohms into 30 ohms. Satisfactory.

Speech input equipment to transmitter -
600 ohms into 600 ohms. Satisfactory.

Portable speech input equipment to speech input Equipment -
600 ohms into 600 ohms. Satisfactory
Speech input equipment to loudspeakers -

750 ohms into 12 ohms. Unsatisfactory.

(A transformer would have to be used here for impedance matching purposes.)

Computations of power levels throughout the station equipment from microphone to transmitter (20) are shown below.


It is essential that sufficient amplifying power be available between the microphones and the antenna in the tube stages provided; a calculation of this will be shown. The "decibel" (db) which is a logarithmic ratio between power output and power input will be used.

\[
\text{db} = 10 \log_{10} \frac{P_2}{P_1} \]

Where db = Decibel

\(P_2\) = Power output (of a stage, device, or several stages).

\(P_1\) = Power input.

\(\log_{10}\) = Logarithm of the ratio taken to the base ten.
Positive values of db indicate a gain through the stage while negative values indicate a loss.

**TYPE 633A DYNAMIC MICROPHONE**

Power output level of microphone (when terminated by a resistance of 20 ohms) is -56 dbm. (21)

(21) "dbm" represents a decibel rating referred to one milliwatt as reference level; 10 dynes/sq. cm. sound pressure.

**TYPE 633B COMBINATION DYNAMIC AND VELOCITY MICROPHONE**

Power output level of microphone (when terminated by an impedance of 25 to 50 ohms) is -56 dbm.

**TYPE 23C SPEECH INPUT EQUIPMENT**

Gain 96 db through microphone channels. Gain 64 db through program line channels. Monitor gain 18 db above that of line amplifier.

**TYPE 22D PORTABLE SPEECH INPUT EQUIPMENT**

Maximum gain of approximately 92 db.

**TYPE 755A LOUDSPEAKER**

Power handling capacity 8 watts continuous.

**TYPE 451A-1 TRANSMITTING EQUIPMENT**

Input level +20 dbm for 100% modulation.

Starting with the power output of the weaker microphone, (neglecting line losses) the power may be built up to a maximum of -56 + 92 = +36 db which is ample to provide 100% modulation for the transmitter. Converting
this to watts, (with 1 milliwatt as 0 db level) it becomes:

\[ 36 = 10 \log_{10} \frac{P_2}{1 \text{ mw}} \]
\[ 3.6 = 10 \log_{10} \frac{P_2}{1} \]
\[ 3980 = \frac{P_2}{1} \]

\[ P = 3980 \text{ milliwatts or } 3.98 \text{ watts} \]

maximum available to drive the transmitter.

Whereas the amount required by the transmitter is only

\[ 20 = 10 \log_{10} \frac{P_2}{1} \]
\[ 2 = \log_{10} \frac{P_2}{1} \]
\[ 100 = \frac{P_2}{1} \]

\[ P_2 = 100 \text{ milliwatts or } .1 \text{ watt} \]

Therefore it can be seen that ample power is available. For the portable speech input equipment, its output would be fed over a telephone line having relatively large attenuation. However, when the program reaches the station, it is again amplified by the permanent speech input equipment, so no trouble is anticipated here.

Now to examine the audio station monitoring equipment. The output of the monitoring amplifier of the speech input equipment is given as 2.5 watts. The loudspeakers are rated at 8 watts maximum (each of three)
speakers). This is believed to be a satisfactory arrangement since it will not be necessary to operate the loudspeakers at their maximum ratings. However, if sufficient drive is not available, it would be a simple matter at a later date to add an additional stage or two of audio amplification to the loudspeaker input circuit.
THE ANTENNA

Since a location for the antenna has already been decided upon (see previous chapter) it would be wise to determine the capabilities of the antenna. There are many variables which enter into the calculation of an antenna's output, so that calculated results are likely to be in error. However, they will not be so far in error as to give false impressions of the coverage. Field strengths at various distances from the transmitting antennas will be calculated and tabulated. Whether these values will be sufficient to provide the listener with radio programs will depend on many factors, although opinions have been expressed on this point. Eckersley (22) in Great Britain recommends a minimum of 2.5 mv/m for rural areas during the summer. The F.C.C. recommends 0.5 mv/m as a signal strength satisfactory to be heard over noise levels in towns of up to 2,500 population. For 2,500 to 10,000 population, a figure of 2.0 mv/m is given.

Whether a signal strength will be adequate for the listener is going to depend on many factors; i.e. the amount of static present, the amount of man-made interference, the acuteness of hearing of the individual listener, and the quality of the receiver. The requirements for a
rural area would be much less than those for a city.

The antenna to be used will be a Blaw-Knox 190' tower, guyed and insulated. See Plate No. 21. The matter of insulation to ground is discussed by Morrison (23)


If the antenna is insulated, it means that greater expense of installation is required, since a strong insulator supporting the weight of the antenna would be needed. Also the necessary filter would be required in the antenna lighting circuit, since it would be necessary to keep the antenna R-F from following the wires to ground. There would also be required a lightning discharge gap and protection for the transmitter against any static electricity coming back from the antenna along the antenna feeder to the transmitter.

A grounded antenna eliminates all the above, and in addition is thought to radiate as much energy as the ungrounded type. Tests have been made on a Detroit broadcasting station with satisfactory results. A special connection, however, is required for the grounded type in that the feeder taps onto the antenna at some distance above the ground. (With the other type, the feeder is attached to the bottom). A series condenser is placed in the feeder circuit also. The height of connection to the antenna is
Ground Wires
Bare Copper

.4 \lambda \text{ Long}
Plowed 2' Under,
Not all shown.
Spaced 3'

Plan

Guy Wire

Concrete Block Support

Insulators

Static Electricity Spillover

Elevation

PLATE NO. 21
determined to correspond to the impedance of the transmission line.

For the installation in mind, it is thought wise to use a more time-tested method and therefore the insulated antenna will be specified. This is no condemnation of the shunt-fed antenna, however, and it may easily be that in the future some enterprising M.S.M. engineers may desire to run comparative tests on the two types.

There is also the decision required as to whether the antenna will be guyed or self-supporting. The guy wires, even though properly broken up with insulators, still will absorb some of the energy and decrease the effective radiation. Discussion of this matter with radio station owners leads to the conclusion that the slight amount of energy saved is not worth the additional expense required to install a self-supporting antenna. Therefore the guyed, insulated antenna is decided upon.

This being a class IV station (24), the minimum

(24) Class IV stations are defined in part as those which "operate on local channels normally rendering primary service only to a city or town and the suburban and rural areas contiguous thereto with powers not less than 0.1 kW or more than 0.25 kW.

height of antenna is 150 feet or a minimum effective field intensity of 75 mv/m for 250 watts. At 1250 kc, the minimum height is 150 feet (it becomes greater as the frequency decreases). The antenna height decided upon,
190 feet, is therefore on the conservative side of the figure quoted above. It is advantageous, since the antenna will not be very high, to keep it under 200 feet. The reason is that the antenna must be properly safeguarded at night with red lights to prevent airplane accidents. The requirements for lighting are more stringent (and therefore more expense is involved) above 200 feet antenna height. Hence it is desirable to be on the low side of 200 feet. It will probably be easier, too, to obtain approval from the C.A.A. if a low antenna is used. The lighting requirements call for two electric lamps, red, mounted on top of the antenna and also two lamps placed one-third the way up, and two lamps placed two-thirds of the way up. The lamps are not of the flashing type. A time switch will be required to turn the lights on at sunset and off at sunrise.

The actual calculation of probable field strengths at various geographical locations may be made in several different manners. Various authors have worked out different methods. Four methods will be shown. The calculations depend on how many of the many variables which are encountered are to be considered. For instance, the antenna is said to radiate both a ground wave and a sky wave. The ground wave travels outward along the surface of the earth, being gradually attenuated due to the earth being a poor conductor. Actual currents are generated in
the ground, which means a power loss to the wave. Hence the wave is attenuated. The amount of attenuation increases as the frequency increases; in other words, signals sent out above 500 meters in wavelength travel for hundreds and even thousands of miles along the earth's surface and are still receivable, while short-wave radio has only a short ground-wave which usually fades out well below 100 miles away.

The sky wave, however, has practically no attenuation. It simply is sent up from the antenna and is reflected from the ionized layers back to the earth. Reflection may take place several times between the earth and ionized layers as the wave moves along.

Since the ground wave and not the sky wave will be relied on to provide the listener's radios with proper excitation, efforts will be confined to calculations of the ground wave only. It is a well-known fact that radio waves travel better over sea water than land, but fitting this fact and others to a mathematical formula may become somewhat complicated. Consider a wave traveling over Missouri terrain. In populated districts, much attenuation would be expected. Over the hills and valleys and wooded sections, the attenuation would also be high, but it would vary with the change in altitude, the density of forestation, number of ravines, brooks, etc.

An interesting sidelight on the matter of attenuation
of a radio wave as it passed over rough country was explained by an engineer of the British Broadcasting Company. The company was running some field strength tests and comparing them with calculated data. During the tests, at a certain distance from the transmitter, they set a receiver in a ravine which ran radially out from the transmitter. The signal received was practically negligible. They then placed the receiver in a similar ravine at another place nearby, but at the same distance from the transmitter. This ravine now ran in a direction perpendicular to the first; that is, its direction was tangent to a circle drawn through the point with the transmitter antenna as a center. The receiver now gave a signal strength almost as good as if the receiver had not been in the ravine.

Radio waves are assumed to penetrate the ground to a depth from 10 feet to approximately 50 feet, depending on ground conductivity. Radio waves will even penetrate sea water a few feet, so that it is possible for a submarine to receive radio signals even though the submarine is completely submerged. The wave attenuation is high, however. Conversely, the submarine could also send out waves which might be heard a few miles away. All of which is brought out to show that minor irregularities in the earth's surface would have little effect on a radio wave: rather, the major irregularities in height and the
conductivity of the ground would cause the attenuation.

To show variation of the ground conductivity throughout the United States, an F.C.C. chart giving these values is included. Plate No. 22 reveals the fact that central Missouri has a ground conductivity of $3 \times 10^{-14}$ emu. The northern part of the state has a value of $15 \times 10^{-14}$ emu and the southern part (including Rolla) a value of $4 \times 10^{-14}$ emu.

The formulas and calculations which follow are applications of ground wave field strength calculations to the state of Missouri. The constants used in each method are given and sample calculations, where applicable, are shown. No calculations are made on the sky wave, since this wave is too inconsistent for good reception. The ground wave may be relied on to provide fairly constant values regardless of daytime or nighttime, winter or summer. The sky wave varies considerably (as to the point where it returns to the earth) throughout the day and also varies with the season. While it is true at times that radio stations are heard hundreds of miles away, nevertheless this is the exception rather than the rule. The exception cannot be counted on in this case to furnish consistent radio coverage.
Federal Telephone and Radio Corporations' Method

The formula (greatly simplified) for the ground wave field intensity is given as

\[ E = 150 \sqrt{P_t} \text{ millivolts per meter at 1 mile} \]  
[1]

Where \( P_t \) = Transmitter output power in kilowatts.

\( E \) = Field intensity in millivolts per meter.

This formula is considered as typical for well-designed stations with a vertical antenna length of .15 to .25 \( \lambda \).

The 190' antenna to be used with the M.S.M. station would have an antenna length of

\[ \frac{190}{240 \times 3.281} = .241 \lambda \]

Where 190 = antenna height in feet.

3.281 = conversion factor - convert meters to feet.

240 = The wavelength corresponding to 1250 kc. (the assumed frequency of the transmitter).

Substituting in equation [1] above,

\[ E = 150 \sqrt{.250} \]

\[ = 150 \times .5 \]

\[ = 75 \text{ millivolts per meter at one mile.} \]
This calculation, then, gives the field intensity at one mile from the antenna or the inverse-distance field. To determine the field strength for other distances, it is necessary to use the graphs given in the reference book (26).

(26) Ibid.

Of the graphs shown, that which most nearly coincides with the conditions in central Missouri is that shown for poor earth, where $\sigma$ is $2 \times 10^{-14}$ emu. and $E$ is 5 esu.

$\sigma$ = Ground conductivity in electromagnetic units.

$E$ = Dielectric constant of the ground in electrostatic units.

The graph is calculated on the basis of a field strength of 186 millivolts per meter at one mile. Therefore all values taken from the graph must be corrected by a factor $\frac{75}{186}$ to take into account the decreased power of the station.

Sample calculation.

To determine the field strength 5 miles from the antenna, read the graph at the "5 mile" mark. This coincides with a field strength (for 1250 kc) of 10,000 microvolts per meter (or 10 millivolts/meter). Applying the correction factor, the following is obtained.

$$\frac{75}{186} \times 10 = 4.03 \text{ mv/meter}$$

See Table F for other calculated values using this method.
To go into the calculation of field strength a bit more thoroughly, cognizance must be taken of several more factors. A wave, radiated from an antenna completely isolated in space, permits relatively simple field intensity calculations. A wave, traveling over a perfect ground, may offer more difficulty of solution. To investigate the strength of a wave traveling over a finitely conducting spherical earth (not a perfect conductor) is more complicated. The ground wave travels through both the air and the ground, and at different velocities in each. It is attenuated more as it passes through the ground than through the air. The ground wave not only travels along the ground, but since the transmitting antenna is usually high in the air part of the wave is sent down to the ground where it is reflected back up to the receiving antenna. This reflected portion is called the "ground-reflected" wave. That portion traveling through the air directly from the transmitting antenna to the receiving antenna is the "direct-wave", and that portion traveling along the junction of the two media is known as the "surface wave". All three combined make up the ground wave, as distinguished from the sky wave.
The complete formula given by Norton for field strength calculations at short distances over a plane earth follows:

\[
E = \frac{E_0}{d} \left[ \cos^3 \psi_1 e^{i2\pi r_1/\lambda} + R \cos^3 \psi_2 e^{i2\pi r_2/\lambda} 
\right. \\
\left. + (1-R) \int (P.B) \cos^2 \psi_2 e^{i2\pi(r_2/\lambda + \phi)} \right] 
\]

Where \( E \) = Field intensity in millivolts per meter
\( E_0 \) = Free-space field intensity at unit distance
\( i = \sqrt{-1} \)
\( d \) = See Plate No. 23. Expressed in miles.
\( r_1 \) = See Plate No. 23. Expressed in miles.
\( r_2 \) = See Plate No. 23. Expressed in miles.
\( \psi_1 \) = See Plate No. 23. Expressed in miles.
\( \psi_2 \) = See Plate No. 23. Expressed in miles.
\( \lambda \) = Wavelength expressed in miles.

In formula [2], the first term on the right inside the brackets is the "direct wave"; the second term is the "ground-reflected" wave; and the third term is the "surface-wave". The first two together are known as the "space-wave."
Also: 
\[ \tan \psi_1 = \frac{h_1 - h_2}{d} \] [3]
\[ \tan \psi_2 = \frac{h_1 + h_2}{d} \] [4]

\[ R = \frac{(q_1 + q_2) e^{i(\pi/4 - b/2)}}{2p} - 1 \] [5]
\[ \frac{(q_1 + q_2) e^{i(\pi/4 - b/2)}}{2p} + 1 \]

\[ p = \frac{\pi r_2}{\lambda} \cos \frac{2b''}{x \cos b'} \] [6]
\[ = 2b'' - b' \] [7]

\[ q_{1,2} = \frac{2\pi h_1,2}{\lambda} \left[ \cos \frac{2b''}{x \cos b'} \right]^{1/2} \] [8]

\[ x = \frac{1.79731 \times 10^{15} \sigma_{\text{emu}}}{\text{fmc}} \] [9]

\[ \tan b' = \frac{(e - \cos^2 \psi_2)}{x} \] [10]

\[ \tan b'' = e/x \] [11]

\[ R = \frac{q_1 + q_2 e^{i(\pi/4 - b/2)}}{2p} - 1 \] [12]
\[ \frac{q_1 + q_2 e^{i(\pi/4 - b/2)}}{2p} + 1 \]

\[ f(p, \theta) = \frac{4 F(p, \theta)}{(1 - R)^2} \] [13]

Where \( p \) = Sommerfeld's "numerical distance"

\( P, B, Y, x, b'', b', b \) = Parameters

\( q_1 \) = Numerical transmitting antenna height

\( q_2 \) = Numerical receiving antenna height

\( \sigma'_{\text{emu}} \) = Ground conductivity expressed in electromagnetic units.
EXPLANATION OF CONSTANTS FOR FIELD INTENSITY CALCULATIONS

- $h_1$ - Transmitting antenna height
- $h_2$ - Receiving antenna height
- $\psi_1$, $\psi_2$ - Angles

PLATE NO. 23
\( \epsilon = \text{Dielectric constant of the ground referred to air as unity.} \)

\( R = \text{Plane wave reflection coefficient of the ground.} \)

For distances of less than \( \frac{50}{(fmc)^{1/3}} \) miles the above formula is satisfactory. This amounts to distances less than 45 miles from the transmitting antenna.

A calculation will be made first using the given formula, and then a simpler graphical solution will be used to complete the column of data in Table F.

Earlier in this chapter a value of ground conductivity was determined as:

\[ \sigma = 4 \times 10^{-14} \text{ emu.} \]

From "Reference Data for Radio Engineers" (29) is obtained the dielectric constant of the ground as:

\[ \epsilon = 10 \text{ esu.} \]

Given a wavelength of 240 meters corresponding to a frequency of 1,250 kc, and assuming antenna heights as shown,

\[ \lambda = \frac{240 \times 3.281}{5280} = .149 \text{ mi.} \]

\[ h_1 = \frac{190}{2 \times 5280} = .0180 \text{ mi.} \]

\[ h_2 = \frac{40}{2 \times 5280} = .00379 \text{ mi.} \]

\[ d = 5 \text{ mi.} \]
\[ \tan \psi_1 = \frac{h_1 - h_2}{d} = \frac{0.0180 - 0.00379}{5} = 0.00285 \]
\[ \psi_1 = 0^\circ 10' \]
\[ \cos \psi_1 = 1 \]
\[ r_1 = \frac{d}{\cos \psi_1} = \frac{5}{1} = 5 \]
\[ \tan \psi_2 = \frac{h_1 + h_2}{d} = \frac{0.0180 + 0.00379}{5} = 0.00436 \]
\[ \psi_2 = 0^\circ 15' \]
\[ \cos \psi_2 = 1 \]
\[ r_2 = \frac{d}{\cos \psi_2} = \frac{5}{1} = 5 \]
\[ x = \frac{1.79731 \times 10^{15}}{f_{mc}} = \frac{1.79731 \times 10^{15} \times 4 \times 10^{-14}}{1.25} = 57.5 \]
\[ \tan b' = (\varepsilon - \cos^2 \psi_2) x = \frac{10 - 12}{57.5} = \frac{2}{57.5} = 0.0345 \]
\[ b' = 8^\circ 54' \]
\[ \cos b' = 0.9879 \]
\[ \tan b'' = \frac{\varepsilon}{x} = \frac{10}{57.5} = 0.174 \]
\[ b'' = 9^\circ 52' \]
\[ \cos b'' = 0.9852 \]
\[ b = 2b'' - b' = 18^\circ 104' - 8^\circ 54' = 10^\circ 50' \]
\[ q_1 = 2 \pi h_1 \left[ \frac{\cos^2 b''}{x \cos b'} \right]^{1/2} = \frac{2 \pi \cdot 0.018}{0.149} \left[ \frac{0.9852^2}{57.5 \times 0.9879} \right]^{1/2} = 0.0995 \]

\[ q_2 = 2 \pi h_2 \left[ \frac{\cos^2 b''}{x \cos b'} \right]^{1/2} = \frac{2 \pi \cdot 0.00379}{0.149} \left[ \frac{0.9852^2}{57.5 \times 0.9879} \right]^{1/2} = 0.0210 \]

\[ p = \frac{\pi r_p}{\lambda} \left[ \frac{\cos^2 b''}{x \cos b'} \right] = \frac{\pi}{0.149} \left[ \frac{0.9852^2}{57.5 \times 0.9879} \right] = 1.802 \]

From \([12]\),
\[ R = \frac{0.099 + 0.0208}{2 \times 1.802} e^{\frac{1(\pi/4 - 10^051')}{2} - 1} - \frac{0.099 + 0.0208}{2 \times 1.802} e^{\frac{1(\pi/4 - 10^051')}{2} + 1} = -0.95 \]

From the graph provided by Norton and for values of \( p \) and \( b \) as calculated above, we obtain as a value of \( \mathcal{K}(p,b) \):
\[ \mathcal{K}(p,b) = 0.24 \times 1.802 = 0.432 \]

But from \([13]\),
\[ \mathcal{K}(p,b) = \frac{4 \mathcal{K}(p,b)}{(1-R)^2} = \frac{4 \times 0.432}{[1 - (-0.95)]^2} = 0.454 \]

Also from the graph provided we obtain \( \phi \).
\[ \phi = 118^0 \]
E₀ yet remains to be determined. This is given as 

\[ E₀ = 97.3 \]

for a vertical quarter-wave antenna at the surface of a perfectly conducting earth, with one kilowatt of energy radiated. To correct this to a value corresponding to 250 watts radiated energy instead of one thousand watts, we have

\[
\frac{E₀}{1000} = \sqrt{\frac{250}{1.000}}
\]

\[ E₀ = \frac{5}{4} \times 97.3 = 48.65 \text{ millivolts/meter} \]

Substituting in formula [2],

\[
E = \frac{48.65}{5} \left\{ 1^{3}e^{i273.5} + (-.95) 1^{3}e^{i273.5} \right\}
\]

\[ + \left[ 1 - (-.95) \right] .454 \ 1^{2} e^{i(273.5 + 118°)} \]

\[ = 8.61 \text{ mv/meter at 5 miles} \]

Graphical Solution by Norton's Method =

From previous calculations we had the fact that

\[ r_2 = \frac{d}{\cos \psi_2} \]

Substituting in equation [6],

\[
p = \frac{\pi d}{\cos \psi_2} \frac{\cos^2 b''}{x \cos b'}
\]

Solving for \( d \),

\[
d = \frac{p \lambda x \cos b' \cos \psi_2}{\pi \cos^2 b''}
\]
Then let $p = 1$ and solve for $d$ (To obtain the value of $d$ corresponding to $p = 1$)

$$d = \frac{1 \times .149 \times 57.4 \times .9879 \times 1 \times 240 \times 3.281}{\pi \times .9851^{\frac{2}{5280}}}$$

$$d = \frac{18.6 \times 240 \times 3.281}{5280} = 2.78 \text{ miles}$$

Next, calculate $\frac{2 E_0}{d}$ and draw a straight line on a piece of log-log graph paper as shown on Plate No. 24. This is the inverse distance line.

$$\frac{2 E_0}{d} = \frac{2 \times 48.65}{d} = \frac{97.30}{d}$$

Insert various values of $d$ (widely separated) in the above formula to plot the straight line. To obtain the field intensity vs. distances less than 45 miles, place the sheet over the curve provided, move it horizontally until 2.8 miles corresponds with $p = 1$, and vertically until the two inverse distance lines coincide. Then trace the curve corresponding to $b = 10^0 50'$. See Plate No. 24 for the curve thus obtained for Rolla and vicinity.

At distances greater than 45 miles, account must be taken of the curvature of the earth. This is done by means of curves given in the reference.

A constant $K$ must first be calculated.

$$K = \left[\frac{\lambda}{2\pi ka}\right]^{1/3} \left[\frac{x \cos b'}{\cos^2 b''}\right]^{1/2}$$
Where \( K \) = A parameter

\[
K = A \text{ constant} \quad (4)
\]

due to refraction of radio waves caused by decrease of the refractive index of the air with height.

\( a = \) Radius of the earth

\[ K = .126 \]

Also

\[
\eta_o = (k^2 a^2 \lambda)^{-1/3}
\]

Where \( \eta_o \) = A parameter,

\[ \eta_o = .00621 \]

Also

\[
\rho_o \quad (\text{From reference}) = 1.52
\]

Where \( \rho_o \) = A parameter

\[
\gamma \quad (\text{From graph provided}) = .0011
\]

Where \( \gamma \) = A parameter

Then

\[
E(h' = 2) = 2 E_o \eta_o \gamma = 97.3 \times .00621 \times .0011
\]

\[ = .000665 \text{ mv/meter} \]

\[
d(h' = 2) = \frac{2}{\rho_o \eta_o \gamma} \quad = \frac{2}{1.52 \times .00621}
\]

\[ = 212 \text{ miles} \]

The distance of 212 miles is then plotted (see small circle on Plate No. 24) and sheet is then placed over the reference curve. The curve corresponding to \( K = .126 \) is traced.

Data taken from the curve of Plate No. 24 is shown in Table F.
FIELD INTENSITIES AT VARIOUS DISTANCES FROM ROLLA

PLATE NO. 24
This method makes use of the same ideas put forth in preceding paragraphs, but is somewhat simplified. Some of the same constants are used, and where applicable data will be used which has already been calculated.

\[ E_{su} = \frac{2 E_0}{d} A \frac{d}{(f_{mc})^{1/3}} \text{ mile} \quad [14] \]

Where \( E_{su} \) = Surface wave field intensity

\( A \) = Attenuation factor due to losses as the wave passes over the earth.

A distance of five miles will again be arbitrarily chosen for calculation. (Other distances and corresponding field strengths are shown in Table F). At this distance, \( p = 1.802 \) and \( b = 10^050' \). A value of \( A = .42 \) corresponds to these values of \( p \) and \( b \).

Substituting in 14,

\[ E_{su} = \frac{2 \times 48.65}{5} \times .42 \]

\[ = 8.18 \text{ mv/meter at five miles distant from the antenna.} \]
A somewhat different method of approach to the matter is taken in Mr. Eckersley's method. No dielectric constant of the ground is used, and for the ground conductivity a value of $\sigma = 10^{-13}$ is given. This figure applies to open pastoral country as would be found in England. Mr. Eckersley's calculations and measurements were made in England for the British Broadcasting Corporation and hence the values he gives would naturally be worked out for conditions found in the British Isles. The next higher value of ground conductivity was $10^{-12}$, applying to marshy flat land. The next lower value of ground conductivity was $0.2 \times 10^{-13}$, corresponding to hills and valley varying from 200 feet to 1000 feet above sea level. Obviously Ozark country would be somewhere between these two extremes, so a value of $10^{-13}$ was used.

The curves given are based on an antenna of T formation and 10 ohms dead loss resistance. These conditions are different for the M.S.M. transmitter, but investigation indicates that the T radiator field strength would be only slightly greater than the field strength for a plain vertical radiator of the same height. Therefore the data will be used, although results may be somewhat optimistic.
The data worked out in this method is based in part on the formulas of Sommerfeld, Van der Pol \(32\), T. L.


Eckersley, Stuart Ballantine, Professor Appleton and the U. S. Bureau of Standards.

The procedure is given herewith:

\[E_x \alpha \frac{1}{x} \quad (S)\]

Where \(E_x\) = Field intensity at a point removed "x" units from the antenna

\(x\) = Distance from antenna

\(S\) = Multiplier to take into consideration the attenuation resulting from the wave passing over the earth

\[S = \sqrt{d_n}\]

\[d_n = \sqrt{\frac{\sigma}{\lambda}} (\frac{1}{2 \sigma \lambda \nu})\]

Where \(d_n\) = numerical distance from antenna

Where \(\nu\) = is the velocity of light.

The above data may almost all be obtained from curves. The values follow:

Multiplier to correct for antenna height = 7.7

Multiplier to correct for 250 watts antenna power instead of 50,000 watts is given =

\[\sqrt{\frac{25}{50}} = 0.707\]
Multiplier to correct field strength data for 250 watts instead of 1000 watts as given =

\[
\frac{.25}{1} = .5
\]

\(E (25.5)\) is then obtained for 8.05 km (5 miles) where \(= 10^{-13}\) and 1 kW of energy is radiated.

Therefore,

\[E_x = E \times \text{correction factors} = 25.5 \times 7.7 \times .0707 \times .5\]

\[= 6.94 \text{ mv/meter at five miles.}\]

Field intensities at other points are shown in Table F.

Eckersley claims his calculated values for the B.B.C. checked within 15% of actual measured field strengths for the long-wave Daventry station.

Perusal of Table F emphasizes to the reader something which he knew all along - that radio reception in Rolla of any outside station is poor! If .5 mv/meter is taken as the weakest signal still giving satisfactory reception, then the 250 watt station will be audible over a range of only 15 to 20 miles. Of course with good receivers it could be heard at greater distances, and also at a hundred or more miles from the transmitter the sky wave should be picked up - but these are exceptions rather than the rule.

Increasing the antenna height and also the power would help some. Referring to the table again, suppose a transmitter the size of KNOX (50,000 watts) were located
Table F

A Comparison of Results obtained in the calculation of field strength of the M.S.M. transmitter by using different formulas.

<table>
<thead>
<tr>
<th>Radial Dist. from MSM Antenna Miles</th>
<th>Federal Tel. and Radio Corporation Method Millivolts / meter</th>
<th>K.A. Norton's graphical method Millivolts / meter</th>
<th>F.E. Terman's graphical method Millivolts / meter</th>
<th>P.P. Eckersley's method Millivolts / meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75.0</td>
<td>75.0</td>
<td>68.0</td>
<td>not applicable</td>
</tr>
<tr>
<td>2</td>
<td>16.1</td>
<td>32.0</td>
<td>29.2</td>
<td>not applicable</td>
</tr>
<tr>
<td>3</td>
<td>8.0</td>
<td>19.5</td>
<td>16.2</td>
<td>not applicable</td>
</tr>
<tr>
<td>5</td>
<td>4.0</td>
<td>6.61</td>
<td>8.18</td>
<td>6.94</td>
</tr>
<tr>
<td>10</td>
<td>4.44</td>
<td>2.2</td>
<td>1.75</td>
<td>2.51</td>
</tr>
<tr>
<td>25</td>
<td>.12</td>
<td>.25</td>
<td>.23</td>
<td>.37</td>
</tr>
<tr>
<td>50</td>
<td>.028</td>
<td>.05 (33)</td>
<td>.05 (33)</td>
<td>.053</td>
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<tr>
<td>100</td>
<td>.004</td>
<td>.009 (33)</td>
<td>.009 (33)</td>
<td>not applicable</td>
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The last two entries under Norton's Method and the last two entries under Terman's Method are identical since both methods use the same formulas for distances beyond the line of sight.
in Rolla. Converting the mv/meter quantities from the table to correspond to a transmitter of 50,000 watts, a value of only 50 to 70 miles is found to be the maximum range for .5 mv/meter (assuming no change in antenna height, frequency, or other constants.) The main cause of the large attenuation around Rolla is the poor ground conductivity and low dielectric constant of the earth. An increase, say in $f$ from $4 \times 10^{-14}$ to $10 \times 10^{-14}$ emu. would make a sizeable increase in field intensities.

The values in Table F compare with each other favorably. Probably the most reliable set would be that calculated according to Norton's formulas. Greater pains are taken in this method than in the others, and more constants are evaluated. Eckersley's method does not consider the dielectric constant of the earth. The Federal Telephone and Radio Corporation's method is too general in its application. Terman's method closely parallels Norton's ideas with some simplifying assumptions.

To give a better idea of the coverage to be expected from the M.S.M. transmitter, turn to Plate No. 1. On this plate have been drawn the mv/meter contours.
THE COST

Following is a list of the approximate price of various items. Due to changing business conditions, these may vary considerably as time goes on. They are intended to give only a rough idea as to what it would cost the State of Missouri to install a 250 watt broadcast transmitter at the Missouri School of Mines.

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete block building to house the transmitter and studios (See Plate No. 10) complete with pump and well, furnace and sewage system</td>
<td>1</td>
<td>$19,000</td>
</tr>
<tr>
<td>W.E. type 451A-1 250 watt radio transmitting equipment complete with 2 sets of tubes</td>
<td>1</td>
<td>3,400</td>
</tr>
<tr>
<td>W.E. type 25C Speech Input equipment complete with tubes and power supply</td>
<td>1</td>
<td>765</td>
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<tr>
<td>W.E. type 633-A microphones</td>
<td>3</td>
<td>145</td>
</tr>
<tr>
<td>W.E. type 639-A microphones</td>
<td>3</td>
<td>300</td>
</tr>
<tr>
<td>W.E. type 755-A loudspeakers</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>W.E. type G 2 Deluxe turntables</td>
<td>2</td>
<td>310</td>
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<td>W.E. type 274 Oscilloscope</td>
<td>1</td>
<td>130</td>
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<tr>
<td>W.E. type 22-D remote speech input equipment for battery and AC operation, complete with tubes</td>
<td>1</td>
<td>490</td>
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<tr>
<td>W.E. type 22-A floor microphone mountings</td>
<td>4</td>
<td>90</td>
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<tr>
<td>W.E. type ES 764305-2 floor stand weights</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>W.E. type 24A microphone mountings</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>General Radio type 1181-A frequency deviation monitor, complete with tubes</td>
<td>1</td>
<td>720</td>
</tr>
<tr>
<td>Item</td>
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<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>1 - General Radio type 1931-A modulation monitor, complete with tubes</td>
<td>$410</td>
<td></td>
</tr>
<tr>
<td>1 - Tower, 190 ft. high, guyed, insulated</td>
<td>2,500</td>
<td></td>
</tr>
<tr>
<td>1 - Tower lighting equipment for 190 ft. tower</td>
<td>515</td>
<td></td>
</tr>
<tr>
<td>1 - Set of recordings and record file cabinet</td>
<td>2,500</td>
<td></td>
</tr>
<tr>
<td>Misc. - Plugs, jacks, adapters, microphone cables, several thousand feet of wire, piano, rugs, furniture, and office equipment</td>
<td>2,000</td>
<td></td>
</tr>
</tbody>
</table>

**Total (not including price of land)** $33,400

The cost of the land on which to build the transmitter has not been included. This figure would be subject to wide variations depending on the location and on the present owner. Then again, it may be possible to lease the land rather than make an outright purchase, causing a wide variation in the amount of money required for the transaction.

In general, it is believed that the above figure gives a price which at this time would not be exceeded if the equipment specified is used. By careful buying and sacrifice of quality it would be possible to decrease the cost somewhat. It would also be possible to get by initially with considerably less equipment than that shown, and then gradually build up the station as time goes on.
CONCLUSIONS

As a result of the investigation involved in the preparation of this manuscript, it seems entirely possible for the School of Mines to build and operate a radio station serving the populace excellently within a radius of 15 to 20 miles of Rolla. This station could reach all of Rolla and the following additional towns: Vichy, Lanes Prairie, St. James, Rosati, Fanning, Cuba (possibly), Yancy Mills, Edgar Springs, Salem (possibly), Lenox, Flat, Looker, Dixon, Arlington, Newburg, Jerome, and Vienna. These locations should receive programs at any hour of the day that the transmitter is operating and during any season of the year. Other points further away would also receive the programs, but not as consistently as those inside the .5 mv/meter contour.

It is further believed that sufficient operating personnel could be furnished from the faculty and student body to operate the station. Some building maintenance would be required, but this could be handled by the School maintenance personnel. Further, an appropriation by the State Senate of $33,400 would cover the initial cost of erecting the building and equipping it as outlined previously.

A radio station operated by the Missouri School of Mines would benefit both the school and the populace served. The people would receive more entertainment and education.
The School would increase its training facilities and to a certain extent, spread its educational activities to a larger group than the normal student body.
SUMMARY

In the first chapter, various geographical locations for a 250 watt broadcast transmitter for the Missouri School of Mines were investigated. Matters of ground contour, elevation and nearness to good ground conductivity were emphasized. A total of four locations were considered and after studying the pros and cons of each, a final selection was accomplished. No effort was made to ascertain whether the ground was actually available for sale or lease. The picked location is in a broad valley, not too deep, with a small stream flowing through it giving better ground conductivity than would otherwise be available. It has power and telephone lines available, and can be easily reached by automobile.

The building to house the transmitter and studios is shown on Plate No. 10. It was laid out to suit the needs of a school broadcasting station, and consists essentially of two studios, a control room, office and reception room. Concrete block construction is used, except for some haydite bricks to give sound insulation and a few glass bricks in the front to provide natural lighting.

A deep-well and pump are included as well as a sewage disposal system. Neither water nor underground sewer pipes are available at the location. A parking lot is provided to the north of the building.

No matter how good a location is selected nor how
fine a building is erected, the station still will do no more than the transmitter and associated electrical equipment is capable of doing. Therefore some care should be exercised in laying out and equipping the station, keeping in mind the operational viewpoint as well as the eye appeal of the station. Accordingly high quality electrical equipment was selected, with reasons for including the various pieces of apparatus. The material included a transmitter, speech input equipment, microphones, loudspeakers, portable speech input equipment, frequency monitor, modulation monitor, antenna, turntables, and other less important parts. The reasons for using the items were brought out where needed. Calculations were made to show how the pieces of equipment would fit together electrically (i.e. impedance matching and power level comparison).

Finally, calculations were made on the field strengths which might be expected from the installation. These data were made by four different methods and at eight different distances from the antenna. The data compared favorably with each other and were used as a guide in determining the coverage to be expected by the 250 watt radio station. It was concluded that receivers within a radius of 15 to 20 miles from Rolla would receive programs consistently. Other sets farther away would of course hear the programs, but not as loudly or as consistently throughout the day and night, winter and summer.

The estimated cost of the building and contents was determined. This amounted to $33,400.00.
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VITA

The author was born October 21, 1914 in St. Louis, Missouri. He graduated from Purdue University in 1936 with a degree of Bachelor of Science in Electrical Engineering. After a total of six years in industry, and four and one-half years in the Army, he came to the Missouri School of Mines as an instructor in electrical engineering.

While teaching, work was begun towards the Master's Degree in Electrical Engineering.