LOUDSPEAKER PAGING SYSTEMS

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1. GENERAL

1.01 This section discusses the transmission considerations involved in the design of loudspeaker paging systems.

1.02 This issue completely reorganizes the section; transmission considerations are treated in detail and references to equipment are limited to transmission characteristics. Because revisions of the text are extensive, arrows indicating changes are omitted.

1.03 Because of the broad field of use for paging systems, requirements for individual systems as regards size, power, and control functions will vary widely. The application of paging systems in business and industry may range from the comparatively simple function of summoning to the telephone a person whose location is not precisely known, to the broadcasting of alarms and dispatching of emergency equipment. The dissemination of background music in the intervals between announcements is frequently required.

1.04 It is the purpose of this section to give the engineer the information needed and procedures to be followed in the transmission design of a paging system to meet a specific requirement.

2. DESIGN OBJECTIVES

2.01 The objective in providing a paging system is to enable people at some location or in some specific area to hear announcements clearly and without effort. This must be achieved in such a way that people working in a fixed location are not annoyed by uncomfortably loud sounds coming from the loudspeakers.

2.02 Where the system must convey information of a general nature to a number of people at once, the margin of paging level above room noise should be 10 db. In extremely quiet locations the sound intensity should not be less than 55-60 db above R.A.P. for satisfactory service. Reference Acoustic Pressure (R.A.P.) is 0.0002 dyne/cm^2 at 1000 cycles. This is equivalent to 2×10^{-4} microbar or 10^{-16} watts/cm^2. When the system is used to call individuals by name, with the understanding that a person so paged should call a switchboard operator or his office a margin of about 6 db above room noise is usually adequate.

2.03 Noise in the paging system must be kept to a level which is 50 db or more below the signal. It is especially important that no audible noise (hum, etc) be present continuously when the system is idle. Switching functions should be so arranged that they do not cause impulse noise in the system.

2.04 The reliability which a system exhibits must be adequate for its intended use. If the system is to be operational (essential to the continued function of the business involved) then the highest reliability is required of all components. This is not of such great importance in a system which is operated as a convenience. The needs of the subscriber for reliability must be carefully evaluated and considered along with other design requirements.

2.05 Of prime importance in paging system design is that the speech heard at the receiving location be highly intelligible. This will require that the system components be capable of smooth frequency response between 130 and 4,400 cycles per second and that this frequency response be modified only by equalization as covered in Paragraphs 4.20, 4.21, and 4.22 and by transmitter selection.

2.06 An installation may involve sound reinforcement. This would be the case in a church or a school auditorium. In this service the system must provide intelligible sound at a comfortable level over the required area. A desirable ultimate objective is that it will not be obvious that the speaker's voice has been artificially reinforced.

2.07 Where the dissemination of background music is an alternate function of the paging system some additional requirements must be considered. The source of the music may be a radio tuner, disc or magnetic tape recording, or connection to a commercial supplier of music. Paging system components must then be selected for their ability to distribute the music suitably. The band of frequencies involved in this service is between 75 and 8,000 cycles per second.

2.08 The paging system designer should be aware that a paging system which is engineered for high intelligibility will not sound like a high quality music system and that a music disseminating system will not exhibit high intelligibility in noisy areas. In quiet areas a music system should be adequate for paging, however.

3. TRANSMISSION ASPECTS

Determination of System Requirements

3.01 The first step in engineering a paging system is to study the location where the paging system is proposed. This usually requires a visit to the premises but in some cases (such as where the building construction has not been started or is incomplete) it must be done by studying available building plans. In most cases it will benefit the engineer to procure a set of blueprints of the building in advance of any visit. On this set of blueprints he can record anticipated or measured room noise levels, tentative loudspeaker or announcing station locations and special notations such as the requirement for explosionproof loudspeakers, sound treatment on walls or ceilings, etc. After engineering is complete the blueprint can become a part of the engineering office records on the system and copies of it forwarded to installation groups to show equipment locations.

3.02 Coincident with a study of physical conditions in the paging area a study must be made of the functions to be provided by the paging system. This study must answer many questions including:

(1) What is the fundamental purpose of the paging system?

(2) Must the paging system cover an entire plant or only certain areas?

(3) Who is to do the paging—switchboard operators, receptionists, foremen, etc?

(4) Should loudspeakers be grouped so that calls can be directed to specific areas as well as being heard in all locations at once?

(5) Should certain announcing stations be given access to only one or two specific loudspeaker groups?

(6) Where several announcing stations are employed what system busy indication should be provided, if any?

(7) Should any announcing stations be able to override a busy condition?

(8) If more than one plant or building is involved, should separate systems be provided; if so, should they interconnect?

(9) Will the paging system be used for purposes other than voice announcements—transmission of distinctive tones for fire or emergency alarm, shift changes, etc, or for music dissemination?

(10) If access to the paging system is through a dial telephone system, what arrangements should be provided to control or prevent unauthorized use of the system; how will acoustic feedback be controlled?

3.03 The above questions are representative of those which must be answered before the functional layout of the system can begin. In most cases the subscriber will not have ready answers for such questions, but will ask the advice of the system designer. It should be obvious at this point that the engineer must be thoroughly familiar with the capabilities of the control circuitry which can be supplied as part of the paging system. The engineer can then recommend an arrangement which will provide the needed functions.

Feedback

3.04 The control of feedback is of major importance in the transmission design of a paging system. Feedback is the coupling of energy in the output circuit of an amplifier to the input circuit or circuits within the amplifier. This coupling may be such that the energy from the output circuit is in phase with the input signal. This is called positive (or regenerative) feedback and its effect is to increase the gain of the amplifier. Where energy is fed from the output to the input circuit out of phase with the original signal the arrangement is referred to as degenerative or negative feedback. This is often employed in amplifier design to improve the frequency response and distortion characteristics of the amplifier.

3.05 The feedback which is of concern to the system designer is the electrical and acoustical coupling between the input and output circuits which may result in an oscillating system. Electrical feedback is generally caused by inadequate shielding. Acoustic feedback is the result of sound energy from loudspeakers arriving at a microphone location at a level high enough to cause singing or audio oscillation. A condition of incipient feedback results when the radiated sound output is inadequate to sustain oscillation but causes an increase in reverberation time or echo effect. These conditions must be avoided by proper separation of loudspeakers and microphones, by control of acoustical coupling conditions, or through the use of such devices as loudspeaker cutoff circuits or differential microphones.

Other Factors Affecting Transmission

3.06 Safety standards set by outside agencies may have a bearing on the transmission design of a paging system. The Standards of the National Board of Fire Underwriters and the National Electrical Code adopted by the National Fire Protection Association are examples. It is particularly important that the installation in any location designated or qualifying as a hazardous area be made in accordance with applicable safety standards. It is always advisable to discuss possible industrial hazards with the subscriber's safety engineer.

3.07 Unusual transmission problems should be recognized early and provided for in system design. If transmitter leads appear to be of excessive length then an amplifier may be required at the announcing station. Where inductive fields caused by electrical equipment are present it may be necessary to use transmitters which will not be affected by such fields. Adverse atmospheric conditions such as low temperatures (which contribute to moisture or frost accumulation in the transmitter), or metallic dust in the air should not be overlooked.

3.08 It is occasionally necessary to arrange the transmitter so that it will be used properly by untrained employees of the subscriber. In such cases the use of the telephone handset is indicated, since people are more familiar with this device than with any other kind of transmitter. An example of this can be found in a paging system requiring a large number of announcing stations which are spread over a large area and in an industrial atmosphere. The announcing station arrangement in this case might consist of a multistation telephone intercom circuit which is connected to the distribution bus feeding the amplifiers in the plant. An advantage of this arrangement is that a system busy condition is easily recognized by the average worker.

4. SYSTEM COMPONENTS

Announcing Stations

4.01 An announcing station is any assembly of equipment which is used to make announcements on the paging system. This equipment will include the transmitter, its mounting equipment, busy lamps and keys or pushbuttons for the control of the paging system. An announcing station might be simply a telephone instrument having access by dial or key to the paging system or a jack on the PBX switchboard whereby the operator could make announcements. Where the announcing station is remote from the paging amplifiers so that low level interconnecting circuits are impractical (— 50 to — 80 vu at the input end) an amplifier suitable for increasing the level from the transmitter level to normal line level (about 0 vu) may be located with the announcing station equipment. The signal may then be connected to other amplifiers by means of exchange or house cables containing other telephone circuits. Measurements should be made if there is doubt as to whether or not the signal-to-noise ratio will be adequate.

4.02 The location of the announcing station will generally be fixed by the subscriber's requirement as to the person or persons who are to do the announcing. This will usually include PBX attendants, receptionists, information desk attendants, cashiers, watchmen, foremen, etc. Where some latitude in the choice of location is permissible, the location should be chosen so as to be in an area of relatively low room noise and at sufficient distance from the nearest loudspeaker that feedback will not occur; selection of the location should be made so that excessively long leads from low level transmitters will be avoided and serious wiring or other installation problems will not be present. In most cases it will be advantageous to locate the station so that the announcements will be made by a trained announcer since this will contribute to the intelligibility of announcements in high noise areas.

Transmitters

4.03 Selection of the transmitter type involves the requirements of the system and the conditions at the announcing station and loudspeaker locations. Several general rules which should be considered are as follows:

(1) Where the paging system is intended for use in quiet locations, a transmitter should be used which has a smooth (flat) response characteristic; the intelligibility available with this type transmitter will allow the sound from loudspeakers to be adjusted to a comfortable level above the room noise and be easily understood. Several transmitter types are suitable in this application.

(2) Where the paging system loudspeakers are installed in high noise areas such as industrial plants, a transmitter should be selected having a response characteristic designed for a high degree of intelligibility, such as a standard telephone transmitter.

(3) Where the announcing station is in a noisy area, a transmitter designed for "close-talking" (1″-6″ from the lips) should be used. This will result in a favorable ratio between the level of the announcer's voice and that of the background noise. The "broadcast microphone" is not recommended in this application because when so used it has an appreciably higher output in the low frequency range (under 600 cycles) which requires equalization. The transmission of these lower frequencies would require a large fraction of the total amplifier output power without a corresponding contribution to system intelligibility; they would also cause overload in horn type loudspeakers with consequent distortion. Telephone carbon transmitters and receiver units in telephone handsets are often used under such conditions. Differential or "noise canceling" transmitters may be required if the noise is severe.

(4) In instances where the announcing station is subject to unfavorable atmospheric conditions such as acidic vapors, metallic dust particles, extreme temperatures, etc, it is desirable to provide a microphone which is inexpensive, rugged, readily replaced, and/or does not have any internal magnetic structure. In such cases the standard telephone transmitter is recommended.

4.04 A carbon transmitter can be separated from its associated amplifier by a considerable cable distance. This may be as much as 12 db at 1000 cycles, depending on battery supply conditions, noise in the cable, and the amplifier input requirements.

4.05 Transmitters using elements other than carbon have a much lower output level and preliminary amplifiers are usually required. Crystal, dynamic, variable reluctance, and velocity transmitters are in this category. The circuit connecting one of these transmitters with its preliminary amplifier should be separately shielded and should not exceed 500 feet in length.

Amplifiers

4.06 The amplifiers used in paging system service should have amplitude characteristics of sufficient uniformity that they will not affect the frequency response objectives specified in Paragraphs 2.05 and 2.07. Amplifier distortion should not exceed 5 per cent at full power output. The characteristics of several types of amplifiers are discussed in other sections of the practices.

4.07 Consideration must be given to proper location of an amplifier so that it will be available for maintenance, protected from damage, and close enough to its loudspeaker load to avoid excessive power loss in the distribution network. Provision of primary power of the proper voltage and frequency at the proposed amplifier location must be assured. Operation of amplifiers within their rated limits of ambient temperature is of importance. Where hazardous atmospheres are a problem it is usually better to locate amplifiers and control equipment outside of the hazard area. Unless this is done serious equipment housing and ventilation problems may arise and maintenance problems under such conditions are very likely to be severe. A good building ground should be connected to the amplifier grounding terminal.

4.08 Amplifiers must be selected for compatibility with transmitters, loudspeakers, and switching equipment. Input circuits must be suitable for the electrical characteristics of the signal source. For example, the W. E. Co. type 116B and 141A amplifiers were designed with the assumption that one side of the input circuit would be grounded and so electrostatic shields were not provided in the input transformers. If these amplifiers were to be connected to telephone lines, isolation transformers should be provided. This requirement may affect switching arrangements which are used to control the system. Input and output circuit shields should be grounded only at the amplifier. It is not considered good practice to connect amplifier output circuits in parallel on the same feeder, but this apparent limitation can be used to advantage in large areas by connecting adjacent loudspeakers to alternate amplifiers. When this is done, one of two or more amplifiers may be shut down for maintenance without causing a complete loss of paging in a given area.

Audio Power Distribution

4.09 Two methods of power distribution have found wide use. The older (and now obsolete) system used the principle of keeping the amplifier terminated in a constant impedance, usually 500 or 600 ohms. This system effected an efficient power transfer from the amplifier to its load. However, the calculation of transformer settings for a system was cumbersome when a number of loudspeakers operated at several different power outputs were involved and usually required that all transformers be readjusted when the system load was changed for any reason. The present system is known as the "70-volt" system and requires the amplifier to develop a given voltage on the distribution bus. Loudspeakers equipped with suitable transformers are connected to this bus and adjusted to radiate a predetermined amount of power. The advantages of this system are particularly valuable in an installation where a large number of loudspeakers are operated and where they may require readjustment periodically because of changes in ambient noise level. The use of 70-volt distribution is recommended for new paging systems; conversion of constant impedance distribution lines to the 70-volt arrangement is advisable where it can be done economically. This will usually be coincident with an amplifier replacement or other major change in a a paging system.

4.10 The principal features of the now standard 70-volt system include:

(1) Low amplifier internal output impedance to provide good audio level regulation; the actual amplifier internal output impedance will be considerably less than the rated load impedance.

(2) High line voltage to keep losses in the distribution line low.

(3) Transformers to reduce the signal voltage to that required by the loudspeaker voice coil.

Amplifiers which are designed to operate into this distribution system will develop 70 volts rms across their line terminals when transmitting steady sine wave tone and when fully loaded. If properly designed amplifiers are used, the level change at the amplifier when going from full load to no load should not exceed 1 to 2 db. This represents an excellent degree of regulation, and several advantages will be realized through the use of such a system. The minor changes necessary in loudspeaker levels when a system is first installed can be made without causing level changes at other loudspeakers on the system, and as the system grows, additional speakers and more powerful amplifiers can be used without changing the levels on the system.

4.11 The power loss in a distribution system should not exceed 0.5 db. The length and gauge of distribution line should be controlled so as to meet this requirement. The chart in Fig. 1 indicates the maximum length of run permissible as a function of power delivered for each of 5 conductor sizes when the 70-volt system is used. Some of the curves are limited by the maximum current rating for the conductor size. Since this type of information is required when engineering an addition to an existing system which uses a constant impedance distribution method, the chart in Fig. 2 will be useful. This indicates the maximum length of run as a function of load impedance for each wire size. When using this chart, the engineer must see that the conductor size chosen is adequate for the maximum current which will flow in the circuit. The distribution network should be suitably isolated from telephone circuits operating at normal levels and from amplifier input circuits if crosstalk and feedback conditions are to be avoided. The necessary isolation may be achieved through the proper use of shielded wiring and/or physical separation of the circuits.

4.12 Amplifier output circuits are normally ungrounded. If the output circuits are shielded the shield should be grounded only at the amplifier. Shielding should be continuous and not disconnected by switching functions. Where switching or patching functions are required the circuit power and impedance must be checked to see that voltage and current ratings of relay and jack contacts are not exceeded. As an example, consideration can be given to the case where an amplifier feeds three loudspeakers through relays used to select the speakers individually or in combination. If connections are made at loudspeaker impedance, about 8 ohms, then the current through the relay contacts may be excessive when appreciable power is transmitted. This may ultimately cause relay contact degradation with resultant intermittent or noisy system operation. This kind of trouble can be avoided by restricting switching functions in output circuits to high impedance points such as the 70-volt bus.

Loudspeakers

4.13 The loudspeaker converts electrical energy into sound energy and radiates this sound energy into the air. There are two main types of loudspeakers: the direct radiator, which radiates sound directly from a vibrating member into the air and the horn-type loudspeaker which consists of a driving unit and a horn to couple the unit to the air. Direct radiators are usually lower in cost and efficiency than horns, being used for low acoustic level applications; the horns have application in the high power field. Horns are also used in outdoor locations and in hazardous or corrosive atmospheres since they can be more easily designed for resistance to chemical attack and weathering. The fundamental difference between the two types is that the direct radiator must be designed with a low acoustic impedance to match that of the air. The horn has a driving unit with a higher acoustic impedance in which greater efficiency is possible; acoustic impedance matching is accomplished by coupling the driver unit to the air with a horn, usually having an exponential taper. Because of the appreciable physical length required of a horn used to reproduce the lower voice frequencies, it is generally folded in some manner which will result in an over-all size that is considerably less than the length of the acoustic path from the driver unit to the horn's mouth. In many cases the driver unit and the horn are separate units; coupling arrangements are designed so that several combinations are possible. This allows the designer to select driver unit and horn combinations which will have the proper power, frequency response, and directional characteristics. It must be remembered that both driver unit and horn characteristics affect the frequency response of the combination. Horn type loudspeakers should be protected against low frequency overload through the use of equalizers or by proper selection of transmitters.

4.14 The frequency response of the paging system will usually depend on the loudspeaker and its enclosure more than on any other part of the system. The frequency response of most units will vary up to 6 db above and below the average response through the usable range.

4.15 The electrical impedance of loudspeakers is usually very low, being on the order of 4, 8, 12, and 16 ohms in most commercial units. The voltages necessary to drive these units to rated output is considerably less than that of the distribution circuit and so some efficient matching device is required. A transformer is usually employed. Taps are provided so that the output may be varied over an appreciable range, generally in 3 db steps. This provides a convenient means for adjusting each loudspeaker to the proper level.

4.16 There are two ways to distribute the sound energy which will provide adequate level in a given area. The first is to employ one or more loudspeakers in a single cluster operated at such a level as to be heard everywhere in the area to be covered. This is referred to as high level reproduction. It has application out of doors and indoors where reverberation is not a problem. Another method, referred to as low level reproduction, involves the placement of a number of loudspeakers throughout the area. These loudspeakers operate at a low level so that they are heard only by persons in the immediate vicinity of each loudspeaker. This method of operation avoids the acoustic excitation of the entire enclosure and gives a high ratio of direct to reverberant energy; it is the only practicable solution in highly reverberant rooms. This is discussed in detail in Part 5.

Volume Limiters

4.17 In a system where a considerable investment is made in loudspeakers which will normally be operated at or near their power limit, consideration should be given to the use of volume limiting amplifiers in order to prevent damage to loudspeakers from overload. Volume limiting amplifiers are available in several grades; the simpler ones are generally used in paging systems. Limiting amplifiers having very precise characteristics are available since they are used in radio broadcasting stations. These are usually not economical except in the largest paging systems.

Level Control

4.18 Level control allows announcers to make adjustment for differences in voice levels or changes in noise levels in the paging area. It can be provided through the use of a visual indicator or similar means. An example of this would be a volume level indicator provided so as to enable an announcer to observe whether or not his speech was at the correct level.

4.19 A form of level control is involved when pads or other controls are provided to change the paging level in the listening area in accordance with the noise in that area. In some installations a monitor transmitter might be located in a receiving area. Its output could then be connected to a volume level indicator. With such an arrangement the announcer could apply level control so that the signal to noise ratio was constant at a predetermined level.

Equalizers

4.20 Equalizers may be required in paging systems to protect equipment, correct for amplitude distortion occurring in the system or to compensate for undesirable acoustical conditions under which the system must work. Equalizers for these conditions are usually connected in low level circuits. Equalizers which are provided to protect horn-type loudspeakers from low frequency overload may be placed in a low level circuit or in the distribution circuit. Other system elements which may require equalization include carbon transmitters and receiver units used as transmitters and high quality transmitters used in close-talking applications.

4.21 The degree to which equalization is required is usually determined after the loudspeaker locations and types have been selected. The chart in Fig. 3 will be a convenient aid in designing the equalizer network. Four curves are shown on the chart. The shape of the response curve and amount of equalization which can be obtained by varying the value of resistance R will fall between Curve 1 (R = infinity) and Curve 4 ($R = 0$). The chart is arranged so that it can be used to determine the loss at any frequency for a given equalizer if the reference frequency (F_0) is known. The formula shown on the chart can be used in computing the value of the equalizer components when the source and load impedances are known and the frequency has been chosen at which the loss of the equalizer will be 3 db when R = infinity (Curve 1).

4.22 The characteristics of equalizer Curve 1, 2, or 3 should be adequate for most applications. Curve 1 should be chosen if the equalizer is provided to correct for room reverberation time or where low frequency overload of loudspeakers is to be avoided. In the latter case F_0 would be chosen as being at the rated low frequency limit of the loudspeaker. Where the equalizer is used to correct for excessive bass response of transmitter used in a close-talking position, Curve 2 or 3 might be selected. F_0 in this case might be chosen as any frequency between 600 and 1,000 cycles, depending on the amount of correction required and the frequencies where it is needed. Curve 2 or 3 will be found useful in improving intelligibility where excessive low frequency room noise is present. If two or more conditions requiring equalizaton are present then the provision of an equalizer for the most severe problem may be adequate for the system. An exception to this would be found in a large system where one equalizer was provided to correct for transmitter characteristics (per Curve 3) and a second one provided (per Curve 2) in one branch of the distribution bus to prevent low frequency overload of horn-type loudspeakers. The most desirable place in the system circuit for the equalizer is between a preliminary amplifier and a power amplifier. If the equalizer can be obtained as an electrical part of the system amplifiers this is also recommended.

4.23 As an example of equalizer computation, assume that equalization is to be made so that at 500 cycles the response of the system will be 3 db below normal and that the loss characteristics should be similar to Curve 1 in Fig. 3. The equalizer is to be placed between a preamplifier and a power amplifier. The preamplifier is designed to work into a 600 ohm load; it has an output impedance of 40 ohms. The input impedance of the power amplifier is 600 ohms. Since Curve 1 was chosen it will be necessary to compute only the value of the series capacitor K, the resistance R being infinite. The formula used is:

$$K = \frac{1,000,000}{2\pi F_0 \ (G+L)} \text{ microfarads}$$

$$F_0 = 500 \text{ cycles}$$

$$G = 40 \text{ ohms}$$

$$L = 600 \text{ ohms}$$

then

$$K = \frac{1,000,000}{6.28(500)\ (640)}$$

$$= \frac{1,000,000}{2,015,000}$$

$$= 0.496 \text{ microfarad}$$

If response similar to that shown in Curve 2 was required, the capacitor would be shunted by a resistance having the value:

$$R = 5\ (G+L)$$

$$= 5\ (640)$$

$$= 3200 \text{ ohms}$$

5. LOUDSPEAKER POWER COMPUTATION

5.01 After the transmission requirements have been determined as outlined in Part 3, it is then possible to plan the assembly of equipment which will provide the required service. Control functions should be considered in detail at this stage. It is often helpful to the designer to sketch out a block diagram of the system on which these functions and other equipment requirements can be indicated. With System requirements firmly established the power required by each loudspeaker can be computed and suitable amplifier arrangements selected.

Sound Distribution

5.02 The computation of loudspeaker power can be done in three ways. The first involves acoustic excitement of the entire room volume and is referred to as high level reproduction. The total acoustic power capacity of a room for a given resulting sound level is determined from the chart in Fig. 4. The Hopkins-Stryker efficiency rating of the loudspeaker to be used is then applied to convert the acoustic power capacity to an electrical power requirement. Where loudspeakers are used outdoors, in highly damped (nonreverberant) areas or in a low level distribution system where the acoustic energy reaching the listener is nearly all direct from the loudspeaker and very little is due to reverberation then computation is based on the loudness pressure rating of the loudspeaker and the attenuation of acoustic level with distance (Fig. 6) under outdoor conditions. A third method can be used if the system designer is working with a room of moderate volume and wishes to use loudspeakers for which the Hopkins-Stryker efficiency rating is not available. The chart in Fig. 7 will be helpful in correcting the sound levels computed with the loudness pressure rating for the effects of room reverberation. This is recommended only as a last resort, however, and will require the system designer to make a detailed study of the room and the acoustic absorption qualities of all of its surfaces and furnishings. Referring to the reverberation gain curves (Fig. 7) it will be noted that the sound level drops off much more rapidly in a highly damped room than in a reverberant room. This apparent advantage of live rooms should, of course, be discounted to take into account the impairment of intelligibility resulting from repeated reflections from walls, floor and ceiling. In such rooms, better results will be obtained by utilizing a number of loudspeakers operating at moderate levels rather than attempting to cover a large area with one loudspeaker operating at a high level. The treatment of the loudspeaker problem will vary somewhat depending on the area in which the loudspeaker is located. This is reflected in the divisions of the discussion which follows.

The Auditorium

5.03 The following paragraphs refer to an auditorium of modest size such as might be found in a business office, factory or school. It will be assumed that the auditorium has suitable acoustical properties and that room noise will not exceed 70 db. Problem areas such as an auditorium having poor acoustical properties, theaters and concert halls are beyond the scope of this section.

5.04 In an auditorium of correct acoustical design there are two ways in which loudspeakers can be located so as to provide adequate sound coverage. In the first way a few loudspeakers capable of radiating the required power are located at the stage end of the auditorium at or near ceiling height. With this method good illusion of direction is maintained and feed-back into a transmitter on the stage will be kept to a minimum by reason of the separation of the transmitter and loudspeakers and also because of the directional characteristics of the two. In the second method a larger number of loudspeakers are mounted on the ceiling so as to project downward vertically. The loudspeakers must be distributed over the area so that coverage is uniform. This method does not provide as good illusion of direction as the first, but is less likely to give rise to troublesome echoes, particularly if the auditorium has a relatively low ceiling or where the only acoustic treatment is on the ceiling; loudspeakers in such locations are usually mounted flush with the ceiling. Where this method of coverage is used and the ceiling is unusually high, it may be desirable to mount the speaker in a fixture which can be suspended from the ceiling at a height of 10 to 20 feet from the floor. The choice between the two methods must be made after a study of the auditorium and the function of the paging system.

5.05 The total acoustic power required for an auditorium having good acoustic properties can be determined from the chart shown in Fig. 4 if the total volume in cubic feet of the auditorium is known. The curve is located so that the sound level at the listener will be approximately 80 db R.A.P. If both speech and music are to be reproduced, the acoustic power requirement should be increased by 15 db. When the acoustic power requirement has been determined and the loudspeaker type selected, the electrical power can be computed through the use of the Hopkins-Stryker efficiency rating.

5.06 As an example, assume that speech is to be reproduced in an auditorium having a room noise level below 70 db and having characteristics as follows:

Length	70 feet
Width	50 feet
Height	20 feet
Volume	70,000 cu. ft.

Cone type loudspeakers have been chosen in order to meet the frequency response requirements. The unit selected for this illustration has characteristics (from Section AB22.335.1) as follows:

Type	P8SX
Input Power Capacity	7 watts
Frequency Response	80-8000 cycles
Efficiency Rating	—19.6 db
Loudness Pressure Rating	46.3
Angle of Coverage	70°

5.07 The acoustic power capacity of the room for speech is (from Fig. 4) 9.25 dbm. The total electrical power which will be required for this type of loudspeaker is found by adding the acoustic power capacity of the room and the efficiency rating of the loudspeaker (neglecting the negative sign associated with the efficiency rating) thus:

Power Capacity	9.25
Correction for Speaker Efficiency	19.6
Total Electrical Power Required	28.85 dbm

The amount of electrical power corresponding to 28.85 dbm (rounded off to 29) is (from Fig. 5) 0.8 watt. While a single loudspeaker could easily handle this amount of power more uniform coverage could be obtained by mounting several loudspeakers in the ceiling. In order to find the number of loudspeakers which will be required we consider the coverage angle of the loudspeaker and the height of the room. A simple calculation (tangent of ½ the coverage angle times loudspeaker height) shows that each loudspeaker will cover a circular area having a radius of about 14 feet. If several circles of 14 feet radius are drawn on a plan of the room it will be seen that the minimum number of loudspeakers which should be used in a ceiling arrangement in this room would be 6. This number could be reduced to 4 if it is desirable to provide extra margin against acoustic feedback as discussed below.

5.08 If a permanent stage is provided or if for other reasons it can be assumed that the person speaking will always be in one area of the auditorium, then the sound coverage in this area can be kept somewhat below (6-12 db) the level in the rest of the room to give margin against acoustic feed-back; the total acoustic power in the room should remain constant, however. Power requirements would be increased by the same number of decibels that the normal room noise exceeded 70 db; this case should be rare, however.

5.09 Frequently, low frequency equalization (see Paragraphs 4.20, 4.21, 4.22) is required to correct for the auditorium acoustics. This equalization should be provided so that speech is reproduced without any accentuation of the low frequencies. The amount of equalization and the frequencies involved will depend upon the room acoustics and upon the type of transmitter and loudspeaker selected. Proper equalization and coverage has been achieved when one can walk from the vicinity of the person talking to any point in the room while hearing the speaker's voice clearly and without change in quality.

5.10 While no reliable formula is available for determining F_0 for a particular room, the following rules provide a point from which to start subjective tests. If the voice of a person can be heard clearly everywhere in the room and needs only reinforcement, F_0 should be set at 300 cycles. If the voice is not easy to understand, 600 cycles can be chosen. If reverberation distorts the sound of the voice severely F_0 should be set at 1000 or 1500 cycles.

Large Noisy Rooms

5.11 In large volume rooms such as an exhibition hall or transportation terminal very poor acoustic conditions can be expected unless special treatment has been provided. In covering such areas for paging it is desirable to utilize low level transmission to the maximum extent possible. Loudspeakers should be placed close to the areas where the listeners will be found; this may require a considerable number of loudspeakers. Low frequency equalization is of particular importance here to avoid excessive reverberation which would impair intelligibility. If a true low level system can not be provided because of physical conditions then some compromise must be made but this will degrade the intelligibility of the system.

5.12 The computation of power for a low level system in noisy areas is done as in the following example:

Assume that loudspeakers can be mounted at such a height that the average distance between a listener and the nearest loudspeaker is 20 feet and that the measured room noise is 76 db; a loudspeaker with a loudness pressure rating of 46.5 is to be used.

Room noise	76 db
Margin required	10 db
Level required at listener	86 db

Loudness pressure rating at 30′	46.5 db
Correction to 20 feet distance (Using Fig. 6 or the curve a=s on Fig. 7)	3.5 db
Sound level at 20 feet for 1 mw:	50.0 db
Required output	86 db
Output at 1 mw (0 dbm)	50 db
Electrical power required:	36 dbm

As computed above each loudspeaker would require +36 dbm or (from Fig. 5) 4 watts of electrical power.

5.13 Direct radiators are considerably less efficient than horn-type loudspeakers and an extensive system may require several power amplifiers. It is advisable to compute the comparative cost of providing direct radiators with the attendant higher power requirement with the cost of providing horn-type loudspeakers and fewer power amplifiers. Since reverberant areas require a great deal of low frequency equalization, either horn-type loudspeakers or small, relatively cheap direct radiators should perform satisfactorily. Other factors being equal, the most economical system should be recommended.

5.14 It is well to consider the possible requirement for level control (as discussed in Paragraph 4.19) in an area of this kind.

Industrial Locations

5.15 In providing paging in indoor industrial areas, several adverse conditions must be considered. Noise levels will usually be high and subject to variation with time of day and production conditions. Distances are usually great and acoustic treatment not economical. It may be desirable to provide two or three different paging signal volumes so that the level can be adjusted in steps for the prevailing noise level in the plant. It will often be desirable to confine the paging to those areas where people are moving from one place to another, with reduced coverage in those areas where people generally remain in a small area. Here again, the purpose of the paging system will control the general design objectives.

5.16 To provide paging in a big industrial plant usually appears to be a formidable problem, but such large areas can be subdivided and treated as several small systems with common input arrangements. There are several advantages to this method of approach. Where the subscriber is uncertain of the necessity or effects of paging in the plant, a system can be installed in only one section or building and its effect evaluated. The division of the system into small units may simplify grouping problems and will usually result in optimum maintenance conditions. Amplifiers having power ratings from 10 to 100 watts can be used singly or in groups with good economy.

5.17 In rooms of such size and shape that only one loudspeaker will be required to give adequate coverage the location of the loudspeaker involves consideration of placing it as close as possible to greatest number of listeners, at the same time making sure that as many as possible potential listeners are within its range. Where the principal group of listeners is located near a source of severe noise, the best signal-to-noise ratio will be obtained by locating the loudspeakers near the listeners. Where the use of more than one loudspeaker is involved the desirable objective is to arrange them so that a listener at any one point is conscious of only a single sound source. In establishing loudspeaker locations, it will be desirable to avoid directing them at reflecting surfaces and thus minimize reverberation which degrades the intelligibility of the system.

5.18 Some industrial areas will be encountered where the acoustic conditions are so poor that good general coverage can not be obtained without excessive cost. In these cases only spot coverage of key locations should be attempted. Alternatively, a tone or other distinctive signal can be transmitted which will serve to call people to the nearest loudspeaker and so enable them to hear an announcement which will follow the tone after a suitable length of time.

5.19 When consideration is being given to possible loudspeaker locations full advantage should be taken of building architectural features. Columns, beams and roof structures may provide ideal locations for mounting loudspeakers. The acoustical effects of aisles created by storage bins, partitions, etc, must not be overlooked. A factor to be considered in determining the location of a loudspeaker is the annoyance to persons close to the unit. For example, it may frequently work out that a loudspeaker operating at high enough output to furnish comfortable acoustic level at a distance will be uncomfortably loud to workers located near the unit. This will be of great importance in places where the locations of people in their normal duties is fixed with reference to the loudspeakers. It is usually advantageous to mount loudspeakers 10 to 20 feet from the floor. Refer to Paragraphs 2.01 and 2.03.

5.20 Care should be taken to assure that the loudspeaker location selected will not expose the loudspeaker to damage or create hazardous installation or maintenance conditions. Loudspeakers should not be mounted where they can be contacted by parts of or loads suspended from overhead cranes. They should not be mounted where they will be subjected to direct heat from industrial furnaces or where they are likely to be splashed with chemicals, paints or molten metals. The locations selected should not require installers or repairmen to work close to exposed electrical conductors such as crane trolleys or a current bus in a plating mill or welding shop.

5.21 Paging equipment arrangements must not constitute a hazard. Where the paged area may be subject to explosive dust or chemicals in the atmosphere the safety engineer or other person with equivalent responsibility must designate the limits of the hazardous area. Loudspeakers must be so rated and distribution circuits protected in a manner approved for service in the hazardous area.

Offices

5.22 Acoustic conditions in business offices may vary widely. If the acoustic conditions are good—low noise and an appreciable sound absorption—then the room can be treated in the same way as described in the section on an auditorium. Care must be taken to see that the sound level of the reproduced speech is higher than the room noise by sufficient margin. If the acoustics are poor then an office area should be covered by a low level system and the loudspeaker power computed as in the section on noisy rooms.

5.23 As a rule direct radiator loudspeakers in bidirectional enclosures can be used with good effect. The objectives stated in Paragraph 2.01 are of importance in office areas. Low level sound distribution is to be preferred unless system usage time is extremely small. Level control will often be required, particularly in those cases where music is to be disseminated.

Outdoor Locations

5.24 To provide adequate coverage in an outdoor area requires more power than an indoor area of similar size. This is because the sound energy reaching the listener is nearly all direct energy and is not reinforced by reverberant energy. The sound level at the listener should be 10 db above the ambient noise level but not less than about 70 db. R.A.P.

5.25 The same care must be used in the selection of outdoor locations for loudspeakers as is required elsewhere. The primary consideration is the location of the loudspeaker with respect to the area it serves. Location and position must be such that it will not be subject to damage or misuse and if the sound from the loudspeaker must project upward, the unit selected must be arranged so that debris, rainwater, etc, will not collect and stand in it.

5.26 When computing the power requirements for outdoor locations the loudness pressure rating is used. This rating as listed in Section AB22.335.1

is equal to the sound level produced 30 feet from the loudspeaker when a standard test signal at 1 milliwatt power is fed to the loudspeaker. As an example of the computation for outdoor conditions assume a noise level in the area of 73 db, a distance of 150 feet between the loudspeaker and listeners and a required margin of 10 db. The loudspeaker is chosen for suitable coverage angle and frequency response. It is rated at 25 watts and has a loudness pressure rating of 54 db.

Computation:

Noise level	73 db
Margin	10 db
Distance loss (from Fig. 6)	14 db
Required level at 30 feet	97 db
Loudspeaker rating at 30 feet for 1 mw	54 db
Electrical power required	+43 dbm

Using Fig. 5 it is evident that the loudspeaker will require 20 watts of electrical power.

5.27 It is usually not practicable to provide more than incidental coverage to areas which are more than 400 or 500 feet from a loudspeaker. To provide a sound level of over 80 db at this distance requires prohibitive quantities of electrical power and it will usually be found that the use of additional loudspeakers is more desirable, both from the standpoint of economics and from the considerations of equipment problems and incidental conditions in the area near a loudspeaker which produces sound levels high enough to cause acoustic shock in persons nearby.

5.28 It is recognized that there are applications for paging systems which have special requirements involving high levels, several kilowatts of audio power, and special requirements for loudspeakers such as operation under water or in the presence of very high atmospheric pressure waves. These applications are beyond the scope of this section and the latest information should be obtained.

6. VERIFICATION OF SYSTEM PERFORMANCE

6.01 When the installation of the system has been completed and the components are known to be functioning properly then the system as a whole should be checked to see that it performs as intended in regard to noise, distortion, operating levels, and coverage area. It is usually desirable to check these items in the order listed because of the possible relation of one to another.

Noise

6.02 In checking for system noise it is usually convenient to disconnect the normal distribution bus from the amplifier and substitute a loudspeaker at the amplifier location. Noise can be evaluated and eliminated without confusion with troubles which may be present in the distribution circuit or loudspeakers. In regard to relations with the subscriber it is most desirable that noise in the system be eliminated before the loudspeakers are connected to their respective amplifiers.

6.03 The signal-to-noise ratio measured at the amplifier output should be not less than 50 db. Noise can be measured with the 2B noise set (or equivalent) using flat weighting. Loudspeakers should be disconnected when this measurement is made. Switching noises should be negligible; where switching noise is present it may be the result of inadequate grounding of the amplifier or switching equipment. It may also be due to improper grounding of the input circuit shields. When carbon transmitters are used, the DC supply must be established through the transmitter and induction coil before the coil is connected to the amplifier input. When noise measurements are made care should be exercised so that room noise at the transmitter location is not interpreted as electrical noise contributed by the input circuit. It will usually be necessary to substitute a resistance for the transmitter when measuring the electrical noise attributable to the input circuitry.

6.04 Oscillation can occur at almost any frequency, even at frequencies in excess of 100 kilocycles. This usually is the result of inadequate shielding of the input circuits and if it is above the normal range of audible frequencies may manifest its presence as a continuous and unusually high reading on the output level meter, arcing within the amplifier, red hot areas on the plates of the amplifier output tubes, distortion of speech from the amplifier, or operation of line fuses. Oscillations in the audible range such as squeals or motorboating are generally the result of inadequate shielding or amplifier grounding; insufficient isolation between switching devices in input and output circuits can also cause this trouble. Noise which is of power supply frequency or its low order harmonics is usually corrected through proper grounding of the amplifier and its input circuits and the shielding associated with the input circuits. Occasionally this noise is caused by magnetic or static fields generated in nearby electrical equipment; the usual remedy is to remove the amplifier from the influence of the field.

Distortion

6.05 Distortion can be caused by amplifier oscillation or the presence of high level noise of low frequency; it may be due to improper impedances connected to the amplifier output such as loudspeakers connected to the distribution line without benefit of matching autotransformer, or with the autotransformer wired with the line and voice coil connections reversed. Such troubles cause the amplifier to work under almost short-circuit conditions and distortion is inevitable. The output circuit can be easily checked, however. The amplifier output feeding a 70-volt distribution circuit should not change more than 2 db between no load and full load condition. A change in output level of more than this indicates that the load impedance is improper for the amplifier. This may be due to trouble in the output circuit, wiring error, or connection of greater loudspeaker load than that for which the amplifier was designed. Distortions in the speech reproduced by horn-type loudspeakers may be the result of overloading the loudspeakers with low frequency energy.

Level Adjustment

6.06 When the system is in good working order then the various gain controls or pads can be adjusted to provide proper operating levels at amplifier input and output points. Preliminary amplifiers associated with transmitters, phonographs, or music supply circuits are usually adjusted to provide an output level of about 0 vu. Power amplifier output should be adjusted to an indicated +33 vu on speech for operation on 70-volt lines. This is strictly a voltage measurement and is not indicative of the power which is being furnished to the load.

6.07 One device commonly used for the measurement of these levels is the 753-type volume indicator. The 753C (obsolete) or 753F can be used directly; a large number of 753E volume indicators are in use in the field and can be used for this purpose if modified locally by the addition of a 20 db pad either internal or external to the indicator. A modified indicator is shown in Fig. 8a. The modification consists of the addition of a high impedance 20 db pad and an extra jack on which the resistors comprising the pad are mounted. The modification is shown schematically in Fig. 8b. A useful accessory to the indicator is a length of two conductor cordage equipped with a 241-type or equivalent plug at one end and insulated alligator clips on the other. This cord can be connected in the volume level indicator jacks as required for testing circuits operating at levels between −10 and +26 or +24 to +46. The use of separate jacks for the two ranges reduces the probability of damage to the meter through operating error when it is used for testing the higher level circuits.

Listening Tests

6.08 After all parts of the system are properly adjusted then listening tests should be conducted to verify that sound quality and coverage under the existing acoustic conditions are adequate. The importance of this test must not be underestimated since it is the test which the subscriber will use in judging the quality and effectiveness of the system.

6.09 It is generally desirable to repeat the tests for distortion noise and coverage after the system has been installed and working about a month. In this time the electronic parts of the system have had time to stabilize and system users have had an opportunity to become accustomed to it. It is frequently found at the time this check is made that persons making the announcements need additional training on the proper use or control of the system. Loudspeaker locations should be checked to see that their operation is unchanged. Loudspeakers may be found to have been turned toward the ceiling, stuffed with foreign material, or otherwise damaged. Incidents of this nature are reliable indication that the sound from the loudspeaker has annoyed someone and the loudspeaker should be either relocated or readjusted to a lower level.

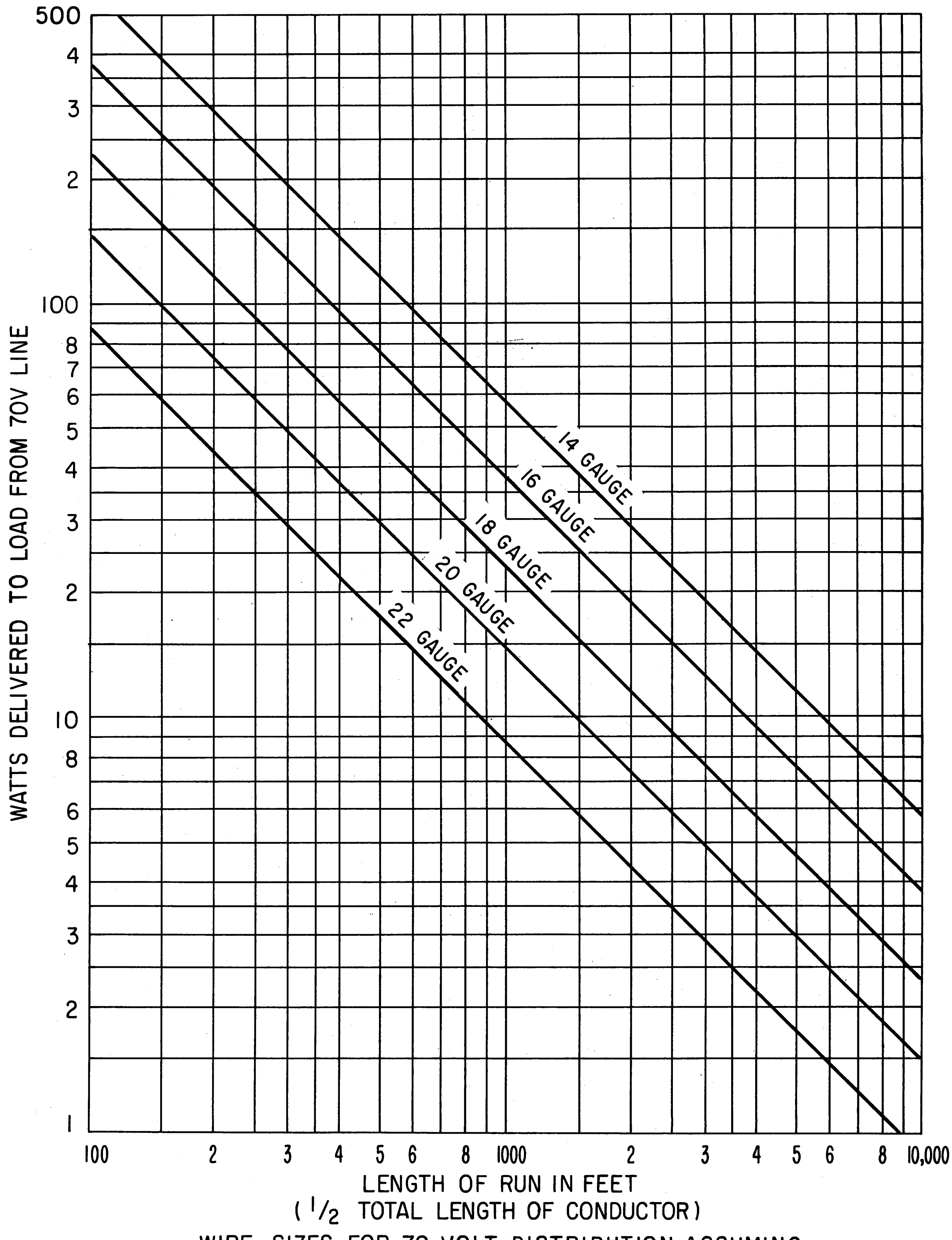
7. RELATED INFORMATION

7.01 Information which will be of benefit to the paging system designer may be found in other sections of the practices. These sections include:

AB22.335.1	Transmission Characteristics of Loudspeakers
AB22.375	Measurement of Room Noise
AB47.870 AB47.871 AB47.872	The Decibel
AB48.	(Various Sections) Audio Apparatus Data
AA466 E27. E37. E47.	Electrical Characteristics and Maintenance Practices for Amplifiers
E47.153 E47.153.1	752, 753, and 754-Type Volume Indicators

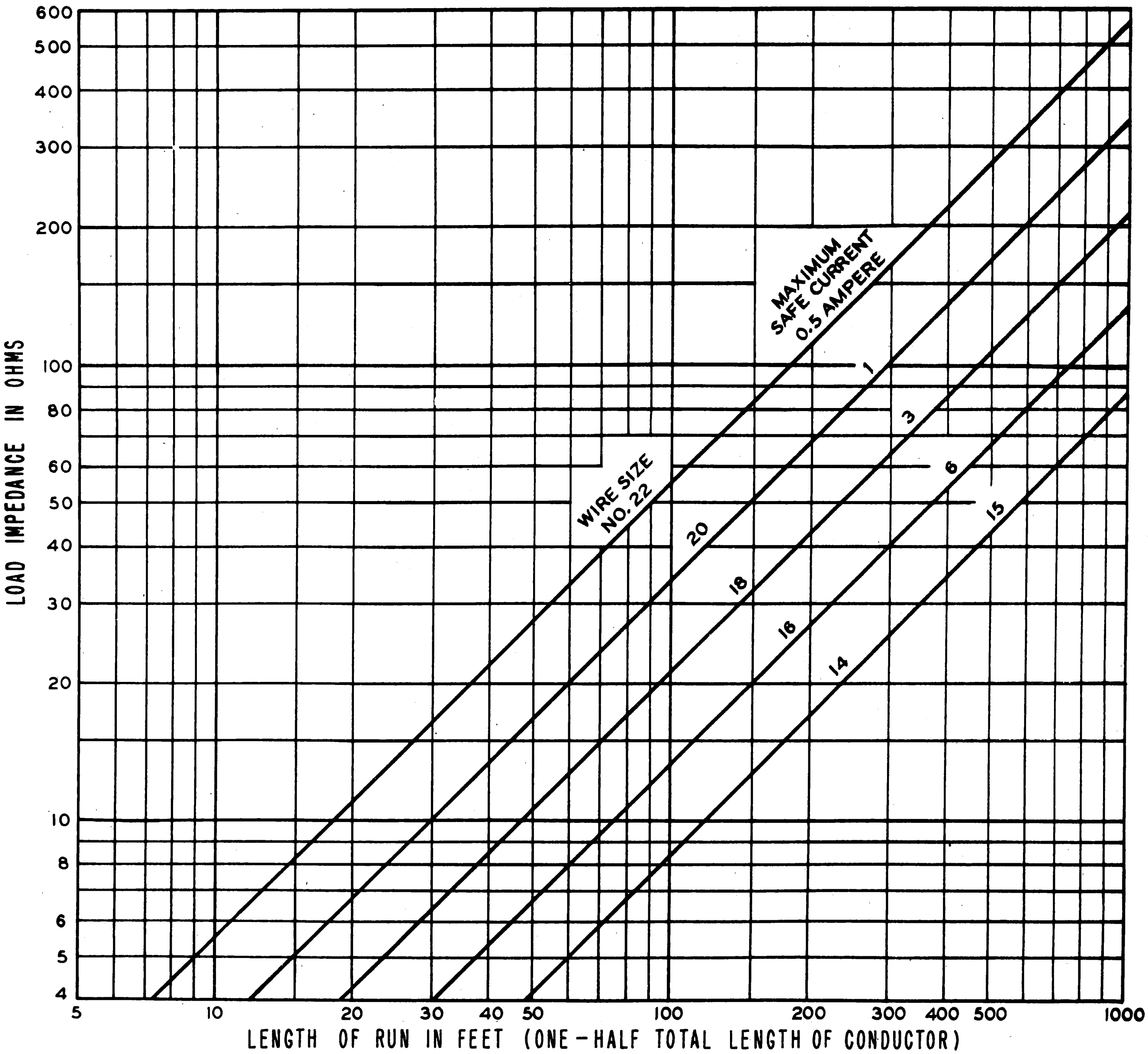
7.02 Other publications of interest to the paging system designer include the items discussed in Paragraph 3.06 and:

Bell System Monographs
1557, 1577, 1608
RETMA Bulletin No. 39
RETMA Standards:
SE 101 Amplifiers
SE 103 Loudspeakers
SE 105 Microphones
SE 106 Sound Systems



WIRE SIZES FOR 70 VOLT DISTRIBUTION ASSUMING
MAXIMUM LOSS OF 0.5 DECIBEL

Figure 1

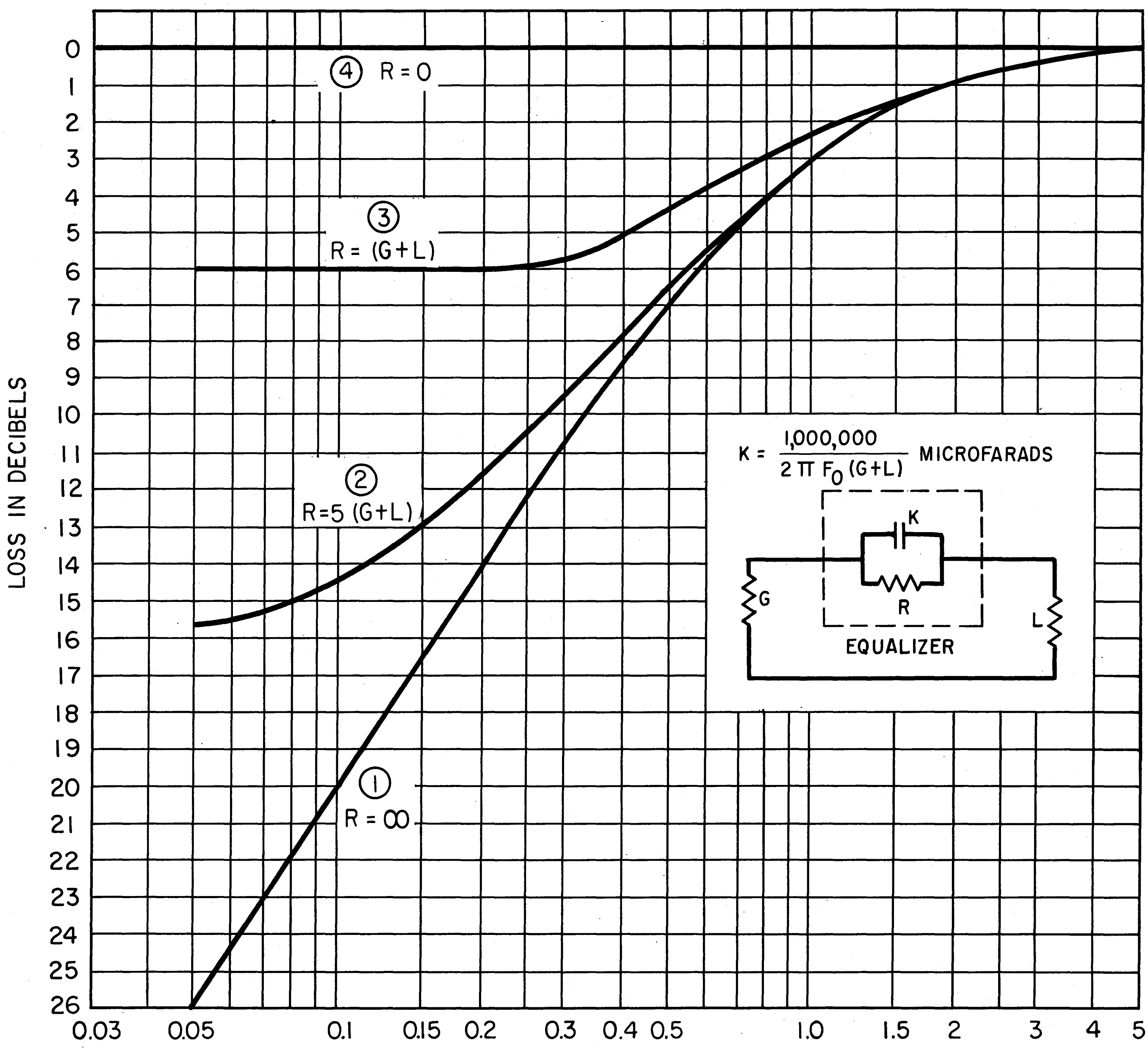


WIRE SIZES FOR LOUDSPEAKER CIRCUITS ASSUMING MAXIMUM LOSS OF 0.5 DECIBEL

CONSTANT IMPEDANCE SYSTEM

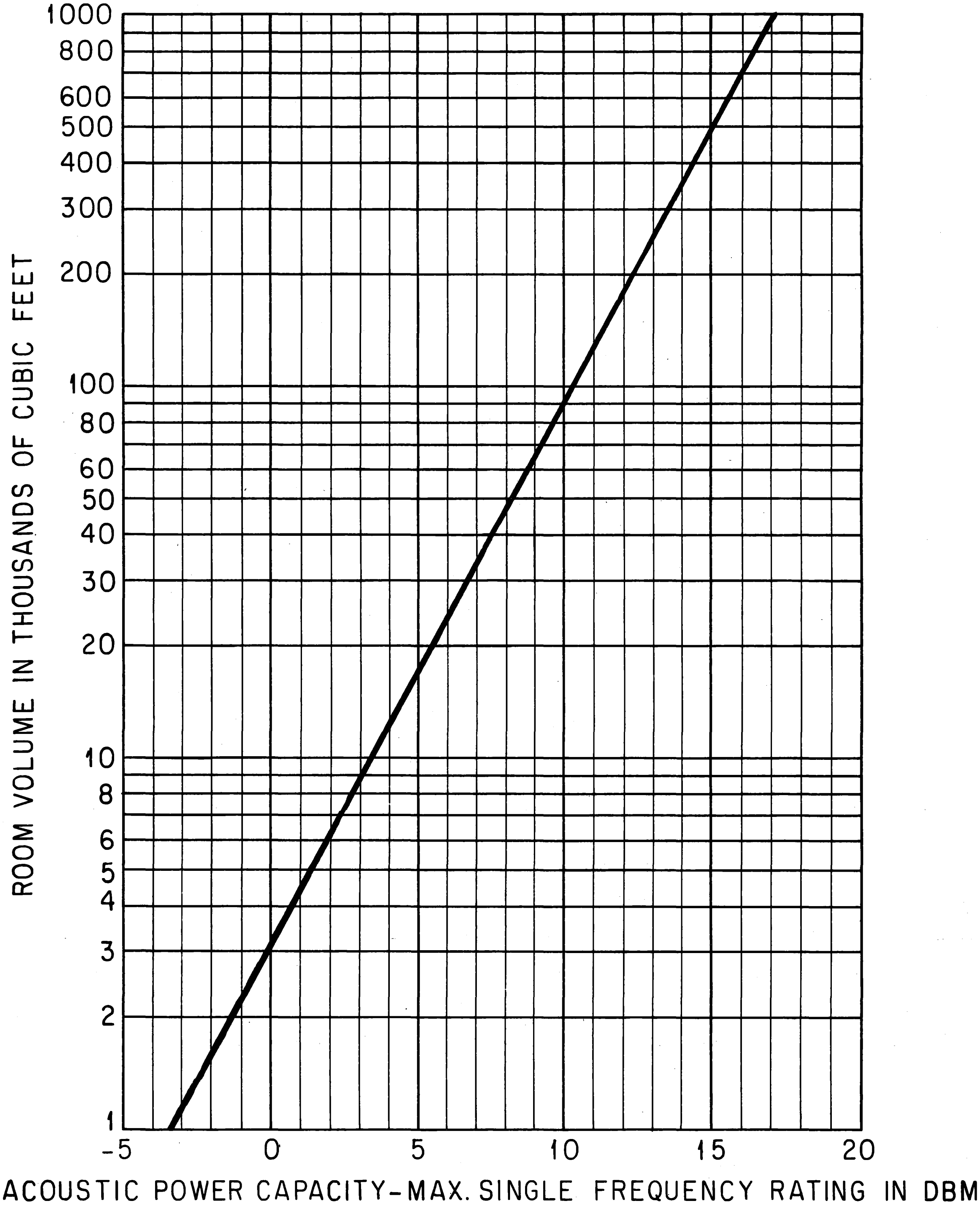
Figure 2

EQUALIZER TO REDUCE LOW FREQUENCIES



F = FREQUENCY OF SIGNAL
F_0=FREQUENCY WHERE LOSS OF CURVE ① IS 3 DECIBELS

Figure 3



ACOUSTIC POWER CAPACITY OF
A ROOM FOR SPEECH REPRODUCTION

Figure 4

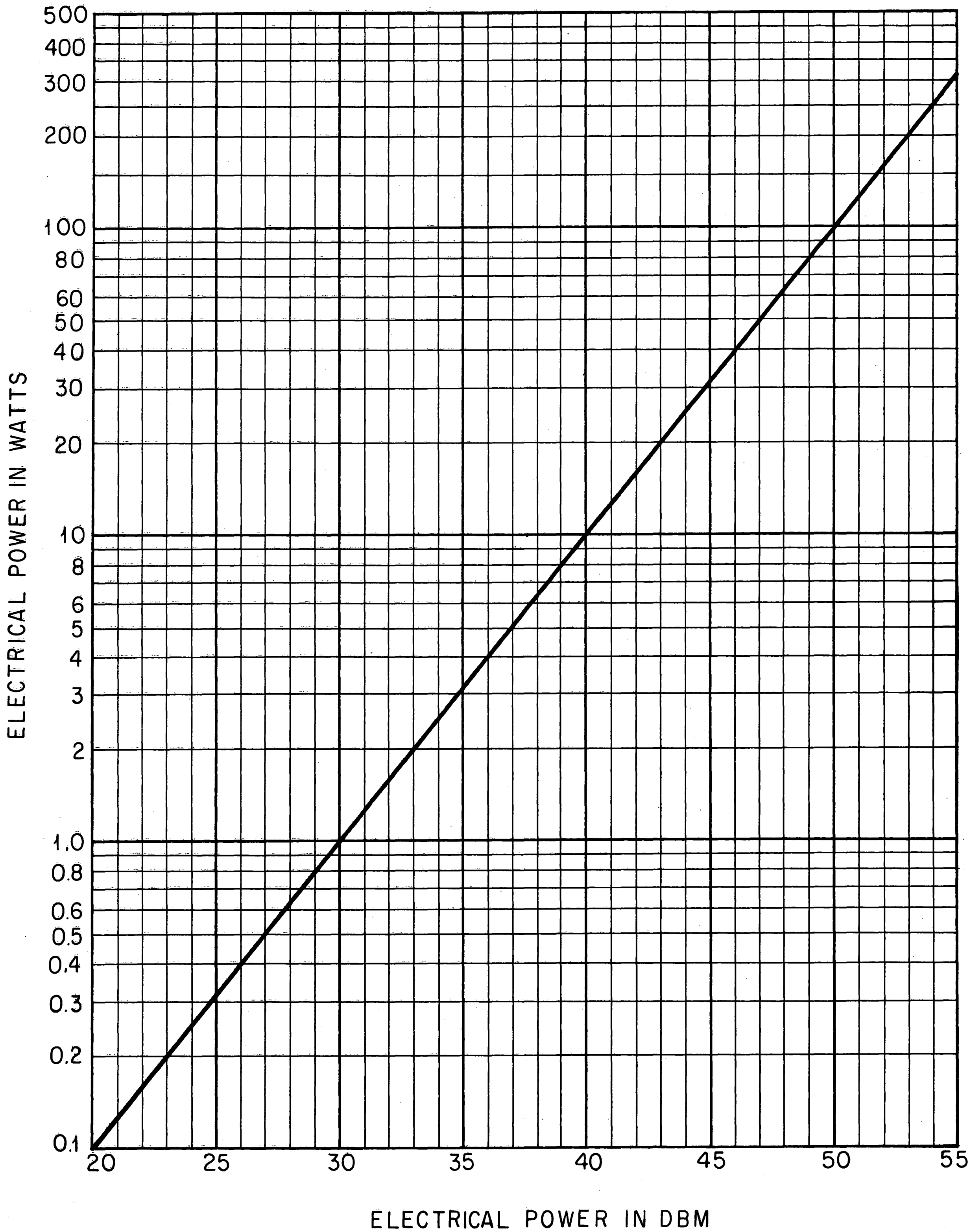
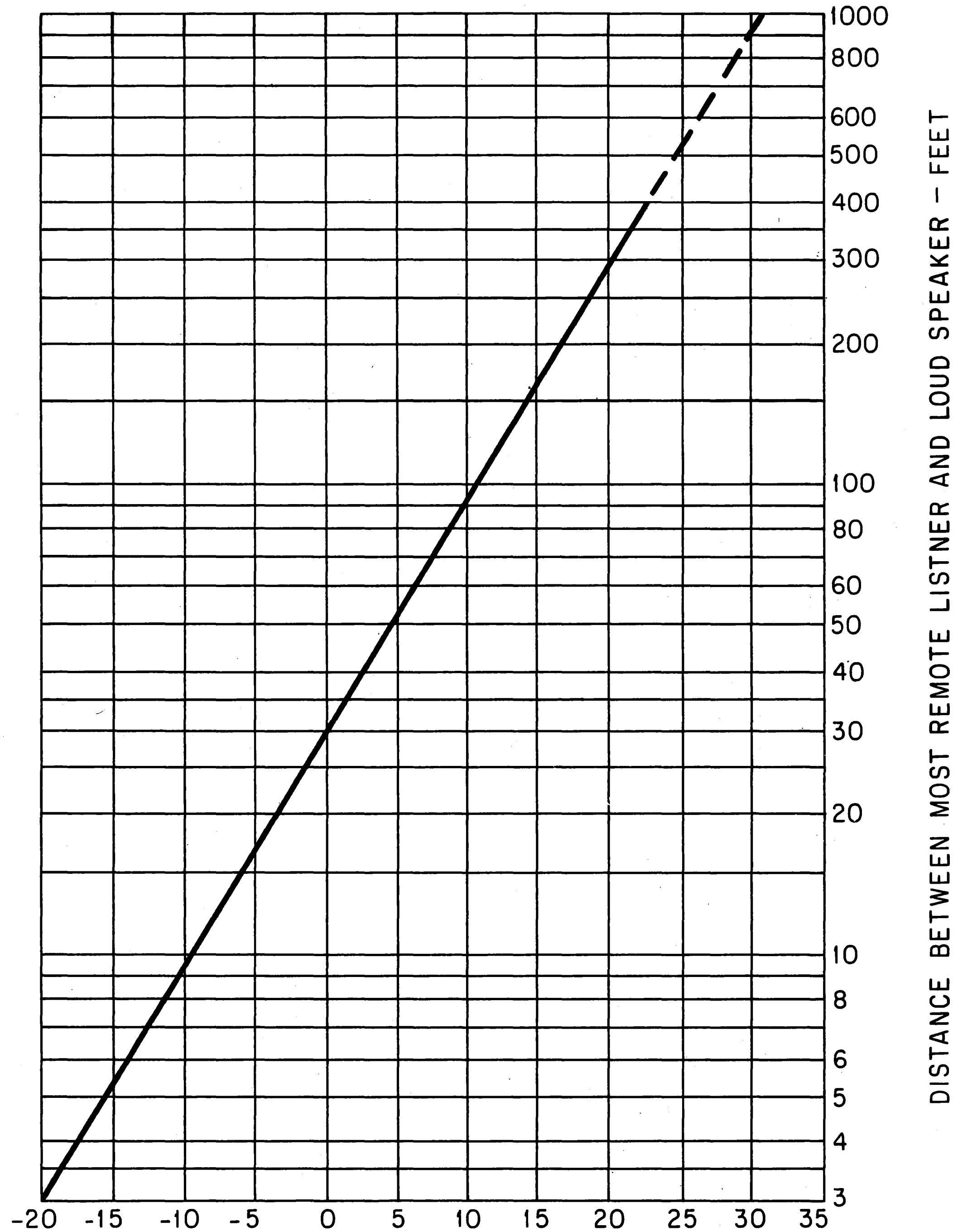

ELECTRICAL POWER IN WATTS
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1.0
0.8
0.6
0.5
0.4
0.3
0.2
0.1
20
25
30
35
40
45
50
55
ELECTRICAL POWER IN DBM

Figure 5



Sound Level at Listener vs. Sound Level 30 Feet from Loud Speaker

ESTIMATED LOSS OF SOUND INTENSITY
AT
VARIOUS DISTANCES FROM THE LOUD SPEAKER
FOR
OUTDOOR CONDITIONS

Figure 6

ESTIMATED GAIN OF SOUND INTENSITY AT VARIOUS DISTANCES FROM THE LOUD SPEAKER FOR VARIOUS AMOUNTS OF ROOM REVERBERATION

$$F = \frac{as}{s-a}$$

s = Total surface of walls, ceiling and floor in square feet.

a = Total absorption in room in square feet of equivalent open window area.

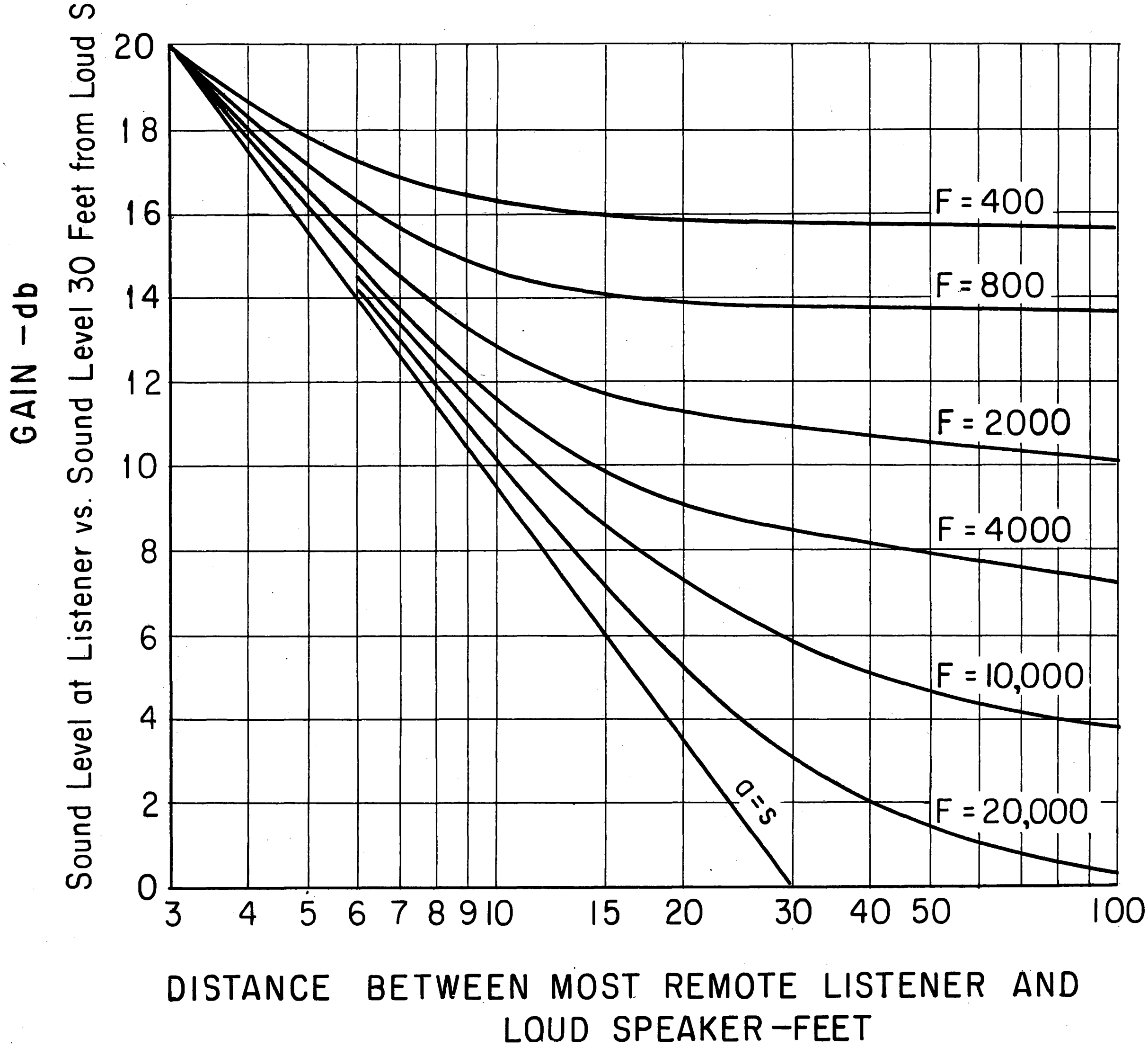


Figure 7

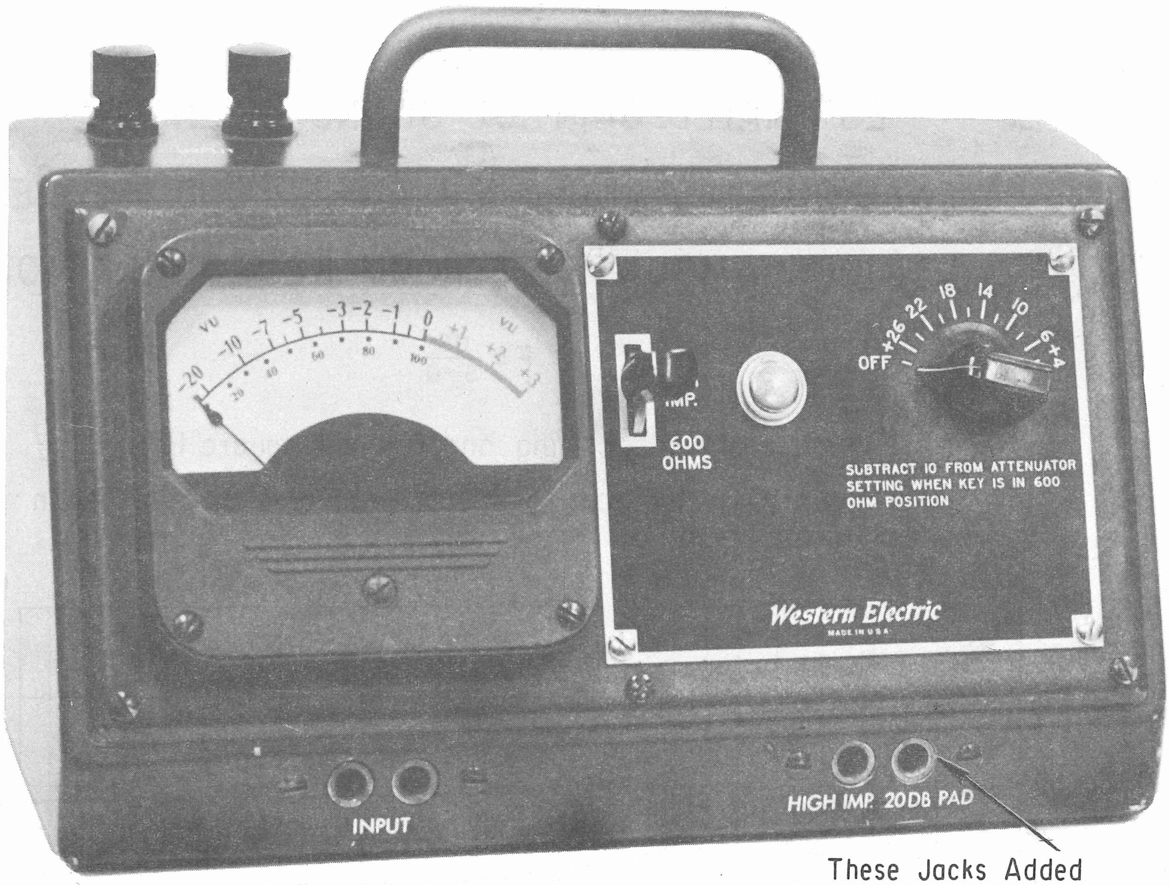
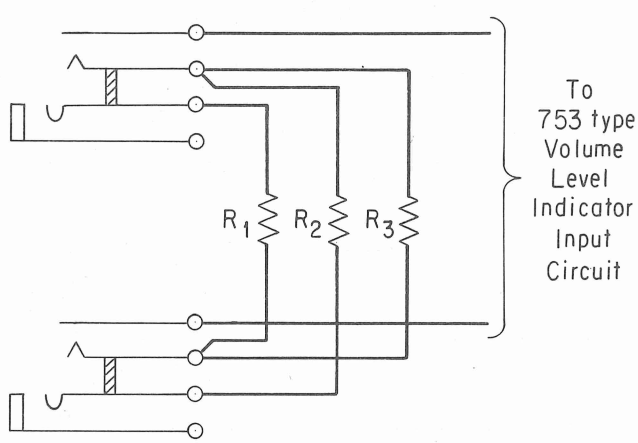


Fig. 8A—Modified Volume Indicator



R_1, R_2 = 16,875 ω

R_3 = 7,500 ω

Jacks : 215 Type

Fig. 8B—Schematic of 20 db Pad and Jacks