AMERICAN SPEECH-LANGUAGE-HEARING ASSOCIATION

Guidelines for Fitting and Monitoring FM Systems

ASHA Ad Hoc Committee on FM Systems

This document is a revision of the Guidelines for Fitting and Monitoring FM Systems published by the American Speech-Language-Hearing Association (ASHA) in 1994. The ASHA Ad Hoc Committee on FM Systems developed the present revision that was approved by ASHA's Legislative Council in 1999 (LC 29-99). Members of the committee are Arthur Boothroyd (chair), Dawna Lewis; Barbara R. Murphy; Richard Nodar (vice president for professional practices in audiology, monitoring officer); and Evelyn Williams (ex ofdficio). These guidelines, an official statement of the American Speech-Language-Hearing Association, provide guidance on use of specific practice procedures but are not official standards of the Association. These guidelines supersede the Guidelines for the Fitting and Monitoring of FM Systems (ASHA, 1994).

Preface

The principal change is in the recommendation for relative adjustment of the strengths of the signals received via the local (hearing aid or "environmental") microphone and the FM microphone. The earlier guidelines recommended that inputs of 65 dB into the local microphone (representing speech at conversational distances) and 80 dB into the FM microphone (representing speech at a few inches) generate equal outputs in the listener's ear. There are conditions under which this "equal output" condition is appropriate. There are two conditions, however, under which it is not. The first is when conversational input to the local microphone does not generate a high enough output for optimal audibility. This condition often is in cases of profound hearing loss because of gain constraints imposed by acoustic feedback. In such cases advantage should be taken of the opportunity for increased output in the FM channel. The second condition applies when the local microphone and FM microphone are active at the same time (and the system has no provision for FM precedence). In this condition, the local microphone determines the noise level in the listener's ear. Equating the two output levels, therefore, equates the two signal-to-noise ratios—thereby eliminating the signal-to-noise advantage that the FM microphone was designed to provide. The writers of the 1994 guidelines emphasized the complexity of the topic and acknowledged that there would be conditions under which the "equal output" recommendation would be inappropriate. In reviewing those guidelines, the present ad hoc committee felt that profound hearing loss and simultaneous use of local and FM microphones are common enough to warrant particular attention. The committee is, therefore, recommending steps designed to conserve, in the listener's ear, the signal level and signal-to-noise benefits of the FM microphone.

Reference this material as: American Speech-Language-Hearing Association. (2002). Guidelines for fitting and monitoring FM systems. *ASHA Desk Reference.*

Index terms: Amplification, assistive technology, audiologic rehabilitation, audiology, auditory training, FM systems, FM transmitter with loop, hearing aid evaluation, hearing loss, personal FM system, sound field testing

Document type: Standards and guidelines

Introduction

Frequency modulated (FM) systems/auditory trainers have been standard equipment for children with hearing loss in educational settings for many years. FM systems are sometimes called auditory trainers. Traditionally the term *auditory trainer* has been used to refer to hard-wired, FM, infrared, or any amplification system other than a personal hearing aid. Because of the ambiguous nature of the term, only *FM systems* will be used in these guidelines. Their merit lies in the fact that a microphone placed a few inches from the mouth of a talker receives speech at a much higher level than one placed several feet away. The increase in speech level also means an increase in signal-to-noise ratio. The FM link provides a wireless connection to the listener's amplification system. The resulting improvements of signal level and signal-to-noise ratio in the listener's ear are recognized as the primary benefits of FM use (Ross, 1992).

Although originally developed for children with hearing loss, application has been extended to adults with hearing loss and to persons with normal hearing who exhibit disorders of articulation, auditory processing, attention, learning, and language (ASHA, 1991c; Bess, Klee, & Culbertson, 1986; Blake, Field, Foster, Platt, & Wertz, 1991; Cargill & Flexer, 1989; Loose, 1984; Pfeffer, 1992; Ross, 1992; Smith, McConnell, Walter, & Miller, 1985). It should be noted, however, that the present guidelines only address applications to persons with hearing loss.

The availability and use of FM systems have increased as a result of Public Law 101-336, the Americans with Disabilities Act, and PL 105-17, the Individual with Disabilities Education Act (IDEA) Amendments of 1997, and Section 504 of the Rehabilitation Act of 1973 (PL 93-112). All of these laws mandate access to technology for persons with hearing / communication deficits in order to reduce communication barriers.

The signal level and signal-to-noise benefits of the FM microphone are, typically, in the range of 15 to 20 dB (Hawkins, 1984). The resulting improvements in the audibility and clarity of speech in the ear of a child with hearing loss can have positive effects on language development, speech understanding, and academic attainment (Ross & Giolas, 1971; Ross, Giolas, & Carver, 1973). Optimal benefits are to be expected when an FM system is considered early in the process of fitting amplification. In fact, the use of an FM system as primary amplification, rather than as a supplement, has been suggested (Madell, 1992a, 1992b; Maxon & Smaldino, 1991). Reported additional benefits of an improved signal-to-noise ratio include increased attention span, reduced distractibility, and increased sound awareness and discrimination (Blake et al., 1991; Casterline, Flexer, & DePompei, 1989; Flexer, 1989; Stach, Loisell, & Jerger, 1987).

Although FM systems are of potential benefit for many listeners in a variety of settings and applications, the following issues need to be considered:

1. Little regulatory consumer protection has been mandated because most states do not classify these devices as hearing aids.
2. FM systems are available commercially, and many are purchased without consultation with an audiologist.
3. The American National Standards Institute has not yet issued a standard for performance measurements of FM systems.
4. No standards currently exist for the selection, evaluation, and fitting of FM systems for persons with hearing loss or for use by persons with normal hearing.
5. Researchers have raised concerns regarding specific problems related to electroacoustic performance factors—for example, variability, nonlinearity, lack of stability, coupling and maintenance (Hawkins & Schum, 1985; Thibodeau, 1990; Thibodeau & Saucedo, 1991).
6. Candidacy, effectiveness, cost, lifestyles, needs, and aesthetics are important concerns and must be considered on an individual basis.

By addressing these issues, as well as the benefits and limitations of FM systems, the audiologist facilitates the successful use of FM amplification. For the benefit of readers wishing to learn more about this topic, a bibliography is provided in Appendix A.

Scope

This document provides guidelines for fitting and monitoring of personal and self-contained FM systems for children and adults with hearing loss. (See also ASHA Ad Hoc Committee on Hearing Aid Selection and Fitting, 1998. Guidelines for hearing aid fitting for adults. *American Journal of Audiology, 7* (1), 5–13. Included are preselection and management considerations, as well as recommended procedures for performance measurement. The appropriate personnel responsible for selecting, fitting, and monitoring are defined. The committee acknowledges the complexity and the continuing evolution of FM technology. In that it is not possible to consider every configuration of design and implementation, these guidelines are intentionally limited in scope. In particular, the reader is reminded that the guidelines do not apply to the use of FM amplification with persons who have normal auditory thresholds but who might benefit from improved signal-to-noise ratio because of disorders in such areas as auditory processing or attention.

Personnel

The audiologist is the professional who is uniquely qualified to select, evaluate, fit, and dispense FM systems. Section IIA of the ASHA Code of Ethics (ASHA, 1992) states that "Individuals shall engage in the provision of clinical services only when they hold the appropriate Certificate of Clinical Competence or when they are in the certification process and are supervised by an individual who holds the appropriate Certificate of Clinical Competence." For purposes of the present document, the ASHA Certificate of Clinical Competence in Audiology is considered to be the appropriate certification. IIB of the Code of Ethics further states that "Individuals shall engage in only those aspects of the profession that are within the scope of their competence, considering their level of education, training, and experience." Daily monitoring checks by other personnel (including speech-language pathologists, teachers, etc.) are appropriate, however, after such personnel have received instruction in monitoring techniques from an ASHA-certified audiologist.

Preferred Practice Patterns for the Profession of Audiology (ASHA, 1997), specifically 14.0 (Audiologic Rehabilitation Assessment), 15.0 (Audiologic Rehabilitation), 20.0 (Product Dispensing), 21.0 (Product Repair / Modification), 19.0 (Hearing Aid Fitting), and 22.0 (Assistive Listening System / Device Selection), are consistent with these guidelines.

Other ASHA policies and reports have addressed the appropriateness of the audiologist as the professional qualified to select, evaluate, and fit amplification devices. They include Amplification as a Remediation Technique for Children With Normal Peripheral Hearing (ASHA, 1991a), The Use of FM Amplification Instruments for Infants and Preschool Children With Hearing loss (ASHA, 1991c), Scope of Practice in Audiology (ASHA, 1996a), Scope of Practice in Speech-Language Pathology (ASHA, 1996b), Maximizing the Provision of Appropriate Technology Services and Devices for Students in Schools (ASHA, 1998), Guidelines for Graduate Education in Amplification (ASHA, 1991b), and Guidelines for Audiology Services in the Schools (ASHA, 1993). Federal regulations Part II, 34 CFR Subpart A, d300.24(b)(1) (*Federal Register* 1999) and PL 105-17, Part A, Section 602(22) and Part C, Sections 632(4)(E), and 632(4)(F)(ii) (Public Law 105-17, 1997) further define and support the audiologist's role in the evaluation and habilitation of the population between birth and age 21.

Preselection

Before selecting an FM system for personal use, it is necessary to assess auditory capacity and the current level of auditory and communication function and to identify other factors related to device use. Implicit in the preliminary stages is determining whether to use a personal FM system (in which the output of the FM receiver is coupled to personal hearing aids) or a self-contained FM system (in which the output of the FM receiver is amplified for direct presentation to the ear). If a personal FM system is being considered, the personal hearing aids must have appropriate coupling capabilities and flexibility. For instance, the hearing aids should have provision for direct audio input, or, if neck loop coupling is to be used, they should have sensitive telecoils. In addition, hearing aid switch options (such as Microphone / Telephone / Both) must be carefully considered so as to provide flexibility of listening arrangements. If a self-contained FM system is going to be used, decisions must be made relative to the gain, frequency response, input / output functions, and saturation sound pressure level requirements for the individual listener.

Other factors to be considered in the preselection process include:

- the person's ability to wear, adjust, and manage the device;
- support available in the educational setting (e.g., in-service to teachers, classmates);
- acceptance of the device;
- appropriate situations and / or settings for use;
- time schedule for use;
- compatibility with personal hearing aids and other audio sources as well as options for coupling;
- individual device characteristics and accessories;
- external source interference (e.g., pagers, radio stations, computers, etc.);
- cost and accessibility; and
- legislative mandates.

During the preselection process, assessments may include, but are not limited to, audiological evaluation, observation of auditory performance in representative settings, consultation with the user or others knowledgeable about the user's performance, questionnaires and scales, hands-on demonstration, and a trial period.

The issue of potential damage to the auditory mechanism should be considered when fitting any assistive listening device. This is of special concern when considering the fitting of a self-contained FM system to a person with near-normal hearing, mild hearing loss, or fluctuating hearing loss.

Management

Orientation

The user's (and caregivers') ability to accept and use an FM system depends on several factors, including but not limited to (a) a hands-on demonstration of the FM system and its types and components, and (b) the training of personnel (e.g., speech-language pathologists, teachers) in its appropriate use and troubleshooting.

Hands-on demonstration provides the user and family an opportunity to assess the components of the FM system(s) as they relate to specific needs. This process serves to establish the user's / caregivers' role in (re)habilitation.

The audiologist is responsible for the training of individual(s) responsible for the use and maintenance of the FM system (Johnson, Bensen, & Seaton, 1997). As part of this training, the audiologist should ensure that the user, caregivers, and support personnel understand the modes of use (i.e., FM only / FM plus Aid / Aid only).

Trial periods and return policies vary by manufacturer and by state and local laws. Applicable policies should be investigated and discussed with the user and family. Research on the trial use of FM systems in the home with parents and toddlers (Benoit, 1989) and with college students (Flexer, Wray, Black, & Millin, 1987) suggests that acceptance and compliance may depend on the user's knowledge of how the system works in relation to the hearing loss and the perception that the benefits outweigh the inconvenience. In light of these factors, the audiologist may choose to make available loaner and / or rental equipment.

Monitoring

A. Daily Checks

All amplification equipment is subject to failure (Bess, Sinclair, & Riggs, 1984; Hoverstein, 1981; Maxon & Brackett, 1981). Daily checking is, therefore, required. The daily check can be performed by the parent, teacher, speech-language pathologist, or any one who has received appropriate training by the audiologist.

Generally, a daily check consists of visual inspection of the device and its coupling, followed by listening to the sound quality. In a sense, the user monitors sound quality continuously and may well detect such problems as intermittent function or a condition that "doesn't sound normal." Indeed, one of the goals of management should be to encourage self-monitoring. However, an individual with normal hearing should also perform a listening check. This ensures detection of problems that the user cannot identify. If possible, the listening check should be performed in the room(s) where the FM system will be used so that any interference will be detected.

The user or other appropriate individuals should have accessory supplies available to remedy routine problems as they occur. These supplies typically include such items as spare microphones, receivers, boots, batteries, cords, and neck loops. If a malfunction persists or otherwise cannot be identified and remedied through the daily check procedure, the audiologist should be notified.

B. Comprehensive Monitoring

Periodic comprehensive monitoring of the FM system by the audiologist may include electroacoustic analysis, probe microphone measurements, and other in-depth troubleshooting measures. These comprehensive procedures should also be performed whenever an unresolved problem is identified during the daily check. In any event, they should be performed routinely at least once a year for adults and children 5 years of age or older. They should be performed more frequently for children under 5 years of age—perhaps as often as every 3 to 6 months. At the time of writing, there is no standard electroacoustic measurement procedure for FM systems. However, many manufacturers make these measurements and provide the results with their devices. Therefore, until a measurement standard procedure is available, devices should be evaluated at least according to the measurement procedures used by the manufacturer, which are typically those of ANSI S3.22 (1987) Specifications of Hearing Aid Characteristics. Measurements such as full-on gain, SSPL90, and harmonic distortion should be obtained and should be compared to the manufacturer's values. Both the FM and environmental microphone(s) should be evaluated separately, with care taken to properly position the FM microphone transmitter in relation to the test signal source.

C. Audiologic Reevaluation

Periodic evaluations of hearing, and of performance with the FM device, are necessary to monitor stability of hearing, appropriate device settings, function, and degree of benefit. These evaluations should be performed at least annually for adults and children 5 years of age or older. They should be performed more frequently for children under 5 years of age and for individuals with fluctuating or conductive hearing loss.

These assessments may include, but are not limited to, audiologic evaluations, real ear performance measurements, assessments of speech recognition, consultations, observations of performance in normal-use settings, questionnaires, and subjective scales of performance benefit.

Fitting and Adjustment

General Principles in Assessment of FM Systems

Although FM systems are amplification devices similar to hearing aids, there are some distinct differences that need to be taken into account in developing measurement strategies. First, and perhaps most important, the input level of speech to the FM microphone is more intense than to the hearing aid microphone. With the FM microphone appropriately located 6–8 inches from the talker's mouth, the overall level of speech is approximately 80–85 dB SPL (Cornelisse, Gagne, & Seewald, 1991; Hawkins, 1984; Lewis, 1991; Lewis, Feigin, Karasek, & Stelmachowicz, 1991). This is 15–20 dB more intense than the typically assumed 60–70 dB SPL input to the microphone of the personal hearing aid 1–2 meters from the talker. If output measurements are being made to adjust FM systems, then typical input levels should be used. This is particularly important given that most FM microphone transmitters employ some type of input compression. The gain and output of the FM system may be quite different if lower-level signals, which are not representative of the speech input to the FM microphone, are used in the measurement procedure. It is for this reason that the recommended input level in these fitting guidelines is 15 dB higher for the FM microphone than for the local microphone.

A second issue relates to the increased complexity of the FM systems compared with hearing aids. Many FM systems have several microphone-input possibilities. These include lapel, lavaliere, boom, and conference microphones for the transmitter and ear-level or body-worn microphones at the receiver. There may be one or two environmental microphones, and they and the FM microphone may be omnidirectional or directional. It is important that each input channel in the FM system be evaluated and that the microphones be positioned in the proper manner. Input levels may also need to be altered for different microphone types and locations.

In a similar vein, the FM system may have more than one volume control wheel (VCW). Some units have one VCW for the FM signal and one for the environmental microphone(s). On personal FM systems, there will be one VCW for the FM system and one for the personal hearing aid. In addition, there may be a VCW on the FM microphone transmitter. It is important that careful thought be given to the setting of these VCWs, as certain combinations can produce undesired results (Hawkins & Schum, 1985; Hawkins & Van Tasell, 1982; Lewis, 1991, 1992).

Finally, modifications must be made in some testing procedures to account for the way certain systems are physically arranged on the user. For instance, if a personal FM system with a neck loop is to be evaluated in a 2-cc coupler, then the hearing aid and neck loop must be in the same relative positions and orientations as they would have on the listener. For self-contained FM systems that use earbuds or Walkman-type headsets, probe microphone measures may be preferred because those receivers cannot be coupled adequately to the 2-cc coupler. The best way to satisfy this criterion is to place the neck loop and hearing aid on a person—preferably the actual user.

Typical electroacoustic evaluation includes measurement of output when using an input of 90 dB SPL. The result (SSPL90) is intended to provide a measure of the maximum output of the system. The audiologist should note, however, that compression in the FM microphone / transmitter will most likely prevent the hearing aid (or FM receiver / amplifier) from reaching its maximum output for FM input alone. A low SSPL90 when testing with FM microphone input alone should not, therefore, be interpreted as a low SSPL90 for the system as a whole. The true estimate of SSPL90 for the system is that obtained with 90 dB SPL input to the local (hearing aid or environmental) microphone.

General Goals for Fitting FM Systems

There are two aspects of fitting to be considered. First is the amplification of sounds received via the local (environmental) microphone (which is sometimes the microphone of the personal hearing aid). Second is the amplification of sounds received via the remote (FM) microphone.

Following are the general goals for amplification via the local microphone:

1. *Gain and frequency response* should be such that speech of average effort, produced at a distance of between 3 and 6 feet from the local microphone, is brought to an optimal level of audibility, over as wide a frequency range as possible, consistent with comfort.
2. *Saturation sound pressure level* should be high enough to provide an adequate dynamic range above the threshold of audibility but low enough to avoid discomfort or damage from unusually loud sounds.
3. *Input/output characteristics* should be such that a reduction of talker distance to a few inches (as in self-generated speech) can be accommodated without causing discomfort, or reducing intelligibility.

4. If possible, *input/output characteristics* should be such that an increase of talker distance beyond 6 feet can be accommodated without reducing intelligibility.
5. *Acoustic feedback* should be low enough to permit the gains called for in 2 and 4 without causing instability (whistling).

An additional goal relates to amplification via the remote (FM) microphone:

6. *Gain* and input / output characteristics should be such as to preserve, in the user's ear, all or most of the signal-to-noise benefits for speech produced at a few inches from the remote microphone.

For purposes of these guidelines, it will be assumed that goals 1 through 5, relating to amplification via the user's personal hearing aid have already been met to the audiologist's satisfaction. It will also be assumed that, for a self-contained FM system, the characteristics for amplification via the local (environmental) microphone have been matched as closely as possible to those of the user's personal hearing aid. It is important to use the same type of signal (such as pure tones or speech-weighted noise) when making measurements on the hearing aid and FM system for comparison purposes. The remaining issue faced by the audiologist, therefore, is adjustment of gain in the FM channel so as to maintain an appropriate FM advantage. These guidelines deal with this last issue.

Operational Goal for Adjustment of Gain in the FM Channel

The basic recommendation of these guidelines is that a pure tone input of 80 dB SPL into the remote microphone shall give an output that is 10 dB higher than that produced by an input of 65 dB SPL into the local (environmental or hearing aid) microphone—as illustrated in Figure 1. Note that the figure of 10 dB is offered only as a general guide. As will be explained below, there are specific situations when a lower or higher value may be appropriate. (See also Appendix B.)

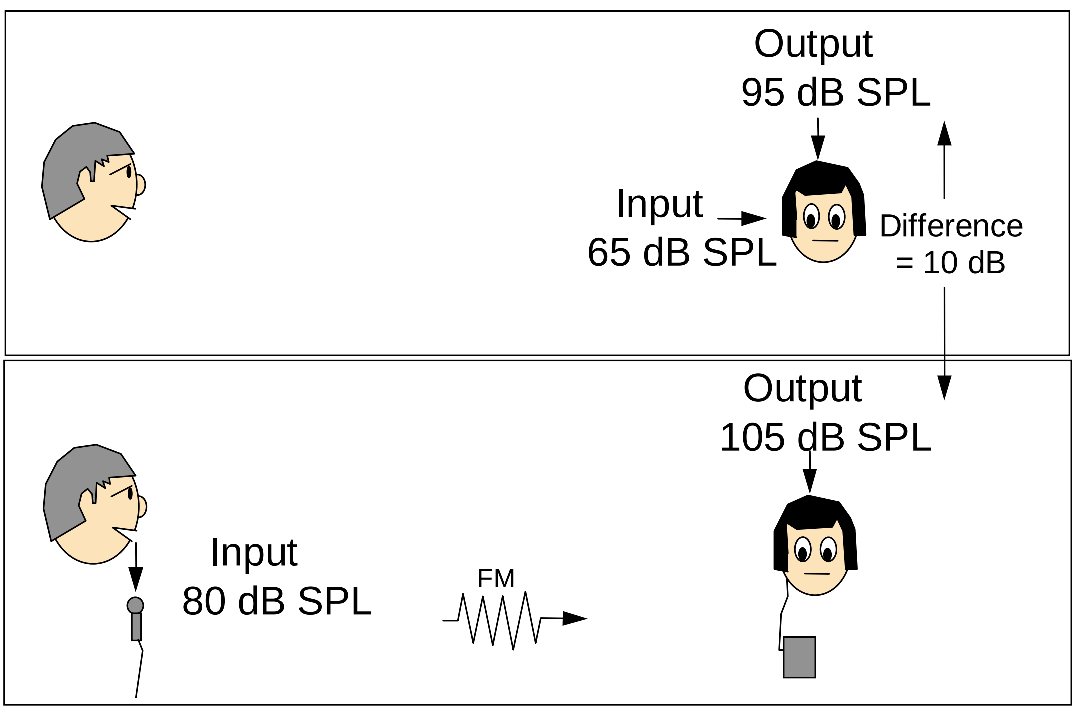

Figure 1. The basic goal is that the FM system should increase the level of the perceived speech, in the listener's ear, by approximately 10 dB.

Suggested Procedure for Adjusting Gain in the FM Channel for a Personal FM System Used as an Accessory to an Existing Hearing Aid

1. Ensure that the Volume control, Tone control, Saturation Sound Pressure Level, and any compression characteristics of the hearing aid are adjusted as normally used and that the aid is functioning properly.
2. Measure output into a 2-cc coupler for an input to the hearing aid microphone of 65 dB SPL at a frequency of 1000 Hz—as illustrated in Figure 2(a).
3. Couple the FM receiver to the hearing aid in the appropriate manner that is to be used by the wearer. If using a standard neck loop, make sure the shape and orientation of the loop, and the distance and orientation of the aid in relation to the loop, are the same as in actual use.
4. Adjust the FM volume control of the FM receiver so that a 65-dB SPL, 1000-Hz input to the remote microphone generates the same output from the hearing aid as that measured with the local microphone; see Figure 2 (b).
5. Increase the input to 80 dB SPL. You should find that the output from the hearing aid increases by at least 10 dB; see Figure 2(c). If so, then the adjustment can stand.

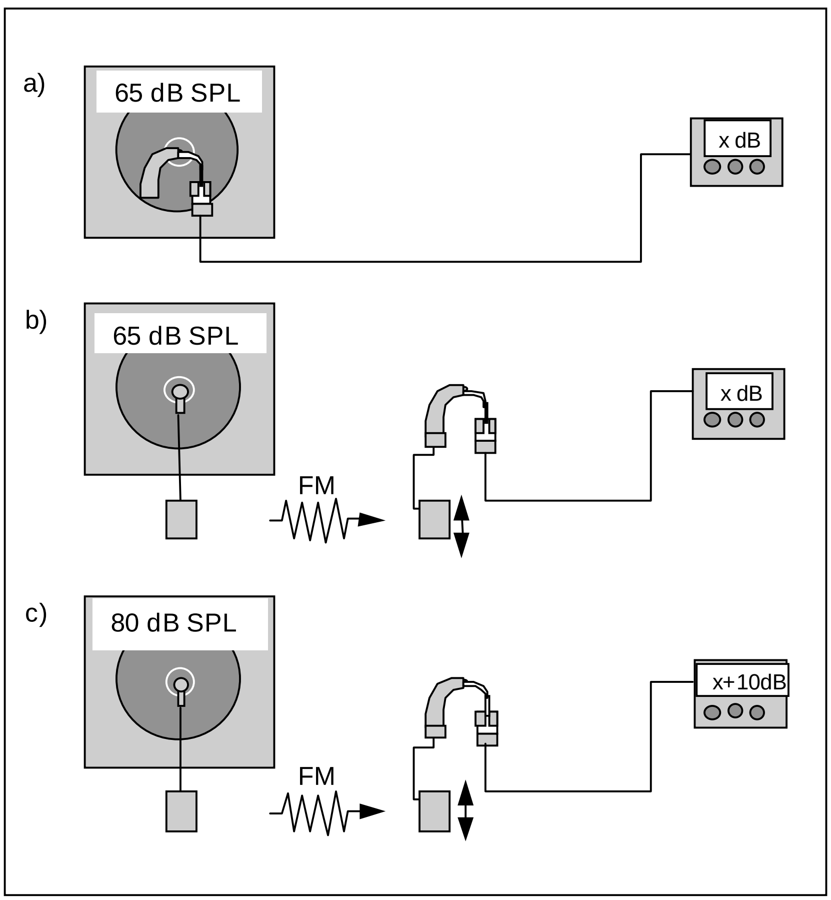

Figure 2. A suggested procedure for adjusting FM gain so as to preserve a 10 dB FM advantage. a) Using a 1000 Hz tone, measure output for 65 dBSPL input to the local microphone. b) Provide 65 dB SPL input to the remote microphone and adjust FM gain to give the same output (the two channels now have equal gain). c) Increase input to 80 dB SPL. If the output increases by 10 dB, the process is complete. If it does not, increase FM gain to give an FM advantage of between 5 and 7 dB (see text).

6. If the increase was 15 dB, you may reduce the FM volume control of the FM receiver so that the output into the 2-cc coupler falls by 5 dB.
7. If the increase was only 5 dB, increase the FM volume control of the FM receiver to provide an additional 2 or 3 dB of output (giving a 7 or 8 dB FM advantage rather than a 10 dB advantage).
8. If there was no increase of output when the input changed from 65 to 80 dB SPL, you may assume that the FM transmitter has a very low compression threshold. In this case, increase the FM volume control of the FM receiver to provide a 5 dB increase of output (giving a 5 dB FM advantage).

When dealing with a self-contained FM system, in which the FM receiver and amplifier are in a single unit, first adjust the characteristics of amplification via the local (environmental) microphone to match those of the user's personal hearing aid (which we assume to have been fitted properly). Then follow the procedure just outlined.

Depending on the nature of the audiologist's test equipment, it may be easier to carry out the above procedure with a swept tone or speech-weighted noise input so as to produce a complete curve showing output as a function of frequency. In this case, the focus should be on output in the 500 to 2000 Hz range rather than just at 1000 Hz.

Even if a single frequency is used for initial adjustment, full response curves should be run to confirm that the desired FM advantage is maintained over the 500 to 2000 Hz range —and further adjustments made if necessary. In addition, it is advisable to assess performance with a speech-weighted stimulus as input.

Some acoustic analysis systems offer 85 dB SPL as a signal representing input to the FM microphone. Even if this higher signal is used, the recommended procedure should still be followed. That is, first equate outputs for a 65-dB input so as to provide equal gain. Then, if necessary, increase gain in the FM channel so that the output increases by around 10 dB when the input increases from 65 to 85 dB SPL.

A 1000-Hz pure tone at 80 dB SPL was chosen for the present guidelines as representative of the frequency and amplitude peak for vowels, in speech produced at a distance of a few inches from the FM microphone. A primary concern of these guidelines is the negative effect of compression in the FM transmitter on the speech level and signal-to-noise ratio in the user's ear. Compression is most likely to be activated by the vowels.

Some FM systems automatically reduce gain via the local microphone whenever the FM and local microphones are active at the same time. This feature helps to maintain the signal-to-noise ratio benefits for speech received via the FM microphone. Unfortunately, it also reduces audibility of other talkers who are not wearing the FM microphone. If simultaneous use of the FM and local microphones is the rule rather than the exception for a given individual, then the adjustment of gain via the local microphone should be made with the FM channel turned on, but receiving no input. Similarly, the local microphone must be turned on, but receiving no input, when adjusting the FM volume control.

Exceptions

1. If the proposed pattern of use does not involve simultaneous activation of the local and remote microphones (i.e., if the local microphone is normally turned off when the remote microphone is in use) and if the user's hearing loss is no greater than 80 dB, it is appropriate to turn down the FM volume control so that 80 dB SPL input to the remote microphone gives the same output as 65 dB input to the local microphone (as recommended in the 1994 ASHA guidelines). The reasoning is: First, the user's hearing is good enough that adequate audibility of speech can be maintained via the remote microphone in spite of the reduced FM gain. Second, because the local microphone is turned off, the signal-to-noise benefit for speech into the FM microphone is not compromised by noise picked up at the local microphone.
2. An FM advantage of 0 dB is also appropriate if the FM system incorporates an automatic FM precedence feature to reduce the sensitivity of the local microphone whenever close speech input is detected in the FM channel.
3. At the other extreme, users with profound hearing loss may need an FM advantage in the region of 15 dB. The reasoning is: When the hearing loss exceeds 90 dB it becomes difficult to provide optimal audibility for speech received via the local microphone. Basically, the problem of acoustic feedback prevents the audiologist from providing enough gain. Under these circumstances, a primary benefit of FM ampli-

fication is that the increased input to the FM microphone can provide greater audibility of speech at a distance. This will only happen, however, if the gain in the FM channel is maintained at a high enough level (Boothroyd & Iglehart, 1998).

Electroacoustic Confirmation

At the time of fitting and during routine follow-up, the audiologist should confirm that the electroacoustic fitting goals have been attained or maintained.

Recommendations for 2-cc Coupler Assessment

1. Attach the hearing aid, or the receiver / amplifier of a self-contained FM system, to the 2-cc coupler and place in the test box with the microphone in the calibrated position.
2. Using swept tones or a complex noise, measure output as a function of frequency following standard procedures. The results should include:
   a. an estimate of maximum output as a function of frequency
   b. an estimate of full-on gain as a function of frequency
   c. an estimate of actual gain as a function of frequency at user settings for conversational input (65 dB SPL)
   d. if the aid incorporates full dynamic range compression, estimates of user gain as functions of frequency for low (50 dB SPL), typical (65 dB SPL), and high (80 dB SPL) input levels
   e. estimates of distortion as a function of frequency under normal conditions of use
3. Remove the hearing aid, still attached to the coupler, from the test box.
   a. If this is a personal FM system, couple the FM receiver to the personal hearing aid. Note that if Direct Audio Input is being used, the sensitivity of the hearing aid microphone may change. The system should, therefore, be retested with input to the hearing aid microphone before assessing FM input.
   b. If neck loop coupling is being used, make sure that the configuration of the loop, and the position and orientation of the aid in relation to the loop, represent real conditions of use. The ideal way to meet this requirement is to place them on the actual user (see Figure 3). An alternative is to use

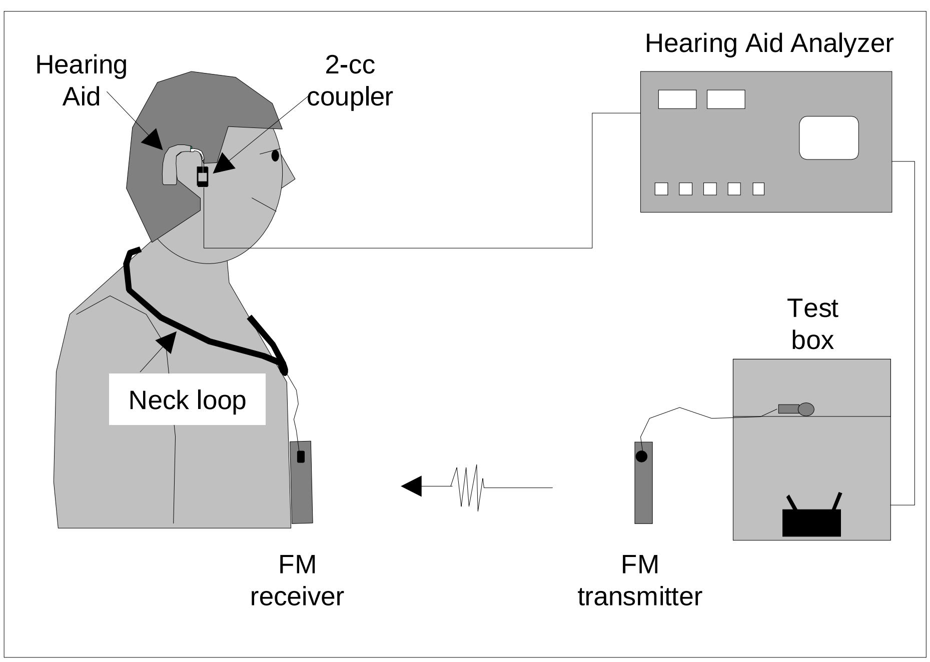

Figure 3. Suggested arrangement for electroacoustic assessment of a personal FM system that uses neck loop coupling.

another person or a manikin. With all three options, it may be necessary to support the weight of the coupler as it hangs in front of the ear.

4. Place the FM microphone in the test box in the calibrated position.
   a. If possible, turn off the local (“environmental” or hearing aid) microphone. If it is not possible, the measurements must be done in a quiet environment such as the audiometric test booth. Note that when testing a self-contained FM system in which the environmental microphone can be turned off the receiver / amplifier can remain in the test box.
5. Set all volume controls to their normal use positions.
6. Repeat the output measurements to obtain:
   a. an estimate of gain, as a function of frequency, for a high input level (80 dB SPL).
   b. an input-versus-output curve to obtain an estimate of compression threshold in the FM transmitter.

Real-Ear Assessment

If electroacoustic confirmation is to be carried out using output measurements in the ear canal of the user, rather than in a 2-cc coupler, the audiologist should follow standard procedures for testing via the local or hearing aid microphone. When testing via the FM microphone, this should be placed as close as possible to the location of the reference microphone. (See Hawkins, 1992, 1993; Seewald et al., 1991; Sullivan, 1987.)

Limitations of Aided Sound Field Threshold as a Means to Estimate Gain

Although behavioral measurements of real-ear performance such as functional gain have been recommended by some investigators (Madell, 1992b; Turner & Holte, 1985; Van Tasell, Mallinger, & Crump, 1986), several distinct limitations of this approach have been described recently (Lewis et al., 1991; Seewald & Moodie, 1992). The major problem with the functional gain approach is that the input levels to the FM microphone at the aided threshold will typically be quite low during the measurement procedure. These lower input levels would not be representative of the talker’s voice entering the FM microphone during actual use of the FM system. These input level differences, combined with the fact that most FM microphone-transmitters incorporate input compression, make the aided sound field threshold values difficult to interpret. The sound-field threshold values do represent the lowest intensity signal that the user can detect with the FM system. Unfortunately, they lead to an overestimate of both the amount of gain for the FM signal under normal use conditions and the sensation level at which speech is presented to the user (Lewis et al., 1991; Seewald, Hudson, Gagne, & Zelisko, 1992; Seewald & Moodie, 1992).

Behavioral Validation

At the time of fitting and during routine follow-up it is imperative that the fitting be validated behaviorally.

Comfort and Quality

At the time of fitting and during routine follow-up, the audiologist should confirm that speech at both a few feet and a few inches from the local microphone, and speech at a few inches from the FM microphone, are within a comfortable range and of acceptable quality. Any evidence of discomfort must be addressed immediately by adjustment of the SSPL and / or compression characteristics of the hearing aid or hearing aid / FM receiver. Older children and adults may be expected to provide verbal reports. For very young children, the audiologist may be limited to confirming the absence of aversive reactions to loud speech at a few inches from the microphones.

Speech Perception

At the time of fitting and during routine follow-up, the audiologist should measure speech perception under a set of representative conditions. These conditions should represent typical speech produced at a few inches and a few feet from the microphone and at a few inches from the FM microphone. They should be made in quiet and in noise. And, ideally, they should be made by Aid alone, Aid plus FM, and FM alone. If time constraints preclude such comprehensive testing, priority should be given to testing in noise under the Aid plus FM condition—this being the true validation of the FM adjustment.

Some writers have recommended placing the FM microphone within a few inches of a loudspeaker in order to simulate placement on an actual talker. It should be noted, however, that the pattern of radiation from a loudspeaker and a human talker are very different—especially when the loudspeaker assembly contains different elements for different parts of the acoustic spectrum. As a result, both the speech spectrum and the input level may deviate considerably from what is intended. This procedure is not, therefore, recommended. An alternative is to test with monitored live voice with the tester wearing the FM microphone in its appropriate position.

For the hearing aid condition, it is recommended that speech perception be assessed with a speech signal of 55 dB HL and a background noise of 50 dB HL. The resulting signal-to-noise ratio of 5 dB is typical of many elementary school classrooms (Crandell & Smaldino, 1995; Finitzo-Hieber, 1988; Markides, 1986). Assuming the sound field has been calibrated for a 45-degree azimuth, the intensity of the speech would be 68 dB SPL, a level that should be typical of the input to the hearing aid microphone. Instead of using the plus and minus 45-degree azimuth loudspeaker arrangement, the audiologist may prefer that speech originate from 0 degrees and noise from 180 degrees. This would eliminate the possibility of a head shadow effect for either the speech or noise in the case of monaural fitting. If the 0/180 arrangement is used and the sound field is calibrated with the appropriate 17 dB reference, then the speech signal can be presented at 50 dB HL (67 dB SPL) and the noise at 45 dB HL (62 dB SPL). A measure of speech perception should then be obtained with an age- and language-appropriate test. When testing via the FM microphone, the noise should remain at 50 dB HL, but the speech signal will increase from 55 dB HL to around 70 dB HL (83 dB SPL) (Hawkins, 1984). The effective signal-to-noise ratio at the FM microphone will now be +20 dB. Under the Aid plus FM condition, however, the signal-to-noise ratio in the user's ear is likely to be less than 20 dB. If the goals of fitting have been attained, it will be in the region of 15 dB.

Recommendations for Monitored-Live-Voice Assessment of Speech Perception With an FM System

1. Select an appropriate speech recognition test giving consideration to the user's developmental age, language skills, and primary language.
2. Make sure that all controls on the FM system are set for customary use and that the system is working.
3. Place the FM microphone on yourself in the position normally worn but turned off.
4. Place the hearing aid(s) and personal FM receiver (or self-contained FM receiver/amplifier) on the client.
5. Place the user in the calibrated sound field and yourself at the audiometer controls—as shown in Figure 4. Note that the loudspeakers are located at plus and minus 45 degree azimuths.

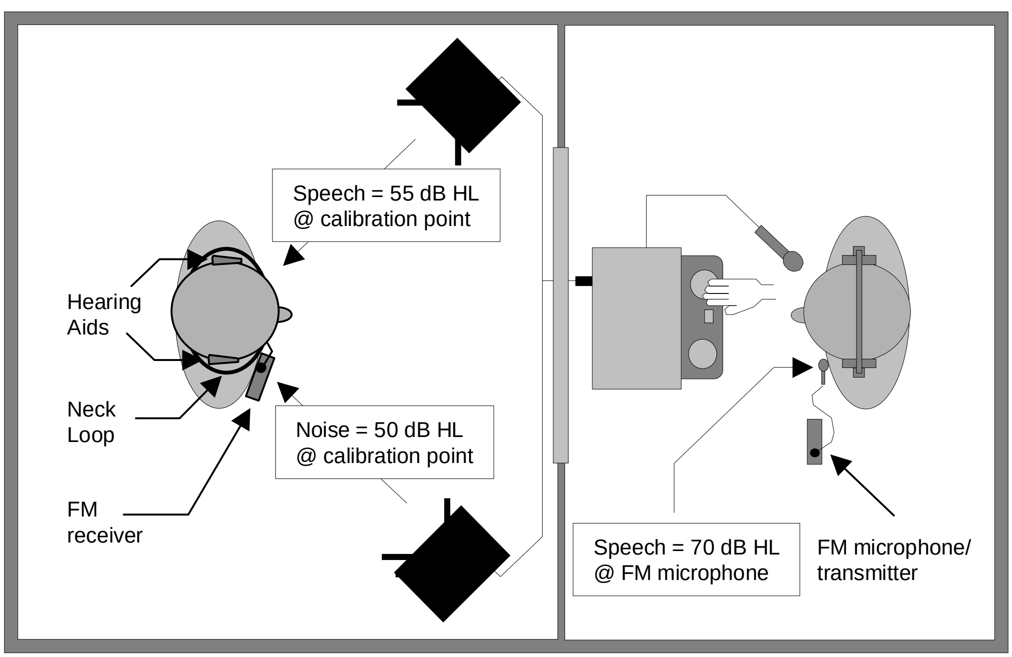

Figure 4. Suggested test arrangement for speech perception assessment with an FM system using monitored live voice

6. Measure speech perception in quiet and noise via the local microphone(s):
   a. Set the speech level to 55 dB HL (68 dB SPL) and obtain a speech perception score through the loud speaker (FM microphone off).
   b. Turn on speech-shaped noise at 50 dB HL (63 dB SPL), producing a S / N ratio of +5 dB. Obtain a second speech perception score.
7. Measure speech perception in quiet and noise via the FM microphone(s):
   a. Without making any other changes, turn ON the FM microphone and obtain a third speech perception score via Aid plus FM in noise.
   b. Turn OFF the noise and obtain a final speech perception score via Aid plus FM in quiet.
8. Evaluate the results:
   a. The score obtained in quiet by Aid alone should be commensurate with other speech perception scores for this client obtained either aided or under headphones.
   b. The score obtained in noise by Aid alone should be poorer than that obtained in quiet.
   c. When the FM microphone is turned on, the score in noise should return to a value that is not significantly lower (and may be higher) than that obtained in quiet by aid alone. If the score remains below that obtained by Aid alone in quiet, the gain in the FM channel is probably too low.
   d. Turning off the noise in the Aid plus FM condition should not produce a significant change of score. If there is a significant increase of score, the gain in the FM channel is probably too low.
9. At all points in the test process, confirm with the client that the speech levels are within an acceptable range of loudness and perceived quality—making due allowance for the negative effects of the noise.

Summary

1. FM amplification systems have much to offer the person with hearing loss in terms of improved signal level and improved signal-to-noise ratio for speech produced at a considerable distance.
2. Such systems should be selected, fitted, and adjusted by ASHA-certified audiologists.
3. The decision to use FM amplification must be based on both audiological and non-audiological factors.
4. Before fitting, the user and other affected persons should receive orientation and counseling.
5. After fitting, performance must be monitored on a regular basis.
6. The fitting goals for amplification via the local microphone do not differ from those for personal amplification.
7. The additional goal for amplification via the FM microphone is that the signal level and signal-to-noise ratio advantage be preserved in the ear of the listener.
8. At the time of fitting, and during subsequent monitoring, the audiologist should confirm that the electroacoustic goals of fitting have been attained or maintained.
9. At the time of fitting, and during subsequent monitoring, the audiologist should confirm the appropriateness of the fitting through behavioral validation.
10. Functional gain measurement is not recommended as an appropriate technique for evaluating FM amplification systems.
11. This document includes specific recommendations for
    a. adjustment of gain for signals received via the FM microphone
    b. electroacoustic assessment of an FM system using a 2-cc coupler
    c. speech perception assessment as part of the behavioral validation of an FM fitting

Limitations

These guidelines were developed to provide direction to audiologists in the selection and fitting of FM systems. The committee recognizes the complexity of the technology (including microphone and coupling strategies and the use of FM with digital and advanced signal-processing hearing aids) and the many unresolved issues of measurement (including input stimulus type and level). These guidelines should be viewed as a reflection of the current understanding of these issues. Future technology and research will mandate consideration of other approaches and tools.

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Appendix A: Readings on FM Amplification

The following reading list includes, but is not restricted to, some of the publications referred to in the guidelines. It was prepared by Dawna Lewis.

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Appendix B: Signal-to-Noise Ratio in the Listener's Ear During Simultaneous Use of FM and Local Microphones

During simultaneous use of the FM and local microphones, the noise level in the listener's ear will, essentially, be the more intense of the noise levels coming from the two microphones.[1] Consider the situation in which the background noise in a classroom is a uniform 60 dB SPL, and make the following assumptions:

1. The teacher's speech reaches the FM microphone at a level of 80 dB SPL, giving a 20 dB signal-to-noise ratio.
2. The teacher's speech reaches the student's hearing aid microphone at a level of 65 dB SPL, giving a 5 dB signal-to-noise ratio.
3. The gain in the student's hearing aid is 40 dB.

When amplified by the hearing aid, the level of the teacher's speech in the student's ear is 105 dB SPL (i.e., 65 +40); the level of the noise is 100 dB SPL (i.e. 60 +40); and the signal-to-noise ratio is 5 dB, as illustrated (respectively) in Figures A1, A2, and A3.

Now consider three different criteria for adjustment of gain in the FM channel:

1. The "equal output" criterion (see Figure A1). Under this criterion, FM gain is set to 25 dB so that the teacher's speech at the FM microphone generates 105 dB SPL in the student's ear (i.e., the same as that generated by 65 dB SPL into the hearing aid microphone). The noise at the teacher's microphone generates only 85 dB SPL in the student's ear, apparently preserving the desired 25 dB signal-to-noise ratio. However, because the hearing aid microphone is still active, the noise in the student's ear is actually 100 dB SPL, and the signal-to-noise ratio for the teacher's speech is still 5 dB even though it has been transmitted via the FM link. Clearly, this criterion is appropriate only if the hearing aid microphone is turned off (or, at least, desensitized) when the FM microphone is in use.

[1] When adding two sounds, the appropriate equation is:

$$C = \log_{10}(10^{A/10} + 10^{B/10})$$

where A and B are the two sound levels and C is the combined level, all expressed in dB. If A and B differ by more than 6 dB, C is very close to the higher of the two. If A and B are equal, C is only 3 dB higher than A.

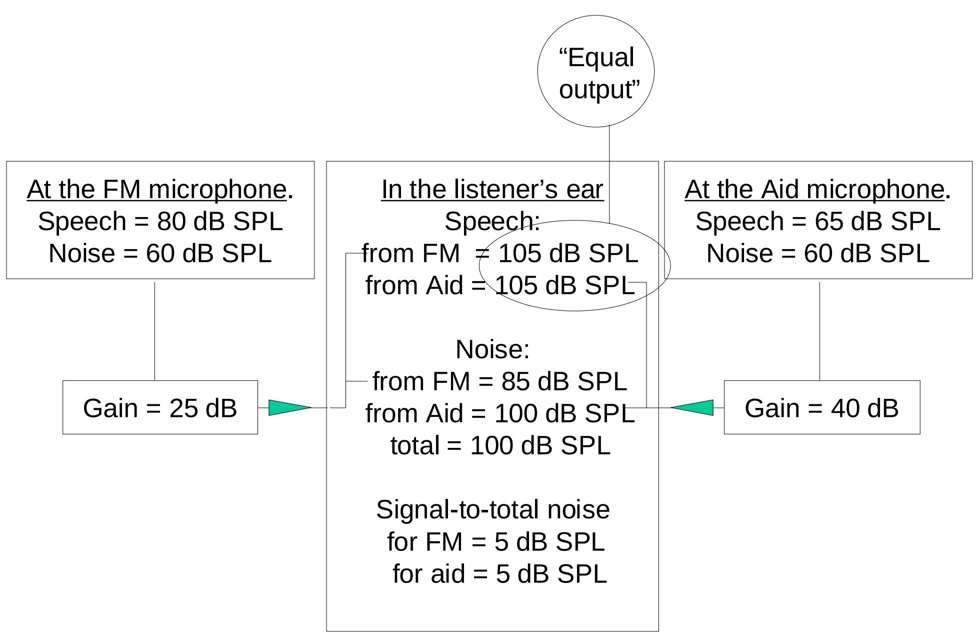

Figure A1. Adjustment of FM gain under the "equal output" criterion.

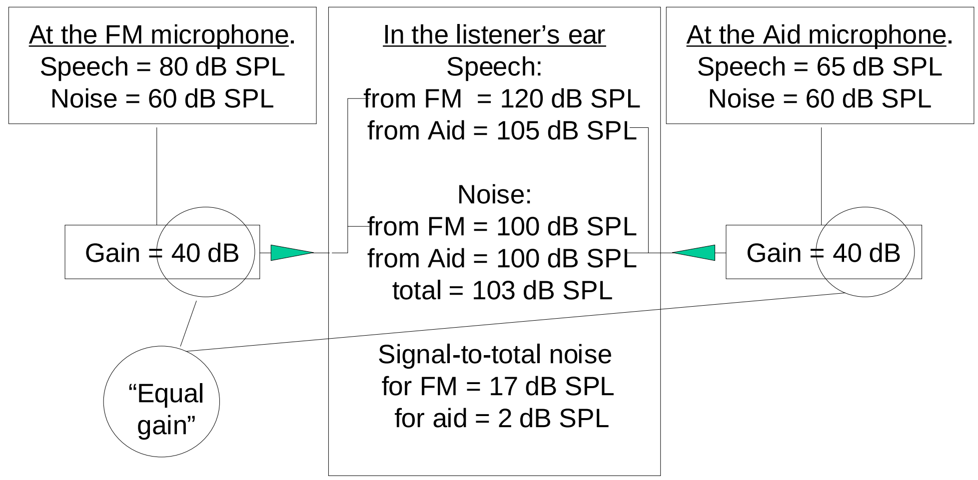

Figure A2. Adjustment of FM gain under the "equal gain" criterion.

2. The "equal gain" criterion (see Figure A2). Under this criterion, FM gain is made identical to that of the hearing aid (i.e., 40 dB). Assuming linear amplification, the level of the teacher's speech in the student's ear is now 120 dB SPL, and the noise received via the FM channel is 100 dB SPL (i.e., the same as that received via the hearing aid microphone). The combined noise level is in the region of 103 dB SPL. Under this condition activation of the FM microphone raises the levels of the teacher's speech and the signal-to-noise ratio in the student's ear by 15 dB and 12 dB, respectively. Although the "equal gain" criterion appears to provide the maximum FM advantage, it is not always appropriate. Many students, for example, find the level of speech received via the FM microphone to be unacceptably high. Moreover, the "equal gain" adjustment has been made in the presence of realistic inputs into the teacher's microphone. Under this condition, most FM

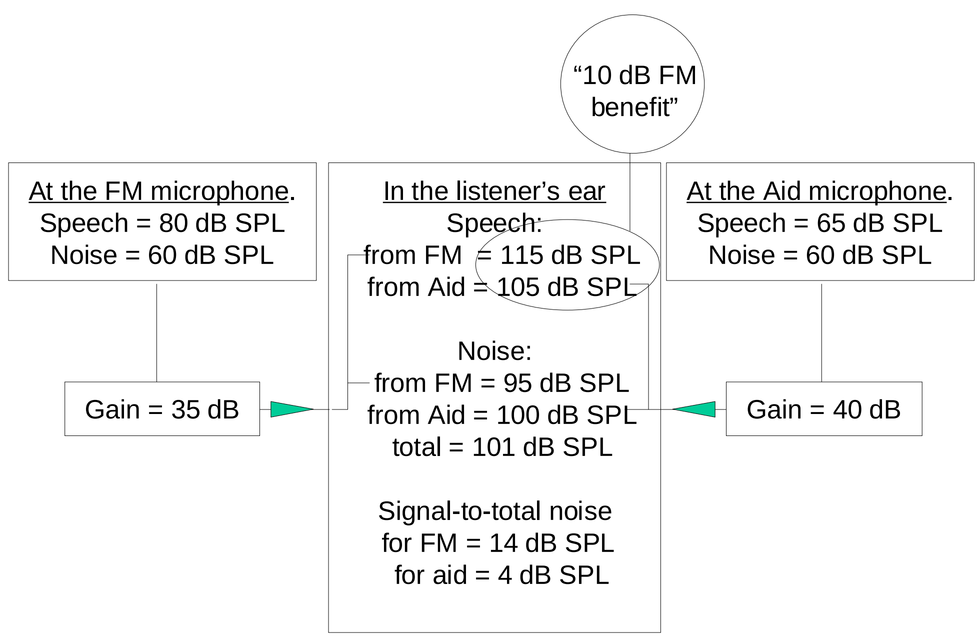

Figure A3. Adjustment of FM gain under the "10 dB FM benefit" criterion.

microphone transmitters will be operating with considerable compression. In actual use, therefore, the FM gain will rise above the "equal gain" criterion whenever there is no speech input to the FM microphone, leading to an increase in noise level in the student's ear and degradation of signal-to-noise ratio for conversational speech received via the hearing aid microphone.

3. The "10 dB FM advantage" criterion (see Figure A3). Under this compromise, FM gain is adjusted to 35 dB (i.e., 105 +10–80) so that the level of the teacher's speech received via the FM microphone is 10 dB higher than that of conversational speech received via the hearing aid microphone. The level of the teacher's speech in the student's ear is 115 dB SPL and the level of noise received via the FM channel is 95 dB SPL. The level of noise received via the hearing microphone, however, is still 100 dB SPL, giving a combined noise level of 101 dB SPL. The signal-to-noise ratio for the teacher's speech is now 14 dB. Although not ideal, this signal-to-noise ratio represents a considerable improvement over that obtained in the "equal output" criterion.

It was the foregoing considerations that led the Ad Hoc Committee on FM Systems to recommend a "10 dB FM advantage" criterion as the basis for adjusting gain in the FM channel. At the same time, the committee acknowledges the many situations in which departures from this goal are appropriate. The committee also acknowledges that the foregoing analysis is theoretical and that there has been much discussion of this issue in the literature. The need for good empirical research on this and other issues related to FM amplification is acute.