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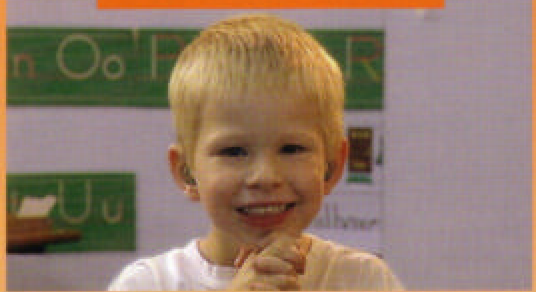

FM Systems for Children: Rationale, Selection & Verification Strategies

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This booklet is designed to supplement the Phonak Video Focus "FM Systems for Children". The figures and references contained herein were selected to clarify the FM coupling options and fitting procedures presented in the video, and to direct interested readers to pertinent literature.

This booklet has been divided into 5 sections:

1. FM Systems
2. Goals
3. Setting the FM System
4. Verification of FM System Performance
5. Inservice Training

FM Systems

One of the most effective methods of overcoming the negative effects of noise, distance and reverberation for individuals with hearing loss is the frequency-modulated (FM) system.

In general, FM systems consist of a microphone and transmitter that are worn close to the talker's mouth and a receiver that is worn by the listener. The signal is sent from the transmitter to the receiver by FM radio waves. The receiver can be coupled to the listener's ear in a variety of ways. The effects of noise and reverberation are reduced because the distance between the talker's mouth and the microphone is so short, usually 6 to 8 inches or less. Distance is no longer a factor because the talker's voice always reaches the listener's ear at a level comparable to what would be expected if that talker were standing right next to the listener.

As the videotape illustrates, there are a number of microphone and transmitter options available for use with FM systems. Lavaliere microphones include the transmitter and microphone in a single case that is worn around the neck. Lapel microphones are clipped to the talker's shirt and attached to a transmitter via a cord. Headworn devices are designed to position the microphone very close to the talker's mouth. In each of these arrangements, the microphone remains close to the talker at all times. Another type of microphone, which serves a slightly different purpose, is the conference microphone. This microphone usually is placed on a table and is designed to pick up the voices of multiple talkers. Newer styles of microphones have been designed to be hand-held by the user, allowing him/her to "focus in" on particular talkers or groups of talkers. For some microphones, the degree of directionality also can be manipulated by the user. The benefits and limitations of various microphone/transmitter options are listed in Table 1.

There also are a number of options available when selecting an FM receiver to be worn by the listener. Personal FM receivers usually are worn in conjunction with personal hearing instruments via either direct audio input or a neckloop coupling. For direct audio input, an

audio boot is attached to the hearing instrument and a cord attaches it to the FM receiver. To utilize a neckloop, the hearing instrument must be equipped with a telecoil. The loop is placed around the child's neck and the hearing instrument is set to the telecoil or "T" position. The signal is routed from the FM receiver to the hearing instrument using electromagnetic induction.

Self-contained FM receivers have internal controls that allow adjustments for the user's degree and configuration of hearing loss. Although, they primarily are worn in place of personal hearing instruments, it is possible to couple them to hearing instruments using direct audio input or neckloops.

FM receivers can be coupled to lightweight headphones or bone conduction transducers. They also may be used in conjunction with a cochlear implant.

Recent advances in FM technology have resulted in miniaturization of FM receivers. In one type of system, the FM receiver is completely contained in a small audio boot which is attached to the child's personal hearing instrument. In other systems, the FM receiver and hearing instrument are housed in a single earlevel unit. The benefits and limitations of FM receiver coupling options are listed in Table 2.

Table 1. Benefits and limitations of FM System Microphone Options

Microphone Style	Features	Advantages	Disadvantages
Lavaliere	• Microphone and transmitter in one case • Antenna extends from case • Microphone usually directional • Worn around the neck	• Single case may simplify use • No need for waistband or belt to attach to transmitter	• Weight of device around the neck may be uncomfortable for some users • Single case for all components may complicate troubleshooting • Poor placement or head movement may affect signal
Lapel	• Microphone and transmitter are separate • Antenna in cord of lapel microphone • Microphone clips to lapel or may hang around neck • Transmitter usually clips to belt or waistband • Microphone may be directional or omnidirectional	• May be easier to troubleshoot because of separate components	• Poor placement or head movement may affect signal • Fit may be uncomfortable • Some benefit may be lost if worn differently than recommended
Headworn	• Microphone and transmitter are separate • Antenna in microphone cord • Worn on headband or glasses • Microphone usually directional	• Headworn microphone improves S/N ratio • May be easier to troubleshoot because of separate components	• Poor placement may affect signal • Fit may be uncomfortable • Some benefit may be lost if worn differently than recommended
Conference	• Microphone and transmitter are separate • Antenna in base of microphone • Microphone placed in single location (usually table top) • Microphone is omnidirectional	• No need to pass microphone • Able to pick up numerous talkers from single micro-phone location	• May amplify other, unwanted, sounds in the room • Greater distance of microphone from mouth of talker, reducing S/N ratio advantage
Hand-held	• Newest models allow selection of different levels of directionality • User holds microphone and directs it toward talker	• Portable • Can point, rather than pass, microphone, when there are multiple talkers • Directional capabilities attenuate unwanted sounds from sides and back	• Listener responsible for transmitter during use • User or caregiver must understand appropriate use • Distance of microphone from mouth of talker greater, reducing S/N ratio advantage

Table 2. Benefits and Limitations of FM System Coupling Options

Coupling Options	Advantages	Disadvantages
Self-Contained Units	• Can receive FM signal when hearing instruments are not operational • May be less complicated to set when a hearing instrument is not involved • FM only and FM plus environmental microphone options available on most units	• Frequency response not as flexible • Frequency response may differ from that of the personal hearing instrument • Traditional systems not cosmetically appealing
Direct Audio Input	• Desired frequency response more easily obtained • Amplification not affected by orientation and distance	• More likelihood of breakage • FM only and FM plus environmental microphone option may not be available • Separate cords and boots must be in stock for each student's FM system
Neckloops	• Cosmetically appealing • Less chance of breakage • Desired frequency response may be more easily obtained	• Amplification varies with orientation and distance • Amplification limited by strength of telecoil • Frequency response may differ from that of HA alone • Affected by electromagnetic interference • FM only and FM plus environmental microphone options may not be available
Silhouette	• Cosmetically appealing • For hearing instruments with weak telecoils, provides a stronger signal	• Often produces higher harmonic distortion and internal noise • Changes in HA output may occur with movement of silhouette
Non-Occluding Headphones	• Child able to monitor own voice and hear classmates • Ear canal resonance will not be lost • May be more cosmetically appealing	• Can be hot or otherwise uncomfortable • Do not easily adjust to all head sizes, resulting in an unstable fit
Behind-The-Ear Hearing Instrument/ FM Receiver	• May be more cosmetically appealing • Receiver at ear level may be more practical for a variety of situations • May be practical as full-time amplification for many users	• Absence of "low battery" and "no FM" lights • Large earlevel receiver may not fit well on some ears • Shorter transmission range than body-style systems • Receiver antenna may break or become loose
FM Receiver in an Audio Boot	• May be more cosmetically appealing • Receiver at ear level may be more practical for a variety of situations • May be practical as full-time amplification for many users • Can be used with a variety of different HA models	• Absence of "low battery" and "no FM" lights • Shorter transmission range than body-style systems • Currently only available for use with HA's • Durability unknown due to recent introduction to marketplace

Goals

An important factor in the selection of an appropriate FM system is an understanding of how the system will be used throughout the day. The general goals of an FM system fitting are:

1. to allow the child to hear the primary talker (usually the teacher) at a level that is consistently audible above background noise.
2. to allow the child to monitor his/her own voice.
3. to allow the child to hear the voices of others who are not wearing the FM microphone.

It is important that all amplified signals be comfortable and free of distortion. The extent to which each of the goals can be achieved will be affected by the degree and configuration of the child's hearing loss, the coupling option that has been selected and the listening environment in which the system will be used. It may not be possible to achieve all three goals in all situations. In many cases compromises will be necessary and the goals will need to be prioritized.

FM systems generally provide up to three options for the mode of operation in a given situation: FM microphone only, FM plus hearing instrument or environmental microphone (EM), and hearing instrument or EM only. Depending upon the situation, the child/teacher/parent will select the operating mode that is appropriate for that listening environment.

In the FM only mode, the FM microphone is active but the EM is de-activated. This option provides the maximum S/N ratio advantage for the FM. However, since the EM is not active, the child wearing the receiver will not be able to hear others who are not using the FM microphone or monitor his/her own voice. The FM only mode

of operation is most appropriate for listening situations where there is one primary talker, such as a lecturer.

In the FM plus EM mode, both the FM and environmental microphones are active simultaneously. This option allows the person wearing the receiver to hear the teacher, hear others not wearing the FM microphone and monitor his/her own voice. However, the degree to which the teacher's voice is amplified above background noise is compromised by the addition of signals entering the EM. The FM plus EM mode is most appropriate for situations such as a classroom discussion where it is important to hear the teacher, other students, and one's own voice.

In some situations, the input to the FM system may come from an auxiliary device such as a television, tape recorder or computer. Decisions about whether and how to couple the auxiliary device to the FM transmitter or the receiver will vary depending upon the device and other listening requirements.

Footnote

The microphone of a personal hearing instrument or an FM receiver has been referred to as the hearing instrument microphone, the local microphone or the environmental microphone. For the remainder of this booklet, that microphone, through which the user monitors his/her own voice and hears the voices of others, will be referred to as the environmental microphone (EM).

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Setting the FM System

To determine how well each of the three listening goals can be achieved, the FM system should first be preset in a standardized 2-cm³ coupler. A range of signal levels should be used to represent the different inputs to the FM and environmental microphones (Table 3). At a minimum, these should include levels to represent the primary talker's voice, the child's voice and the voices of others not using the FM microphone.

Table 3. Input Levels to FM and Environmental Microphones
FM Microphone
Chest level = 80–85 dB SPL
Headworn = 90–95 dB SPL
Conference = 60–70 dB SPL
Environmental Microphone
Own voice at ear level = 75–80 dB SPL
Own voice at chest level = 80–85 dB SPL
Own voice at waist level = not recommended
Other, raised voices, at approximately 1 meter = 70 dB SPL
Other voices at average conversation level at approximately 1 meter = 65 dB SPL
Other, softer voices = 60 dB SPL

When setting the FM system, it is important to begin with the target gain values for the child's personal hearing instrument. The process of hearing instrument fitting with young children is addressed in detail in the companion videotape "Pediatric Hearing Instrument Fitting" in this Phonak Video Focus series.

For children, the Desired Sensation Level (DSL) approach, developed by Richard Seewald and his colleagues, is often used because it was designed specifically for this population. However, the principles involved in setting an FM system can be applied to any prescriptive fitting procedure. Since the FM system will be measured with a variety of input levels, it is most appropriate to make measurements in dB SPL rather than gain. In this way, direct comparisons regarding output of the system with different input levels can be made.

Step 1. Hearing instrument gain, in a 2-cm³ coupler, is set to match preselected target values. Generally, measurements are made using 60–70 dB SPL input levels to represent average or raised voice at one meter. These measures then are converted to dB SPL to allow comparisons to measures made with the FM system. For all measurements other than maximum output, it is recommended that speech shaped signals rather than constant level signals be used to represent speech input to the instrument microphones. The maximum output of the hearing instrument also is set to match target values. This measurement is made using a 90 dB SPL swept pure tone input.

Step 2. The FM microphone is placed in the calibrated position in the test box sound chamber. The hearing instrument, coupled to the FM receiver, is attached to the 2-cm³ coupler, and placed at least 60 centimeters from the transmitter (Figure 1). In the case of an FM system coupled via a neckloop, testing should be performed with the neckloop placed on the user and the hearing instrument, attached to the coupler, held at ear level to simulate actual use (Figure 2).

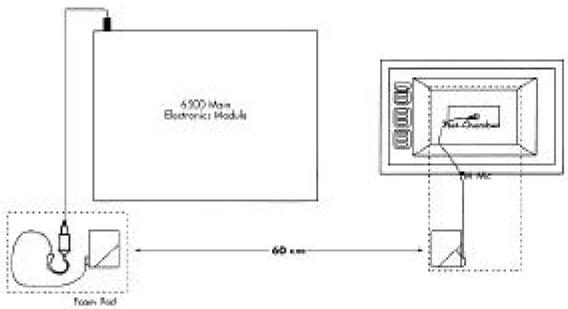

Fig. 1: Physical arrangement for coupler measures of an FM system in the FM mode of operation. (Adapted from Frye Electronics, 1993. Used with permission)

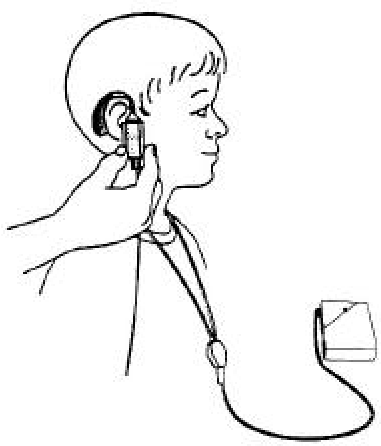

Fig. 2: Physical arrangement for coupler measures of an FM system coupled to a personal hearing aid via a neckloop. (Adapted from Frye Electronics, 1993. Used with permission)

The FM system output is measured using an input level representative of the microphone location during use (Table 3). These results are compared to the output of the hearing instrument alone or to preselected targets. Ideally, the output of the system in the FM mode would be equal to or slightly higher than the original targets for the hearing instrument to ensure audibility of the FM signal. In practice, however, the desired relationship between the output of the two may vary depending upon the FM system circuit characteristics and the child's hearing loss.

Step 3. The output of the EM is evaluated when the FM system is set to the FM plus EM mode. It is important to ensure that the signals the child receives through the EM remain audible in all modes of operation (Figure 3).

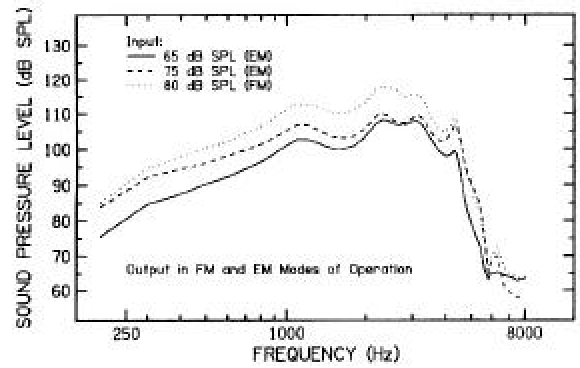

Fig. 3: Coupler *output* of an FM system in the FM and EM modes of operation.

When the FM and environmental microphones are active simultaneously, it is desirable for the FM output (usually the teacher's voice) to be 5–10 dB higher than the voices of those not wearing the FM microphone in order to preserve the S/N ratio advantage. The extent to which this can be achieved depends, at least in part, on the degree of hearing loss, the characteristics of the FM system and the available coupling options (Table 4).

Table 4. Setting Output in FM and EM Modes of Operation for Different FM Systems

	Goal	EM Settings	FM Settings	Comments
Systems with automatic fixed EM reduction in FM/EM mode	The goal is to maintain approximately a 10 dB difference between the FM and EM signal when both are active.	Set to DSL targets using a 70 dB SPL speech weighted (SW) signal. Use DSL targets to set he maximum output using a 90 dB SPL swept pure tone (SPT) signal.	Set to DSL targets + 0 to 10 dB using an 80 dB SW signal. Document maximum output with a 90 dB SPT signal.	The amount to which the FM can be set above targets may be limited by the degree of hearing loss, maximum output of the system, AGC in the teacher's mic, and the method of output limitation used (e.g. peak clipping vs. compression).
Systems with FM precedence	The goal is to maintain approximately a 10 dB difference between the FM and EM signal when both are active. In actual use, the precedence circuit will provide a further reduction of the EM signal beyond what is measured electroacoustically.	Set to DSL targets using a 70 dB SW signal. Use DSL targets to set he maximum output using a 90 dB SPT signal.	Set to DSL targets + 0 to 10 dB with 80 dB SW signal. Document maximum output with a 90 dB SPT signal.	The amount to which the FM can be set above targets may be limited by the degree of hearing loss, maximum output of the system, AGC in the teacher's mic, and the method of output limitation used (e.g. peak clipping vs. compression).
Systems without FM precedence or automatic EM reduction in FM/EM mode	The goal is to maintain approximately a 10 dB difference between the FM and EM signal when both are active. For some degrees of hearing loss it may be necessary to reduce the EM gain below DSL targets.	Set to within 0 to –5 dB of DSL targets using a 70 dB SW signal. Use DSL targets to set the maximum output using a 90 dB SPT signal.	Set to DSL targets + 0 to 10 dB with 80 dB SW signal. Document maximum output with a 90 dB SPT signal.	The amount to which the FM can be set above targets may be limited by the degree of hearing loss, maximum output of the system, AGC in the teacher's mic, and the method of output limitation used (e.g. peak clipping vs. compression).

Step 4. The maximum output of the FM system is evaluated. These measures are made for all modes of operation, using a 90 dB SPL pure tone input. Results are compared to targets to ensure that the signal will be comfortable and safe in all modes of operation (Figure 4).

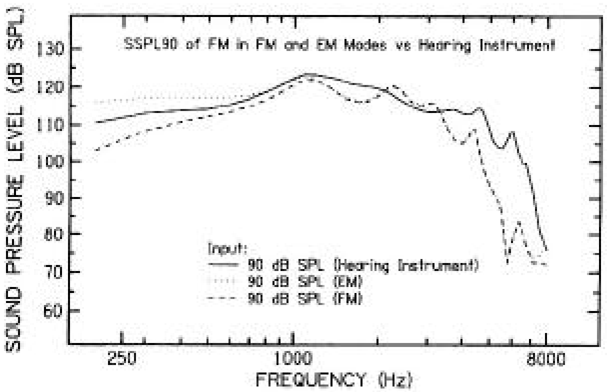

Fig. 4: Coupler SSPL90 of an FM system in FM and EM modes of operation compared to a hearing instrument.

Verification of FM System Performance

Once the FM system has been set in the coupler, verification of results can be completed using one of three methods: traditional probe microphone measures, coupler measures in conjunction with individually measured real-ear-to-coupler differences (RECD) or coupler measures in conjunction with average RECD values. Benefits and limitations of each method are listed in Table 5.

Table 5. Benefits and Limitations of Verification Methods

Method	Benefits	Limitations
Probe Microphone Measures	Can evaluate the amplification received by the user at input levels comparable to those at the FM microphone Provide information about maximum output Can define frequency response quickly and comprehensively	Typically do not provide information on harmonic distortion Require access to a probe-tube microphone system Require user to be cooperative, still, and have ear canals free of cerumen
2-cm³ Coupler Measures	Can evaluate amplification received by the user at input levels comparable to those at the FM microphone Provide information concerning maximum output Provide information about harmonic distortion Can define frequency response quickly and comprehensively Do not require the user to be present	Require access to a 2-cm³ coupler and analysis system Require the 2-cm³ coupler values for a hearing instrument already demonstrated to provide satisfactory performance in the real ear OR Require use of average values and correction factors to estimate the desired real-ear SPLs OR Require use of the individual's own real-ear to 2-cm³ coupler difference values to be added to 2-cm³ values to predict real-ear SPLs

When evaluating an FM system using traditional probe microphone measures, the first step is to calibrate the system. Once calibration is completed, the FM microphone is placed in the calibrated position. This is done to ensure that the input level to the FM microphone is similar to levels expected in actual use. A probe tube then is placed in the child's ear and the FM system is coupled to the ear. The child is moved as far away from the probe microphone system loudspeaker as possible (Figure 5).

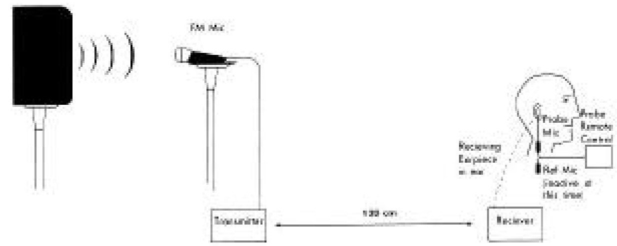

Fig. 5: Physical arrangement for probe microphone measures of an FM system in the FM mode of operation. (Adapted from Frye Electronics, 1993. Used with permission)

This is especially important if the FM and environmental microphones are active simultaneously. Measurements are made at the same input levels used during coupler measures. The saturation response of the FM system is tested using a 90 dB SPL pure tone input. If the FM system is coupled to a hearing instrument or the FM system has an EM, probe microphone measures also should be completed in the FM plus EM mode of operation. For measurements of the EM portion of the system, the child is moved to the calibrated position near the loudspeaker of the real ear measurement system. As with coupler measures, when evaluating EM portion of the FM system, input levels should be used to represent the levels of other voices reaching the microphone as well as the level of the child's own voice.

A slightly different approach is used when verifying performance of an FM system coupled to lightweight headphones for a listener with normal hearing. In this instance the goal is to maintain the level of the teacher's voice at a level comparable to what would be expected if he/she were always standing close to the listener. No additional amplification is necessary. Thus, when performing probe microphone measures, the goal is to achieve unity gain (output equal to input). *This is the only instance when FM System measurements are made in gain rather than output.* First, an ear canal resonance is measured using an 80 dB SPL input signal. The set-up for testing the FM system is the same as shown in Figure 5.

Using an 80 dB SPL input signal to the FM microphone, an attempt is made to match the FM curve as closely as possible to the ear canal resonance curve.

When coupler measures are used in conjunction with individually measured or average RECD values, the child need not be present during the FM system evaluation. The FM system is evaluated in the hearing instrument test box and the RECD is added to those values to predict output in the child's ear (Figure 6).

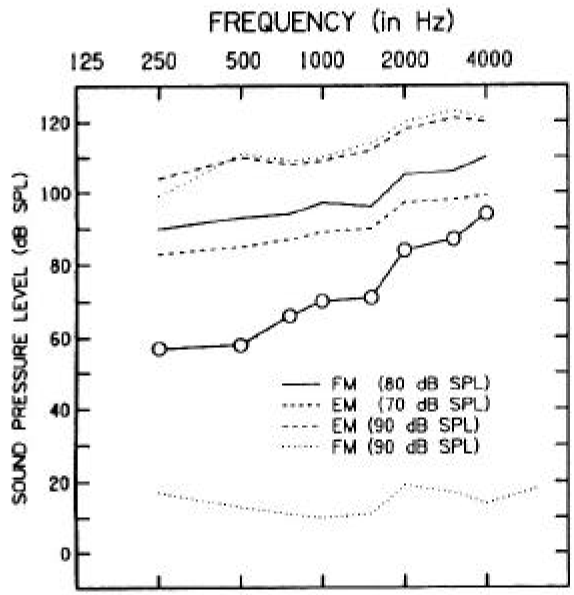

Fig. 6: Real ear sound pressure level measures of an FM system in the FM and EM modes of operation for an individual with a moderate to severe hearing loss.

Measurement of the RECD is covered in detail in the companion videotape "Pediatric Hearing Instrument Fitting" in this Phonak Video Focus Series. A summary of the procedure can be found in the booklet accompanying that videotape.

For testing, input signals and levels are chosen to represent the various inputs to the FM and environmental microphones. Test box measures are completed in both the FM and EM modes.

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Inservice Training

Whenever an FM system is recommended for classroom use, it is important to provide inservice for educational personnel in addition to the student and his/her family. The staff, and the child as appropriate, should be able to perform a daily listening check to ensure proper functioning on a daily basis. Anyone who is using the system should understand which of the different modes of operation are appropriate throughout the school day and be able to change modes as needed. If the system is not used appropriately, the child may not receive the intended benefit. If the FM microphone is active when the teacher is not talking to the student, the result may be confusion. If the EM is not active when the student needs to hear himself or others, important information will be lost. In some cases, interference from outside sources may affect the performance of the FM system. Therefore, the quality of the signal may need to be evaluated throughout the day to ensure that it is clear and undistorted whenever it is being used. Performance in the classroom should be monitored on an ongoing basis to ensure that the system is functioning adequately. Changes in the system may be needed as listening needs or hearing status changes.

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