

# Digital, Analogue and Directional: Will the real winner please step forward



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Hearing in noise is the number one complaint from people who wear hearing aids. Background sounds interfere with conversation, making speech difficult to understand. Even the best hearing aid circuits don't completely solve the problem. Some time ago the frequency response of hearing aids garbled or muffled so much speech information that hearing in noise was almost impossible. During that time, everyone – with either normal or impaired hearing – could hear better at a loud party unaided. The circuitry of these instruments resulted in distortion, a narrow bandwidth, and an irregular frequency response.

Over the years, improved hearing aid design and hearing aid fitting have removed the previous defects from hearing aids. By 1990, Class D amplifiers, wide bandwidth, smooth real-ear response, appropriate variable-recovery-time compression, and improved fitting targets and real-ear measurement techniques brought the signal-to-noise ratio (SNR) at which hearing aid wearers could understand speech down to what appeared to be an irreducible floor. By 1990, we had reached the point where hearing-impaired individuals routinely heard better in noise with the better hearing aids available; sometimes 5-10 dB better in low-level noise, and no worse even in high-level noise. The introduction of digital signal processing hearing aids did not provide a further reduction in SNR for understanding speech, although their increased fitting flexibility may have made it easier to reach that minimum in some cases.

Unfortunately, the problem of hearing in noise remains. A greater SNR is required on average as greater hearing losses are encountered, but some subjects with 40-50 dB loss require signal-to-noise ratios 15 dB greater than normal, while other subjects with 50-60 dB loss can perform at almost normal levels. It is thus useful to distinguish two different aspects of hearing loss:

## TWO MEASURES OF HEARING LOSS

1. The pure-tone AUDIOGRAM measures loss of sensitivity for quiet sounds
2. The SIN (Speech In Noise) TEST measures loss of ability to hear in noise

Figure 1

## THE TWO QUANTITIES MEASURED

1. **Hearing Loss** (HL on the audiogram) is the increased dB SPL required by someone with a hearing loss to hear a tone, relative to normal.
2. **SNR Loss** (Signal-to-Noise-Ratio Loss) is the increased dB *signal-to-noise ratio* required to understand speech by someone with a hearing loss, relative to normal.

Figure 2

How can the SNR loss differ so much? The presumed explanation is that the former subjects have extensive inner hair cell damage, while the latter have a hearing loss characterized by mostly outer hair cell loss. When outer hair cells are lost, the person exhibits a threshold hearing loss and their hearing is not as sensitive to quiet sounds. When inner hair cells are lost, the person loses information; even loud sounds lose clarity. An individual with extensive inner hair cell loss will have trouble understanding some speech in quiet and trouble with nearly all speech in noise.

Hearing aids can solve the problem of loss of sensitivity. Provided the hearing aids don't distort and don't have a bad frequency response, someone with only an outer hair cell loss can be expected to do quite well, even in high level noise. Hearing aid circuits cannot solve the "SNR loss" problem that accompanies loss of inner hair cells, however. Figure 3 illustrates the likely explanation. ▶

## HOW EVERYTHING MAY BE AUDIBLE BUT NOT UNDERSTANDABLE IN NOISE

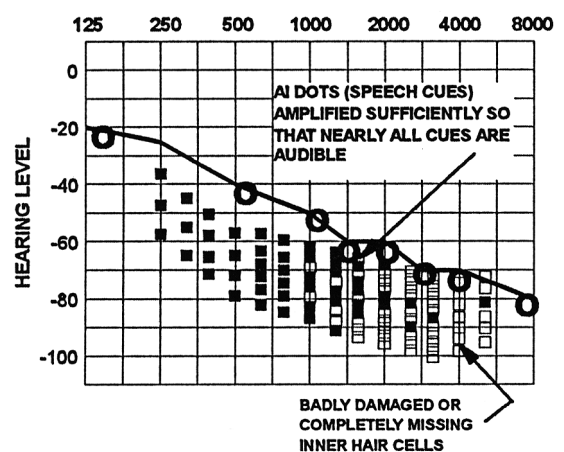


Figure 3

## Distribution of SNR loss

The Speech-In-Noise (SIN) Test™ is the test we have used for determining the SNR required to repeat 50% of words-in-sentences presented in background noise. This uses a female talker as target and 4-talker babble as noise. In each block of this test, five sentences are presented at each of four SNRs (+15, +10, +5, and 0 dB). In each of the five sentences, five key words are scored for a total of 25 scored words at each SNR. Half credit is given for partially correct words. The percent correct is then determined for each SNR.

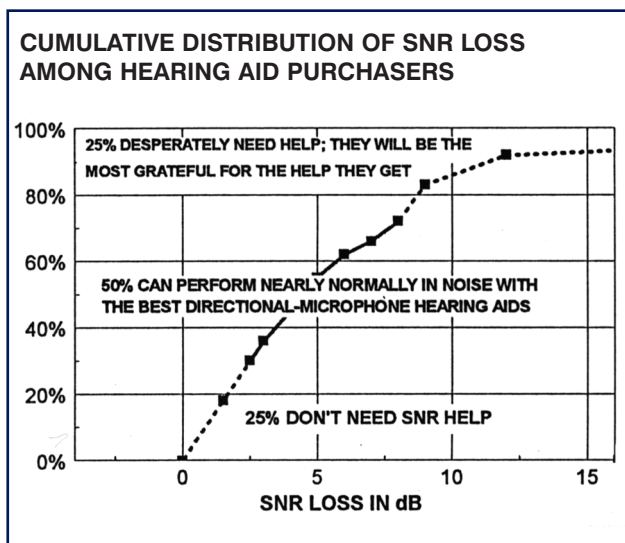
We are now developing an abbreviated version called the Quick SIN Test for use in clinical settings. Only one sentence (5 key words) is used at each SNR as shown in the Figure 4 example below. Statistical reliability is sacrificed for speed – only one minute per block – giving the patient's SNR loss within 3 dB (95% confidence interval). The average of two blocks gives SNR loss within 2 dB.

Figure 4

SCORING THE QUICK SIN TEST: 27.5 dB minus (WORDS CORRECT)			
SENTENCE	SNR	FIVE KEY WORDS IN SENTENCES (SCORE .5 FOR CLOSE)	
1.	25 dB SNR	The <u>brown</u> <u>house</u> <u>was</u> on <u>fire</u> to the <u>attic</u>	5
2.	20 dB SNR	The <u>club</u> <u>rented</u> the <u>rink</u> for the <u>fifth</u> <u>night</u>	5
3.	15 dB SNR	The <u>navy</u> <u>attacked</u> the <u>big</u> <u>task</u> <u>force</u>	5
4.	10 dB SNR	The <u>grass</u> <u>curled</u> <u>around</u> the <u>fence</u> <u>post</u>	4.5
5.	5 dB SNR	The <u>slush</u> <u>lay</u> <u>deep</u> <u>along</u> the <u>street</u>	3
6.	0 dB SNR	<u>Bail</u> the <u>boat</u>	0
TOTAL			22.5
SNR (for 50% correct) = 27.5 - 22.5 = 5dB			
SNR LOSS = 5dB - 2 dB = 3dB			

The distribution of SNR loss obtained from SIN Test data is shown in Figure 5.

Figure 5



## What can be done?

What then is the next step for improving the signal-to-noise ratio? Directional microphones have been shown to improve speech understanding in noise by reducing sounds coming from the sides and rear. In the past, directional microphones were designed to produce a 15-25 dB rejection of sounds from the rear when suspended by themselves in an anechoic chamber. Unfortunately, when worn on the head, those designs often provided much less directivity. Improved designs resulted when head diffraction and reflection were taken into account. The latest design for in-the-ear hearing aids utilizes an improved first-order directional microphone. This provides both omni-directional and directional outputs, thus allowing hearing aid users to select the microphone response that is best for each listening situation.

## How much benefit?

The amount of benefit a person obtains depends on their hearing loss and the listening situation. The best of the available directional microphones can provide an average 4.4 dB improvement in AI-DI compared to an omnidirectional microphone mounted in a typical ITE hearing aid. Subjects who understand only 20-30% of words in sentences with an omni-microphone can be expected to obtain 50- 85% correct (a 30-55% increase) with a directional microphone. Subjects with moderate-severe high frequency loss, however, can expect greater improvements. Figure 6 shows expected benefit as a function of type of hearing loss, based on the data of Killion and Christensen, 1998.

EXPECTED SNR IMPROVEMENT WITH D-MIC VS. TYPE OF LOSS (TYPICAL RESTAURANTS AND PARTIES), BASED ON EXPERIMENTAL REAL-WORLD FINDINGS:	
1. NORMAL HEARING	4.4 dB
2. FLAT LOSS	4.4 dB
3. MODERATE-SEVERE HIGH-FREQUENCY LOSS	6.5 dB
4. MODERATE-SEVERE REVERSE LOSS (EST.)	3.3 dB
NOTE: AI-DI IMPROVEMENT OVER TRADITIONAL OMNI ITE MICROPHONE: 4.4dB OVERALL, 6.5dB AT LOW FREQUENCIES, 3.3dB AT HIGH FREQUENCIES	

Figure 6

The amount of benefit also depends on the circumstances. Directional microphones attenuate the pickup of sounds from the sides and the rear. When the noise comes predominantly from behind, the improvement can be as much as 20 dB; when the noise comes from all around, the improvement ranges from 3-5 dB depending on the design of the microphone. In a typical room, even if all the noise from behind is rejected, noise from the rear will pass by the listener, bounce off the front and side walls, and arrive only a tiny bit later from the front. Some dramatic demonstrations can be made by placing the signal in front and the noise in back, but these tend to overstate the (still significant) benefit in real-world situations. Figure 7 attempts to estimate benefit with hearing loss and hearing. ▶

Figure 7

SUMMARY: D-MIC EXPECTATIONS FOR SNR IMPROVEMENTS:		
	FLAT LOSS	SLOPING LOSS
1. TALKER AND NOISE IN FRONT:	0dB	0dB
2. OUTDOORS, NON-REVERBERANT*		
a. TALKER IN FRONT, NOISE BEHIND:	10-15dB	12-18dB
b. TALKER IN FRONT, NOISE ALL AROUND:	4.5dB	6.5dB
3. INDOORS, REVERBERANT	4.5dB	6.5dB
4. CHURCH, REVERBERANT		
a. FRONT PEW:	4dB(?)	6.5dB(?)
b. REAR PEW:	0dB	0dB
* ALSO HOLDS FOR TEST BOOTHS		

In conclusion, one of the severe limitations to hearing aid utilization is the failure of circuits to solve the noise problem. The individual thinking about getting hearing aids probably already believes they won't work; he or she has a relative or friend who can't hear in noise with hearing aids! MarkeTrak studies report only a 45% user satisfaction rating with those older hearing aids. Villchur has argued that this is the true source of the stigma associated with hearing aids, and not any cosmetic considerations.

For example, if you see someone wearing glasses, you don't offer them a large-print edition of the newspaper; you assume they can see just fine. In the past, when we saw someone with a hearing aid, however, we knew from experience that he or she couldn't hear very well, especially in noise. As the proportion of hearing aid wearers who do well in noise increases with the use of directional microphones, we can expect hearing aids to move toward the status of glasses: a nuisance, but a welcome relief from not being able to see well. More recent MarkeTrak studies show a 91% consumer satisfaction index with a hearing aid having a user-switchable directional-microphone.

Hearing aids of the future will surely solve the problem of hearing in noise. If Villchur is right, the stigma should gradually fade. Already study results show that many subjects with moderate hearing loss can perform about as well as normals in noise when they use directional microphone hearing aids. ●

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### References

Borg E, Canlon B, Engstrom B. Noise induced hearing loss: literature review and experiments in rabbits. *Scan Aud* 1995; 24 (40). Christensen LA, Killion MC, Niquette PT and Revit LJ. Some instructions to readers on using the Journal's real-world audio CD. *Hear J* 1998;51(8):68-75. Killion MC. The SIN report: Circuits haven't solved the hearing-in-noise problem. *Hear J* 1997;50(10):28-30,32. Killion MC. Guest editorial: Hearing aids: Past, present, future: Moving toward normal conversations in noise. *Brit J Aud* 1997;31:141-148. Killion MC. SNR Loss: "I can hear what people say, but I can't understand them." *Hear Rev* 1997;4(12):8,10,12,14. Killion MC and Christensen LA. The case of the missing dots: AI and SNR loss. *Hear J* 1998;5 (5):32-47. Killion MC, Schulein R, Christensen L, et al. Real-world performance of an ITE directional microphone. *Hear J* 1998;51(4):24-38. Killion MC, Villchur E. Kessler was right – partly: But SIN test shows some aids improve hearing in noise. *Hear J* 1993; 46(9):31-35. Kochkin S. Customer satisfaction and benefit with CIC hearing instruments. *Hear Rev* 1995;2(4):16-26. Kochkin S. Customer satisfaction and subjective benefit with high performance hearing aids. *Hear Rev* 1996;3(12):16-26. Soede W. Improvement of speech intelligibility in noise. PhD thesis, Delft University of Technology, Delft, The Netherlands, 1990. Tillman TW, Carhart R, Olsen WO. Hearing aid efficiency in a competing speech situation. *J Speech Hearing Res* 1970;13:789-811. Villchur E. A different approach to the noise problem of the hearing impaired. In Beilin J, Jensen GR eds. *Recent Development in Hearing Aid Technology. Proceedings of the 15th Danavox Symposium, Danavox Jubilee Foundation (Taastrup, Denmark) 1993;69-80.*