Part 1: A comprehensive analysis of K-AMP circuitry and what it offers patients

The K-AMP hearing aid: a summary of features & benefits

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Part 1 of this article will provide an overview of what K-AMP® circuitry does, its features, and the benefits of these features for hearing-impaired persons. Part 2 will give a summary of how well the K-AMP high fidelity hearing aid works as demonstrated by the results of the first 70 units fitted and some representative clinical cases.

Over the past 20 or more years in the field of audiology, the size of hearing aids has decreased and the frequency response has gradually widened. Today, a typical linear hearing aid has a frequency response of 200 to 5000 Hz and an output of 107 to 112 dB SPL. Natural ear canal resonance characteristics can be preserved in the aided ear with 2700 Hz peaks in the frequency response[5]. In 1979, Killion[1] showed that it was possible to obtain a high fidelity wide-band clean sound in an experimental hearing aid. In spring 1990, the K-AMP high fidelity hearing aid kit was made available to the hearing aid industry.

A few hearing aid manufacturers took up the production challenge. Two years later, most hearing aid manufacturers now offer a version of the standard K-AMP circuit. The new K-AMP high fidelity hearing aid[2,3,4] and its variant circuits is one of the most significant technological advances in hearing aids in the last 20 years. A K-AMP high fidelity hearing aid is easy-to-use, self adjusting, automatic and relatively inexpensive. It amplifies the quiet sounds that hearing- impaired persons want to hear but need help to hear, and provides little or no distortion of intense sounds. This is now possible because of the K-AMP integrated circuit wide-band (50 to 16 kHz) input amplifier chip and a Class-D high power amplifier/receiver that allows undistorted outputs to 115 dB SPL.

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Problems and solutions

Recruitment—Hearing impairment, especially sensorineural hearing loss, is typically associated with recruitment: an abnormally rapid growth of loudness. From another point of view, recruitment is a loss of sensory ability to hear quiet sounds. Most hearing-impaired people can hear intense sounds quite well. In fact, many do not like or want to hear intense sounds. Recent research on the inner ear[7] demonstrated that the outer hair cells provide more gain for the quiet sounds, suggesting that the loss of hearing for quiet sounds is the result of loss of function of the outer hair cells. The K-AMP hearing instrument helps the hearing-impaired ear do what it used to be able to do for itself: amplify the quiet sounds. The K-AMP circuitry compensates for recruitment. It has a high ratio of compression in the high frequency bands and a low ratio of compression or none in the low frequency bands.

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Conventional linear instruments—Linear hearing aids are simple devices, providing moderate fidelity and volume control (VC) adjusted gain: Once the VC is set, the gain is fixed. The linear aid provides the same gain over a range of input levels, until the device's maximum level is reached. Then, it saturates and clips unless limiting is used (e.g., ceiling limiter, peak clipping or high ratio compression). The conventional hearing aid is unable to handle high-level sounds without distortion. With either transient intense or long-duration intense (80 to 90 dB SPL) inputs, the amplified sounds are distorted. The hearing aid overloads, or saturates above 97 to 112 dB SPL output limit levels, and often begins to break up with inputs of 75 to 90 dB SPL.

The hearing-impaired person cannot hear the quiet sounds and uses the hearing aid like a step stool to reach those quiet sounds. However, the size of the step on a linear hearing aid is the same for both quiet and intense inputs. Concerning the problem of recruitment: for quiet inputs, listening through a linear aid can be comfortable with the volume control (step) set at high gain. However, with either transient intense or long-duration intense (80 to 90 dB SPL) inputs, the wearer's immediate response is to turn down the volume. The same volume control position (step size) is too high (i.e., too big) for high amplitude input signals because of recruitment. People who use linear hearing aids keep the volume low to avoid the amplification of intense sounds and especially transient sounds, such as from jangling keys or from a spoon crashing onto a china plate, which not only are too loud but are often distorted. These people often complain that the hearing aid sound is too intense, especially in noise.

Processing to hear better in noise

The hearing aid wearer's most common complaint is difficulty in understanding speech in noise. Initial attempts of members of the hearing aid industry to reduce the effects of background noise made use of passive manual switches (e.g., to change frequency response), dispenser controlled potentiometers (e.g., low frequency roll-off, clipping threshold), user controlled toggle switches (e.g., high frequency limit, low frequency roll-off, resonance peak control) or automatic gain control compression circuits to reduce low frequency sound inputs.

In more recent years, the most common "automatic signal processing"

(ASP) approach used level-dependent frequency response circuits that reduce low frequency sound as input sound level increases. The goal was to reduce amplification in the presumed frequency region of the noise. Typically, the amplification of low frequency sounds was reduced and the amplification of other frequency sounds (consonants) was maintained in an attempt to enhance speech intelligibility. This type of ASP, classified as BILL, or *bass increase at low levels*[6], has had measurable success with persons exposed to low frequency noises (motors, etc.), since it reduces the distortion typically introduced by Class A linear amplifiers when they are overloaded by intense low frequency sounds.

The K-AMP circuitry provides a different type of automatic signal processing, classified as TILL, or *treble increase at low levels*[6]. The K-AMP hearing aid circuit provides curvilinear amplification with a level-dependent frequency response: for quiet sounds, it provides more gain for high frequencies. For very quiet sounds (with inputs <40 dB SPL), there is a presettable fixed gain (under patient and dispenser control).

For inputs from 40 to 90 dB SPL, the high frequency output is compressed 2:1 compared to the input, and high frequency emphasis is reduced as the input level is increased. At higher inputs (90 to 115 dB), the circuit produces a flat wide-band frequency response, the amplification is linear, and the gain may be adjusted to some low value or to 1 (no gain). With 110 to 115 dB inputs, there is no further increase in output. The output is essentially undistorted for inputs as high as 115 dB SPL. Thus, the output frequency response and, necessarily, the gain changes as a function of the input level. The insertion gain decreases as the input level increases.

As a single-channel compressor with level-dependent frequency response, the K-AMP circuitry has features similar to multi-band compressor hearing aid systems[8]. It provides a high ratio of compression (2:1) in the high frequency bands and a low ratio of compression (1.2:1) or no compression in the low frequency bands.

The primary advantage of the K-AMP circuitry is its ability to compensate for recruitment, with a low knee point of compression (40 dB SPL). It provides more gain and more high frequency boost for weak signals and less full-range gain for strong signals. It maintains high frequency emphasis at low and moderate levels. This is optimal for speech intelligibility. [9]

K-AMP features

The high fidelity K-AMP hearing aid circuit (Versions 1 & 2) requires the use of a damped horn and can provide the very wide band frequency response of 100 to 16,000 Hz.[2-5] The smaller K-AMP hybrids, for in-the-canal hearing aids (Version 3 and 4), may use a damper in the receiver tube and provide a manufacturer-dependent, wide band, high frequency response from 6000 Hz to 10 kHz. Behind-the-ear K-AMP hearing aids also differ in available wide band frequency response.

K-AMP circuits (Versions 2, 3 & 4) include Adaptive Compression™ (via a license agreement with Telex Communications Inc.) which provides a quick attack and release for short duration intense sounds and a slower attack and recovery for longer duration intense sounds.[5,8] Adaptive Compression helps to reduce low frequency compressor pumping[5,8]. The effects of intense environmental acoustic transients are reduced by the fast attack times.

All of the K-AMP circuits contain a low battery warning indication: when the battery voltage drops below an acceptable level, the hearing aid makes an audible purring or motorboating sound.

A K-AMP circuit based hearing aid can be designed with numerous options. The low frequency control (LFC) potentiometer reduces low frequencies (more at high gain or high volume control positions). A threshold knee (TK) control adjusts the compression threshold and governs the amount of gain and high frequency boost available at low input levels. For purposes of discussion, maximum TK is maximum compression (factory setting) which provides maximum change in gain and the maximum high frequency boost in quiet. With minimum compression, the compression knee corresponds to 65 dB SPL and provides a maximum high frequency gain of 13 dB for quiet sounds. With maximum compression, the standard 40 dB SPL compression knee is obtained, and provides a normal 25 dB increase in high frequency gain for quiet inputs.

A flat fixed frequency response (FFR) control provides greater low frequency amplification with less level dependent high frequency change. A single toggle switch can be added to enable the user to optionally select the K-AMP or linear circuits. The "linear" option preserves the low level K-AMP characteristics but provides greater gain for loud and moderately loud sounds. Considerable flexibility is available through the selection of various K-AMP and transducer options.

Impressions

The introduction of the K-AMP high fidelity hearing aid with Adaptive Compression permits the design and fitting of high quality hearing aids with which patients are generally happy. The amplified sound is, by report, comfortable for new hearing aid wearers and more comfortable than their previous hearing aids for experienced wearers. The output is essentially free of distortion to high output levels. The frequency response adjusts as a function of input level so that at high levels the hearing aid can become transparent; providing no gain, or it may provide a moderate amount of wide band gain. The K-AMP circuitry boosts the high frequency region where the soft sounds of speech are often mis-heard or missed by hearing-impaired persons, especially those with sensorineural hearing loss. The "standard" K-AMP based hearing aid design works for a fairly wide range of hearing losses. The availability of K-AMP variants, including combinations of the numerous options, different microphones and receivers and circuit modifications to obtain desired frequency response, can extend the fitting range to meet the requirements of most mild to severe hearing losses.

K-AMP hearing aids are not without problems. Some complaints remain. One complaint is caused by the occlusion effect. Some patients will hear their own voices as though they were "in a box." Real ear probe measurements demonstrate prominent gain for the "ee" sound and for other low frequency vowels. Hearing aid fittings with reduced canal contact until the shell is deep in the canal helps to reduce this effect in some patients; unfortunately, there still is no good solution to this problem.

A second complaint is audible low level instrument noise and some residual pumping (too rapid release) of the compression circuit. This is most audible to patients with normal low frequency hearing. Until there is a good solution for this phenomenon, it is recommended that the K-AMP hearing aid only be fitted on persons with greater than 20 dB low frequency hearing loss.

Another complaint is feedback at relatively low input levels and gain settings. This is caused by the large amount of low level, high frequency gain of the hearing aid. The proper use of dampers (in the Version 2 K-AMP),

limitation of venting and accurate shell size, in addition to circuit modifications, help to reduce the feedback. The use of the TK control to reduce gain and high frequency boost at low levels does reduce the feedback but also defeats the purpose of the K-AMP design. For this reason, use of the TK control to curb feedback is a least desirable option.

Although it has been possible to fit some steep ski-slope hearing losses with special variations in the K-AMP circuitry, these are generally not successful. There is, however, a new circuit modification that should extend the fitting range to include the ski-slope loss[8].

Summary

In summary, the K-AMP hearing aid and its variants appear to be one of the most significant advances in hearing aid technology in the past 20+ years. It provides a wide range of fitting capability and high quality, low distortion, "high fidelity" and comfortable sound. Hearing impaired persons fitted with the K-AMP hearing aid generally report that they make fewer adjustments in a given listening situation. ❐

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EDITOR'S NOTE: *In Part 2 of this article, the authors will present their clinical impressions of K-AMP fittings, with case histories of actual users.*