Onset of Feedback Howl in Hearing Aids

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1. INTRODUCTION

Acoustical feedback howl in hearing aids limits the amount of gain that can be provided to a user. Feedback arises when some of the amplified sound leaks back, usually through the vent, to the microphone input port. When external conditions change, such as when a handset is brought near the pinna, there is an increased sensitivity of a hearing aid to feedback (Hellgren *et al.*, 1999). As a consequence, considerable effort is being devoted to feedback cancellation. According to the Nyquist criterion, the onset of feedback howl occurs when the overall feedback gain (i.e., the open-loop transfer function) is unity. Here, we report quantitative tests of this criterion, making using of hearing aids mounted in the pinna of a mannikin.

2. THE NYQUIST CRITERION

Consider the hearing aid shown in Figure 1. An incident sound pressure p_i is received at the microphone of the hearing aid. This signal is processed by the internal circuitry of the aid, producing an amplified signal in the ear canal. Some of this signal can leak out of the canal and get back to the microphone port, contributing a component p_{fb} to the total sound pressure $p_T = p_i + p_{fb}$ and creating a feedback condition. There are several possible feedback paths but the dominant one is usually through the hearing aid vent. The size of the feedback signal depends on the amplification settings of the hearing aid, the properties of the ear canal, and the transmission characteristics through the vent and out to the microphone. The overall gain G through the hearing aid system is given by $p_{fb} = G\, p_T$. It may then be shown that $p_T = p_i / (1\text{-}G)$. The total pressure gets very large as the gain approaches unity. According to Nyquist (1932), feedback howl will occur when the magnitude of G exceeds unity and the phase of G is zero. Because G is measured in an open-loop condition, it is referred to as the *open-loop transfer function.*

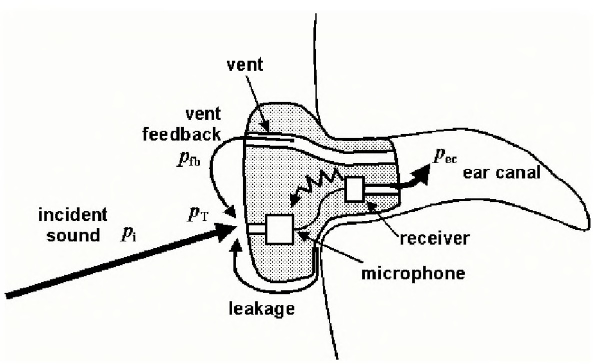

Fig. 1. Sketch of a hearing aid in an ear canal, showing several possible feedback paths.

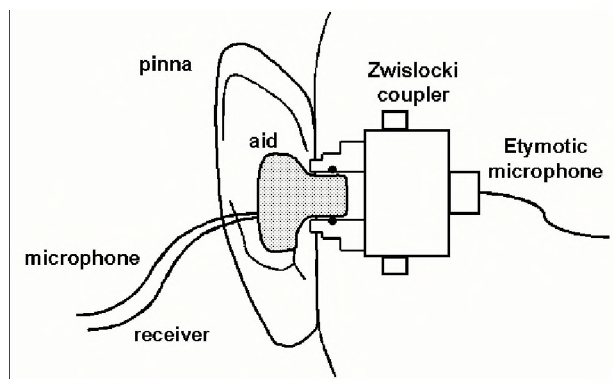

Fig. 2. Procedure for measurement of open-loop transfer function and ear canal sound pressure.

3. EXPERIMENTAL PROCEDURE

Hearing aids were mounted in an artificial pinna on a KEMAR mannikin, as sketched in Figure 2. A Zwislocki coupler terminated the model ear canal and an Etymotic microphone monitored the "ear canal" sound pressure. The hearing aids have been modified, with the circuitry between microphone and receiver broken and breakout leads installed. To measure G, an electrical signal of known voltage is input into the receiver and the output from the microphone recorded; the ratio of these voltages is the open-loop transfer function (Stinson and Daigle, 2004). Shorting the two breakout leads restores normal function of the hearing aid. If conditions for feedback howl are met, the howl will be evident at the ear canal microphone. Measurements were made in an anechoic chamber. A telephone handset could be positioned near the pinna – its proximity to the pinna modified the acoustical feedback, typically increasing the open-loop transfer function at lower frequencies.

4. RESULTS

Figure 3 shows measured results for a Unitron Vista canal aid, a linear ITC aid. A telephone handset was in place just touching the pinna. The top two panels show the measured open-loop transfer function G, magnitude and phase. The magnitude is greater than unity (0 dB) between 600 Hz and 4000 Hz. Within this range, there are two zero crossings of

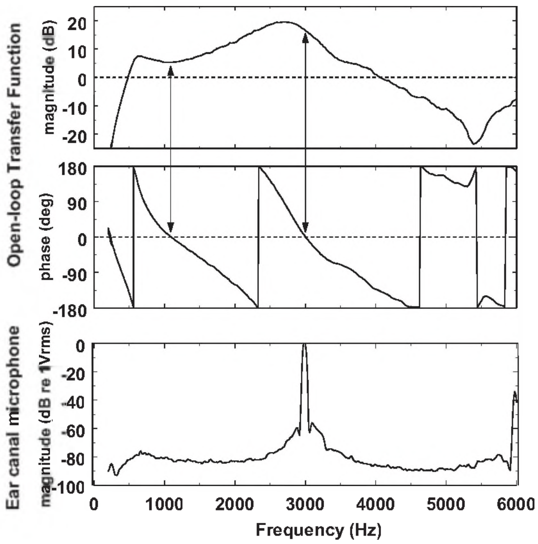

Fig. 3. Open-loop transfer function of a linear ITC hearing aid and its closed-loop response in the ear canal.

the phase component, i.e., 1100 Hz and 3000 Hz: these are the two possible frequencies of oscillation, according to the Nyquist criterion. When the breakout leads are shorted and normal operation restored, the hearing aid howls. The third panel shows the measured sound pressure inside the ear canal – the peak at 3000 Hz (the frequency having the largest open loop transfer function) is clearly evident.

The electroacoustic behaviour of this hearing aid was modified by introducing a low-pass filter (1.5 kHz corner) between the microphone and receiver components of the aid. The new open-loop transfer function is shown in the top two panels of Fig. 4. There are only two frequencies, 650 Hz and 1300 Hz, that satisfy the Nyquist criterion. In operation, the hearing aid howls at the latter of these. (Also seen are harmonics of this frequency.)

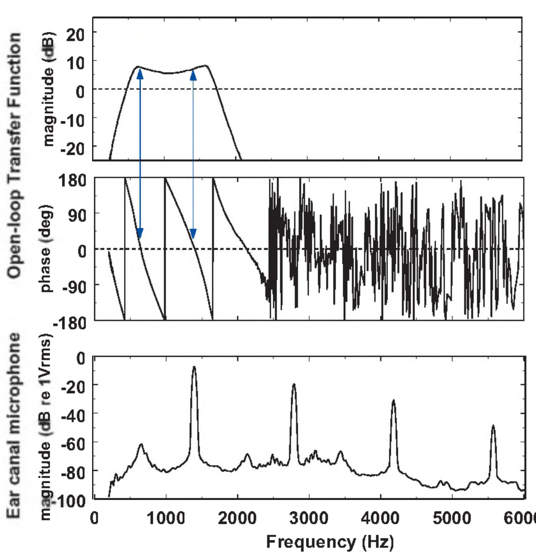

Fig. 4. Linear ITC hearing aid, with a low-pass filter inserted between microphone and receiver of hearing aid.

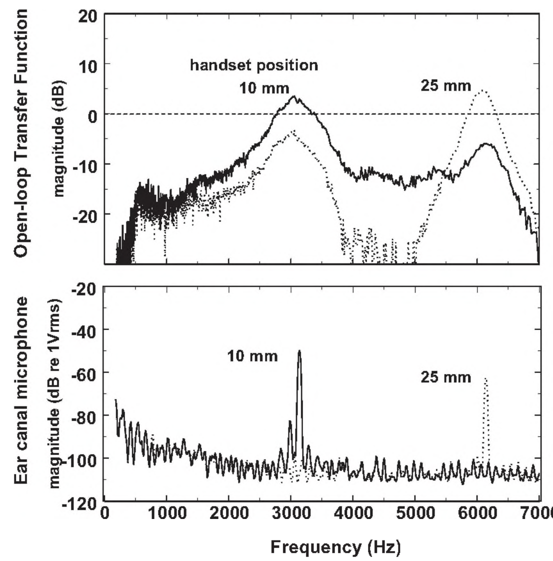

Fig. 5. Open-loop transfer function of a nonlinear ITE hearing aid and its closed-loop response, for two positions of a telephone handset.

A Unitron Conversa ITE hearing aid was also investigated. This hearing aid is inherently nonlinear as it incorporates compression and low-level expansion, so the open-loop transfer function will vary with input SPL level. There is a linear regime, nominally between 30 and 50 dB input SPL; the open-loop transfer function is constant and maximal here and measurements of it correspond to this region. For this hearing aid, the phase component of the open-loop transfer function changes rapidly, with zero-crossings occurring every 140 Hz. The magnitude component is shown in the top panel of Figure 5; the lower panel shows the closed-loop ear canal response. Two sets of results are shown corresponding to different positions of a telephone handset. For the solid curve, the handset was located 10 mm from the pinna. The open-loop transfer function exceeds unity for frequencies between 2700 Hz and 3200 Hz and feedback howl occurs at 3100 Hz. With the handset located 25 mm from the pinna, the open-loop transfer function exceeds unity between 5850 Hz and 6250 Hz and feedback howl occurs at 6100 Hz.

These tests, and others, confirm the applicability of the Nyquist criterion for predicting the onset of acoustic feedback in hearing aids.

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