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# AND9023/D

# Feedback Path Measurement Tool

**ON Semiconductor®**

## APPLICATION NOTE

## INTRODUCTION

The Feedback (FB) Path Measurement Tool is a new capability included with ON Semiconductor digital amplifiers, beginning with the SA3286. This tool uses the built−in features of the amplifier to measure the maximum stable gain (MSG) of a hearing aid in a straight forward way. Knowledge of MSG is useful during hearing aid design and fitting: it can be used to either limit the gain or to determine if feedback management strategies are required.

The FB Path Measurement Tool consists of embedded routines running inside the digital amplifier as well as software routines for controlling the measurement and extracting the measured feedback path information. To illustrate how these capabilities can be used to perform a feedback path measurement, a sample application is also provided. This sample application is written in Visual Basic and is included as part of the ARK installation package for SA3286. The source code provided for this sample application serves as an example of how the FB Measurement Tool can be used to obtain a feedback−path measurement.

This information note describes the principles of operation for the FB Measurement Tool and provides step−by−step instructions for performing a measurement using the sample application.

## FEEDBACK PATH MEASUREMENT PRINCIPLES

The Feedback Path Measurement Tool uses the adaptive feedback canceller (FBC) provided in ON Semiconductor' digital amplifiers to identify the impulse response of the feedback path. A measurement is performed by generating a known stimulus signal from the output of the hearing aid and allowing the FBC to adapt to the feedback observed at the microphone.

Due to the acoustic nature of the measurement and the fact that it is obtained using an adaptive system, care must be taken to ensure that an accurate measurement is obtained. Several factors can affect the accuracy of measurements obtained using the Feedback Measurement Tool, including the following:

- Digital amplifier configuration
- Ambient noise in the room where the measurement is being performed
- Measurement settling time
- Transducer saturation

ON Semiconductor digital amplifiers provide several features that can be used to overcome these factors and maximize the accuracy of the measurement. These features are described in more detail below.

**Amplifier Configuration**

To understand the configuration parameters that affect FB path measurements, it is important to know how the FBC is connected within the amplifier. A simplified block diagram of a ON Semiconductor digital amplifier equipped with an FBC is shown in Figure 1. This diagram includes Head Room Extension (HRX), compression section (WDRC), volume control (VC), post−AGC biquads (PB), DAC and H−bridge power amplifier (HB) and shows the internal connections for the FBC.

As shown in Figure 1, the FBC forms a closed loop around the WDRC and VC blocks. While it is operating, the feedback seen by the FBC is only affected by blocks outside this loop. The FB path identified by the FBC thus includes the expected elements: DAC and H−bridge amplifier, receiver, microphone and any acoustic path from receiver to microphone. As shown in the diagram, however, the measured feedback path also includes the Head−Room eXtension (HRX) circuitry. This is important to note since the gain of the HRX block is different when it is enabled compared to when it is disabled. When HRX is off, the observed gain of the feedback path will be 18 dB higher than that observed with HRX on. While this change in gain distribution is handled automatically by ON Semiconductor IDS software, it must be corrected in any user−developed software prior to predicting the MSG of the instrument.

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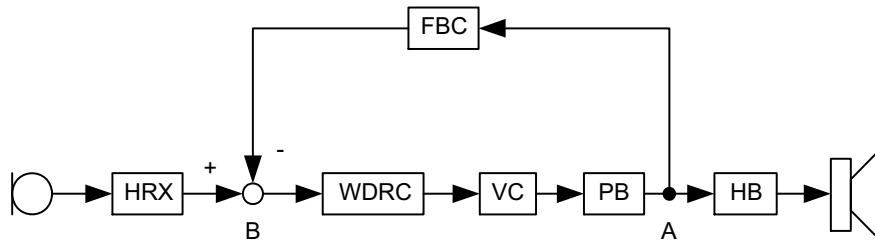Publication Order Number:
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**Figure 1. An illustration of the major functional blocks within a ON Semiconductor digital amplifier showing adaptive feedback canceller connections.**

To improve the accuracy of the feedback path measurement, the forward audio path through the hearing aid should be muted. This prevents the feedback signal from propagating around the loop more than once and it reduces the impact of ambient noise on the measurement.

The best way to mute the audio path is to set the coefficients of a post–AGC biquad to zero. The signal–path location of post–biquads 3 and 4 is shown by the PB block in Figure 1. This ensures that the audio path is completely muted while still allowing the microphone signal to propagate to the WDRC block. As described below, level detectors within the WDRC block can then be used to assess ambient noise conditions and to assess the accuracy of the measurement. The sample application uses post biquad number 3 for this purpose.

Finally, a noise stimulus signal must be injected into the hearing aid output. This can be accomplished using the built–in tinnitus–noise generation feature. For proper operation, the injection point must be after the point at which the audio path is muted, preferably after the volume control (post VC option). Additionally, the option to add tinnitus noise to the audio signal must be selected, otherwise the audio path blocks are disabled. The sample application illustrates the steps required to inject stimulus noise in this way.

Once these steps are taken, the audio path within the amplifier should appear as illustrated in Figure 2.
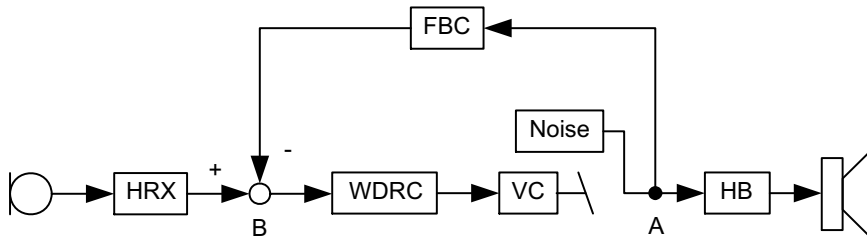


**Figure 2. Audio signal path in a ON Semiconductor digital amplifier that is configured for a feedback path measurement.**

**Ambient Noise**

Acoustic feedback must be measured using a live hearing–aid microphone. The microphone will pick up both the real feedback signal plus any ambient noise that exists in the room at the time of the measurement. The presence of significant ambient noise can enter the FBC calculation and corrupt the measured feedback path. For this reason, it is important for the measuring software to be aware of the level of ambient noise and to adjust the measurement procedure accordingly.

ON Semiconductor amplifiers allow user software to determine the ambient noise level by reading the instantaneous values of the built–in WDRC level detectors. The values read from the level detectors can be compared against an absolute threshold to determine if the ambient noise level is too high to ensure a proper measurement. In addition, by comparing level detector readings before and after activation of the stimulus noise, it is possible to identify the level of feedback in relation to the ambient noise. This

can be used to provide a rough indication of measurement accuracy. The sample application provided by ON Semiconductor illustrates the use of the level detectors to measure ambient noise levels. This is described in more detail below.

**Setting Time**

Settling time is another important factor in to consider in measurement accuracy. The FBC requires a certain amount of time to determine the feedback path, once the stimulus noise is started. The exact amount of time required is variable and depends on the nature of the feedback path and the strength of the feedback signal observed at the microphone, relative to ambient noise. In general, a feedback path with a narrow–band frequency response will be identified faster than a broad–band one; similarly, a strong feedback signal will allow faster measurements than a weak one.

For a given application, the best settling time must be determined through trial−and−error. Repeated measurements using different settling times should be compared to see if they are converging to the same data. This comparison should be performed on the frequency−response data since low−frequency noise can disturb the impulse response but is of no consequence to predictions of feedback. Once a stable reading is obtained, the accuracy can be verified by checking that the measurement correctly predicts the frequency and gain at which feedback occurs in the instrument.

While the appropriate settling time for a given application must be determined through this type of experimentation, ON Semiconductor suggests settling times in the range of 15 to 30 seconds as a starting point.

**Transducer Saturation**

Transducer saturation can also affect the measured feedback path. This can occur if the selected stimulus noise level is too high. When a transducer is saturating, the apparent feedback path will appear to be lower in amplitude than it is under nominal conditions. This will most likely occur near frequencies where there is strong feedback. Unfortunately, the tool cannot detect if external saturation is occurring; however, saturation can be identified by reducing the stimulus level and re−measuring the feedback path. If saturation is occurring, the measured frequency response will be gradually reduced as the stimulus noise level is increased. This will be particularly acute near frequency response peaks. Such compression of the measurements for higher stimulus levels indicates a saturation problem.

If saturation is suspected, the stimulus level should be reduced to a level that is within acceptable limits for the chosen transducers. Repeated measurements at reduced stimulus levels should be performed to ensure that the measured data is converging to the same frequency response.

## UNDERSTANDING FEEDBACK PATH DATA

The data returned by the Feedback Measurement Tool is a representation of the impulse response, or time response, of the feedback path. Since the tool uses the FBC to determine the impulse response, the time duration of the impulse response is limited to 40 samples. The time window of the measurement can be offset, however, using the acoustic pre−delay parameter. The acoustic pre−delay determines the time offset at the beginning of the measured impulse response. If the acoustic pre−delay is set to a value other than zero, then there will be a corresponding number of zeros appended to the beginning of the measured impulse response. Therefore, the number of data points returned by the Tool is 40+AcousticPredelay−1. A more complete picture of the total impulse response can be obtained by repeated measurements using different acoustic pre−delay settings and combining the resulting data.

On its own, the impulse response data is difficult to interpret and does not directly provide an indication of MSG. To determine MSG, the impulse response data must be converted into a frequency response. This is accomplished by calculating the Fourier Transform of the impulse response using an algorithm such as the Fast Fourier Transform (FFT). This step must be implemented by end−user software but there are a number of freely available numerical routines for calculating the FFT.

As an example, the tool was used to measure the feedback path for an open−fit receiver in the ear (RITE) instrument. The resulting measured impulse response is shown in Figure 3. For this measurement, the acoustic pre−delay was set to 12 so the measured data has been automatically appended with leading zeros by the FB Tool software. The corresponding frequency response is shown in Figure 4.

This curve was obtained by calculating the 512−point FFT of the data returned by the FB Tool.

The feedback−path frequency response curve shows the level of feedback observed at the microphone signal (point A in Figure 2), relative to the hearing−aid output signal (point B in Figure 2). For this device, the feedback response peaks at −35 dB at a frequency of 6 kHz; therefore, it is possible to apply up to 35 dB of digital gain to this device before feedback. This is the maximum stable gain of the instrument.

NOTE: The feedback path measurement provided by the tool already includes the effects of transducers, acoustics, amplifiers and converter gains. Therefore, the MSG suggested by the tool applies only to the amplifier's digital gain. This includes: WDRC settings, volume control, wideband gain, graphic equalization, generic biquads and a correction term that depends on the HRX setting.

For HRX on, 18 dB is automatically added to the digital gain by the IDS software. This 18dB **does not** appear in the measured FB path. An 18dB correction must be added to the measured data to correctly predict the maximum digital gain that can be added before feedback. If HRX is off, then 18 dB is removed from the digital gain and added to the microphone preamplifier. This 18 dB **does** appear in the measured FB path, so no digital gain correction is required. In other words, if the same instrument is measured once with HRX off and again with HRX on, then the two measurements will display an 18 dB gain difference.

For example, if the measured FB−path frequency response has a peak of −35 dB, then the maximum digital gain that can be applied before feedback is 35 dB. If HRX was on during the measurement, then the maximum IDS gain is 35−18, or 17 dB; if HRX was off, the maximum IDS gain is 35 dB.
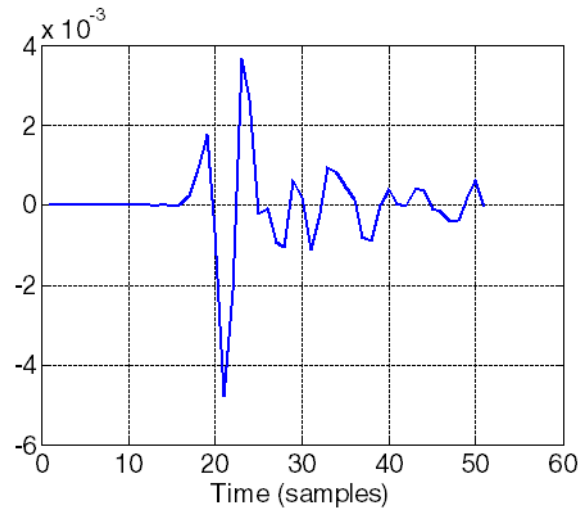


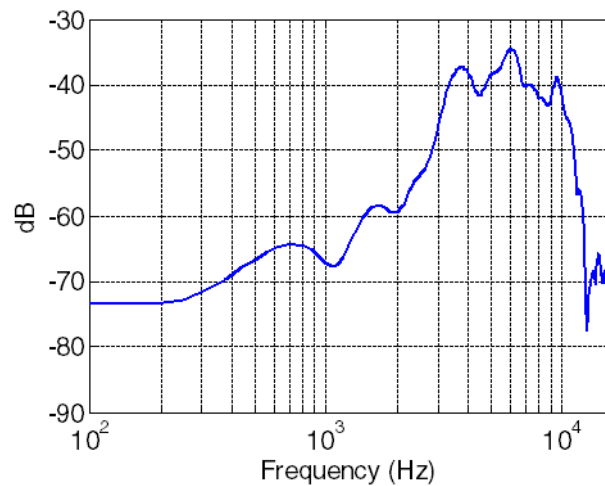**Figure 3. Impulse response of an open−canal hearing aid measured using the FB Tool**



**Figure 4. Feedback−path frequency response corresponding to the impulse response shown in Figure 3**

## PRODUCT LIBRARY REQUIREMENTS

There are certain requirements for a product library to work properly with the FB Path Measurement Tool:
- The selected library and product must support the Tool (e.g. *Inspiria Extreme (SA3286) Demo Library* and *8 Channel ITE/ITC 119/63, ALL Generic Biquads 32kHz* product).
- The selected library must have Tinnitus Treatment enabled so that the Measurement Tool has a source of white noise.

- Feedback Canceller and Acoustic Delay parameters must be enabled.
- The Post 3 Filter must be set to a Generic Biquad and its coefficients must be programmable.
- Either of the FE Modes (*1 mic omni* or *rear only*) must be enabled.

## MEASURING FEEDBACK PATHS USING THE SAMPLE APPLICATION

The FB Path Measurement Tool Sample App is a fully functional Visual Basic 6 application. It is intended to be used as an example to help software developers incorporate the FB path measurement capability into their own software. ON Semiconductor provides the source code and executable module as part of the ARK installation package (source code is distributed with the ARKsdk package and executables are included with ARKbase) for digital amplifiers that support this feature, such as SA3286.

In addition to the product library requirements above, the Sample Application requires the following:
• Four pre−filters set to generic biquads with programmable coefficients
• Four post−filters set to generic biquads with programmable coefficients
• Both *1 mic omni* and *Rear Only* must be enabled in the library

• HRX must be enabled
• Memory A is the active memory
• Data in registers matches data programmed into EEPROM (can be ensured by restarting the device)

NOTE: These elements are included for simplicity in developing the sample application and need not be included in manufacturer's software. Refer to the Feedback Path Measurement Principles section for a description of the minimum requirements. A product component that includes all these features in included as part of the SA3286 demo library.

The following sections explain the use of the Sample Application as it is delivered from ON Semiconductor. A screen shot is provided in Figure 5.
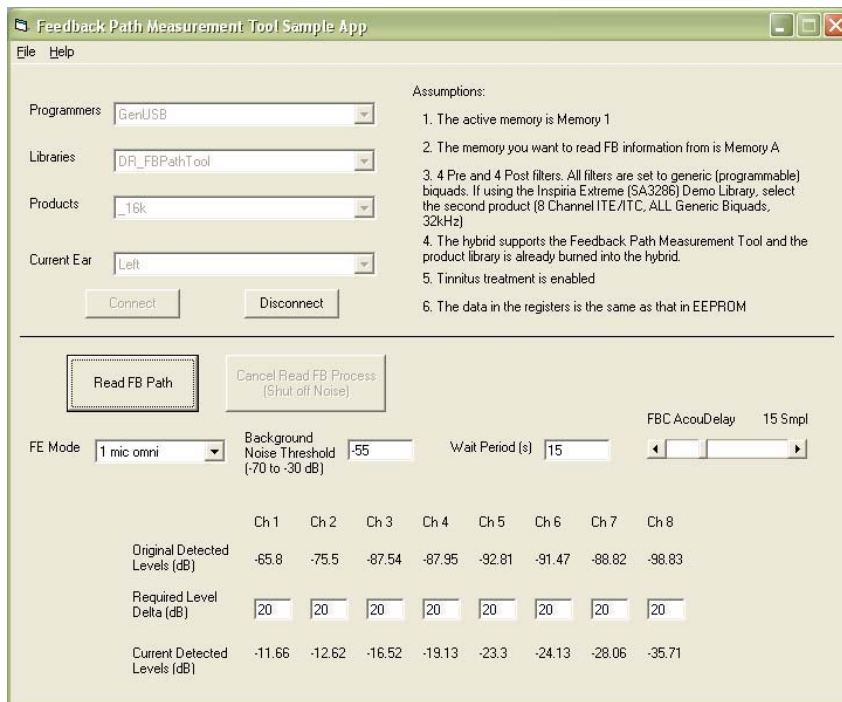


**Figure 5. Screen shot of the Feedback Path Measurement Tool Sample Application**

### Connecting to the Device

The first step in reading the FB Path is to connect to the device. Selecting the appropriate Programmer, Library, Product, and Ear side, and clicking **Connect** will cause the Sample App to connect to the device. An error message will be displayed should an error occur while attempting to connect to the device. Otherwise the **Read FB Path** button will be enabled.

### Setting the Feedback Path Measurement Parameters

The FE Mode drop−down box allows the user to select which FE Mode to use. The FE Modes **1 Mic Omni** and

**Rear Only** are the only valid modes for use with the Feedback Path Measurement Tool. The **Background noise Threshold** textbox allows the user to set the maximum ambient noise level, above which the tool will not execute. The ambient levels observed in all channels need to be below this threshold before an FB Path measurement can be performed. The **Wait Period** textbox allows the user to control the time that the FB Path Measurement Tool waits for the FBC to settle. The appropriate wait period depends on the device and the expected ambient noise levels (see the Setting Time section). Users will need to determine

appropriate wait times for their application through experimentation (see the Feedback Path Measurement Routine section), but ON Semiconductor suggests settling times in the range of 15 to 30 seconds as a starting point.

The **FB AcouDelay** slider controls the FB Canceller Acoustic Pre−Delay. As described above, this determines the time offset applied to the beginning of the FBC. In normal FBC operation, it is intended to compensate for the varying acoustic delays in different hearing instruments. Recommended pre−delay settings for different hearing aid styles are provided on the feedback canceller tab in IDS.

**Feedback Path Measurement Routine**

When **Read FB Path** is clicked, the program first sets up the hybrid for an FB Path Measurement. The Post 3 biquad's b0 coefficient is set to '0'. All other biquads are turned off.

NOTE:  By modifying the source code, it is possible to use filters other then generic biquads for all filters, except Post 3, but the filters need to be turned off.

HRX is turned on. FE Mode is set to *1 mic omni* or *rear mic only.* WDRC slow detectors are set to 4 ms attack time and 32 ms release time.

Next, the background noise in each channel is read using the level detectors. The measured background noise must be below the *Background Noise Threshold* in each channel for the FB path measurement to proceed. An appropriate Background Noise Threshold value will need to be determined through experimentation for each particular style of hearing aid.

Assuming that the measured background noise level is below the Background Noise Threshold in all channels, the program proceeds to initiate noise generation – flat noise, set to Post VC (Noise + HA audio). It should be noted that the generated noise RMS level for an 8kHz bandwidth product is 3 dB higher than for a 16 kHz bandwidth product. The program then raises the noise level (as measured at the input by the level detectors) until it is above the background noise level measured in each channel by a margin specified in the *Required Level Delta* row. It does this iteratively by increasing the generated output noise in 6 dB steps and measuring the noise at the input. The purpose of generating the noise at a level above the channel background noise level by a certain delta is to ensure that the noise stimulus is loud enough to make a good FB Path measurement. Some level of experimentation is needed to establish appropriate Required Level Delta settings so that the FB Path measurements are accurate, while ensuring that the patient is not harmed or put through unnecessary discomfort in the process. Keep in mind that the required deltas do not have to be the same size. For example, a hearing aid may not have a very strong low frequency FB Path, therefore little of the low frequency energy from the receiver will reach the mic. In this case, it might not be possible to produce noise that registers much more than 5 to 10 dB as measured by the low frequency level detectors. Furthermore, it may be necessary

for very low levels of feedback to turn HRX off in order to get a more stable reading of the feedback path. For the sake of time in a fitting situation, an alternative to establishing an appropriate noise level to be generated as described above may be to use a constant tinnitus noise level, or a level near the Loudness Discomfort Level (LDL) of the user.

With the noise being generated at a suitable level, the program turns on the FB Canceller and waits for the time period specified in the **Wait Period** textbox to pass. This is intended to give the FB Canceller time to properly adapt and settle. For a given noise level and hearing aid model, it is possible to establish, through experimentation, an appropriate wait time for the FB Path measurement to properly settle. Although the amount of time required for the measurement to stabilize varies with SNR, wait periods on the order of 15 seconds or more typically provide acceptable results.

Once the wait period has elapsed, the FB Path measurements are taken by reading the FB Canceller coefficients while the FB Canceller is operating. The Sample App makes a call to the *ReadFBPathSafe* function to read the FB Path coefficients. Alternatively, a non−Visual Basic program could make an API call to the *ReadFBPath* function, which is embedded in the product library DLL, to do the same. In order to get a more accurate reading of the FB coefficients, the FB Path coefficients are read a number of times and the average of the readings is taken. The variance and standard deviation of the measurements are also calculated to get an idea of how much the readings vary from each other. Although it is not strictly necessary to perform measurement averaging, it is known that this can help in certain situations.

Generation of the noise is stopped upon having completed the measurements. The device is then returned to its previous settings and the results (i.e. individual measurements, averages, variances, and standard deviations) are saved to a comma separated values (CSV) file.

The user is encouraged to review the data to determine if the measurements were stable at the time of recording (i.e. the FB Canceller had properly converged by the time the measurements were taken). For a given hearing aid model and generated noise level, a large variance and standard of deviation may indicate that the FB Canceller had not properly converged at the time the measurements were taken. In this case, a greater *Wait Period* (e.g. 5, 10, 15, 20 seconds) may be warranted to achieve more accurate and reliable results. On the other hand, a low variance and standard of deviation indicate that it may be possible to reduce the Wait Period (and thus the fitting time) without necessarily sacrificing results. The coefficients in the CSV file are those of an impulse response, an example of which is depicted in Figure 3. From this impulse response, it is possible to calculate a frequency response, although the Sample App itself does not do this. It has been left up to the hearing aid manufacturer to further process the impulse

response according to their needs and their preference in how they want to view the response.

For more details about the FB Path Measurement Tool Sample App, please see the source code for the application.

The code and its accompanying comments should give hearing aid manufacturers a good idea of how to incorporate the Measurement Tool into their software.

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