# Use of Average Detection in Gennum's AGC-O Amplifiers GS3026/GS3044

APPLICATION NOTE



## CIRCUIT DESCRIPTION

The GS3026 and the GS3044 hybrids are output compression AGC (automatic gain control) amplifiers for use with class D receivers in CIC applications. The circuits consist of a newly designed AGC preamplifier and internally coupled class D compatible output stage, which together provide high output levels with low distortion output limiting. System gain and compression thresholds can be independently adjusted using two external resistors/trimmers connected to ground. System gain can be varied from 0 - 38 dB (electrical), and the output compression threshold can be adjusted within a 16 dB range. The hybrids also feature an integrated voltage regulator and on-board decoupling capacitor for powering the microphone.

The front-end AGC preamplifier operates as a linear amplifier below the compression threshold. Above threshold, the circuit compresses the incoming signal at an 8:1 compression ratio, providing low distortion output limiting. The AGC control circuitry utilizes a single averaging detector with an electrical (RC) time constant of 270ms, selected to provide optimal sound quality over the full range of sound and listening environments.

The use of average detection, together with a high dynamic headroom design, allows for good estimation of signal loudness while maintaining the fidelity of the speech sound envelope.

The actual attack and release times (as per ANSI test specifications) are typically 40 ms and 150 ms respectively when the circuit is fully in the compression region of operation (measured times will vary depending on gain and threshold settings).

The small size and optimized pad layout of the hybrids make them ideal for CIC applications. All that is required for a complete hearing instrument design are a microphone, integrated class D receiver, battery, volume and threshold trimmers (or resistors), and a decoupling capacitor. Output pads are positioned for easy assembly around the battery compartment.

### TYPICAL HEARING INSTRUMENT DESIGN USING THE GS3026

Figure 1 shows a typical hearing instrument application of the GS3026, using an EM5046 microphone and ES3127 integrated receiver. Note recommended use of a 2.2µF decoupling capacitor (C in Figure 1) across the integrated class D receiver. In general terms, the larger the value of this capacitor, the better the total system distortion performance (particularly when operating the GS3026 at maximum threshold settings).

The circuit below was tested acoustically according to the ANSI 3.22-1987 standards using the FONIX 6500 Hearing Instrument Test System with a 2cc coupler.

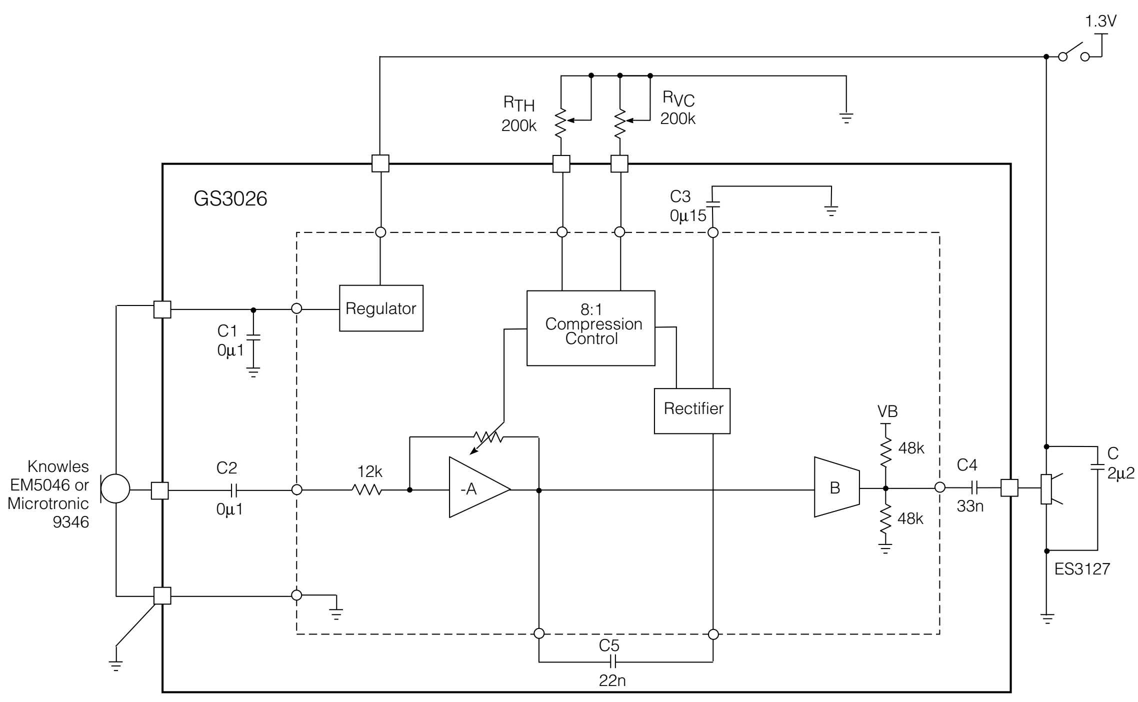


Fig. 1 Typical Hearing Instrument Application

Revision Date: September 2000

Document No. 521 - 82 - 02

GENNUM CORPORATION P.O. Box 489, Stn. A, Burlington, Ontario, Canada L7R 3Y3 tel. +1 (905) 632-2996
Web Site: www.gennum.com E-mail: hipinfo@gennum.com

Figures 2 and 3 show the test results. Figure 2 is the ANSI test result performed with the compression threshold of

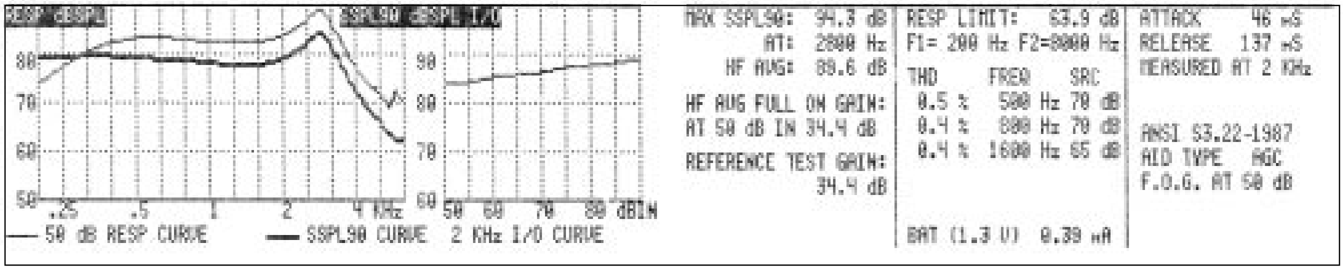


Fig. 2 Minimum Threshold

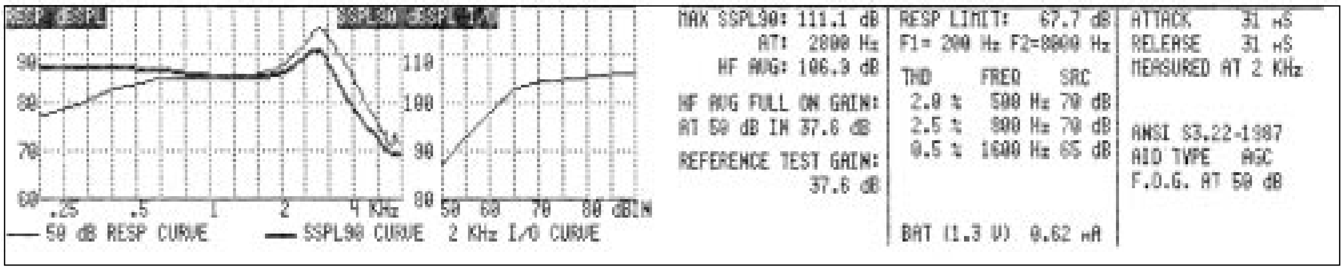


Fig. 3 Maximum Threshold

the GS3026 set to minimum ($R_{TH}$= 220kΩ) and Figure 3 shows the test results with the compression threshold set to maximum ($R_{TH}$=0 kΩ).

**COMPARISON OF PEAK AND AVERAGE DETECTORS**

All AGC (automatic gain control) systems incorporate some form of variable gain element and level sensing circuitry to sense the listener environment and adjust the system gain accordingly.

The level detection circuitry generally measures an alternating voltage signal and generates a DC control voltage (or current) which is used to set the value of the variable gain element. This is done by rectifying (full-wave or half-wave) the sensed signal and smoothing (filtering) the result. A key point to recognize is that a system's dynamic response characteristics (i.e. attack and release times) are a direct function of this resultant control signal.

When designing an AGC system, there are a number of potential level detector schemes from which to choose, including peak detectors, average detectors, RMS detectors, and variants thereof.

It is highly recommended that the GS3026 (and GS3044) be used with the compression threshold set at least 8dB to 15dB below the maximum. This will virtually eliminate the distortion and provide the best possible sound quality.

The GS3026 (and GS3044 ) was not designed to operate without recommended headroom, so when the compression threshold is set closer than 10dB below maximum, the recommended headroom will be eliminated (I/O curve of Figure 3 illustrates that) and it will result in higher distortion and degradation of the sound quality.

*Peak detectors*, for which the gain of the system is adjusted according to the peaks of the signal being sensed, are quite common in traditional first-generation AGC circuits.

Attack and release times can be made completely independent or a fixed ratio of one another, depending on the circuit design. The attack time of a peak detector is usually set to be short (1-10ms) to quickly respond to and protect the listener from sudden loud sounds. Conversely, the release time is typically set long (>100ms) to gradually return the system gain to its previous state. Potential problems with a peak detector system are that the short attack time can cause rapid gain fluctuations which can be perceived by some listeners as audible distortion (“pumping” effect). To reduce those fluctuations release time is set long but that might cause the system to stay in compression for too long and result in loss of speech cues.

The following graph illustrates how a typical peak detector responds to a speech signal. The black line is the output from the peak detector. Notice how the output quickly responds to the peaks of the speech signal and then gradually falls upon release.

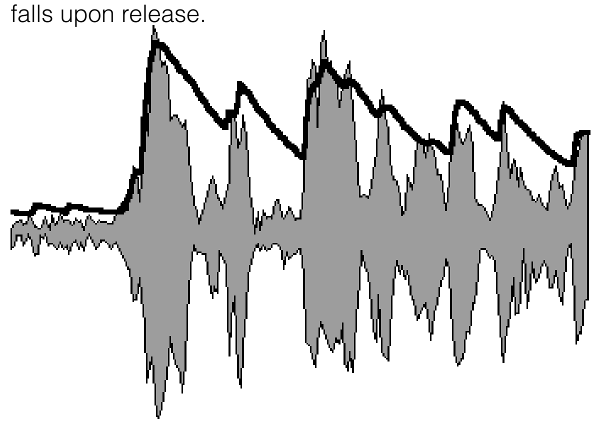

Fig. 4 Peak Detector Output

As previously mentioned, the level detector output directly controls the gain of the AGC amplifier. The circuit gain over time can be plotted as the inverse of the peak detector output curve from Fig. 4:


Fig. 5 Gain versus Time - Peak Detector

An alternate means of level detection is to do *average detection.*

In *average detector* circuits, the control signal is derived from the electrical average of the sensed signal. The attack and release times of an average detector circuit are a function of the component values selected for the smoothing filter (a single-pole RC network in the case of the GS3026 and GS3044) and, unlike the situation for peak detectors, are not independent of one another. This is not to say that the attack and release times are necessarily the same, but rather that changing the RC time constant of the circuit changes both the attack and release times (a further discussion of attack and release times is included towards the end of this application note).

Because an average detector follows the average sound level intensity, it will be less sensitive to the peaks in the input signal and therefore the gain of the system will be more constant. The graph below again shows a sample speech waveform together with the output from both a peak and average detector. Note that the average detector output is smoother and fluctuates less than the output of the peak detector, resulting in more stable gain (as illustrated in Figure 7) and a more natural sound for the amplified signal.

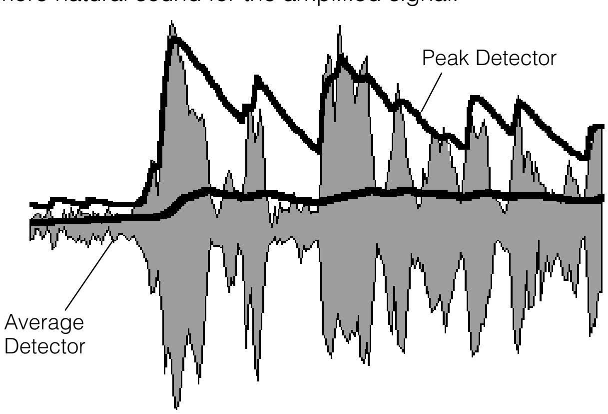


Fig. 6 Average Detector Output

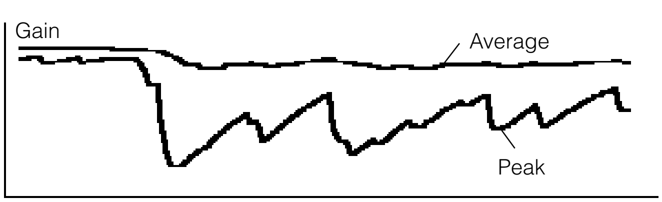


Fig. 7 Gain versus Time - Average and Peak Detectors

PERCEIVED LOUDNESS AND CREST FACTOR

Another observation from Figure 6 is that there is a significant difference in the magnitude of the detector outputs. As well as being smoother, the average detector output is consistently lower in magnitude than that of the peak detector. Remembering again that this output signal directly controls the gain of the AGC, it is clear that an average detection based system will provide relatively more gain than a peak detector system in response to the same input. In other words, an average detector system will have a *greater perceived loudness* than a peak detector system in all cases (since all real signals will have instantaneous peak values that are higher than the average signal level), all else being equal. Furthermore, the magnitude of the difference in perceived loudness between peak and average detector systems will be directly proportional to the ratio of the peak and average levels of the particular input signals being amplified, a quantity related to a signal's *crest factor.*

Crest factor is an attribute of a sound (or any other) signal which is used to describe the "peak-iness" of the signal. By definition, a signal's crest factor is simply the ratio of the absolute peak instantaneous signal level to the RMS (root-mean-square) level over an arbitrary time period. Since in practice a signal's RMS level is quite close to its average level, the peak-to-average ratio is in fact a good approximation of the crest factor.

For example, for a continuous sine wave the peak to average ratio is 3.92dB and the true crest factor (peak-to-rms) is 3dB. Real life signals have crest factors that are signal dependent (music is different than speech), and greater than that for a sine wave. Crest factors of 12 - 20dB are not hard to find in real world situations.

The issue of signal crest factor is important to the understanding and application of AGC circuits because of the implications on choice of detector topology. As has been demonstrated previously, peak detectors are quite sensitive to crest factor whereas average and RMS detectors are not. Since the human ear is NOT sensitive to waveform crest factor, it seemed appropriate that an AGC amplifier that is less sensitive to crest factor would be desirable.

**EFFECT OF DETECTOR TYPE ON SOUND QUALITY**

In an earlier section, it was pointed out that the short time constants associated with peak detectors result in a more rapidly fluctuating gain for the amplifier than is the case with average detection. To visualize what effect this can have on a speech signal, consider the following example.

The graph in Figure 8 is a time waveform representation of the sentence:

"Joe took father's shoe bench out, she was seated at my lawn".

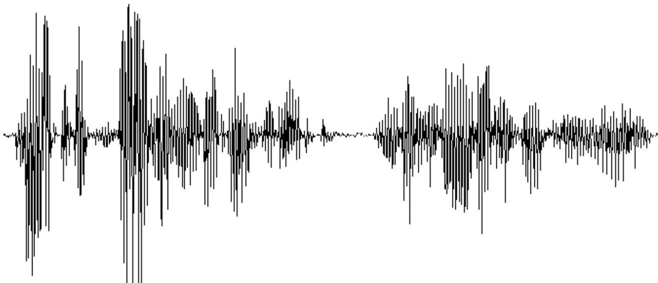

Fig. 8 Source Waveform

The next graph (Figure 9) is the time waveform representation of the same sentence processed by a compression amplifier with a peak detector. Because of its fast attack time the peak detector reduces the peaks in speech, distorting the speech envelope and degrading sound quality.

Fig. 9 Source Waveform Processed by Peak Detector Based Amplifier

An average detector, on the other hand, does a better job of maintaining the speech envelope, providing better sound quality. The final graph, (Figure 10) illustrates the original sentence processed by the GS3026 circuit with average detection. Notice how the speech peaks are preserved and the resulting waveform resembles the original source much more closely than for the peak detection case.

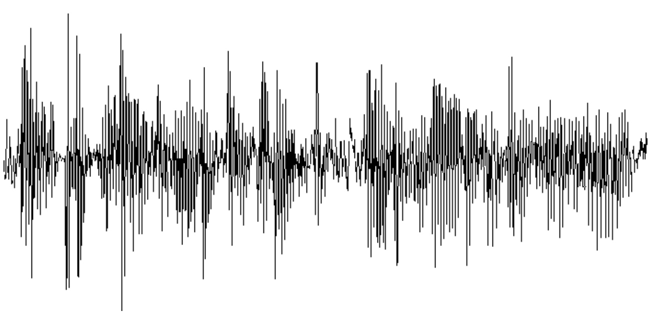

Fig. 10 Source Waveform Processed by Average Detector Based Amplifier

It is important to remember, however, that to maintain good sound quality the peaks in the processed signal should not be clipped. As a result, an average detector will need relatively higher headroom than a peak detector, since its gain is prevented from changing as quickly. One might initially conclude that this is a bad thing in that it would result in a lower achievable maximum output (SSPL90) for a hearing instrument design.

While it is true that a lower SSPL level (as measured using pure tone sine waves on an audio test box) must be selected to avoid clipping in the receiver, this does not present a problem in application, since the average detector circuit will provide greater effective gain (perceived loudness) to the user in most listening conditions (i.e. high crest factor signals such as speech and music), as previously demonstrated. Note that, given a peak detector and average detector which are matched for output using pure tone test signals, the average detector system will be perceived as being louder.

**FURTHER NOTES ON ATTACK AND RELEASE TIMES**

The GS3026 and GS3044 use a single time constant average detector. The time constant is determined by the selection of the resistor (on-chip) and capacitor (on the hybrid) component values for the RC network which acts as the smoothing filter for the AGC. For the GS3026 and GS3044, this RC time constant is nominally 270 ms, a value determined empirically to provide the best sound quality over a broad range of listening environments. This AGC time constant is related to, *but should not be confused with*, the ANSI attack and release times for the circuit.

Another important note to consider is that measured ANSI attack and release times will vary depending upon gain and threshold settings of the GS3026/GS3044. The ANSI test specifies a test signal which “attacks” from 55 dBSPL to 80 dBSPL and then “releases” from 80 back to 55 dBSPL. Because of the high AGC kneepoint associated with an AGC-O system and the ability to move the kneepoint (with respect to the input) by changing the threshold and gain settings, the test range may fall fully within, fully outside of, or straddle the compression region.

If the GS3026 (or GS3044) is set such that the test signals fall completely within the compression region of operation (i.e. at maximum gain and low threshold levels), then the measured attack and release times will be typically 40 ms and 150 ms respectively. As you increase the compression threshold (decrease $R_{TH}$ resistor value), the test points will be straddling the compression kneepoint (jumping between the linear and compression regions of operation), resulting in shorter reported attack and release times. If one was to turn the gain down, a point would be reached where the full burst range (55 - 80 dBSPL) would fall within the linear portion of operation, never reaching the compression threshold. In this case, the attack and release times would be meaningless.

The following graphs illustrate how measured attack/release time and input/output characteristics of the GS3026 hearing instrument change with the increase of the compression threshold level ($R_{TH}$ is being reduced). The test were done using FONIX 6500 Hearing Instrument Test System with the 2 cc coupler.

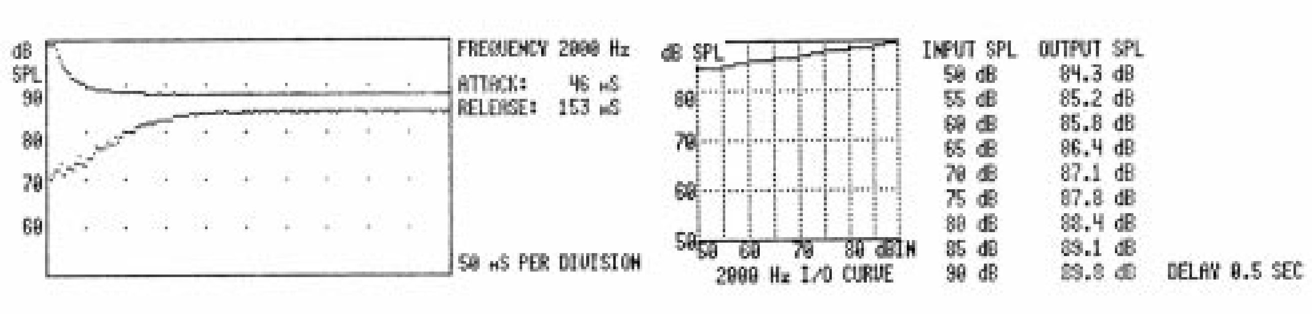


Fig. 11a Attack & Release envelopes & IO curve for $R_{TH}$ = 200 kΩ (GS3026)

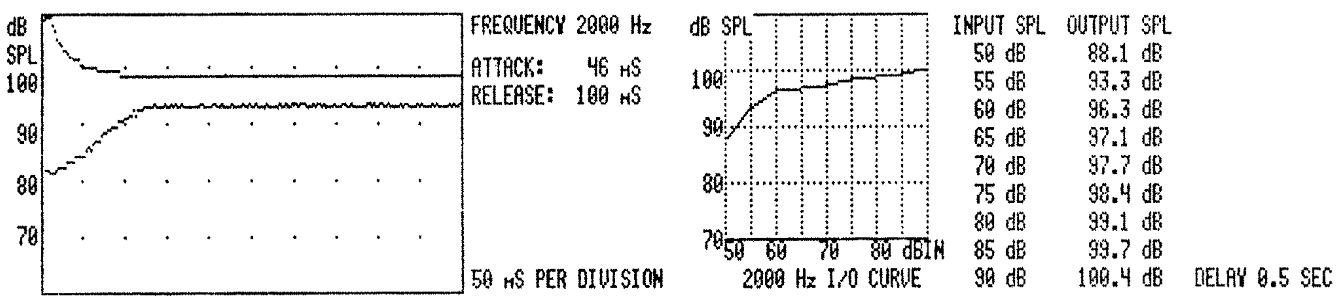


Fig. 11b Attack & Release envelopes & IO curve for $R_{TH}$ = 25 kΩ (GS3026)

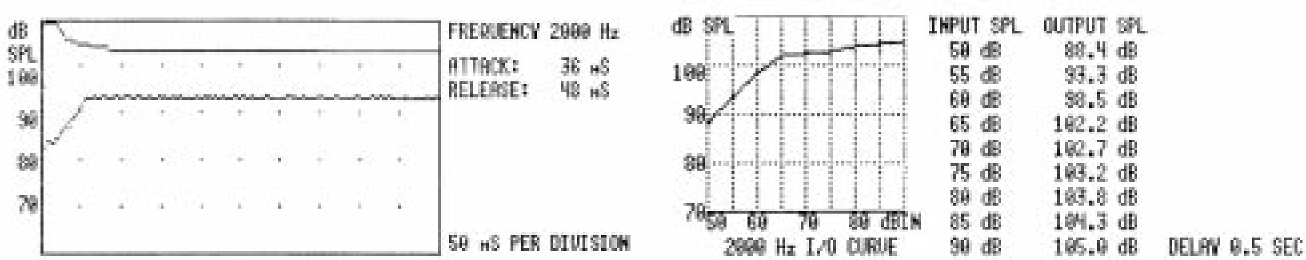


Fig. 11c Attack & Release envelopes & IO curve for $R_{TH}$ = 5 kΩ (GS3026)

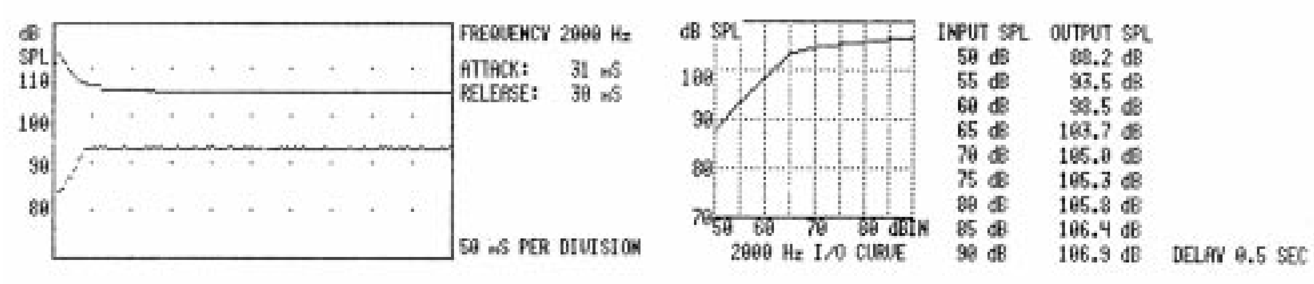


Fig. 11d Attack & Release envelopes & IO curve for $R_{TH}$ = 0 kΩ (GS3026)

REVISION NOTES:
Corrected typing error.

*For latest product information, visit www.gennum.com*

GENNUM CORPORATION
MAILING ADDRESS:
P.O. Box 489, Stn. A, Burlington, Ontario, Canada L7R 3Y3
Tel. +1 (905) 632-2996 Fax +1 (905) 632-2814
SHIPPING ADDRESS:
970 Fraser Drive, Burlington, Ontario, Canada L7L 5P5

GENNUM JAPAN CORPORATION
C-101, Miyamae Village, 2-10-42 Miyamae, Suginami-ku
Tokyo 168-0081, Japan
Tel. +81 (3) 3334-7700
Fax: +81 (3) 3247-8839