Current Mode Class H Amplifier

GS3013 APPLICATION NOTE

INTRODUCTION

This application note introduces Gennum's new current mode class H amplifier. This amplifier class was initially developed in early 1977 and included a variety of designs. The signal handling capabilities of the output stage, is adjusted according to the level of the incoming signal. Recent state of the art audio equipment uses this concept to provide high fidelity amplification.

Gennum has adapted and incorporated these principles in the development of GS3013 amplifier. The output stage of this new hybrid adjusts the biasing current to the incoming signal's requirements. In this type of operation the current consumed by the receiver depends on the output level while maintains sufficient headroom.

In general class B and class D output stages provide significant current savings compared to class A devices. Unfortunately they introduce switching distortions, and in addition, class D may produce aliasing effects. Class H amplifiers provide current savings and headroom without the penalties inherent to class B and class D output stages.

This Application Note provides the theory of operation of Gennum's (*Current Manager*) new Class H amplifier. Some typical application circuits are also discussed.

Class H Current Mode Theory of Operation

The simplest and purest of power amplifier configurations is the class A amplifier. The underlying principle is to bias a transistor at an appropriate bias current level and let the signal swing about this level. The current drawn from the power source (battery) varies with the signal but the average current is simply the bias current itself (Figure 1).

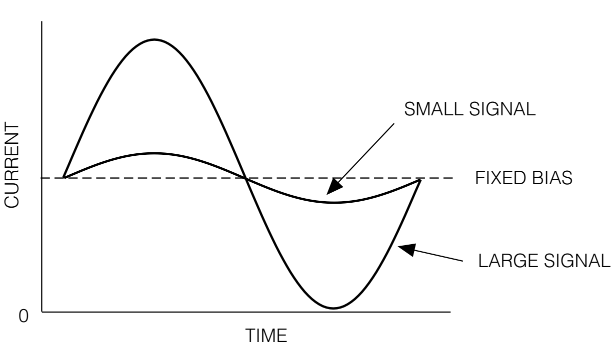

Fig. 1 Traditional Class A

The maximum signal excursion swings between zero (since the most the transistor can do is turn off) and two times the bias current.

The bias current is chosen to allow for the largest desired signal. In hearing aid design the desire for acceptable battery life can necessitate compromising on the maximum output power (hence bias current), leading to the phrase "starved class A". The bias conditions are starved relative to those "required" for a higher output level.

Class H Current Mode

Obviously for signals less than the maximum output level the bias current required is also less. If the bias current is adaptively adjusted to the requirements of the signal being processed then a current savings can be realised (Figure 2 illustrates the concept). This type of operation is classified as class H.

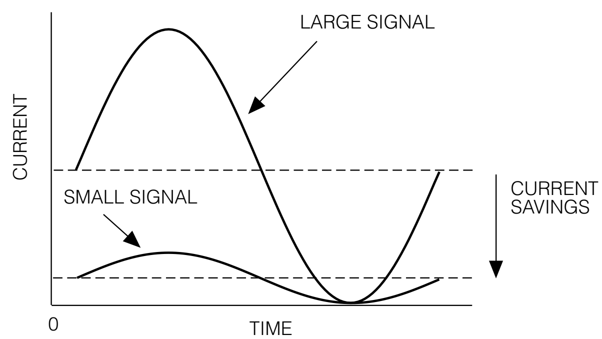

Fig. 2 Current Savings

The bias current required for a distortionless sine wave along with the fixed bias current of a true class A amplifier is shown as a function of output level in Figure 3.

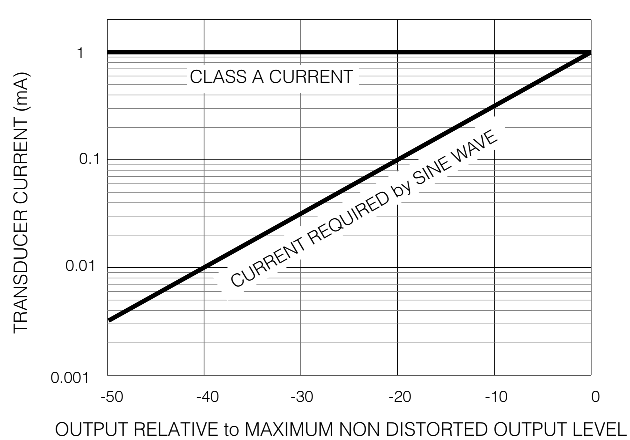

Fig. 3 Minimum Current Required

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The difference between the two curves represents the excess current consumed. The idealised case is difficult to achieve since real world signals are more demanding then the sine waves used for illustration so far. In order to adapt the bias to the signal being amplified, the signal is rectified and averaged in order to determine it's level.

The averaging time constant needs to be chosen such that there are no audible artifacts from the bias shifting, hence the bias can not change instantaneously. The time delay between a signal increasing in level and the bias adapting requires that a certain amount of dynamic headroom be provided in order that the signal remain undistorted (Figure 4 illustrates the headroom).

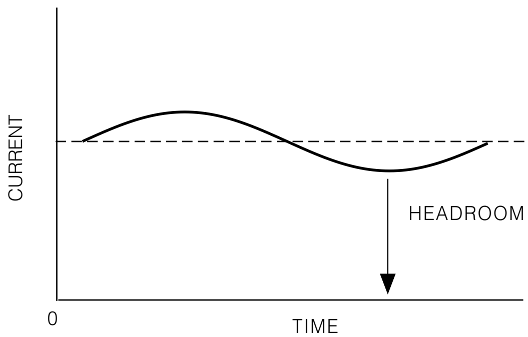


Fig. 4 Dynamic Headroom

The bias current versus relative output level graph for a practical design is given in Figure 5. The design is such that the minimum bias current is a factor of ten (20 dB) below the maximum. A dynamic headroom of 14 dB was chosen.

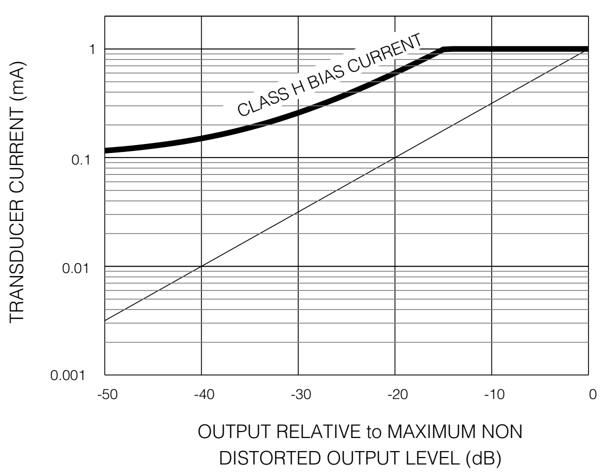


Fig. 5 Practical System - Current

Starting at the maximum non distorted output level (0 dB) and moving backwards it is seen that for the first 14 dB there is no reduction in bias current. Reducing the output further results in linear reduction in bias current with output level for approximately the next 20 dB. Any further reduction in output requirements results in no further decrease in bias current, the minimum bias current has reached a value of approximately one tenth that of the maximum.

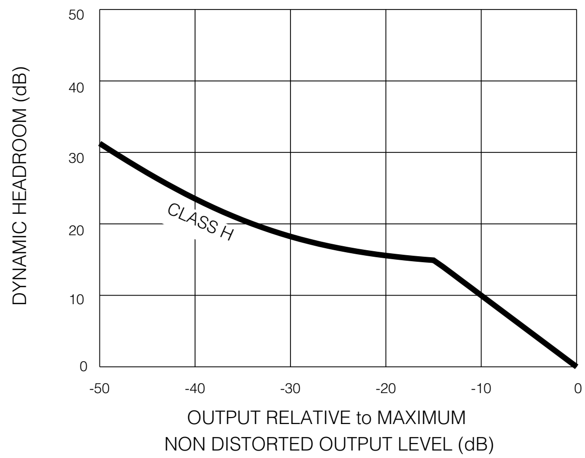


Fig. 6 Practical System - Headroom

The difference between the class H current and the sine wave current line (Figure 5) represents the dynamic headroom. The dynamic headroom versus relative output is shown in Figure 6. As the output level decreases from the maximum the headroom is increased. In the highest output power region the headroom is identical to that of a traditional class A of similar output capability.

Practical Implementation - GS3013

The GS3013 is a linear hybrid containing three amplifier stages. The block diagram and typical application circuit of the hybrid are presented in Figure 7.

Stages A and B are designed around standard 508 type amplifying blocks. Those stages can be used for filtering and/or gain adjustment. The open loop gain characteristics are provided in the Data Sheet 520-87. To provide proper biasing, stages A and B needed to be AC coupled. To provide the coupling between a microphone and the IC an 82 nF input coupling capacitor is included on the hybrid. It provides approximately 160 Hz low frequency roll-off.

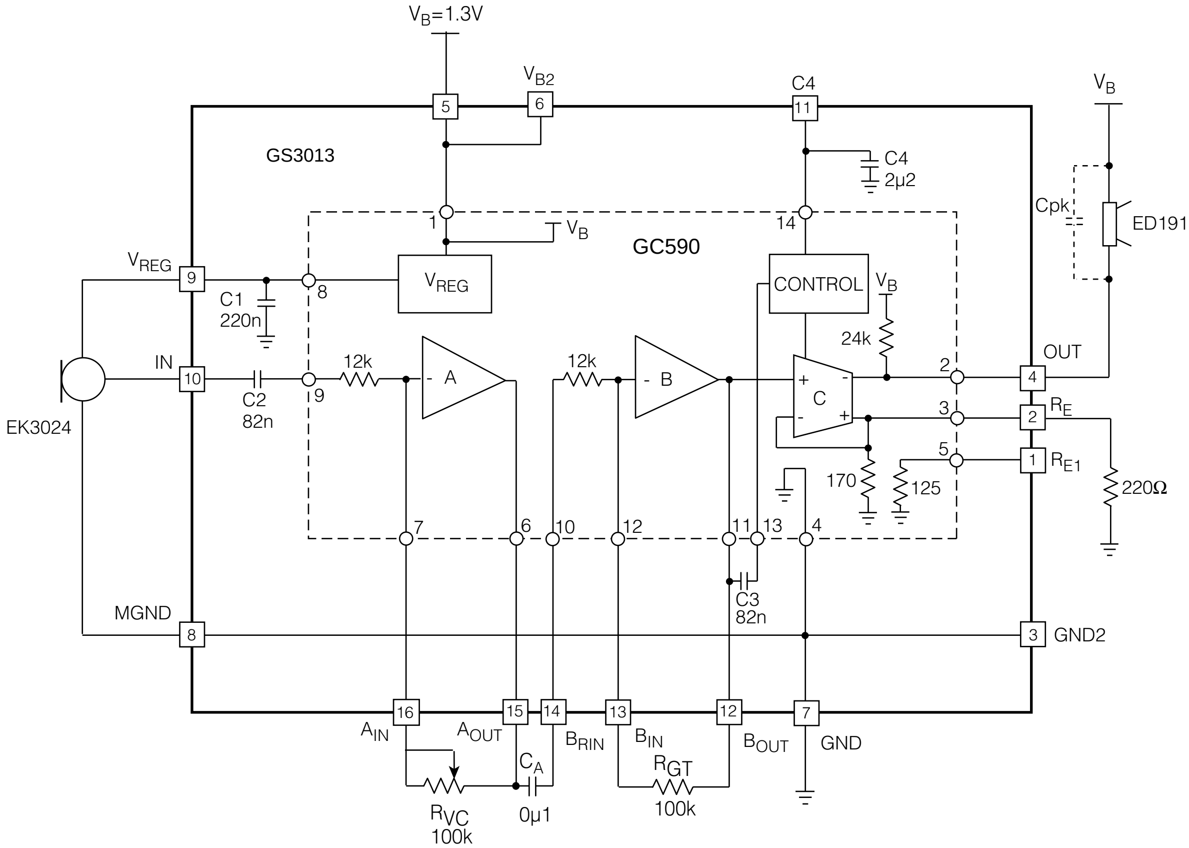
The power output stage uses the current mode class H circuit. It consists of control circuitry and a current drive output stage.

The control circuit takes care of the following functions:-

- change biasing level of the output stage in response to amplitude of the incoming signal.
- provide headroom to accommodate fast transients.
- control how fast biasing level is changing (attack and decay time of the biasing level)

The attack and decay times are determined by the 2.2 µF averaging capacitor.

This capacitor value produces the 100 ms time constant of the system.



All resistors in ohms, all capacitors in farads unless otherwise stated

Fig. 7 Typical Application Circuit

By choosing a long time constant the energy associated with shifts in the bias current occurs at very low frequencies. Masking effects will ensure that shifts are inaudible.

Figure 7 illustrates the GS3013 hybrid configured as minimum parts, medium power, hearing instrument. The EK3024 series of the microphone and ED1913 receiver are used. The calculation of the R_E resistor should be performed identically to any of Gennum's class A current drive output stages. The maximum emitter voltage (ie. 66 mV) should be used for calculating the maximum output power. The class H control circuit will lower bias current automatically during times when less output is required.

ED1913 receiver will require 700 µA for biasing translating to $R_E = 220\ \Omega$. The hybrid offers two possible stages to be used as a volume control. In this application, stage A is configured as a volume control and stage B as a gain trim. We have selected a feedback resistance value of :

$$R_{GT} = 100\ k\Omega \text{ max} \quad \text{and } R_{VC} = 100\ k\Omega \text{ max}$$

to illustrate some acoustic characteristics of the system.

The system current savings characteristic of the GS3013 versus the output level is presented in Figure 8.

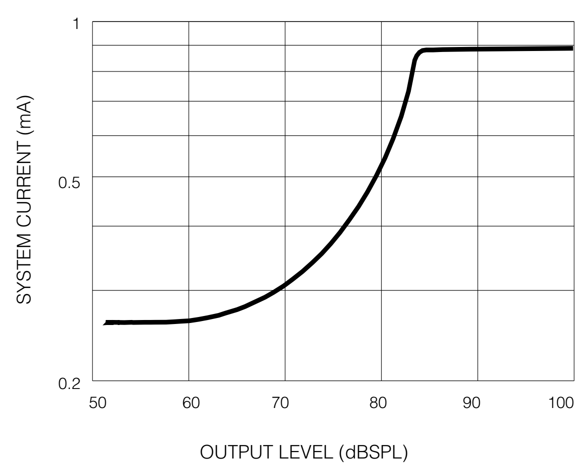


Fig. 8 System Current vs Output Level

The application circuit used to generate the above graph is shown in Figure 7. A microphone was replaced with electrical signal source and 3.9 k microphone resistance simulator. As seen from the graph the actual system current consumed between very loud and very soft sounds is approximately a 3.5:1factor.

The acoustic responses for different output levels and corresponding system currents are shown in Figure 9.

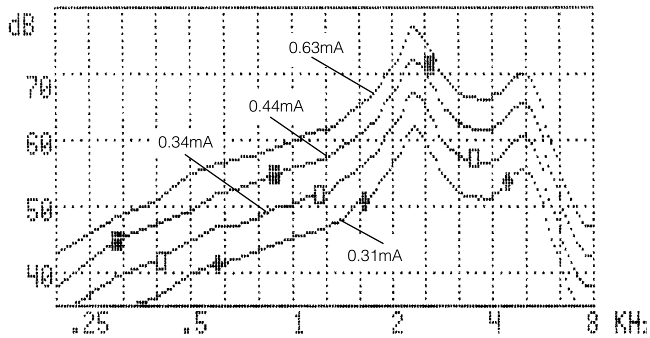
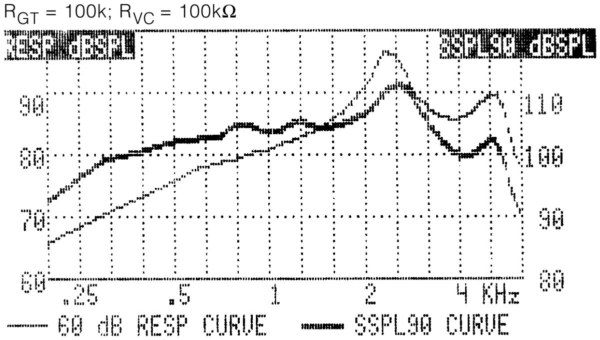


Fig. 9 System Currents for Different Output Levels

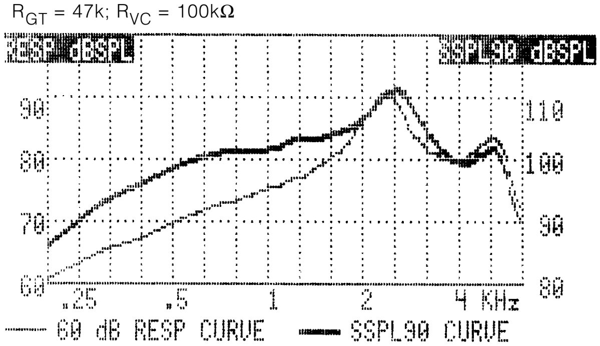
Figure 10 shows the results of the SSPL90 measurements using Frye 6500 acoustic test box for different system gain settings.

R_{GT} = 100k; R_{VC} = 100kΩ



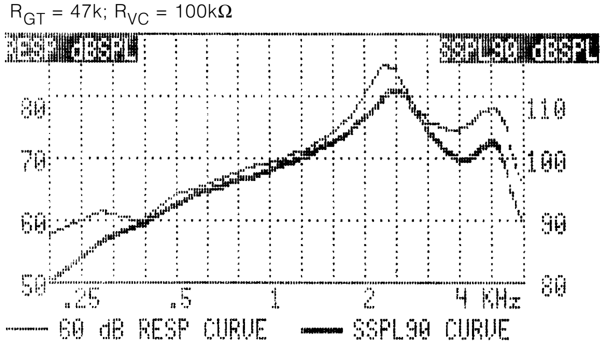
MAX SSPL90: 111.5 dB AT: 2600 Hz HF AUG: 106.5 dB HF AUG FULL ON GAIN: AT 60 dB IN 27.6 dB REFERENCE TEST GAIN: 27.3 dB SSPL90-77: 29.5 dB	RESP LIMIT: 67.4 dB F1=243 Hz F2=8000 Hz THD FREQ SRC 2.1 % 500 Hz 70 dB 3.7 % 800 Hz 70 dB 1.7 % 1600 Hz 65 dB BAT (1.3V) 0.89 mA	ANSI S3.22-1987 LINEAR TYPE AID F.O.G. AT 60 dB

R_{GT} = 47k; R_{VC} = 100kΩ



MAX SSPL90: 111.3 dB AT: 2600 Hz HF AUG: 106.5 dB HF AUG FULL ON GAIN: AT 60 dB IN 21.5 dB REFERENCE TEST GAIN: 21.5 dB SSPL90-77: 28.5 dB	RESP LIMIT: 61.5 dB F1=220 Hz F2=8000 Hz THD FREQ SRC 1.4 % 500 Hz 70 dB 1.3 % 800 Hz 70 dB 0.4 % 1600 Hz 65 dB BAT (1.3V) 0.53 mA	ANSI S3.22-1987 LINEAR TYPE AID F.O.G. AT 60 dB

R_{GT} = 47k; R_{VC} = 100kΩ



MAX SSPL90: 111.0 dB AT: 2500 Hz HF AUG: 103.9 dB HF AUG FULL ON GAIN: AT 60 dB IN 15.8 dB REFERENCE TEST GAIN: 15.7 dB SSPL90-77: 26.9 dB	RESP LIMIT: 55.9 dB F1=200 Hz F2=8000 Hz THD FREQ SRC 0.6 % 500 Hz 70 dB 0.6 % 800 Hz 70 dB 0.3 % 1600 Hz 65 dB BAT (1.3V) 0.37 mA	ANSI S3.22-1987 LINEAR TYPE AID F.O.G. AT 60 dB

Fig. 10

Class H versus Class A

The purest and simplest amplifier of all - class A, has one main disadvantage - excessive power consumption. The GS3013 hybrid allows for clean comparison of the current consumption between class A and class H. To achieve this goal, the GS3013 hybrid can be converted to operate in class A mode. If Vb potential is applied to pin 11 (Figure 7) the averaging capacitor is fully charged and the control circuit force maximum biasing current for all levels of the signals. This type of operation is equivalent to class A.

The comparison between current consumptions for different type of output stages will be addressed in a separate publication. For now however, we can only attempt to predict class H current savings. If a user's typical output requirements are 20 dB below the maximum output, then an expected 6 dB(20 dB below maximum output minus 14 dB of headroom) reduction in transducer current can be expected.

If 2cc coupler values of SSPL 90 are the assumed maximum output, then additional savings may be expected as a result of the typical increases seen when the instrument is inserted in real ears (owing to the smaller residual volume).

Another possibility is to set up the system to provide more output than before (i.e. not starving the amplifier).

Building further on the previous example (where the typical use is 20 dB less than maximum output), for the same current consumption as the fixed bias case, it would be possible to achieve 6 dB more output.

Frequency Shaping

The GS3013 class H output stage is a current drive system. It is possible to dampen or shift the resonant peaks in the frequency response by placing a capacitor (Cpk) across the receiver. The system configuration is shown in Figure 7.

The value of the Cpk was changed and the responses on the frequency characteristics are presented in Figure 11.

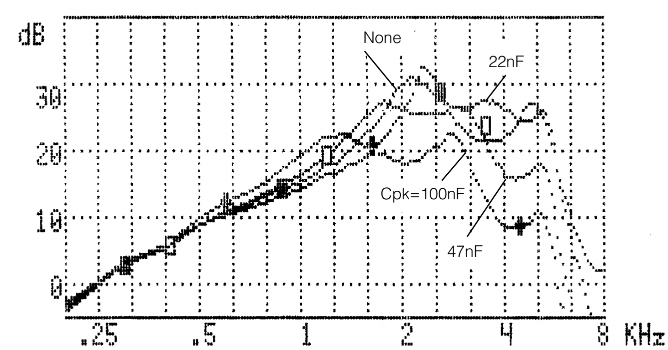


Fig. 11 Acoustic Responses for Different Values of Cpk

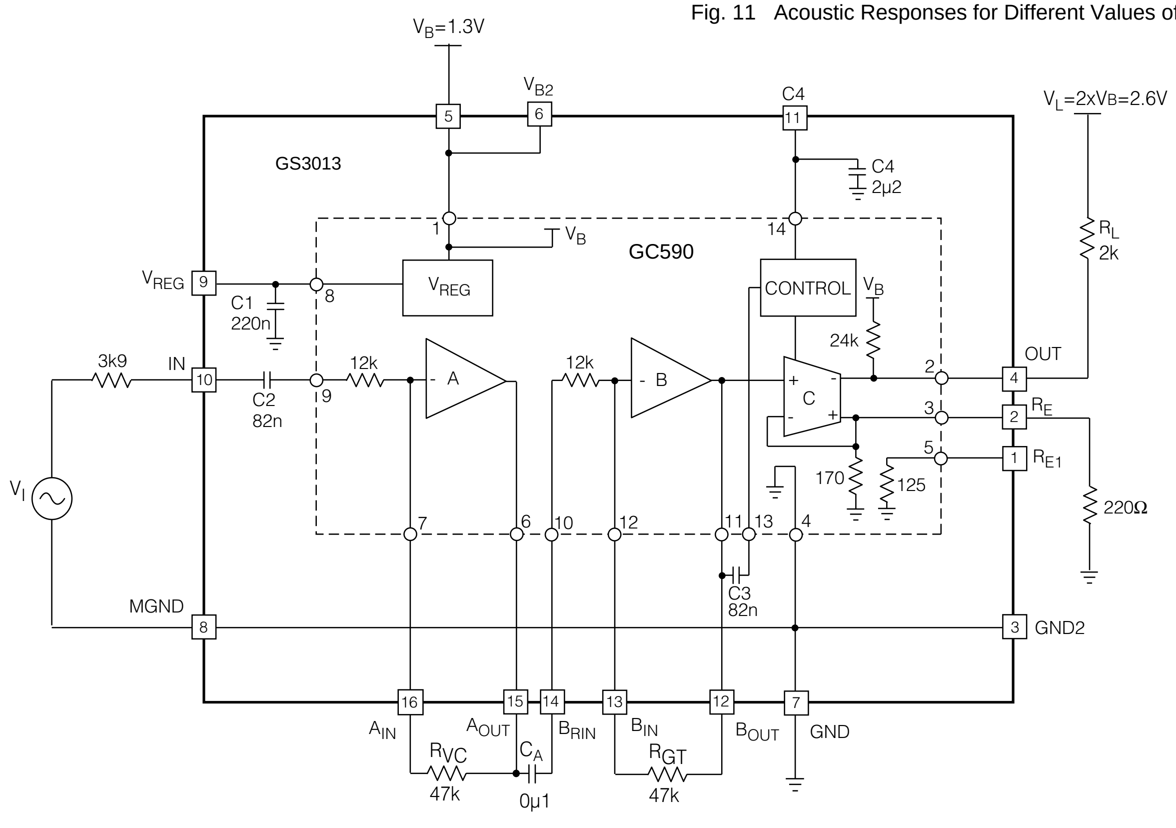


Fig. 12 IMD Characterization Circuit

Intermodulation Distortion

The Intermodulation Distortion test is intended to measure the distortion products generated by non-linearities in an amplifier. Different test methods exist which will yield different results. One popular method (CCIF) uses two swept tones ($f1$ and $f2$) separated by a constant difference frequency (ie. $f2$-$f1$ = 200 Hz). The resulting waveform has a large envelope modulation, as can be seen in Figure 13.

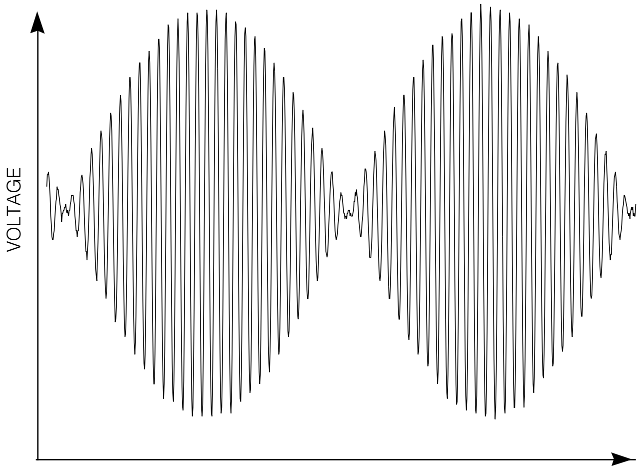


Fig. 13 CCIF ($f2$-$f1$) Test Signal

The class H control circuit monitors the envelope of this waveform and adjusts the bias accordingly. The CCIF technique expresses distortion as a ratio between the amplitude of the difference frequency and the composite twin tones. The graph shown in Figure 14 and 15 (CCIF methods) would indicate high levels of distortion. The characterization circuit used is shown in Figure 12.

As discussed in the Theory of Operation, the output signal consists of the actual amplified signal and the bias shifting component.

The elevated IMD distortion number results from detecting low frequency bias shifting. This is normal operation for this amplifier, and the placement of the energy at low frequencies makes them inaudible by masking effects.

Other IMD measurement techniques such as $2f1$- $f2$ indicates the excellent linearity of the class H output stage as shown in Figures 14 and 15 ($2f1$-$f2$).

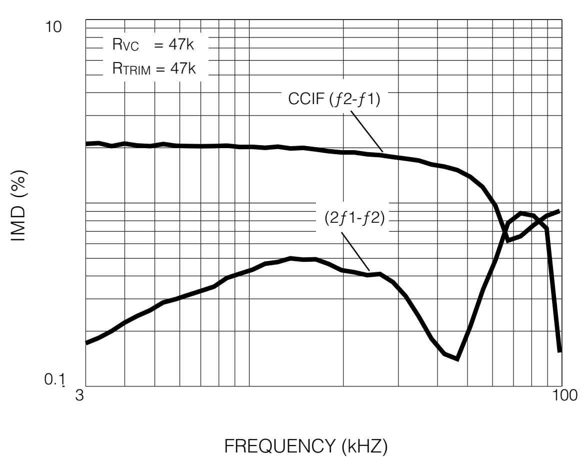


Fig. 14 IMD vs Frequency

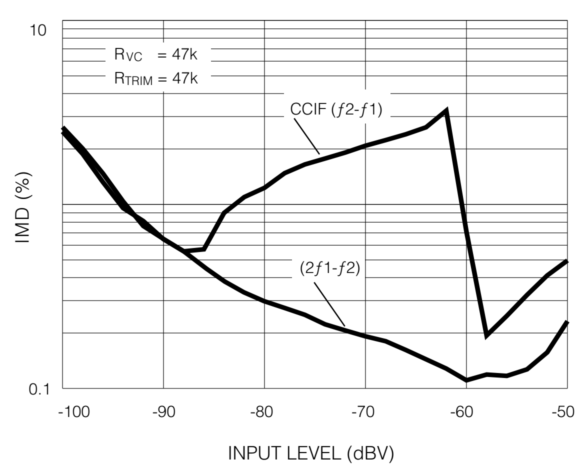


Fig. 15 IMD vs Input Level