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Concepts, Products, and Circuits for Audio • Analog / Digital

Audio System Level Diagrams

Application Note AN-6 **by Christopher Moore**

Introduction

As audio signals pass through a system, they negotiate a perilous course between the twin hazards of noise and clipping. A well designed audio product will carry out its processing without adding perceptible noise or distortion to the signal. Level diagrams can help designers achieve clean and quiet audio products by tracing a signal through the various stages to the output, calculating the signal and noise levels at each stage.

Why bother with level diagrams?

Even simple audio systems occasionally reach the marketplace with flaws in signal handling. The belated discovery that end users are connecting higher level sources than you anticipated and are overloading the input stage can hurt sales and be expensive to correct in the field. More complicated products, such as mixers, active crossover networks, and multimedia systems, whether implemented in analog or digital form, are especially vulnerable to these errors. By taking the time to construct level diagrams early in the project, you can expect to:

- accommodate the full range of sources
- understand and account for the many states your system can assume
- place the volume control where it belongs
- ensure adequate headroom throughout the signal path under all conditions
- keep the circuit noise below the required output noise floor
- determine the optimum order for the stages
- identify and define the requirements of gain control(s), limiters, and compressors
- modularize and define each block in the signal path, encouraging concurrent design

Example: preamp for multimedia codec

Let's look at a relatively simple audio system, a preamp that must condition signals from audio line level sources for presentation to a multimedia codec's ADC. The key specifications are:

- Sources can range from -20dBV (100mV) to +20dBV (10V) at maximum level.
- The ADC reaches full scale with a 0dBV (1V) input signal and is powered from 0 and +5 volts. It must not be driven beyond the power supply rails and does not achieve the theoretical 98dB noise floor that its 16 bit conversion would imply, with a noise floor at -84dB re full scale.
- The preamp must have a limiter to make it harder for the user to accidentally overdrive the ADC.

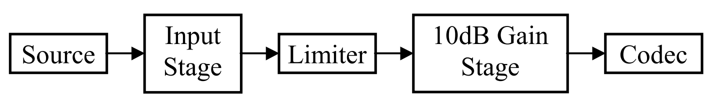
Our design philosophy dictates that the system must remain transparent to any source within the specified range of levels. This means that noise from all parts of the preamp, at any gain, must remain at least 3dB below the effective noise floor of the ADC, -87dBV here. Under no conditions should any stage clip before the ADC reaches full scale; i.e., the preamp must have adequate "headroom."

Initial design

The initial design indicates that the following blocks are required:

- input stage, with user adjustable gain from off to +20dB, input overload at greater than +20dBV, and output clipping point of +3dBV. The equivalent input noise voltage (EINV) of this stage varies with its gain, and is -122dBV when the gain is set to +20dB and --80dBV at a gain of -20dB.
- limiter, with gain of -1dB until its input reaches -10dBV, after which it operates at a slope of 10:1 (10dB of input increase results in only 1dB of output increase). By the time the input to the limiter has risen to 0dBV, its gain has dropped to -10dB. Output clipping occurs at +3dBV. The limiter's equivalent input noise is -120dBV at a gain of -1dB and -113dBV at a gain of -10dBv. The limiter is operated with a loss so that the momentary output overshoot before gain reduction occurs will not be clipped.
- 10dB gain stage to make up for the loss in the limiter. Its output clipping point is +3dBV, and the EINV is -123dBV.

All stages are powered from 0 and +5 volts, providing the input overload protection required by the codec.



System Block Diagram

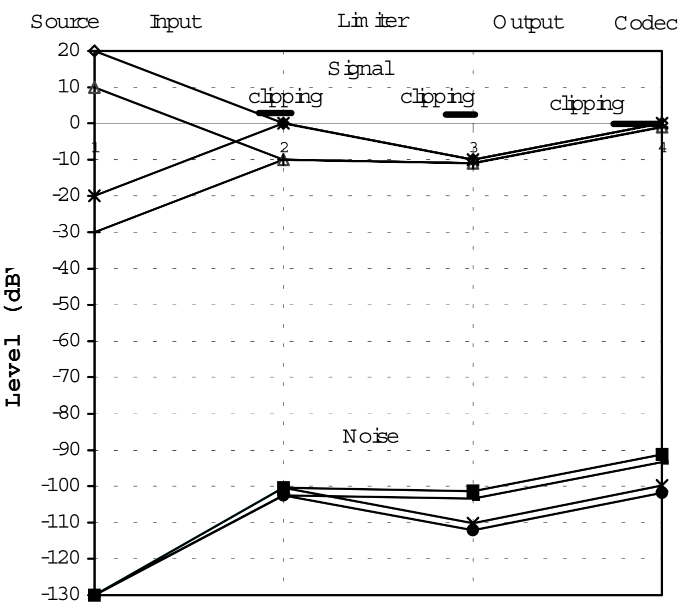
Spreadsheet creation

Our level diagram is implemented as an Excel spreadsheet for convenience in exploring various scenarios and for graphing assistance. There are columns for the source and for the input, limiter, and gain stages. There are rows for stage gain, stage output signal level, stage EINV, and cumulative output noise level. To create various scenarios, you copy the basic block and edit the source level, stage gain, and stage EINV data cells. The stage output level row gives the signal level from the source on through to the output of the last stage, which is the signal presented to the codec input. The output noise level row shows the noise as it builds up passing through each stage.

While the stage clipping levels are not accounted for in the spreadsheet, you can inspect the output level row to be sure they have not been exceeded. You could always expand the spreadsheet to detect clipping.

Discussion of results

Four scenarios of signal level and gain setting are sufficient to probe how this system will handle the highest and lowest expected source levels and how the limiter will work over its active range. Referring to the level diagram, we note that we can attenuate the highest level signal without overload and present it to the codec at full scale, with noise below the codec's noise floor. We see that with the gain set for the highest signal level, the limiter takes 9dB out of the top part of the source dynamic range.



Level Diagram

Shows progression of signal and noise from source through three stages to codec input, under four scenarios.

Reducing the source level to the minimum anticipated level, -20dBV, we raise the gain of the first stage and note that we again can present the codec with a full scale signal, with the limiter working at 9dB gain reduction, and with noise still below the codec's noise floor.

We can also deduce that, with the gain set for a +20dBV source, a source exceeding +20dBV will first cause clipping in the codec itself, then in the output of the input stage. There is headroom everywhere, and the codec is the system limit. Similarly, with the gain set for the lowest expected source, -20dBV, the codec's own noise dominates.

Noise computation

To find the stage EINV, set the gain to the desired value and use noise analysis methods to solve for the output noise. Then reflect that noise back to the effective input point (including any gain controls that may have been lumped with the stage), modifying its level by the effective signal gain of the stage. This permits the noise to be treated by the same stage gains as the signal.

To find the noise output level of a stage, add the noise carried forward from the prior stage to the EINV of this stage by an rms sum, then apply the stage gain.

More difficult situations

This technique becomes less obvious and more demanding when some of these situations crop up:

- there is a wide variety of sources, varying in level, dynamic range, and impedance
- stages that mix multiple sources
- stages with non-flat response
- stages where internal nodes may exhibit signal levels greater than the input or output, as in sharp cutoff elliptic filters
- stages with a limiter, compressor, or noise gate
- situations where the output is sent to an acoustic transducer and is heard under varying ambient noise conditions
- digital implementation, where quantization noise, finite resolution of data and coefficients, redithering, and other factors must be considered
- channels such as magnetic recording and perceptual coders that introduce noise related to the source itself

Conclusion

The construction of a level diagram early in the design process puts the designer on the right track. It will help him define circuit modules, consider the variety of sources, create user application scenarios, and test proposed designs against the total system requirements. Level diagrams will help designers get the product right the first time, saving time in the product development cycle.

Mission statement of Seven Woods Audio

I am an electrical engineering consultant specializing in the conception and design of products and circuits used in audio applications. My company, Seven Woods Audio, is committed to helping manufacturers quickly create digital or analog audio products that generate a good return on investment, work right the first time, sound excellent, and please the end user. Seven Woods Audio works with manufacturers of professional audio, consumer audio, broadcast, telecommunications, and computer equipment.

SEVEN WOODS AUDIO, Inc.

Concepts, Products, and Circuits for Audio • Analog / Digital

44 Oak Avenue Belmont, MA 02478-2715 USA

voice/fax 617 489 6292

SevenWoodsAudio@compuserve.com

http://www.world.std.com/~cmoore/