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Naim Discrete Regulator

DESIGN, ENGINEERING AND TECHNOLOGY

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Objective

To design a discrete-component voltage regulator whose technical performance and enhancement of the sound quality of Naim audio circuits surpasses that of commercial three-terminal monolithic voltage regulators.



The new Naim Discrete Regulator

Overview

Naim has long recognised the importance of power supplies to sound quality and paid meticulous attention to optimising power supply design in its products. The addition of outboard power supplies additionally offers an established upgrade path for many Naim products, enhancing sound quality by improving the supplies themselves, by removing the electromagnetic field of the transformer and interference generated by the rectifier diodes, and by eliminating transformer vibration from the product case, so it cannot affect the circuitry. Voltage regulators are widely deployed – sometimes in series for enhanced performance – to ensure that our audio and digital circuits operate with a stable, low noise supply voltage, thereby maximising their performance.

A voltage regulator is an electronic device designed to maintain a constant DC output voltage regardless of fluctuations in its supply voltage and variations in current draw from its output. An ideal voltage regulator would add zero noise and have zero output impedance – but all practical voltage regulators

generate finite output noise and show some transient variation in output voltage if current demand changes suddenly. In developing the Naim Discrete Regulator we have created a discrete-component regulator that betters industry standard monolithic voltage regulators in these respects and, even more importantly, has had its design and component selection refined in the listening room to deliver maximised sound quality from Naim's audio circuits.

Products

Naim Discrete Regulator will initially be used in the following five products:

- 555 PS
- 552 PS
- SuperCap
- XPS
- HiCap

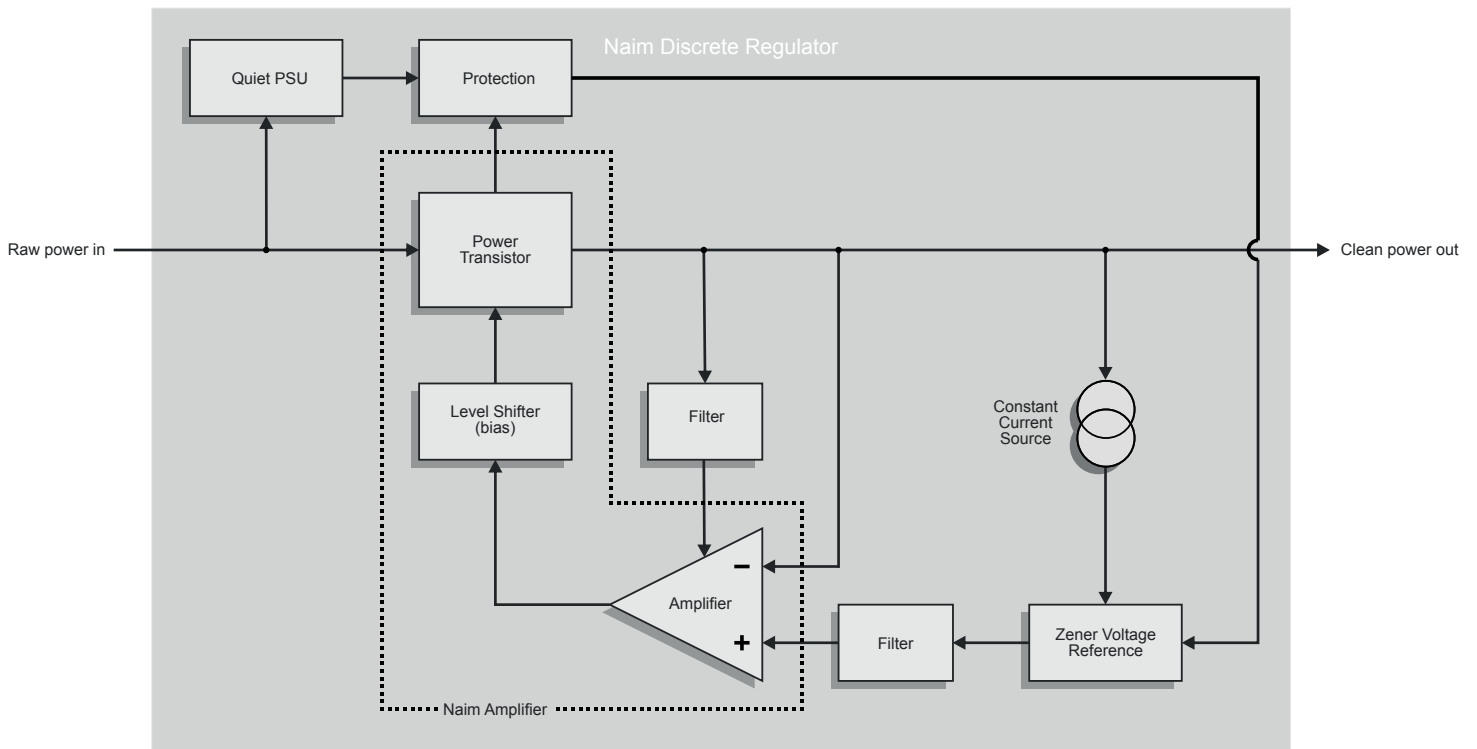
Circuit topology

The simplified circuit topology of the Naim Discrete Regulator is shown in the block diagram of Figure 1. A regulator circuit of almost this form was first used in the NAP 500 power supply, since when the concept has been further refined by incorporating an enhanced voltage reference. This topology, which was benchmarked against various alternatives and refined over a two year period, has proven itself to be inherently low noise and capable of fast recovery to transient current demands. It also has the advantage that it works equally well for both positive and negative supply rails.

Circuit overview

Naim Discrete Regulator is a series regulator, with a power transistor as the series regulating device. Output from the power transistor is monitored at the inverting input of a differential amplifier which is configured, like the subsequent stages, much like a Naim power amplifier. This provides the negative feedback by which the Naim Discrete Regulator exerts tight control over the output voltage. Connected to the amplifier non-inverting input is the voltage reference, which is fed, via a constant current source, from the regulator output rather than the regulator input, to ensure as stable and low noise a reference voltage as possible.

Block diagram of the Naim Discrete Regulator



Voltage reference

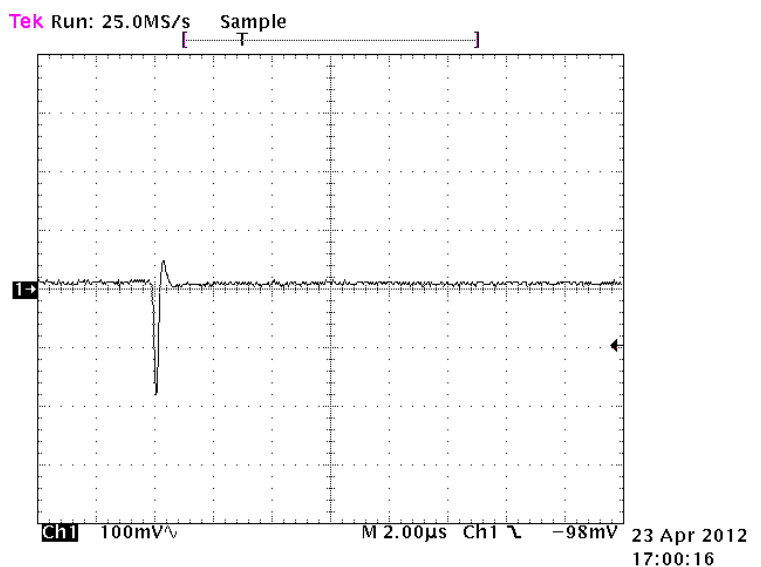
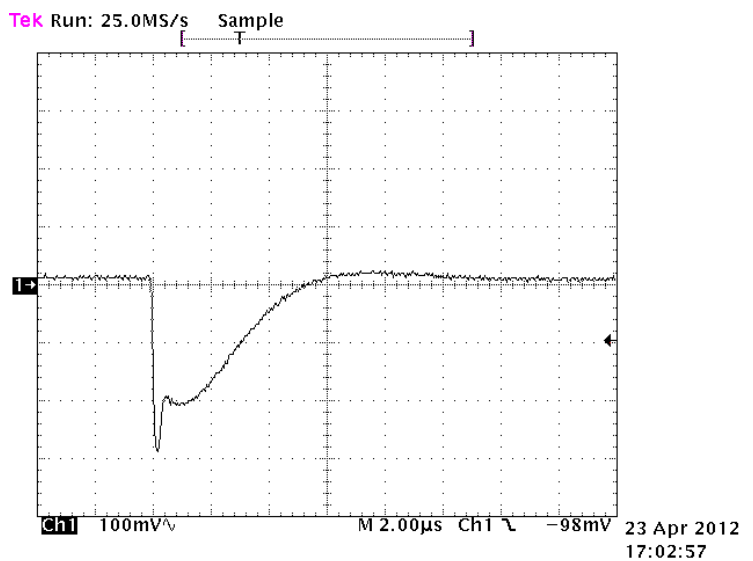
At the heart of every voltage regulator is a voltage reference that should be as clean and as constant as possible since any noise or other fluctuations in the reference will be carried through to the regulator output. Naim Discrete Regulator uses a 6.9 volt 'subsurface' zener diode in this role, a type which is more accurate and more stable than conventional surface zeners because the breakdown region is formed below the silicon surface and covered by a protective diffusion. This isolates it from the impurities, mechanical stresses and crystal lattice dislocations at the surface which have the effect of increasing noise and reducing long-term stability. Additional components within the zener package decrease its dynamic impedance and provide temperature compensation to ensure that it always provides a constant reference voltage.

Constant current source

The performance of the voltage reference is enhanced in two ways: by powering it from the 'clean' output of the regulator rather than the 'dirty' input (a technique known generally in electronics as bootstrapping) and by incorporating a two-transistor constant current source in place of the resistor more typically used. Together these features isolate the zener from the ripple and noise in the regulator input voltage, thereby keeping the reference voltage – and the regulator output voltage that depends on it – clean and stable.

Filter

Despite these measures there is still inherent noise within the zener reference voltage, which the Naim Discrete Regulator attenuates before it reaches the amplifier stage by means of two-stage RC (resistor-capacitor) filtering. The first stage of filtering has a low corner frequency to provide wideband noise suppression, the second stage a higher corner frequency to enhance the removal of RF (radio frequency) noise. Although this filtering adds its own noise because of the thermal (Johnson) noise of the series resistors, extensive listening tests have established that sound quality is improved with the filtering in place. Even with this additional noise contribution the Naim Discrete Regulator's output noise remains extremely low.



Transient performance comparison of the old regulator circuit (top graph) and Naim Discrete Regulator (bottom graph), showing the change in output voltage when a load current of 0.65A is suddenly applied (rise time 250ns). The much faster settling time of the Naim Discrete Regulator is obvious

Amplifier

The role of the amplifier is to compare the reference voltage on its non-inverting input with the regulator output voltage on its inverting input and, if there is a disparity, generate an error signal that brings the output voltage back to the desired value. For this part of the Naim Discrete Regulator a modified version of Naim's power amplifier circuit is used, incorporating those changes necessary for its different role here. Common features are a long-tailed pair input stage with a two-transistor constant current source in its 'tail' to enhance common mode rejection ratio

(ensuring that it amplifies only the difference between the reference voltage and the regulator output voltage) and a single, common-emitter connected transistor with an active load that provides most of the open-loop voltage gain. Differences include the output stage where, because the output is DC rather than AC, a compound follower replaces the power amplifier's quasi-complementary push-pull arrangement. Also unlike a power amplifier, a voltage regulator has to be able to drive large capacitors on its output so nested feedback loops are used to enhance stability.

The third principal difference is that standing currents in the first and second amplifier stages are reduced in the regulator circuit as this improves performance.

Protection circuit

A protection circuit monitors the regulator and shuts it down, via the zener voltage reference, if too much current is drawn (in the unlikely event, for instance, of a short circuit on the output) or if the regulator's temperature exceeds 70C. The protection circuit is powered by its own 'quiet' power supply and is designed to draw very low current, so minimising the load on the unregulated supply that feeds the regulator.

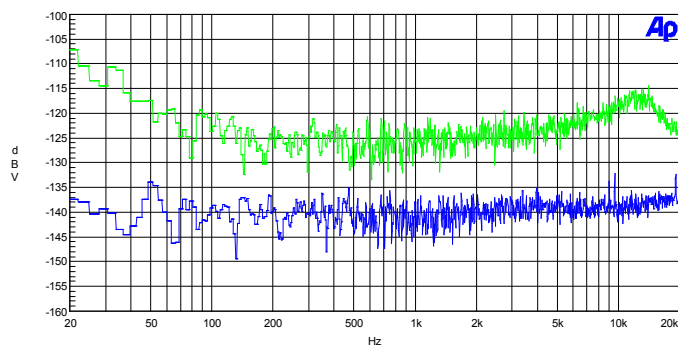
Component selection

As in all Naim circuits, the components used in Naim Discrete Regulator were carefully selected to optimise performance in listening tests. The compensation capacitors in the amplifier stage are polystyrene types, just as used in our high-end amplifiers; the filtering capacitors are film types, not microphonic ceramics; the decoupling capacitors are tantalum electrolytics not aluminium electrolytics; and while extensive use is made of surface-mount components, the critical feedback resistor in the amplifier stage is a selected through-hole type.

Conclusion

Significant as it is, the Naim Discrete Regulator is just one part of a Naim power supply, so we have reviewed and optimised every aspect of the products into which it has been incorporated. Transformer mounting, wire gauge, wire routing, mechanical decoupling, internal layout and reservoir capacitors have all been scrutinised to ensure that the Naim Discrete Regulator's benefits are fully realised. The result is a demonstrable upgrade in sound quality.

Audio Precision FFT SPECTRUM ANALYSIS 04/23/12 15:00:19



Sweep	Trace	Color	Line Style	Thick	Data	Axis	Comment
1	1	Green	Solid	1	Flgen.Ch.1 Ampl	Left	
3	1	Blue	Solid	1	Flgen.Ch.1 Ampl	Left	

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Wideband noise spectra, 20Hz-20kHz, of the outgoing HiCap (green trace) and the latest HiCap fitted with the Naim Discrete Regulator (blue trace). The midband improvement is about 15dB (5.6x) with still larger improvements at low and high frequency

Power transistor

A power transistor is used as the regulator's series control element. As it carries the full load current, it must have both current and power capability sufficient for the circuits it will power and is mounted on a small extruded aluminium heatsink to assist heat dissipation. A thick ceramic spacer is used between the power transistor and the heatsink to reduce the stray capacitance between the two, thereby improving their electrical isolation, without compromising heat conduction.