



APEC 2013

CogniPower Predictive Energy Balancing for Switched-Mode Power Amplifiers

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Predictive Energy Balancing Controls

Predictive Energy Balancing (PEB) is a control method for switched-mode power conversion that allows each control cycle to be completely self-contained.

That, in turn, allows the theoretical best transient response while maintaining intrinsic stability.

The familiar tradeoffs between agility and stability do not apply when using PEB.

We begin with a quick summary of how PEB works.



PEB Provides Intrinsic Stability

Predictive Energy Balancing effectively removes the output filter pole from the feedback path by employing prediction.

The result of an inductive energy transfer can be calculated before the switching decision is made, eliminating the filter delay from the decision.

The math, based on the fundamental energy equations, can be done real-time in analog or digital fashion.

Take the flyback case, which is the simplest.

The Underlying Energy Formulas:

The kinetic energy held in an inductor, **L**, is

$$\mathbf{KEL} = (\mathbf{I}^2 \times \mathbf{L}) / 2$$

where **KEL** is inductive energy in joules, **I** is current in amps, and **L** is inductance in henries.

The kinetic energy held in a capacitor, **C**, is

$$\mathbf{KEC} = (\mathbf{V}^2 \times \mathbf{C}) / 2$$

where **KEC** is capacitive energy in joules, **V** is voltage in volts, and **C** is capacitance in farads.

The Energy Balance Equation

At the regulation voltage, V_{reg} , the energy in joules held in the output filter capacitor, C , will be

$$KE_{Reg} = (V_{reg}^2 \times C) / 2$$

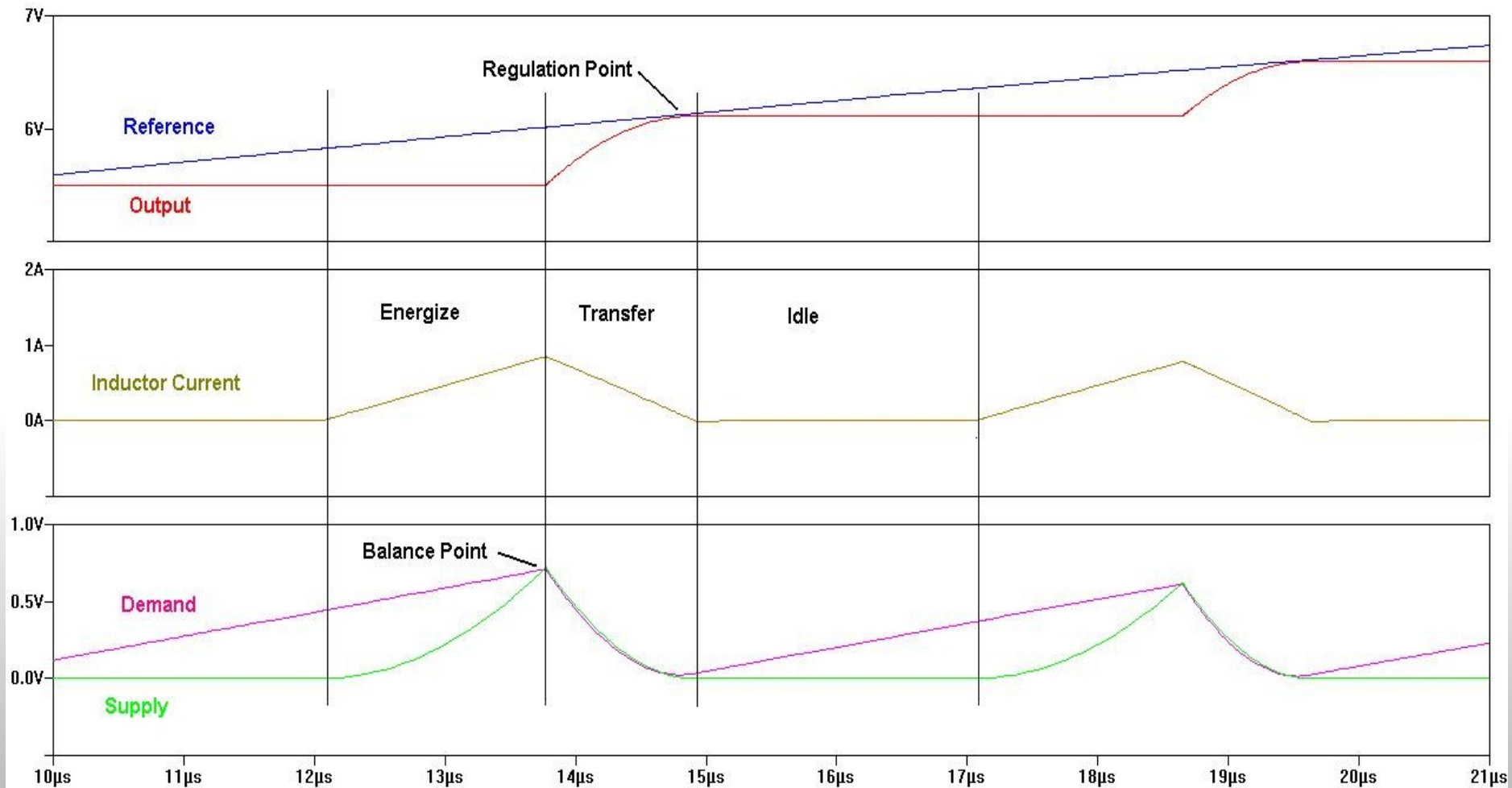
Therefore, the capacitive energy deficit at the output, $Demand$, is the energy at regulation minus filter energy

$$Demand = KE_{Reg} - KE_C$$

The energy balance point is the moment when the energy supply, KE_L , is equal to the capacitive energy deficit

$$KE_L = Demand$$

SPICE Waveforms



The balance point is when supply and demand meet.

PEB Control Loops Show Intrinsic Stability

With the balance properly scaled, the voltage on the filter capacitor will equal the regulation voltage after the inductive energy transfer completes.

Both the **Supply** term and the **Demand** term will be approximately zero at that point in time.

Each control cycle becomes a self-contained operation, not reliant on previous conditions or clock rate.

Excellent transient response, without sub-harmonic behavior, is the direct result.

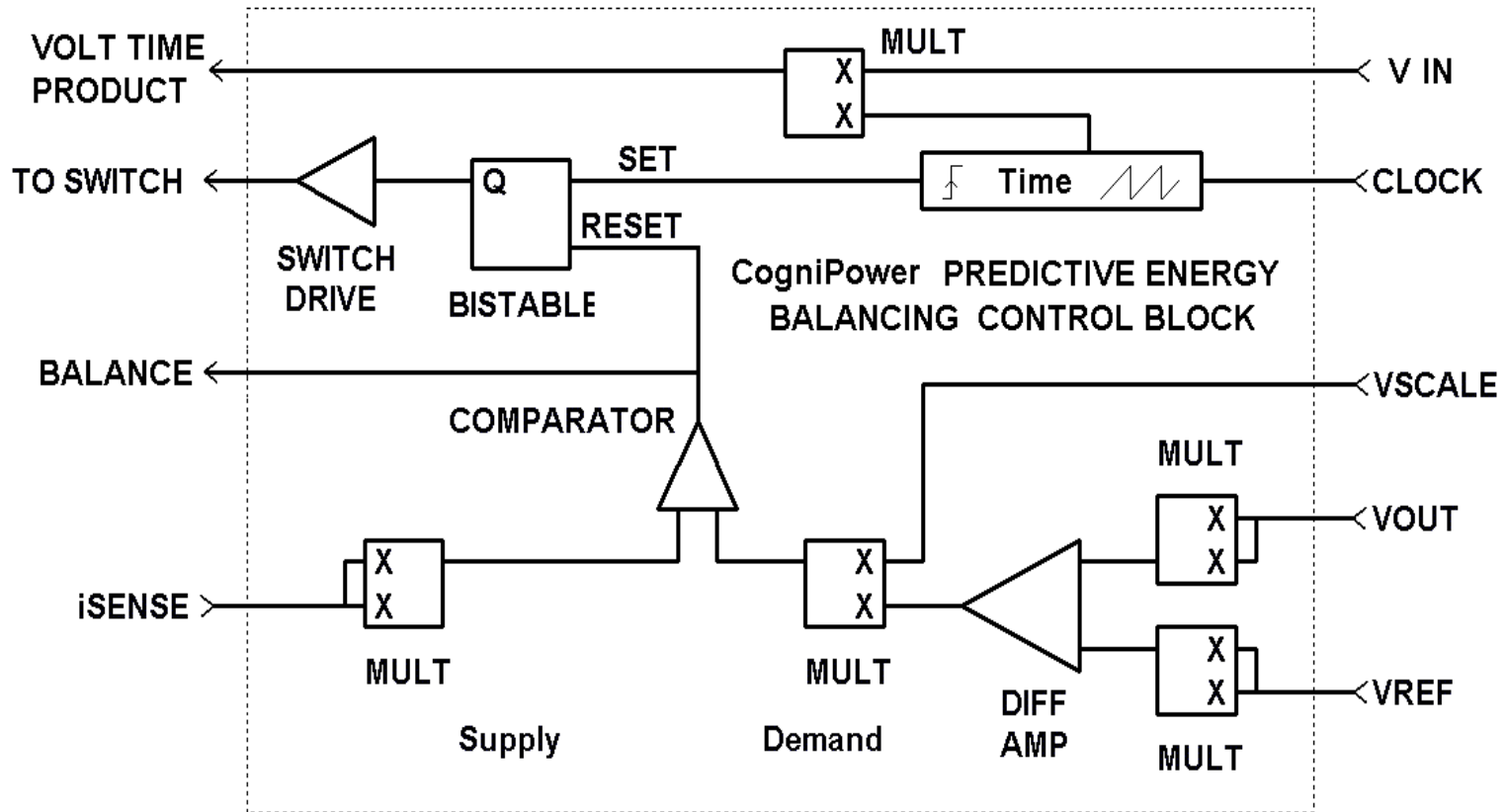
Practical Demonstration

This demonstration board, introduced at APEC 2011, is a simple flyback PEB converter producing 5 volts from a 1.5 volt battery.

The additional circuitry (red outline) added to implement PEB occupies about 0.2 square inches.

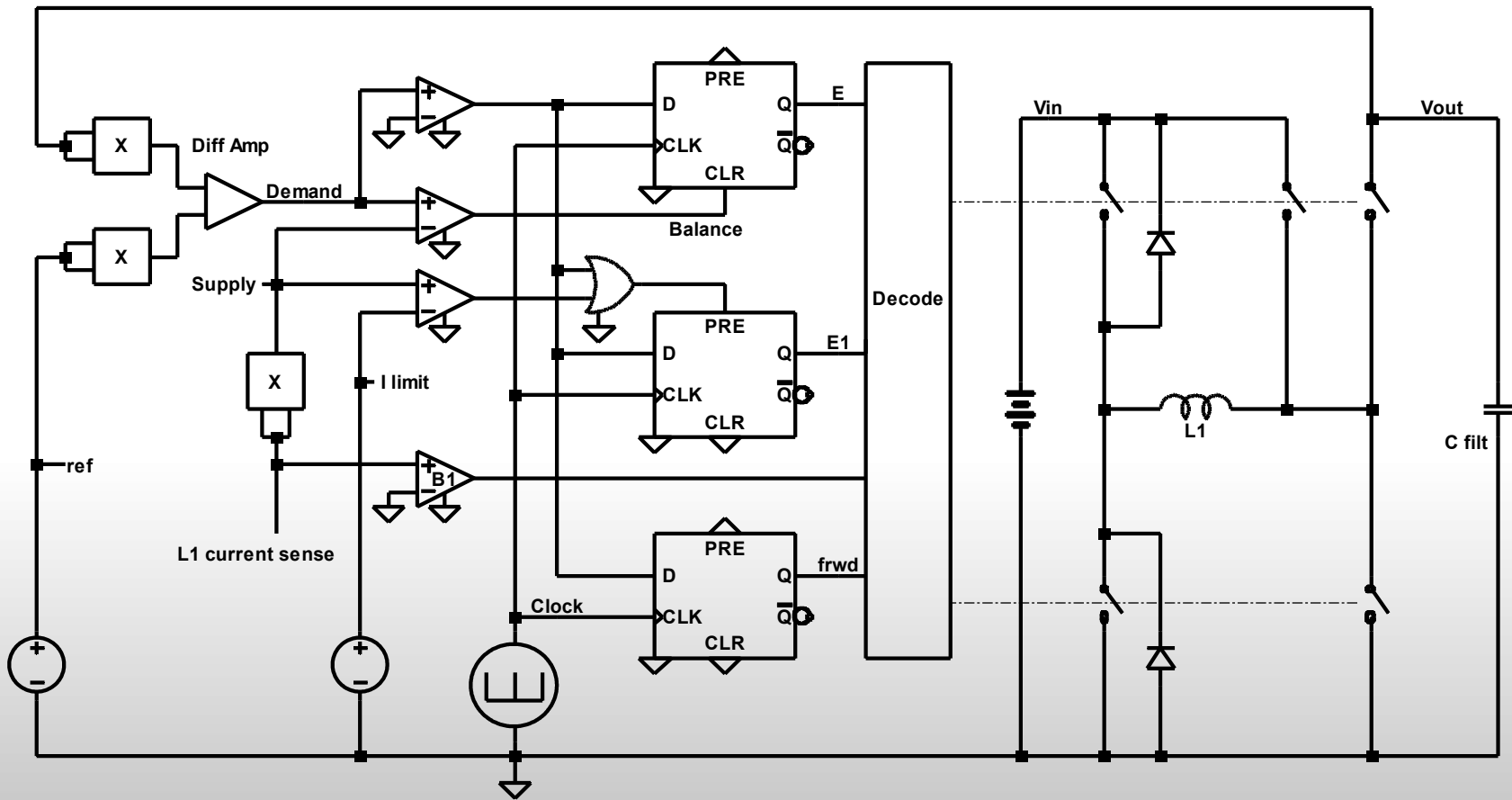


Control Block for PEB SMPC or Amplifier



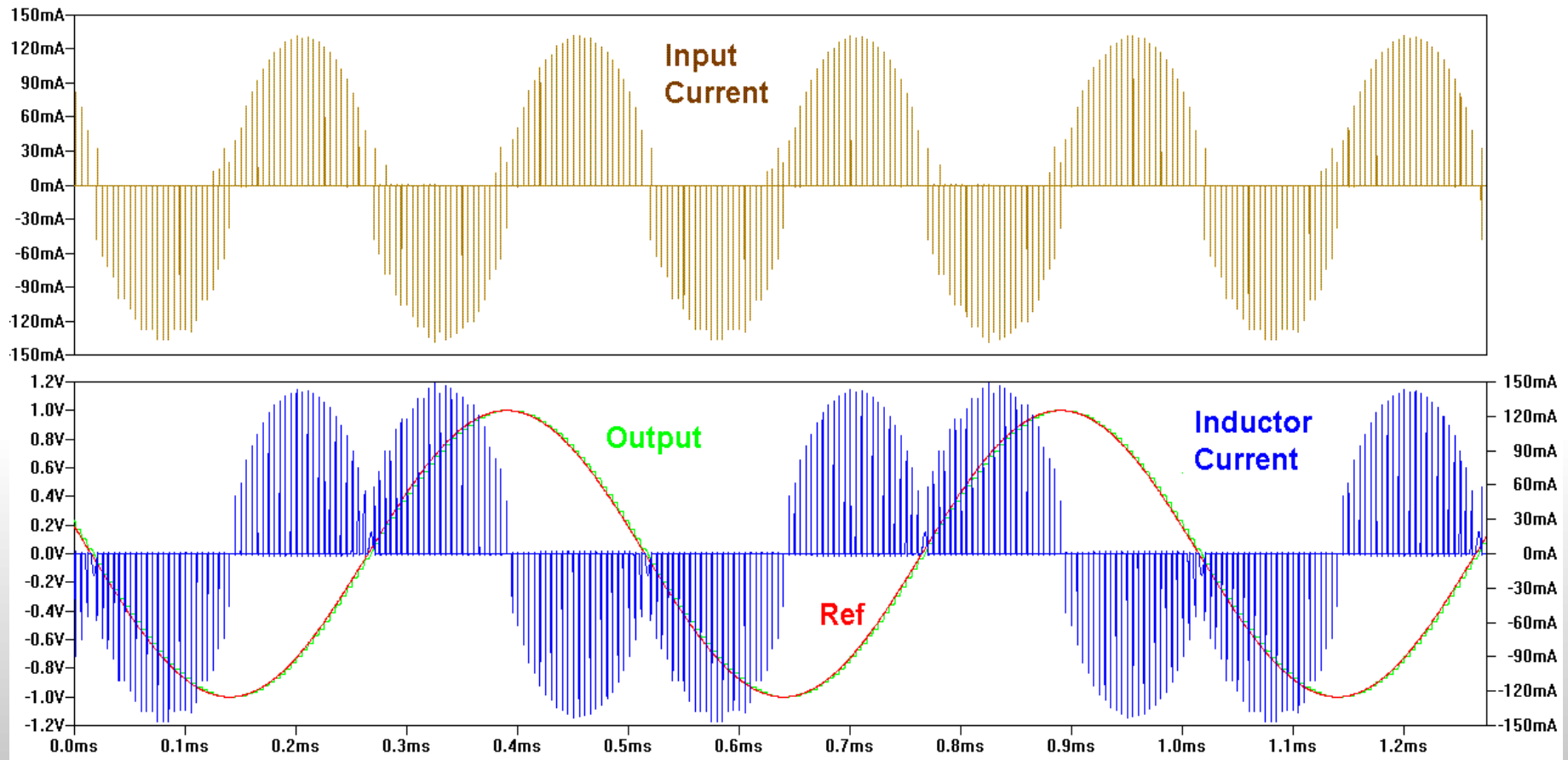
A volt time product can replace a sensed inductor current.

Bipolar, Bidirectional Power Amplifier



An SMPC that can follow a changing reference is a form of amplifier.

Power Amplifier SPICE Output



A bipolar output is generated from a unipolar input.

Switched-Mode and Fully Feedback

Energy is moved from input to output when the output magnitude increases.

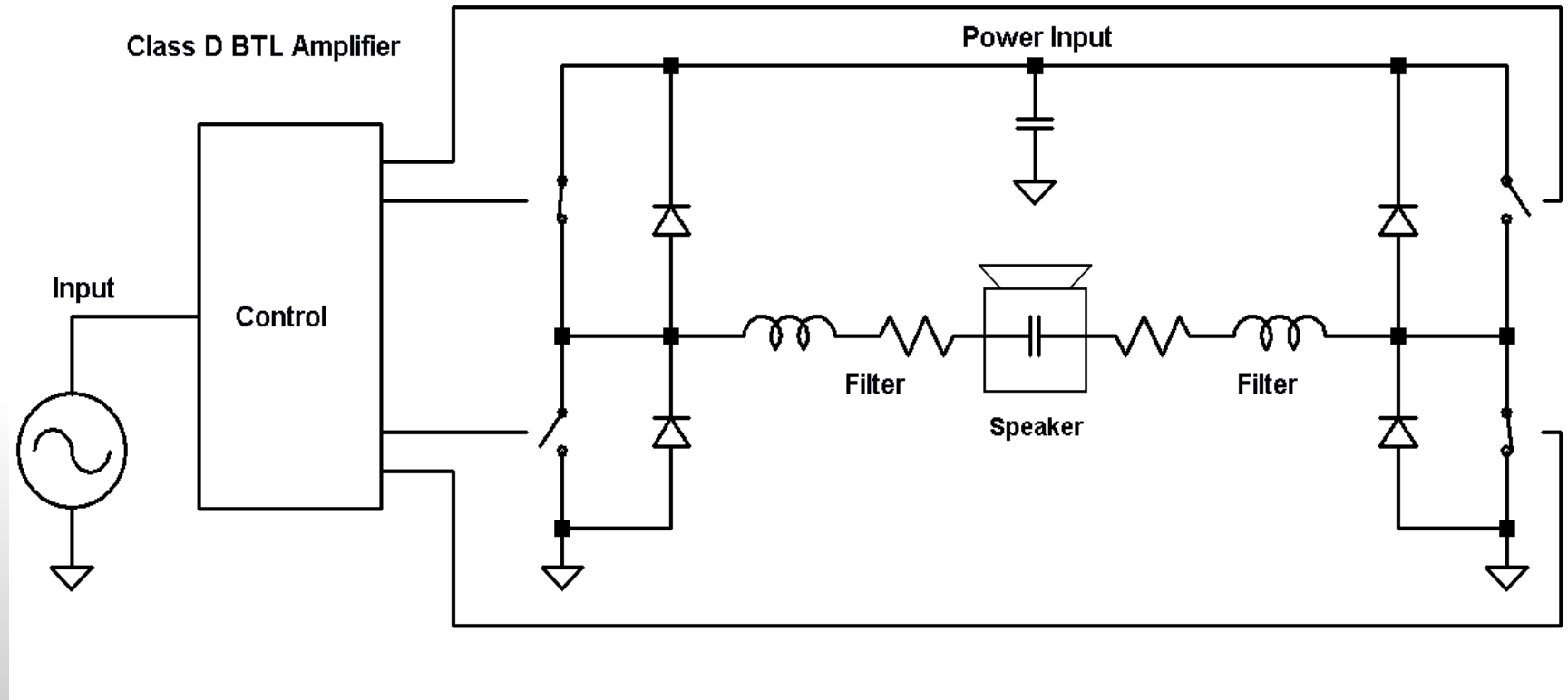
Energy is moved from output to input when the output magnitude decreases.

Note that the average current at the power input approaches zero when driving a capacitive load (as in the previous slide).

The PEB amplifier has the efficiency of a switched-mode amplifier with the distortion of a linear amplifier.

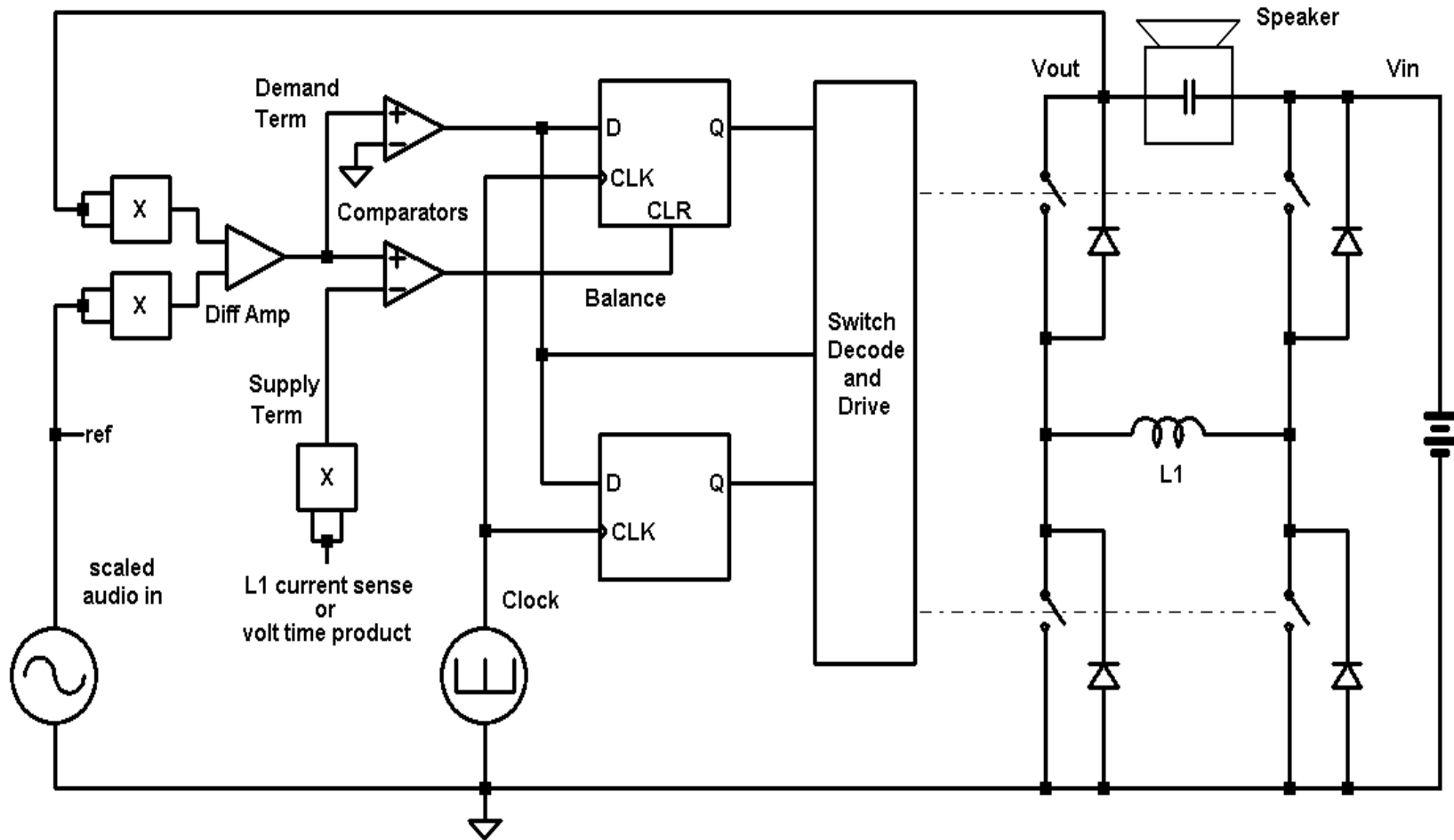
Output voltage swing is not limited by input voltage.

Piezo Speaker Class D Audio Amplifier



Here is a typical bridge-tied load amplifier for cell phone audio.

PEB Audio Amplifier as an Alternative



What is the Difference?

One small switched inductor replaces two large filter inductors and two filter resistors.

Direct voltage feedback becomes possible.

The Result:

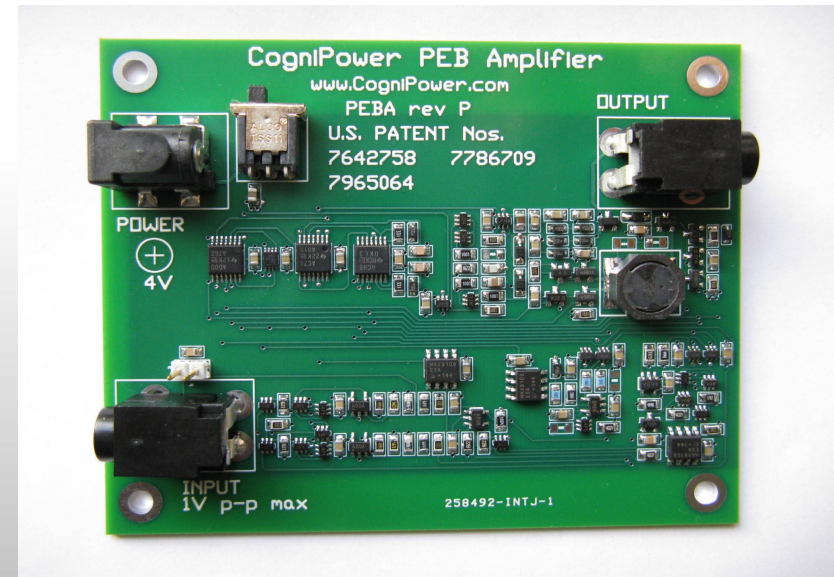
Lower distortion

Higher efficiency

Smaller size*

Lower cost*

*after integration



PEB Amp Demo Board

PEB Cell Phone Audio Amplifier Advantages

The audio amp efficiently produces AC output from a single, unregulated power rail.

Total Distortion has been measured at under 0.1%.

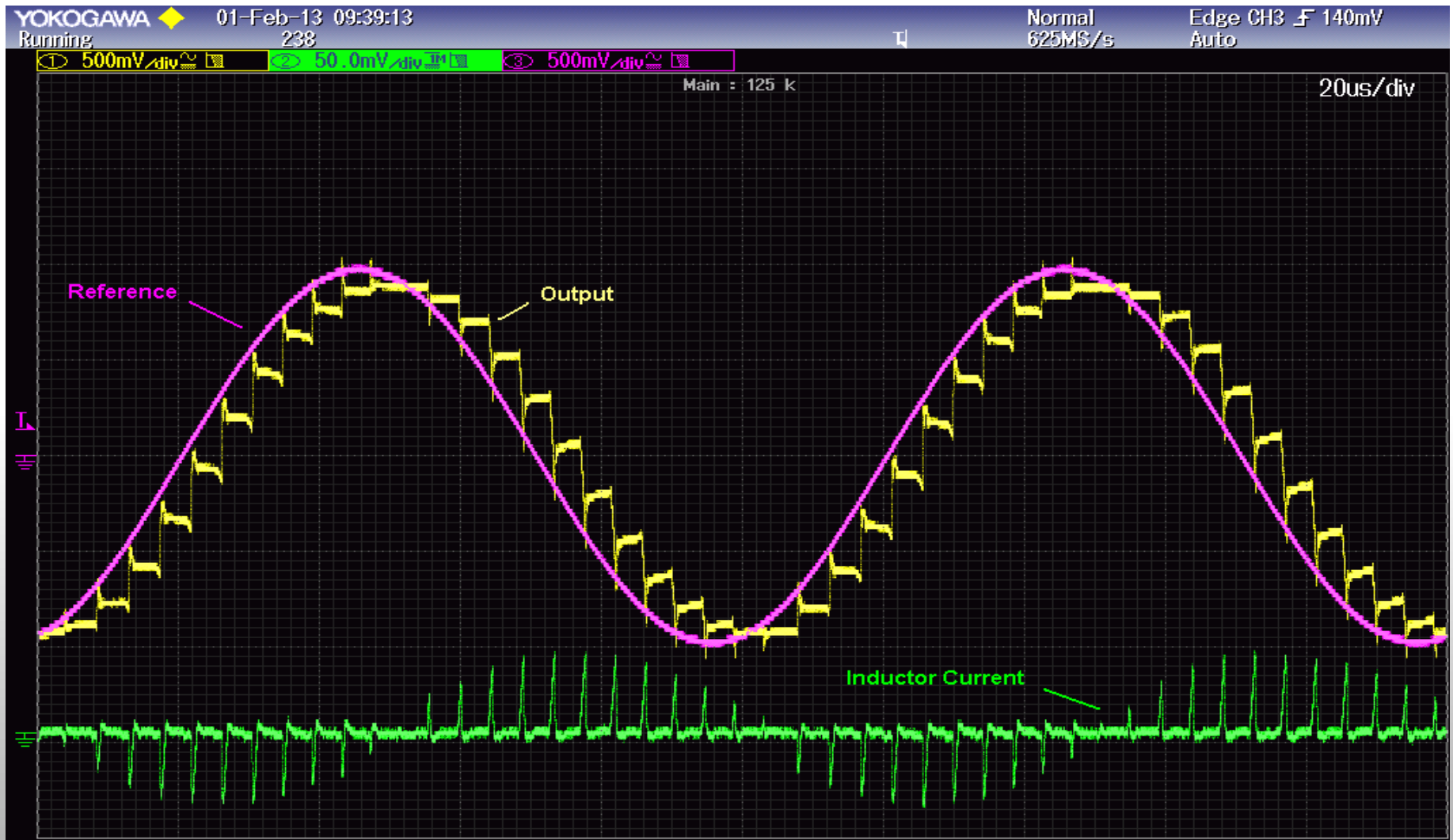
Deadtime and filter non-linearities are inside the feedback loop.

Clock rate can be $\frac{1}{4}$ that of Class D for similar fidelity.

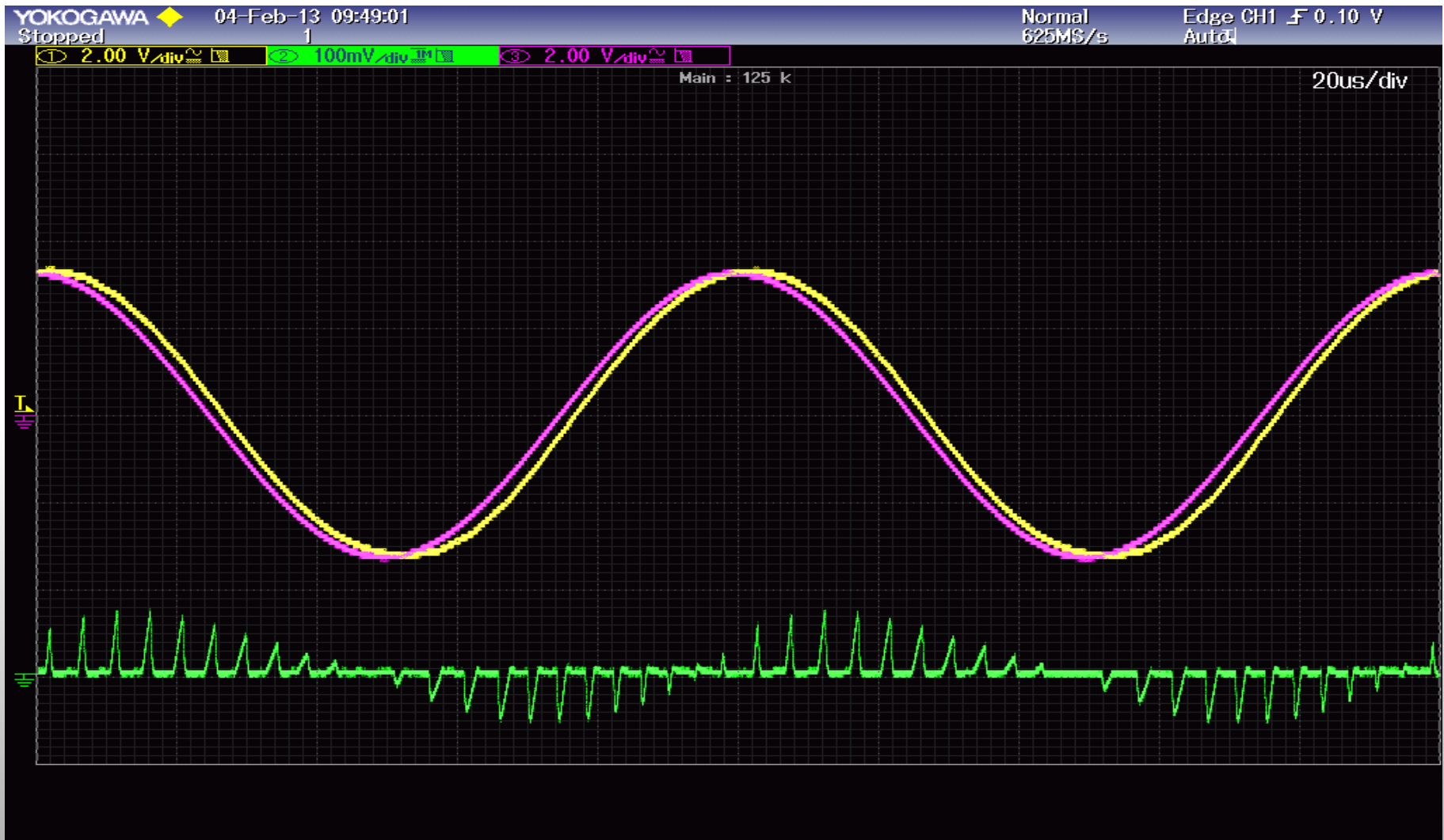
Self-termination flattens the response curve, even with a piezo speaker having a strong resonant peak.

A PEB bidirectional amplifier can harvest ambient energy from the speaker for charging the battery.

PEB Audio Amplifier Screenshot, 2V, 10kHz



Filtered PEB Amp Screenshot, 6V, 10kHz



PEB vs Class D BTL Comparison

	<u>PEB</u>	<u>Class D</u>
Fully feedback	Yes	No
Step-up voltage	Yes	No
Drive piezo speakers	Yes	with resistor
Adaptive clocking	Simple	Complex
Self-terminating	Yes	No
Smaller inductor	Yes	No
Non-critical dead time	Yes	No

Other PEB Applications

DC/DC Converters

DC/AC Converters

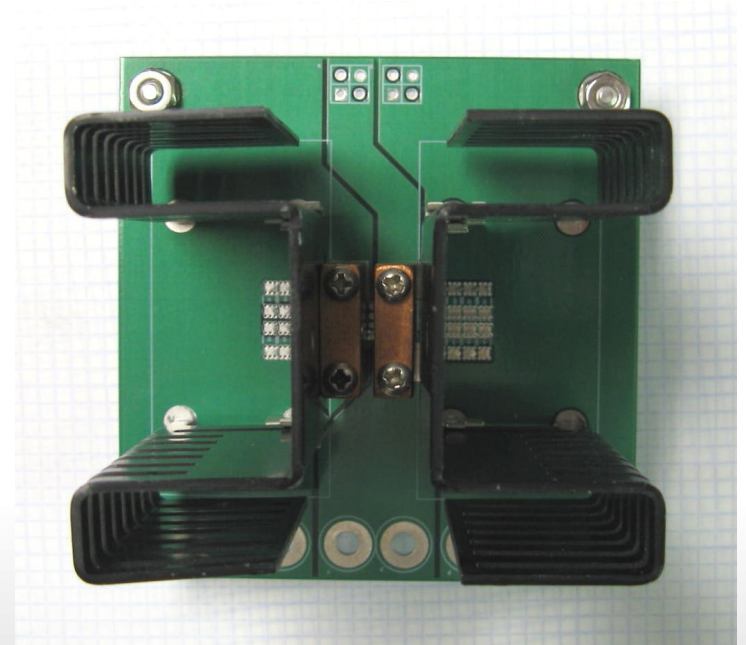
Motor Drives

Envelope-Tracking

Hearing Aids

Non-volatile Memory Power

Computer SMPS for aggressive power management



1 kW Totem Pole Switch

Summary

CogniPower holds six issued patents, including three fundamental patents covering Predictive Energy Balancing.

The PEB Amplifier is covered by four issued patents.

Many more patents are in process for SMPC building blocks, controls, and topologies.

Predictive Energy Balancing enables more capable power converters that combine stability, agility and efficiency.

Various prototypes and demonstration systems, from 50 mW to 1 kW, have been built and tested.

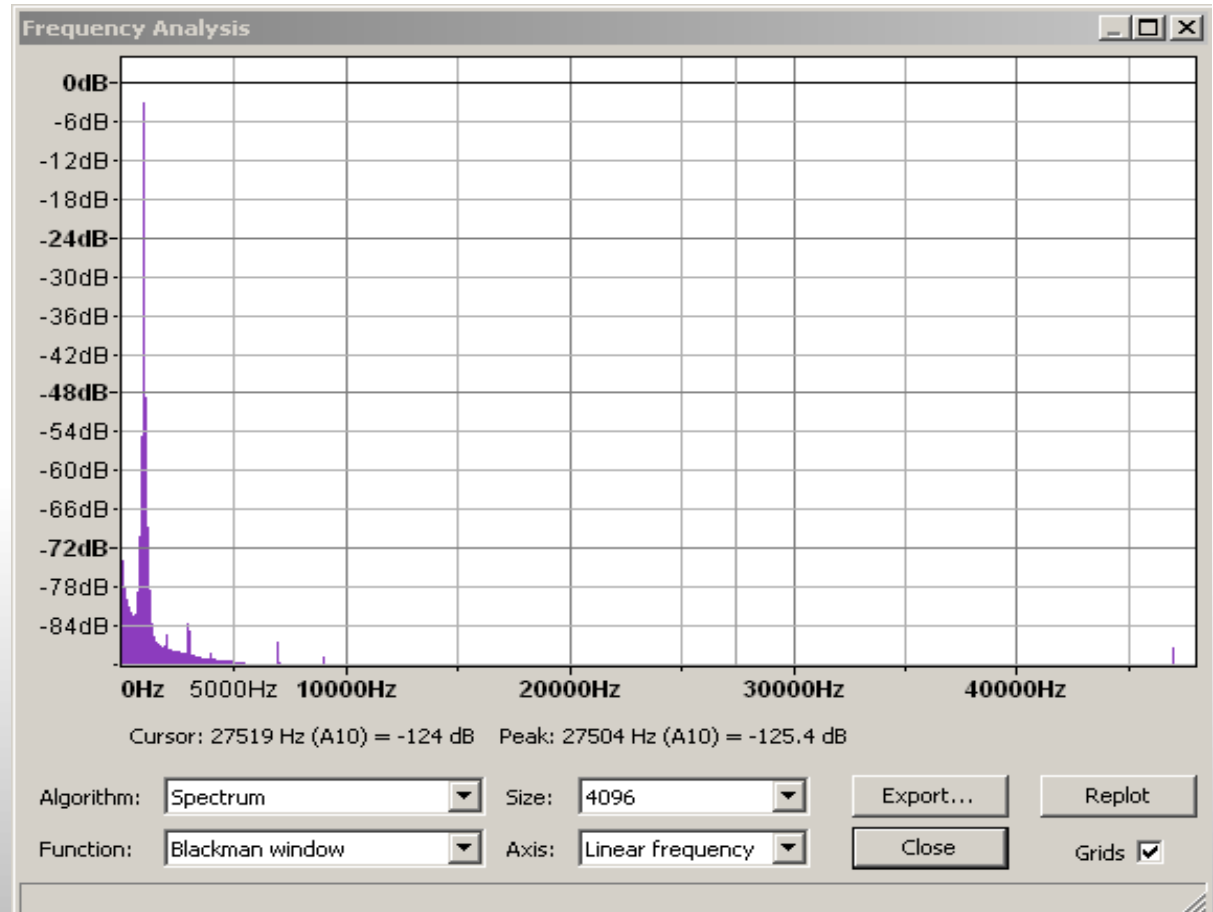


Questions?

Opportunities exist for licensing, strategic alliance, or sale of IP.

Come see a live demonstration in Booth #122.

Thank you.



www.cognipower.com

PEB Amplifier 1 kHz FFT

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