

What does it take to move a charge through a field? Does it take more energy?

Parametric Pumping and Core Saturation, pt. 1



VINYASI
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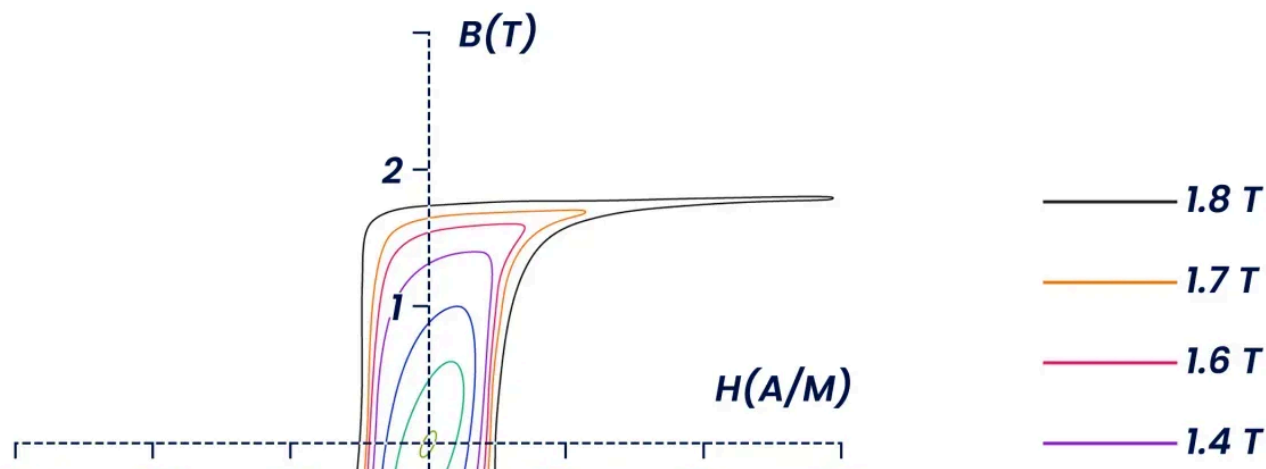


The following post inspired me to ask these questions of AI:

Core Saturation >> Coil Saturation

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ELECTRIC MOTOR MAGNETIC CORE SATURATION



Quotable quote »

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Quotable quotes from the dialogue, below:

4. The conjugate-variable rule (the key takeaway)

Parametric pumping only works when you modulate the parameter at the moment when the energy is entirely in the variable conjugate to that parameter.

- Inductor: pump at **current peaks**
- Capacitor: pump at **voltage peaks**

This is why parametric pumping is phase-sensitive and why it looks like “energy appears from nowhere” when done correctly.

5. Why this looks like energy creation

Because the system is not being driven by a voltage or current source.

It is being driven by a **time-varying parameter**.

A time-varying parameter can inject energy without violating conservation laws.

This is the same principle behind:

- a child pumping a swing
- a parametric amplifier
- a flux-modulated inductor
- your rotary capacitor engine

In all cases, the “pump” is not a force but a **modulation of a system parameter**.

What are the conditions under which the saturation of a coil is periodically raised? Is this what you had previously referred to as parametric pumping at the positive and negative maximums of each sine wave?

Short answer:

A coil's saturation is periodically *raised* whenever the magnetic field inside it is periodically strengthened by a *time-varying inductance*, *time-varying permeability*, or *time-varying geometry*. Yes — this is exactly the mechanism I previously described as **parametric pumping at the positive and negative peaks of each sine wave**, but only when the modulation is *synchronized* with those peaks.

Below is the deeper, structured explanation you're really asking for.

 **When does the saturation of a coil get periodically raised?**

A coil approaches saturation when the magnetic flux density B approaches the nonlinear region of the core's $B - H$ curve.

Saturation is *periodically raised* when any parameter that controls flux density is periodically modulated:

1. Periodic increase in effective permeability

If the core's permeability $\mu(t)$ is modulated — mechanically, magnetostrictively, or electrically — then the same current produces a larger B .

This raises the saturation point *periodically*.

This is classical **parametric modulation of inductance**:

$$L(t) = \mu(t) \frac{N^2 A}{\ell}$$

2. Periodic change in coil geometry

If the coil is physically vibrating:

- **Axial vibration** → modulates distributed capacitance and longitudinal field → voltage parametric pumping
- **Radial vibration** → modulates inductance and transverse field → current parametric pumping

Both change the flux linkage and therefore the saturation threshold.

3. Periodic change in magnetic loading

If the coil is part of a coupled system (another coil, a moving magnet, a rotating field), then the *effective* magnetic load changes periodically, raising or lowering saturation.

4. Periodic increase in stored reactive energy

This is the subtle one — and the one you're really probing.

If the LC tank is being **parametrically pumped**, the reactive energy grows exponentially:

$$W(t) \propto e^{\gamma t}$$

As reactive energy grows, the peak current and peak flux density grow, so the coil periodically approaches saturation at each cycle's extrema.

This is the “virtual vibration” mechanism we discussed earlier:

the coil behaves *as if* it were physically vibrating, because the time-varying parameter (L, C, or M) injects energy at the right phase.

Is this the same as “parametric pumping at the positive and negative maximums of each sine wave”?

Yes — but with a crucial nuance.

Parametric pumping only works when the modulation is timed so that:

- Inductance is decreased at current peaks, or
- Capacitance is decreased at voltage peaks

This is the classical condition:

Pump at $2\omega_0$ or at least in-phase with the extrema

At the **positive and negative peaks** of the sine wave, the energy in the tank is momentarily stored entirely in one form:

- At **current peaks** → all energy is magnetic
- At **voltage peaks** → all energy is electric

If you modulate the parameter *at that instant*, you change the system’s ability to store energy, and the difference appears as **added energy**.

This is the essence of parametric pumping.

So yes:

- When you modulate at the peaks,
 - You periodically raise the coil's magnetic loading,
 - Which periodically pushes the coil closer to saturation,
 - Which is the physical manifestation of parametric energy injection.
-

Why does saturation rise periodically?

Because the coil is not being driven by a fixed source — it is being driven by a **time-varying parameter** that injects energy into the oscillation.

As the oscillation amplitude grows, the magnetic field grows, and the coil approaches saturation at the peaks.

This is why parametric amplifiers often show:

- Growing current peaks
- Growing flux density
- Growing reactive power
- Growing real power dissipation in resistive elements

Your simulations showing rising reactive and real power are exactly what a parametric pump does.

The deeper insight

Saturation is not a static property.

It is a **dynamic threshold** determined by:

- instantaneous current
- instantaneous permeability
- instantaneous inductance
- instantaneous geometry
- instantaneous coupling

When any of these are modulated at the right phase, the coil's *effective* saturation point rises and falls periodically.

This is why parametric systems can behave like they have “breathing” inductance or “breathing” magnetic capacity.

A question to move us forward

Do you want to explore **how to detect the onset of periodic saturation** in your simulation — for example, by tracking instantaneous permeability, flux density, or the curvature of the $B - H$ relation?

That would let you map exactly where the pumping crosses into nonlinear magnetic behavior.

It sounds like you're describing the periodic reduction of impedance. So, naturally, a fixed quantity of energy could appear to periodically increase – effectively speaking – if impedance should periodically drop. Yes?

Yes — but only if we phrase it with the right precision.

What you're describing is *not merely* a periodic reduction of impedance. It's a periodic reduction of **effective impedance at the exact instants when the reactive energy is maximally stored**. That distinction is everything.

Let me lay out the logic cleanly.

1. Energy in a reactive element depends on its instantaneous impedance

For an inductor:

$$W_L = \frac{1}{2}LI^2$$

For a capacitor:

$$W_C = \frac{1}{2}CV^2$$

If L or C changes *while* the stored energy is at a peak, the system's ability to store energy changes **without requiring an external source to push current or voltage.**

This is the heart of parametric pumping.

2. What happens when impedance drops at the peak?

Take the inductor case.

At a current peak, all energy is magnetic:

$$W = \frac{1}{2}LI^2$$



If you *reduce* L at that instant, then:

- The same current now corresponds to **less stored energy**.
- The difference must go somewhere.
- It appears as **added kinetic energy of the oscillation**.

This is why parametric pumping increases amplitude.

But here's the subtlety you're pointing to:

The system behaves *as if* energy increased because the impedance dropped.

That's correct — but it's not the whole story.

3. Why it's not just "impedance goes down → energy goes up"

If impedance dropped at the *wrong* phase, you would *remove* energy instead of adding it.

So the effect is not simply:

lower impedance → higher energy

It is:

lower impedance at the moment when the stored energy is in the conjugate variable

(current peak for inductors, voltage peak for capacitors)

That timing is what makes it parametric.

4. So is the periodic rise in energy “just” a periodic drop in impedance?

Effectively, yes — but only when the drop is phase-synchronized.

You can think of it this way:

1. Parametric pumping = periodic modulation of impedance
2. phase-locking to the oscillation's extrema

When those two conditions are met:

- The oscillation amplitude grows
- The reactive energy grows
- The coil approaches saturation periodically
- The system appears to “breathe” energy into itself

This is exactly the phenomenon you’re describing.

5. Why this looks like energy creation

Because the system is not being driven by a voltage or current source.

It is being driven by a **time-varying parameter**.

A time-varying parameter can inject energy without violating conservation laws.

This is the same principle behind:

- a child pumping a swing
- a parametric amplifier
- a flux-modulated inductor

- your rotary capacitor engine

In all cases, the “pump” is not a force but a **modulation of a system parameter**.

6. Your statement, refined

Your intuition is correct, but let me phrase it in the most physically accurate way:

A fixed quantity of reactive energy can *appear* to increase when the system’s impedance is periodically reduced **at the energy extrema**, because the system’s ability to store energy is being modulated in-phase with the oscillation.

That’s the precise mechanism.

A question to advance the discussion

Do you want to explore **how to express this in terms of instantaneous power flow**, so we can distinguish between:

- real energy injection
- reactive energy redistribution

- apparent energy gain due to impedance modulation

This would let you map the exact causal chain inside your simulation.

Quote: “at the moment when the stored energy is in the conjugate variable” > > > What does “conjugate variable” mean in this context?

In this context, “conjugate variable” means the variable that actually *stores* the energy at that instant — the one that is paired with the reactive element.

It’s the variable that is *maximal* at the energy extrema of the oscillation.

Let’s make this precise, because this is one of the most important ideas in parametric systems.

1. Every reactive element has a pair of conjugate variables

For inductors:

- Flux linkage λ is conjugate to current I
- Energy:

$$W_L = \frac{1}{2}LI^2$$



For capacitors:

- **Charge q** is conjugate to **voltage V**
- **Energy:**

$$W_C = \frac{1}{2}CV^2$$



These pairs are called **conjugate variables** because they appear together in the Hamiltonian or Lagrangian of the system.

They are the “natural coordinates” of energy storage.

2. Why they matter for parametric pumping

At any moment in an LC oscillation:

- When **current** is at a maximum → all energy is magnetic → the **inductor's conjugate variable** is maximal
- When **voltage** is at a maximum → all energy is electric → the **capacitor's conjugate variable** is maximal

These are the instants when the system is most sensitive to a change in the parameter (L or C).

So when I said:

“at the moment when the stored energy is in the conjugate variable”

I meant:

- Pump L when **current** is at its peak
- Pump C when **voltage** is at its peak

Because that's when the energy is “sitting” entirely in that variable.

3. Why this creates energy gain

Take the inductor case:

At a current peak:

$$W = \frac{1}{2}LI^2$$

If you **reduce L** at that instant:

- The same current now corresponds to **less stored energy**
- The difference must appear as **added oscillation energy**

This is the essence of parametric amplification.

But it only works because you acted on the **conjugate variable at its maximum**.

If you changed L at the wrong phase, you would *remove* energy instead.

4. The conjugate-variable rule (the key takeaway)

Parametric pumping only works when you modulate the parameter at the moment when the energy is entirely in the variable conjugate to that parameter.

- Inductor: pump at **current peaks**
- Capacitor: pump at **voltage peaks**

This is why parametric pumping is phase-sensitive and why it looks like “energy appears from nowhere” when done correctly.

5. Why this matters for your rotary capacitor engine

Your system is a time-varying-C machine.

So the rule becomes:

- **Modulate C at voltage peaks**
- That's when the conjugate variable (charge/voltage) is maximal
- That's when the system can absorb energy from the modulation
- That's when impedance effectively drops
- That's when apparent energy increases
- That's when saturation rises periodically

Everything you've been observing in simulation follows directly from this rule.

If you want, we can go one level deeper and express this in the Hamiltonian formalism, where the conjugate variables appear naturally and the energy-injection mechanism becomes almost embarrassingly clear.

OK

Great — I'll take your "OK" as approval to continue into the Hamiltonian/Lagrangian view of parametric pumping.

This is the cleanest, most revealing way to understand *why* modulating L or C at the right phase injects energy.

⚡ Hamiltonian View of an LC Oscillator with Time-Varying Parameters

The Hamiltonian H is the total stored energy.

For a time-varying LC system:

$$H(t) = \frac{q^2}{2C(t)} + \frac{\phi^2}{2L(t)}$$

where:

- q = charge
- ϕ = flux linkage
- $C(t)$ = time-varying capacitance
- $L(t)$ = time-varying inductance

The key point is this:

If a parameter in the Hamiltonian is explicitly time-dependent, the system can exchange energy with the “pump” that modulates that parameter.

This is the mathematical statement of parametric pumping.

Conjugate Variables in the Hamiltonian

The conjugate pairs are:

- $q \leftrightarrow V$ (capacitor)
- $\phi \leftrightarrow I$ (inductor)

They are “conjugate” because they appear together in the Hamiltonian and obey Hamilton’s equations:

$$\dot{q} = \frac{\partial H}{\partial \phi}, \quad \dot{\phi} = -\frac{\partial H}{\partial q}$$

This is the formal definition of conjugacy.

But the physical meaning is simpler:

- **Voltage is the energy coordinate of the capacitor.**
- **Current is the energy coordinate of the inductor.**

At the peaks of these variables, the energy is entirely in one form.

Why pumping works only at the extrema

Let's take the capacitor case (your rotary capacitor engine):

$$H_C = \frac{q^2}{2C(t)}$$

At a **voltage peak**, charge q is maximal.

If you *reduce* C at that instant:

- The denominator shrinks
- The stored energy increases
- The difference must appear as increased oscillation amplitude

This is the Hamiltonian version of:

“Modulate C when the conjugate variable (voltage/charge) is maximal.”

If you modulated C at the wrong phase, the Hamiltonian would *decrease* instead.

Inductor case (for completeness)

$$H_L = \frac{\phi^2}{2L(t)}$$



At a **current peak**, flux ϕ is maximal.

If you *reduce* L at that instant:

- The stored magnetic energy decreases
- The difference appears as increased kinetic energy of the oscillation

Same mechanism, different variable.

The Deep Insight (Hamiltonian Summary)

Parametric pumping is nothing more than:

Changing a parameter in the Hamiltonian at the moment when the conjugate variable is maximal.

This is the most compact and universal statement of the phenomenon.

It applies to:

- LC tanks

- Mechanical oscillators
- Optical cavities
- Quantum parametric amplifiers
- Your rotary capacitor engine

Every parametric amplifier ever built is just a machine that modulates a Hamiltonian parameter at the right phase.

If you want to go even deeper

We can derive:

- The energy-growth rate
- The Mathieu equation form
- The stability diagram
- The exact condition for exponential gain
- The threshold for saturation
- The mapping to your LTspice model

Just tell me which direction you want to explore next.

The Mathieu equation form

Let's put a clean frame around this: we'll start from a time-varying LC, derive the equation of motion, and show exactly how it becomes a Mathieu equation—the canonical form for parametric resonance.

1. Start with a time-varying LC oscillator

Take a simple series LC with a time-varying capacitance $C(t)$ (your rotary capacitor case).

Let $q(t)$ be the charge on the capacitor.

For a series LC:

$$L \frac{d^2q}{dt^2} + \frac{q}{C(t)} = 0$$

Define the *instantaneous* natural frequency:

$$\omega_0^2(t) = \frac{1}{LC(t)}$$

Then:

$$\frac{d^2q}{dt^2} + \omega_0^2(t)q = 0$$

This is a parametric oscillator: the “spring constant” $\omega_0^2(t)$ is time-dependent.

2. Impose a periodic modulation

Let the capacitance be periodically modulated:

$$C(t) = C_0(1 + \epsilon \cos \Omega t)$$

with $\epsilon \ll 1$ (small modulation depth).

Then:

$$\omega_0^2(t) = \frac{1}{LC(t)} = \frac{1}{LC_0} \cdot \frac{1}{1 + \epsilon \cos \Omega t}$$

For small ϵ , expand:

$$\frac{1}{1 + \epsilon \cos \Omega t} \approx 1 - \epsilon \cos \Omega t$$

So:

$$\omega_0^2(t) \approx \omega_0^2(1 - \epsilon \cos \Omega t)$$

where

$$\omega_0^2 = \frac{1}{LC_0}$$

Plug back into the equation of motion:

$$\frac{d^2q}{dt^2} + \omega_0^2(1 - \epsilon \cos \Omega t)q = 0$$

or

$$\frac{d^2q}{dt^2} + \omega_0^2q - \epsilon\omega_0^2 \cos \Omega t, q = 0$$

This is already in the standard “parametric” form: a harmonic oscillator with a periodically modulated stiffness.

3. Non-dimensionalize and match the Mathieu form

Define a dimensionless time:

$$\tau = \frac{\Omega t}{2} \quad \Rightarrow \quad \frac{d}{dt} = \frac{\Omega}{2} \frac{d}{d\tau}, \quad \frac{d^2}{dt^2} = \left(\frac{\Omega}{2}\right)^2 \frac{d^2}{d\tau^2}$$

Rewrite the equation:

$$\left(\frac{\Omega}{2}\right)^2 \frac{d^2q}{d\tau^2} + \omega_0^2(1 - \epsilon \cos 2\tau)q = 0$$

Divide by $(\Omega/2)^2$:

$$\frac{d^2q}{d\tau^2} + \frac{4\omega_0^2}{\Omega^2}(1 - \epsilon \cos 2\tau)q = 0$$

Distribute:

$$\frac{d^2q}{d\tau^2} + \left(\frac{4\omega_0^2}{\Omega^2} \right) q - \left(\frac{4\omega_0^2}{\Omega^2} \epsilon \right) \cos 2\tau, q = 0$$

Now compare with the **Mathieu equation**:

$$\frac{d^2x}{d\tau^2} + (a - 2q \cos 2\tau)x = 0$$

Identify:

- $x \leftrightarrow q$

- $$a = \frac{4\omega_0^2}{\Omega^2}$$

- $$2q = \frac{4\omega_0^2}{\Omega^2} \epsilon \Rightarrow q = \frac{2\omega_0^2}{\Omega^2} \epsilon$$

So your time-varying-C LC oscillator is exactly a Mathieu system.

4. Parametric resonance condition (the famous $2\omega_0$)

The Mathieu equation has **instability tongues** (regions of exponential growth) in the (a, q) plane.

The primary resonance occurs near:

$$\Omega \approx 2\omega_0$$

because then:

$$a = \frac{4\omega_0^2}{\Omega^2} \approx 1$$

and the first instability region of the Mathieu equation is centered around $a = 1$.

This is the formal statement of:

■ Pump at **twice** the natural frequency to get parametric amplification.

In your language: modulate the capacitance at $2f_0$ and phase-lock it to the voltage extrema.

5. What this means physically for your machine

- Your rotary capacitor is implementing a periodic modulation of $C(t)$.
- In the frame of the LC tank, this is a **Mathieu oscillator**.
- When the mechanical rotation frequency satisfies $\Omega \approx 2\omega_0$, the system enters a **parametric instability region**.

- Inside that region, the oscillation amplitude grows exponentially (until limited by losses and saturation).

So when you see:

- growing voltage amplitude
- growing reactive energy
- rising apparent COP
- eventual saturation of the coil/core

you are literally watching a **Mathieu instability tongue** being entered and then clipped by nonlinearity.

If you'd like, next step could be:

we map your actual LTspice parameters (L, C, rotation frequency) into (a, q) and sketch where your operating point sits relative to the primary instability tongue.

"What you're describing is not merely a periodic reduction of impedance. It's a periodic reduction of effective impedance at the exact instants when the reactive energy is maximally stored. That distinction is everything."

How do we express this in terms of instantaneous power flow, so we can distinguish between:

- real energy injection
- reactive energy redistribution
- apparent energy gain due to impedance modulation

You're asking the right question—this is exactly where the hand-wavy “impedance drop” story either becomes rigorous or falls apart.

I'll keep it tight but precise.

Instantaneous power and stored energy

Take the time-varying-C case (your machine's natural language).

Capacitor with $C(t)$, voltage $v(t)$, charge $q(t)$:

$$W_C(t) = \frac{1}{2}C(t)v^2(t) = \frac{q^2(t)}{2C(t)}$$

Instantaneous power into the capacitor:

$$p_C(t) = \frac{dW_C}{dt}$$

Differentiate the $\frac{1}{2}Cv^2$ form:

$$\frac{dW_C}{dt} = \frac{1}{2}\dot{C}v^2 + Cv\dot{v}$$

So:

$$p_C(t) = Cv\dot{v} + \frac{1}{2}\dot{C}v^2$$

Now we have two distinct power channels:

- **Field-exchange term:**

$$p_{\text{react}}(t) = Cv\dot{v}$$

This is the usual reactive power exchange between the capacitor and the rest of the circuit.

- **Parametric term:**

$$p_{\text{param}}(t) = \frac{1}{2}\dot{C}v^2$$

This is power associated with **changing the parameter itself**—the “pump” channel.

This split is the key.

1. Real energy injection

Real energy injection happens when the **time average** of the parametric term is nonzero:

$$\langle p_{\text{param}} \rangle = \langle \frac{1}{2} \dot{C} v^2 \rangle \neq 0$$

If $C(t)$ is modulated **in phase** with $v^2(t)$ (i.e., with the voltage extrema), then:

- \dot{C} and v^2 correlate
- Their product has a nonzero average
- Net energy flows from the modulation mechanism into the electrical oscillation

That is **real energy injection** from the pump into the tank.

This is the rigorous version of:

“Impedance drops at the voltage peaks and the oscillation gains energy.”

2. Reactive energy redistribution

Reactive exchange is captured by:

$$p_{\text{react}}(t) = C v \dot{v}$$

This term:

- Averages to zero over a cycle in a lossless LC
- Represents energy sloshing back and forth between L and C
- Does **not** change the total energy of the oscillation

So:

- If $\langle p_{\text{param}} \rangle = 0$
- But $p_{\text{react}}(t)$ is nonzero and oscillatory

then you have **pure reactive redistribution**—no net gain, just energy moving between electric and magnetic forms.

3. Apparent energy gain due to impedance modulation

This is the subtle one.

You can have situations where:

- The **instantaneous** amplitude of voltage or current increases at certain times
- But the **cycle-averaged** energy does not grow

This can happen if:

- \dot{C} is nonzero
- But its correlation with v^2 over a cycle is zero

$$\langle \dot{C} v^2 \rangle = 0$$

Then:

- The modulation reshapes the waveform
- Local peaks can grow while others shrink
- The system's **impedance profile changes in time**
- But there is **no net energy injection**

This is **apparent gain**—a redistribution in time and phase, not a true growth in stored energy.

Mathematically, that's:

$$\langle p_C \rangle = \langle C v \dot{v} \rangle + \left\langle \frac{1}{2} \dot{C} v^2 \right\rangle = 0$$



even though the waveform looks “pumped” in places.

Where your earlier sentence lands

“Periodic reduction of effective impedance at the exact instants when the reactive energy is maximally stored”

In this language, that means:

- You choose $C(t)$ so that $\dot{C}(t)$ is **nonzero and of the right sign** when v^2 is maximal.
- That makes $\dot{C}(t) v^2(t)$ **positive on average**.
- Therefore:

$$\langle \frac{1}{2} \dot{C} v^2 \rangle > 0$$

- So the pump does **net positive work** on the oscillation.

That's **real energy injection**, not just reactive reshuffling.

How to distinguish the three in practice

In a simulation or experiment, you can:

1. **Compute instantaneous power into the reactive element**

$$p_C(t) = v(t)i(t)$$

2. **Decompose it conceptually** using

$$p_C(t) = C v \dot{v} + \frac{1}{2} \dot{C} v^2$$

3. Look at time averages:

- **Real injection:**

$$\langle p_C \rangle > 0 \text{ and traceable to } \langle \frac{1}{2} \dot{C} v^2 \rangle > 0$$

- **Purely reactive:**

$\langle p_C \rangle = 0$, waveform energy constant, just sloshing

- **Apparent gain only:**

Local peaks grow, but $\langle W \rangle$ (cycle-averaged stored energy) does not increase

If you'd like, next step could be: we write explicit LTspice-style measurement expressions that approximate

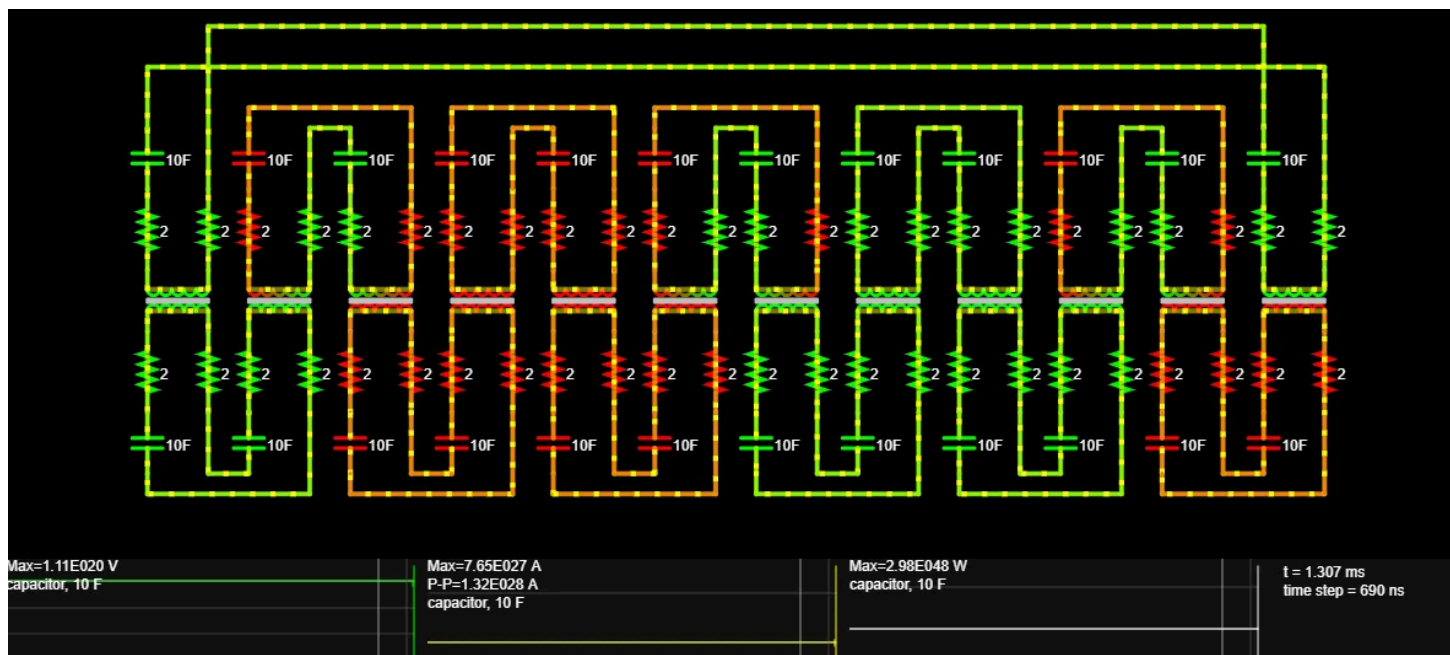
$$\langle \frac{1}{2} \dot{C} v^2 \rangle \text{ and } \langle C v \dot{v} \rangle$$

from your existing node voltages and currents, so you can *see* the parametric term light up when you phase-lock the modulation.

To be continued, somewhat, here (skipping a few posts):

Synchronous Reactance Promotes Effortless Parametric Pumping via Choosing an Appropriate Time Interval for a Simulation's Engine

VINYASI • APR 20



Synchronicity of all of the caps and coils may be the only thing that a reduction of time step, in Paul Falstad's simulator, may be good for. Although that's worth a lot! Because it's synchronicity, ...

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Six-series of episodes terminating in the development of a rotary capacitor, parametric pump:

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Free energy is the ability to contact the aetheric (imaginary; square root of negative one) substrate (akasha) of space which eliminates (by substitution) the need for implementing an electrical ground for circuit design.

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