[SQUEAKING] [RUSTLING] [CLICKING]

DAVID PERREAULT: OK. Why don't we get started? So last class, we took up the topic of isolated DC/DC converters. And I'd like to expand on our discussion today. If you recall, the first converter we introduced last time was called the flyback converter. And this is sort of like an isolated buck boost.

And the idea is I'll come in from, say, V-in. I will have a transformer. And that transformer will also have a magnetizing inductance. It has some magnetizing current that represents the energy stored in the transformer. Then I'll have a switch, Q of T, and a diode, and that's about it.

And we worked this out. And we said, OK, in the first part of the cycle, I apply V-in across the magnetizing inductance. Second part of the cycle, I turn this switch off, and then I apply the reflected voltage from V-out across the magnetizing inductance. And I need a 0 average value across the magnetizing inductance.

And if you apply that, what we get is V-out over V-in is equal to N2 over N1 times D over 1 minus D. So I could have made it minus N2 over N1 times V-in minus D. It's just a question of how I define V-out. And I can define it either way because this output circuit is electrically disconnected from the input-side circuit. So I can reference the output any way I want.

And we said, OK, if I looked at L mu in this circuit and I looked at I mu, it ramps up in the first part of the cycle, and down in the second part of the cycle, and just does that. I mu-- or L mu acts exactly like the inductor in a buck boost converter.

And so I'm storing energy in I mu. And I'm taking energy from the input and putting it in I mu. And then I'm taking that energy out and putting it into the output, just like a buck boost converter. So this is a very popular isolated converter.

We looked at a different example. And I should say, by the way, in order to do this, because I'm storing all the energy in the magnetizing inductance, I usually use a gapped core because what I really want to do is store the magnetic energy in the gap to make the core as small as possible. So I'm using this transformer like an energy storage element, not like an ideal transformer.

We also looked at a different converter here, which I will call a forward converter. And there's different versions of this. But this is basically an isolated buck. Sometimes, they would call this a buck-derived isolated converter. And the idea is this-- we will have V-in. And I'll use this transformer basically just to give me galvanic isolation.

I'll add on a diode. And then I will have an inductor and get V-out. And the notion here is that this voltage-- I'll call this, say, Vx-- is when the switch is on. When the switch is on, I get V2 N2 over N1 V-in here. This diode is forward-biased. This diode is reverse-biased. And I get some scaled version of the input applied here at Vx.

And then when I turn this switch off, this diode conducts and I get 0 at Vx. So this is DT. This is T. So as far as voltage Vx is concerned, this looks just like what a buck converter would do. So what I get in this voltage Vx is N2 over N1 V-in is what voltage is the peak voltage here. So what I get is V-out over V-in is equal to N2 over N1 times D. So it's just like that of a buck converter, but scaled by some turns ratio, N2 over N1.

So In this converter, really what I'm doing is I'm using the inductor L here as my energy storage element. That's what's filtering this pulsating voltage Vx to give me a constant V-out. The transformer I'm really trying to use is an ideal transformer. I just want to apply an AC voltage across the transformer and generate this voltage-- generate a voltage here, which then gives me Vx.

Nonetheless, I do have to respect the fact that any real transformer has some parasitic magnetizing inductance. I have L mu here and I have I mu here. So I do need to make the average voltage across the magnetizing inductance 0 or bad things will happen.

The other thing I should recognize is that, in this circuit, if I plotted I mu, even if I start off with it being 0 at the beginning of the cycle, I mu rises for a time DT. Why? Because when the switch is on and I'm applying V-in across the magnetizing inductance, that magnetizing current stores energy. It has to have somewhere to go.

And thus far, I have not provided it with any place to go. And that would be bad. I need to do something to so-called reset the core and give myself a means of recapturing that energy, either recapturing or dissipating that energy. There's a lot of ways you could do it. Here's one. Here's a different one than we used last time.

Maybe I will add one more winding onto this transformer, like this, and the diode. And what I will then do is orient this, this way. And maybe this will have a number of turns, N sub r. So what then happens is that, when I turn the switch off, this magnetizing current, if I think of the white plus the plus-- plus this winding as being an ideal transformer and I deal with three-winding transformer, current will circulate out of that dot into this dot and come back to the input.

So I could dump this energy into a Zener. Or I could use another winding, and recirculate, it and bring it back to the input. That's called a tertiary winding or an additional winding to recover the energy. Any questions about how that works? Yeah?

STUDENT: So what happens in that winding when the switch is on?

DAVID PERREAULT: Excellent question. So we said if this is series wound, this requires one core with three windings on it. So the core looks sort of like this. And I have N1. I have N2. And then I have some tertiary winding, like this. And this is. N3, like that.

So what happens? So because these all link the same flux, their voltages are scaled versions of one another's. So what happens is, when I have Q of T on, I get V1 here. That means I get this way Nr over N1 V1 here. And it just reverse-biases this diode.

So this winding is disconnected when the switch is on. And then it's connected when the switch is off. Any other questions? Yeah? Does that answer the question?

STUDENT: [INAUDIBLE].

DAVID PERREAULT: All right. Yeah, go ahead.

STUDENT: [INAUDIBLE].

DAVID PERREAULT: Yeah.

STUDENT: But right, now the switch only affects the path for [INAUDIBLE]. Or does it matter?

DAVID PERREAULT: Well, the switch is-- I mean, the switch is switching this winding on and off with V-in. Whether you say it's in series or not because of this path is another thing. The function of the switch hasn't changed. Does that answer your question?

I mean, from the perspective of this winding, when the switch is on, this winding is connected across V-in. When the switch is off, this winding is disconnected from V-in. That's the function of the switch. Talking about whether it's in series or not, I mean, you wouldn't want to put the switch here. But you could put the switch here, if you wanted. And this is just acting as another uncontrolled switch that does what you want. Let me just come back to this question.

STUDENT: Somewhat switch-related, not necessarily related to this implementation, but why are the switches coming after the transformer in these implementations?

DAVID PERREAULT: Yeah, it's because if I have an N-channel transistor, the voltage I need to apply to run this is the gate source voltage. So I have some driver circuit here that can be referenced to-- if you imagine this is my ground, it can be referenced right here.

If I put the switch up here, the source terminal, where my switch is referenced, is here. This node would be flapping up and down. So you'd like to put your switch usually where you can use a very simple driver to drive it. And that's the reason why both the flyback and the forward would tend to put their switch right here, because you can put all your logic here, and your driver here, and life is good. That make sense?

STUDENT: I was wondering the current going back to the source.

DAVID PERREAULT: Huh?

STUDENT: How was the source able to reuse that?

DAVID PERREAULT: Well, I mean, if I have a-- really, what would I have here in parallel with my whatever source and source resistance? I usually have a capacitor across the input. So basically, energy is coming out of that capacitor and the input and going into the magnetizing inductance. And then it's coming back. You can do a lot of other things. There's a converter called a fly forward, where they take that energy and throw it to the output instead of back to the input. It's not as widely done for a variety of reasons, but you could do that.

So this design, we have to reset the core. So this purple winding, in other words, when the switch turns off and this diode turns on, the current will ramp back down to 0. And then it'll stay 0 until the beginning of the next cycle. So this is T. And this is some reset time here.

And so the smallest transformer I can get, if I think about the energy source of the transformer, which is essentially the energy stored in this magnetizing inductance, tends to be smaller when the magnetizing inductance is bigger. And that ends up meaning that you typically used an uncapped core or a minimally gapped core in this kind of converter. So in this design, you want sort of an ideal transformer, but you've got to deal with its parasitics. In the flyback design, you are really using it like an inductor with an extra winding on it.

Now, these are only two of a plethora of isolated converter designs I could choose from. Why might I choose from one versus the other? What's the real benefit of the flyback? Look, it's got one magnetic component-- it's both my transformer and my inductor-- one ground reference switch, and one diode, and some capacitors. Very, very simple. Very few components.

So in a low power circuit, where component count and cost is really important, that's a great circuit. And in fact, a lot of laptop adapters or little wall warts that use some version of that circuit. They'll put a rectifier. And then they'll use that as a DC/DC converter to supply your outputs.

So flyback is really good for low component count and simplicity. On the other hand, we said it's an isolated version of a buck boost. And we said buck boost converters have a lot of stress on the components. It has a very big inductor. It has high voltage and current stresses on the switches.

And so as I go up in power, that starts to become unpleasant. The forward converter now has two magnetic components. So that's more magnetic components. On the other hand, this is based around a buck. So this inductor requires typically a lot less energy storage than the magnetizing inductance of the buck boost.

And so while I've got to throw in a transformer, maybe I can make this transformer very compact at high power levels. And so maybe in the balance I have more components in this design. But at a higher power level, maybe this one can be more efficient or smaller because there's less stresses on all the components.

So this is something you might do at hundreds of watts or above or a kilowatt. So the designer will always play some trade-off between higher complexity and component account versus simplicity based on what components you can get and what that implies for the design.

But you will see a lot of telecom converters, for example, they come in-- you might find in a cell base station or powered from 48 volts to supply some voltage to run a board in a microprocessor rack system or something. Forward converters, especially the active clamp forward converter, which has a slightly different configuration of the clamping circuit, but it's the same basic circuit, very popular in that application.

Both of these, we said, what are the reasons why we wanted to use an isolated converter? One is galvanic isolation. And both of these mean I can be isolated from primary to secondary for protection, for safety. They also help you with large conversion ratios. Why? Because if I wanted to do a 10 to 1 voltage conversion with a buck converter, I need a 10% duty ratio. If I want a 20 to 1, I need a 5% duty ratio.

I'm just pulsing the switch. I've got a lot of stress. It's not very easy to do. Here, I can pick a turns ratio, and rescale that, and, by using a 10 to 1 or 20 to 1 turns ratio, suddenly be running at 50% duty cycle again and have lower stresses. So I get an additional design freedom that helps me get to wide conversion ratio ranges. The third reason-- first of all, let me stop there. Are there any other questions about either of these circuits as examples of different ways you might do isolated converters?

STUDENT: Could you quickly go over how to do the component stresses?

DAVID PERREAULT: Right, so what we said was-- for example, in this circuit, if I ignore the magnetizing currents because it's small, when I turn the switch on, if this is an output current I2 and it's almost constant, when I turn the switch on, I2 is coming this way, which means I2 is coming this way. And I see N2 over N1 I2 through the switch.

When the switch is off, I see the reset voltage, which is some minimum multiple of V-in. So I can relate the switch voltage to-- in this case, the input voltage and the switch current to the output current. And then it helps me pick my switches.

I can do the same thing for the indirect kind of converter. And what you'll see is, for a given conversion ratio with optimally chosen turns ratios, it's worse for that one than it is for this one. Moreover, you can see the same thing about the energy stored in that magnetizing inductance versus this physical inductance.

So what was the other reason I said we wanted to do, quote unquote, "isolated converters," not for isolation, but its ease of doing multiple outputs. Why? Because, A, I often need multiple related outputs. But B, I can often do that just by adding windings to my transformer.

So for example, suppose I have a forward converter. And all I might do is say, OK, I'll build this transformer. And what I can do is I can say, OK, here's N1. I'll have a second winding, N2. This is my first output. That's V2. And then I could just build another winding on my same transformer and call that V3 with a number of turns, N3.

So all I do is I throw one more winding on my transformer-- same idea, series-wound, just like this guy. And then, yes, I've got to add two more diodes and another inductor, but I get another output. So it's not like I've got to build a whole nother converter. I just add a few more components to my existing converter.

And what should I get? Ideally, whereas this voltage became N2 over N1 scaled times V-in, this voltage becomes N3 over N1 times V-in. So what I get is V3 is equal to D times-- is equal to-- I'm sorry, V2 is equal to N2 over N1 V1 times D. And V3 is equal to, ideally, N3 over N1 V1 times D.

So if I wanted a 5-volt output and a 12-volt output, I just make N3 12/5 of N2. And boom, I've got my extra output and life is good. That make sense to everybody? And of course, I'm not showing-- I still need a reset mechanism over here, whether it's that one or some other one.

So we often see converters with a lot of outputs when we're building them. We do have to, however, start thinking, especially when we have many windings, what are the impacts of all the transformer parasitics beyond the magnetizing inductance? And that's why we spent time thinking about what are the transformer parasitics.

So let's think about this. If I did this-- Suppose I come back to my single output magnetizing-- my single output design here. What other kind of transformer parasitics might I have?

STUDENT: [INAUDIBLE].

DAVID PERREAULT: Leakage inductances, yes. So this circuit, this extra winding in the diode, will help me capture, recapture, recycle the magnetizing energy back to the input. So whereas in the converter I showed you last time, I threw it away, here, I can recycle it back to the input.

On the other hand, suppose I have some primary leakage here, LL1. Energy stored there doesn't get caught. That won't get recycled. It's in series with a switch. I turn the switch off, it's going to get dumped into the switch. Now, maybe I just rate my switch to take that energy when it turns off and eat it. And you often do that.

Or maybe I go and I add a little Zener diode, or a clamp, or some other thing, a snubber, which we'll talk about next class, snubbers, to eat that energy. But I have to think about that. And because we're going to be interfacing switches and transformers, we often have to worry about leakages that are bigger than I have to think about in a non-isolated converter.

All right, I can do that. Let's think about the impact of leakage in a different scenario. Let's again just simply-- let's ignore the primary side leakage. This circuit would take care of eating any primary side leakage effects. But let's think about the leakage effects on the secondary side.

So suppose I build my forward converter again. And here is my transformer, my ideal transformer. And I am going to run out of room if I draw it that way. So here's my transformer. Here's my V1. Here's my transformer. Here's my switch, N1 to N2.

Now, let me worry about a second element. Let me worry about L leakage 2. This is the secondary side leakage inductance. And then this runs into this diode pair. And then this runs into an inductor. I'll call that current I2. Let's assume this inductor is really big. And then I get V2.

Well, what happens in this circuit when I'm switching? Well, I might think about a voltage that I'm going to call Vy. Let me use this color for Vy. Here's Vy, here. What does Vy look like? Vy, when I turn the switch on, Vy looks like N2 over N1 V1. This is Vy in the first part of the cycle.

In the second part of the cycle, it goes negative to some value that's determined by the clamp that I'm not showing. There's some transformer reset mechanism that's going to make this node clamped, whether I use this method or some other method. And it's going to clamp to some value. And then maybe it'll go to 0 before the beginning of the next cycle, something like that.

So this is what voltage Vy looks like. Everybody buy that? So let's think about what happens where I have this secondary side leakage. And I particularly want to look at-- I'll call this I leakage 2. And let me call this device-- I'll call this D1. And I'll call this D2. So let's plot that.

So here's my voltage, Vy. And it's going to do something like this. And I don't have to worry about what happens. As long as the core resets, I'm happy. So this is N2 over N1 times V1 here. So let's think about that. And I can really think about Vy as just being an equivalent source there. So what's going to happen to that current, IL leakage 2? So here's what that's going to look like.

When I turned on the switch L leakage 2 had no current in it because, before I turned on the switch, D2 was conducting. So over here, D2 is conducting. And there's no current through D1 and no current through I leakage 2. So he's 0.

What's going to happen when I turn the switch on? Well, suddenly Vy becomes positive. On the other hand, I can't change the current through L leakage 2. So D2 can't turn off. D1, however, turns on. So what I'm going to get-- this is what we talked about at the beginning of class. We're going to get a commutation interval.

So what happens is I'm going to get an interval where D1 and D2 are on. And so I can think of this circuit as being like this during that interval. I have Vy, which is exactly this. Then I have I leakage 2. This is L leakage 2. And then I have D2 one is on and D2 is on.

And maybe I think of the output network as just being constant during this time. So this is I 2. So this is a simplified circuit model there for the interval after the switch turns on, when D1 and D2 are on. Does that make sense to everybody?

So what should happen? I basically have Vy applied across L leakage 2. And so I have a constant voltage across L leakage. So I should expect that I leakage 2 should just ramp up like this, linearly. How long is it going to ramp up linearly? It's going to ramp up linearly until I leakage 2 equals I2, at which point this diode will turn off.

So once I hit I2, then this is going to cease increasing. This diode is going to turn on. And then I leakage 2 is just going to carry I2. And it's going to do this. If I followed the rest of the cycle, it'll do the same thing in this, after I turn off the switch. There's D2. And it'll go back to 0 the beginning of the next cycle.

So this is what happens with I leakage 2 in this case. And all I'm doing-- and during this interval, D2 is-- D1 is on. So I go from D2 on to D1 and D2 on to D1 on. Everybody follow that?

So why am I dragging you through this? Because of the following-- let me look at a different voltage now. Let me look at the voltage Vx. It's this voltage here. This voltage is going to be 0 whenever D2 is on.

So what I'm going to get Is D2 is on. Vx was 0 because D2 is on. After this switch turns on, it stays 0 until D2 turns off. And once D2 turns off, IL2 has a constant current through it. So it has no drop across it. And then this will just jump up to a value that is N2 over N1 times V1. And it'll stay there until DT. Then D2 will turn on again and so forth until T.

So let me call this time-- I didn't specify what this time is called. Let me call this delta T. And this is DT. And the question we have is, what is the average output voltage of this circuit? Well, clearly, V2 is just equal to the average voltage of Vx. So V2, It's the average of this voltage. V2 is equal to the average voltage of vx, which is equal to D minus delta T over T times N2 over N1 times V1. Does that make sense to everybody?

Well, what's delta T? We have V is equal to L dI/dT. So delta T is simply going to be equal to L leakage 2 times delta I, which is I2 over V, which is N2 over N1 V1. So this is my expression for this time. It's just V is equal to L dI/dT. That's how long delta T has to be with a constant applied voltage.

So I can rewrite this as being equal to D N2 over N1 V1 minus delta T times N2 over N1 V1 L leakage 2 I2, which just gives me minus L leakage 2 over T times I2. And this is V2. Does that make sense to everybody?

This is precisely load regulation, just like we talked about with rectifiers before. But we don't have sinusoidal waveforms anymore because we're building a DC/DC converter. But the point is that the output voltage V2 no longer just depends upon the input and voltage and duty ratio. But it depends upon my load current.

This load current influences my output voltage. As I2 gets bigger, V2 tends to droop. Is that a problem? Well, not really. It's a little bit of a problem. If I have a low load current, if I2 goes towards 0, well, I just get my ideal relationship. If I get heavier and heavier load, depending upon how big our leakage is, the output voltage droops. So all I would have to do is to get the right V2, to the one I really wanted, I'd use a slightly larger duty ratio. Yeah?

STUDENT: Would it also affect the [INAUDIBLE]?

DAVID PERREAULT: Ah, you've put your finger on the real problem of this. Yes. It probably doesn't matter very much in-- I mean, if L leakage is huge, then I've always got a problem. But if L leakage is small, maybe I don't care so much. But it's exactly what you're saying.

Suppose I have my two-output converter. I only have one duty ratio. Both of those outputs are being regulated by the same duty ratio. And if I wanted ratiometric outputs scaled by N3 over N2, that's fine. But now, once I put in leakage, suddenly I have this term where I have to vary duty ratio based on the load of L2.

I can only control one output. And the other output, I get what I get. And so what will happen is I'll get something called cross regulation. That is, suppose I'm controlling V2. I'm picking duty ratio by my controller to get the V2 I want. If I get a heavier load, I turn D up, V2 goes back to where I wanted, but V1 changes because I changed the duty ratio. So the load on output two affects the voltage on output 3. And I tend not to like that. I'm stuck with that. Yeah?

STUDENT: Doesn't that work the other way around? Couldn't you do the same analysis for circuit 3, and then get an equivalent?

DAVID PERREAULT: That's right. It depends if there's much leakage there, too, with respect to winding 1. Yes, certainly. So there's two points. First of all, the two outputs are going to influence one another, which I don't like. Generally, if I want 5 volts at my output, I want 5 volts in my output. What can I do about that? A few things.

One thing I might do is the output I really care about that has to be precise, that's the one I regulate. And then the other one, if it drifts around a little bit, maybe I don't care. Or maybe I put a linear rate, I make it go a little high, so when it drifts around, it's always high enough. And then I put a linear regulator there or I put another conversion stage there. But now, I'm adding complexity, and loss, and everything else.

So an upside to these multiple output converters is that I can get multiple outputs. The downside is maybe I can only get one of them to be precisely what I want. And the other moves around a little bit. How much does it move around? It depends on your transformer parasitics. And that's where you start to think very carefully about how you design your transformer. Questions about that?

STUDENT: This might be simple, but can you explain [INAUDIBLE] in terms of current being commutated, could you explain like the current paths?

DAVID PERREAULT: Sure. So what's happening is that what I would ideally like-- if I didn't have any leakage, before the switch is on, the current's coming through D2. The output current is considered I2 constant. It's coming through D2.

When I turn the switch on, what I would like is the current come out of this winding of the transformer and into this winding of the transformer. That's easy to do in a buck converter because I'm connecting those nodes together. But here, I've got a transformer in between. He has some leakage. And that's what causes the headache.

Nonetheless, we can often get away with still having just multiple windings. And many, many converters are built exactly that way. So I'm not saying it's impossible. I'm just saying it's another thing you've got to watch out about, is how precise can you get your winding outputs and which output do you care the most about. And that's the one you'll precisely regulate.

Let's keep going. I've only introduced two isolated converters. And there are arbitrary numbers of kinds of isolated converters you can build. But one of the things we said was, well, why would I choose a forward instead of a flyback? Because when I get higher power, this tends to be more compact, even though it has more components. Particularly, it has more devices and everything.

But because the energy storage elements are smaller, I'm happier. And the energy storage elements tend to dominate the overall size. What happens if I went still further up in power? What might I think about doing? Well, I might end up-- it turns out that these are both considered, quote unquote, "single-ended" converters. They drive the transformer one way, and then let something else reset the core, apply the voltage that resets the transformer or drives the transformer flux to 0.

I could get more clever. Let me show you a different circuit. It is very closely related to the forward converter. And maybe it looks like this. Maybe I will get a full bridge inverter. I'll have two switches here. So I'll have a transformer. And let me call this Q1, Q2, Q3, and Q4.

So now, instead of one switch, I have four. Here's my transformer, N1 to N2. Now, I'm going to take the secondary winding and I'm going to do the same thing, except I'm going to have four diodes. And there's a lot of different versions of this. I'm just showing you one. And I'll call this I2. And here's my output, V2.

And I will connect this one this way, like this. So now, what have I done? Instead of having a forward converter where I have one switch and some reset mechanism, I've got four switches. Instead of having two diodes, I've got four diodes. So this looks like-- geez, I wouldn't like this very much, would I? Because I've got a lot more components.

But what happens? Let's think about this. Let me show you the switching patterns of this guy. What we're going to do is we're going to control this so that-- let me call this voltage V sub mu. And keep in mind, I do have a magnetizing inductance and a magnetizing current I mu here.

So what I'm going to get is this. I'm going to control this thing in the following way. First, I'll turn on Q1 and Q2 so that I will apply a V mu that's V1. This is V mu. It's going to go to V1 until some time DT.

So here, I've got Q1 Q2. Then I'll turn on Q2 Q3. So I'll just short circuit the transformer. And I'll get V mu is equal to 0 until some time T. So here's Q2 Q3 until time T. And then I'll turn Q3 Q4 on. So now, I'm going to apply the voltage across the transformer the reverse way. And this is minus V1. So this is Q3 Q4 until T plus DT. And then I'll have Q4 Q1 until 2T, like this, and then I'll repeat, so forth.

So what I'm going to do is I'm going to go Q1 Q2 Q2 Q3 Q3 Q4 and Q4 Q1, and then I repeat. So my actual repeating pattern is in some time 2T. Why do I do that? If I apply V mu, I just get a scaled version of that on the secondary. And then if I look at this voltage, remember this voltage here, we had some voltage Vx. Let's look at Vx now on this one.

Here's Vx again. Vx is just going to take the scaled version of V mu and then rectify it with this full bridge rectifier. So it's going to be a flipped version of that and scaled by the transformer turns ratio. And what I'm going to get is this. It's going to look like this.

This is going to be N2 over N1 V1 for DT. And then it's going to be 0. And then at T plus DT, it's going to be positive again. And at 2T, it's going to be here. So this is DT T T plus DT 2T and et cetera. And what's V2 going to be equal to? V2 is going to be the average value of Vx. It's just going to be equal to D N2 over N1 V1. So this circuit does the exact same thing as my standard forward converter-- turns ratio N2 to N1, control it like D. It's basically a buck converter. Make sense to everybody?

So why would I go through all this trouble to do that? There's a couple reasons I might do it. Let's look at I mu. What does I mu look like? Well, I mu, when I'm applying positive, it's flowing positive like this. Then it's 0. Then it slows down to negative. And then it's 0, change, and then it shows positive again. So this is I mu. And this is delta I mu peak to peak, which is proportional to delta B peak to peak in the core.

So here's the idea. There's a whole bunch of reasons why this circuit's a lot prettier, in terms of its performance. Here, my transformer flux or my magnetizing current swung in one direction. It swung between 0 and a positive value. Maybe that could be limited. If I translate the magnetizing current to magnetic flux [INAUDIBLE] it's limited to B-max, which is below B-sat.

Here, I get to use the negative to the positive. So I can swing my transformer flux more before I saturate it. So if I'm limited by saturation, this converter is going to lead to a smaller transformer than the forward converter because it's double-ended. It swings the flux in both directions.

Even in cases where you're not limited by the saturation, you're limited by core loss. Some core materials actually tend to have-- well, we didn't cover this. Some core materials tend to have less loss if you don't have an offset flux in them. So this can still be better. Even if you're not caring about saturation, this can be still better. And you get more headroom with respect to your saturation with this circuit than that circuit.

The other thing that happens is, notice, these switches all switch once for every 2T. But the ripple frequency that's on that output inductor is every T. So what that means is, for the same switching frequency, I can have higher ripple frequency and hence a smaller inductor in this circuit.

So what you can see then is I'm making some trade-off. I'm saying, I'm going to have more components. Now, I'm going to have four switches. And I'm going to have four diodes. But my transformer got better and my inductor got better. And this is a very typical trade-off that you see in power electronics design generally, but in isolated converters especially, that I will throw more components at it, I'll have more sophisticated flux swings or controls.

But what I get is smaller passive components. And so if your life is dominated by the physical size of your passive components and not by the total component count, this strategy is better. So this strategy would be good for 5 kilowatts or 10 kilowatts. Maybe I would do something like this.

There's a whole bunch of other advantages and trade-offs I'm not talking about, relating to soft switching and other things. And we'll talk about those later in the class. But this is just to show you the idea from the progression from simple circuits that maybe have high stresses to more sophistication, to more sophistication, to get higher levels of performance, which tend to become more important at higher power levels.

I should say, as a final comment, there are lots of other kinds of isolated converters. I show you a converter on the last page of the lecture notes, which is essentially like an isolated boost converter. But there are isolated converters that don't really have any counterpart in the non-isolated world because they just choose to use transformers.

And that's your advantage as a good designer, is saying, I'm going to be more clever than my colleague about which circuit I choose to use for what and hence have a smaller, cheaper, higher performance, more efficient circuit, and hence win in the competition of who's going to make a better overall system. So I'm done there. Are there any final questions before we wrap up today?

STUDENT: Are these other converter designs in the textbook?

DAVID PERREAULT: Yeah, sure. And many I didn't talk about. So I'm just trying to illustrate how things go. But yes, the isolated converters chapter, it goes even beyond any of the ones I'm showing here and shows a whole bunch of other ways to do it.

And the last thing I'll note is next class, we're going to come back-- I'm actually not going to-- Dr. Zahn is going to present. But he's going to talk about some very important things. How do you deal with stuff like leakages and capturing that energy?

And then we'll talk about other things like thermal, like how do I deal with all the heat that we don't want to generate, but we do. So in the next couple of classes, we're going to talk about some of these very practical implementation issues. Have a great day.