PLANAR VERSUS CONVENTIONAL TRANSFORMER

Usually the first step on any power supply designer's checklist is to choose an appropriate power transfer circuitry, commonly referred as topology, based on the customer's requirements, and whether they need to design an isolated or non isolated unit. The different topologies or the way the power is transferred from input to output are Buck, Boost, Flyback, Forward (Push-pull, Half bridge, Full bridge), and resonant to name a few.

After choosing the topology, transformer design is the most critical step. This requires choosing the other elements like primary main power switches (MOSFETs), output rectifiers (Schottkies, Fast and Ultra fast), and snubbers.

In the majority of power supply applications, with wattage levels in between few watts and a few hundred watts, the market demands attention to a few key issues:

1. Small size.

2. High power density.

3. High efficiency.

As in the majority of the power supply designs, transformers and inductors are the major contributors to the size. Increasing the operating frequency can reduce the size of these magnetic. This desire for smaller size forces the power supply designers to increase the switching frequency. For example in a PoE discontinuous flyback with Duty of.275 and 46Vin to 3.3Vout at 3Amp output load for a given core, the needed primary inductance can be lowered to 19uH from 39uH when the frequency increase from 200Khz to 400Khz respectively.
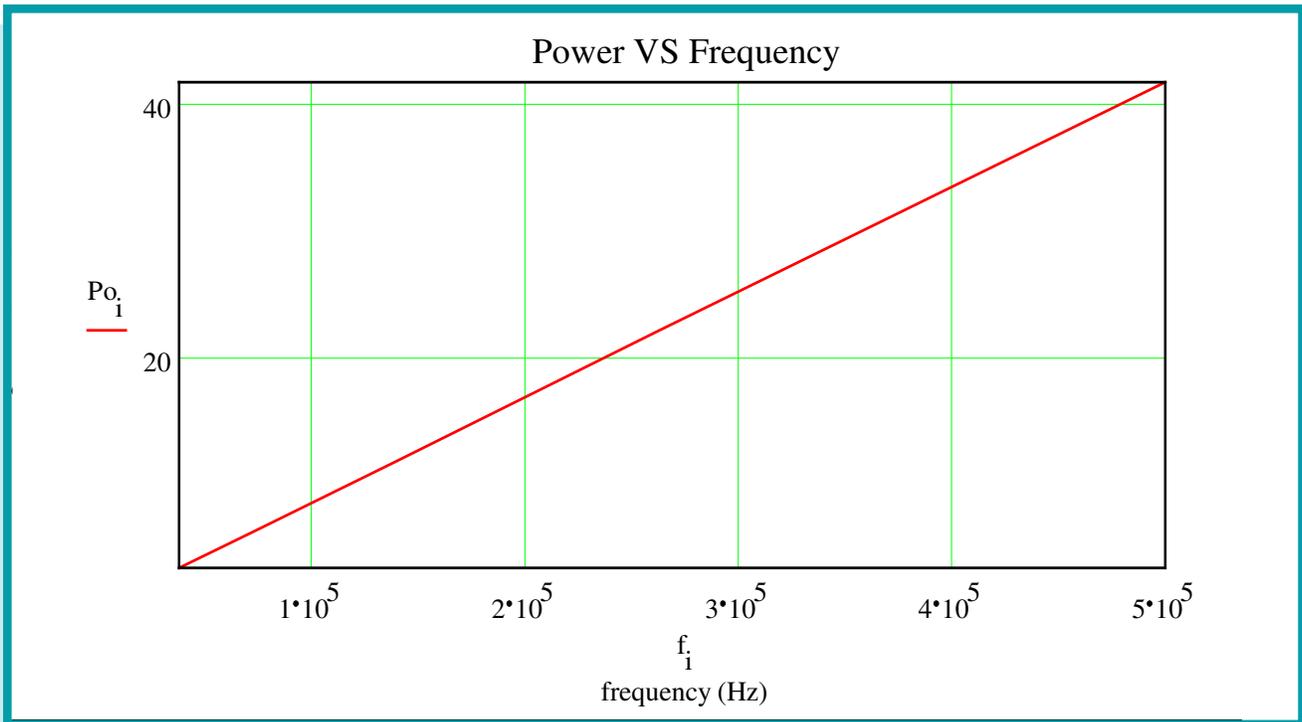
Power VS Frequency

The Above graph also shows the increase in thru-put Power for a given size when increasing the switching frequency. But increasing the operating frequency does cause more switching losses in active devices specially the main switching FET which reduces the efficiency of the power module. Here is where choosing a planar approach versus conventional transformer can come to help to increase the efficiency.

Before we go any further, we need to define what the definition of High Frequency is? Is 10 KHz a high frequency, how about 200 KHz or 1 MHz? The answer depends on the following;

The frequency at which the skin effect starts to influence the current distribution through a conductor is what we define as High frequency. When the current does not fully use the cross sectional area of the entire wire, it will have higher resistance at different frequencies per fig below.

Skin depth vs Frequency

δmils$_i$

f_i
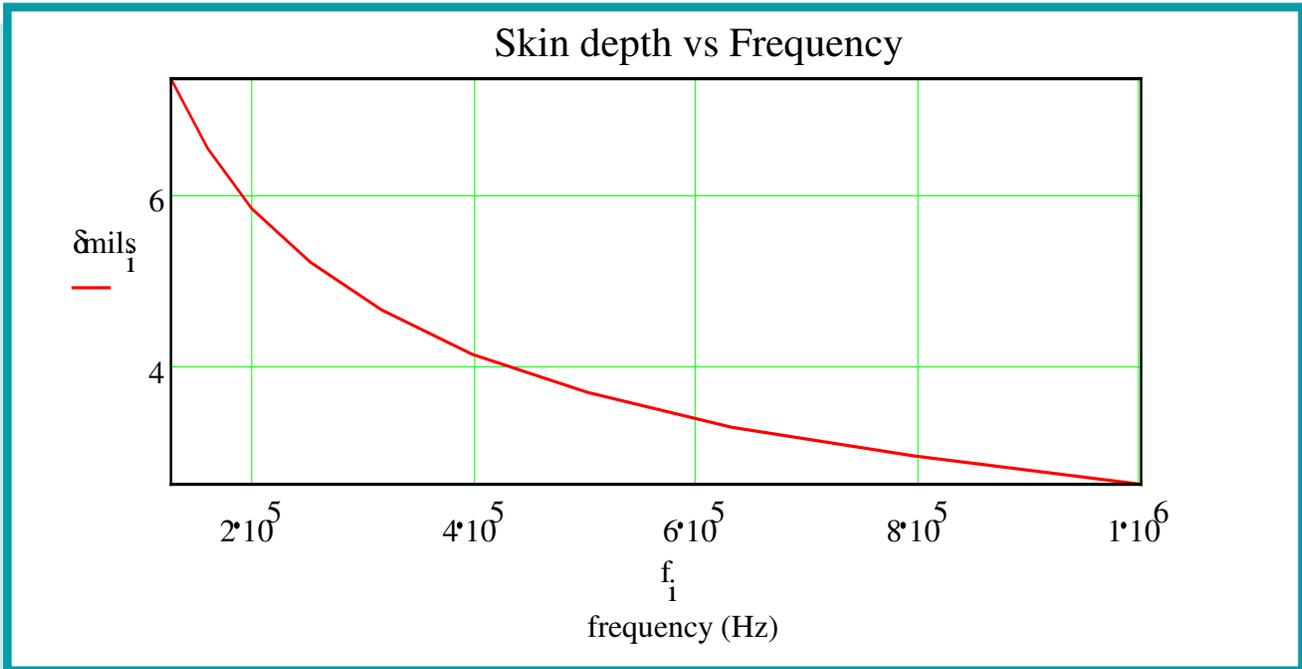
frequency (Hz)

The fig above shows that as the frequency increases, the usable cross sectional area of the wire diminishes decreases, causing an increase in resistance. For example, the figure below shows a resistance of 50 inches of 20Awg round wire at different frequencies.

Resistance of round wire VS Frequency

R_i

f_i

frequency (Hz)
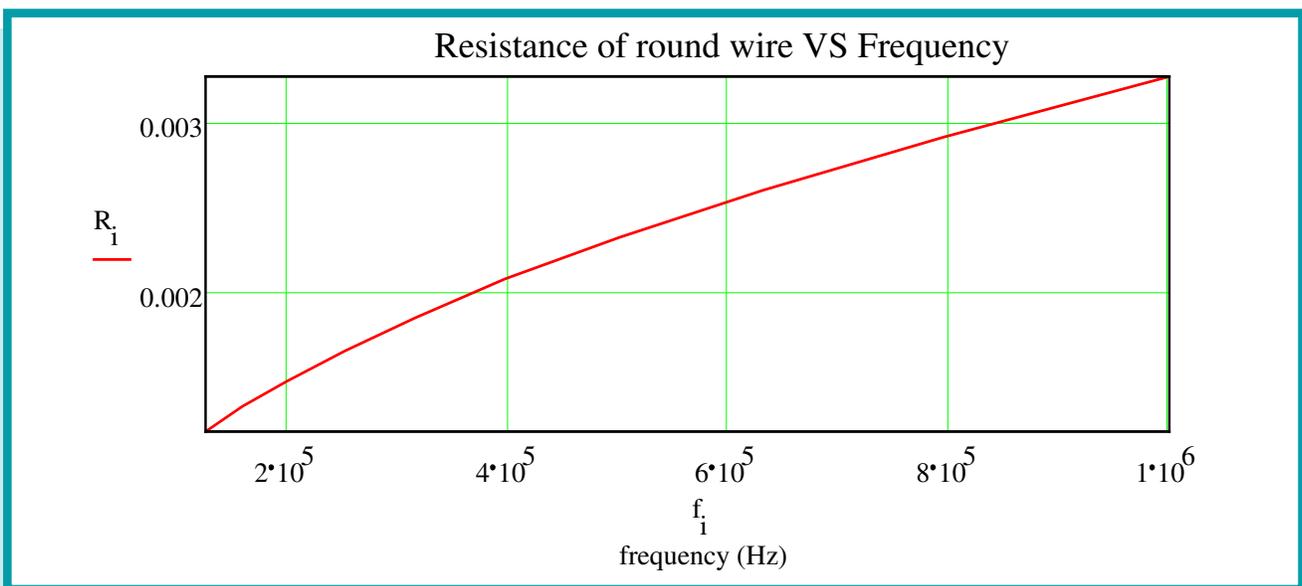
One solution to the problem shown in above fig is to use a bundle of smaller gauge wires or litz wires instead of a single thick wire gauge. Although this approach helps to reduce the AC resistance down, it creates other problems indicated below:

1.   It is difficult to terminate a number of strands of wires to a single pin on the bobbin, this forces the designers to allocate a greater number of pins for termination. This reduces the number of available pins for other windings in multi winding applications and might force the designers to use custom bobbins.

2.   The insulation coating of the Litz wires reduces the available bobbin area in order to fit all the turns, we need to create more layers and increase the height of the bobbin. This increases the height of the transformer.

3.   Increasing the height of the bobbin increases the magnetic path length (Le) which in effect increases the core volume. Since core loss is a function of the core volume this additional increase in volume will raise the core loss.

4.   Increasing the number of layers will also increase the amount of leakage energy in between the layers. This will reduce the coupling coefficient between primary and secondary windings and increases the leakage inductance. For example, in a fly- back topology this increase in leakage inductance will force the designer to use a higher voltage rated Mosfet which is more expensive and has higher On resistance (Rdc-on).

Now, by using a thin (2x skin depth) and wide copper foils or traces instead of round wires we can utilize most of the copper cross sectional area and either lower the height of the bobbin or do more interleaving to reduce the AC resistance caused by proximity effect.

cross sectional area of wire not being used

$2X\delta$ δ = Skin Depth
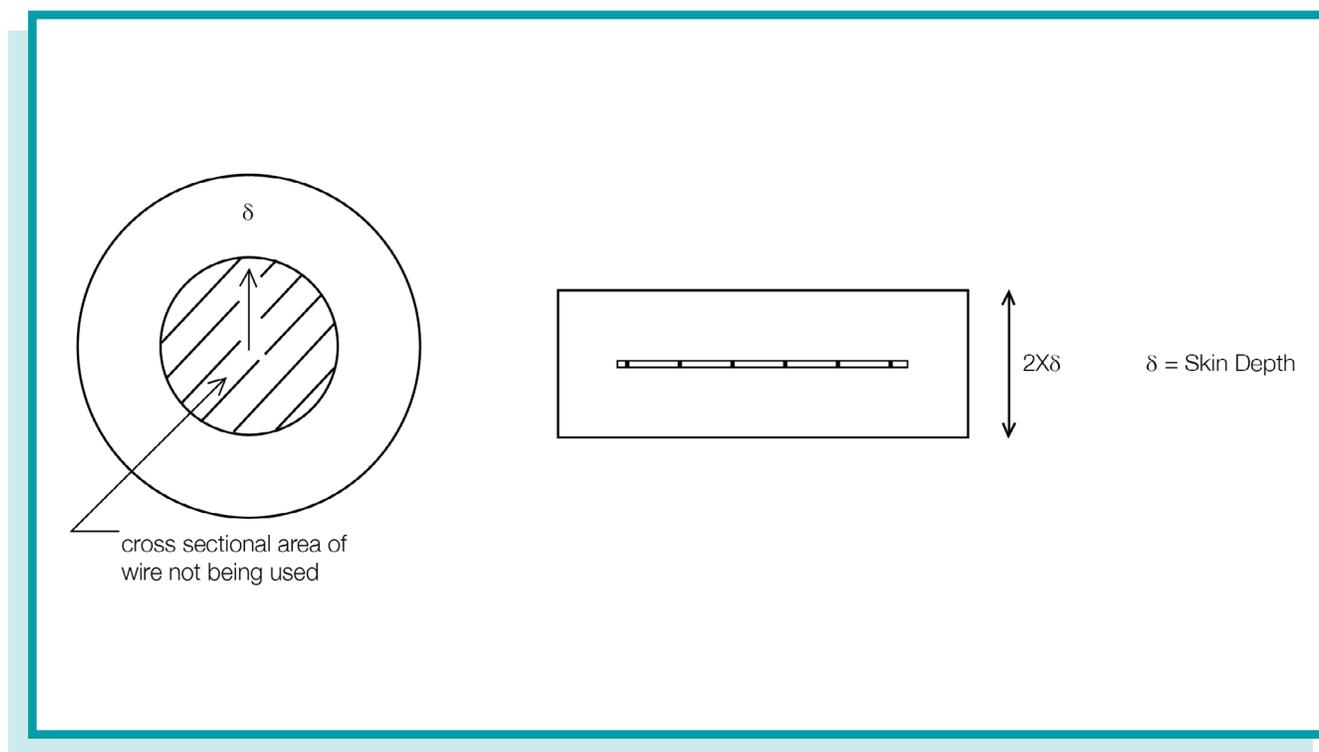
Contrary to Skin effect that causes current to go to the surface of a conductor, the Proximity effect causes the current to flow ONLY on surfaces closest to each other. It is important to understand that unlike skin effects (in which the overall Rac will always decrease slightly with increasing conductor size), too thick a conductor will actually result in higher Rac due to the fact that currents will be induced in the «extra» copper.

Furthermore, the conductor height (width of foil or diameter of wire) from a proximity standpoint which is considered to be the conductor height times the number of layers, in high frequency designs conductor size and number of layers must be optimized.

This proximity effects depend on the magnitude of the external field. If the external magnetic field is normalized then it can be shown that in a non-interleaved design the H field reaches a magnitude of 10. However, in an interleaved design, one of the windings is split and hence the H field magnitude decreases to 5. Less H field means less proximity effects, lower AC resistance and more efficient transformer.

With Planar we can accomplish more interleaving to reduce the effect of proximity effect. This interleaving can be customized to either reduce the leakage inductance or to have a specific amount of leakage needed for application like Zero voltage switching.

Planar transformers if designed properly can offer the advantages of:

1. Consistent spacing between turns and layers which translates into consistent parasitics. Both the leakage and intra-winding and inter-winding capacitances can be maintained to very predictable and tight values. Foil thickness optimization for both DC & AC current.

2. Ability to do more interleaving to reduce the AC conductor losses.

3. Foil thickness optimization for both DC & AC current.

4. Lower profiles can be achieved with low volume causing less core loss.

5. All regulatory spacing and dielectric voltage breakdowns can be done by proper spacing and coating.

6. Planar magnetic has higher power density over conventional designs.
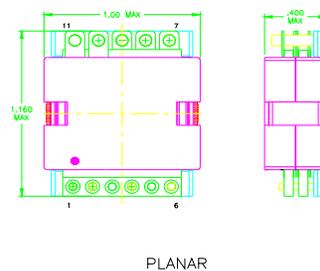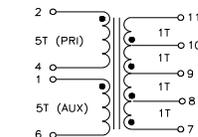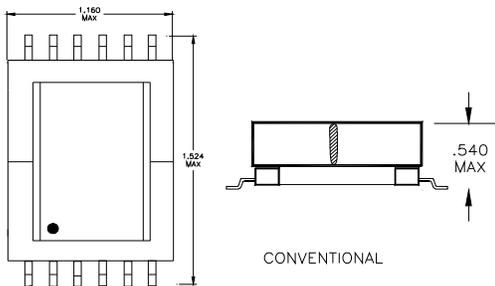
Let's use an actual example to understand more about both conventional and planar approaches to transformer designs:
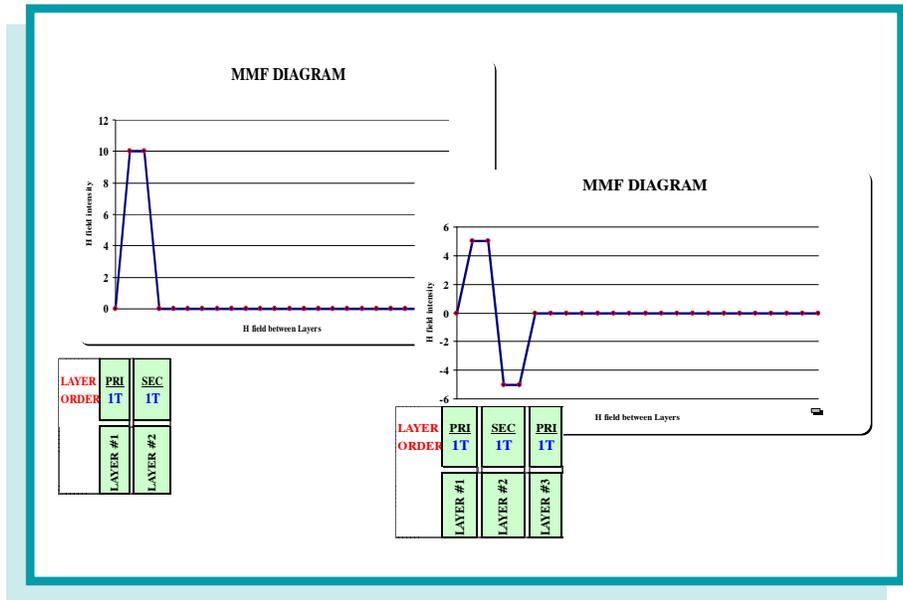
Application:
240 Watt Full Bridge (36-75V input, 250 KHz, 12V/20A output)

	Ae cm^2	Le cm	Npri	Nsec	Core loss	Copper loss	Total loss	Size (Inch)	Cost/100Kqty $
Planar	0.835	3.41	5	2;2	0.656	2.189	2.845	1.0x1.16x0.4	3.1
Conventional	0.546	7.31	7	3;3	0.62	2	2.62	1.524x1.16x0.54	1.9

Conventional transformers have advantages of:

1. Mature technology.

2. Wide range of selection in core and bobbin sizes.

3. Time to sample is short and modifications are cheap, easy and fast.

Planar on the other hand have disadvantages of:

1. Newer technology.

2. Lack of comfort factor among designer in designing planar magnetic and limited available platforms to choose from.

3. Time to sample is longer and modifications are more timely and expensive.

Choosing the planar versus conventional depends to number of factors that were mentioned in above. The planar approach will allow the designer in make a decision in either reducing the size for a given loss or reducing the losses for a given size.

The example above was tailored toward reducing the size of the transformer for a given loss. As planar gains acceptance among designers, and production volumes increases, it should help in bringing the costs low. But till then, if you have the available space and height within your system, the best bet is to stay with conventional approach.

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