StackPack™ Cores: Magnetic Device Design

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Introduction

In the power industry, there are many applications that require the use of “U” cores, or Special sizes of “E” Cores. The driving factor behind these requirements are the VA rating of the device being designed and/or the voltage level of the primary. The VA rating of a magnetic device determines WaAc required to minimize losses of the core. The primary voltage determines two characteristics of the core: The Ae of the core, (needs to be optimized to minimize the number of turns), and in conjunction with the VA rating, the size of the wire required. The main issue is that there are limited standard sizes available. Frequently a core is required that is not offered. There are two options to overcome this. The first, (and most expensive), is to have a custom core manufactured for you. While this may result an optimized solution, it can be cost prohibitive. The second option is the StackPack™ core. This provides a set of building blocks that can be used to create a design that can be put into production very easily.

Scope

This paper and the accompanying presentation outline the characteristics required to design a magnetic device. Data will be provided on three different designs. The data is provided as a starting point to set the expectations of the designer. Some ideas will be presented to introduce concepts for sizing the design not only for the operating characteristics, but also the isolation requirements required by the system.

The StackPack™

While there are companies that will provide bars to allow you to make a “custom” core, they typically do not have any way of securing the pieces together. They also need to be cut to the length that is required. The table 1 below shows the three components to the StackPack™, and the materials that are available. The advantage of the StackPack™ product is that the pieces are in standard sizes that allow a mechanical connection to be made to hold them in place.

Table 1: StackPack™ Components

Section	Material	Part Number	Size
Corner	N87	B67410A0250X187	1.58” L x 1.7” W x 1.35” H
	N49	B67410A0250X149	
Leg	N87	B62110A6018X087	1.23” ϕ x 1.78” H
	N49	B62110A6018X049	
Spacer	N87	B67410A0249X187	1.78” L x 1.7” W x 1.35”H
	N49	B67410A0249X149	

The material used for the experiments was the N87 material. In the next section data is presented on both the “Leg” and the “Spacer”. What makes the StackPack™ unique is that a designer can mix and match to make any shape that is required. One could easily use either a single Leg or a single Spacer as the basis for an inductor or small transformer.

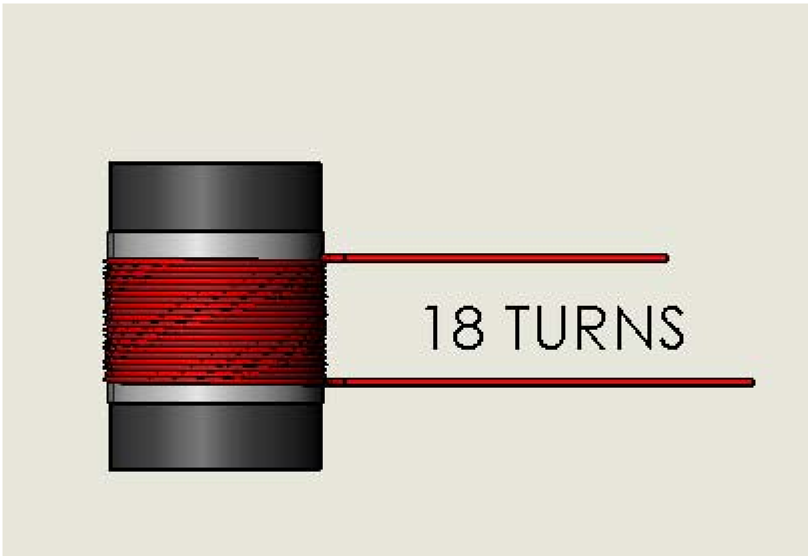
Characteristics

Testing was performed on different configurations of the components to determine the characteristics of each segment and various stacks.

Leg Characteristics

Six legs were wound with 18 turns of wire as shown in figure 1 below.

Figure 1: Leg Winding



After each leg was wound the inductance was measured From this the A_L was measured. The data is shown in Table 2. Note that the Ac, (also known as Ae), for this is 7.24cm^2. Throughout the rest of this document this is the value that will be used in all equations.

Table 2: Test Data for Single Leg

STACK PACK PART	# Turns	A_L	Variation	INDUCTANCE (uH)
Leg	18	136	100%	44.20
	18	140	103%	45.30
	18	133	98%	43.20
	18	135	99%	43.90
	18	133	97%	43.00
	18	140	103%	45.40
Calculated A_L Value	136	136	+/-12%	44.17

Spacer Characteristics

Six spacers were wound with 20 Turns of wire as shown in Figure 2. From this the A_L was measured. The data is shown in Table 3.

Figure 2:Spacer Winding

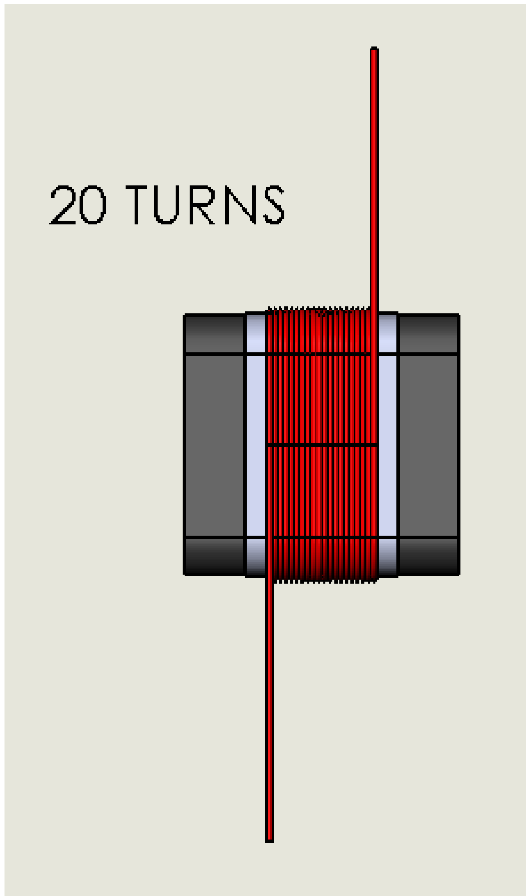


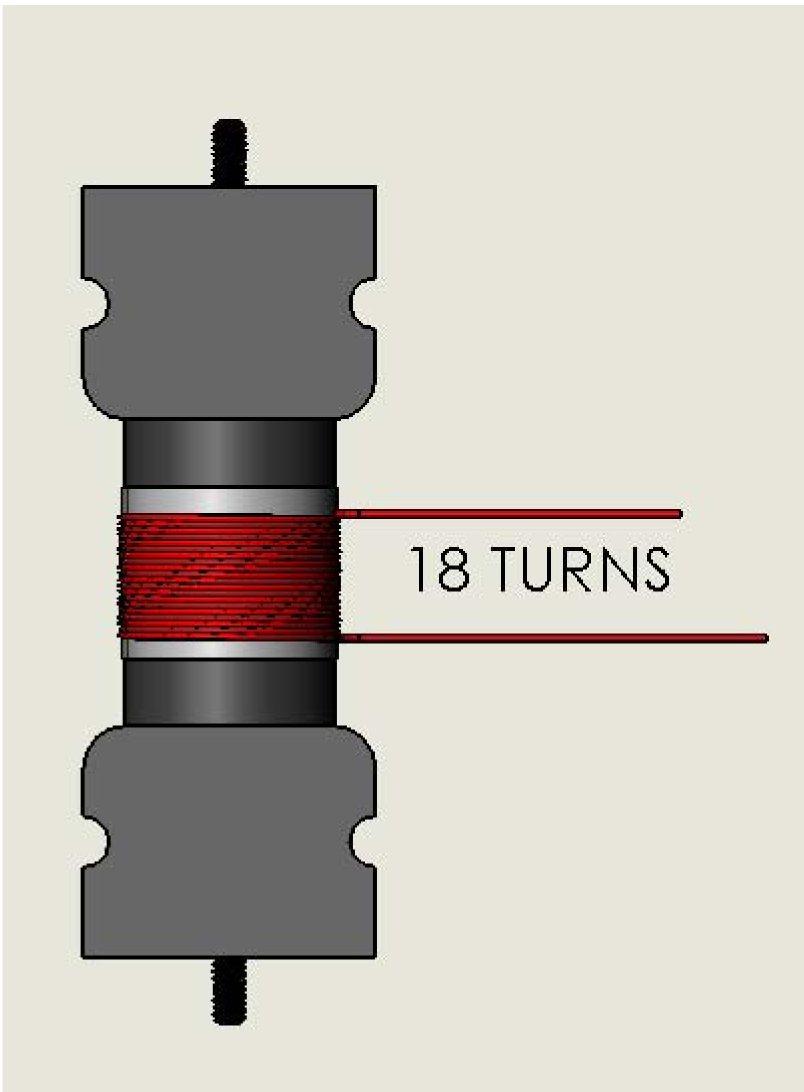
Table 3: Spacer Winding Data

STACK PACK PART	# Turns	A_L	Variation	INDUCTANCE (uH)
Spacer	20	173	117%	69.1
	20	161	109%	64.3
	20	168	114%	67.2
	20	158	107%	63.1
	20	155	105%	61.8
	20	148	100%	59
Calculated A_L Value	160	160	+/-12%	64.08

Leg and Two Corners

Figure 3 shows the configuration of a stack comprised of two corner pieces and on leg. The leg used in this was one of the six that were previously wound. Data was taken at four different frequencies to measure the inductance and the increase in A_L due to the addition of the corners. The data for this is shown in Table 4.

Figure 3: Corner - Leg - Corner Winding



Spacer and Two Corners

Figure 4 shows the configuration of two corners and one spacer and the winding placement. One of the wound spacers from the previous section was used. Data for this configuration is shown in table 4.

Figure 4: Corner - Spacer - Corner Configuration

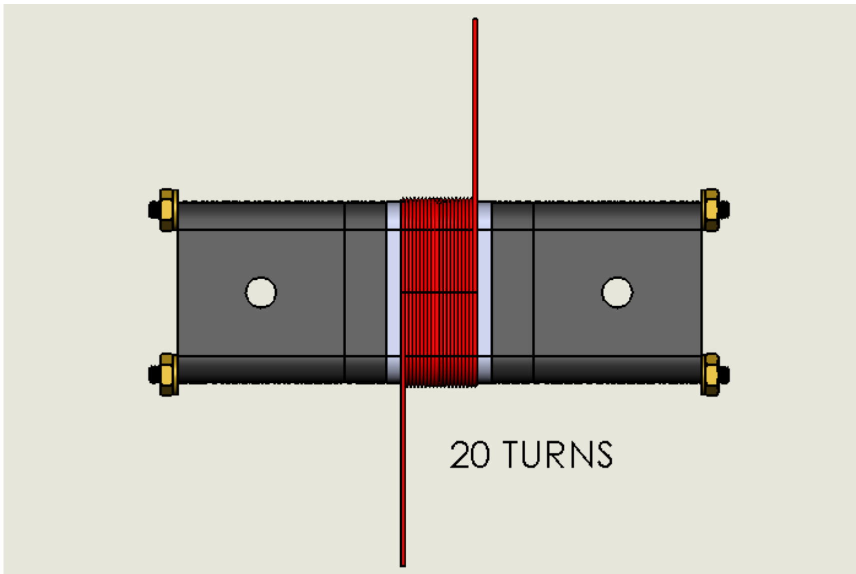


Table 4: Inductance Measurements

	Inductance			
Frequency	1KHz	10KHz	100KHz	150KHz
Leg	46.152	45.92	45.72	45.57
Spacer	67.27	67.24	67.2	67.24
Corner - Leg - Corner	100.8	100.7	100.5	100.45
Corner - Spacer - Corner	128.4	127.29	125.5	123.1

Table 5: AL Evaluation

Frequency	**A_L for 1 Leg**	**A_L for 1 Corner - Leg - Corner**	**ΔA_L**	**A_L for 1 Spacer**	**A_L for 1 Corner - Spacer - Corner**	**ΔA_L**
1KHz	142.44	311.11	168.67	168.18	321.00	152.83
10KHz	141.73	310.80	169.07	168.10	318.23	150.13
100KHz	141.11	310.19	169.07	168.00	313.75	145.75
150KHz	140.65	310.03	169.38	168.10	307.75	139.65

Full Rectangle

A complete rectangle was configured as shown in figure 7 below. This was built utilizing components from the previous sections. The data for this is shown in table 6.

Figure 5: Rectangular Transformer

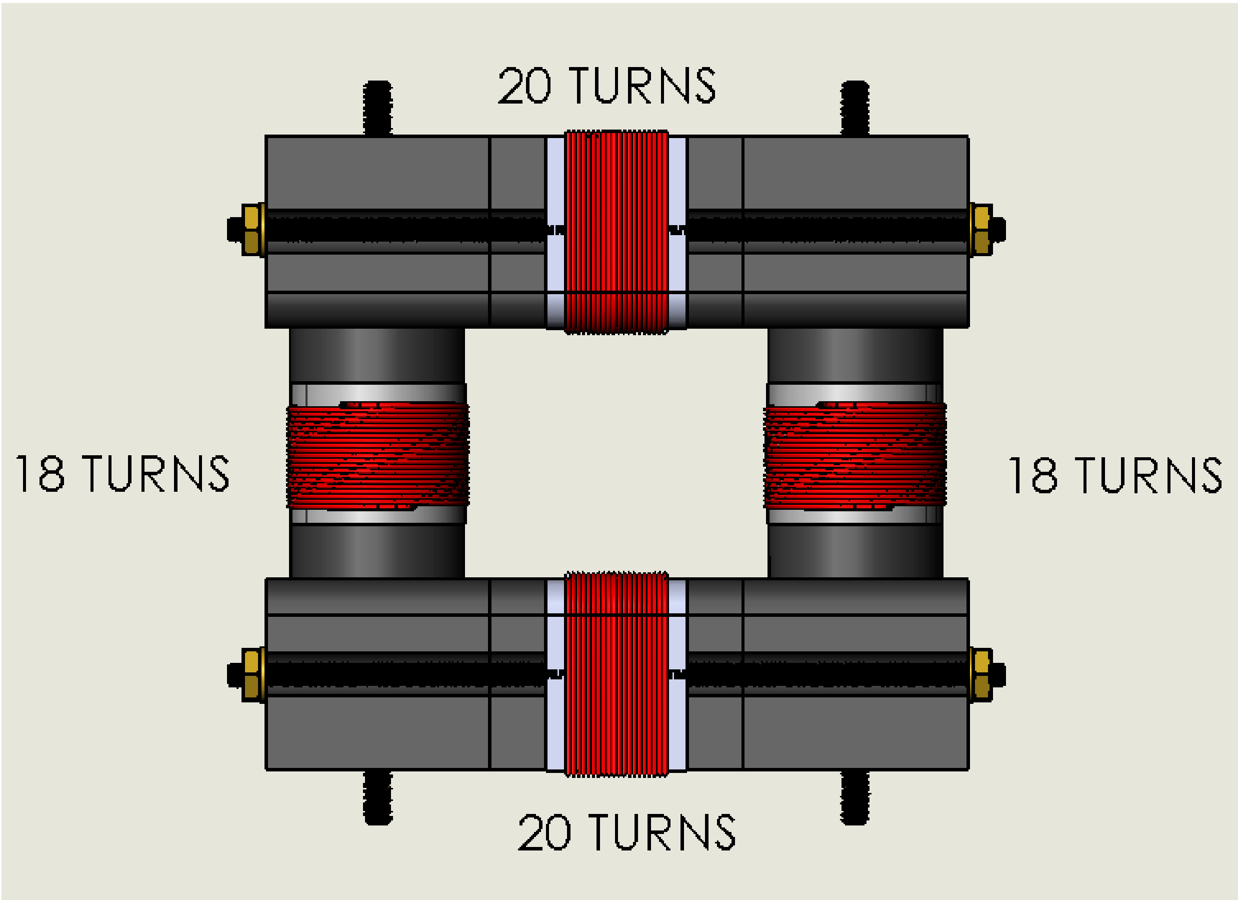


Table 6: Data for Configuration Shown in Figure 5

Rectangular Build: 2 Legs, 2 Spacers, 4 Corners				
	Inductance (mH)	**Leakage Inductance (uH)**	**Turns**	**A_L**
Left Leg	1.261	127	18	3892
Right Leg	1.259	136	18	3886
Top Section	1.578	136	20	3945
Bottom Section	1.577	136	20	3943

Full Rectangle – Two Spacers and 2 Legs

The final configuration to look at is a core comprised of four legs, four spacers, and four corners. This is shown in Figure 6.

Figure 6: Four Legs, Four Spacers, Four Corners

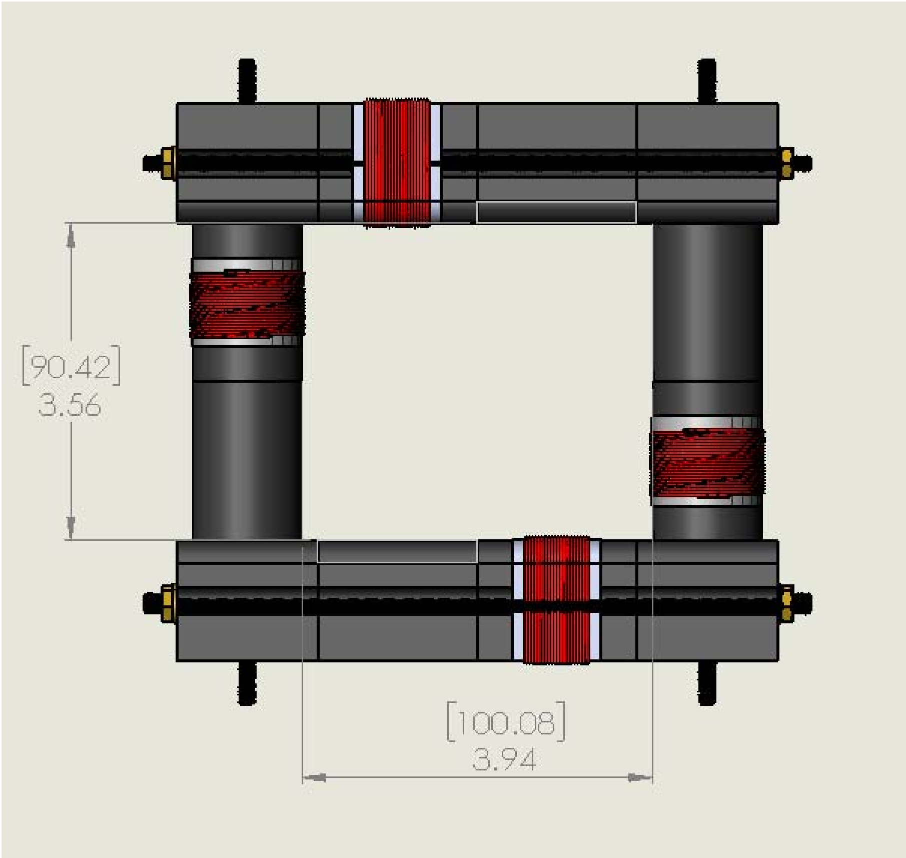


Table 7: Data for Configuration in Figure 8

Rectangular Build: 4 Legs, 4 Spacers, 4 Corners				
	Inductance (mH)	**Leakage Inductance (uH)**	**Turns**	**A_L**
Left Leg	1.605	128	18	4954
Right Leg	1.607	129	18	4960
Top Section	1.978	170	20	4945
Bottom Section	1.976	169	20	4940

Power Handling

One of the key factors in designing High VA transformers and inductors is the value of WaAc. This is the product of the winding area and the effect cross sectional area of the core. This is written as:

$WaAc = Wa * Ae$. Where Wa is the winding area of the core and Ac, (also known as Ae), is the cross-sectional area of the core. There are two ways of looking at the winding area. The first is the raw winding area. This is the area within the perimeter of the core. The second, and more useful, is to look at how much of the winding area can be filled in a production environment, this is the fill factor.

Example 1: WaAc

The figure 7 below shows the dimensions to be used for calculating the winding area. Note that the units to be used in this calculation is cm. The winding area is defined as the height of the window times the width of the window. For this configuration, the result is:

$$Wa = 5.461 * 4.521 = 24.69cm^2$$

We know that from a practical standpoint the window cannot be wound to 100% of the window area. Depending on the manufacturing techniques and the equipment used the fill factor will vary. The value that I prefer is 75%. This will leave room for assembly and for insulation. In this example, we are using four windings. Let's assume that the windings on the spacers are used in parallel, and the windings on the legs are two separate windings. Each winding can now take up 1/3 of the winding area. First, we will calculate the effective winding area: $Wa_{efective} = Fill\ Factor * Wa = 0.75 * 24.69 = 18.51$. Now we calculate how much of the effective area can be used for each winding. This results in: $Wa_{winding} = \frac{Wa_{effective}}{3} = \frac{18.51}{3} = 6.17cm^2$. To calculate WaAc we substitute the Ac value of 7.24cm^2 into the equation: $WaAc = 18.51cm^2 * 7.24cm^2 = 134.01cm^4$

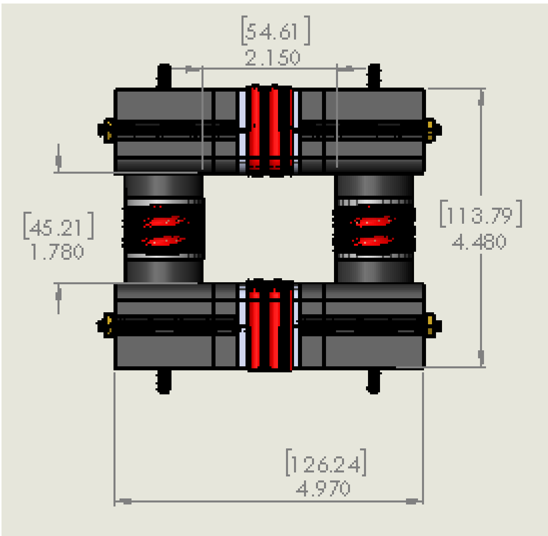


Figure 7: Winding Area

The table below shows the characteristics of five different configurations of the StackPack™ components. The configurations are shown in Figure 8.

Figure 8: Configurations of StackPack™ Parts

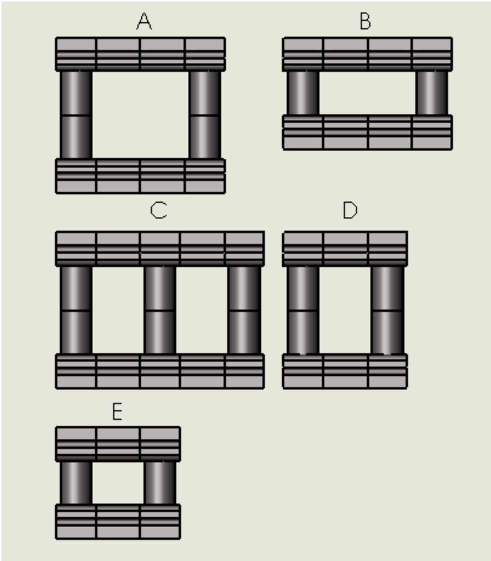


Table 8: Characteristics of StackPack™ Parts

Configuration		Ac (cm^2)	Wa (cm^2)	WaAc (cm^4)	Volume (cm^3)	Weight (kg)
A	4 corners, 4 Legs, 4 Spacers	7.24	90.49	655.16	607.6	4.38
B	4 Corners, 2 Legs, 4 Spacers	7.24	45.25	327.58	542.14	3.9
C	"E" Core	7.24	49.38	357.50	782.18	5.63
D	4 Corners, 4 Legs, 2 Spacers	7.24	49.38	357.50	478.69	3.45
E	4 Corners, 2 Legs, 2 Spacers	7.24	24.69	178.75	413.22	2.98

Bringing It All Together

Once you have determined the minimum size of the core required for your design you need to determine the amount of winding space required. This is referred to WaAc. The next step is to determine the amount of fill that your manufacturing operations will allow. This is referred to as the Fill Factor. By calculating the minimum Ac for the Primary, one can determine the minimum size of the transformer winding area. This is determined by the equation: $A_c = \frac{V_{rms}*1E^4}{k_f*B*n*F}$. Where:

k_f is a constant: 4 for a square wave, and 4.4 for a sinewave

B is the desired flux density

n is the number of turns on the primary

F is the operating frequency.

Depending on the type of transformer the desired flux density can range from 45% to 65% of the saturation level of the material. For most applications, the Volts per Turn can range from 1 to 2.5V per turn. The number of turns required is calculated by: $n = \frac{V_p}{V/_{Turn}}$. From this information two things can be quickly derived: the size of the wire required and the build of the windings. Now that you have determined the minimum size of the transformer and the winding area required, the minimum WaAc required can be determined. Once you have this information the raw WaAc of the core can be determined by using: $WaAc = \frac{WaAc_{min}}{Fill\ Factor}$. This is where the StackPack™ comes in! Chances are you will a challenge ahead of you trying to find a core that is not excessively big to fit your needs. By using the StackPack™ components you can utilize off the shelf parts that are readily available to build your own core that truly meets your needs.