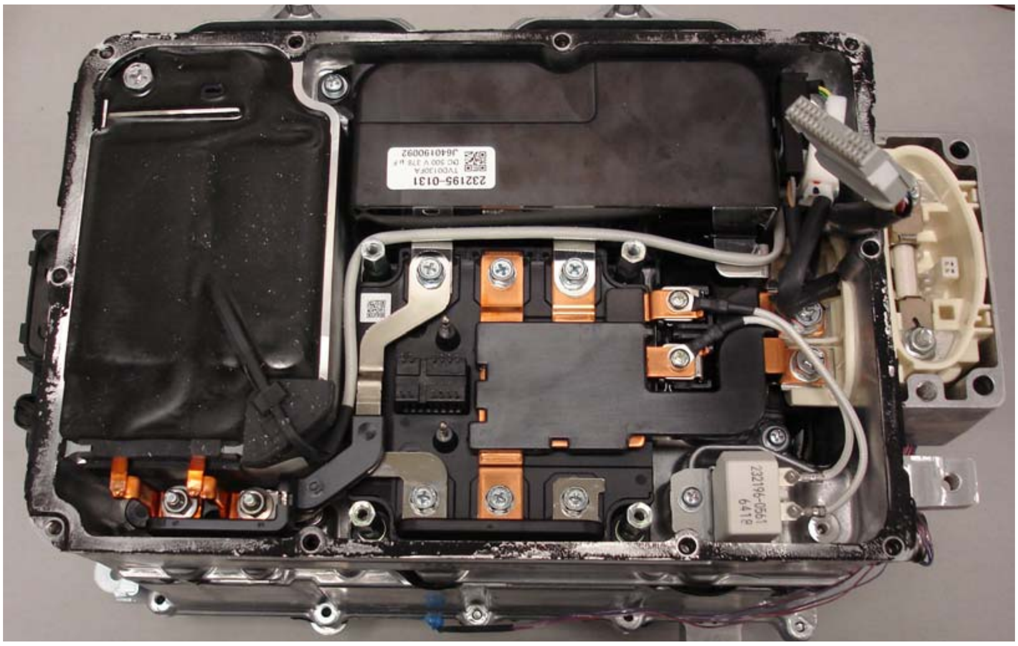

Fig. 2.3. Boost converter compartment with lid and intelligent power module (IPM) driver board removed.

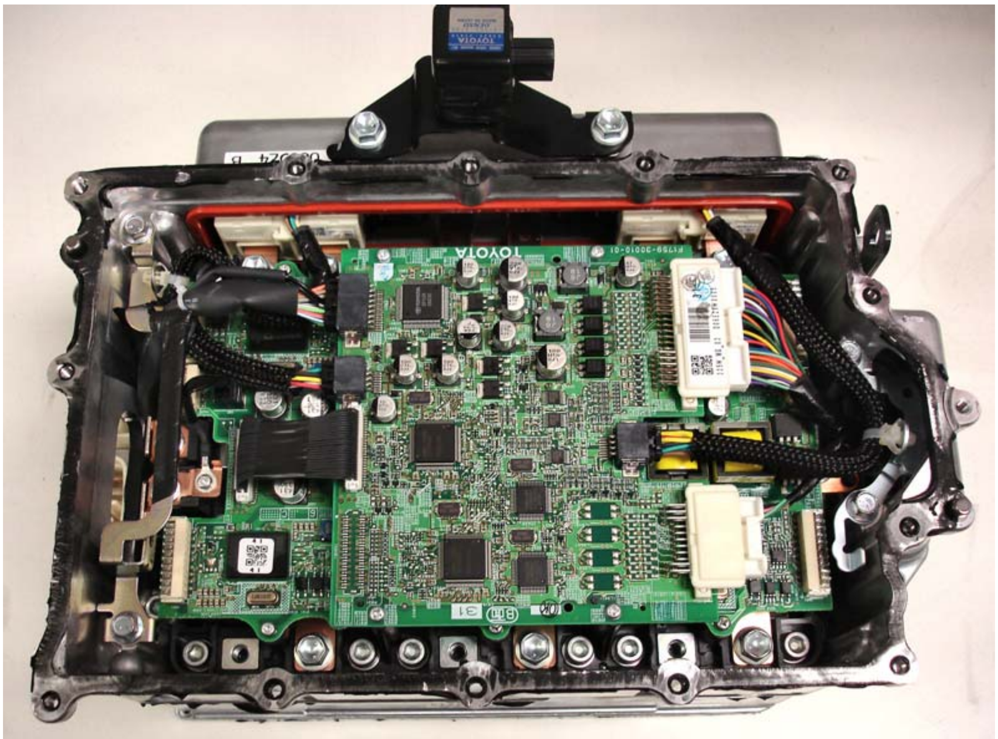

Fig. 2.4. Inverter compartment (upside down) with dc-link capacitor and casing removed.

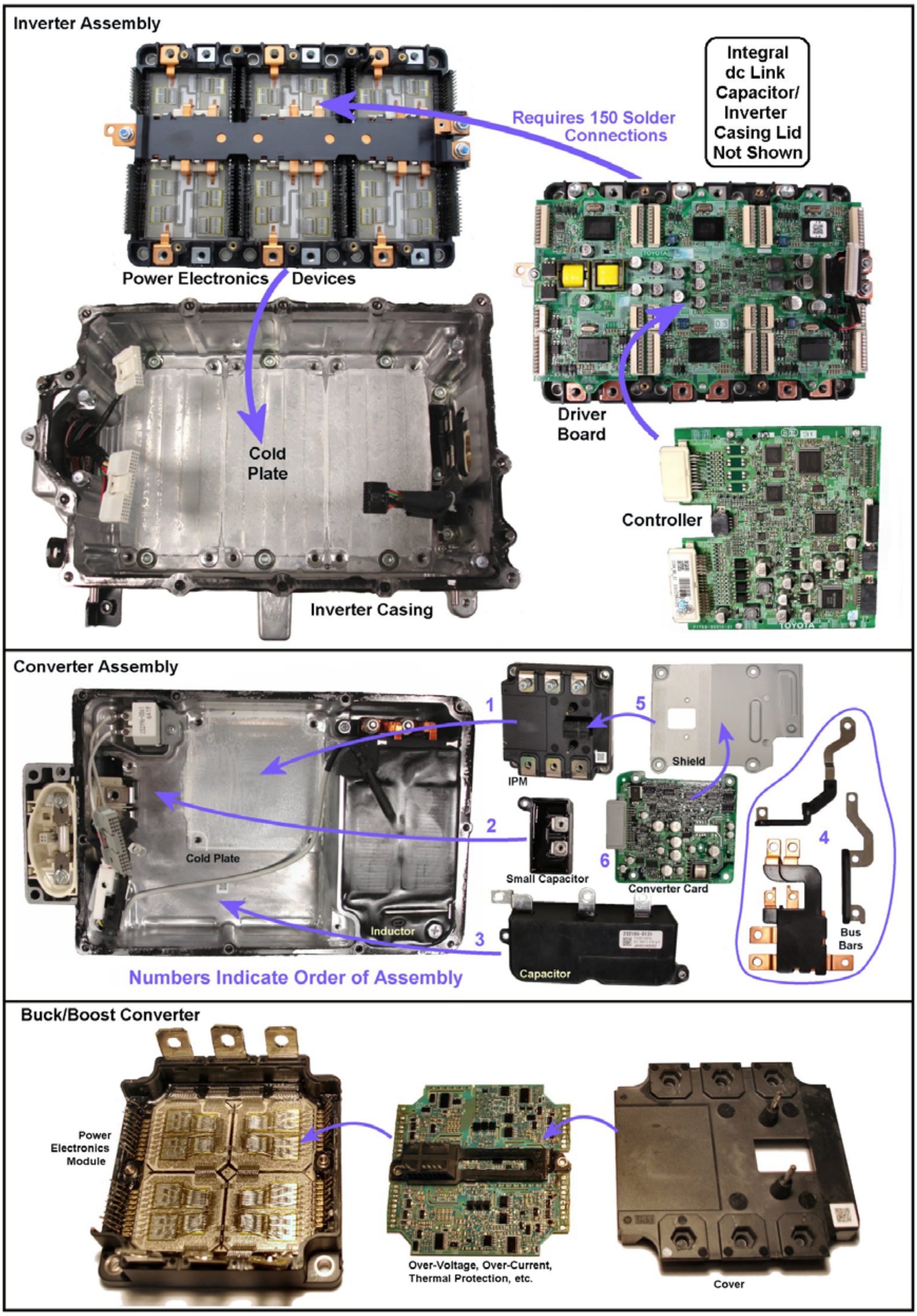

Fig. 2.5. General assembly and packaging of the Camry inverter and converter.

The converter compartment contains the IPM, IPM driver, power supply board, LV filter capacitor, large inductor, bus bars, and an electromagnetic interference (EMI) shield for the circuit board. Additionally, a small filter capacitor and resistor are located in the upper portion of the PCU and are connected to the HV dc link. Connectors are also included for the inductor thermistor and safety interlock device feedback signals.

The Prius has an inverter which supplies power to the air conditioning (A/C) compressor, and it is located in the bottom section of the PCU, whereas the Camry A/C inverter is not housed within the PCU. A dc-dc converter which converts the high battery voltage of about 200V to an accessory voltage level of about 14V is also located in the bottom section of the Prius PCU, whereas this component is located in the battery module of the Camry.

Figure 2.6 shows the cooling plate coolant paths for the converter (top view) and inverter (bottom view) and an enlargement of the converter coolant path configuration. The inverter photo was flipped to make comparisons easier. The holes for the inlet and outlet coolant fittings are shown in the upper and lower left-hand corners of the cold plates. The fins increase the surface area and heat transfer, and the ripples are fabricated in the fin casting to create turbulence, which also increases heat transfer. Asymmetric features in the channel walls and/or no-fin areas promote mixing. In general, the design features are likely the result of detailed heat transfer/coolant flow modeling.

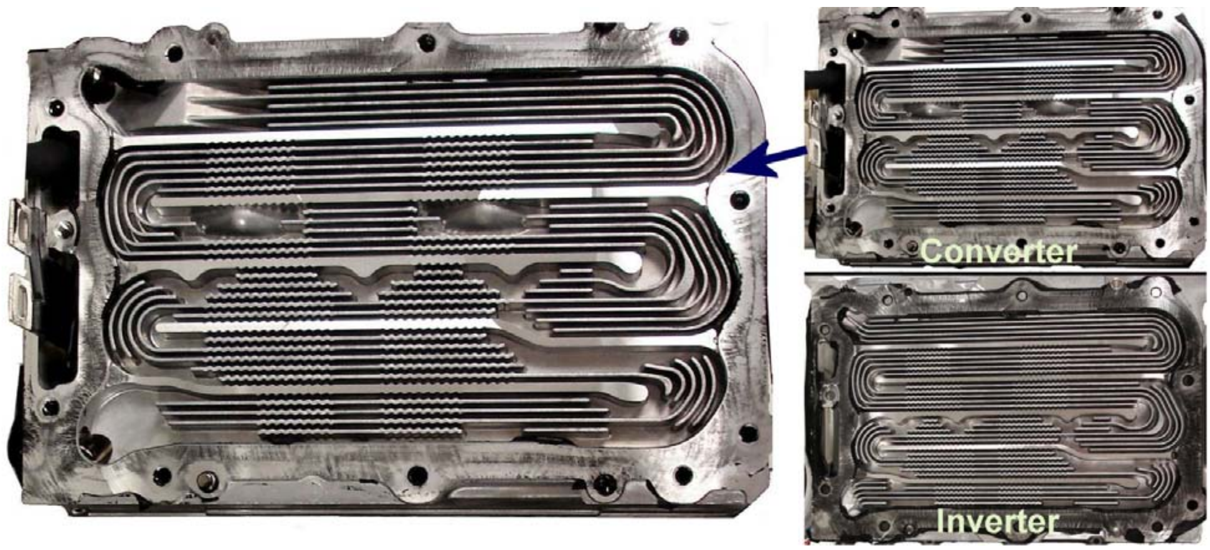

Fig. 2.6. Coolant flow paths in mating converter and inverter cold plates.

Table 2.3 provides physical measurements of the hybrid Camry inverter and boost converter. The inverter/converter casing was unbolted and separated in order to obtain precise mass measurements that are reflected in the total mass shown for each subsystem. The table also gives estimates for the mass and volume of the motor inverter by itself (i.e., excluding the generator inverter).

For certain components, the dimensions and volumes are approximate since the geometries are sometimes irregular. The entire aluminum casing unbolts and separates midway through the thickness of the cold plate and the volumes are divided up between the inverter and converter accordingly.

The mass of the large, potted inductor used in the buck/boost converter, although an integral part of the converter casing, is estimated to be 3.0 kg. This estimate was derived by subtracting the estimated mass of the converter aluminum (2.0 kg) from the total measured mass of the two (5.02 kg).

Table 2.3. Mass and volume measurements for the hybrid Camry inverter and converter

Item	Mass (kg)	Volume (L)	Dimensions (cm)
Inverter/converter as received from OEM.	17.86 (17.42 without mounting brackets)	11.7	Summation of inverter and converter sections (below)
Inverters (MG1 and MG2)			
DC-link capacitor mold in an aluminum case.	3.57	2.6	18.5 × 27 × 5.3
Side housing assembly containing the three-phase bus connectors and current transformers (CTs).	1.2	0.98	~4.5 × 23 × 9.5
Inverter electronics and main casing to mid-point of cooling plate.	5	4.3	18.5 × 27 × 10.5
Connector and housing at end of casing.	(incl. above)	0.31	10.2 × 3.8 × ~8
Complete inverters	**9.8**	**8.19**	Combine the above
Inverter for motor only			
DC-link capacitor mold in an aluminum case.	3.57	2.6	18.5 × 27 × 5.3
Side housing assembly containing the three-phase bus connectors and CTs.	0.69	0.56	~4.5 × 12 × 9.5
Inverter electronics and main casing to mid-point of cooling plate.	~3.3	~2.8	11.1 × 27 × 10.5
Complete motor inverter	**~7.5**	**~6**	Combine the above
Converter			
Boost converter inductor.	~3.5	1.14	8.8 × 17.5 × 7.4
Converter filter capacitor.	0.57	0.84	6.3 × 18.1 × 7.4
Electronics compartment and casing.	~ 0.9 + 1.7	1.51	11.3 × 18.1 × 7.4
Complete converter	**~6.6**	**3.5**	17.5 × 26.9 × 7.4

Based on the results shown in Table 2.3, Table 2.4 provides the peak power density and peak specific power of both the motor inverter and the bi-directional boost converter. Comparisons to corresponding estimates for the Prius are also shown. The Camry specifications in Table 2.4 are very impressive as the power density of the motor inverter and bi-directional boost converter has more than doubled when compared to that of the Prius. The Camry motor inverter specific power is also significantly larger, yet the boost converter specific power is only slightly higher as the mass increase closely followed the rated power increase.

Table 2.4. Specific power and power density estimates for inverter/converter

Parameter	Camry	Prius
Motor inverter peak specific power (without converter), kW/kg.	70/~7.5 = **~9.3**	50/8.8 = **5.7**
Motor inverter peak power density (without converter), kW/L.	70/~6 = ~**11.7**	50/8.7 = **5.7**
Bi-directional boost converter specific power, kW/kg.	30/~6.6 = **~4.5**	20/4.8 = **4.2**
Bi-directional boost converter power density, kW/L.	30/3.5 = **8.6**	20/5.1 = **3.9**[1]

[1] This low converter power density is largely the result of the non-optimal packaging of the converter filter capacitor in the Prius inverter/converter housing.

It is interesting to note that the converter mass increased by 38% and the volume decreased by 31% in going from the 2004 Prius to the 2007 Camry PCU design. A mass increase is likely unavoidable given that the power increased from ~20 kW to ~30 kW. Regarding the decrease of volume, the Camry converter has a small amount of associated null space as is evident in Fig. 2.7 while the Prius converter design (Fig. 2.8) integrates a tall inductor next to a short IPM resulting in wasted space above the IPM and additional wasted space exists around both components. Not shown in Fig. 2.8 is the volume of the converter portion of the monolithic capacitor module and surrounding space. Although the *potential* exists for easily reducing the volume of the Prius converter, the volume calculation is based on the actual dimensions of the casing. However, the component specifications are provided separately to allow for various approaches of calculating specific power and power density. See Appendix A for details on the measurement of the Prius PCU and motor inverter mass and volumetric assessment details.

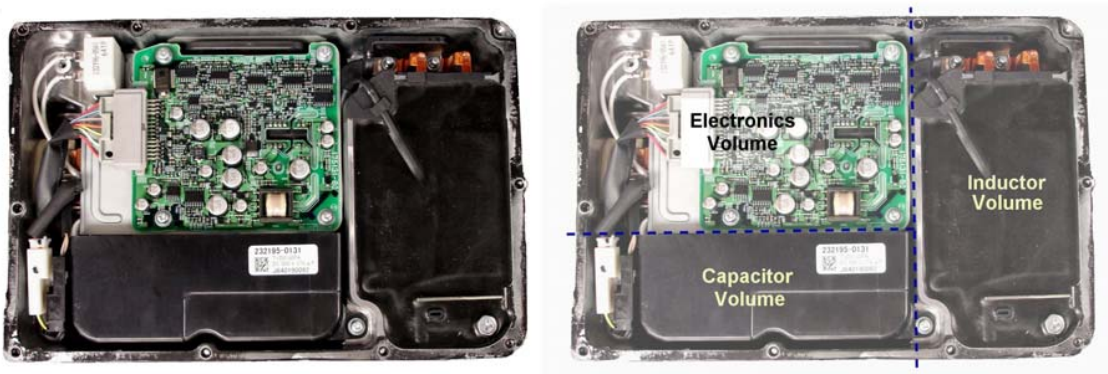

Fig. 2.7. Converter assembly with subsections shown consistent with volume measurements.

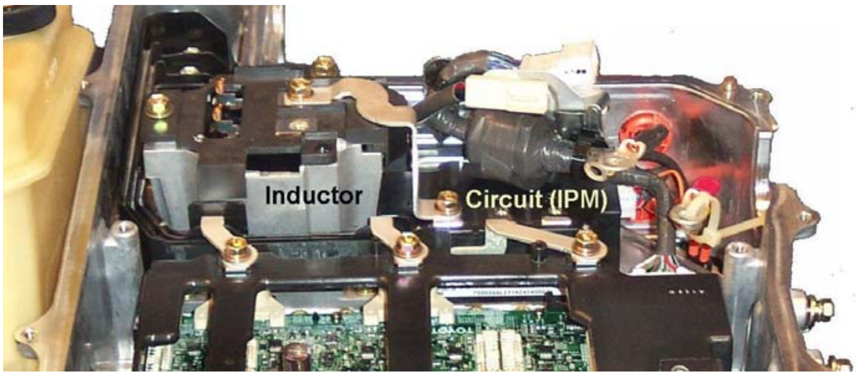

Fig. 2.8. Non-optimized packaging used in the 2004 Prius converter.

All capacitors located within the Camry PCU are shown in Fig. 2.9 for a comparison of sizes. It is important to note that that the Prius capacitor module contains both capacitors which are connected to the HV and LV side of the bi-directional boost converter as well as a small filter capacitor, whereas the Camry capacitors are housed in separate modules. Figure 2.10 shows the Camry dc-link capacitor and a negative image of an x-ray of the capacitor. The x-ray shows that there are two rows of 12 discrete sub-modules inside the entire capacitor module, with each capacitor having a capacitance of 87 μF. The equivalent Prius capacitor has 8–142 μF capacitors in parallel to provide a total capacitance of 1,130 μF. Figure 2.11 shows the 378 μF Camry filter capacitor and an x-ray of the capacitor which is across the battery input of the PCU. As suggested by the x-ray image, the 378 μF capacitance is attained with two 189 μF capacitors in parallel. Similarly, the small 0.9 μF capacitor is made up of two 0.45 μF capacitors,