Electrical Noise Suppression and Common Mode Choke

Common Mode Choke Design with Different Winding Techniques and Wire Shape

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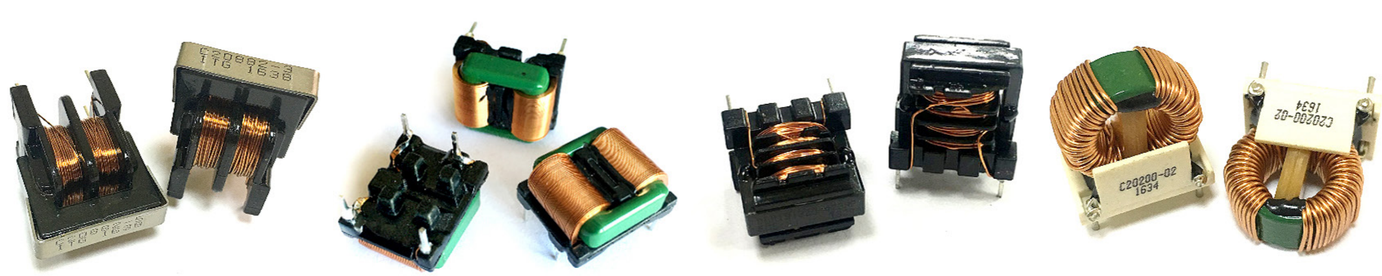

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Common Mode Choke Design with Different Winding Techniques and Wire Shape

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Abstract -- At higher frequencies the impedance of a common mode choke becomes an important factor to effectively suppress EMI noise. This paper will discuss common mode noise generators and how it can be suppressed by using a common mode choke; further discussing impedance improvements by using different winding techniques and wire shapes that enhance the performance and efficiency of the common mode choke.

I. INTRODUCTION

Continuous electrical humming noise can be very annoying and may be harmful to hearing. This paper will briefly discuss the noise; electromagnetic interference, common mode and differential mode noise and how common mode choke functions with description and effect of a common mode filter. Further discuss the general and inductive impedance and comparisons of different winding technique and wire shape to provide a better efficient choice of common mode choke selection.

II. NOISE AND EMI

Noise is an unwanted, loud, or confused sound which is meaningless but disruptive to hearing. There are typically two different types of noise, acoustical noise and electrical noise.

Acoustical noise is any unwanted sound or vibration that is audible to the human ear and/or tangible via touch.

Electrical noise is by literal definition, not particularly audible or discernible by tactile interaction with the component or equipment.

To further explain the electrical noise, it is not audible to the human ear. Even in high-end audio equipment, actual electrical noise is not audible, but its effect on the analog audio output is audible as distortion at many or just certain frequencies. The noise itself requires specialized test equipment to detect, analyze, and define.[1]

By standard definition, electrical noise is any unwanted variation in an electrical signal. In fact, all circuits have some inherent electrical noise. Once again, depending on the circuit or system, electrical noise may be acceptable within certain limits.[1]

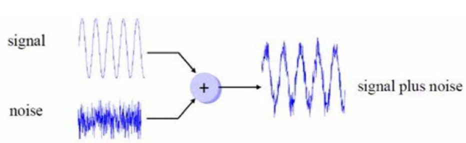


Fig. 1 Noise Combination Signal

Electromagnetic interference (EMI) falls under the category of electrical noise. A basic change of state (such as On/Off) in an electronic component has the potential to generate EMI. Typical examples are electronic switch mode power supplies, clocks, electronic controls, power supplies, inverters, fluorescent lights, motor brushes, etc.…

The EMI noise can be either **radiated** through the air or **conducted** through the power line which includes common mode noise, and differential mode noise.[2]

A common mode noise is a signal transferring between all the lines in the same direction to the ground in a circuit.

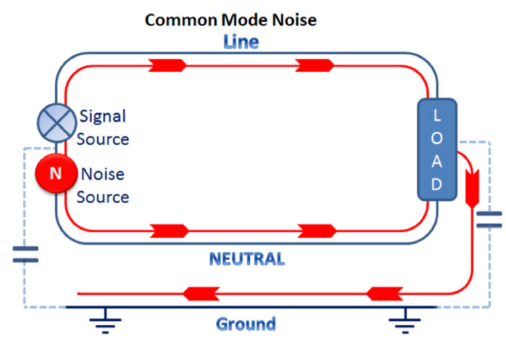


Fig. 2 Common Mode Noise

Differential mode noise is a signal conducting between Vcc and ground in the opposite direction.

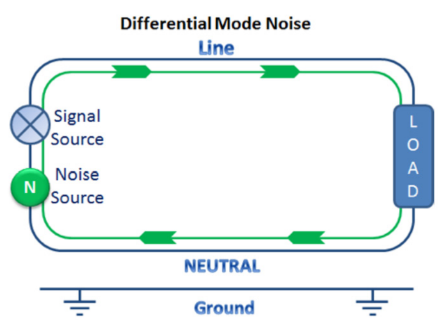


Fig. 3 Differential Mode Noise

III. COMMON MODE FILTER

Common-mode chokes (CMC) in theory are made up of a single core with two identical coils which are wound around the core in different directions.

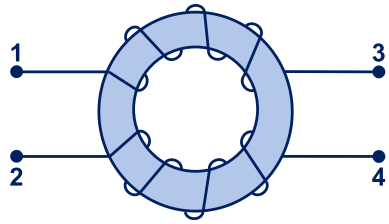


Fig. 4 Common Mode Choke

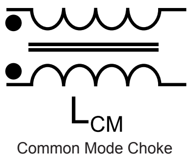


Fig. 5 CMC Electronic Symbol

It is primarily used to prevent electromagnetic interference (EMI) from the power supply lines. This can help prevent electronic equipment in an AC circuit from malfunctioning. CMC is in fact a bifunctional filter: *To filter out external common mode electromagnetic interference and to prevent sending out electromagnetic interference.*

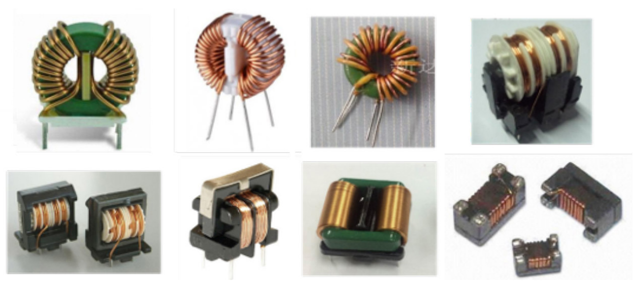


Fig. 6 CMC Samples

To further understand how CMCs function, when the currents enter the CMC in opposite directions, they produce two magnetic fields in the windings that cancel each other. The choke then presents very little inductance or impedance and the core will not saturate even with large input currents.

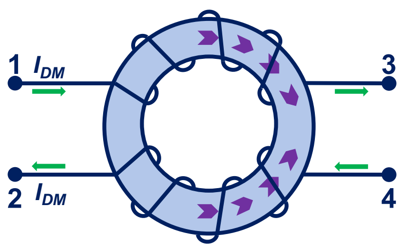


Fig. 7 CMC w/Differential Mode Current

On the other hand, if the currents enter the CMC in the same direction, the two magnetic fields are adding together to provide a very large inductance or impedance, which will play a role in suppressing common mode noise.

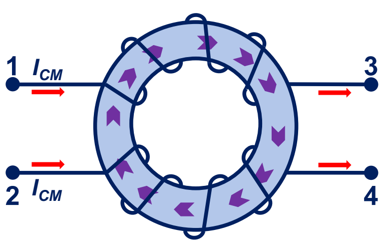


Fig. 8 CMC w/Common Mode Current

When a common mode choke is being designed to act as a circuit filter in the circuit, it attenuates the energy down to a given frequency, which reduces the unwanted noise entering the load. The choke then produces a large inductance, and filters out the common mode noise only, but allows the differential mode signal to pass through the filter.

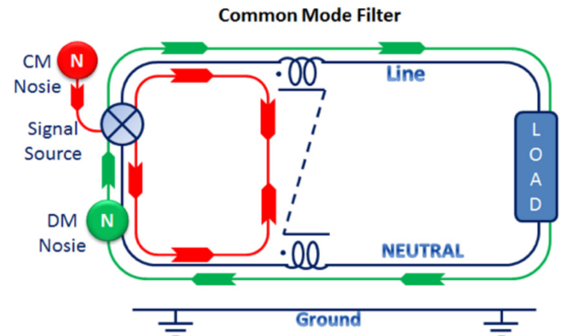
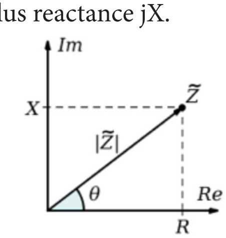


Fig. 9 Common Mode Filter

IV. IMPEDANCE

Impedance is the AC equivalent to a concept of resistance in DC; it is a comprehensive expression in forms of opposition to electron flow, including both resistance and reactance. It is present in all circuits, and in all components. The reactance could be inductive or capacitive. When alternating current goes through impedance, a voltage drop is produced that is somewhere between 0° and 90° out of phase with the current. Impedance is mathematically symbolized by the letter "Z" and is measured in the unit of ohms (Ω);[3] it is a complex form of resistance R plus reactance jX.

$$Z = R + jX$$



Calculating,

$$Z = \sqrt{R^2 + X^2}$$

When AC passes through a component that contains reactance, energy might be stored and released in the form of a magnetic field, in which case the reactance is inductive; or energy might be stored and released in the form of an electric field, in which case the reactance is capacitive.[4]

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

When the net reactance is inductive only,

$$Xc = 0$$

then

$$Z = \sqrt{R^2 + {X_L}^2}$$

where $X_L = 2\pi f L$

and Z becomes the inductive impedance.

V. IMPEDANCE COMPARISON

The following are some comparison between different winding techniques, different winding location, and round wire/flat wire common mode choke with comparison of the traditional T-Core and rectangular flat wire common mode choke. Let see if there is any performance change in between.

Table 1 shows a few different winding techniques as single-layer, multi-layer and cross winding. All of them are using round copper wire with diameter of 0.8mm and wound with 22 turns. They all have similar inductance, DCR and parasitic capacitance. But the single-layer shows the lowest leakage inductance with higher series resonant frequency (SRF). Cross winding also shows high SRF, but this technique is hard to wind and not compatible with machine winding as well.

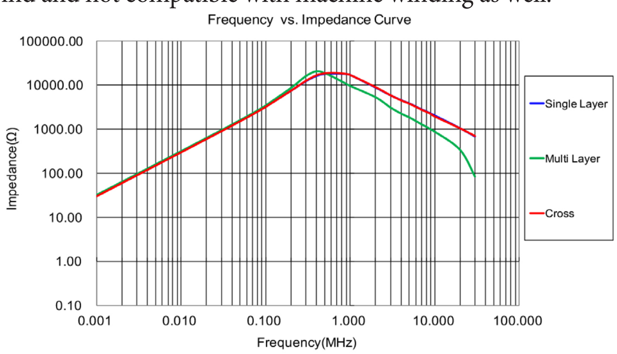


Fig. 10 Impedance Curves I

From the impedance vs frequency curve, it shows that the single-layer and cross winding have similar results, both are better than the multi-layer, and single-layer has lower leakage inductance and is machine windable, which cross winding is not.

Type 1	Type 2
Long-Side Winding	Short-Side Winding

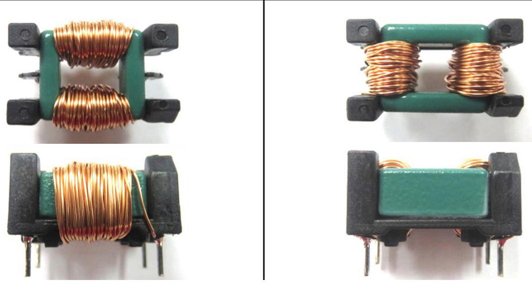


Fig. 11 Different Location Winding

Now let's see with a rectangular core body if winding in different locations affects performance. The coils were wound on the longer side vs the shorter side of the rectangular core body as the picture shows.

	Type 1		Type 2	
	Long-Side Winding		Short-Side Winding	
Winding Parameter	1.Wire: Round copper wire: Size: 0.4mm 155°C; 2.Turns: 48Ts;		1.Wire: Round copper wire: Size: 0.4mm 155°C; 2.Turns: 48Ts;	
Electrical	L @+25°C: at 16KHz/1V:	L(1-2)=9.810mH L(4-3)=9.810mH	L @+25°C: at 16KHz/1V:	L(1-2)=10.080mH L(4-3)=10.080mH
	Lk @+25°C:at 16KHz/1V:	Lk(1-2)=86.22uH	Lk @+25°C:at 16KHz/1V:	Lk(1-2)=141.84uH
		Lk(3-4)=86.18uH		Lk(3-4)=141.67uH
	DCR @+25°C:	DCR1(1-2)=143.90mΩ	DCR @+25°C:	DCR1(1-2)=159.83mΩ
		DCR1(4-3)=158.54mΩ		DCR1(4-3)=153.75mΩ
	C @+25°C: at 16KHz/1V:	C(1-4)=13.030PF	C @+25°C: at 16KHz/1V:	C(1-4)=13.030PF
	SRF:	346 KHz	SRF:	382 KHz

Table 2 Different Location Comparison

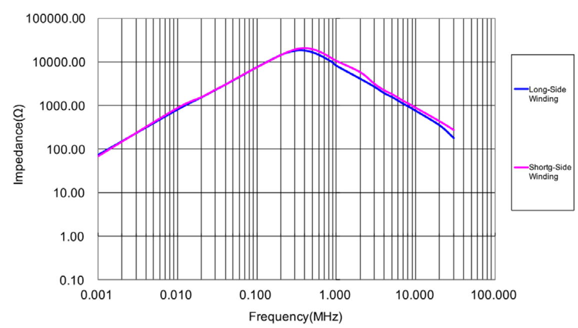


Fig. 12 Impedance Curves II

From the electrical result in ***Table 2***, and with the same round wire of 0.4mm diameter and wind 48 turns, the short side winding gives a higher leakage inductance and was more difficult to wind compared to long-side winding.

The impedance comparison curves show both long-side winding and short-side winding have a very similar result, and the short side winding actually comes out with a little higher SRF. But it also gives a higher leakage inductance.

Now let's compare the round wire and flat wire with two identical rectangular core bodies and see if there is any difference.

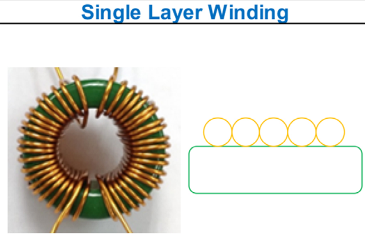
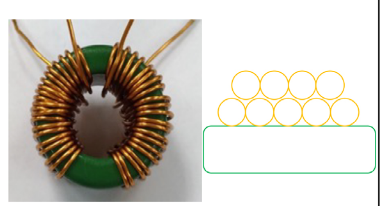
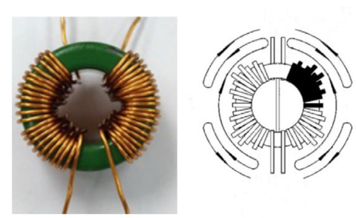
	Type A		Type B		Type C	
	Single Layer Winding		Multi Layer Winding		Cross Winding	
Picture						
Winding Parameter	1.Wire: Round copper wire: Size: 0.8mm 155°C; 2.Turns: 22Ts; 3.Winding Method: N1:clockwise / N2:Anti-clockwise;		1.Wire: Round copper wire: Size: 0.8mm 155°C; 2.Turns: 22Ts; 3.Winding Method: N1:clockwise / N2:Anti-clockwise;		1.Wire: Round copper wire: Size: 0.8mm 155°C; 2.Turns: 22Ts; 3.Winding Method: N1:clockwise / N2:Anti-clockwise;	
Electrical	L @+25°C: at 10KHz/50mV:	L1(1-2)=4.87mH L2(4-3)=4.87mH	L @+25°C: at 10KHz/50mV:	L1(1-2)=4.906mH L2(4-3)=4.906mH	L @+25°C: at 10KHz/50mV:	L1(1-2)=4.708mH L2(4-3)=4.708mH
	DCR @+25°C:	DCR1(1-2)=35.84mΩ	DCR @+25°C:	DCR1(1-2)=35.85mΩ	DCR @+25°C:	DCR1(1-2)=36.13mΩ
		DCR1(4-3)=35.45mΩ		DCR1(4-3)=35.56mΩ		DCR1(4-3)=35.55mΩ
	C @+25°C: at 10KHz/50mV:	C 1(1-4)=96.0PF	C @+25°C: at 10KHz/50mV:	C 1(1-4)=92.8PF	C @+25°C: at 10KHz/50mV:	C 1(1-4)=94.0PF
	Lk @+25°C:at 10KHz/5.mV:	Lk 1(1-2)=23.39uH	Lk @+25°C:at 10KHz/5.mV:	Lk 1(1-2)=27.25uH	Lk @+25°C:at 10KHz/5.mV:	Lk 1(1-2)=29.50uH
		Lk 1(3-4)=23.93uH		Lk 1(3-4)=27.31uH		Lk 1(3-4)=29.40uH
	SRF:	L1 : 655 Hz	SRF:	L1 : 464 Hz	SRF:	L1 : 655 Hz

Table 1 Different Winding Comparison

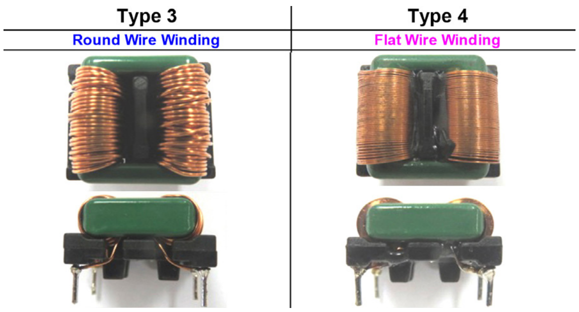


Fig. 13 Round Wire vs Flat Wire

	Type 3 Round Wire Winding		Type 4 Flat Wire Winding	
Winding Parameter	1.Wire: Round copper wire: Size: ∮0.40mm 155°C; 2.Turns: 48Ts;		1.Wire: Flat Wire: SFT-UEWH 180°C, Size: 0.13x1.0mm; 2.Turns: 48Ts;	
Electrical	L @+25°C: at 16KHz/1V:	L(1-2)=11.36mH L(4-3)=11.32mH	L @+25°C: at 16KHz/1V:	L(1-2)=10.98mH L(4-3)=11.02mH
	Lk@+25°C: at 16KHz/1V, Short other pins :	Lk(1-2)=81.64uH Lk(4-3)=81.45uH	Lk@+25°C: at 16KHz/1V, Short other pins :	Lk(1-2)=88.38uH Lk(4-3)=88.62uH
	DCR @+25°C:	DCR(1-2)=133.27mΩ DCR(4-3)=133.84mΩ	DCR @+25°C:	DCR(1-2)=128.24mΩ DCR(4-3)=128.43mΩ
	Capacitance: at 16KHz/1V:	C(1-4)=13.02PF	Capacitance: at 16KHz/1V:	C(1-4)=5.65PF
	SRF:	315.0KHz	SRF:	700.0KHz

Table 3 Round Wire vs Flat Wire

Fig. 13 shows two identical cores with round wire of 0.4mm diameter on the left, compared to flat wire of the same cross sectional area on the right, with identical 48 turns. From **T*able 3*,** the electrical result shows the flat wire winding provides a little higher leakage inductance, but it also shows lower DC resistance (DCR) with less than half of the parasitic capacitance. The SRF of flat wire is more than double comparing to the round wire. The ***Fig. 14*** impedance cuves result shows a big jump in the SRF for flat wire comparing to the round wire. This tells that the flat wire will offer superior noise suppression performance at higher frequency.

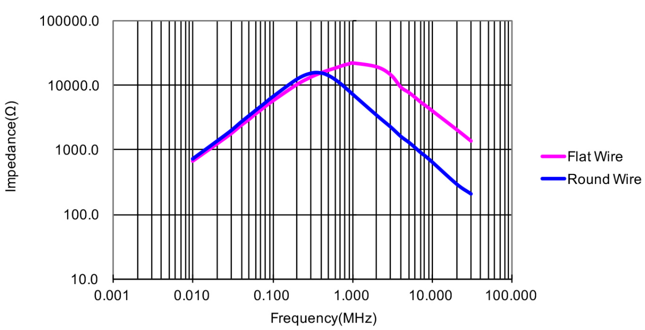


Fig. 14 Impedance Curve III

It can be very easy to tell from ***Table 4*** that the flat wire offers the highest impedance at the highest frequency of all the four comparison above.

Finally, let's do a comparison between the traditional T-core with round wire vs rectangular core with flat wire.

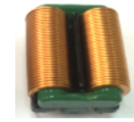
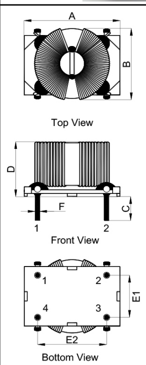
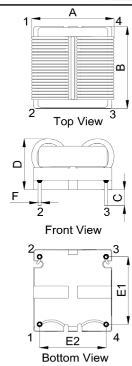
P/N	T-Core CMC		Flat Wire CMC	
				
Mechanical		A 33.0 Max mm B 30.0 Max mm C 3.5 ± 0.5 mm D 19.0 Max mm E1 15.3 ± 0.5 mm E2 22.8 ± 0.5 mm F Φ1.2 ± 0.1 mm		A 23.0 Max mm B 26.0 Max mm C 3.5 ± 0.5 mm D 14.5 Max mm E1 21.0 ± 0.5 mm E2 17.0 ± 0.5 mm F Φ0.8 ± 0.1 mm
Electrical	L@+25°C:at 1KHz/0.25V	L=5.30mH Typ.	L@+25°C:at 1KHz/0.25V	L=5.30mH Typ.
	DCR@+25°C:	DCR=26.9mΩ Typ.	DCR@+25°C:	DCR=20.8mΩ Typ.
	Irated:(△T=40℃)	5.5A Typ.	Irated:(△T=40℃)	6.0A Typ.

Table 5 T-Core w/Round Wire vs Rectangle Core w/Flat wire

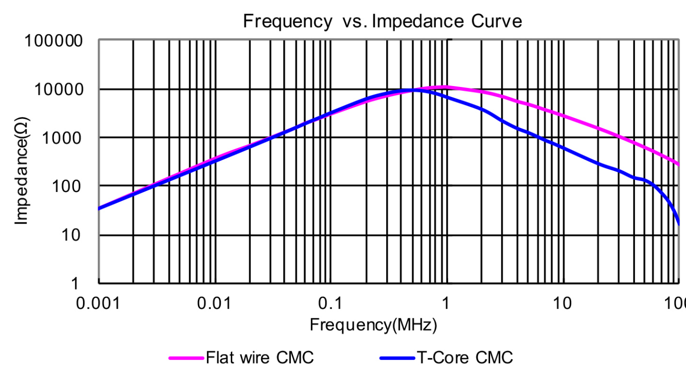


Fig. 15 Impedance Curve IV

The mechanical result shown in ***Table 5***, indicates the area of the flat wire common mode choke is much less than the T-core common mode chokes which can save almost 40% on the PC board layout. It also has a lower profile to save about 25% of height. The total volume can then save over 54% and flat wire common mode choke

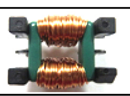
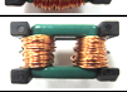
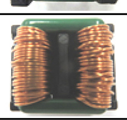
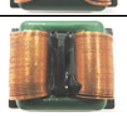
Sample		L (mH)	Lk (uH)	DCR (mΩ)	SRF (KHz)	Frequency (MHz)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	2	3	4	5
Type 1 Long-Side Winding		11.56	86.22	143.90	346.00	Z(Ω)	7435	14120	17630	17850	16270	14260	12380	10800	9520	8026	4028	2654	1888	1542
Type 2 Short-Side Winding		11.58	141.84	159.83	382.00		7407	14082	18792	20256	19126	17130	15000	13125	11575	10345	5706	3127	2217	1814
Type 3 Round Wire		11.36	81.64	133.27	315.00		6792	12685	15740	15905	14445	12610	10920	9495	8345	7420	3490	2290	1645	1342
Type 4 Flat Wire		11.02	88.38	128.24	700.00		5740	10285	13450	15645	17255	18520	19780	20860	21660	22260	19400	14500	9366	7790

Table 4 Data Result

comes with 1.2x the power density of the traditional T-core. From the electrical result, with the same level of inductance, flat wire common mode chokes offers lower DCR and higher current level. The impedance curves of ***Fig. 15*** also show the flat wire common mode choke offers higher impedance with higher frequency.

VI. CONCLUSION

In conclusion, the impedance becomes much more important in the common mode choke design at higher frequency. By looking at a number of different winding techniques and flat wire vs round wire comparisons, the flat wire with rectangular core body common mode choke shows its best result with the following:

I. Fully automatic high precision winding machines insure competitive costs.

II. The single-layer winding design which lowers the skin effect and creates higher performance at a higher frequency.

III. The lower distributed capacitance means a higher performance at high frequency.

IV. The lower DCR means better thermal performance.

V. The higher power density results in up to 50% space saving.

VI. The higher reliability results in extended product life time.

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[4] *Impedance* http://whatis.techtarget.com/definition/impedance