

Design and Development of Wireless power transfer system for Intracranial pressure monitoring devices

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Abstract. Wireless power transfer was today used for many applications regarding high power and low power transmission. Biomedical applications are lower power applications where WPT occurs between the power coils, one of which will be implanted in the body whereas other will be outside the body as Transmitting coil. Here the paper refers to the Wireless power transfer system to Intracranial Pressure monitoring devices. The proposed system operates at 180 KHz frequency for both Magnetic resonant coil design and WPT system analysis. The Mixed Resonance scheme at receiving side will be used as compensation topology for compatibility in Power delivered to load. Analysis and comparison for different coil structures are also verified for best suitable configuration for efficient power transfer.

1 Introduction

Intracranial pressure is the pressure present in craniospinal compartment, which is closed consisting of fixed volume of neural tissues, blood and cerebrospinal fluid. It is measured in mm Hg. For a normal person value of ICP ranges from 5-15 mm Hg.

When amount of fluid surrounding the brain increases the value of ICP increases which is due to certain reasons like bleeding in the brain, tumor, stroke, aneurysm, high blood pressure or brain infection. Increased ICP results in serious complications to the person. so, ICP monitoring devices are used for continuous monitoring of ICP levels for patient suffering from brain diseases. Some diseases due to ICP are likely Hydrocephalus, CSF Leak and Pseudo tumor cerebri[2].

ICP monitoring is done either by invasive or non-invasive techniques. Invasive methods of ICP monitoring are ventriculostomy and microtransucers. Of the two invasive techniques mentioned ventriculostomy is widely used. However invasive method has a little disadvantage of hemorrhage and infection. Ventriculoperational Shunt (Catheter) is the surgical treatment procedure of Hydrocephalus, which is used for diversion of excess CSF in the ventricles of brain [1,3].

So ICP should be regularly monitored and treated accordingly. Sensors and monitoring systems will be powered by conventional battery[4]. So wireless power transfer system can be used for charging the battery.

In the following sections of the paper, WPT approach for ICP monitoring device is discussed.

In section 2, compensation topology for the WPT system of ICP monitoring device is proposed. In section 3 power coils for the system is designed in different layer configurations in different structures is discussed. In section 4 Analysis of the proposed system was discussed. Finally the Conclusions were drawn based on the simulated model.

2 Proposed System

In the proposed system the compensation topology used for tuning of transmitting and receiving is, basic series compensation at the transmitting side and mixed resonance scheme at the receiving side.

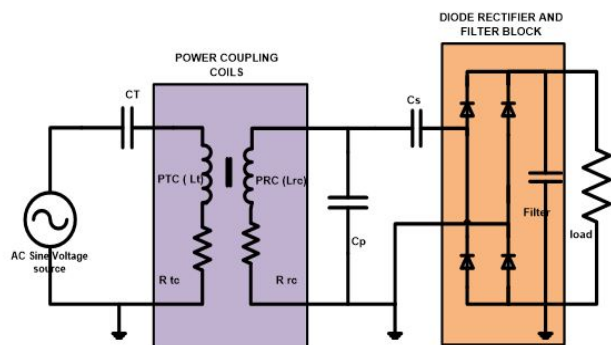


Fig. 1. WPT System Circuit with Compensation Topology of Power coils.

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Table.1. Comparison of Coil structures and Magnetic Flux Distribution of each topology

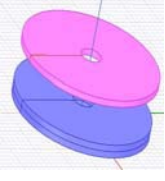
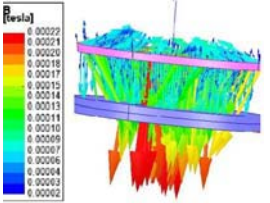
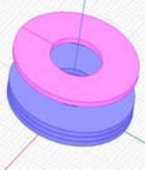
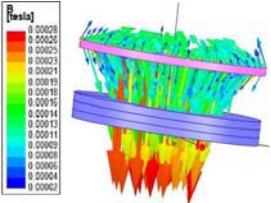
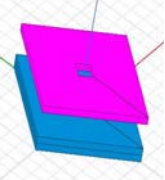
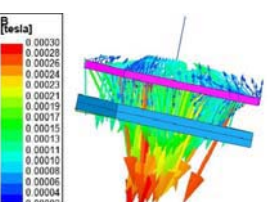

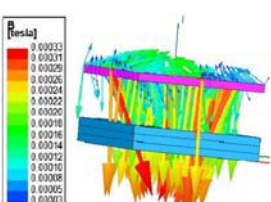
Type of coil	Double layer PTC	B-Plot of Double layer PTC	Triple layer PTC	B-Plot of Triple layer PTC
Circular coils				
Square coils				

Table.2. Comparison of Specifications and Simulated Results of each topology

Section of Comparison	Parameters compared	Circular Double Layer PTC		Squared Double Layer PTC		Circular Triple Layer PTC		Squared Triple Layer PTC	
		PTC	PRC	PTC	PRC	PTC	PRC	PTC	PRC
Physical Parameters	Height h(mm)	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
	Outer and inner radius(mm)	25, 3.75	25, 3.75	25, 3.75	25, 3.75	25, 10.84	25, 10.84	25, 10.84	25, 10.84
	No of Turns N	12	12	12	12	8	8	8	8
Distance between power coils d(mm)		10	10	10	10	10	10	10	10
Electrical Parameters	Current I(A)	3.3	1.7	3.3	1.7	3.3	1.7	3.3	1.7
	Frequency f(KHz)	180	180	180	180	180	180	180	180
Output Parameters obtained	Inductance of total coils L(μH)	8.801	3.21	9.35	2.61	13.59	2.407	12.28	2.09
	Coefficient of coupling (k)	0.2987		0.247		0.34		0.251	

Mixed resonance scheme is used as it delivers efficient amount of power to receiver unit in comparison to series and parallel resonance schemes. The proposed system is operated at 180KHz frequency and load resistance is considered as 6.5 Ω. The following equations are the basic formules used for analyzing the proposed system[5,6]:

Resonating Frequency of the system

$$f = \frac{1}{2\pi\sqrt{L_t C_t}} = \frac{1}{2\pi\sqrt{L_r C_r}} \dots \dots \dots (1)$$

Coupling coefficient

$$k = \frac{M}{\sqrt{L_t L_r}} \dots \dots \dots (2)$$

Compensation components can be calculated by using the following formulae to tune the power coils at a particular frequency[5].

The parallel capacitance (Cp) in the receiver side

$$C_p = \frac{\sqrt{Rrc^2 + w^2 Lrc^2} - Ri}{wRl\sqrt{Rrc^2 + w^2 Lrc^2}} \dots (3)$$

$$C_s = \frac{(1 - w^2 LrcCp)^2 + (RrcwCp)^2}{w^2[Lrc(1 - w^2 LrcCp) - Rrc^2 Cp]} \dots (4)$$

The Series Capacitance (Cs) of the Receiver coil

Where w represents the angular frequency of the system, Rrc represents the receiver resistance and Rl is Load resistance.

Table.3. Circuit model specifications of different layer PTC coils in circular and square coil structures

Input and Compensation parameters	Double layer Circular PTC coil	Triple layer Circular PTC coil	Double layer Square PTC coil	Triple layer Square PTC coil
Input Voltage(V)	20	20	20	20
Input Frequency(Hz)	180000	180000	180000	180000
PTC Inductance (H)	8.81e-6	13.59e-6	9.35e-6	12.28e-6
PRC Inductance(H)	3.21e-6	2.407e-6	2.61e-6	2.09e-6
Input Resistance (Ω)	7.05	7.05	7.05	7.05
Coupling coefficient	0.2987	0.34	0.247	0.251
Load Resistance (Ω)	6.5	6.5	6.5	6.5
Transmitting Capacitance (F)	88.8e-8	57.5e-8	83.6e-8	63.7e-8
Parallel receiving coil capacitance(F)	245e-12	190e-12	203e-12	171e-12
Series receiving coil capacitance(F)	0.244e-6	0.327e-6	0.301e-6	0.375e-6

3 Designing of Power Transmitting and Power Receiving coils

Transmitting and receiving coils of ICP are investigated in double and triple layers of circular and square structure of power transmitting coil (PTC) and single layer circular and square structure for receiving coil unit.

For double layered structure of PTC coil is designed for 24 turns with 12 turns per layer and for triple layer it is designed for 8 turns per layer and single layer of PRC coil number of turns is 12 turns for double layer and for triple layer its is designed for 8 turns. The system is operated at 180KHz.

The design specifications of the coils and the corresponding output results of simulation inductances of coils and coefficient of coupling are listed in table 2.

From the results obtained from simulation of coils in different coil configurations it has been observed that,

- ✓ For the same shape of coils with increase in number of layers, the inductance values of PTC is increased for triple layer configuration whereas inductance value is decreased in PRC for triple layer when compared to double layer configuration. The coefficient of coupling is higher for triple layer configuration than double layer.
- ✓ For the same number of layers when different coil structures are compared it is observed the circular coil has better coefficient of coupling in comparison with square coil structure and the

value of inductance in receiving coil is lower in square coil structure than circular coil structure.

4 Analysis of Proposed Network for WPT system

For the same shape of coils with increase in number of layers inductance values of power transmitting coils is increased for triple layer configuration whereas inductance value is decreased in receiving coil for triple layer when compared to double layer configuration.

As input voltage given to all models are same but the performance varies based on the compensation parameters, coefficient of coupling between the coils and the Inductances obtained by simulation. The battery nominal voltage was 3.1-3.3V.

The potential range of battery as per Charging and discharging cycles was treated was 1.5-4.5V. The voltage output obtained at the load was within the limited range so the model can be used for practical purpose. The Triple layer circular model Load voltage was better comparatively as per Table 4.

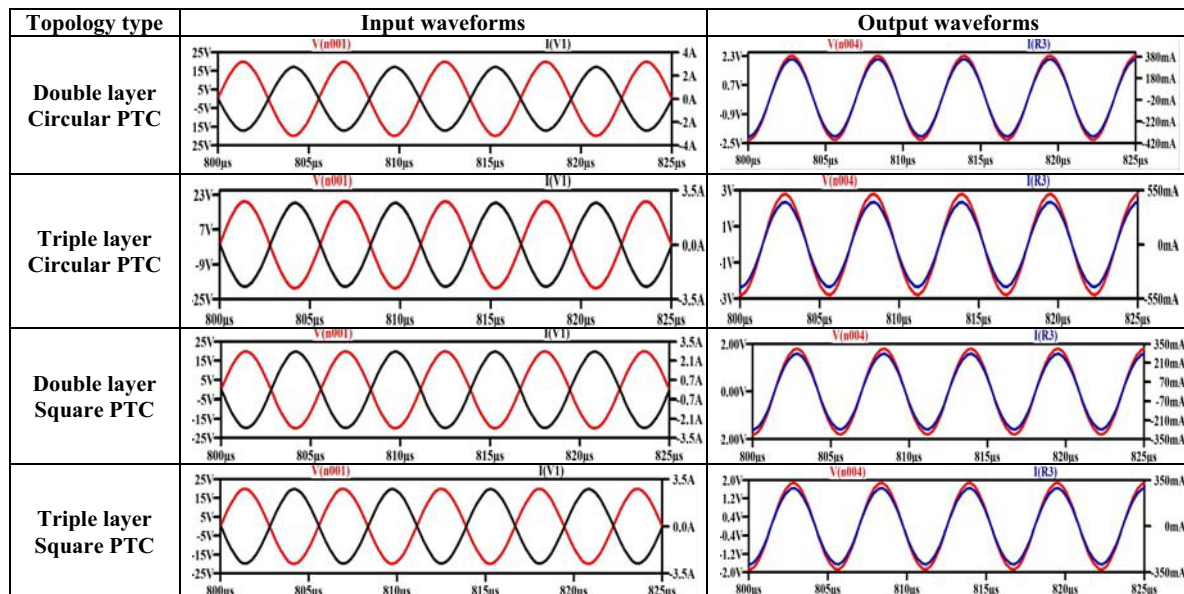
Table.4. Comparison of Simulated results of PDL and PTE of each coil configuration

Quantity	Double layer Circular PTC coil	Triple layer Circular PTC coil	Double layer Square PTC coil	Triple layer Square PTC coil
Input Voltage	19.92	19.92	19.92	19.92

(V) V_i				
Input Current (A) I_i	2.72	2.68	2.76	2.76
Output Voltage(V) V_o	2.31	2.792	1.80	1.88
Output Current (A) I_o	0.355	0.429	0.278	0.289
Input Power	27.07	26.69	27.48	27.52

P_{in} (W)				
Output Power P_o (W)	0.820	1.198	0.503	0.543
Efficiency η %	3.03	4.49	1.82	1.97

Table.5. Representation of Simulation resulted Waveforms of each coil configuration



The Power delivered to the load required was around 766mW and the obtained Power which is delivered to the load was good for Circular models as they are customized due to their easy and well suited size and structure for better alignment between the coils and easy design. The Power Efficiency was also more in Triple layer Circular model as 4.49% and the least efficient model as per the results was Double layer Square model. Finally based on all the simulations as per design and analysis the well suited type of topology was conventional Circular Double layer PTC with PRC model.

5 Conclusions

In the above proposed system of ICP monitoring devices the distance between coils are 10mm considered for all the models with operating frequency of 180 KHz where power output required as 500mW to 900mW and we obtained on an average of 766mW for all the models based on our component requirement we can select the model of design required. Worst case obtained output power has an efficiency of 1.82% as per the least performance of the designed square model. Conventional circular coil models here double layered PTC model

were best suited for practical hardware based on the performance levels in all aspects.

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