ISSN : 2278 - 0181
Online Print Version

International Journal of
Engineering Research & Technology

IJERT

Volume - 2, Issue - 3, March 2013 Edition

Website : www.ijert.org, E-mail : info@ijert.org

International Journal of Engineering Research & Technology (IJERT)

Published by ESRSA Publications

ESRSA, Engineering and Scince Research Support Academy Publications publish monthly journal under ISSN 2278-0181.

Online Version (e-copy)
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Print Version
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96	Supporting Competent And Measurable Group Communication Over Mobile Adhoc Networks	IJERTV2IS3256	716	722
97	A Smart Texting System For Android Mobile Users	IJERTV2IS3261	723	726
98	Simulation Of Power Losses Improvement With Unified Power Flow Controller (UPFC) On Transmission Line System Of Southern And Western Sulawesi (Sulselbar) Using Neplan Software	IJERTV2IS3267	727	733
99	Data Normalization And Identification Of Differentially Expressed Genes By Multiple Hypothesis Testing Procedures	IJERTV2IS3268	734	741
100	Green Inhibitors: Inhibitory Effect Of Acacia Auriculiformis And Ixora Coccinea Extracts Against Corrosion Of AA5083 In Acidic Medium	IJERTV2IS3269	742	747
101	Approximation of a Function f Belonging to Lip Class by (N, p, q)C 1 Means of its Fourier Series	IJERTV2IS3279	748	751
102	Toxicological Potentials Of Repeated Frying On Antioxidant Status Of Vegetable Oils	IJERTV2IS3280	752	757
103	Optimization Of Memory Built In Self Test And Repairability By Using March-Ss Algorithm For SRAMS	IJERTV2IS3283	758	765
104	WAD-HLA: Wormhole Attack Detection Using Hop Latency And Adjoining Node Analysis In MANET	IJERTV2IS3284	766	771
105	Optimum Power Flow With Multi-Types Of Facts By Using Particle Swarm Optimization (PSO)	IJERTV2IS3285	772	778
106	Survey On Sql Query Progress Indicator	IJERTV2IS3286	779	783
107	A Study On Point-Based Clustering Aggregation Using Data Fragments	IJERTV2IS3287	784	788
108	Performance-Aware Design Of Dynamically Reconfigurable System-On-Chips With Quality Of Service Guarantees	IJERTV2IS3289	789	795
109	Use Of Artificial Intelligence In Highly Adaptive Exam E-Revision Systems	IJERTV2IS3293	796	815
110	Fpga Implementation Of Mimo-Ofdm For Baseband Modem Parallel Architecture	IJERTV2IS3295	816	821
111	Image Encryption Using Random Scrambling And XOR Operation	IJERTV2IS3297	822	828
112	SPIN: A Data Centric Protocol For Wireless Sensor Networks	IJERTV2IS3303	829	837
113	A Comparative Assessment Of The Bend, Chemical And Tensile Properties Of Reinforcing Steel Bars In The Nigerian Construction Industry	IJERTV2IS3305	838	856
114	Design Of Vertical Pressure Vessel Using Pvelite Software	IJERTV2IS3311	857	864
115	Image Classification Using Multiresolution Color, Texture And Shape Features Hybrid Features	IJERTV2IS3315	865	875
116	*A Study Of Different Types Of Biometric Techniques*	*IJERTV2IS3320*	*876*	*883*
117	Implementation Of Secure Ranked Keyword Search By Using "RSSE"	IJERTV2IS3324	884	887
118	Electromagnetic Radiation Effects Of Mobile Phone On Human Health	IJERTV2IS3326	888	897
119	Energy Audit In Industrial Drives	IJERTV2IS3328	898	902
120	Automated Inventory Control and Management for Auto Spare Parts in Developing Nations	IJERTV2IS3329	903	919
121	Design And Development Of Electronic Prescription And Patient Information Systems For Developing World	IJERTV2IS3330	920	929
122	Ontology Based Load Balancing For User Profile	IJERTV2IS3331	930	936
123	An Approach Of Dictionary Generation For Diabetic Retinopathy Detection	IJERTV2IS3333	937	941
124	Research On Energy Efficient Routing Protocol LEACH For Wireless Sensor Networks	IJERTV2IS3335	942	946
125	Improved Unsupervised Segmentation Algorithm For Tissue Pathology	IJERTV2IS3338	947	952
126	Novel Forensic And Anti-Forensic Techniques Identification Based On Game Theory Frame Work	IJERTV2IS3339	953	957
127	Commercially Available Fpgas And Its Architecture- Survey	IJERTV2IS3340	958	963
128	Survey On Movie Rating And Review Summarization In Mobile Environment	IJERTV2IS3344	964	968
129	A Concept Based Mining Model For NLP Using Text Clustering	IJERTV2IS3345	969	973
130	Manifold Entrust Scheme	IJERTV2IS3347	974	979
131	Efficient Routing Protocol For Mobile Ad Hoc Networks (MANET)	IJERTV2IS3349	980	983
132	Overview Of Interplanetary Internet System	IJERTV2IS3350	984	991
133	Data Auditing In Cloud Using Trapdoor Commitment Scheme	IJERTV2IS3351	992	995
134	A Survey On Occlusion Detection	IJERTV2IS3352	996	1002
135	CFD Analysis Of Gearbox	IJERTV2IS3353	1003	1005
136	Measurement Of Supplier Service Quality Dimensions In The Supply Chain	IJERTV2IS3354	1006	1009
137	Determining Thermal Life Expectancy Of Power Transformer Under Non Linear Loads Using FEM By ANSYS And MATLAB	IJERTV2IS3355	1010	1015
138	Image Enhancement Techniques: A Selected Review	IJERTV2IS3357	1016	1019
139	A New Quadruples E-Core Transformer To Minimize Output Ripple Current	IJERTV2IS3361	1020	1025
140	Balancing The Capacitor Voltage In NPC - APF Using Pulse Width Modulation Control	IJERTV2IS3362	1026	1032
141	Survey On Service Discovery Protocols (SDP) In Vehicular Adhoc Networks	IJERTV2IS3363	1033	1036
142	Design And Implementation of an Efficient And Modernized Technique of a Car Automation Using Spartan - 3 FPGA	IJERTV2IS3367	1037	1041
143	An Approach To Secure Teredo Tunneling Technology	IJERTV2IS3368	1042	1047
144	Estimation Of Formant Frequency Of Speech Signal By Linear Prediction Method And Wavelet Transform	IJERTV2IS3371	1048	1053
145	Managing Information Integrity In Information Systems	IJERTV2IS3376	1054	1066

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

A New Quadruples E-Core Transformer To Minimize Output Ripple Current

Herawati Yusuf

Abstract

A new quadruples E-transformer made of ferrite is proposed in this paper. In order to control magnetic flux (ψ) in the ferrite with coil in the primary and secondary core transformer, wire coil should be twisted 50° with tiny air gap, resulting in higher efficiency. However, it should be suitable to heavy system loads. Otherwise, it will influence the duty cycle, and it will create ripple current for about 10 percents. The fixed air gap should be evaluated with respect to magneto motive (mmf), as one of their electromagnetic field sources in the system. In addition, the adjusted magnetic flux (ψ) also can be controlled by inserting air gaps, and the magnetic flux can be justified by varying the width of gap.

In this experiment six air gaps are inserted in the quadruples E-transformer. The coil is composed of a ring wire gauge in which each ring wire gauge has radius r is 0.0004 m give the ripple current 0.036%. So The New quadruples E-transformer help greatly to make system more stable.

Keywords: Boost converter, E type ferrite, geometry, air gap, gyrator-capacitor, low ripple current.

1. Introduction

Nowadays, a lot of industry activities such as electroplating and chemical processing require a good electrical system which has low ripple current since that ripple current could causes losses and disturb the output of the process. The ripple current from an electrical system usually treated as a noise and it has to be limited e.g. in chemical processing, the permitted ripple current is 3% but basically the smaller noise, the better system. Experiment hypothesis later on sees that ripple current could be reduced significantly by using the gyrator-capacitor [1] and twisting the winding of conductors [2].

The equivalent electric circuit approached from the modification is resulting new quadruples E transformation as total capacitor [3], where magnetic networks using the ferrite core. The ferrite become parasitic capacitor or inductor which simultaneous to counter the variable loads. It becomes simultaneous switching noise [4]. The properties of ferrite are lumped so there are no losses [5]. Also the air gap is generating magnetic flux [6]. Actually, interposed air can be utilized as a controller of input and output mmf and even some more technologies applied could be controlled the automatic system.

This paper proposed Cuk converter Slobodan with transformer four E type core, six air gap and twisted winding as new quadruples E core transformer to minimize the output ripple current.

2. Quadruples E-transformer design

2.1. The Model quadruples core E Type with six air gap and a couple winding

This paper is using a new quadruples E transformation modeled as the total capacitance approach and magnetic source as gyrator.

Gyrator is a coil that analyze through approach on magnetic circuit to electric circuit [1], which the core have been applied to the coils system. Gyrator must be paired to each other, so that it can make an optimal result that creates the electromagnetic coupling like the ideal transformer ones [2].

Gyrator must be applied in boost converter Cuk Slobodan and put it in second core magnetic E type [3] as a universal in load resistance as seen in Figure 1, and it will get the percentage of output ripple current about 0.036 %.

Gyrator in Cuk Converter can reduced the ripple less than 3%. With parallel RLC load, the ripple could make it up to only 0.036%. The magnetic core type must be at quadruples range as seen in Figure 1.

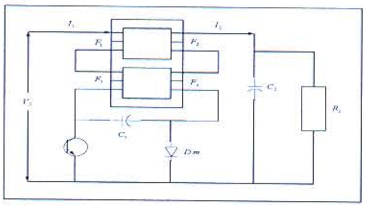


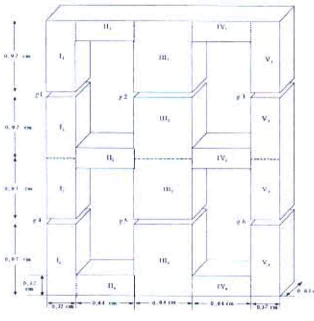
Figure 1. Modification boost Converter and quadruples E Type with six air gap.

The Cuk converter in Figure 1 is still loaded by resistance (R). Modification boosts Converter with second E Type with four air gap about 0.036%. If the RLC load, the ripple current becomes more than 3 %. It must be redesign with quadruples E-transformer with six air gap [3].

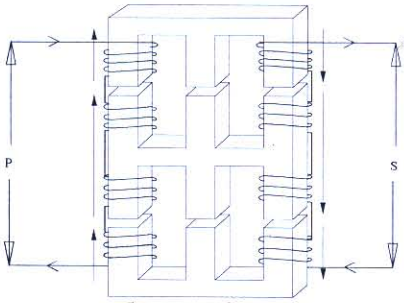
2.2. New approacing parameter in electric quadruples E-core transformer

The proposed geometry of quadruples E-transformer is shown in Figure 2.a. The structure geometry core of quadruples E-type is ferromagnetic which is composed as shown in the Figure 2. Air gaps are in structure between quadruples of E-type. The dimension is adjusted to obtain the best performance.

Based on Figure 1, the Cuk Converter could be analyzed by using a boost converter with 9 volt input [4], The air gap cross-section at each base is 1 mm. The geometry of Figure 2.a. is provided in table 1.



(a)



(b)

Figure 2. Geometry and coil winding on ferritecore transformer.
(a) Transformer with air gap.
(b) Geometry of E core Type with 6 air gaps.

Table 1. Reluctance and Permeance from a part 1 transformer.

Part of Geometry E type	Long Race (cm)	Cross-section area (cm^2)	Reluctance (AT/Wb)	Permeance (H)
Left Foot Core I_1	1	0.18	$0.442\ 10^{6}$	$2.262\ 10^{-6}$
Part II_1 Core	0.6	0.18	$0.265\ 10^{6}$	$3.773\ 10^{-6}$
Middle Foot core III_1	1	0.36	$0.221\ 10^{6}$	$4.524\ 10^{-6}$
Part IV_1 Core	0.6	0.18	$0.265\ 10^{6}$	$3.773\ 10^{-6}$
Right Foot Core V_1	1	0.18	$0.442\ 10^{6}$	$2.262\ 10^{-6}$
Left Foot Core I_2	1.42	0.4185	$0.0270.10^{6}$	$37.017.10^{-6}$
Part II_2 Core	0.9	1.488	$0.0024.10^{6}$	$415.317.10^{-6}$
Middle Foot core III_2	1.42	0.8742	$0.0129.10^{6}$	$77.324.10^{-6}$
Part IV_2 Core	0.9	1.488	$0.0024.10^{6}$	$415.317.10^{-6}$
Right Foot Core V_2	1.42	0.4185	$0.0270.10^{6}$	$37.017.10^{-6}$
Left foot of core Trafo I_3	1.42	0.4185	$0.0270.10^{6}$	$37.017.10^{-6}$
Right foot of middle core Trafo III_3	1.42	0.8742	$0.0129.10^{6}$	$77.324.10^{-6}$
Right foot of core V_3	1.42	0.4185	$0.0270.10^{6}$	$37.017.10^{-6}$
Left Foot Core I_4	1.42	0.4185	$0.0270.10^{6}$	$37.017.10^{-6}$
Part II_4 Core	0.45	0.744	$0.0048.10^{6}$	$207.659.10^{-6}$
Middle Foot core III_4	1.42	0.8742	$0.0129.10^{6}$	$77.324.10^{-6}$
Part IV_4 Core	0.45	0.744	$0.0048.10^{6}$	$207.659.10^{-6}$
Right Foot Core V_4	1.42	0.4185	$0.0270.10^{6}$	$37.017.10^{-6}$

The calculation results of all Part of geometry in Figure 2.b. [3], like reluctance and permeance .The core and air gaps can be derived by magnetic material approach into the electric network [3], reluctance [6], capacitance and permeance [3]. The geometry of Figure 1 and the reluctance calculation (7) are provided in table 1.

Refers to Figure 3, the calculation involves all parameter values including for substituting the air gap and reluctance calculations are noted into Table 2. The air gap 1, 2, 3, 4, 5 and 6 are same. Because of the same, so all the air gap table is similar with table 2.

Table 2. Assess Reluctance and Permeance of air gap 1 up to six.

Air Gap1 (mm)	Cross section area (cm2)	Reluctance (AT/Wb)	Permeance (H)
0.1	0.18	0.00442 109	226.244 10-9
0.2	0.18	0.00884 109	113 10-9
0.3	0.18	0.0132 109	75.75 10-9
0.5	0.18	0.0221 109	45.24 10-9
0.6	0.18	0.0265 109	37.73 10-9

Variable total capacitance and variable air gap could be showed in figure 3.

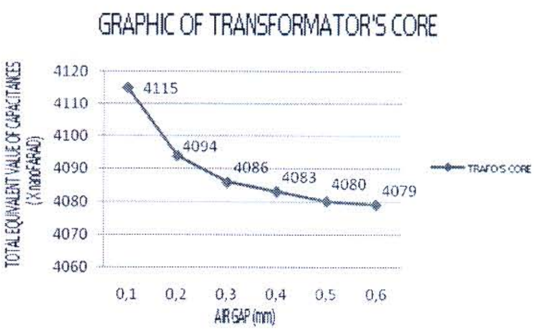


Figure 3. The relation of total capacitance in new quadruples with six air gap.

3. A new quadruples E-core transformer as gyrator-capacitor in Cuk Slobodan Converter.

3.1. Magneto motive force as Gyrator

The windings are evaluated as three conductors or two connected polar tide approach of electric network and magnetic network [3]. The voltage and the current equations (1 and 2) represent the interaction between electric field and magnetic field which can be seen on Figure 4. It is a quadruples-port polar electric network with hybrid parameter [5].

Based on Figure 2a, the primary voltage winding V_1 depend on the current on secondary is obtained by equation 1, and vise versa the voltage winding of secondary which V_2 depend on the current input of source is approached by magnetic circuit to electric circuit [1].

$$V_1 = r \cdot i_2 \quad \text{and} \quad V_2 = r \cdot i_1 \qquad (1)$$

Voltage Control Current Source (VCCS) where 1/r is gyrator, desribed as equation 3 below:

$$I_1 = g\,V_2 \quad \text{and} \quad I_2 = g\,V_1 \qquad (2)$$

Where:
V_1 = input Voltage (V)
V_2 = output Voltage (V)
r = the resistance of Gyrator (Ohm)
g = gyrator (mho)
f = frequency (Hz)
L = Inductance (Henry)

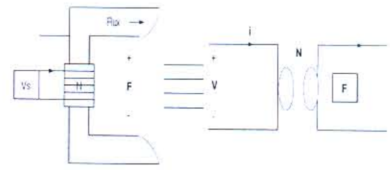
The implementation of modified equation is [1]:

$$g = \frac{1}{R} \qquad (3)$$

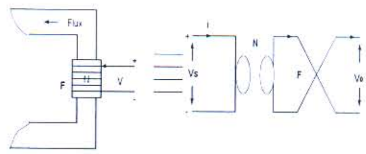
All parameters are calculated using Psim-val simulation. By substituting equation (1) and (2) into equation (3), the output ripple current in Cuk converter Figure1. is obtained by the equation 4.

$$\Delta I_2 = \frac{-V_s(1-k)}{f L_2} = \frac{kV_s}{f L_2} \qquad (4)$$

The VCCS and the CCVS configuration can be seen, respectively, on Figure 4a for Gyrator at primary side and Figure 4b. For air gap core coil Gyrator at secondary side.



(a)



(b)

Figure 4.(a) Gyrator model of transformer in primary and (b) Gyrator model side of secondary of the transformer.

3.2. Gyrator - Capacitor model could Reduce output ripple current of Cuk Converter.

From the Table 1 and table 2, the total capacitance and gyrator model in Figure 4 a and b. could be integrated, like shown in Figure 5.

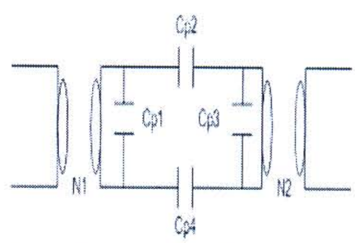


Figure 5. The Gyrator - Capacitor model.

Gyrator-Capacitor model Figure 5. could be integrated with boost converter Cuk Slobodan in Figure 1. because four E core type and six air gap was modifie with the model of gyrator-capasitor. It can be seen as Figure 6.

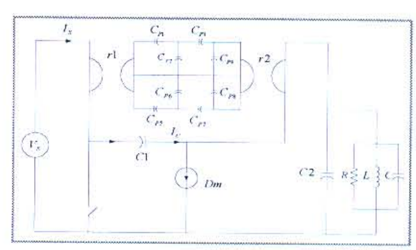


Figure 6. Quadruple E-transformer in Cuk Converter Slobodan

4. Simulation and experiment.

4.1. Simulation

The experiment uses 1 – 6 mm variable air gaps in the permanent magnetic cores, which results in the best performance at 4 mm, constructed by 3 coil windings and twisted at 50o. By designing the load, we could find that the gyrator resistance will stabilize the load changing. Also, through the simulation it could be seen that the smaller gyrator resistance, the smaller magnetic resistance and capacitance.

We find the resistance of gyrator from the total approach of capacitance of ferrite material and air gap, RG at Table 1 and 2. For RG = 0. 2 Ohm and the output current ripple about 2 % in Figure 8.a.for full load.

for RG = 0. 0128 Ohm, result in the output ripple 1. 6 %. This is the same as Figure 8.b. that the resistance gyrator is about 0.098 ohm.

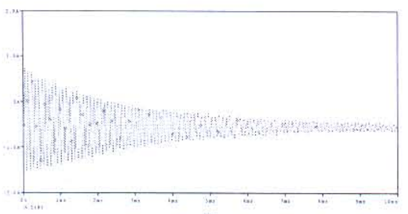
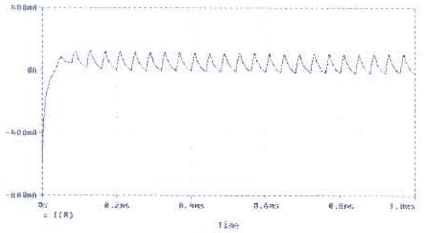


Figure 7. The output ripples current before modification.

Later on, it found that the total gyrator resistance must be suitable to material, air gap and coil winding. With that kind of total gyrator resistence, the ripple could be be reduced into 0.036 % (as long as the load is normal).



(a)

(b)

Figure 8. The graph of Current Gyrator IG and current hybrid IH respect to time for RG = 0.0128 Ohm.
(a) The output ripple current more than 2 % with RLC load and double E-transformer.
(b) The output ripple current 0.36 % With RLC load and quadruples E-Transformer (Pspice simulation).

On Figure 8.b, the output current ripple is 0.36% for gyrator-capacitor. After calculating the twisted winding, it produces smaller ripple and makes the system more stable, like Figure 8.b. The efficiency is 99.8%.

4.2. Experiment

The experiment on Figure 9 could be seen both with and without air gap. The first time experiment held with air gap.

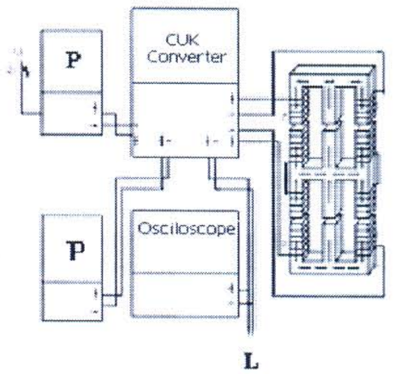
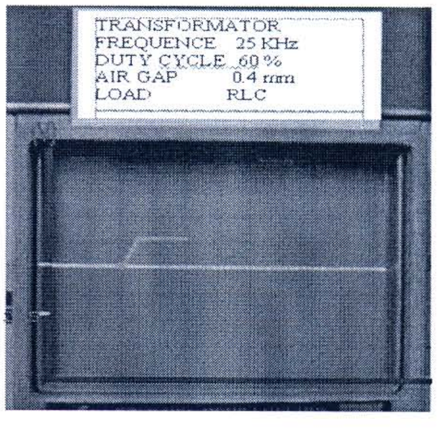


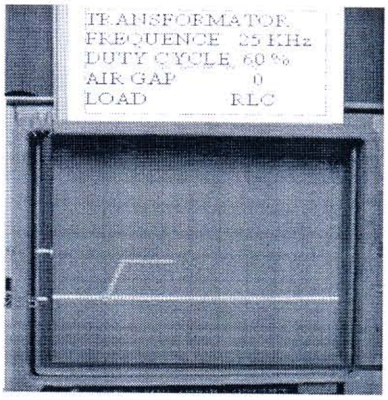
Figure 9. Block Diagram experiment of Quadruple E-transformer in Cuk Converter Slobodan.

The output voltage increasing until 21 Volt on RLC load. The air gap is about 0.4 mm with output ripple 0.36%. see Figure 10a.

The second experiment then was the one without air gap condition. The output ripple current turned into less than 1% but the output voltage is 12 Volt (Fig. 10b).



(a)



(b)

Figure.10. Experiment of Quadruple E core transformer in Cuk Converter Slobodan. (a) with air gap, and (b) without air gap.

Figure 11 will shows many variable load and no load, the best air gap in 1 mm or 3 mm air gap. If more than 1mm the voltage will be decrease until more than 2mm the voltage will increased become maximal voltage 34 Volt in 3 mm for frequency 25 KHz for RLC load.

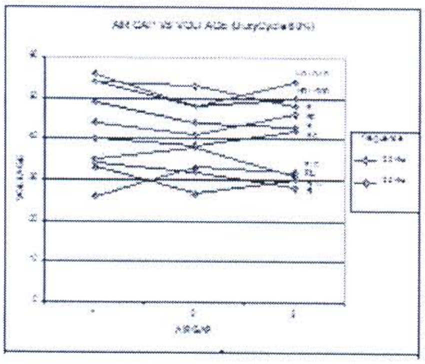


Figure 11. Graphic Air gap Vs Voltage at frequency 20 KHz and 25 KHz.

In Figure 11. The variable load R, L, C, RL, RC, and RLC load on frequency 20 KHz and 25 KHz. With 60% duty cycle. in frequency 25 KHz with air gap 0.3 mm on load RLC the voltage increase but on 20 KHz With 60% duty cycle in air gap 0.3 mm the voltage load decreased.

5. Discussion.

Based on the simulation, it can conclude that the resistance of gyrator could change the output ripple; the less resistance of gyrator would make the less output of ripple current, where shown at the calculation of the capacitance parameter approach from the geometry of magnetic core. In the other hand, experiment shows that the voltage is increasing when it loaded by RLC loads, both for with and without air gap. Air gap could be increase the voltage about 18.5 Volt (see Figure 10.a and 10.b.), if the air gap of Quadruple E core transformer in Cuk Converter Slobodan load condition about 0.4mm on RLC load.(in experiment), in PSpice simulation the air gap could be increase the voltage about four Volt. The optimal air gap about 0.4 mm, duty cycle 60 on RLC load. The output ripples current about 0.36%. on RC, RL load condition the ripple more than 1 %. The experiment could increase the voltage higher then simulation on RLC load.

In the simulation and experiment, almost show the same output ripple current.

6. Conclusion

By making the air gap equal to 4 mm in the six air gaps, the best output performance is achieved. The modeled of quadruples E-type ferrite is given by coil winding radius of wire r = 4. 10-4 m,at metal strain before twisting. The output ripple current is 1.8 %, and after twisted is 1.6 %. For radius coil r = 8.10-4 m at metal strain before twisted, the output ripple current is 1.6 %, and after twisting the output ripple current is 1.4 %. For radius r = 16. 10-4 m at metal strain before twisted, we obtain the ripples are 1.4%, and after twisting became 1.2 %.

The total impedance consists of air gap, geometry of materials, permeability, and twisted, could be reduce the ripple current about 0.036%.

The prototype could be applied to any system, it was done and tested.

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