A Study on Novel Power Supply for Microwave Oven Using HVC Embedded High Frequency Transformer

Jun-Seok Cho, Kang-Hee Park, Byung-Hwan Jeong, Hyung-Soo Mok
Dept. of Electrical Eng. Konkuk Univ. 1 Hwayang-Dong. Kwangjin-Gu, Seoul, Korea
E-mail : hsmok@konkuk.ac.kr

ABSTRACT – This paper describes novel high voltage capacitor(HVC) embedded high frequency transformer and novel inverter power supply topology for driving magnetron in microwave oven. This transformer is used to achieve down-sizing, low-cost and efficiency improvement. Proposed transformer has HVC in its secondary winding. Therefore, this transformer does not need external high voltage capacitor which used in conventional power supply. As use of this transformer, output voltage is shifted from ground to above 2000[V] and efficiency of microwave oven can be improved. The weight of proposed transformer is about one sixth of conventional one and efficiency is improved by seven percent compared to the efficiency of the conventional system.

1. INTRODUCTION

The microwave oven has become very popular as a cooking appliance in the household. It is very convenient to heat up food by means of electro magnetic energy. It can automatically cook food, using a microcomputer and various sensors. Moreover, improvements, reducing cooking time and an increase in cooking menu, are demanded. A conventional power supply to drive a microwave oven has ferro-resonant transformer and high voltage capacitor(HVC). Though it is simple, transformer is bulky, heavy and low-efficiency. To improve this defect, a high frequency inverter type power supply has been investigated and developed in recent years. However, because of additional control circuit and switching device, inverter-type power supply is more expensive than conventional one.[1][2]

In this paper, a novel HVC embedded high frequency transformer(HEHT)is proposed. This transformer includes high voltage capacitor in its secondary winding. And a novel circuit topology for driving magnetron is proposed.

This circuit topology is expected to improve of efficiency. This transformer need not external high voltage capacitor. So it has advantages in size, cost and efficiency improvement. In addition, equivalent circuit model is derived by impedance measurements. And the operation of proposed power supply is verified by simulations and experimental results.

2. PROPOSED NOVEL POWER SUPPLY

2.1. Structure and principle of proposed HEHT

Fig. 1 shows the structure of proposed HVC embedded high frequency transformer. It consists of primary winding, filament winding, and secondary windings. Secondary winding consist of N2 winding and N3 winding. N2 of secondary winding is made of foil type dielectric (Polyethylene) - conductor(Aluminum)'s double layer.

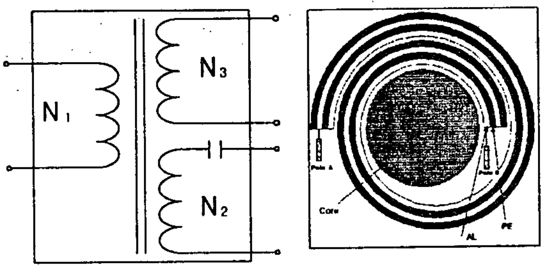


Fig.1. Structure of HVC Embedded Transformer.

Then, two aluminum conductors are open from the viewpoint of a physics but from the viewpoint of electrical engineering, they are connected by capacitance between two conductors. So we can say that equivalent capacitor is embedded in secondary winding N_2. Consequently, when using this transformer, external voltage doubling capacitor can be removed from the power supply for magnetron. And the power supply has advantages of size, simplicity and price.

2.2. Proposed Power supply using HEHT

A. Circuit description

Between some conventional topologies for driving magnetron, half-wave doubling type is most popular. Because of low cost and easy insulation. However it has defect of low efficiency. So, a new circuit topology using HVC embedded transformer is proposed. Moreover, proposed power supply has just one diode on its secondary side, so this power supply has advantage of simplicity, easy insulation and low cost.

Fig. 2 shows power circuit using HVC embedded transformer. This power supply is composed of single-phase diode bridge, half-bridge inverter, HVC embedded high frequency transformer, diode for secondary voltage doubling circuit and magnetron as a load.

B. Operation mode

Fig. 3 shows output voltage waveforms of the conventional half-wave voltage doubling circuit and proposed power supply. Fig. 4 shows the equivalent circuit of the power supply in each operation mode. During the first half cycle, when the SW 1 turned on, voltage across a magnetron becomes N_3 winding's induced voltage V_{N3}. And voltage across embedded capacitor becomes summation of V_{N2} and V_{N3}. When SW 2 turned on, voltage across magnetron becomes sum of charged voltage in embedded capacitor and N_2 winding's induced voltage V_{N2}. Therefore, output voltage waveform of proposed power supply is similar to full-wave doubling type power using only one high voltage diode and magnetron output efficiency can be improved.

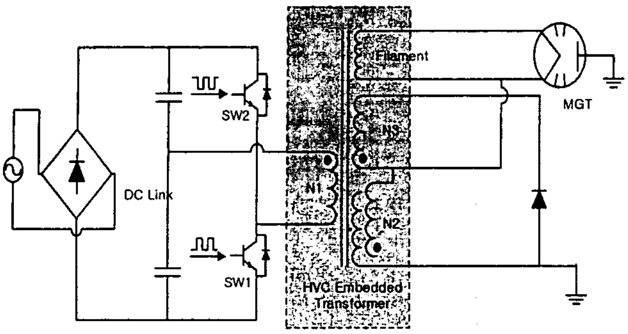


Fig.2. Power Circuit of Proposed Pulse Power Supply.

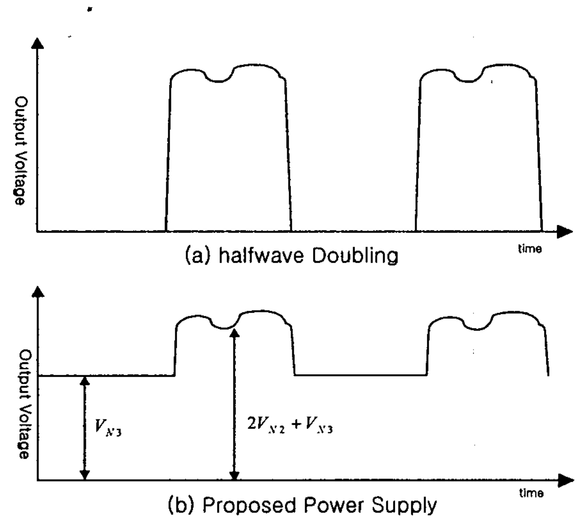


Fig.3. Output Voltage waveform.

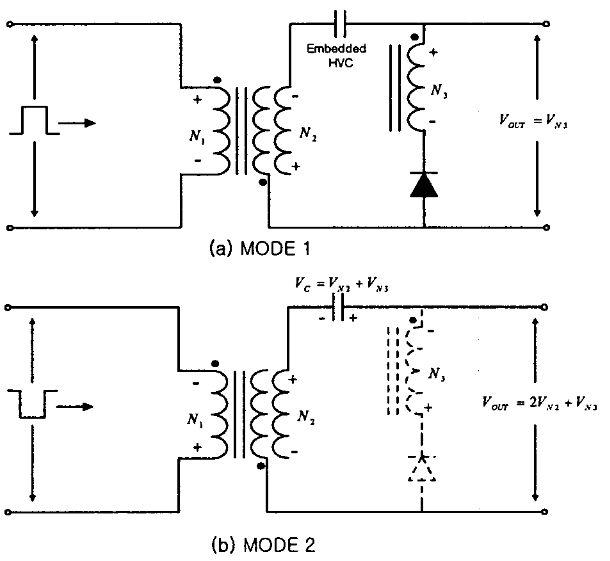


Fig.4. Equivalent circuit of each operation mode.

3. EMBEDDED CAPACITANCE ANALYSIS OF PROPOSED TRANSFORMER

The embedded capacitance of proposed transformer depends on geometry of secondary winding N_2 and it's too difficult to analyze the embedded capacitance by analytical methods. So, embedded capacitance has been calculated by finite element method(FEM) in this paper.

The capacitance between two conductors can be represented as (1).

$$C=\frac{Q}{V_0}=\frac{\oint \varepsilon E\cdot ds}{-\int E\cdot dl} \tag{1}$$

where Q : Total Charge, V_0 : Potential difference.

And, if secondary winding N2 is divided into n-pieces conductor, capacitance of it can be represented as n by n matrix as (2).

$$\begin{bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_n \end{bmatrix} = \begin{bmatrix} -C_{11}+\sum_{i=0}^{n} C_{1i} & -C_{12} & \cdots & -C_{1n} \\ -C_{21} & -C_{22}+\sum_{i=0}^{n} C_{2i} & \cdots & -C_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ -C_{n1} & -C_{n2} & \cdots & -C_{nn}+\sum_{i=0}^{n} C_{ni} \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} \tag{2}$$

In this paper, HVC embedded winding N2 is divided into many tetrahedrons for FEM analysis. And Total energy stored in winding was calculated by potential at each edge. Then capacitance matrix can be calculated by total energy. Table 1. show simulation results according to turn and surface area of winding. From this table, approximated capacitance equation of embedded capacitance can be represented as (3).

$$C=0.138S+0.0059[nF] \tag{3}$$

where S : Surface Area[cm2]

Table 1. FEM Simulation results of Embedded Capacitance.

Turn	Surface Area[cm2]	Capacitance[nF]
1	19.1	1.42
2	38.3	4.30
3	57.6	7.10
4	77.0	9.91
5	96.5	12.8
6	116.1	15.8
7	139.5	18.7
8	155.7	21.6
9	175.6	24.7

4. HVC EMBEDDED HIGH FREQUENCY TRANSFORMER DESIGN

Because of high frequency operating for down sizing, many parameters - topology of supply, core materiel, output power, switching frequency, skin effect, loss, temperature rise –considered of design procedure.[3] Table 2 shows design results of proposed transformer and Fig. 5 shows exterior view of proposed transformer.

Table 2. Design Result of Proposed HVC Embedded Transformer.

Core	PM7, UTV 5177S		
Primary Winding	Litz wire, AWG 30 – 33Strands, 15[T]		
HVC Embedded Winding N2	AL –PE Foil	AL : 16[mm]× 15[μm]	80[T]
		PE : 23[mm]× 50[μm]	
Secondary winding N3	Single wire, AWG 25 300[T]		

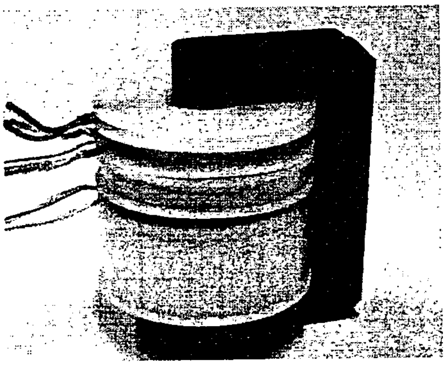


Fig.5. Exterior view of HVC embedded transformer.

5. MODELING OF PROPOSED TRANSFORMER

In this paper, equivalent circuit model of proposed HVC embedded transformer is derived from winding parameters. it is derived from impedance characteristic which is measured. Fig. 6 shows impedance characteristics of each winding. From these impedance characteristics, winding parameter can be extracted. For example, primary winding has LC parallel resonance at w_1, w_3 and serial resonance at w_2. and at these points, phases shift 180 degree. Therefore, double poles and zeros exist at each resonance. Consequently, primary winding is composed of series connection of two RLC parallel tanks as in Fig. 7(a). Total impedance of Primary winding can be represented as (4).

$$Z = Ks\frac{s^2 + \alpha s + \beta}{(s^2 + As + B)(s^2 + Cs + D)},$$

where $\alpha = \frac{1}{C_{eq} + C_{s1}}(\frac{1}{R_C} + \frac{1}{R_{s1}})$, $\beta = \frac{1}{C_{eq} + C_{s1}}(\frac{1}{L_m} + \frac{1}{L_{s1}})$

$A = \frac{1}{R_C \cdot R_{s1}}$, $B = \frac{1}{L_m \cdot C_{eq}}$, $C = \frac{1}{R_{s1} \cdot C_{s1}}$

$D = \frac{1}{L_{s1} \cdot C_{s1}}$, $K = \frac{C_{eq} + C_{s1}}{C_{eq} \cdot C_{s1}}$.

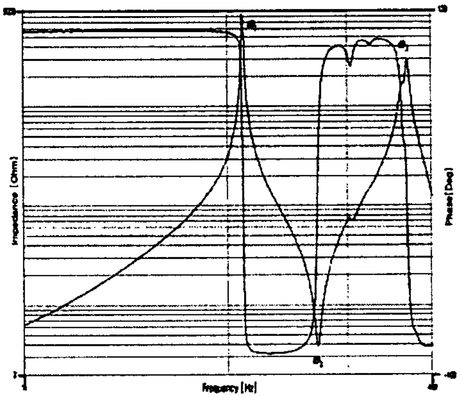
Therefore, from (4) and impedance at each resonance, magnetizing inductance Lm, parallel equivalent capacitance Ceq, Core resistance Rc can be calculated by (5). And L_{s1} can be calculated by relation of each resonance(6), and C_{s1}, R_{s1} can be calculated by (7).

$$L_m = \frac{|Z|}{2\pi f_{sw}} \quad (4)$$

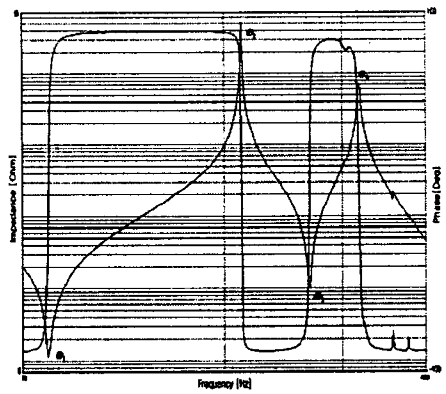
$$C_{eq} = \frac{1}{(2\pi f_1)^2 \cdot L_m}, \qquad R_C = Z_{f1} \quad (5)$$

$$L_{s1} = L_m \times \frac{f_1^2(f_3^2 - f_2^2)}{f_3^2(f_2^2 - f_1^2)} \quad (6)$$

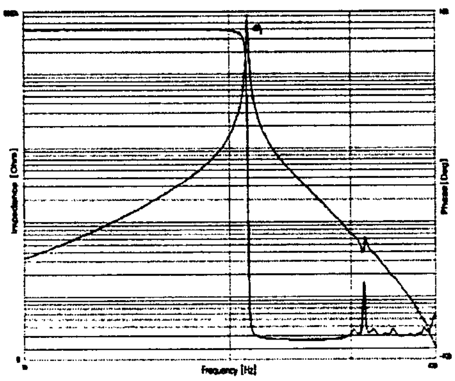
$$C_{s1} = \frac{1}{(2\pi f_3)^2 \cdot L_{s1}}, \qquad R_{s1} = Z_{f3} \quad (7)$$



(a) Primary winding

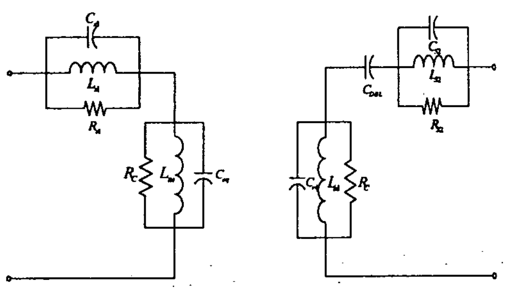


(b) HVC embedded winding N2

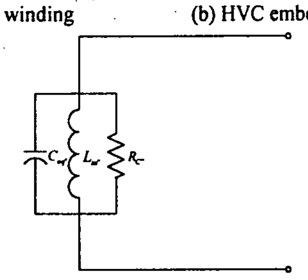


(c) Secondary winding N3

Fig.6. Measured Impedance characteristic.



(a) Primary winding (b) HVC embedded winding N2



(c) Secondary winding N3

Fig.7. Equivalent circuit of each winding.

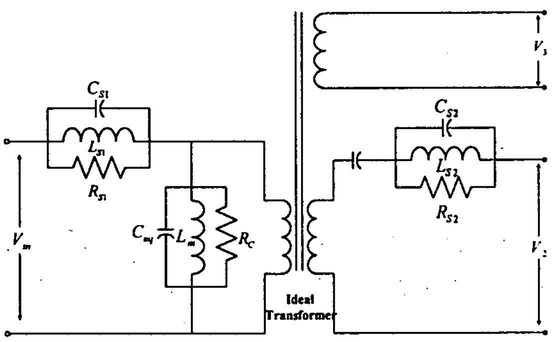
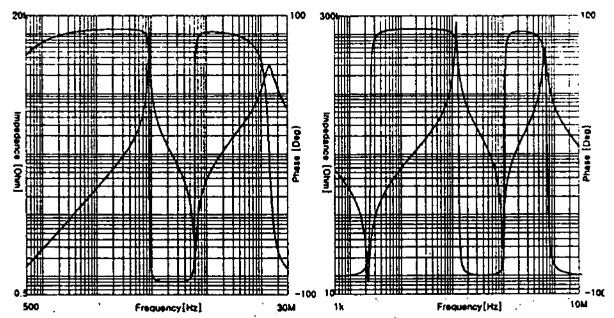
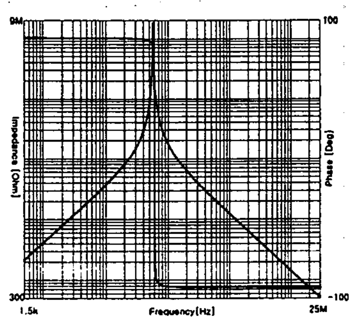


Fig.8. Equivalent circuit model of proposed HVC embedded transformer.



(a) Primary winding (b) HVC Embedded winding N2



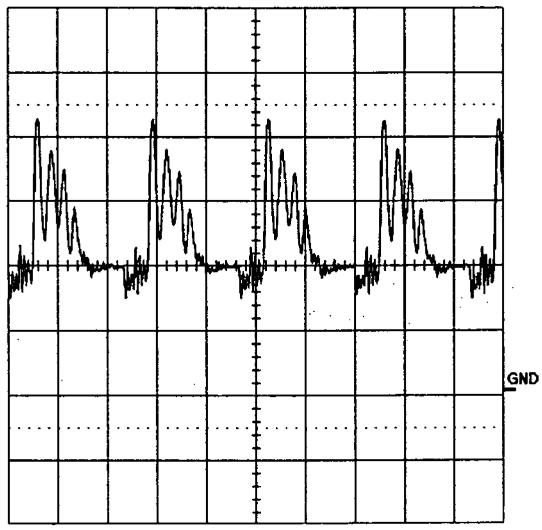
(c) Secondary winding N3

Fig.9. Simulation Results of Derived equivalent circuit model.

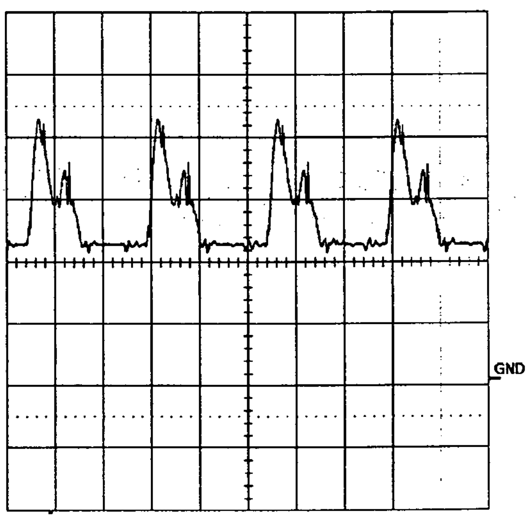
Other winding parameter also can be calculated same method. Fig. 8 is combined equivalent circuit of each winding model. From the secondary winding of equivalent circuit, It is verified that embedded HVC is connected with magnetizing inductance in series. Fig. 9 shows simulation results of each winding. They seems very similar to measured value, therefore derived equivalent model can be said that has sufficient accuracy.

6. EXPERIMENTAL RESULTS

The output voltage waveform, weight, volume and efficiency are compared between conventional power supply and proposed power supply. Fig. 10 shows output voltage waveform of proposed power supply under 8[$k\Omega$] resistance load and magnetron load. In the figure, the voltage waveform is about 2500[V] during Mode 1 and is 4000[V] during Mode 2. And it is shown that output voltage during Mode 1 is lower than voltage ratio because of voltage drop of leakage component.



(a) Resistance Load (1000[V/div])



(b) Magnetron load(1000[V/div])

Fig.10. Experimental results of proposed power supply.

Table 3. Comparison of conventional and proposed power supply for magnetron.

	Weight(HVT)[g]	Volume[cm3]	Efficiency
Conventional Power Supply (Halfwave Doubler)	3,018	560	51.39
Inverter Power Supply (Fullwave Doubler)	--	--	51.21
Proposed Power Supply	408	135	54.83

Table 3 compares weight, volume, and efficiency between conventional half-wave doubling supply and proposed power supply. As using proposed power supply, weight is reduced to 13.5[%], volume reduced to 24.5[%] and efficiency is improved to 6.7[%] than conventional one when normalized. Efficiency is measured according to rules of 43FR15330.

7. CONCLUSIONS

In this paper, a novel HVC embedded high frequency transformer and a novel power supply have been presented for magnetron drive. And, embedded capacitance in secondary winding is analyzed by FEM. Also equivalent circuit model has been derived by parameter extraction and verified by simulation. And, size and efficiency of proposed power supply have been measured and compared with conventional one. The weight and volume of proposed transformer are about one sixth and one forth of conventional one. And, the efficiency of magnetron has been improved seven percent than conventional one when normalized.

ACKNOWLEDGEMENT

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