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# Modeling of New Single-Phase High Voltage Power Supply for Industrial Microwave Generators for N=2 Magnetrons

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**ABSTRACT**

In this paper, we propose to study the modeling and the simulation, using the EMTP code, of the operation in nominal mode of a new high voltage power device, based on the same use principle of an only transformer with shunts, but this time for several magnetrons. This modeling can lead to the determination of the construction parameters of the new transformer, to ensure the correct operation in nominal mode of the new power supply, while respecting the control criterion of the current in each magnetron. The knowledge of these parameters (size of the magnetic circuit, the magnetic quality, the air gap, the size of the shunt and the number of turns, etc.), determines the cost of the dimensioned transformer for its realization. In the following, we will treat all possible states for operation of this new power supply with two magnetrons (Power supply for two magnetrons: case of two magnetrons in service, case of one magnetron in service and one magnetron in failure, case of tow magnetrons in failure). This provides relative to the current device gains of space, volume, cost of implementation and maintenance.



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## 1. INTRODUCTION

The figure 1 shows the overall scheme of the new high voltage power supply for two magnetrons delivering 1600Watts-2450MHz, used as a source of microwave energy. It contains, in its simplicity, a single-phase HV transformer with magnetic shunts supplying two cells voltage doublers and current stabilization. Due to the saturation of the magnetic circuit, the special transformer with shunts ensures the stabilization of the average anodic current in each magnetron. A $\pi$ equivalent scheme of this transformer is presented. Each inductance of the model is characterized by a non-linear relation between flux and current where the determination is obtained directly from the construction geometrical parameters of the transformer.

To contribute to the development of the technological innovation in the manufacturing industry of the power supply for magnetrons of microwave ovens for domestic or industrial use, this work is part of the development of a new type of HV power supply for microwave generators with several magnetrons. This has multiple benefits in terms of reducing weight, volume, electrical wiring and cost during the implementation and maintenance of such a new device. The tendency towards the new device of power supply will be considered a different version of the single-phase model currently manufactured at the manufacturers of domestic or industrial microwave ovens.

Our approach to the study of the new power supply for microwave generators with several magnetrons therefore consists, by the exploitation of the model developed by Chraygane for the current power supply with one magnetron [1-10] and using the EMTP code, to determine, relative to the base case (Appendix A), the new dimensioning of the transformer and then to study the sensitivity of the current in each magnetron used with respect to voltage variations of the treated power supply network for the microwave generators.

The paper consists of three essential parts:

firstly, we discuss in detail the modeling and the simulation using EMTP code of the actual operation in nominal scale of the new single-phase power supply for microwave generators with N=2 magnetrons debiting so an output up to 2x800=1600Watts at 2450 MHz. A verification of the regulating process of the current in each magnetron is presented.

Secondly, we treat the modeling of the nominal operation of the new power supply for two magnetrons: case of a magnetron running and the other broken down. During simulation, we verified the stability of current changes in the magnetron works with respect to the mains voltage for the respective cases 200 V and 240 V (±10% of the nominal voltage).

Thirdly, we check the operation of this new power supply if the two magnetrons are broken down.

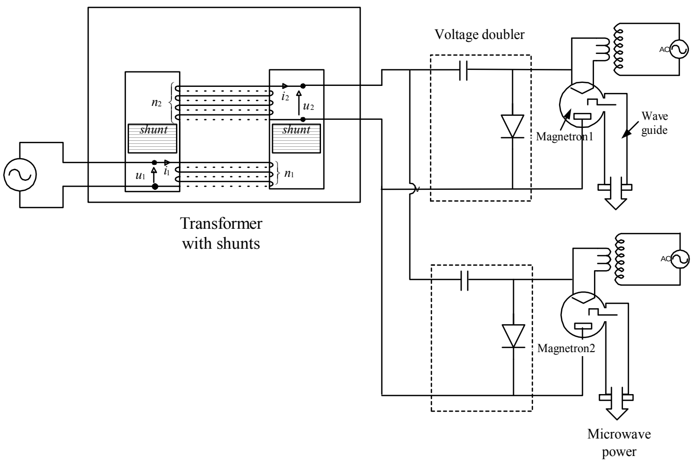


Figure 1. Single-phase power supply for N=2 magnetrons (Amperex Type)

## 2. MODELING AND SIMULATION, USING EMTP CODE, THE NOMINAL OPERATION OF THE NEW POWER SUPPLY FOR TWO MAGNETRONS

The study develops in detail the modeling and the simulation, using EMTP code, the actual operation in the nominal scale of the new single-phase power supply for microwave generators with N=2 magnetrons 2 debiting so a power up to 2x800=1600Watts at 2450 MHz (Figure 1). It focuses on the dimensioning of the only single phase transformer with shunts, will make the magnetrons work with their nominal mode so that each magnetron outputs its full power microwaves envisaged by the manufacturer.

### a. Dimensioning of the New Transformer with Shunts

The cuirassed structure of the new transformer with shunts of the new power supply for two magnetrons is identical to that of the transformer used in the classical power supply for only one magnetron [1-10]. the theoretical modeling already developed of a HV power supply for one magnetron can therefore be applied to find the numerical results giving the nonlinear variation laws $n_2\Phi_1(i'_p)$, $n_2\Phi_2(i_s)$, and $n_2\Phi_3(i'_{sh})$, of respective inductances $L'_p$ , $L_s$ and $L'_{sh}$ of the $\pi$ model of the new transformer to dimensioning for new power supply.

The transformer uses the same structure in the figure 2 for the new power supply with two magnetrons 800 Watts - 2450 MHz, it must provide for operation in nominal mode a instantaneous secondary current sufficient to supply correctly and at the same time two identical charges constituted each one of a voltage doubler and a magnetron.

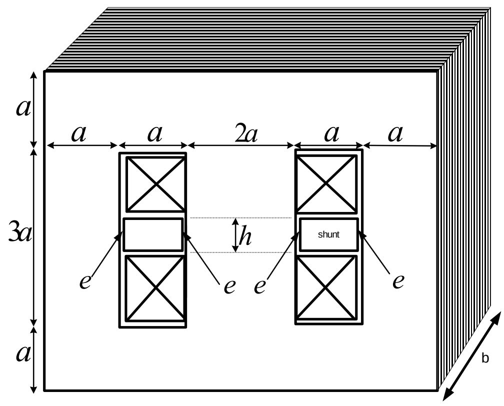


Figure 2. Cuirassed structure of the new transformer with shunts to dimensioning

This current must be double at every moment of that delivered by the secondary of the HV transformer used in the power supply with a single charge consists of a voltage doubler and a magnetron 800 Watts – 2450 MHz

Since, the nominal voltage in the primary of the transformer does not change the distribution of flows is kept the same. If the instantaneous current in the output of the quadruple model (classic power supply for one magnetron) double, all the other instantaneous currents of all the remaining branches of the quadruple must also double.

**b. Characteristics "Flow-Current" $L_p'$ , $L_s$ of Inductances of the New Transformer**

The maintenance of the similar distribution of instantaneous flows $\phi_1$ (primary side) and $\phi_2$ (secondary side) involves that the instantaneous currents $i_p' = \frac{n_2\phi_1}{L_p'}$ and $i_s = \frac{n_2\phi_2}{L_s}$ double.

The expressions of inductances according to the corresponding reluctances are the following [11, 13]:

$$L_p' = \frac{n_2^2}{R_P} = \frac{n_2^2}{\frac{6,5a}{\mu_1 S_1}} \; \& \; L_S = \frac{n_2^2}{R_S} = \frac{n_2^2}{\frac{6,5a}{\mu_2 S_2}}$$

This expressions show that the division of inductances by two is satisfied if:
* The same magnetic states $\mu_1$ and $\mu_2$ are preserved.
* The number of secondary turns is kept constant.
* The width of the unwound core is doubled.
* Sections $S_1$ and $S_2$ are kept constant.

Like $S_1$=$S_2$= (2a * b), the sections remain constant to satisfy the previous conditions if the width of the corresponding core to the number of the piled plates of the magnetic circuit is divided by two.

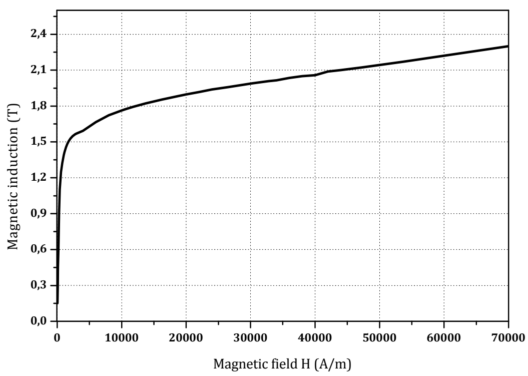


Figure 3. B (H) curve of the materiel used: SF19

By using the same curve B (H) (Figure 3) of the saturable material for a transformer with shunts used in the power supply for a magnetron and by exploiting the geometrical data of construction (Table 1), we obtain the digital values of the relation "flow-current" of Table 2 for the two inductances $L_p'$ and $L_s$ of the $\pi$ quadruple model of the new transformer with shunts for the new power supply of the generator microwaves with two magnetrons of power each one 800 Watts.

**Table 1:** Power supply for N=2 magnetrons: nominal mode
Identical characteristic 'flux-current' of the inductances $L_p'$ and $L_s$

- Number of secondary turns : $n_2$= 2400
- Unwound core width: a = 50 mm
- Width of the magnetic circuit : b = 30 mm

| Inductance $L_p'$ | Inductance $L_s$ |
|---|---|
| *Section : $S_1$=2a*b=3000 mm² | *Section : $S_2$=2a*b=3000 mm² |
| *Length of way AB : $l_1$=2a=100 mm | *Length of way DA : $l_2$=2a=100 mm |
| *Length of way BC : $l_{11}$=4,5a=225 mm | ***Length of way CD :** $l_{22}$=4,5a=225 mm |
| *Length of way ABC: $lp = l_1 + l_{11}$=325 mm | *Length of way CDA: $ls = l_2 + l_{22}$=325 mm |

**Table 2:** (Appendix B)
Identical characteristic 'flux-current' of the inductances $L_p'$ and $L_s$

| B (T) | H (A/m) | $n_2\Phi_P = n_2BS_1$ <br> $n_2\Phi_S = n_2BS_2$ <br> (mWb) | $i_P = (\ell_P/n_2)H$ <br> $i_S = (\ell_S/n_2)H$ <br> (A) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0,1515 | 00050,0 | 1,0908 | 0,0068 |
| 0,0303 | 00100,0 | 2,1816 | 0,013 |
| …….. | ……… | …….. | …….. |
| ……. | ……… | …….. | …….. |
| ……. | ……… | …….. | …….. |
| 2,3000 | 70000,0 | 16,56 | 9,4792 |
| 2,3125 | 72000,0 | 16,65 | 9,750 |

**c. Characteristic "Flow-Current" of the Inductances $(L_{sh}')^f$ and $(L_{sh}')^e$ of the New Transformer**

The maintenance of the similar distribution of instantaneous flow $\Phi_3$ (side shunts) involves that the instantaneous currents $(i_{sh}')^e=\frac{n_2\Phi_3}{(L_{sh}')^e}$ and $(i_{sh}')^f=\frac{n_2\Phi_3}{(L_{sh}')^f}$ double if the values are divided by two of the following expressions of instantaneous inductances of the model $(L_{sh}')^f$ and $(L_{sh}')^e$ relating to the shunt are equivalent to the whole of the two shunts of the new transformer:

$$(L_{Sh}')^f = \frac{n_2^2}{R_{Sh}^f} = \frac{n_2^2}{\frac{1}{2}(\frac{\ell_3 - e_3}{\mu_0 S_3})} \ \& \ (L_{Sh}')^e = \frac{n_2^2}{R_{Sh}^e} = \frac{n_2^2}{\frac{1}{2}(\frac{e_3}{\mu_3 S_3})}$$

That returns, according to the same paragraph quoted above, to divide by two the following expressions of inductances, relative to each of the two identical shunts of the new transformer, according to the corresponding reluctances:

$$L_3^f = \frac{n_2^2}{R_3^f} = \frac{n_2^2}{(\frac{\ell_3 - 2e}{\mu_0 S_3})} \ \& \ L_3^e = \frac{n_2^2}{R_3^e} = \frac{n_2^2}{(\frac{2e}{\mu_3 S_3})}$$

The two following suggested solutions can satisfy this division by two:

**Solution 1:**

* The same magnetic state $\mu_3$ is preserved.
* The number of secondary turns is kept constant.
* The thickness of the air gap "**e**" is multiplied by two and the section $S_3$ is kept constant.

**Solution 2**:

* The same magnetic state $\mu_3$ is preserved.
* The number of secondary turns is kept constant.
* The thickness of the air gap "e" is kept constant and the section $S_3$ is divided by two.

Like $S_3$= (H * b)=0,5*n3*b, the constraint adopted in the II.2 paragraph of division by two of the width b, of the corresponding core to the number of piled plates of the magnetic circuit, automatically imposes the choice of the second solution.

By using the same curve B (H) of the saturable material for the two shunts and by exploiting the geometrical data of construction (Table 3), we get the results of the digital values of the relation "flow-current" (Table 4) for the two inductances $(L'_{sh})^f$ and $(L'_{sh})^e$ of the π quadruple model of the transformer for the new power supply used in the microwave generators with two magnetrons 800Watts – 2450 MHz.

**Table 3:** Power supply for N=2 magnetrons: nominal mode
Determining the parameters of the transformer model with shunts from the construction data: Characteristic 'flux-current, of the inductances $(L'_{sh})^f$ **and** $(L'_{sh})^e$

- Width of the unwound core: **a = 50 mm**
- Number of secondary turns: **$n_2$ = 2400**
- Width of the magnetic circuit : **b = 30mm**
- Number of stacked plates of a shunt: **$n_3$ = 18**
- Height piled plates by shunt : **h = 0.5 mm * $n_3$**
- Section of a shunt: **$S_3$ = h * b = 9 * 30 = 270 mm2**
- Thickness of an air gap: **e = 0.55 mm**

| ***Inductance*** $(L'_{sh})^f$***: variable (non-linear)*** | ***Inductance*** $(L'_{sh})^e$***: constant*** |
|---|---|
| ➢ Thickness: $\ell^e_{Sh} = \frac{e_3}{2} = e = 0{,}55\text{mm}$ <br> ➢ Air permeability $\mu_0 = 4.\pi.10^{-7}\,\text{MKSA}$ <br> ➢ Reluctance: $R^e_{Sh} = \frac{\ell^e_{Sh}}{\mu_0.S_3} = 1616842\text{H-1}$ <br> ➢ Inductance: $(L'_{Sh})^e = \frac{n_2^2}{R^e_{Sh}} = 3562\,\text{mH}$ | ➢ Thickness of a sheet of shunt=0,5 mm <br> ➢ Length of the way CA without air-gaps: $\ell^f_{Sh} = \frac{\ell_3 - e_3}{2}$ <br> $\ell^f_{Sh} = (2{,}5a - 2e)/2 = 61{,}95\ \text{mm}$ |

## 3. SIMULATION OF THE NEW MODELED POWER SUPPLY

Compared to the case treated the modeling of the current power supply for a magnetron 800 Watts – 2450 MHz, we modified the values of the construction parameters (figure 2), by doubling the width of the unwound core "a" and while dividing by two the width "b", of the core corresponding to the number of piled plates of the magnetic circuit.

The study of the simulation of the electrical behavior of this device which can deliver a 2*800=1600 Watts power microwave useful at 2450MHz, was carried out with a suitably dimensioned transformer with shunts which can carry on its nameplate the characteristics 220/2200V, 50Hz, 2*1500= 3000 VA.

During the simulation, we observed by introducing the new numerical values given in the tables 1, 2, 3 and 4 the waveforms of the different electrical quantities of the various branches of the overall HV circuit in nominal primary voltage of 220V.

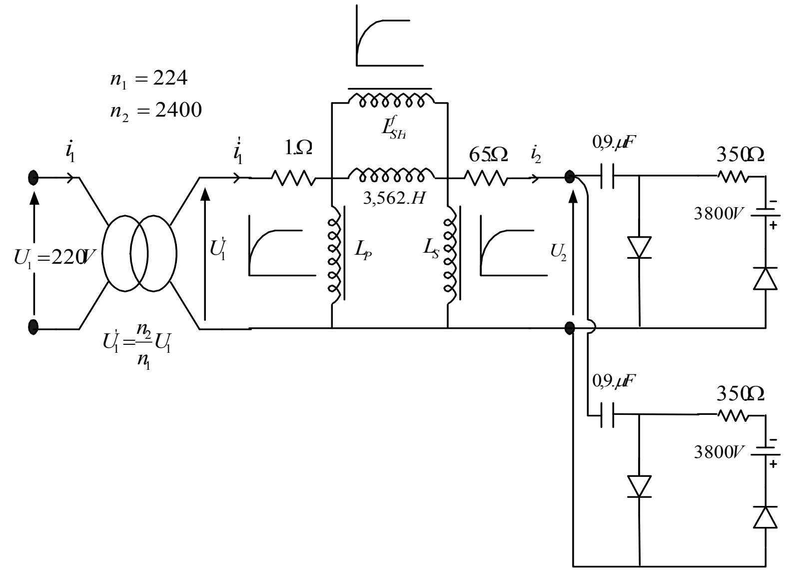


Figure 5. The operating simulation of the assembly equivalent to that of the figure 4

The oscillograms obtained of the electrical signals are represented on the figures 6, for the voltages (voltage across the secondary of the transformer and in each of the two magnetrons) and 7 for currents (current in each diode, the current in each magnetron, secondary current).

It is observed that the maximum value of the current amplitude for each magnetron stays below the limit 1.2A imposed by the manufacturer, that respects the constraints of the correct operation of each magnetron tube with an average current of 300mA without exceeding the peak recommended current.

The voltage signals shown in the figures 6 and currents 7 have the same form that those of a conventional power supply having only one transformer for one magnetron only, excluding that the amplitude of the currents at each instant is twice, thus confirming that each magnetron delivers its full nominal power (800 Watts-2450 Mhz). This confirms the absence of any interaction between the magnetrons powered depending on the configuration indicated in the figure1. The operating points of these magnetrons are not thus disturbed any more, which paramount for a stabilized current power supply The difference between the different voltages across the same magnetrons has not been seen since their characteristics disparity has not been taken into account. However, this gap not exceeding one hundred volt even, if it exists, remains without effect on the operation of all the two magnetrons.

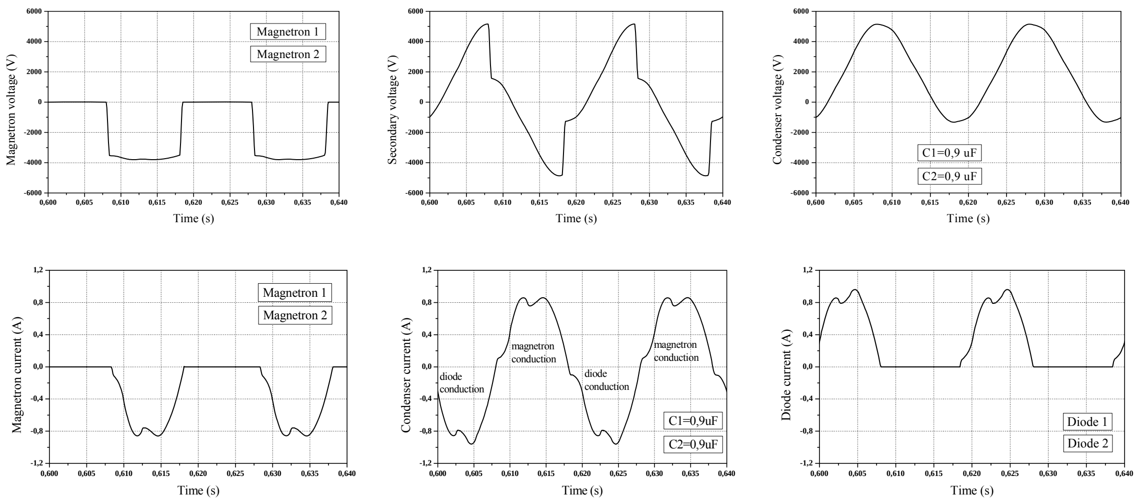


Figure 6. Waveforms of currents and voltages of the new power supply for two magnetrons

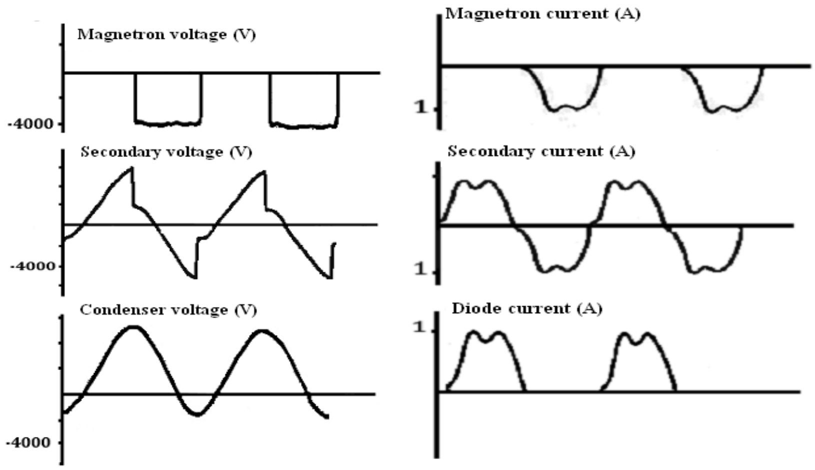


Figure 7. Experimental waveforms of currents and voltages of the current power supply for a magnetron (nominal mode)

## 4. CHECKING THE REGULATION PROCESS OF THE CURRENT IN EACH MAGNETRON

During the simulation of this new power supply for two magnetrons, we succeeded in observing the stability of the variations of the current in each magnetron with respect to the sector voltage. The figures 9.A and 9.B show the identical waveforms of the current in each magnetron for the respective cases 200 V and 240 V (±10% of the nominal voltage of the power supply grid). By assessing that the maximum amplitude of the current never exceeds the acceptable limit value recommended by the manufacturer, we can confirm that with this model of the transformer with shunts, the stabilization process of the current in each magnetron is completely checked.

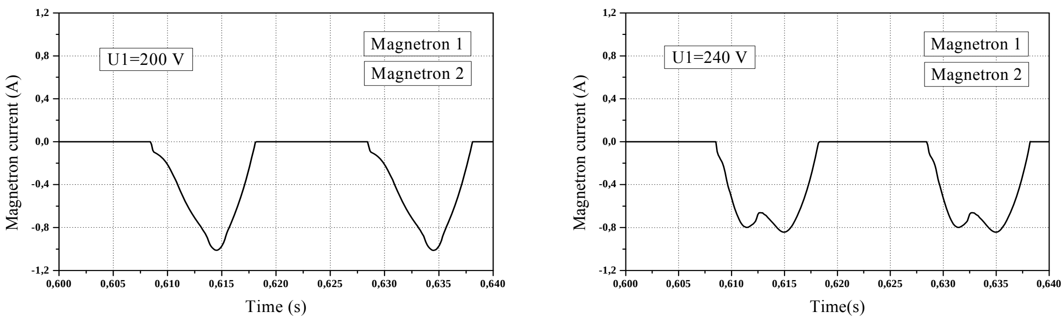


Figure 9. Stabilization of the anodic current in each magnetron compared to the variations of the sector voltage by ±10% of the nominal voltage

## 5. CONCLUSION

We have described the modeling using the EMTP code of a new single-phase HV power supply for microwave generators with two magnetrons 800 Watts can therefore deliver up to 1600 Watts useful at 2450 MHz. After the correct dimensioning of the leakage transformer, we were able to show correctly the nominal operation of such power supply in non linear mode.

The simulation using EMTP code of the modeled newsystem has allowed recovering the control process in each current magnetron, which ensures the protection of all magnetrons against any possible variation of the input voltage of the power supply grid.

The encouraging and the satisfying results of the operation of the new simulated electrical power supply for microwave generators with two magnetrons 800 Watts-2450 MHz have led us to undertake the detailed study of the modeling with EMTP code in nominal mode a new type of power supply for microwave generator with N = 3,4, .... magnetrons.

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