International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Design of Rectangular Wave Guide to Coaxial Line Microwave Source System for the Differential Dielectric Heating in Agriculture Using Parallel Plate Applicator

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Submitted: 20/07/2023 **Revised**: 11/09/2023 **Accepted**: 24/09/2023

Abstract*:* In this paper a microwave source for dielectric heating is discussed. A low cost source for the purpose of dielectric heating to control the insect pests on tomato plant with the help of parallel plate applicator is simulated and developed. A magnetron operated at 2.45GHz is used to transfer the power from rectangular waveguide to coaxial line port with 50 Ω impedance is discussed. In this paper, transfer of microwave power from the magnetron is launched into rectangular waveguide and transferred to coaxial port to couple the power more than 85%. The hatching rate of insect eggs and mortality of 'Helicoverpa armigera' larvae up to 3rd instars is observed on tomato plant at the power of 360 W using developed microwave sources.

Keywords: *Waveguide to coaxial adapter, Differential heating, dielectric heating, insect control*.

1. Introduction

The Integrated Pest Management (IPM) is very effective system in agriculture. The use of electromagnetic non-ionized radiation is one of the solutions to control the insect pests at their different life stages. The differential heating concept is very efficiently used in controlling the insect pests in agriculture in grains, post harvested agro-products and food industry as RF dryer. The use of microwave oven energy to control weed in agriculture, heating of soil experimented. [1][2].

To provide a low cost, compact and low power source to control the insect pests in agriculture during the growth of plant is big challenge. The Low power source up to 250 W used with parallel plate applicator for dielectric heating to control insect pests in anechoic chamber [3][4]. To make an applicator handy, a compact and low cost RF and microwave power source is need to design. It observed that low power up to 250 W is not much effective on larvae stage of the insect pests as compare to eggs and hence power more than 250Wsource is required. Also, during differential dielectric heating, exposed power should not damage the host plant and fruits [5]. To develop such a RF and microwave source system; magnetron can be one of the low cost and easy solution. The low and high power magnetrons at 915 MHz and 2.45 MHz are available with power supply for domestic and industrial applications [8]. The domestic LG MC-7880PSR model (28-liter capacity) microwave oven is studied and it understood that the electromagnetic power of magnetron can be coupled to a coaxial wire by using magnetron launcher waveguide and waveguide to N-type coaxial adapter [6][7]. To calculate the rectangular waveguide dimensions, cut-off frequency and wavelength were calculated using Equations (1) & (2) for TE10 mode and are given as:

$$(f_c)_{mn} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (1)$$

$$(\lambda_c)_{mn} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2}} \quad (2)$$

Where fc is cutoff frequency, 'a' is longest dimension of a waveguide, 'b' is shortest dimension of a waveguide, 'm' is the number of half - wavelength variations of the fields in the 'a' direction, 'n' is the Number of half-wavelength variations of the fields in the 'b' direction, ε is Permittivity and μ is Permeability [9]. The low and high frequency is determined from Equations (3) to (5).

$$f_c = \frac{c}{2w_m} \quad (3)$$

Where wm is the width in meter of the rectangular waveguide.

$$f_{high} = 1.89 f_c \quad (4)$$

$$f_{low} = 1.25 f_c \quad (5)$$

The waveguide impedance is calculated using Equation (6) [7].

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$$Z_{TE} = \frac{z_0}{\sqrt{1-\left(\frac{f_c}{f_0}\right)^2}} \quad (6)$$

Where Z0 is characteristics impedance of waveguide and f0 is free space wavelength.

2. Material and Methods

2.1 Simulation of RF and Microwave source

The COMSOL Multiphysics software is used to simulate the magnetron launching inside the rectangular waveguide and coaxial adapter. The magnetron of 2.45 GHz is used during experimentation due to polarization of water molecules at this frequency is high and need small size parallel applicator [3]. To couple power at 2.45GHz to an applicator, the standard WR 340 waveguide dimensions (86.36 x 43.18 x 370 in mm) are used. The position of microwave oven magnetron (LG-2M214) port in COMSOL Multiphysics is at 192 mm from back short of magnetron launcher waveguide. The diameter of port is 15mm. The thickness of all wall sides is 3mm. The separate coaxial adapter with dimensions (86.36 x 43.18 x 95) mm is attached to magnetron launcher waveguide. The N-type female connector (coaxial port) is placed at 25mm from back short of coaxial adapter. The placement of magnetron output port and coaxial waveguide adapter port are optimized and placed for better power coupling and is shown in Figure 1. To simulate this structure, the boundary condition is 'Perfect Electric Conductor'.

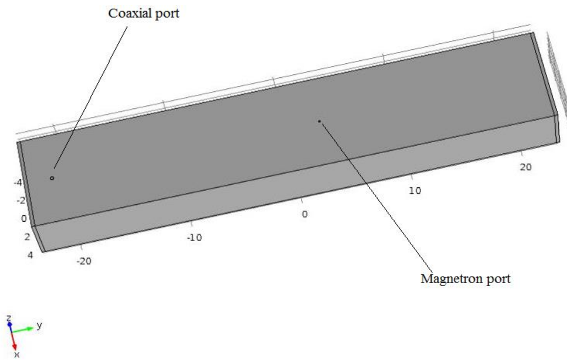

Fig. 1. Magnetron launcher and coaxial adapter design in COMSOL Multiphysics.

2.2. Hardware design

The fabrication of simulated microwave launcher waveguide is made in brass. The testing of developed microwave source conducted on Vector Network Analyzer (VNA: 9KHz to 13.5GHz R&S-ZVL model) at N-type coaxial port is shown in Fig. 2. During experimentation a power supply of LG microwave oven model MC-7880 is used to power up the magnetron. Testing of developed source system along with applicator and commodities are conducted in anechoic chamber at the power 180W, 360W,

Fig. 2. Testing of magnetron launcher and coaxial adapter using VNA (R&S-ZVL model).

and 540W as per the available step size of the used microwave oven power supply. The magnetron power supply kept outside the anechoic chamber in control room to set the power and the exposure duration. The effect of 5 m long wire; 4 sq. mm is analyzed by heating a cup of water in microwave oven and its heating time and current has been observed. The tested results of microwave oven with and without extended wire are given in Table 1.

Table 1. Effect of five-meter extended wire connected between the power supply and magnetron

Power set by micro wave oven (W)	Direct connection to magnetron from supply (load in microwave oven: One cup water @10 sec.)		Five meter long wire connection to magnetron from supply (load in microwave oven: One cup water @10 sec.)	
	Current (A)	Change in temperature (^{0}C)	Current (A)	Change in temperature (^{0}C)
180	0.4 to 0.7	7.4	0.4 to 0.7	6.2
360	0.4 to 1.2	10	0.4 to 1.2	8.5
540	0.4 to 1.2	10	0.4 to 1.2	8.5
720	0.4 to 1.5	10	0.4 to 1.4	8.5
900	0.4 to 1.2	10.3	0.4 to 1.2	9.1

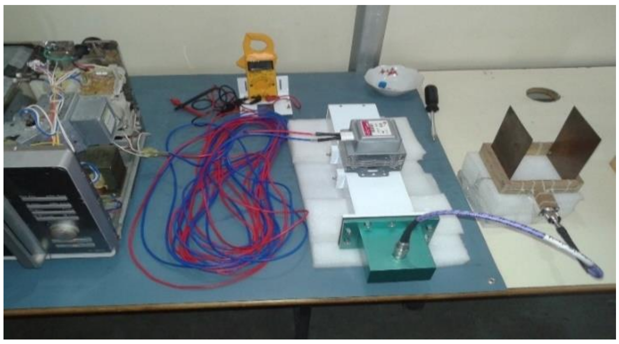

Fig. 3. Setup of power supply, magnetron waveguide launcher and an applicator connection.

A tong tester (MEKO model) and infrared thermometer (Metravi MT-4 model) are used to measure the current and temperature of water. The complete hardware setup of this experimentation interface is shown in Fig. 3.

With the help of field probe, the field intensity and power density inside the applicator has been calculated and is given in Table 2.

Table 2. Measurement of electric field intensity in applicator at different power input to the magnetron.

Input power (W)	E-field intensity (V/m) inside the applicator plate	Power flux density at applicator (W/m^2)
180	232	142.76
360	362	347.59
540	502	668.44

The electric field intensity above the 300 V/m is suggested with low power and compact source system to connect to the applicator for insect control purpose [5].

3. Results and Discussions

The field pattern of designed waveguide for TE10 mode and the power flow from magnetron port to the coaxial port in simulated results are shown in Fig. 4.

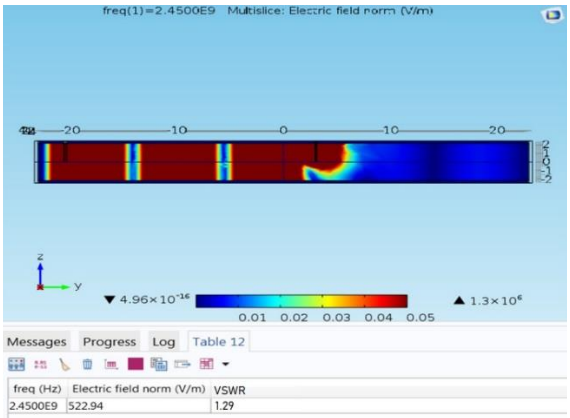

Fig. 4. The field pattern of the simulated microwave launcher and coaxial adapter.

The measured electric field intensity 522.94 V/m at the input power of 500 W and the Voltage Standing Wave Ratio (VSWR) 1.29 is observed, which can transfer the 98.4% of energy from magnetron port to coaxial port.

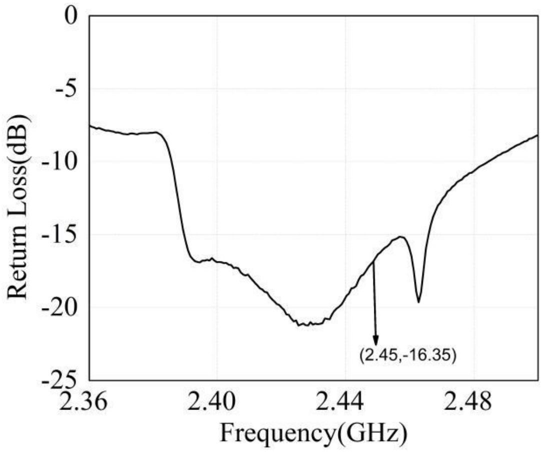

Fig. 5. The return loss (S11) of fabricated microwave launcher and coaxial adapter.

The developed microwave source is tested on VNA for the return loss (S11) 16.35 dB and VSWR 1.34 are shown in Fig. 5 and Fig. 6 respectively.

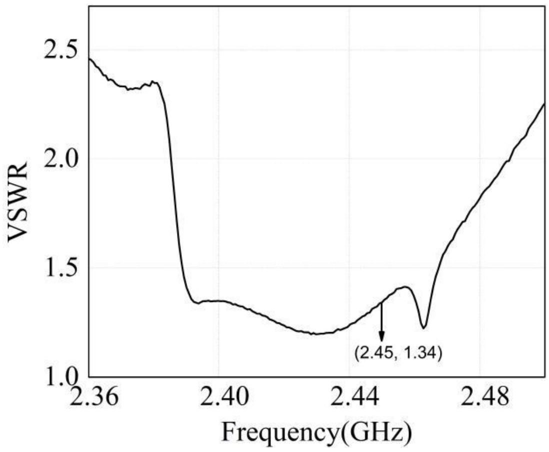

Fig. 6. Voltage standing wave ratio of fabricated microwave launcher and coaxial adapter.

The total power transfer becomes 97.89% of the applied input power to the coaxial port. The Brass material is used to fabricate the waveguide with 3 mm thick side walls; hence its power handling capacity is more than 3KW. During testing of the extended wire from power supply to magnetron from power supply unit of a microwave oven, it is observed that the current from transformer is same, but there are differences in a rise in temperature of the water kept in a microwave oven due to voltage dropped. The actual electric field intensity will be more than measured if developed microwave source will be connected to the power supply without five-meter extended wire.

From the conducted experimentation, it is possible to develop such a source at different RF and microwave frequency by changing the magnetron of 915MHz and 5.81 GHz with its power supply and dimensions of waveguide [8].

It has been observed that, when the electric field intensity set to 349 V/m during exposure; the poor hatching of eggs and mortality of first instar, as well as erratic movement of second and above instar larvae of ‘Helicoverpa armigera’ has been reported [5]. However, more than 300 V/m electric field intensity needed to control the “Helicoverpa armigera” on a tomato plant and hence commodities are tested up to 540W power of developed microwave source. With proper shielding to the applicator, radiation around the applicator can be controlled.

The chemical analysis of tomato plant done after the electromagnetic exposure are given in Table 3 & Table 4.

Table 3. The Bete-caroten after electromagnetic exposure on tomato.

Sample (Tomato)	Beta-carotene (µg/100g) after 05 seconds of exposure at the power.	
	360 W	540 W
Premature	145.06	156.89
Mature	331.02	567.70

Table 4. The pH and Total soluble solid after electromagnetic exposure on tomato.

Sample (Tomato)	pH and Total Soluble Solid after 05 seconds of exposure at the power.			
	360 W		540 W	
	pH	TSS	pH	TSS
Premature	4.4	4.8 %	4.5	5.0%
Mature	4.4	4.0%	4.4	4.0%

The Beta carotene of mature and premature tomato is increased with increase in power. The tomato beta carotene range lie between 230 to 283 (µg/100g)[10][11]. It has been also observed that as temperature increases beta carotene also increase [12]. Whereas the percentage of Total Soluble Solid (TSS) is observed in the range between 4.5% to 6.25% [13]. A very negligible change in pH is observed in tomato during chemical analysis. The hatching rate of eggs is reduced and early hatching has been observed and 1st to 3rd instars mortality observed whereas 4th and 5th instars erratic movement observed. The sample size of the eggs and each instars are 20 and 5 respectively. Hence this power can be suitable to use in the agriculture application without degrading the fruit quality and host plant.

4. Conclusion

The simulated RF and MW source were successfully designed, developed and tested. The simulated microwave source at 2.45GHz is successfully designed, developed and tested. The developed source system is low cost as compare to the available solid state power amplifiers, to satisfy the requirements in agriculture to control the insect pests. The developed microwave source has VSWR 1.34 and 97.89 % of power transferred to the applicator. The band width of the developed microwave source is 100MHz. It has been also observed that there is no diverse effect of electromagnetic radiation from developed microwave source on tomato fruits.

Acknowledgment

The authors express their gratitude to Society for Applied Microwave Electronics Engineering and Research (S.A.M.E.E.R.), Mumbai for their support in the testing process and availing infrastructure.

References

[1] Nelson, Stuart O. "RF and microwave energy for potential agricultural applications." Journal of Microwave Power 20.2 (1985): 65-70.

[2] Nelson Stuart, "Potential Insect-Control Applications for Microwaves", USDA-ARS, 1973; Paper 245.

[3] Gaikwad, Sandeep V., et al. "Low power microwave heating to control insect pests on tomato plants." IMPI’s (2014)

[4] Gaikwad, Sandeep V., et al. "Simulation modeling and implementation of RF and MW system to control the insect pests in agriculture." 2015 Annual IEEE India Conference (INDICON). IEEE, 2015.

[5] Gaikwad, Sandeep Vinayak, and Arun N. Gaikwad. "RF and Microwave Low Power Dielectric Heating Using Parallel Plate Applicator to Control Insect Pests on Tomato Plant." Progress In Electromagnetics Research M 49 (2016): 81-89.

[6] Surducan, V., et al. "Microwave generator for scientific and medical applications." AIP Conference Proceedings. Vol. 1425. No. 1. American Institute of Physics, 2012.

[7] Roussy, Georges, and Nils Kongmark. "Microwave Impedance Matching Strategies of an Applicator Suppliy a Bi-Directional Magnetron Waveguide Launcher." Journal of microwave power and electromagnetic energy 38.4 (2003): 237-242.

[8] Pozar, David M. Microwave engineering. John wiley & sons, 2011.

[9] Adams, S. R., K. E. Cockshull, and C. R. J. Cave. "Effect of temperature on the growth and development of tomato fruits." Annals of botany 88.5 (2001): 869-877.

[10] Abdelmageed, A. H., Nazim Gruda, and Bernd Geyer. "Effect of high temperature on tomato (Lycopersicon

esculentum Mill.) genotypes under controlled conditions." International Conference on Tropical and Subtropical Agricultural Research for Development (Deutscher Tropentag (DTT)). 2003.

[11] Garcia, Elisabeth, and Diane M. Barrett. "Evaluation of processing tomatoes from two consecutive growing seasons: quality attributes, peelability and yield." Journal of food processing and preservation 30.1 (2006): 20-36.

[12] McDonald, R. E., T. G. McCollum, and E. A. Baldwin. "Heat treatment of mature-green tomatoes: differential effects of ethylene and partial ripening." Journal of the American Society for Horticultural Science 123.3 (1998): 457-462.

[13] Mane, P. B. et al. (2017). Watermarking and cryptography based image authentication on reconfigurable platform. Bulletin of Electrical Engineering and Informatics, 6(2), 181-187.

[14] Mandwale, A. J. et al. (2015, January). Different Approaches For Implementation of Viterbi decoder on reconfigurable platform. In 2015 International Conference on Pervasive Computing (ICPC) (pp. 1-4). IEEE.

[15] Mane, P. B., & Mulani, A. O. (2018). High speed area efficient FPGA implementation of AES algorithm. International Journal of Reconfigurable and Embedded Systems, 7(3), 157-165.

[16] Kashid, M. M et al. (2022, November). IoT-Based Environmental Parameter Monitoring Using Machine Learning Approach. In Proceedings of the International Conference on Cognitive and Intelligent Computing: ICCIC 2021, Volume 1 (pp. 43-51). Singapore: Springer Nature Singapore.

[17] Mr.Rahul S Pol, Prof M. Murugan, 'A Review on Indoor Human Aware Autonomous Mobile Robot Navigation Through a Dynamic Environment', International Conference on Industrial Instrumentation and Control (ICIC 2015), held by Government college of engineeing Pune, ICIC2015, 28th-30th May 2015, pp-987

[18] Dr. Rahul S Pol, Dr. B. Sheela Rani, Prof M. Murugan (2021). Optimal Path Planner for Indoor Mobile Robot Environment. Design Engineering, 8297-8309.

[19] Babu, M. C. ., & K, S. . (2023). An Intelligent Optimal Secure Framework for Malicious Events Prevention in IOT Cloud Networks. International Journal on Recent and Innovation Trends in Computing and Communication, 11(3), 117–127. https://doi.org/10.17762/ijritcc.v11i3.6328

[20] Russo, L., Kamińska, K., Christensen, M., Martínez, L., & Costa, A. Machine Learning for Real-Time Decision Support in Engineering Operations. Kuwait Journal of Machine Learning, 1(2). Retrieved from http://kuwaitjournals.com/index.php/kjml/article/view/117

[21] Keerthi, R. S., Dhabliya, D., Elangovan, P., Borodin, K., Parmar, J., & Patel, S. K. (2021). Tunable high-gain and multiband microstrip antenna based on liquid/copper split-ring resonator superstrates for C/X band communication. Physica B: Condensed Matter, 618 doi:10.1016/j.physb.2021.413203