Ka Band 20-Vane Non-π-Mode Magnetron

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Abstract: *We report development at IRE NAS of Ukraine of pulsed Ka band (8-mm/37.5 GHz) 20-vane unstrapped 8-mm magnetron. It operates in a non-π-mode of the "-1" spatial harmonic. Results of numerical modelling and experimental investigations of anode slow wave structure (anode block) for (N/4 – 1)-mode (N = 20) are presented and discussed.*

Keywords: Ka band, spatial-harmonic magnetron, unstrapped anode block, circuit efficiency, non-incandescent cathode

Introduction

Pulsed millimeter-wave (mm-wave) spatial-harmonic magnetrons with thermionic cathode developed in 1947-1975 at Radio-Physics Departments of the Kharkiv Institute for Physics and Technology (KIPT) of Acad. Sci. (AS) of UkrSSR that later became IRE AS of UkrSSR/NAS of Ukraine, which cover the wavelength range from 6.8 mm (44 GHz) down to 1.25 mm (240 GHz), feature non-π-mode as an operational one [1–3]. In Western literature [4,5] such modes of magnetron operation were considered as presenting certain difficulties. In this contribution, we discuss the issue of magnetron operation in a non-π-mode of its anode block and demonstrate acceptability of such a regime for efficient generation of mm-wave radiation.

Degenerate Non-π-Modes

As shown in [4, pp. 215-216], under presence of an inhomogeneity (perturbation), doubly degenerate non-π-modes of magnetron unstrapped anode block split into a pair of close in frequency eigen-oscillations similarly to degeneracy lifting in the standard treatments of mathematical physics. For some reason [5], researches viewed this as one of the obstacles to designing and operating vane-type magnetron devices in those modes. Cited above experimental operation of mm-wave magnetrons at reasonable values of magnetic field demonstrated that one can successfully cope with such an obstacle while taking advantage of a larger separation in operating frequency (and AK gap voltage) from competing neighboring modes (cf. [6]). Typically used quarter-wavelength (active part of the coupling impedance) transformer (cf. [7,8]) introduces such an imaginary part of the coupling impedance perturbation/ disturbance as to reduce circuit efficiencies (see, e.g., [4, p. 200]) in a non-π-mode magnetron to about 10 % level rendering the overall efficiencies very low (independently of the electron efficiencies). Our numerical simulations confirm this assertion: for the quarter-wavelength transformer slot thickness range from 0.02 mm to 0.34 mm the circuit efficiency, $\eta_c = P_{out}/(P_{out} + P_{Ohm\ loss})$, calculated using CST MWS for our 20-vane 8-mm magnetron unstrapped anode block does not exceed 11 %.

For any inhomogeneity (for example, radiation output), degeneracy is lifted and eigen-modes are split into two standing waves with different frequencies (if the perturbation is not small, then they are not very close), one with antinode and the other with a node on the inhomogeneity (in the symmetry plane). Each of these standing waves is represented as a sum of two running towards one another ones. Therefore, the electron cloud, when a resonant (synchronism) condition is fulfilled, can efficiently interact with any of these split modes. At the same time, one of them is strongly coupled with the load (and, therefore, it is more difficult to excite), and the other, with a node on the output inhomogeneity, is coupled weakly. Thus, there is the issue of degenerate non-π-mode competition in a spatial-harmonic magnetron.

To mitigate the issue, it was proposed to extract microwave power from two anode block resonators simultaneously, [9]. Then, for symmetry reasons, the standing wave should be oriented symmetrically with respect to the two outputs, and the field node cannot obstruct both of them simultaneously. The traveling wave of operating harmonic is connected with both outputs. To sum the output power into a single output waveguide, it is necessary to ensure phase matching: the phases of waves entering the waveguide must be the same. Since the two outputs are fed with a certain phase shift, this phase shift must be eliminated before entering the single output waveguide. For this, the coupling of the two outputs with the single output waveguide is implemented as two waveguides of different cross-sections (and of the same length). Recently, we have developed a method for numerical simulation of operating regimes for a non-π-mode magnetron that accounts for different power output designs.

Thus, unlike concerns raised in [5, p. 158], doublet related issues in operating a non-π-mode mm-wave magnetron (see also [8,10]) can be dealt with successfully. However, perturbation/disturbance (namely reactance of the correspond-ding effective coupling impedance) introduced by radiation output λ/4-transformer waveguide coupling (see [11, p. 933] and [12, p. 37]) could be an issue of providing for high total

This work is supported in part by the NATO's Science for Peace and Security Programme under Grant No. G5195.

mm-wave spatial-harmonic magnetron efficiencies while operating in a non-π-mode.

A list of mm-wave magnetrons with thermionic cathodes developed over the years at Radio-Physics Departments of KIPT AS of UkrSSR and IRE AS UkrSSR/NAS of Ukraine is given in [3, p. 15] and reproduced in Table I, where N is the number of the magnetron anode block vane-type resonators, d_a is the anode block diameter, B is the magnetic field induction, U_a is the peak anode voltage, P_{out} is the peak output radiation power and η is the overall magnetron efficiency. The mm-wave magnetrons feature kW-level pulsed output powers for wavelength range from 6.8 to 1.25 mm (45 ÷ 240 GHz) with very reasonable values of necessary magnetic fields attainable with permanent magnet magnetic circuits (see, e.g., [13] and references therein).

TABLE 1: MM-Wave Magnetrons Developed in 1947-1975 at KIPT AS of UkrSSR and IRE AS of UkrSSR/NAS of Ukraine

λ (f), mm (GHz)	N	d_a, mm	B, kG	U_a, kV	P_{out}, kW	η, %
6.8 (45)	16	4.7	5.0	16.5	150	20.0
4.1 (75)	20	3.6	6.0	16.0	100	15.0
3.1 (95)	24	3.3	6.25	15.0	30	12.0
2.2 (135)	28	2.6	7.6	12.0	8.0	5.5
1.5 (200)	40	2.6	7.1	11.5	2.5	2.0
1.25 (240)	36	2.0	10.1	15.0	1.0	0.8

Dispersion Diagram

A dispersion diagram for the 20-vane unstrapped Ka band magnetron under development at IRE NAS of Ukraine is presented in Fig. 1. Using CST MWS, we numerically simulated the main passband eigen-mode frequencies for the fundamental and "-1" spatial harmonics of the magnetron unstrapped anode block. The magnetron is supposed to operate either in (N/4 – 1)- or N/4(π/2)-mode [$\gamma = n + mN$, where $n = 0,1,\ldots,N/2$ is the mode number and $m = 0,\pm1,\ldots$ numbers the spatial harmonics] of the main passband. The both members of numerically calculated frequency-doublets are shown in different shapes (and color) where appropriate (they appear in numerical simulations because rectangular mesh used by the solver is applied to a cylindrically symmetric calculation domain).

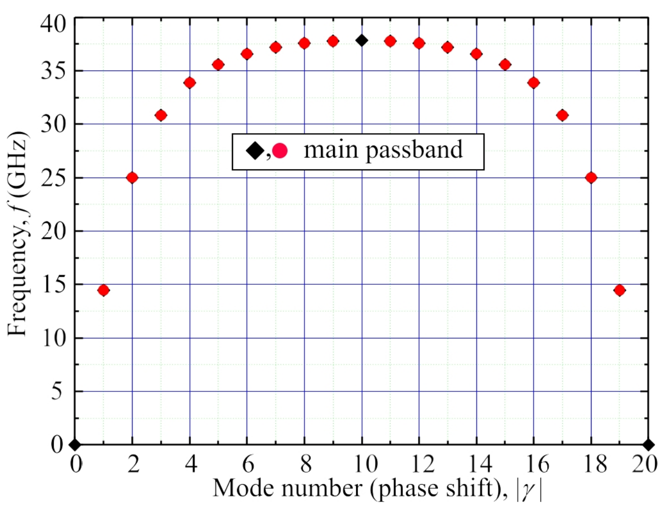

Fig. 1. A dispersion diagram for the 20-vane unstrapped Ka band magnetron shows the main (black diamonds and red circles) passband for the fundamental ($|\gamma| \leq 10$) and "-1" ($11 \leq |\gamma| \leq 20$) spatial harmonics; operational points are those in the "-1" spatial harmonic ($n = N/4$ -1 or N/4, i.e. $|\gamma| = 15$ or 16, respectively) at frequencies around 35 GHz (λ ~ 8 mm).

Conclusion

Usually used quarter-wavelength transformer radiation output is not very well compatible with the wave structure of an operating non-π-mode, which is induced by a rotating electron cloud in a mm-wave magnetron. Early suggestions to overcome these difficulties can be found in [9]. Using CST MWS numerical simulations, we studied circuit efficiency dependence on the dimensions of two-slot equal thickness model radiation output for our 20-vane 8-mm waveband magnetron anode block with operating N/4(π/2)-mode and found the circuit efficiencies varying from 81 % to 50 % for the dimensions ranging from 0.02 mm to 0.26 mm, respectively. These will provide for the necessary overall efficiencies and design flexibilities for long-life non-π-mode mm-wave magnetrons with non-incandescent cathode under development at IRE NAS of Ukraine and State-Owned Enterprise Plant "Generator".

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