Paper

Analysis and optimization of outputs of high power microwave tubes

Paweł Węgrzyniak, Wojciech Gwarek, and Dariusz Baczewski

Abstract— The subject of this work is optimization of outputs of L-band high power microwave tubes. These outputs are constructed as coaxial-to-waveguide transitions with a vacuum barrier in a form of glass or ceramic cup. The goal of optimization is to obtain sufficiently low reflection loss in the predefined frequency band and to avoid so called hot spots caused by excessive dissipation of microwave power in parts of the cup. Electromagnetic simulator has been applied to model the behavior of the optimized transition and to propose its optimum shape. The proposed solutions were verified by Z.E. Lamina SA in prototypes of high power (pulsed 600 kW) amplitrons and are to be used in manufacturing practice.

Keywords—high power microwave tubes, optimization of outputs.

1. Introduction

Design of reflectionless transitions between different waveguiding structures is one of typical problems of microwave engineering. The task becomes difficult when the input is supposed to be placed in vacuum and the output under the regular air pressure. In such a case the transition must incorporate a barrier which for technological reasons usually needs to be made of a high-permittivity dielectric. The difficulties are much amplified when high power is supposed to be transmitted through the transition. The chosen solution must assure suffiently low power dissipation in materials and sufficiently low electric field to avoid berakdown through ionized channels in air. Power dissipation and E-field intensity may rise sharply for resonant frequencies of the transition and thus avoiding of spurious resonances in the band of exitation of the structure is of major interest here.

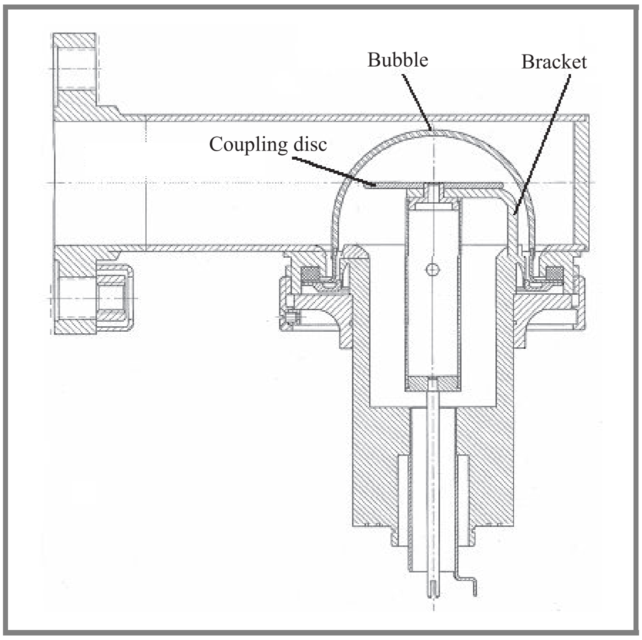


Fig. 1. Long section of the LM113 tube output.

The subject of this presentation is the investigation of the output of chosen high-power tubes of amplitron type [1, 2] manufactured by Z.E. Lamina SA. The tubes are supposed to work in L-band with the central frequency of 1340 MHz and used with a pulsed signal up to 600 kW. The long section of a typical transition considered is shown in Fig. 1. In the original Z.E. Lamina SA production the vacuum barrier was made of glass in a form of a glass bubble.

The manuafacturer found that in some cases hot spots are developed in the glass leading sometimes to the melting of the glas and thus to the damage of the tube.

The aim of this work was:

- to investigate the design options leading to elimination or reduction of the hot spots in glass;
- to investigate the possibility of replacing the glass barrier by a more heat-resistant alumina barrier (such replacing is difficult because alumina has higher permittivity and the cup must be thicker than one made of glass);
- to optimize the structure for lower reflections in the entire band of interest.

The investigation was based on full-wave electromagnetic simulations performed with QuickWave-3D [3] package. The modified structures were manufactured and tested.

2. Optimization of the structure with a glass barrier

The first of the considered structures was the output of LM113 tube manufactured by Z.E. Lamina SA presented in Fig. 1. It can be seen that in that coax-to waveguide transition a mixed magnetic-electric coupling is used. The magnetic coupling is assured by a copper bracelet connecting the inner conductor of the coaxial line with the waveguide wall. The electric coupling is controlled by the size of a copper disc placed at the top of the inner connector inserted into the waveguide. The vacuum barrier has a form of a glass bubble.

Extensive simulations of the structure were conducted. First they concerned the S-parameter characteritics versus frequency using the method of [4] (see Fig. 2). Then we conducted a detailed study of the power distribution inside the glass. Examples of that study concerning the frequencies 1340 MHz and 1000 MHz are presented in Fig. 3. It should be noted that frequency 1000 MHz is placed outside the band of operation of the tube, but it is still below the cutoff frequency of the waveguide. We cannot exclude some parasitic generation of the power by the tube in that band. From Fig. 3b it can be seen that such a generation (even at relatively low level) may cause damage to the tube.

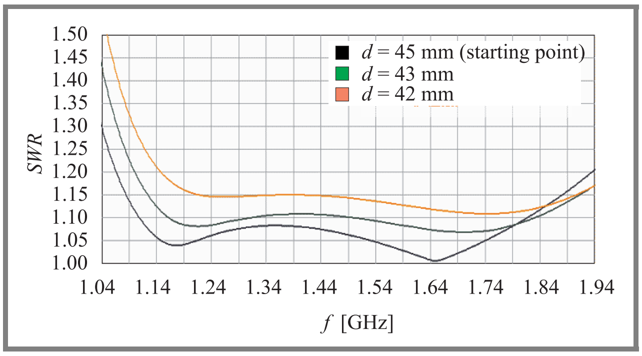


Fig. 2. Standing-wave ratio (SWR) versus frequency of the tube output with different ring size.

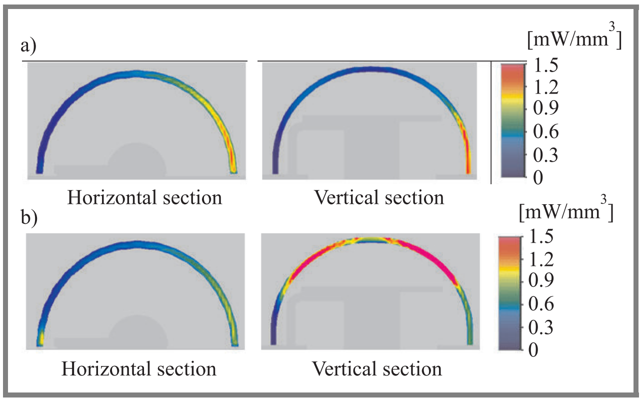


Fig. 3. Average dissipated power density at: (a) 1340 MHz and (b) 1000 MHz.

The results of simulations were confronted with the experience of the manufacturer and the following conclusions were drawn.

- Overheating takes place at glass impurities when they appear in the area of high power dissipation.
- Damages in the upper part of the glass bulb are most probably caused by spurious generations of the tube outside the band of interest.
- Damages below the disc plane are due to the power dissipation during the normal, stable work.

The first two causes of possible problems are beyond the scope of this work. We have concentrated on the third cause concerning normal operation of the tube.

We first approached the tube optimization by assuming that three parameters can be modified: the radius of the disc, its position above the waveguide wall and the radius of the glass tube. We have found that the disc diameter of 43 mm produces is relatively good choice giving the hot spot power density reduced by about 15% and SWR still below 1.1 in the entire band. However the drop of 15% was judged insufficient for full safety of future tubes. That is why we have also conducted investigation of structures with non-circular discs. Very interesting results were obtained with a disc of the cardioidal shape as presented in Fig. 4.

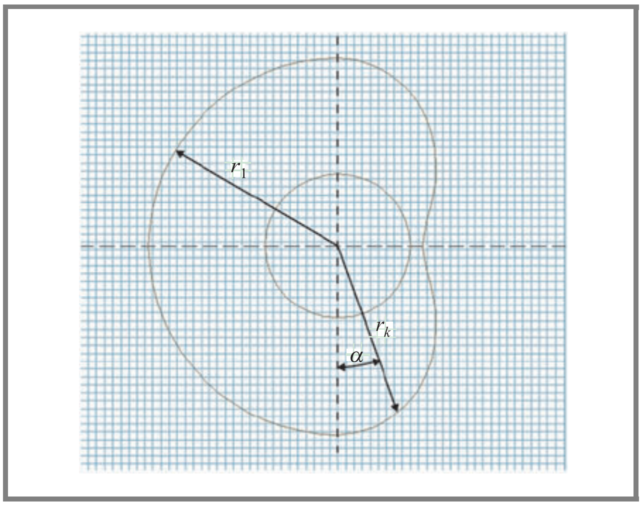


Fig. 4. Coupling disc of cardioidal shape.

Although SWR slightly increased (to 1.15 as shown in Fig. 5), the power dissipated in the hot spot dropped by 36%, as shown in Fig. 6.

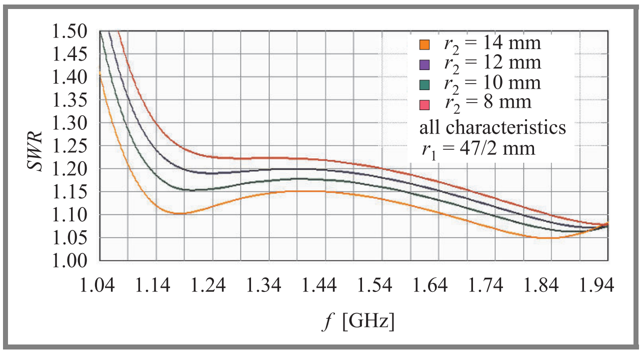
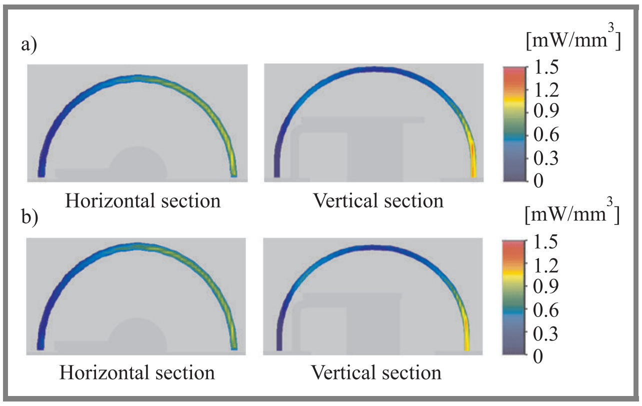


Fig. 5. SWR for LM113 output with cardioidal coupling part.

Above investigation was a basis for improvement of the glass barrier in the new types of tubes. Hardware prototypes of the new types have been tested and improvement of their properties has been experimentally confirmed. However it should be also mentioned that damages of the older



Horizontal section Vertical section

Horizontal section Vertical section

Fig. 6. Average dissipated power density, cardioidal: (a) $r_2 =$ 8 mm and (b) $r_2 = 14$ mm.

types of tubes had incidental character and thus only a long-time observation of several copies of new tubes may be a proof that the problem has been completely solved.

3. Design of a structure with a ceramic barrier

Mechanical and thermal properties of alumina (Al_2O_3) ceramic are clearly superior to those of glass. Moreover alumina barrier shape can be made more repeatable in manufacturing. The main disadvantage of alumina is its high relative permittivity ($\varepsilon_r = 9.8$). The problems are amplified by the fact that it is difficult to make the ceramic cup very thin. Relatively thick material of high permittivity restricts the possibility of wideband matching and enhances the danger of spurious resonances of the structure. These problems caused that Z.E. Lamina SA had not been using the ceramic barriers for such purpose before this study.

We have run investigation of the possibility of application of a ceramic barrier under the same assumptions as in the case of the glass barrier. Examples of simulated $|S_{11}|$ versus frequency for different configurations of the structure are presented in Fig. 7. It was not possible to obtain sufficiently good matching in the entire band of interest (1240–1440 MHz) as it had been the case of the glass barrier. However in fact the entire band is divided into two sub-bands1240–1340 MHz and 1340–1440 MHz served by different types of tubes. Thus the manufacturer has judged that preparation of two types of the output for two different sub-bands is not a major practical problem.

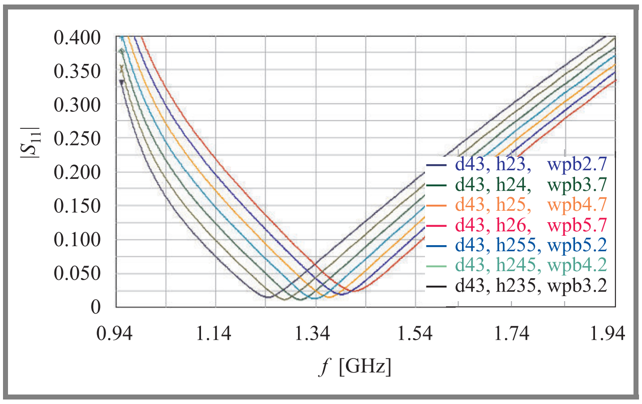


Fig. 7. $|S_{11}|$ for several different dimension configurations.

Prototype of a tube with ceramic barrier has been manufactured by Z.E. Lamina SA and measured. Good results have been obtained as presented in Fig. 8. The heat dissipation properties were tested by measurements of the cooling air temperature versus average output power for both constructions of the tube. It was found that increase of the cooling air temperature above the room temperature was about 30% lower when alumina barrier was applied. Taking into account that alumina can work without damage in much higher temperature than glass this is a very promising result for manufacturing practice.

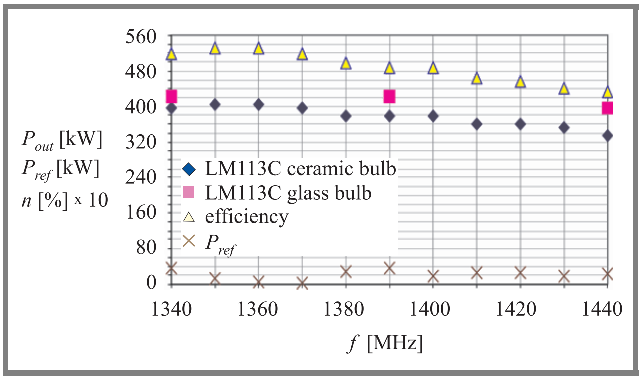


Fig. 8. Output power and efficiency obtained for the tubes with glass and ceramic barriers.

4. Modeling of the entire tube structure

So far we have treated the coax-to-waveguide transition as a stand-alone structure. This does not provide full picture of the physical setup. The transition is placed at the output of a complicated slow wave structure of the tube as shown in Fig. 9. We have used the 3D drawing provided by Z.E. Lamina SA to prepare a QW-3D model of

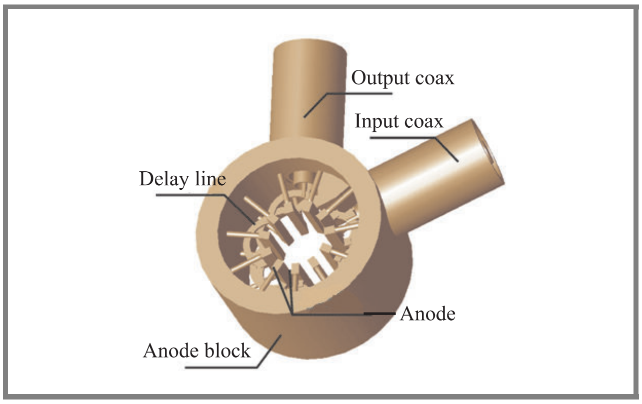


Fig. 9. 3D model of LM113 tube without outputs.

the entire tube. To increase the efficiency of calculations we have segmented the structure into three parts: input transition, slow wave structure and output transition. Each of the parts was calculated separately and the resulting S-matrices were combined using S-Converter [5] of QW-3D package.

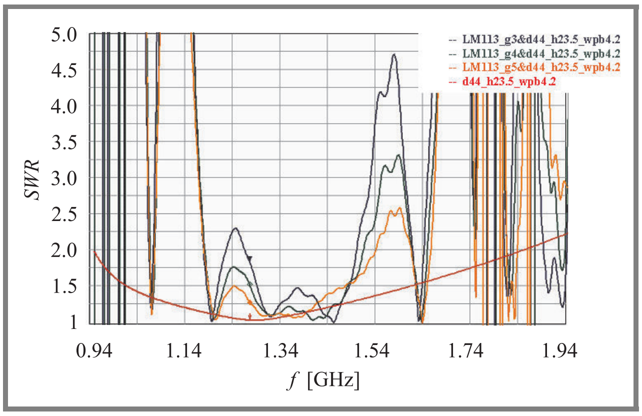


Fig. 10. *SWR* of the structure of whole tube calculated in QW-3D software.

Figure 10 shows calculated *SWR* of the entire structure. The results confirm good properties of the entire structure in the band of interest and indicate possibilities of further optimization. It should be noted however that these results concern so called “cold test” when the tube is not active and electron beam does not interacts with the electromagnetic wave. Relations between the “cold test” properties and actual properties of the tube during its normal operation are beyond the scope of this work.

5. Conclusions

The task of optimization of the output structures of L-band power amplitrons has been conducted. Electromagnetic modeling permitted better understanding of the physical phenomena concerning power dissipation in the coax-to-waveguide transitions used in the tubes. It helped to understand the cause of occasional damage by overheating of the glass bubbles used in the tubes. New design was proposed, manufactured and tested showing its superior properties with respect to earlier designs. Alternative output of the tube using an alumina barrier was designed and tested. It was the first time that such barrier was successfully applied to that kind of tubes. It was also shown that it is practically possible to model the entire structure of the tube comprising the input, output nd the slow-wave structure. This opens new possibilities of optimization of the design of the amplitron tubes.

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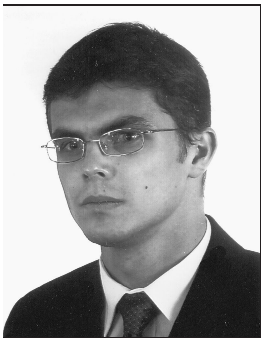

Paweł Węgrzyniak was born in 1980 in Poland. He received the B.Sc. in electronic engineering from Warsaw University of Technology, Warsaw, Poland, in 2004 and studying towards M.Sc. at Faculty of Electronics, Warsaw University of Technology. His research inerests are in the areas of electromagnetic modeling, microwave measurements, and design of microwave circuits.

e-mail: pwegrzyn@qwed.com.pl
Institute of Radioelectronics
Warsaw University of Technology
Nowowiejska st 15/19
00-665 Warsaw, Poland

Wojciech Gwarek graduated in 1970 from the Faculty of Electronics, Warsaw University of Technology, Poland, where he has been employed since. In 1973–74 he did postgraduate course at the Massachusetts Institute of Technology, USA (Center for Advanced Engineering Study) and received M.Sc. in electrical engineering. In 1977 he received his Ph.D. (honours) at the Warsaw University of Technology, and in 1988 became Associate Professor. He is a Full Professor since 1994. His academic activities included co-operation with several foreign institutions in USA, France, and Germany. In 1992–93 he was a co-organizer of the Franco-Polish School of New Information and Telecommunication Technologies in Poznań, directing the Electronics and Physics Department there. He is co-author of “The Theory of Electromagnetic Field” (WNT, 1978, 1985, 1990) – a textbook used by most Polish universities. He has also acted as an industrial consultant for several companies. Professor Gwarek’s specialised field is microwave technology and electromagnetic theory. Since 1984 he has been concentrating on the time domain computational electromagnetics, becoming the world’s recognised expert. The achievements in this domain brought him the rank of Fellow of the IEEE. He is author of over 100 publications, mainly on electromagnetic modeling, including frequently quoted dozen of publications for the “IEEE Transactions on Microwave Theory and Techniques”. He serves as reviewer for several IEEE Journals and as a member of the Technical Programme Committee of the IEEE International Microwave Symposia. Professor Wojciech Gwarek is co-author of QuickWave software, cofounder and President of QWED.

e-mail: W.Gwarek@ire.pw.edu.pl
Institute of Radioelectronics
Warsaw University of Technology
Nowowiejska st 15/19
00-665 Warsaw, Poland

Dariusz Baczewski was born in 1973 in Poland. He received M.Sc. in physics from Division of Solid State Theory in Institute of Physics, University of Łódź, Poland. He works in Z.E. Lamina SA since 2000, as a designer microwaves tubes.

e-mail: dbacz@lamina.com.pl
Z.E. Lamina SA
Puławska st 34
05-500 Piaseczno, Poland