ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-WEPSC01

UNIT FOR MATCHING A DRIVING WAVEGUIDE WITH A CAVITY

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Abstract

To match the driving WaveGuide (WG), usually operating in the fundamental TE10 wave, with the accelerating structure, a device is required that performs the function of a wave-type transformer. In the microwave region, transforming devices with matching windows are usually used, the field distribution in which can also be described as TE-type. At the ends of the window from the side of the structure, regions with an increased density of Surface Currents (SC) inevitably arise, leading to an increase in the surface temperature in a place that is difficult to access for cooling. There are various solutions for matching windows, in order to reduce the maximum SC from the side of the structure, briefly mentioned in the report. A solution based on the dispersion properties of the TE10 wave, providing a significant additional decrease in the SC density, is considered. This solution can be implemented for C-band and lower frequency ranges.

INTRODUCTION

To transmit RF power from RF source to a cavity at frequencies > 300 MHz rectangular WG's, operating with TE10 wave, are usually used. Reasons are in the higher RF power capability and lower attenuation. The simplest solution for appropriate matching of a cavity with waveguide schematically is shown in Fig. 1. Also may be modifications in waveguide dimensions near matching slot, slot shape an so on. A solution, based on dispersion properties of TE10 wave in driving WG is considered below.

MOTIVATION

We can consider cavity excitation by tangential electric field $E_{\tau s}$ of the matching slot [1], and expand cavity field in the set over own modes E_{cn} :

$$\vec{E}_c = \sum_n e_{cn}\vec{E}_{cn},\ e_{cn} = i\frac{\omega_{cn}}{\omega^2-\omega_{cn}^2}\frac{\int_{Ss}\left[\vec{E}_{\tau s}\vec{H}_{cn}\right]d\vec{S}}{\mu_0\int_{Vc}\vec{H}_{cn}\vec{H}^*_{cn}dV}, \quad (1)$$

where ω_{cn} are frequencies of own cavity modes. Here and below subscripts *c,s,w* are connected to the cavity, slot and WG respectively. In the same style we can consider excitation of the slot by tangential magnetic fields of the cavity $H_{\tau c}$ and WG $H_{\tau w}$:

$$\vec{E}_s = \sum_m u_{sm}\vec{E}_{sm},$$

$$u_{sm} = i\frac{\omega}{\omega^2-\omega_{sm}^2}\frac{\int_{Ssd}\left[\vec{E}^*_{sm}\vec{H}_{\tau c}\right]d\vec{S}+\int_{Sst}\left[\vec{E}^*_{sm}\vec{H}_{\tau w}\right]d\vec{S}}{\varepsilon_0\int_{Vs}\vec{E}_{sm}\vec{E}^*_{sm}dV} \quad (2)$$

For the field in the slot is known the model of shortened transmission line [2].

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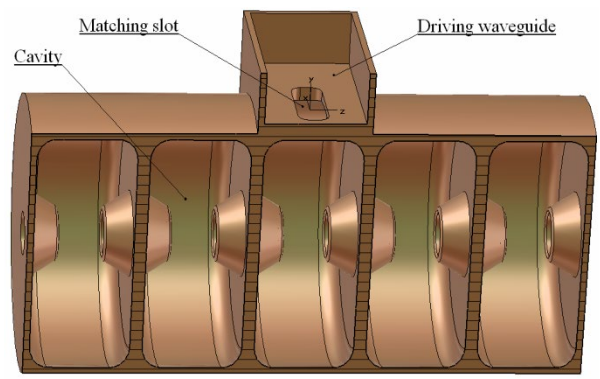

Figure 1: Schematic drawing of the cavity – slot – WG system to be matched.

More descriptive is the slot model, proposed in [3]. The slot is considered as the cavity, bounded by 'magnetic wall' boundary conditions from sides of cavity and WG, Fig. 2.

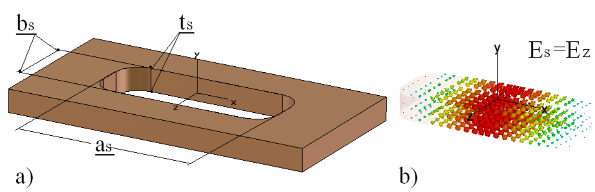

Figure 2: The slot model with dimensions definition, (a), and electric field of fundamental TE10 mode, (b).

In this approximation the field and frequency for fundamental TE10 in the slot are:

$$\vec{E}_{s1} \approx \mathrm{E}_{z0}\cos\left(\frac{\pi x}{a_s}\right), \omega_{s1} \approx \frac{\pi c}{a_s} >> \omega, \mathrm{E}_{z0} = 2\sqrt{\frac{W_0}{\varepsilon_0 a_s b_s t_s}}, \quad (3)$$

Supposing fields of own modes in the cavity E_{nc} and in the slot E_{sm} to be normalized to stored energy $W_0=const$, single mode (n=1, m=1), lossless approximations for cavity and slot, after transformation, from Eq. (1) – Eq. (3) one gets:

$$E_{c1} \approx \frac{4\omega_{c1}\omega a_s^2 b_s H_{c\tau}}{W_0(\omega^2-\omega_{c1}^2)\pi^4 c^2\varepsilon_0 t_s}(H_{c\tau}+BH_{w\tau}),$$

$$B = \frac{2}{\pi}\left(\frac{\sin(\frac{\pi}{2}(1+\frac{a_s}{a_w}))}{(1+\frac{a_s}{a_w})}+\frac{\sin(\frac{\pi}{2}(1-\frac{a_s}{a_w}))}{(1-\frac{a_s}{a_w})}\right) \approx \frac{2}{\pi}. \quad (4)$$

Relations in Eq. (4) approximately describe well known correlations and effects. For effective matching the slot should be posted in the region with strong magnetic field of the cavity. The first term in the right hand side of Eq. 4 reflects inevitable reduction of cavity frequency with slot opening.

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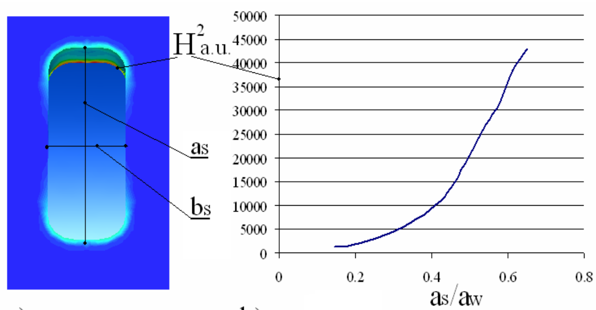
From Eq. 4 one can see straightforward indication for coupling enhancement – increasing of the slot length a_s. But it is directly connected with enhancement of magnetic field at the slot edges from the side of a cavity, Fig. 3a. And related density if RF losses at the slot edge rises very fast with a_s increasing, Fig. 3b



a) b)

Figure 3: Magnetic field enhancement at the slot edges from the side of a cavity, (a) and rise of RF loss density with slot opening, (b).

Slot edges must be rounded, but RF loss density enhancement still remains. It leads to temperature increasing in a vicinity of slot edges.

As one can conclude from a schematic drawing of the cavity – slot – WG system, the vicinity of a slot is not convenient for placing of cooling channels close to the slot. It provides difficulties for cavities, operating with a high heat load due average dissipation of RF power, for example operating in Continuous Wave (CW) mode. Stress value, associated with high temperature, can exceed elastic limit, leading to slot deformation.

For cavities operating with relatively short RF pulse, but with strong fields, an effect of RF pulsed heating takes place, leading to the same results at slot edges.

Relations in the Eq. 4 show also well known ways to reduce slot length for required matching. It is either increasing of the slot width b_s, or increasing of tangential magnetic field $H_{\omega\tau}$ from the side of WG at the slot position.

WG TAPERING

The simplest method to increase the tangential magnetic field $H_{\omega\tau}$ from the side of WG at the slot position is a gradual reduction in the WG height from b_w to h_w, $b_w > h_w$, Fig. 4a, so called WG tapering. Calculated surface for tangential magnetic enhancement is shown in Fig. 4a. To each specified h_w value corresponds the optimal length of tapering l_w to realize the maximal field enhancement.

As one can see from Fig. 4b, the maximal field enhancement is of ~2.4 for $h_w < 0.2b_w$. But residual WG height h_w should be sufficient for slot placing with rounded edges for comfortable mechanical treatment. The practical value of field enhancement is of ~1.6 for h_w ~0.2b_w.

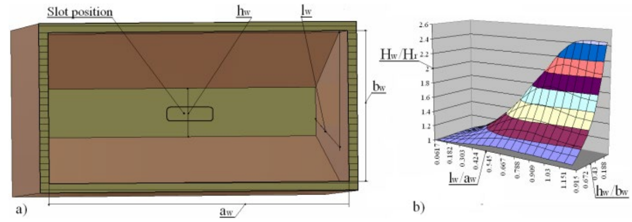


Figure 4: Well known tapering for rectangular WG height, (a), and calculated surface for tangential magnetic field enhancement, (b).

For this usual tapering in the height of rectangular WG symmetry of tapering is not so important. Similar results can be obtained when tapering in height is applied only from one side.

Additional tapering in the WG width a_w provides opposite effect – field enhancement decreases.

T-LOAD

The negative effect of rectangular WG tapering in the width exists due to positive dispersion of TE_{10}.

$$k_z = \sqrt{k^2 - \frac{\pi^2}{a_w^2}}, \frac{dk_z}{dk} > 0, f_{cut} = \frac{c}{2a_w}$$

where k_z is the wave-number of TE_{10} wave in the direction of propagation and k is the wave-number for cavity operating frequency. Decreasing the WG width we increase the local, in the plane $z=const$, cut-off frequency f_{cut} in this tapered WS part with respect to regular WG parts. Due to positive dispersion of TE_{10} wave the field strength in WG parts with reduced width is lower.

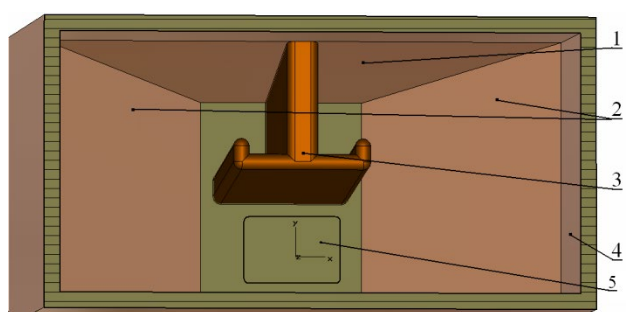


Figure 5: Schematic drawing of WG, tapered in both directions, with T-load. 1- non-symmetric tapering in WG height, 2- tapering in WG width, 3 – T-load, 4- regular WG part, 5- slot position.

Another solution of increasing for tangential field is schematically shown in Fig. 5. An additional element with T-like shape, is introduced into WG near matching slot. This element is placed in antinode of electric field for TE_{10} wave and provides a capacitive load, resulting in decreasing of local cut-off frequency. Below this element is named as T-load.

The strong reduction in f_{cut} in vicinity of T-load with respect to regular WG part is not required and compensated by WG tapering in width. This case improvement in field enhancement is achieved mainly due to reduction of

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surface of WG cross section near slot. Additionally a comfortable window for slot placing remains, Fig. 5.

This element has several degrees of freedom for optimization. Any analitical estimations for T-load optimization for maximal field enhancement, at least at a moment, are not known. This task can be solved with modern software CST, [4]. For geometry, shown in Fig. 5, a typical result, illustrated in Fig. 6, is the field enhancement of ~2.54.

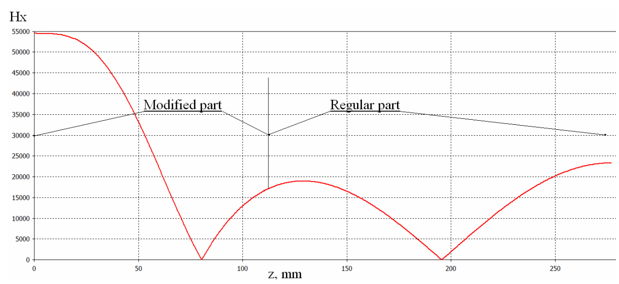

Figure 6: Dependence of tangential magnetic field component *Hx* along WG. Line *x=0, y=0*, see. Fig. 5.

The distribution of tangential magnetic field component at the inner surface of modified WG is shown in Fig. 7. As one can see, tangential field has the maximum not in the place of slot. But at the position of slot placing the distribution is uniform enough. As for high tangential magnetic field at the surface of T-load, it is only requirement of reliable contact between T-load body and WG surface.

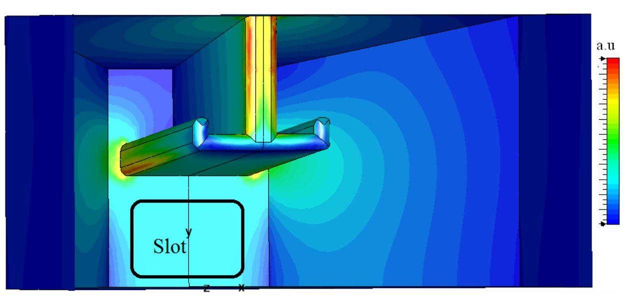

Figure 7: Distribution of tangential magnetic field at the inner surface in modified WG.

For matched case with three cells cavity in Fig. 8 is illustrated the distribution of RF loss density at the surface of modified WG part, slot surface and a part of cavity surface. For the matched case the strength of magnetic field inside cavity is essentially lower, as compared to the filed in the driving WG. The heat load at modifies WG parts, including T-load, is negligible and additional cooling is not necessary. As one see from distribution in Fig. 8, RF loss density at the slot end's from WG side doesn't exceeds density at cavity surface.

Modified WG part is shaped as truncated pyramid and sufficient space is foreseen for matching slot. Together with enhanced magnetic field, it allows to form a wide and short slot with $bs \sim as \ll aw$. It weakens difficulties with strong magnetic field at the slot edges, see Fig. 3, both for average and pulsed RF heating. Additionally it reduces frequency shift of the cavity due to matching slot, see Eq. (4).

According to design idea, T-load can be implemented into rectangular WG for arbitrary frequency range. But realistically, taking into account T-load dimensions, it can be implemented into WG for L-band, S-band ranges and probably for C-band frequency range.

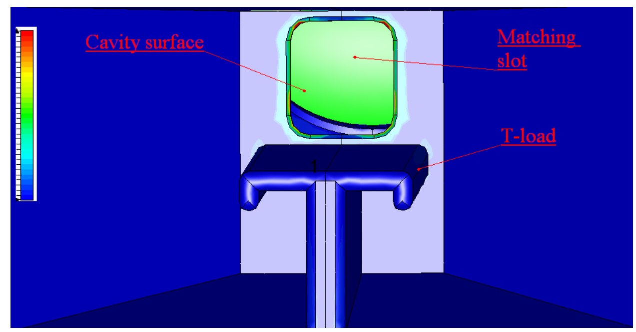

Figure 8: The resulting effect of T-load implementation – distribution of RF loss density in the total system near slot vicinity.

SUMMARY

The new element T-load is suggested to be implemented into driving WG in the vicinity of matching slot. Providing the strong enhancement of tangential magnetic field at WG side in the place of the slot, T-load allows comfortably form shorter slots, resulting in essential reduction of increased magnetic field at slot edges. This case the cooling problem for slot vicinity is essentially relaxed both for average and pulsed RF heating.

ACKNOWLEDGEMENTS

The author is grateful to DESY PITZ group for access, in framework of the collaboration, to the CST software [4].

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