

REDUCED FIELD TE₀₁ X-BAND TRAVELING WAVE WINDOW

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Abstract

The RF electric field is reduced by more than a factor of two using a pair of symmetrically located irises in a new type of klystron window operating in the TE₀₁ mode at X-Band. The advantages of this window over the usual TE₀₁ half-wave resonant window are discussed as well as theory and operating results. Ultra high purity alumina formed by the HIP process is used. This window has been successfully tested at 100 MW with a 1.5 microsecond RF pulse width and is being used on the XL series klystrons.

I. INTRODUCTION

RF electric field breakdown in the output window is one of the mechanisms that frequently limits the peak power that can be produced by klystrons at X-band. Conventional pillbox windows operating in the TE₁₁ mode in single-mode sized circular waveguide are at risk when operated above about 10 MW depending on pulse width. Thicker, sometimes larger diameter, windows have been successfully tested at SLAC to 85 MW in a resonant ring but have a history of failing in the 25 to 60 MW range when operating at pulse widths in the 1 microsecond range [1]

Windows operating in the TE₀₁ circular mode have the advantage of having no electric field lines terminating in the braze fillet area at the edge of the ceramic disk thereby reducing the likelihood of RF breakdown originating at this vulnerable location. The very compact flower petal rectangular TE₁₀ to circular TE₀₁ high power mode transducer [2][3] has recently been incorporated into the

vacuum envelope of the XL series klystrons at SLAC.

Historically, TE₀₁ windows are usually half-wave resonant in thickness and therefore self-matched. There are still several drawbacks that should be mentioned regarding operation in the TE₀₁ mode with a half-wave resonant window. Thick ceramic always have trapped resonances (ghost modes) that may be close to the operating frequency. The bandwidth is narrow (typically 3% where the VSWR is <1.20) unless broadbanding elements are used.

A new type of window, operating also in the TE₀₁ mode, but with the RF electric field in the ceramic reduced by more than a factor of two for a given power has been built and tested in a traveling wave resonant ring to 100 MW with a 1.5 microsecond pulse. Furthermore the field within the ceramic exists in a pure traveling wave.

The field reduction is accomplished by symmetrically locating two circular inductive irises on each side of the window. The resulting RF electric field variation as a function of axial position for a given r and ϕ is shown in figure 1. The field reduction is accompanied by a reciprocal field enhancement further away from the window if the iris is inductive. A conjugate capacitive element would, in theory, produce the same field reduction at the window surface without the accompanying field enhancement. Capacitive irises however are impractical and susceptible to breakdown themselves in TE mode transmission.

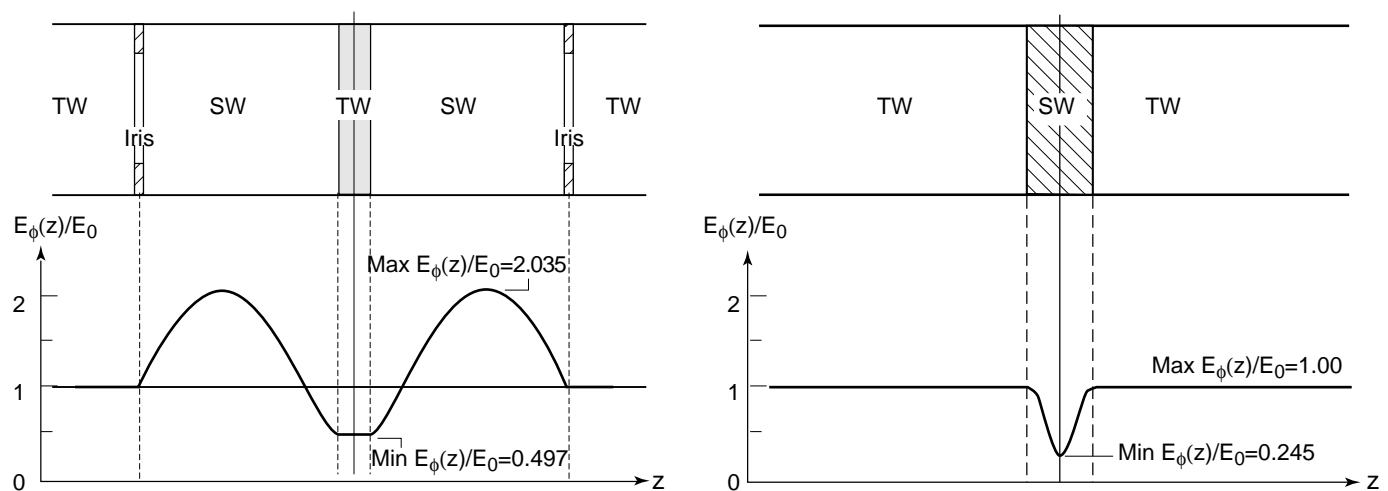


Figure 1. Comparison of the reduced field TW window (left) with a half-wave resonant window (right), both operating in the TE₀₁ circular mode. In addition to the TW version having substantially lower RF electric field at the window surface, the integrated dielectric power losses are only 23% that of the half-wave resonant window. The axial coordinate is expanded for clarity.

Reduced field pure TW windows have been used previously but these were operating in the TE_{11} mode. Sergi Yu. Kazakov described a successful X-Band version of the above at the LC93 Workshop [4]. An S band version was used at SLAC in the early 1980's but was abandoned because it was very narrow band and therefore sensitive to dimensional tolerances and also field emission occurred at the enhanced field location. The field enhancement does not appear to be a problem in the TE_{01} mode because the field is zero at all the metal surfaces.

Among the advantages of the reduced field TW over the half-wave resonant window, both in the TE_{01} mode, are:

- 1) Lower surface electric field ($>2x$)
- 2) Lower dielectric loss (23% that of $\lambda'/2$)
- 3) Better bandwidth
- 4) Uniform loss in axial direction
- 5) Fairly insensitive to ϵ'
- 6) TW at any thickness but $\lambda'_g/4$ is optimum for BW

II. THEORY

The normalized susceptance of each iris required to produce the field reduction and at the same time produce the pure TW condition within the ceramic is given by

$$\left| \frac{B}{Y_0} \right| = \frac{\lambda_g - \lambda'_g}{\sqrt{\lambda_g \lambda'_g}} \quad (1)$$

where λ_g and λ'_g are the guide wavelengths at the design frequency for the TE_{01} modes in the circular waveguide outside and inside the ceramic window respectively.

The distance from the face of the ceramic to the equivalent plane of a thin inductive iris with the above susceptance is given by

$$\ell = \lambda_g \left[\frac{1}{2} - \frac{1}{4\pi} \tan^{-1} \left[\frac{2}{\left| \frac{B}{Y_0} \right|} \right] \right] \quad (2)$$

The resulting symmetrical wave configuration at the given frequency is a partial standing wave between the iris and the window and a pure traveling wave both inside the ceramic and outside the irises.

The RF electric field is reduced at the surface of the ceramic window by

$$\text{RF Field Reduction Ratio} = \frac{\lambda_g}{\lambda'_g} \quad (3)$$

compared with the RF electric field in a TE_{01} traveling wave and that which exists at the surface in a TE_{01} half-wave resonant window. A pure traveling wave exists within the ceramic at only a single frequency. At this frequency the match is independent of the window thickness. The bandwidth characteristics however vary widely with window thickness and it turns out that the optimum passband response is obtained when the dielectric window thickness is approximately one-quarter of a guided wavelength in the dielectric as shown in Figure 2.

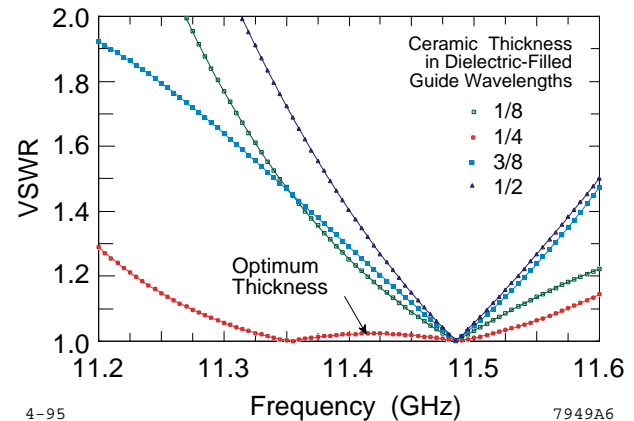


Figure 2. A pure TW condition and a perfect match at 11.486 MHz exists for all thicknesses but BW is optimum for $\lambda'_g/4$.

A program has been written using cascaded equivalent circuit elements to model this window/iris assembly taking into account the behavior with frequency of each element and connecting waveguide electrical lengths.

The response resembles a second order Tchebycheff matching transformer where there are two frequencies where a perfect match exists. The upper frequency match is the pure TW condition just described where the admittance throughout the dielectric is constant and real. The lower frequency match is the condition where the admittance varies throughout the dielectric but is purely real at the ceramic midplane. (A symmetrical structure is matched if the admittance at the plane of symmetry is real.) Since it is usually desirable to operate in the center of the passband it is reasonable to modify the design so that the operating frequency is midway between the upper and lower match frequencies. The field variation within the ceramic at the center frequency is still nearly a pure traveling wave.

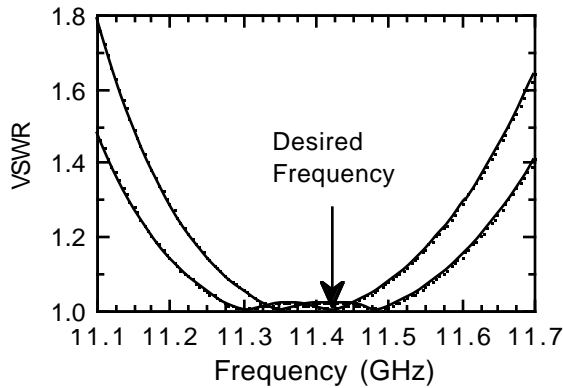


Fig 2 (left) Pure TW at 11.424 GHz but not centered and (right) Pure TW at 11.486 GHz but centered at 11.424 GHz

The theoretical passband responses shown in Figure 2 were calculated for an operating frequency of 11.424 MHz. The curve on the left corresponds to a pure traveling wave at the design frequency but the passband is not centered. By redesigning the window circuit for approximately 11.486 MHz, the passband is centered at the design frequency, midway between the two match frequencies.

The exact size of the TE_{01} iris aperture to obtain the required inductive susceptance in Eq. (1) and its variation with frequency was calculated using mode matching methods.

III. MECHANICAL DESIGN

The mechanical properties of the TW TE_{01} window are similar to the X-band window described in earlier papers [1]. The window surface must be titanium nitride coated to suppress multipactor as described in earlier papers. This requires that the irises be separate from the window cylinder so as not to mask the window surface during the coating process. The exact iris positions relative to the window surface are therefore subject to the amount of torque applied to the bolts on the crush seal flanges. Test were done to determine this effect and the flange dimension adjusted accordingly.

IV. TEST RESULTS

Ceramics formed by the Hot Isostatic Press (HIP) process have been successfully used for two of the six windows of this type that have been built. These two were super high purity alumina that is magnesium free. Both of these were metallized and brazed but one braze developed a very small leak during testing. There has not been enough confidence to date to risk using the super high purity material on a window destined for installation on a klystron because of brazing experience at SLAC and elsewhere.

Four windows were tested on the Traveling Wave Resonant ring to power levels between 75 and 100 MW with a 1.5 microsecond pulse. One of the AL-995 windows failed at 100 MW while the others survived. The two

windows that were installed on 50 MW klystrons are still in operation.

V. SUMMARY

It is believed that past X-Band high peak power window failures at SLAC can be attributed to breakdown originating at the braze fillet at the edge of the ceramic and also to multipactor. The TE_{01} TW window has been shown to be very resistant to both of those failure mechanisms and has enabled us to push RF breakdown thresholds to higher peak power levels and longer pulse widths.

VI. ACKNOWLEDGEMENTS

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