DESIGN CONSIDERATIONS FOR VERY HIGH POWER RF WINDOWS AT X-BAND[*]

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Abstract

RF window designs of the Pillbox type were capable of transmitting peak rf power up to about 10 MW. The power levels now being produced by advanced high frequency power sources is beyond the level that can safely be transmitted through a single rf window of conventional design. New approaches are required to keep the rf electric fields at a manageable level in the vicinity of the rf window.

This paper describes some of the recent rf window designs at SLAC and elsewhere and some of the test results. Windows that operate in larger waveguide in higher order modes such as TE_{01} and in a mix of modes such as TE_{11}, TM_{11} and TE_{12} are described. RF chokes and corona shields, circular polarization and forced electric field reduction are also discussed.

1 INTRODUCTION

The high power window presently used on all of the SLAC X-band klystrons has been reported on previously [1]. It is usually referred to as a TE_{01} reduced field traveling wave window. A pair of symmetrically located inductive irises are used to set up a standing wave in the region between the irises and the 47 mm diameter ceramic window surface. This results in "forcing" a lower impedance at the window surface that exactly matches the characteristic impedance inside the ceramic thereby causing a pure traveling wave condition inside the ceramic. This design has been tested successfully to over 100 MW in a traveling wave resonator (TWR) and has been serving as a single output window on the 50 MW XL-4 series klystrons. This design however, is considered marginal at this power level.

The new 75 MW periodic permanent magnet (PPM) focussed klystron presently uses a pair the windows described above, each passing 37.5 MW. Four TE_{10}/TE_{01} mode transducers are presently required—an expensive luxury due to the cost of the mode transducers.

2 LARGE DIAMETER TE₀₁ TW WINDOW

2.1 Larger Single Window

A single window alternative has been sought that will safely handle the full 75 MW. The 47 mm TW window described above is considered to be very reliable up to a peak power level of about 40 MW where the peak rf electric field at the window is 3.4 MV/meter. Using this electric field level as a design criterion for a single 75 MW window, an increase in diameter to 65 mm would be required. This assumes of course that TE_{01} mode purity is maintained and the reduced field TW scheme is used. A problem that must be addressed in all all overmoded diameter circular windows windows is mode conversion.

TE_{11} windows are susceptable to conversion to TM_{11}, TE_{12} and TM_{12} in the transitions (tapered or stepped) going from single moded to overmoded diameters. TE_{01} windows are not as vulnerable to mode conversion with increases in diameter providing the mode converter has launched TE_{01} with good purity. Gradual tapers maintain TE_{01} mode purity but are not usually very compact. Stepped transitions to larger diameters are normally susceptible to conversion to higher order TE_{0n} modes unless special attention is given to the step design.

2.2 TE01 TW Window with Compact Optimized Step
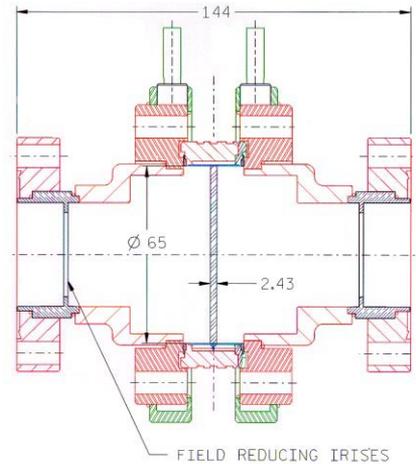
Fig. 1. Compact overmoded 65 mm diameter TE01 window. Field reduction is accomplish by a combination of the 2-stage steps and irises. The double step is optimized to cancel TE_{02} that is created at each indivdual step.
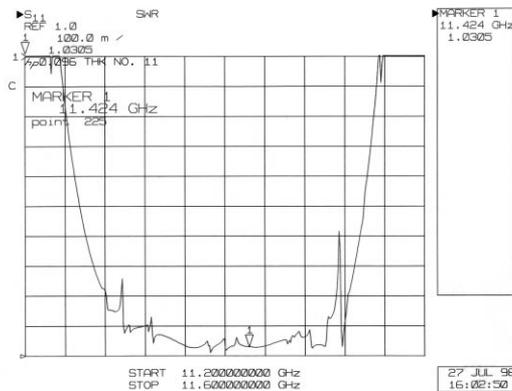
Fig. 2. Cold test results of window in Fig. 1 measured on HP 8510C NWA using old style "Flower-Petal" mode transducers which have narrower bandwidth than the window.

This paper describes a compact 65 mm diameter TE_{01} TW window that is virtually free of higher order modes. The maximum electric field at the surface of this window at 75 MW is about the same as exists at for the previously described window at 40 MW; 3.4 MV/meter. The TE_{01} mode is created in 38 mm diameter circular waveguide using the recently designed compact wrap-around mode transducer [2] shown in Fig 4.
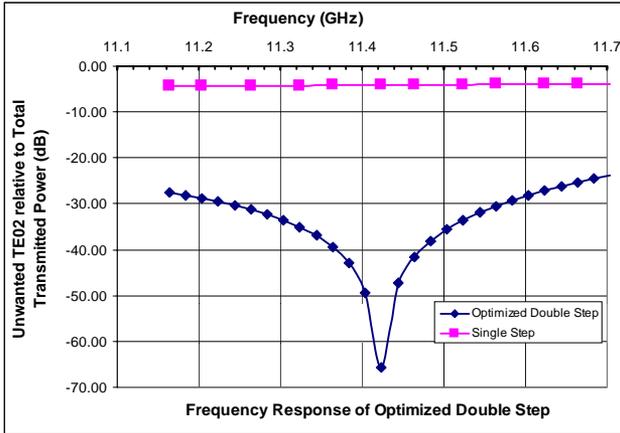
Fig. 3. Comparision of an optimized double step with a single step going from 38 mm to 65 mm with a launched TE_{01} mode.

The input and output ports for this window design are 38 mm diameter. The transition from 38 mm to 65 mm is a two-stage step designed using MLEGO© which sets up the cancellation of the TE_{02} mode excited at each step stage [3]. If one were to use a single sudden step in diameter from 38 mm to 65 mm, the resulting mode conversion is the following: S_{21} of 0.78 for TE_{01} and 0.62 for TE_{02} with only TE_{01} exciting the smaller diameter port. By going to a two-step design, the length and diameter of the intermediate step is optimized to null out the natural conversion to TE_{02}. The optimum intermediate diameter is 58.14 mm with a length of 19.48 mm. The residual S_{21} for TE_{02} drops to 0.00051. The effectivness of this optimized step is shown in the graph in Fig. 3. It is compared with a single abrupt step as a function of frequency. The unwanted conversion from TE_{01} to TE_{02} is mimized for the operating frequency of ll.424 GHz.

All this is accomplished at the expense of a residual TE_{01} mismatch S_{11} of 0.167 in the 38 mm port. This residual mismatch, however, can be used along some help from an additional iris to set up the standing wave that is necessary to force the electric field down at the surface of the ceramic. The result is a pure traveling wave inside the ceramic.

It can be shown that the optimum VSWR needed to produce the TW condition within the ceramic is

$$\sigma_{opt} = \frac{\lambda_g}{\lambda_g{}'}$$

and the total normalized iris susceptance that would give σ_{opt} is given by

$$\left|\frac{B}{Y_0}\right| = \frac{\lambda_g - \lambda_g{}'}{\sqrt{\lambda_g \lambda_g{}'}} = 1.3476$$

where λ_g and λ_g' are the guide wavelengths in the large diameter outside and inside the ceramic window respectively [1]. The double-step reflection of 0.167 corresponds to a normalized susceptance of 0.3388. The difference is made up with symmetrical inductive irises each having a normalized susceptance of

$$\left|\frac{B}{Y_0}\right| = 1.3476 - 0.3388 = 1.0088$$

located properly so that the stored energy between the iris and the 2-stage step is minimum. It is important that the irises be located in the smaller (38.1 mm) port since an inductive iris will convert to TE02 in the larger (65 mm) port.
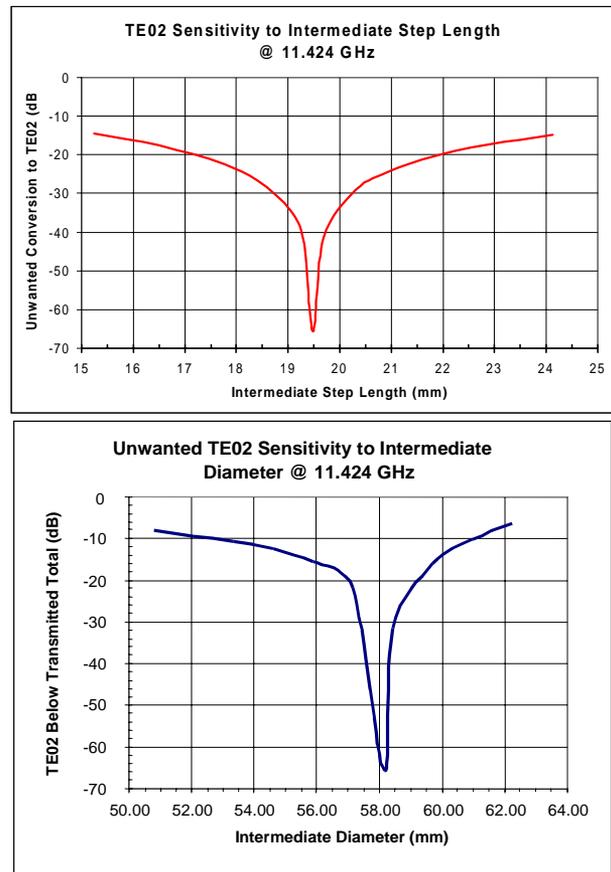
Fig. 3a and 3b. The Double step from 38.1 mm to 65 mm has been optimized to cancel out any TE_{02} conversion occurring at each step at the operating frequency of 11.424 GHz. This was accomplished using the mode matching code MLEGO. The variable parameters are the length and diameter of the intermediate step. The above graphs show the theoretical sensitivity of the conversion to unwanted TE_{02} to each of these parameters while the other is kept at the optimum value.
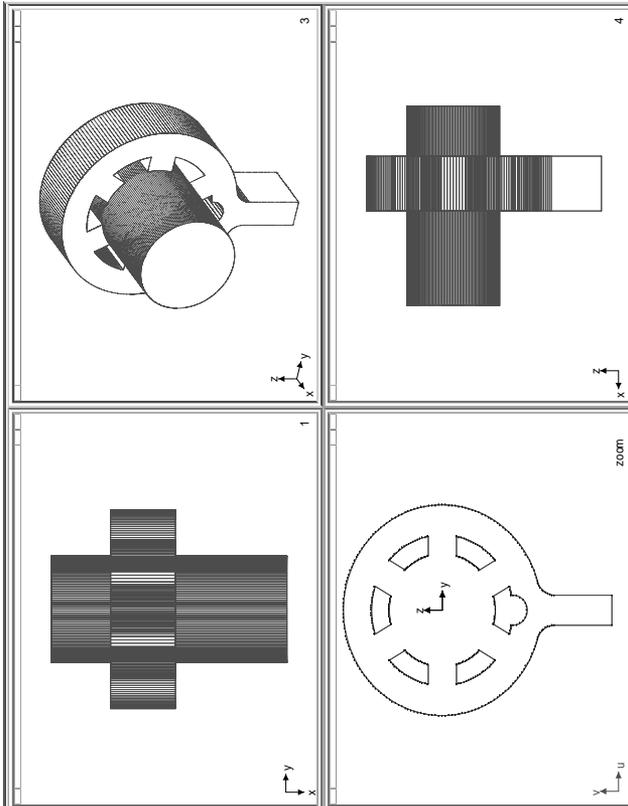
Fig. 4. HFSS output showing the geometry of the new compact Wrap-around TE_{10}/TE_{01} mode transducer that is used to excite the TE_{01} mode in 38 mm circular waveguide.

3 OTHER WINDOWS

3.1 Revisiting TE11 with Chokes

TE_{01} is preferred for technical reasons. The braze fillet is in a zero electric field region. The high cost of the TE_{10}/TE_{01} mode transducers however, diminishes the attractiveness of the TE_{01} design. TE_{11} window designs are not being abandoned entirely for some applications. A window has been designed that uses RF chokes to block RF from the region where the ceramic is brazed into its sleeve. A pair of symmetically placed inductive irises set up the reduced field TW condition similar the the TE_{01} version described earlier. The irises are necessarily thick with a full radius to reduce the local surface electric field as much as possible. A cold test version of this design was built and tested at SLAC. The diameter of the circular waveguide approaching the choke region is 27 mm while the cylinder housing the ceramic is 47 mm. This diameter is larger than necessary and was used because ceramic window blanks were available from the TE_{01} design.

This design has two main drawbacks. The surface electric field on the inside of the irises is high and there is also a strong axial component of RF electric field between the choke lobe tips and the ceramic surface, a fact that was overlooked in the beginning until it was modeled on a later version of HFSS that was capable of resolving total electric field into axial and radial components. A high power version of this design has not

been built for these reasons. There was an effort to modify this design to a larger diameter but we were unable to solve the problem of mode conversion from TE_{11} to TM_{11} and TE_{12} in the larger diameter portion of the window.

3.2 Other Overmoded Windows

There have been some recent designs where the conversion of TE_{11} to combinations of TM_{11}, TE_{12}, TM_{12} were exploited successfully by Sergi Kazakov in a collaboration between BINP and KEK [4]. These designs have window diameters of either 53mm or 64 mm. These use the reduced field TW concept and in some cases the total electric field at the braze fillet has been reduced substantially and the axial component of electric field from TM_{11} is also greatly reduced.

4 REFERENCES

[1] W. R. Fowkes, R. S. Callin, S. G. Tantawi, and E. L. Wright, "Reduced Field TE01 X-Band Traveling Wave Window", Proceedings of 1995 Particle Accelerator Conference, Dallas, May 1995 pp 1587-9.

[2] S. G. Tantawi, "The Wrap-around Converter: A compact TE_{10}/TE_{01} Mode Transducer" (to be published).

[3] MLEGO© A mode matching code, Copyright S. G. Tantawi.

[4] S. Y. Kazakov, Presented at 2nd International Study Group Workshop on Next Linear Collider, ISG2, Tsukuba, Japan, July 1998.