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Compact X-band High Power Load Using Magnetic Stainless Steel *

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Abstract:

We present design and experimental results of a high power X-band load. The load is formed as a disk-loaded waveguide structure using lossy, type 430, stainless steel. The design parameters have been optimized using the recently developed mode-matching code MLEGO. The load has been designed for compactness while maintaining a band width greater than 300 MHz.

I. INTRODUCTION

The high power rf system of the Next Linear Collider (NLC) contains several points where a high power rf load is required, namely, the output of the traveling wave accelerator, the output of the pulse compression system, and the output of the rf source. if the load is terminating the output of a pulse compression system it should be able to handle 400 MW of peak power for t 250 nsec On the other hand, it should be able to handle an average power of 22.5 kW based on an rf power source of 100 MW for a period of 1.25 µsec, and a repetition rate of 180 Hz. The operating frequency is 11.424 GHz. Of course the power could be splited into several ports and dissipated into several loads. However, for obvious reasons, the number of loads should be minimized.

High power water loads have been developed and at X-band. They are composed of "pill-box" windows with water circulating on the down stream side of the ceramic disk to dissipate the power. At very high power levels there is a danger of rf breakdown resulting in water leaking to the vacuum side if the ceramic window fails. Therefore, a vacuum compatible "dry" load is required.

A dry load made from a waveguide loaded with lossy ceramics is under development [2]. However, these loads are expensive because of vacuum compatible ceramics. They are, also, hard to make because of difficulties associated with brazing of ceramics to the copper waveguide walls.

Instead of using lossy ceramics one can use a waveguide made from magnetic stainless. This type of stainless steel is vacuum compatible and at the same time has a relatively high rf surface resistivity. However, the attenuation constant in rectangular guide is not enough to completely absorb the signal in a short length of waveguide. Such a load was built at X-band with a total length of approximately 1.5 meters[3]. An obvious remedy is to spiral the wave guide to reduce the size. Nevertheless, this long length of wave guide requires distributed pumping to guarantee good vacuum, and the resultant load is heavy and expensive.

Indeed, one can match, with a post, a short length of lossy guide terminated by a short circuit. However the resultant load would have a very narrow bandwidth. An alternative is a series of a very low Q resonators. These resonators would absorb the power gradually in short distance while keeping the bandwidth relatively wide. A realization of this idea using a series of chokes in a circular waveguide is presented. The geometry is relatively simple and compact.

In Sec. II the design theory is presented. Simulations using both mode matching code Mlego, and HFSS are compared with both theory and experiment. Finally we present the cold test results of our first experimental load

II. Theory

A. Basic Idea.

Figure 1 illustrates the basic structure of the load. It consists of several chokes placed in a circular waveguide. The circular guide is to be operated in the fundamental mode (TE_{11}).

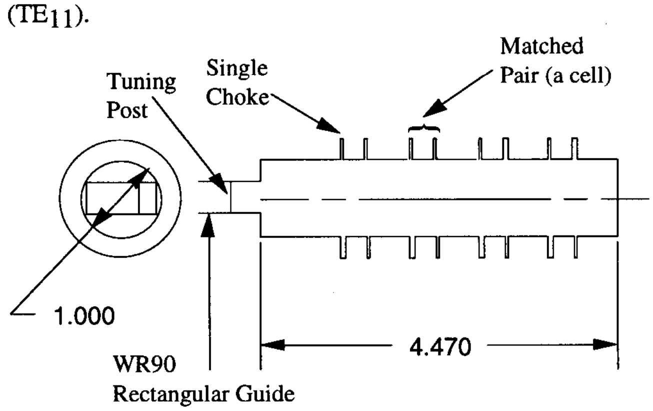

Figure 1. 430 Stainless Steel High Power Load Schematic Diagram (Dimensions are in inches)

If there are no losses and the chokes are tuned near thier resonant frequency, i.e. the choke depth is $\sim \lambda/4$, each choke would have a very high reflection coefficient. However, since the structure is made from 430 stainless steel, there are considerable amounts of wall losses. Hence, each choke couple a considerable amount of power to the next one. On average, each choke has a transmission coefficient that is more or less is equal to the reflection coefficient. By adjusting the distance between two chokes it is possible to match the pair. We call such a pair a load *cell*. By proper design we can adjust each cell so that the power dissipated per cell is a constant.

Finally the input to the circular guide is matched to the standard WR90 rectangular guide using an inductive post. These type of junction has a relatively large bandwidth; hence, it will not be a limiting factor on the load bandwidth.

B. Single Choke Theory.

Consider treating the choke as a three port network with the third port terminated in a short circuit. We define ports one

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and two as the circular waveguide ports and port three as the radial waveguide choke. If we initially assume that this is alossless structure, then, the scattering matrix representing the structure is unitary and we can write

$$\underline{\underline{S}} = \begin{pmatrix} \sin^2(\frac{\theta}{2}) & -\cos^2(\frac{\theta}{2}) & \frac{\sin\theta}{\sqrt{2}} \\ -\cos^2(\frac{\theta}{2}) & \sin^2(\frac{\theta}{2}) & \frac{\sin\theta}{\sqrt{2}} \\ \frac{\sin\theta}{\sqrt{2}} & \frac{\sin\theta}{\sqrt{2}} & \cos\theta \end{pmatrix}; \qquad (1)$$

where θ is a parameter that completely define the scattering matrix. The scattered rf signals $\underline{V}^-$ is related to the incident rf signals $\underline{V}^+$ by

$$\underline{V}^- = \underline{\underline{S}}\,\underline{V}^+; \qquad (2)$$

where $V_i^{\pm}$ represents incident/reflected rf signal from the i.th port. We terminate the third port so that all the scattered power from that port is completely reflected; i.e., $V_3^+ = V_3^- e^{i\psi}$.

To account for losses in the choke, we write

$$V_3^+ = V_3^- \alpha e^{i\psi} \qquad (3)$$

where α is the attenuation suffered by the radial wave during its round trip through the choke. One can show that

$$\alpha^2 = \exp\{\frac{2R_s}{0.637 Z_0 k_0 t} \times \int_{k_0 r_i}^{k_0 r_0} [J_0^2(\rho) + J_2^2(\rho) + Y_0^2(\rho) + Y_2^2(\rho)]\rho d\rho\} \times (1-\Delta) \qquad (4)$$

Here, $J_i(\rho)$ and $Y_i(\rho)$ are the first and second kind Bessel functions of order i, R_s is the rf surface wall resistance, k_0 is the wave propagation constant in free space, r_i and r_0 are the inner and outer radius of the choke, t is the choke thickness, Z_0 is the free space wave impedance, and the term $(1-\Delta)$ accounts for the end wall losses. The term Δ is

$$\Delta = [(J_0(r_0k_0) - J_2(r_0k_0))^2 + (Y_0(r_0k_0) - Y_2(r_0k_0))^2]\frac{R_s r_0 k_0}{0.637 Z_0} \qquad (5)$$

The reflection coefficient and transmission coefficients are then, given by

$$R = \frac{(\alpha e^{j\psi} + 1)\sin^2(\theta/2)}{1 - \alpha e^{j\psi}\cos(\theta)}, \qquad (6)$$

$$T = \frac{(\alpha e^{j\psi} - 1)\cos^2(\theta/2)}{1 - \alpha e^{j\psi}\cos(\theta)}; \qquad (7)$$

and

$$e^{j\psi} = -\frac{H_1^{(2)}(r_0k_0)H_1^{(1)}(r_ik_0)}{H_1^{(1)}(r_0k_0)H_1^{(2)}(r_ik_0)} \qquad (8)$$

where $H_1^{(i)}$ is the Hankel function of kind i and first order.

Finally, following the arguments found in [4], we can show that

$$\sin(\theta) \sim (k_0 t)^{3/2}(1 - (\frac{1.841}{r_ik_0})^2)^{1/4}\left|H_1^{(2)}(r_ik_0)\right| \qquad (9)$$

III. SIMULATIONS

The basic design dimensions for the load were found using the above theory. We refined these dimensions using a the mode matching code Mlego. In this code the structure is divided into several circular Waveguides along the axial direction. The fields in each section are expanded in terms of circular waveguide modes. In finding these modes we assumed that the waveguide has a constant wall impedance Z_s given by

$$Z_s = (\frac{\omega\mu_0\mu_r}{2\sigma})^{1/2}(1+j) \qquad (10)$$

where σ is the conductivity of the guide walls, and μ_r is the relative permeability of the walls. For a discussion of these mode and its orthogonality, the reader is referred to [5].

As usual we match the fields along the cross-sectional area between different waveguide sections. We also demand that the field on the walls along these cross-sectional area satisfy Eq. (10).

Figure 2. compares between the mode matching results HFSS simulations, and theory mode matching and HFSS agree well. However, for speed purpose, we used mode matching in our design.

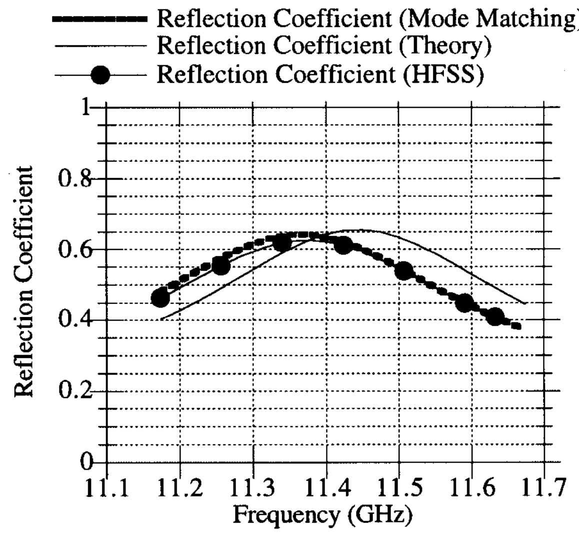


Figure 2a. Comparison between theory and different simulation methods for the reflection coefficient of single choke (t=0.040", r_i =0.5", and r_0=0.755")

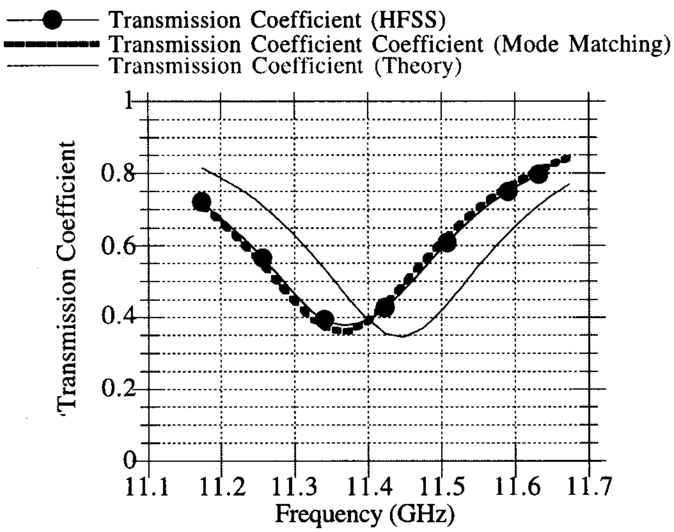


Figure 2b. Comparison between theory and different simulation methods for the transmission coefficient of single choke (t=0.040", r_i =0.5", and r_0=0.755")

IV. EXPERIMENTAL RESULTS

Based on results from the mode matching code we built a matched pair of slots. The distance between the centers of the two chokes is 0.310", and the two chokes have the same dimensions as those of Fig. 2. Figure 3 shows both the transmission and reflection coefficient of this matched pair.

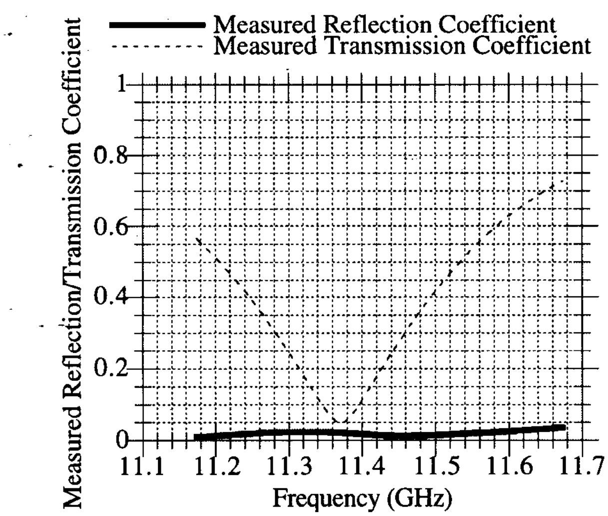
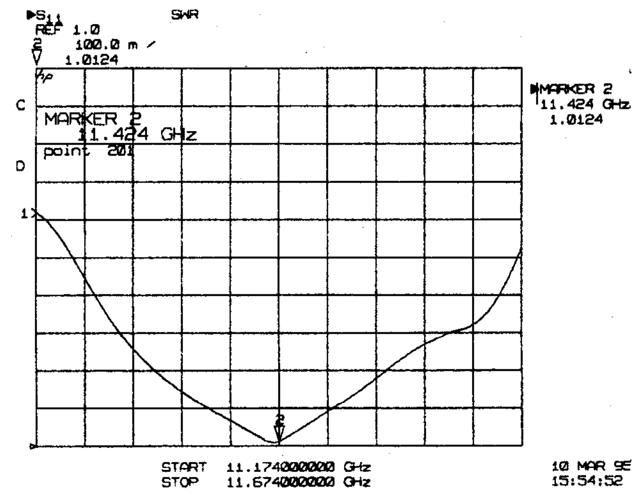


Figure 3. Experimental results of a matched pair of chokes

Finally, Fig. 4 presents the characteristics of a load made of four such cells (Fig. 1). Note that bandwidth is greater than 400 MHz for SWR < 1.5.



Measured SWR for a four cells load with the rectangular to waveguide junction matched with a post.

CONCLUSION

We describe the principles and simulation tools used in designing a compact broad band rf load made of 430 stainless. We also, presente a design theory. Simulations using mode matching and HFSS showed a good agreement. We, also, show agreement between simulation and experimental data. The load has a SWR of less than 1.5 for a 400MHz bandwidth.

V. ACKNOWLEDGMENT

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VI. REFERENCES

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