WAVEGUIDE HARMONIC DAMPER FOR KLYSTRON AMPLIFIER*

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Abstract

A waveguide harmonic damper was designed for removing the harmonic frequency power from the klystron amplifiers of the APS linac. Straight coaxial probe antennas are used in a rectangular waveguide to form a damper. A linear array of the probe antennas is used on a narrow wall of the rectangular waveguide for damping klystron harmonics while decoupling the fundamental frequency in dominent TE_{01} mode. The klystron harmonics can exist in the waveguide as waveguide higher-order modes above cutoff. Computer simulations are made to investigate the waveguide harmonic damping characteristics of the damper.

1 INTRODUCTION

In the APS linac klystron amplifiers, the connectors for the high-voltage connection to the ion pump were burned by the klystron harmonics power. The metallic tube connected to the ion pump passes the higher frequency harmonics power, and the metal screen used to decouple the harmonics was not very effective. Even though more effective rf shielding may be possible, it was not desirable for quality vacuum pumping. The tube to the pump has a cutoff frequency higher than the fundamental klystron frequency, but the harmonic spectrum power, shown in Figure 1, is not attenuated sufficiently. In the APS, five klystrons are used. Each klystron normally delivers 5-microsecond 35-MW peak power pulses to the accelerating structures. The average power of harmonic spectrum in the waveguide is estimated as several tens of watts. In order to eliminate the heating due to the harmonic power, a damping circuit is needed in the waveguide. The harmonic frequency power in the output cavity of the klystron amplifier may couple to the waveguide in the form of waveguide higher-order modes as well as the dominant mode. The klystron harmonic frequency power caused some problem in the APS storage ring, so the harmonics were damped by multiple probe antennas mounted on the narrow wall of the waveguide. A damper design of similar function is needed in the 2.856-GHz linac system. For this reason, the waveguide harmonic damper designs were studied using computer simulation.

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2 HARMONIC DAMPER

In the waveguide transmission line, during normal operations, the fundamental frequency propagates as a travelling wave to the load cavity structure that works as a matched load. However, since the accelerating cavity structure is a narrowband load, the harmonic frequency spectrum may form standing wave resonances in the waveguide between the klystron output cavity and the cavity structure.

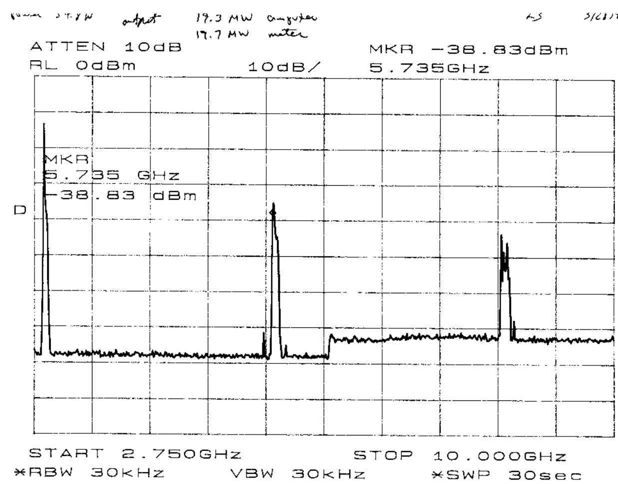

Figure 1. Harmonic spectrum of 2.856-GHz klystron amplifier output.

Figure 2 shows the waveguide harmonic damper design employing coaxial probe antennas. A linear array of five probe antennas is used on a narrow wall of the rectangular waveguide for damping klystron harmonics while decoupling the dominent TE_{01} mode. The rf power for the accelerating structure from the klystron is transmitted in the dominant TE_{01} mode. The harmonic frequencies from the klystron amplifier not only exist in the TE_{01} mode but also in higher-order waveguide modes. Higher order TE_{mn} and TM_{mn} modes couple to the antennas if m=odd and do not couple to the antennas if m=even. The index n must be nonzero for both TE and TM modes.

For the fundamental frequency, the antennas may reflect some power without delivering power to the matched load of the coaxial probes. The input matching of the damper section is important for power transmission of the fundamental frequency. Ideally, the probe antennas do not disturb the TE_{01} mode at the fundamental frequency. However, actual antennas can cause some mismatch for the frequency. Therefore, it is important to find the optimum antenna spacing for minimum reflection at the input.

The waveguide with uniformly spaced antennas is considered a periodic loaded transmission-line structure with a matched load at the output. From [1] it can be shown that minimum reflection occurs if the spacing between antennas is a quarter wavelength. In Figure 2 the antennas are spaced by a quarter wavelength so that the combined reflection from all antennas is minimized at the input. However, since mutual coupling between the antennas and the higher-order mode excitation exist due to finite antenna dimensions, it may be necessary to check the optimum spacing of the antennas for minimum reflection at the input.

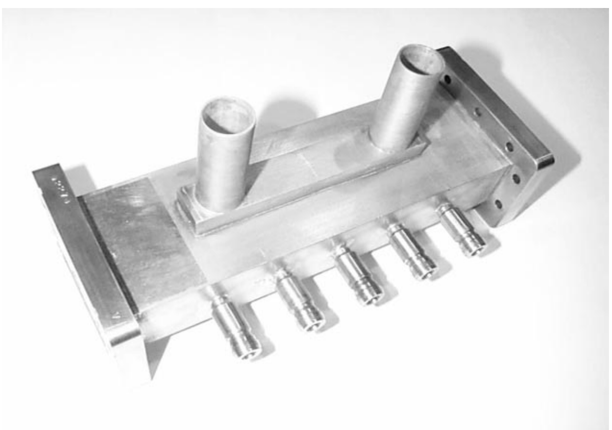

Figure 2. Waveguide harmonic damper with coaxial probe antennas.

3 SIMULATION

The damper structure has been simulated using the High Frequency Structure Simulator (HFSS) code [2]. In the simulations, eight modes were used to predict the input matching and harmonic damping with the structure. The simulations showed that the antennas convert the fundamental TE_{01} mode to some higher-order modes, and these modes do not couple to the antenna terminations if a mode is below cutoff. Since a uniform rectangular waveguide works as a high-pass filter for each mode, the harmonic frequencies, nf_o (n=2,3,4,5,…), can couple to antennas as higher-order waveguide modes.

The distance between the antennas is no longer a quarter wavelength at the higher harmonic frequencies that exist as higher-order waveguide modes. Note that the higher-order modes have pass-bands only above the cutoff frequencies of corresponding higher-order modes. Figure 3 shows the structure used in the simulation.

Figures 4 and 5 show the calculated generalized scattering parameters, $S_{1\_n,1\_n}$ and $S_{2\_n,1\_n}$, respectively, for the first four modes. Figure 6 shows the propagation loss of the four modes in the waveguide damper. Only four modes are shown in the plots for convenience. The fundamental frequency propagates in the dominant TE_{01} mode and the S_{11} is lower at the frequencies around 3GHz. These results of simulations show the properties of reflection, mode excitation and conversion, and damping characteristics of the waveguide modes due to the probe antennas. Probe antennas used in the calculation were 1.2" long and 0.121" in diameter.

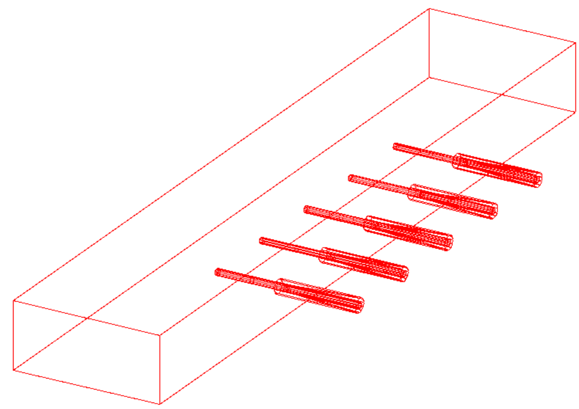

Figure 3. Damper structure with coaxial probe antennas.

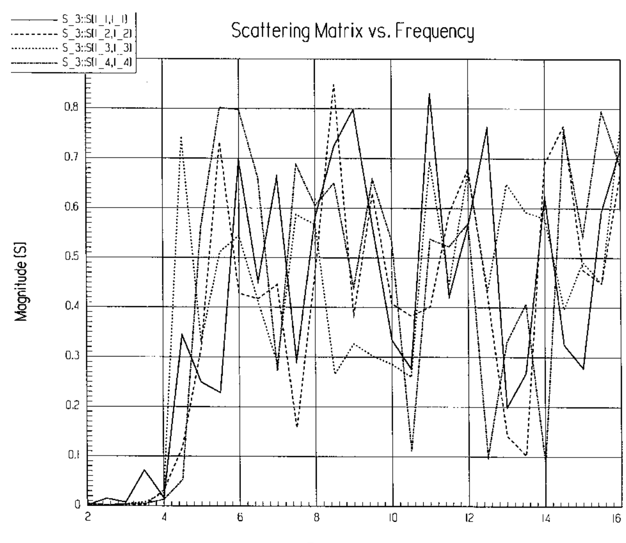

Figure 4. Calculated input reflection of the waveguide modes of the damper.

Since the simulation did not include the klystron amplifier and the accelerating structure as the load, the calculated damping characteristics did not directly describe the actual damping performance. The spacing between the antennas was varied to see the optimum antenna separation. The length of the antennas was also varied. The propagation loss characteristics shown in Figure 6 for the first four modes show that the waveguide higher-order modes can be damped effectively.

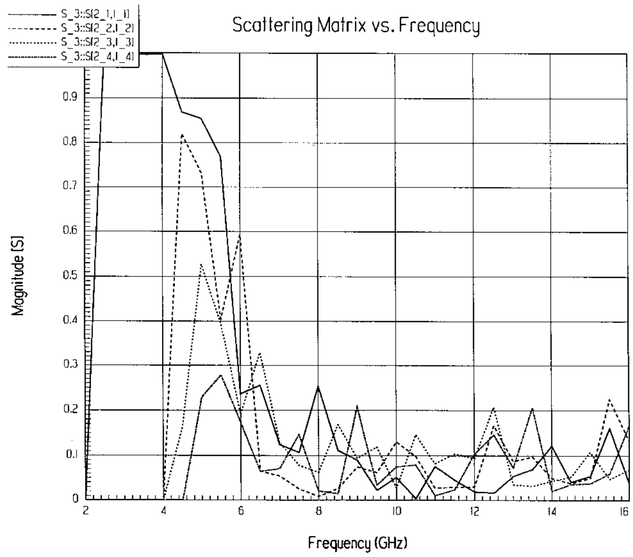

Figure 5. Transfer characteristics of waveguide modes through the harmonic damper.

The input matching and the insertion loss are good only at around 2.5-4GHz for the fundamental mode. Note that the generalized S-parameters are shown in the figures, so that the propagation loss in Figure 6 includes the waveguide cutoff loss for each mode.

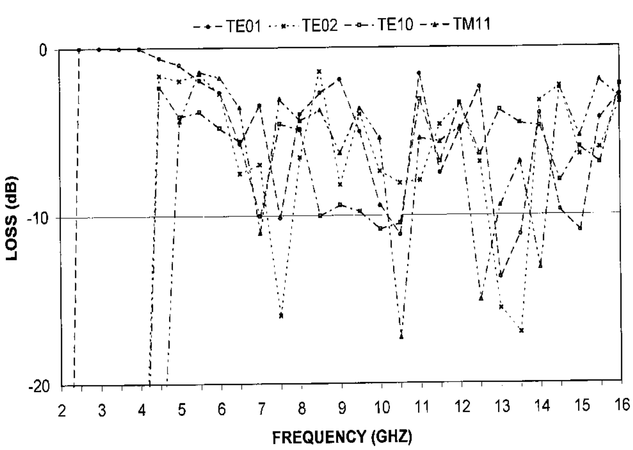

Figure 6. Propagation loss of first four waveguide modes in the waveguide harmonic damper.

4 FABRICATION AND MEASUREMENT

A prototype waveguide damper with coaxial probes has been fabricated and a low-power measurement was made. Five Ceramaseal CDP-20001 coaxial feedthroughs have been used as the probe antennas in the WR-284 waveguide. The antenna feedthroughs are welded to the copper waveguide. The fabricated damper was shown in Figure 2. The coaxial section of the antenna has a 50Ω characteristic impedance and a 50Ω coaxial termination is used in each antenna. Measurement of scattering parameters of the damper at 2.856GHz with a network analyzer confirmed good impedance matching with low insertion loss. At the fundamental frequency, the input return loss and the insertion loss were <–23dB and <0.02 dB, respectively.

The damper was to be inserted in the waveguide between the klystron and the accelerating structure. At the time the prototype was tested, the APS linac system was delivering beam to the users and, unfortunately, the damper could not be used with the actual accelerating structures. Preliminary testing of the damper between a klystron amplifier and a matched load has been planned. Since the accelerating cavity structure is a narrowband load to the klystron, measurement with a broadband resistive load may not show the characteristics of the damper. Testing with an actual accelerating structure is needed and will be performed in the near future.

5 CONCLUSION

The klystron harmonic waveguide damper employing five coaxial antennas in the narrow wall of a rectangular waveguide was simulated, fabricated, and low-power tested for the S-band linac application. The design is applicable to any system using a high-power transmitter with high harmonics content in the spectrum. The damping obtained in the design is considered adequate to protect the high-voltage connectors of the ion pumps. The design may also be useful for damping the cavity higher-order modes coupled to the waveguide.

6 REFERENCES

[1] R. E. Collin, “Field Theory of Guided Waves,” Second Edition, IEEE Press, New York, 1991.

[2] HP 85180A, High-Frequency Structure Simulator, Hewlett Packard.