An Overmoded Coaxial Buncher Cavity for a 100-MW Gyroklystron

M. Castle, J. Anderson, W. Lawson, *Senior Member, IEEE,* and G. P. Saraph, *Member, IEEE*

***Abstract*— An overmoded abrupt transition coaxial buncher cavity has been designed and experimentally cold tested for use in a second-harmonic 17.136-GHz three-cavity 100-MW gyroklystron. Circuit efficiencies of 41% can be achieved with a buncher cavity that has a quality factor of 389 in the TE_{021} mode. Scattering matrix and finite-element codes were used to design and model the cavity theoretically and to determine that the cavity would be stable to oscillation. The experimental cold testing confirmed these results and refined the final dimensions from the theoretical models.**

***Index Terms*— Cavities, cavity resonators, gyroklystron, microwave amplifier.**

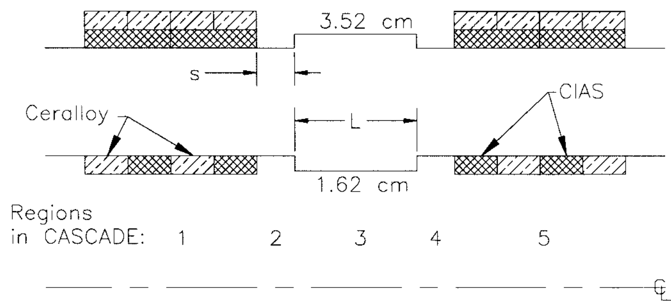

Fig. 1. Schematic of the buncher cavity.

I. Introduction

HIGH-POWER vacuum microwave amplifiers, which may drive future linear colliders, are currently being built and tested [1]–[4]. The gyroklystron is a leading candidate for frequencies above J-band [5]. At the University of Maryland, the feasibility of gyroklystrons for collider applications has been under study for more than ten years [6]. We are now involved with the experimental testing of a 100-MW 8.568-GHz fundamental interaction overmoded gyroklystron. The next experiment will feature a coaxial gyroklystron with second-harmonic interaction at a frequency of 17.136 GHz. That experiment is designed to provide at least 100 MW of power for 1 μs in the TE_{02} mode.

To achieve the requisite power, gain, and efficiency levels at the second harmonic, the proposed system will feature a three-cavity circuit, consisting of an input cavity, which impresses the input signal on the beam, a buncher cavity, which is the subject of this letter, and an output cavity, where power is transferred to microwaves. All of the cavities in the second-harmonic gyroklystron are overmoded coaxial cavities. The buncher cavity's function is to continue and enhance the azimuthal bunching process begun by the input cavity.

The buncher cavity is defined by abrupt nearly symmetric radial transitions in the inner and outer conductor wall. The symmetry of these transitions maintains a low conversion figure to the TE_{01} mode of about -40 dB despite these abrupt changes. Theoretical large-signal code modeling has indicated that the addition of the buncher cavity into the second-harmonic circuit will increase the efficiency by almost 10% and gain by 24 dB to 41% and 49 dB, respectively, from the two-cavity system [7]. The Q required for this circuit performance is given from this code to be 389 for the TE_{021} mode. Stability analysis shows only one potential unstable mode for the operational beam power, the TE_{011} mode. The amplifier will be stable to oscillation in this mode if the TE_{011} Q is less than 55.

Manuscript received April 29, 1998. This work was supported by the U.S. Department of Energy.

The authors are with the University of Maryland, College Park, MD 20742 USA.

Publisher Item Identifier S 1051-8207(98)07957-4.

II. Theoretical Design

A schematic of the buncher cavity is shown in Fig. 1. Straight metallic regions are found on either side of the buncher's main cavity section on both conductors. These straight section radii are the same as the drift tube radii of the ceramic pieces they border. The TE_{01} and TE_{02} cavity modes are cut off at the first and second harmonics, respectively, in these straight sections. Without ceramics in the drift tube, the quality factor is extremely high, loss coming only from ohmic heating in the metal. The presence of these drift tube dielectrics markedly reduces this Q figure by providing diffractive power loss from the cavity. This mechanism is controlled by the length s of these straight cutoff sections which isolate the cavity from the drift tube.

There are two kinds of ceramics used in the gyroklystron circuit. The first kind is a nonporous composite of 80% BeO and 20% SiC. The second kind is a slightly porous in-house produced carbon-impregnated aluminum silicate (CIAS) [8]. Because of the diffusive nature of our production process, nonuniformities in the dielectric constant are present and have an effect on the sensitive Q measurements.

The first theoretical tool used to design the buncher cavity was the program CASCADE [9]. This is a scattering matrix code that accepts coaxial geometries. This code does not model nonmetallic walls, so a five-section model of the buncher cavity was developed to help simulate the important effects of the drift tube ceramics. Sections II–IV were the dimensions of

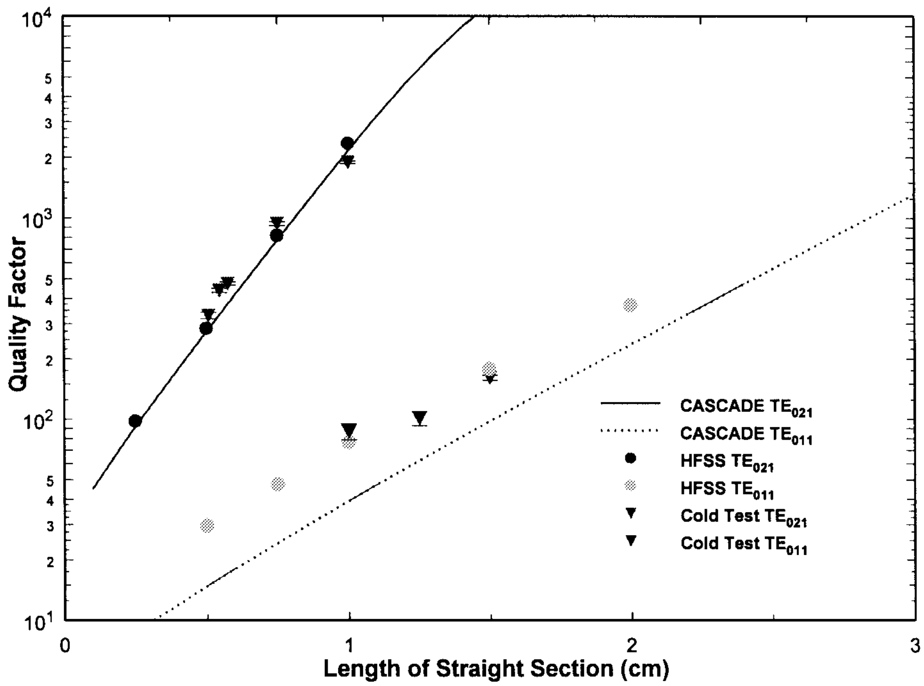

Fig. 2. Plot of Q versus straight section length.

the cavity as discussed above. Sections I and V were specified as regions of increased radii to simulate the diffractive Q effects of the dielectric drift tube. In our model, these radii were the same as the main section. The preliminary design using CASCADE implied the length of the cavity L would be 1.748 cm and the straight section length s would be 0.584 cm. The cavity resonated in the TE_{021} mode at 17.136 GHz and had a Q value of 389 for these dimensions. The TE_{011} mode was indicated as having a resonant frequency of 9.29 GHz and a Q of 17.56.

The second theoretical tool used in the modeling efforts was the HFSS software package (High Frequency Structure Simulator). This uses a finite-element algorithm to solve for the electromagnetic fields and can analyze dielectric materials. The run times were significantly longer for this program, even though symmetry was utilized to minimize computer time. The Q values were obtained in the HFSS program by examining the scattering parameter versus frequency output and computing Q using the half power bandwidth formula $Q = (f_r/\Delta f)$, where f_r is the resonant frequency and Δf is the full width half maximum of power bandwidth. The straight section length was shown to be $s = 0.575$ cm from the HFSS results for the appropriate Q. The resonant frequency for the TE_{021} mode for $L = 1.748$ cm was about 17.126 GHz for these values, which was close to the CASCADE results. The TE_{011} mode was found at a resonant frequency of 9.434 GHz at this straight section length with a $Q = 35$.

III. Experimental Setup

Experimental cold-testing of the buncher cavity was performed to ensure that inaccuracies in the modeling were taken into account and corrected. A small mock-up of the buncher cavity was manufactured and placed inside of a chamber to hold and align the pieces together. The Q measurements in the experimental setup were also computed with the half-power bandwidth formula.

To couple signals in or out of the cavity, apertures were drilled in the radial outer wall of the cavity, 5.1 mm in diameter for the X-band tests, and 2.87 mm in diameter for the Ku-band tests. Rectangular waveguide soldered to special flanges was bolted directly to the outside of the cavity. Special pockets were made on this outer face to minimize reflection and keep the aperture 1 mm long. This setup was minimally intrusive to the cavity performance. Mode identification was performed using a Slater technique [10] probing in the radial component.

IV. Results

Experimentally, only L and s were kept as free dimensions. The main section length found to yield a resonant frequency in the TE_{021} mode of 17.136 GHz was 1.691 cm. The TE_{011} resonant frequency at this length was 9.345 GHz. The experimental cavity length is smaller than the theoretical predictions, but a systematic error can be inferred because of the similarity in the reduction in frequency for both modes. Nonideal dielectric effects are one potential cause.

The straight section length was varied and the data for Q was taken, as shown in Fig. 2. The empirical results are in very good agreement with the HFSS results. The TE_{021} mode has a Q of 389 at a value of $s = 0.524$ cm. Again, this number differs from the HFSS results, most likely due to the same effect of the dielectrics. The TE_{011} mode at this length was indeterminate experimentally; the bandwidths of the low Q modes around 9.3 GHz washed out any distinctive pulse shapes after the straight section length was less than 1.0 cm. However, the available data shows good agreement with the HFSS results. The CASCADE results are substantially different, owing to the simple nature of the model used, which uses large waveguide sections to model dielectrics, missing the resistive loss mechanism and overestimating the field profile. Nonetheless, they do exhibit the same relative change in Q with drift section, underscoring the systematic error inherent in the model.

V. Conclusion

We have presented a comprehensive design and cold test of an overmoded coaxial abrupt-transition gyroklystron buncher cavity. It operates at the second-harmonic frequency of 17.136 GHz with a $Q = 389$ in the TE_{021} mode. The quality factor is controlled by dielectrics in the drift region. The only theoretically competing mode in parameter space is the TE_{011}, which we have shown will not be a threat to self-oscillation with a Q of about 35. An efficiency of over 40% and a gain of 49 dB seems to be realizable with this cavity included in the second-harmonic circuit. The experimental cold testing has been completed and agrees well with the HFSS modeling for the resonant frequency and Q. The gyroklystron project is currently involved in the testing and operation of the fundamental (8.568 GHz, TE_{011}) gyroklystron circuit, and we will soon swap out the output cavity and install the second-harmonic buncher and output cavities and proceed with the operation of the 100-MW second-harmonic gyroklystron.

Acknowledgment

The authors wish to thank B. Hogan, K. Diller, and M. Stattel for their help in construction of the experiment.

References

[1] G. Caryotakis, “Development of X-band Klystron technology at SLAC,” in *Proc. 1997 Particle Accelerator Conf.*, Vancouver, Canada, 1997, to be published.

[2] A. J. Balkcum, D. B. McDermott, R. M. Phillips, A. T. Lin, and N. C. Luhmann, Jr., “250-MW X-band TE_{01} ubitron using a coaxial PPM wiggler,” *IEEE Trans. Plasma Sci.*, vol. 24, pp. 802–807, 1996.

[3] D. Shiffler, J. A. Nation, L. Schachter, J. D. Ivers, and G. S. Kerslick, “A high-power two stage traveling-wave tube amplfier,” *J. Appl. Phys.*, vol. 70, pp. 106–113, 1991.

[4] S. H. Gold, A. K. Kinkead, A. W. Fliflet, B. Hafizi, and W. M. Manheimer, “Initial operation of a high-power frequency-doubling X-band magnicon amplifier,” *IEEE Trans. Plasma Sci.*, vol. 24, pp. 947–956, 1996.

[5] E. V. Zasypkin, M. A. Moiseev, I. G. Gachev, and I. I. Antakov, “Strudy of high-power Ka-band second harmonic gyroklystron amplifier,” *IEEE Trans. Plasma Sci.*, vol. 24, pp. 666–670, 1996.

[6] V. L. Granatstein and W. Lawson, “Gyro-amplifiers as candidate RF drivers for TeV linear colliders,” *IEEE Trans. Plasma Sci.*, vol. 24, pp. 648–665, 1996.

[7] G. P. Saraph, W. Lawson, M. Castle, J. Cheng, J. P. Calame, and G. S. Nusinovich, “100–150 MW designs of two- and three-cavity gyroklystron amplifiers operating at the fundamental and second harmonics in X- and Ku-bands,” *IEEE Trans. Plasma Sci.*, vol. 24, pp. 671–677, 1996.

[8] J. P. Calame and W. Lawson, “A modified method for producing carbon-loaded vacuum compatible microwave absorbers from a porous ceramic,” *IEEE Trans. Electron Devices*, vol. 38, pt. 2, pp. 1538–1543, 1991.

[9] W. Lawson and P. E. Latham, “The scattering matrix formulation for overmoded coaxial cavities,” *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 1973–1977, 1992.

[10] L. C. Maier Jr. and J. C. Slater, “Field strength measurement in resonant cavities,” *J. Appl. Phys.*, vol. 23, pp. 68–77, 1952.