A Second Harmonic Amplifier for Accelerator Applications*

P.E. Latham, W. Lawson, C.D. Striffler, and W. Main
Laboratory for Plasma Research
University of Maryland, College Park, MD 20742

Abstract

The theoretical design of a second harmonic gyroklystron amplifier at a voltage near 500 kV is presented. Because of the relatively high voltage the beam tunnel must be large, so the radiation is not cutoff in the drift tube. To avoid feedback we operate the input cavity at the fundamental, which is cutoff in the drift tube, and design a complex output cavity that emits very little radiation back into the drift tube. The output cavity is described in detail, and the overall gain and efficiency is given.

I. Introduction

For accelerator applications it would be highly desirable to operate a gyroklystron amplifier at the second harmonic, as this would reduce the demands on the magnets. In addition, if subharmonic bunching is used all but the last cavity can operate at the fundamental frequency, allowing a second harmonic device to be easily adapted to an existing fundamental gyroklystron amplifier. The major problem with second harmonic operation at moderate to high voltage, where the Larmor radius is large, is that the radiation may not be cutoff in the drift tube. For instance, the drift sections in the University of Maryland's 500 kV gyroklystron amplifier[1] must be at least 1.5 cm in radius to allow the beam to pass through. At this radius the operating mode, TE_{01}, is cutoff at the fundamental frequency of 10 GHz, but not at the second harmonic. The obvious solution is to operate all but the last cavity at the fundamental frequency and operate the output cavity in the TE_{02} mode at the second harmonic. Then the problem is to make sure that the mode conversion from TE_{02} and TE_{01} is negligible. For multi-megawatt devices the constraints on mode conversion may be so severe that a narrow band filter is needed upstream of the output cavity to keep the radiation from traveling back toward the gun.

In the remainder of this paper we concentrate on the theoretical design of a 20 GHz, second harmonic gyroklystron amplifier consistent with the parameters of the University of Maryland device, which are summarized in Table 1. We will first give the design of the output cavity, then present the nonlinear gain and efficiency.

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Table 1: University of Maryland Gyroklystron Parameters.

Beam voltage	425 kV
Beam current	150 A
Pitch angle, $v_{\perp 0}/v_{z_0}$	1
Magnetic field	5.72 kG
Velocity spread	10%

II. Output Cavity Design

Three output cavity designs, in order of increasing complexity, are shown in Figs. 1a–1c. Figure 1a is the simplest: at radii r_1 and r_3 the TE_{02} mode is cutoff, while at radii r_2 and r_4 the TE_{02} mode may propagate. The tapers are designed for low mode conversion to the TE_{01} mode, and either the length of the lip at radius r_3 or the value of r_3 may be adjusted to control the cavity Q. This type of cavity works well at low Q, but at high Q a substantial portion of the output power may be converted to the TE_{01} mode. This is because the outgoing power in the TE_{02} mode is on the order of $1/Q$ of the circulating power, so the amount of mode conversion to the TE_{01} must be significantly less than $1/Q$. For $Q \sim 1000$, which is typical, the mode conversion must be much smaller than -30 dB. Such low mode conversion may not be practical with reasonable length tapers.

This problem can be eliminated by placing a narrow band 20 GHz mode filter upstream of the output cavity, as shown in Fig. 1b. The filter consists of a cavity that has a low Q resonance at 20 GHz, so it won't interact strongly with the beam. Such a cavity will effectively eliminate any power produced in the output cavity from propagating back to the gun.

There is an additional problem with the cavities shown in both Figs. 1a and 1b; the outgoing TE_{02} may be contaminated by the TE_{01} mode. One way to eliminate this is by using the cavity shown in Fig. 1c, in which the radius r_3 is cutoff to the TE_{02} mode. Thus, all the output power is in the TE_{01} mode. The length of the transition between radii r_2 and r_3 may be adjusted to control the amount of mode conversion and thus the cavity Q. With the mode filter in place all the power will be in the forward direction, producing a pure TE_{01} signal.

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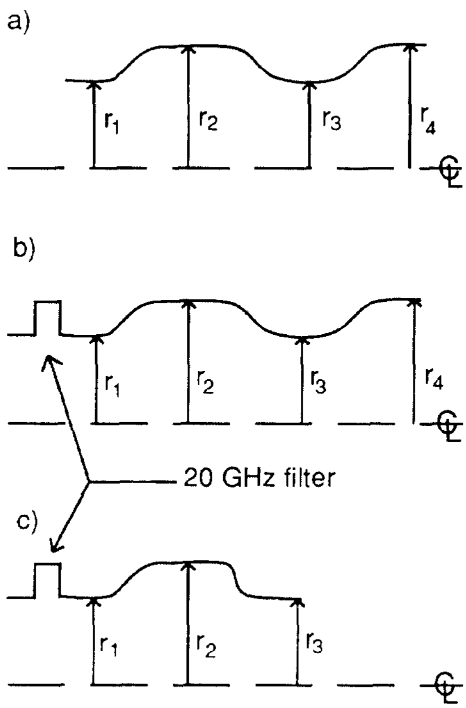

Figure 1: Three output cavity designs in order of increasing complexity.

III. Circuit Design

Our initial design employs two cavities separated by a 1.5 cm radius drift section. The input cavity is 1.7 cm long with a radius of 6.1 cm and a Q of 300. The drift tube is 10 cm in length. For simplicity we chose the output cavity depicted in Fig. 1a. Its dimensions are $r_1 = 1.50$ cm, $r_2 = 1.72$ cm, $r_3 = 1.68$ cm, and $r_4 = 1.80$ cm. At these radii the TE_{01} mode at 10 Ghz is cutoff. All three tapers are 2 cm long, the straight section of the cavity (at radius r_2) is 1.436 cm and the straight section of the lip (at radius r_3) is .330 cm. The resultant Q of the output cavity is 600. With no beam present, analysis of the cold cavity fields indicates that about .3% of the power will propagate back toward the input cavity. This value will probably change when the beam is present.

To calculate the gain and efficiency, we used a nonlinear, partially self-consistent code which computes the steady state amplitude and phase in each cavity[2]. The beam characteristics and applied magnetic field are given in Table 1. For these parameters the efficiency was 22%, corresponding to 15 MW output power. We do not believe that this is an optimized value; there is a large parameter space to search and we have not yet explored all possible combinations of output cavity Q, length and frequency mismatch, and magnetic field. We will continue with our optimization process and report on an improved design at a later date.

The gain of this device was fairly low, only about 16 dB. However, the gain can easily be increased by raising the input cavity Q, tapering the magnetic field or adding an intermediate cavity.

IV. Summary

We have shown that second harmonic operation with bunching at the fundamental frequency is feasible. With a velocity spread of 10%, numerical simulations have achieved an output power of 15 MW (corresponding to an efficiency of 22%) at 20 GHz. We believe that the efficiency will increase significantly as we continue with our optimization. The gain was about 16 dB; this number will also increase with modifications to the input cavity, magnetic field tapering or the addition of an intermediate cavity.

We have also presented a variety of output cavities that can be used to prevent feedback of the output cavity signal into the input cavity and to guarantee that the output will be in a pure mode.

V. References

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