IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

COMMON ANODE AMPLIFIER DEVELOPMENT*

Thomas W. Hardek and William E. Chyna†

Abstract

As accelerator beam intensity increases, loading of the RF system becomes a serious problem. Typical solutions include careful accelerating cavity design and active feedback schemes. Since the goal is to provide a low accelerating gap impedance, it is possible to simply drive the gap with a low output impedance amplifier. The "common anode" (also called cathode follower) configuration seems to be ideally suited for such an amplifier but has not received much attention in high power amplifier applications. This paper describes the construction and testing program of high power common anode configured RF amplifiers carried out at the Zero Gradient Synchrotron (ZGS). While amplifiers of this type seem limited to lower frequency accelerator applications, they may prove to be a viable alternative to the more conventional approaches currently in use.

Introduction

Over the past several years the Accelerator Research Facilities Division of Argonne National Laboratory (ANL) has been involved in the design of high intensity rapid cycling accelerators. These machines are typically first harmonic machines requiring rather low frequency RF systems and exhibiting quite high circulating beam currents. Peak beam currents in excess of 30 A are not uncommon. Low accelerating gap impedances are mandatory but conventional techniques simply cannot provide an acceptable solution.

It is possible to construct low inductance accelerating cavities with large capacitances shunting the accelerating gaps. This provides the desired low impedance for various harmonic components of the beam current while keeping power requirements in bounds. One must rely on an automatic gain control system to compensate for fundamental component beam loading effects. At high repetition rates the burden placed on the AGC system becomes impressive. Problems may also result from resonance effects in these large shunt capacitors. Active RF feedback schemes which detect beam current and compensate for it offer another possibility but the hardware requirements are also impressive. We therefore advocate the use of low output impedance amplifiers directly driving the accelerating gap.[1] The common anode configured (cathode follower) amplifiers[2] proposed for this use exhibit the low output impedance characteristics desired with rather simple circuitry. This approach is unconventional, however, so a development project has been initiated at ANL to demonstrate feasibility. While the development of low output impedance amplifiers is a low budget, limited manpower effort, some encouraging results have been obtained. These results and a description of the equipment follows.

Demonstration Amplifier

Development effort has been centered around construction of a large scale demonstration common anode configured amplifier and the operation of this amplifier under simulated beam loading conditions. Figure 1 shows the schematic diagram of this amplifier and Fig. 2 shows the general layout along with some auxiliary equipment. A restructured Brookhaven accelerating cavity visible in the photograph (Fig. 2) provides the single ended cavity configuration of Fig. 1. With it we may select up to 80 cores of Phillips type 4H ferrite allowing quite a range of cavity conditions. It is also possible to add bias windings for tuning but this has not yet been implemented.

The demonstration amplifier consists of a final stage cathode follower connected Machlett ML7560 water cooled triode capable of 175 kW plate dissipation. The 7560 operates class A single ended with the accelerating cavity completing the dc path from cathode to ground. A second ML7560 driver stage is capacitively coupled to the final. The final stage and driver stage are fed from a single plate supply capable of operating at 18 kV. To minimize average power requirements both stages are biased into cutoff and pulsed to desired conduction for a few milliseconds. It should be noted that this in no way represents an optimum electrical or mechanical design since our only interest is to show feasibility. All components including the tubes were selected because of their availability at the sacrifice of having optimum electrical characteristics.

Computer Simulation

In an effort to verify our concepts and to demonstrate the effects of varying circuit parameters, a Tektronix 4051 computer system was utilized. The Plot 50 Electrical Engineering program package[3] for this system provides for two port analysis of quite a variety of circuit connections. We have adapted the equivalent circuit of Fig. 3 for our simulation. The two port analysis performed, of course, is a small signal approximation assuming linear operation of the various components, but this may not be unrealistic considering the operating ranges of the real components in question. The Tektronix system also provides for stability calculations which are of particular interest to us. Figure 4 displays the computed two port impedances for the component values of Fig. 1 taking care to include stray values wherever they may be expected to exist. Stability diagrams are not included here but indicate that the amplifier should in theory be stable under any loading conditions. By varying circuit components, it is possible to calculate conditionally stable operating regions indicating that some care is necessary in component selection. A procedure to include beam loading into the two port analysis routine is under development, but has not yet produced results.

Tests/Results

The goal of this development effort is to demonstrate that a common anode configured amplifier can produce accelerating voltages approaching 10 kV peak with output impedances in the tens of ohms range without stability problems. It is also intended to delineate the difficulties implicit in these amplifiers and protection circuitry requirements. We initially intended to construct and operate a demonstration amplifier capable of 10 kV peak RF voltages over a 0.7 MHz to 1.5 MHz range, but have actually been operating around 1.9 to 2.5 MHz, a more difficult endeavor. The following tests were performed with a ferrite loaded accelerating cavity resonant in this range.

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*Work supported by the U. S. Department of Energy.
†Argonne National Laboratory, Argonne, IL 60439 USA

0018-9499/79/0600-3959$00.75 © 1979 IEEE

One proposed test was to bring the amplifier output up near 10 kV peak with the cavity resonant at 2 MHz and measure output impedance by resistively swamping the accelerating gap (cathode follower output). The available driver amplifier allowed us to reach only about 3 kV peak, so resistive swamping tests were conducted at this level.

With a 1 kΩ swamping resistor, loading was insignificant. A 300 Ω resistor produced 200 V change and a 150 Ω resistor produced 500 V change. Taking output impedance as $\Delta E/\Delta I$, we obtained values of 20 Ω and 25 Ω respectively. Similar values were obtained for frequencies up to 7 MHz with our driving source being the limiting factor.

Another output impedance measurement was obtained by installing a wire through the cavity beam pipe and pulsing this wire to simulate beam loading. A pair of 4-1000 A tetrodes connected in parallel were operated as constant current sources to pulse the wire. Output impedance data was taken from 1.5 MHz to 10 MHz with approximately sinusoidal wire currents. A Pearson Model 1010 current measuring toroid was installed around the output tube and actual tube current was observed. This toroid agreed well with a Model 150 current transformer utilized for measuring wire current. Peak to peak current levels of 100 mA and 5 A were utilized for the bulk of the measurements but several readings were taken at 7 A and one reading at 10 A. For the Intense Pulsed Neutron Source Accelerator,[4] a 5 A sinusoidal current would correspond to approximately 3×10^{12} protons in a nonaccelerating bucket at 500 MeV.

As a further test, the final amplifier bias was increased so that wire current drove the stage into cutoff. The amplifier remained stable but an anticipated increase in output impedance was observed.

Cathode Follower Problems

The main difficulty we have encountered with cathode follower connected amplifiers is their large drive power requirements. A look at the equivalent circuit Fig. 3 will reveal that one must develop large voltages across the grid to plate capacity of the final stage. The plate capacity of the driver stage itself must also be included further increasing required drive power. As the operating frequency is increased, one finds that as much power is required to drive a cathode follower as is desired out of it. This difficulty makes cathode follower use impractical except for the lower frequency applications. It is possible to compensate the input capacitance with an inductance, but some form of neutralization would then be required adding complexity to the circuitry. Even at rather low operating frequencies (2 to 5 MHz) one must be willing to sacrifice efficiency for low output impedance, a trade-off not uncommon in broad banded accelerator RF systems.

Amplifier stability is another topic for concern. The tube distributed capacities can combine with stray inductances to form a Colpitts oscillator configuration. The grid-to-plate capacity also allows large amounts of feedback energy setting the stage for a tuned-grid-tuned-plate configured oscillator. If precautions are taken, however, these difficulties seem controllable. In particular, the addition of series grid resistance and the careful elimination of resonant circuitry at the follower input seem adequate to provide completely stable operation. No sign of instability has been encountered in the demonstration amplifier which employs both of these precautions.

Future Efforts

The testing program is really just getting underway. There are several tests which we plan to conduct in the near future. While we are presently limited to about 30% of the demonstration amplifier's intended output level, we expect to improve the driver and repeat the loading tests. We plan to replace the wire driving amplifier with a considerably larger model and repeat those tests for currents of 20 to 30 A. We also plan to pulse the wire while simultaneously driving the cavity with the demonstration amplifier. While a large amount of work remains, the prospect of utilizing cathode follower connected amplifiers to solve accelerator problems looks favorable and the anticipated difficulties seem controllable.

Acknowledgments

We would like to acknowledge the efforts of J. D. Simpson for his support of this development effort and his many valuable suggestions and F. E. Brandeberry for his technical assistance.

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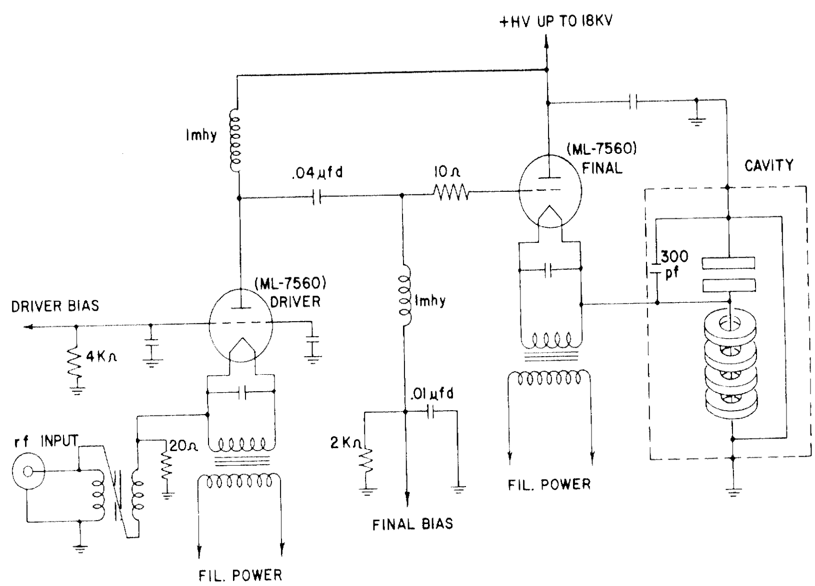

FIG. 1 SCHEMATIC DIAGRAM DEMONSTRATION AMPLIFIER

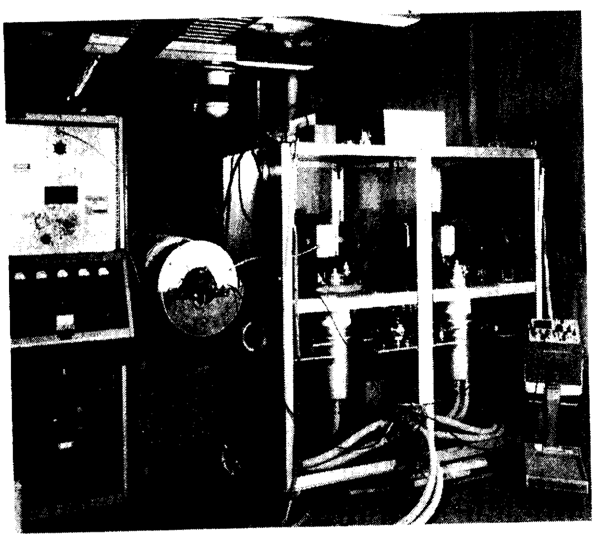

Fig. 2. Demonstration amplifier

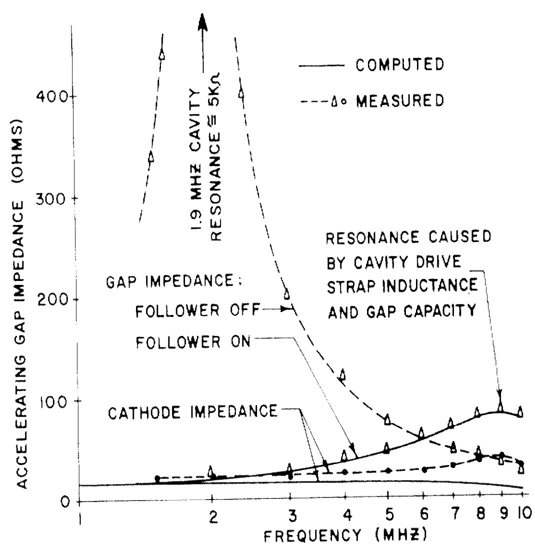

FIG. 4 CATHODE FOLLOWER OUTPUT IMPEDANCE

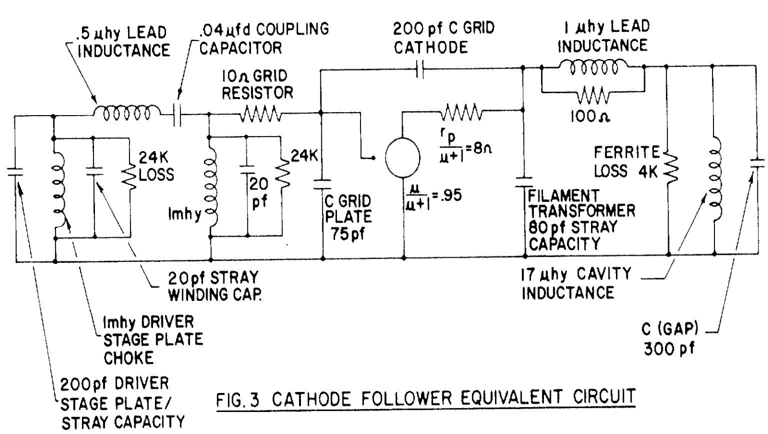

FIG. 3 CATHODE FOLLOWER EQUIVALENT CIRCUIT