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A MEGAWATT RF SOURCE AT 108 MHz

K.H. Knobbe
Herfurth GmbH, Beerenweg 6-8, 2000 Hamburg 50, Fed. Rep. of Germany

D. Böhne
GSI, Gesellschaft für Schwerionenforschung mbH, Postfach 110541, 6100 Darmstadt, Fed. Rep. of Germany

Summary

A novel anode circuit design is described, circumventing a number of constraints, which are usually encountered when a large-size power tetrode is circuited for the 80 to 200 MHz range. The particular feature of the outlined TM mode cavity is the easy applicability of suppression devices for parasitic modes and the generous space available for tuning and coupling devices.

Introduction

In linacs operating at a high duty factor, typically 25-50% for a heavy-ion linac, the average tube power is pushed to the limits of plate dissipation density. Since DC to rf conversion efficiency is a fairly strong demand, too, tetrodes with drive modulation are used and the permanent DC plate voltage cannot be chosen as high as in the case of short pulse plate modulation. This must be compensated for by an increased emission current. Both requirements can only be satisfied by enlarging the active tube geometry. It is the choice of the tube manufacturer, to increase either the length or the diameter of the active system or both. If the length of the active interelectrode area is high, as it acutally is the case for Megawatt short wave tubes, the circuits become difficult to design at higher frequencies and sharp current maxima are found to be close to the tube socket or even inside the tube and generate severe heating problems. In this case, the rf output power has to be derated in a higher frequency application to unattractively low values. If the tube diameter is increased, the resonance frequency for circumferential wave modes in the three interelectrode areas come down into a range (0.5-2 GHz) where the tube still has a high enough mutual conductance to sustain a detrimental self excitation. In practice - however - both problems are vigorously and simultaneously existent, when a gridded tube rf amplifier in the one Megawatt and 80-200 MHz range is envisaged. It should be mentioned that a high power, very high frequency tube, which is usually derived from a short wave tube family, inevitably exhibits parasitic mode excitations, when socketed into a cavity type circuit, whereas it will not, when used in an open lumped parameter circuit. Therfore it remains the burden of the cavity designer to attenuate the Q-value of the outer resonating circuits for unwanted higher frequencies and it is left to the tube designer to provide an as high as possible matching of the characteristic impedance of the interelectrode system to the outside circuit extensions beyond the socket. In essence: The tube manufacturer should bring down to the socket the inherently low characteristic impedance of the electrode system without unduly large impedance steps in the grid support structure, and the circuit designer should endeavour to match this impedance up to an appropriate location along the wave propagation path, where adequate space is available for the incorporation of lossy devices for the unwanted higher frequencies. Those attenuating devices must have the power capacity to sustain the control grid driven harmonics, too. In practice, the circuit designer is faced with voltage hold-off limits, which are much lower on the atmosphere side compared to the vacuum situation inside the tube. That implies that an impedance step between tube structure and cavity geometry is almost unavoidable in principle and the cavity designer is obliged to bring the attenuating devices close to the tube socket. To provide this opportunity, plate-, screeen grid- and control grid-circuits acutally can be optimized.

Comparison of Two Cavity Options

For a high power amplifier, with the specification of 1.6 MW, preferably 2 MW pulse power at 25% duty factor and an operating frequency of 108 MHz, two different circuit designs have been worked out. The second one was selected and was the result of a cold probe model program. In the prototype phase of a high power version it immediately demonstrated the above outlined power characteristics.

Fig. 1 illustrates the classical design with coaxial line type circuits. The 3/4 λ plate circuit is folded upwards. It has the following disadvantages:

1. The tube is poorly accessible for a rapid replacement.
2. Voltage hold-off considerations impair the selection of a low impedance plate circiut and impose the recommendation to eliminate the DC voltage from the rf circuit. As a consequence, a DC blocker must be put close to the tube socket, where the rf current is near its maximum value. Those blockers are of a technologically difficult nature and a source of potential failures. Avoiding the blocker by a λ/2 circuit results again in overvoltage problems, solvable only in an elaborate pressurized concept.
3. The above mentioned impedance step from about 5 ohms to about 25 to 40 ohms reduces the effectiveness of attenuating devices inside the coaxial line, except in the close environment of the tube socket. Cutting

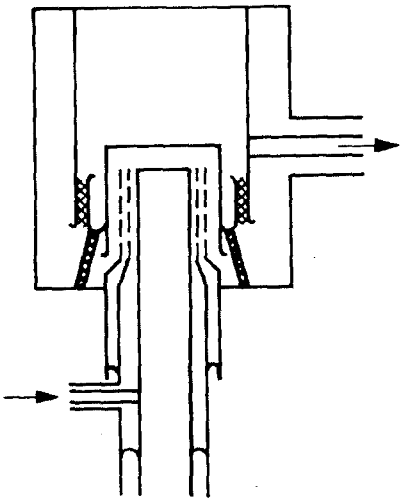

Fig. 1. VHF amplifier circuit with coaxial line cavities.

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longitudinal slots in the outer conductor of the lines, to prevent the current flow of circumferential modes and to radiate those modes into a wave dump, is uncomfortable for mechanical reasons.

4. The access to the socket environment in the grid/cathode circuit, for the installation of attenuating measures, is inhibited by the grid one/grid two circuit.
5. Due to lack of space an adjustable tuning and coupling device on the output cavity is difficult to design simultaneously.

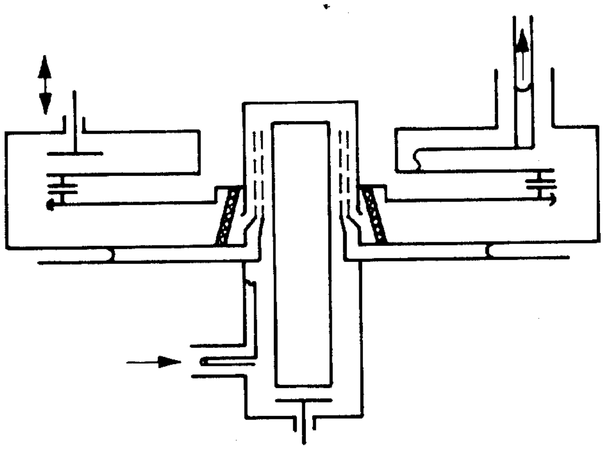

Fig. 2. VHF amplifier with folded TM anode cavity.

Fig. 2 shows an alternate design of the plate and screen grid cavity. Both are assembled from aluminium sheet metal plates and except for the drive mechanism of the adjustable tuning and coupling device, there is no machined component incorporated. The plate cavity is a folded pancake resonator which approximately has a field distribution of a TM_{030} resonator and is equivalent to a 3/4 λ cavity as shown in Fig. 1. The diameter is approximately 1.5 m for 108 MHz and was determined experimentally. Similar cavity geometries are usual in low power tube amplifiers in the 0.5-3 GHz range. The input circuit is a $\lambda/2$ coaxial cavity of a square shaped cross section and with demountable plates to allow for a convenient access to the filament leads and water joints of the tube. One might object that this cavity scheme has an appreciable number of higher and lower wave modes, predominantly of circumferential type. By cutting slots radially in the disc, which is joining the anode, radial modes are inherently suppressed. When bridging those slots by resistors on the field free upper side, circumferential modes, which are excited inside the tube, are perfectly attenuated. There is ample of space for incorporating lossy material in this interface volume of the folded cavity. The equivalent characteristic impedance of the circuit at the tube socket is relatively low, about 15 ohms and drops further down radially. This is due to the radially rising capacitance and decreasing inductance, if one considers a segment of the cavity. Therefore the impedance step between tube and outer circuit is modest and due to the radially decreasing nature of the characteristic impedance the voltage wave in its maximum at the folding point is smaller compared to an equivalent point in a coaxial circuit. A predominant advantage of the cavity scheme is the appreciable circumference at the voltage maximum point. This eases the conception of the blocker, which definitively can be kept rf current free, when the amplifier is operated at a fixed frequency. In the prototype cavity 128 inexpensive and commercially available ceramic capacitors of .16 nF, two pieces in series, have been used. The gap between the capacitor units might be advantagoues for radiating higher frequenvy modes into the interface volume, where they can be absorbed by ferrite blocks. This, however, was not necessary in this case. One remaining parasitic frequency at 1.3 GHz, which resisted to a successful suppression by any measure in the plate circuit, immediately disappeared when a hose with ferrite beads and circulating soda water was placed into the grid one/grid two circuit close to the tube socket. The perfectly convenient access to the grid one/cathode area of the tube socket was not used for parasite suppression explicitly here.

Another preference of the cavity geometry is the generous space for tuning and coupling devices. The capacitive tuning was provided by two semicircular sheet metal rings and two coupling loops were placed in between. In Fig. 2 only one of either devices is shown. The two exiting 100 ohm lines were paralleled in a T-section. It was not attempted to explore, whether this twin structure of tuning and coupling really is necessary.

The authors believe that the above described cavity concept circumvents most shortcomings of a coaxial cavity design, outlined in the previous chapter. And it was appealing to see, how the amplifier, shown in Fig. 3, came up to the design power in a few days with only minor modifications for eliminating hot spots. Peak levels of 2 MW were achieved and the envisaged 1.6 MW for a 5 ms pulse at 50 Hz repetition rate was run continuously into a dummy load.

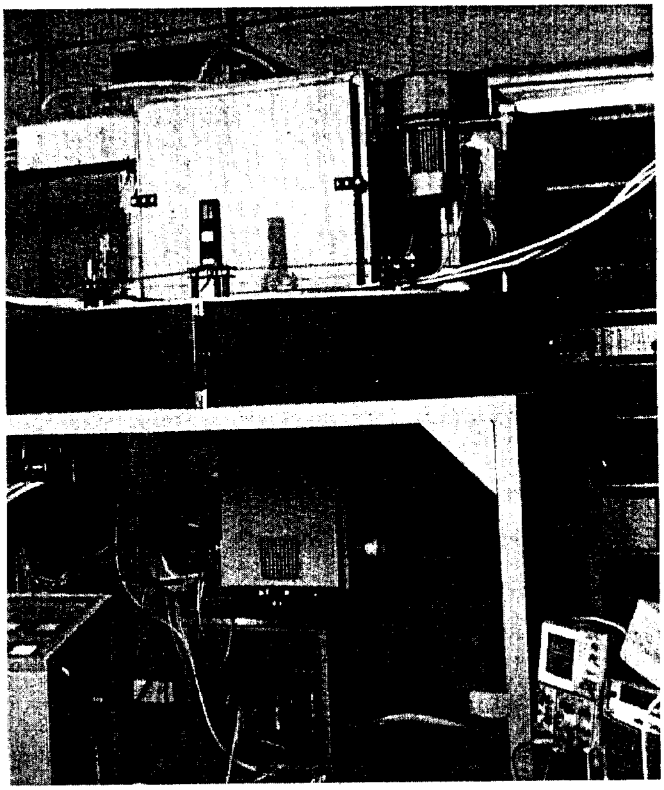

Fig. 3. View of the amplifier prototype.

It is believed that the inherently large size of the cavity has the potential to circuit presently available high power tubes up to the 200 MHz range. A limitation in pulse power, in excess of 2 MW, might exist due to arc-overs at the outer edge of the anode disc, where DC and rf voltage are superimposed. In this case a less comfortable ring shaped capton blocker could be placed between double plates of the anode disc.