208.
9/8/78
BNL 50833

Lib. 453

MASTER

20 kW TRANSMITTER FOR CW OPERATION AT 50 or 17 MHz

J.T. Keane
April 4, 1978

ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973

under contract No. EY-76-C-02-0016 with the
UNITED STATES DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

(Inertial Confinement Fusion
-TID 4500)

20 kW TRANSMITTER FOR CW OPERATION AT 50 or 17 MHz

J.T. Keane

April 4, 1978

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ACCELERATOR DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973

under contract No. EY-76-C-02-0016 with the
UNITED STATES DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Summary:

A 20 kW transmitter was loaned to the HIF group from the Lawrence Berkeley Laboratory, Berkeley, California. The unit has been put into operation and run at 16 and 50 MHz. The circuitry and difficulties encountered are described.

I. Unit Description

The amplifier system is comprised of three basic sections, namely:

- 1) High voltage power supply and controls,
- 2) RF amplifier system,
- 3) Forced air cooling system.

These sections are viewed in figure 1 from left to right.

No noticeable problem was encountered with the forced air cooling system except for the ducting that had to be interconnected between cubicles. In addition, there is an air flow interlock that has never performed properly and has been bypassed.

Some of the more difficult problems with the high voltage power supply and controls sections are itemized below.

On initial turn-on the filament currents of the 6166 were unbalanced. It was found that the original regulatory system had been replaced by Variac controls. A defective brush was replaced and filament currents were then controllable.

During initial turn on there were numerous control problems due to such things as dirty contacts and fuse burn outs. It is noted that some of the high voltage fuses are vulnerable to burn-out if the doors are open while high voltage is on. There is no bleed resistor, just shorting bars.

II. Initial Operation

Collins Radio turn on procedure was followed during start up. The procedure was invaluable. Most of the problems showed up during the initial checks. The voltage range checks given in this procedure are correct, except for small changes in biasing for the first stages. This is due to the fact that 4X150 tubes in the first two stages were replaced by 4X350 A's.

Since Berkeley last ran the unit at 51 MHz that frequency was maintained for the initial turn on. The necessary 1 watt drive power was supplied by a HP signal generator and Boonton amplifier. A water-cooled resistance load rated at 30 kW was the only auxiliary equipment necessary. Again, the Collins procedure was followed with good results.

Once 18 kW of output power was achieved, it was decided to go down in frequency in steps. Power output was achieved at 34, 19, 17 and the desired value of 16.6 MHz. When changing over to 34 MHz a cable carrying driver plate and power amplifier bias intermittently shorted inside a harness causing one of the more difficult problems to solve. During this period the output 3 1/8 coax window was disassembled. In reconnecting, the dc output blocking capacitor was not installed properly. The output of the two final stages was effectively open circuited resulting in a very impressive display of arcing around the tubes. This capacitor connection is blind and if the unit had come in with an improper connection it would have been a very hard problem to solve.

The operation of the rf amplifier section will now be described as well

as modification required to bring the unit down to an operating frequency of 16.6 Megahertz.

III. RF Amplifier Section

The RF amplifier cubicle is shown in figure 2. A pair of 6166 air cooled tetrodes comprise the output stage. Housed below the output tubes are the two driver stages. As shown in the simplified diagram of figure 3, the amplifier is comprised of three amplifier stages with four matching sections interposed. Less than a watt input is required for 20 kilowatts output (CW). By pulsing the input RF the output can run pulsed. In this mode of operation, some of the metering is rendered useless.

IV. 1st Stage

The input stage is comprised of π matching section, transforming the input Z of 90 ohms to 2200 ohms. A 4X350 tube is used for initial amplification. Since the tube draws no current, the input tube circuit Z is loaded with a 2200 ohm resistor (R9202). (See Figs. 4, 4A).

The variable inductor had sufficient range to tune from 60 down to 12 megahertz. Thus, no modifications were required.

For 7.5 volt peak-to-peak (PP) voltage in (min. attenuation on input stage) the output was 110 volt peak-to-peak. This corresponds to an input of 5.8 volts as read on the Input Grid power supply meter.

V. 2nd Stage

The input of the second stage is a symmetrical π section matching an input Z of 4700 ohms (R9204). (See Figs. 5, 5A). Again, the stage draws no grid current. Since the network is symmetrical the 4700 ohm resistor forms the output load for the 1st stage.

The original tuning inductor, L205, had been changed to a fixed inductor. For our purposes two coils were made for 50 & 16 MHz operation. A grid dip

meter proved most effective for determining values of inductance. With the voltages turned off, the inductance was set for resonance as indicated on the grid dip meter. Invariably, only slight modifications had to be made when the unit was powered. A peak reading on the "Driver Grid Volts" meter indicated when proper tuning was achieved. It was not necessary to change any of the neutralization circuits included in the 2nd stage.

VI. 2nd Stage Output

Amplification is provided by two 4X350 tubes driven in parallel. The output loading circuit is shown in Figs. 6 and 6A. In normal operation grid current is drawn by the 6166 tubes (3rd stage). From Equation 6 of the Appendix it is seen that the series combination of the 84 and 204 $\mu\mu$ farad capacitors forms an impedance step up of approximately 12.

$$\begin{array}{l} R_{\text{load}} \\ \text{2nd stage} \end{array} = \left(\frac{C_1 + C_2}{C_1} \right)^2 R_{\text{in}} \quad \begin{array}{l} \\ \text{3rd stage} \end{array} = \left(\frac{204 + 84}{84} \right)^2 R_{\text{in}} \cong 12 R_{\text{in}}$$

The equivalent capacitance of the divider is

$$\frac{C_1 C_2}{C_1 + C_2} = \frac{(84)(204)}{84 + 204} \mu\mu\text{f} = 59.5 \mu\mu\text{f}$$

The resultant resonant circuit loading stage 2 is shown in Fig. 6B.

By adjusting L9210 for a peak on the PA Grid Voltmeter, resonance was obtained at the lower frequency (16 MHz). The variable inductor, L9210, was at the end of its tuning range and breakdown was observed between end coil sections. To alleviate this problem, a series inductance was added that allowed the inductor to operate in its mid-range.

VII. Final Stage Amplifier Output

The third and final stage of amplification is comprised of two 6166 beam

power tubes operating in parallel. The output circuitry is shown in Figs. 7 and 7A. Resonance is achieved by adjusting the values of C_{in} and L9215 (see Fig. 7A). Loading of the amplifier is achieved by adjusting the value of C_{out} . From paragraph B of the Appendix, the value of Z_{out} is approximated by

$$Z_{out} = \left(\frac{C_{out}}{C_{in}} \right)^2 50 \Omega$$

For the higher frequency range this is a variable loading range of

$$\begin{aligned} Z_{out \max} &= \left(\frac{425}{85} \right)^2 50 \Omega = 1250 \text{ ohms} \\ Z_{out \min} &= \left(\frac{325}{85} \right)^2 50 \Omega = 730 \text{ ohms} \end{aligned}$$

The operating manual specified a dc plate output current of 4.7 amperes. Assuming Class B operation of the tubes and a plate swing of 5.5 kV (peak) the calculated effective loading would be 734 ohms. The values given for C9232 and C9272 in Fig. 7 were calculated from the physical size of the components. The approximations of component values seemed to cross check.

Tuning was done by varying L9215 and C9232 for maximum output as indicated by the power output meter. As indicated earlier in the paper, the transmitter was tuned down to 16 MHz incrementally, i.e., power output was achieved at three different frequencies between 50 & 16 MHz. Various values of L9215 were tried. Each time the grid dip meter was used to pre-adjust for resonance with power off. Again, this method was most successful. The original inductor was a parallel wire transmission line whose characteristic impedance was

$$z_0 = 120 \cosh^{-1} \left(\frac{s}{d} \right) \quad \text{where } s = 3" = \text{separation of wires}$$

$$z_0 = 183 \text{ ohms} \quad d = 1.25" \text{ diameter of wires}$$

By varying the location of a short on the end of the wires a variable inductor was formed. The initial adjustment when lowering the frequency was to lengthen the line to its maximum length of 12". The next step was to increase the spacing between wires to 7". (A new shorting plane was made up). This increased the characteristic Z to 360 ohms and thus further increased the value of L attainable. Finally a three-turn inductor using 3/8" copper pipe was made up (can be seen in Fig. 2). During the course of tuning it was noted that the plate current was too low. To rectify this problem, C9236 was removed from the load side of the π network to the tube side. This not only brought the loading up ($\frac{C_{out}}{C_{in}}$ $\uparrow$, Z_{out} $\uparrow$) but also helped reduce frequency by increasing C_{in} .

The full output of 20 kW was achieved at 16.6 MHz. Since the output directional coupler was not calibrated at 16 MHz, two cross checks were made by measuring the temperature change and water flow to the resistive load.

Acknowledgment

The work of E. Meier and K. Riker and the members of the Brookhaven Heavy Ion Fusion Group was essential for the realization of a working system.

APPENDIX

A. Capacitance Matching Section

By equating the complex value of admittances, a parallel combination of a resistance R and a capacitor C' is equivalent to a series combination of a resistance r and a capacitor C . The relations being:

$$r = \frac{R}{1 + (R\omega C')^2} \quad C = C' \left[1 + \left(\frac{1}{R\omega C'} \right)^2 \right] \quad (1)$$

If $R \gg \frac{1}{\omega C'}$ then

$$r = \frac{1}{(\omega C')^2 R} \quad C = C' \quad (2)$$

Similarly if a series combination is given and the parallel combination is to be found the formulae are

$$R = r \left[1 + \left(\frac{1}{\omega C r} \right)^2 \right] \quad C' = \frac{C}{1 + (r\omega C)^2} \quad (3)$$

If $r \ll \frac{1}{\omega C}$ then

$$R = \frac{1}{(\omega C)^2 r} \quad C' = C \quad (4)$$

Given the capacitor divider of Fig. A1 and assuming $R_{in} \gg \frac{1}{\omega C'_2}$ an equivalent series r and C can be found using Eq. (2)

$$r_{in} = \frac{1}{(\omega C'_2)^2 R_{in}} \quad C'_2 = C_2 \quad (5)$$

The resultant series RC circuit can be simplified by combining C_1 and C_2 to form C'_{eq} .

By making use of Eq. (4) and the fact that $r_{in} \ll \frac{1}{\omega C'_{eq}}$ a parallel combination of C'_{eq} and R_{eq} may be found

$$R_{eq} = \frac{1}{(\omega C'_{eq})^2 r_{in}} \quad C'_{eq} = C_{eq} = \frac{C_1 C'_2}{C_1 + C'_2}$$

Using Eq. (5)

$$R_{eq} = \frac{(\omega C'_2)^2 R_{in}}{(\omega C'_{eq})^2} = \frac{C_2^2 R_{in}}{C_{eq}^2} = \frac{C_2^2}{\left(\frac{C_1 C_2}{C_1 + C_2}\right)^2} R_{in}$$

$$R_{eq} = \left(\frac{C_1 + C_2}{C_1}\right)^2 R_{in} \quad (6)$$

Thus, it is seen that the capacitance divider acts as a step up transformer.

B. Resonant "π" Matching Sections

Design charts for "π" matching sections exist in the literature.¹ Since exact solutions were not required for the transmitter, approximation on the effective impedance transformations were found.

Given the π network of Fig. A2 the parallel combination of C2 and R_{out} can be transformed to an equivalent series combination of r and C assuming R_{out} > $\frac{1}{\omega C_2}$ (see Eq. (2)). Then

$$r = \frac{1}{(\omega C_2)^2 R_{out}} ; C_2 = \text{constant}$$

For resonance to exist, a value of effective L can be substituted for the series combination of L and C2 whose value is found as:

$$X_{C1} = X_{LeQ} = \frac{1}{\omega C_1} = \omega LeQ$$

Using the same technique as used in Section A appendix, an equivalent parallel inductance and resistance can be found for a series inductance and

resistance. With the further assumption that $r_{\text{series}} \ll \omega L_{\text{series}}$ then the circuit of Fig. A2c can be formed from Fig. A2b where

$$R_{eQ} = \frac{(\omega L_{eQ})^2}{r} \quad ; \quad L_{eQ} = \text{constant}$$

For resonance $\omega L_{eQ} = \frac{1}{\omega C_1}$

$$\therefore R_{eQ} = \frac{(1/\omega C_1)^2}{1/[(\omega C_2)^2 R_{\text{out}}]} = \left(\frac{C_2}{C_1}\right)^2 R_{\text{out}}$$

For a high Q circuit it is thus seen that the π section shown acts as a step up transformer.

¹ Terman, Frederick E., Radio Engineers' Handbook, pp. 210-215, McGraw-Hill Book Company, Inc., New York, 1943.

Fig. 1. 20^{kw} Collins Transmitter

Fig. 2. RF Amplifier Cubicle

INPUT MATCHING SECTION
FIG. 4

EQUIV. CIRCUIT OF INPUT π MATCHING SECTION
FIG. 4A

2ND STAGE INPUT MATCHING SECTION

FIG. 5

2ND STAGE EQUIV. CIRCUIT OF SYMETRICAL π MATCHING SECTION

FIG. 5A

2ND STAGE OUTPUT CIRCUITRY
FIG. 6

SIMPLIFIED CIRCUIT OF 2ND STAGE OUTPUT
FIG. 6A.

EFFECTIVE LOADING ON 2ND STAGE

FIG. 6B

FINAL STAGE OUTPUT CIRCUITRY

FIG. 7

SIMPLIFIED CIRCUIT DIAGRAM OF FINAL STAGE

FIG. 7A

CAPACITIVE
DIVIDER

FIG. A1

SERIES
EQUIV.

FIG. A1a

COMBINED

FIG. A1b

RESULTANT

FIG. A1c

Π MATCHING SECTION
FIG. A2

USING SERIES EQUIV.
FIG. A2a

FORMING EQUIV. L
FIG. A2b

RESULTANT
FIG. A2c

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the U.S. nor the U.S. Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

PRINTED IN THE UNITED STATES OF AMERICA
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Domestic \$ 4.00

Microfiche \$ 3.00

Printed: 4/78

740 Copies