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NRL REPORT NO. R-3305

DEVELOPMENT OF ELECTRON TUBE FOR SWITCHING RADIO FREQUENCY POWER

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W. H. Flarity

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June 23, 1948

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ABSTRACT

A new type of gas triode has been developed to switch power from a single 1000-megacycle oscillator between two loads in less than a microsecond. The volume of the grid-anode region inside the tube is kept small so that r-f power up to about 8 kilowatts will not initiate a gas discharge in the tube. When a negative voltage of more than about 15 volts is applied to the cathode, the breakdown of the gas reduces the grid-anode impedance to a very low value. Since the recovery time is about 8 microseconds, two tubes, each in a tuned circuit, are used in the switching arrangement.

PROBLEM STATUS

This report concludes the developmental stage of this phase of the problem. Manufacture of the tube is not planned at this time. Work on other phases of the problem is continuing.

AUTHORIZATION

NRL Problem No. R03-06 (BuShips Problem S1234X-S).

DEVELOPMENT OF AN ELECTRON TUBE FOR SWITCHING RADIO FREQUENCY POWER

INTRODUCTION

The present study deals with the problem of switching the radio-frequency power from a single transmitter between two loads in less than a microsecond. The immediate application was to permit the use of only one transmitter to feed the two antennas used in a method of increasing the directivity of a pulse signaling system.

A similar problem of switching r-f power from one path to another occurs in radars which use a single antenna for both transmission and reception. The most common solution in this case is the use of a gaseous discharge tube (at "a" in Figure 1) to detune a resonant cavity placed so as to decouple Load 2 (the receiver) and allow the energy from Source 1 (the transmitter) to pass to Load 1 (the antenna), the tube being fired by the incident high voltage. In the second state of operation, power at a much lower level from Source 2 (the receiving antenna) will pass the tube "a" and be absorbed by Load 2 (the receiver). Because the power level in the second state is many orders of magnitude smaller than the power in the first state, it is possible to employ as a switch a diode which breaks down only at a high power level.

In the present problem where a single source is to be switched into either one of two loads (Figure 2) the two conditions of operation cannot of course be distinguished on the basis of power level. It is therefore necessary to control the gaseous discharge by some other method. This leads to the use of a tube with an additional electrode to control this discharge. If the level of power to be switched is high, means must be found for preventing

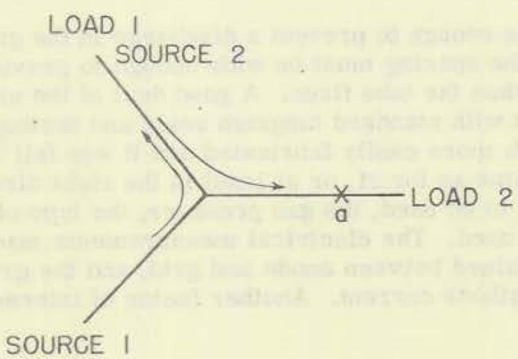

Fig. 1 - Schematic diagram of r-f paths in radar case

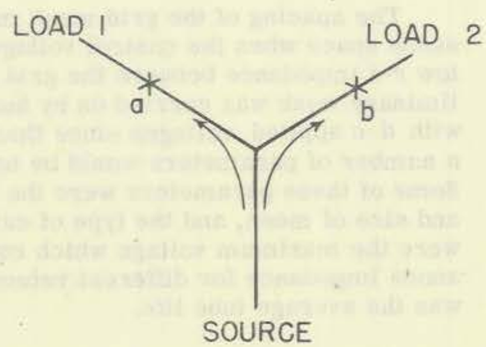

Fig. 2 - Schematic diagram of r-f paths in present case

the high r-f power from firing the tube independently of the control voltage. This requirement is similar to that found in the design of thyratrons for high power modulation and can be met by using the principles of construction of the hydrogen thyratron.

Normally, two tubes are used in a switch to transfer power from one level to another (Figure 2). If the recovery time of a gas discharge could be made sufficiently short it might be possible to build a symmetrical switch in which power entered Load 1 when "b" was fired and entered Load 2 when "a" was fired. However, since it is required in this project to switch power from one load to the other in a matter of microseconds, a recovery time of about one microsecond would be required and this is difficult to obtain. Consequently a switching circuit must be used in which both gas tubes are unfired for the first state of operation (power into Load 1), and both tubes are fired for the second. By this means the switching time is limited only by the time required for the tubes to ionize appreciably. This time can be made considerably shorter than a microsecond.

PRINCIPLES OF CONSTRUCTION OF THE TUBE

A suitable tube has been experimentally developed. It consists essentially of a triode with the space inside the tube between grid and anode, which is exposed to the r-f field, reduced to a minimum; it is filled with a rare gas at low pressure. As shown in Figure 3 the tube consists essentially of a Kovar disc, D, on which the grid structure, G, is mounted; a pin anode, A, sealed through a glass bead, B, and protruding through a hole in the disc nearly to the grid mesh; and an oxide coated cathode, C, mounted just below the grid mesh. The distance between the end of the anode pin and the grid mesh is approximately 1/32 of an inch. The gas used is argon at 150 microns pressure. The grid mesh is made of nickel screen having 40 wires to the inch in each direction. Unless the cathode is made negative by more than about 15 volts with respect to the grid, it is found that the grid-anode space will not break down under high voltage r-f pulses. When a higher negative voltage is applied to the cathode the cathode-grid space breaks down. When a positive or r-f voltage is also present at the anode, the discharge transfers to the grid-anode region and in effect reduces its impedance to a very low value.

It became evident early in the development that the gas volume exposed to the r-f field must be as small as possible to prevent spontaneous discharge if this tube were to be used at the higher levels of power. So the Kover-to-glass type of seal was investigated and a design evolved which so far has proved fairly satisfactory. The gas pressure is low to increase the voltage breakdown by operating on the low branch of the Paschen Law curve.

The spacing of the grid mesh must be close enough to prevent a discharge in the grid-anode space when the control voltage is zero; the spacing must be wide enough to provide a low r-f impedance between the grid and plate when the tube fires. A good deal of the preliminary work was carried on by building tubes with standard tungsten seals and testing them with d-c applied voltages since these are much more easily fabricated and it was felt that a number of parameters would be nearly the same as for rf, or at least in the right direction. Some of these parameters were the type of gas to be used, the gas pressure, the type of grid and size of mesh, and the type of cathode to be used. The electrical measurements made were the maximum voltage which could be sustained between anode and grid, and the grid-anode impedance for different values of grid-cathode current. Another factor of interest was the average tube life.

Argon was the rare gas finally selected as it showed the least decrease in gas pressure due to cleanup. Tubes made with oxide-coated cathodes and filled with argon and tested at 50 milliamperes dc of plate current have lasted more than 1,000 hours before the voltage required for breakdown became excessive. Under r-f pulse conditions, however, sputtering of either anode or cathode material to the glass bead has thus far limited the life of these tubes to a matter of hours.

The first tubes made had thorium oxide coated filaments but these tubes would only give about 100 hours of life under dc conditions. They failed due to gas cleanup, presumably caused by the high temperatures at which the filaments were operated.

Another interesting method of control was discovered during this experimental work. It was found that a dc discharge when present between anode and grid could be stopped by applying two or three hundred volts positive to the cathode. Voltages up to 7 KV applied to the anode through a dropping resistor have been controlled in this way, and have been used to increase the power level of 1 microsecond pulses.

CIRCUIT DETAILS

The circuit for this switch was developed at 1000 Mc/s. The r-f plumbing in which this tube has been used is shown in Figure 4. It consists of two tuned cavities arranged to direct r-f power into line 2. When the cavities are shorted out, as when the tubes are fired, the r-f power is directed into line 3. Following the diagram, cavity "a" when at resonance throws a short on the transmission line at point C, since it acts like a quarter-wave open-ended stub. Cavity "b" is a straight-through transmission cavity which at resonance transmits energy from the transmission line directly to line 2. Figure 5 shows the path of rf when the tubes are unfired. Figure 6 shows the r-f path when the tubes are fired. Switching is accomplished by applying control pulses on the grids of the two tubes in the correct phase relation to the rf passing through the switch.

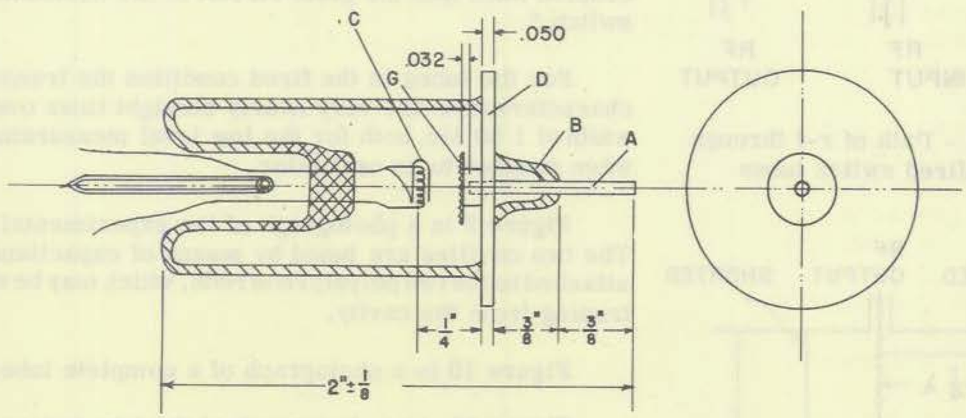

Fig. 3 - Outline drawing of gas switch tube

EXPERIMENTAL MEASUREMENTS

Some of the measurements made on this switch to evaluate its performance are: Bandwidth for each transmission line, switching ratio of power passed to power not passed for each line, insertion loss for each line, and minimum tube recovery time to be ready for the succeeding switching cycle.

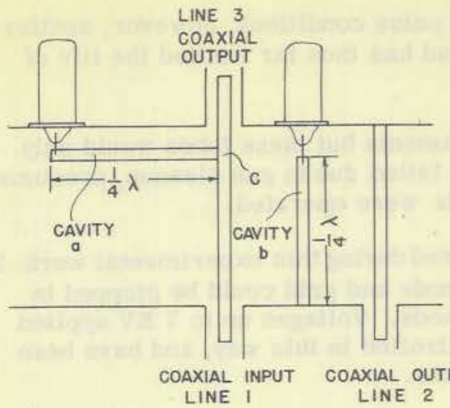

Fig. 4 - Diagram of r-f plumbing

The bandwidth for transmission into line 2, in the unfired condition, is 50 Mc. The bandwidth for transmission into line 3, in the fired condition, is controlled by cavity "b" which now acts like a quarter-wave stub on the line and is greater than 100 Mc.

For the unfired condition line 3 has an attenuation factor of 30 db at a bandwidth of 30 Mc. For the fired condition transmission line 1 has an attenuation factor of 35 db at center frequency and varies as the standard Q curve for a frequency twice the center frequency because it has become a shorted half-wave at this double frequency.

The recovery time of the switch is 8 microseconds.

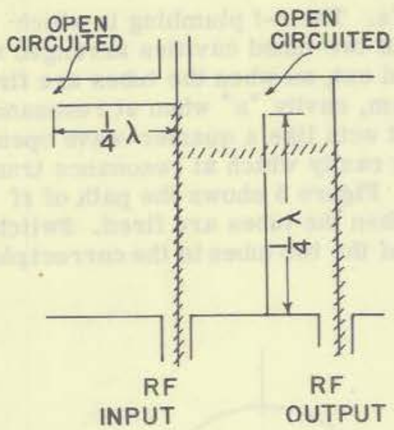

Fig. 5 - Path of r-f through unfired switch tubes

Figure 7 shows the transmission characteristics of the cavity with the tubes inserted. These measurements were made at low level using a signal generator and a matched crystal detector. The insertion loss of the switch for line 1 is about 0 6 db and for line 2 is 0 5 db.

Figure 8 gives the transmission characteristics for the switch when it is coupled to a pulsed oscillator with an output of approximately 500 watts peak. The frequency discontinuities of the oscillator when tuned to either side of the resonance frequency of the switch, was due to the reactance coupled back into the plate circuit of the oscillator from the switch.*

For the tubes in the fired condition the transmission characteristics are very nearly straight lines over a bandwidth of ± 50 Mc, both for the low level measurements and when coupled to an oscillator.

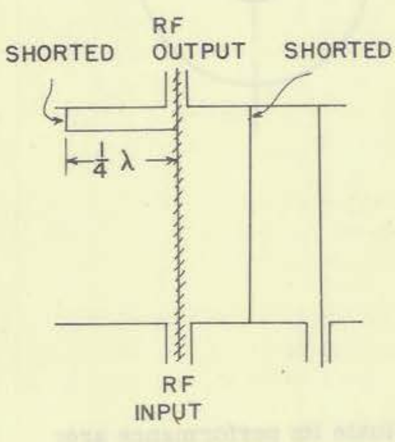

Fig. 6 - Path of r-f through fired switch tubes

Figure 9 is a photograph of the experimental switch. The two cavities are tuned by means of capacitance slugs attached to the two polystyrene rods, which may be seen protruding from the cavity.

Figure 10 is a photograph of a complete tube.

Figure 11 is a photograph of the tube before sealing in the cathode assembly, showing the grid-anode structure in greater detail.

Using two tubes in the special circuit mentioned above, r-f peak powers up to 8 kilowatts at 1,000 Mc/s have been switched successfully; however, at a higher power level,

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* Jack R. Ford and N. I. Korman, Proc. Inst. Radio Engr. 34; pp. 794-799 (1946)

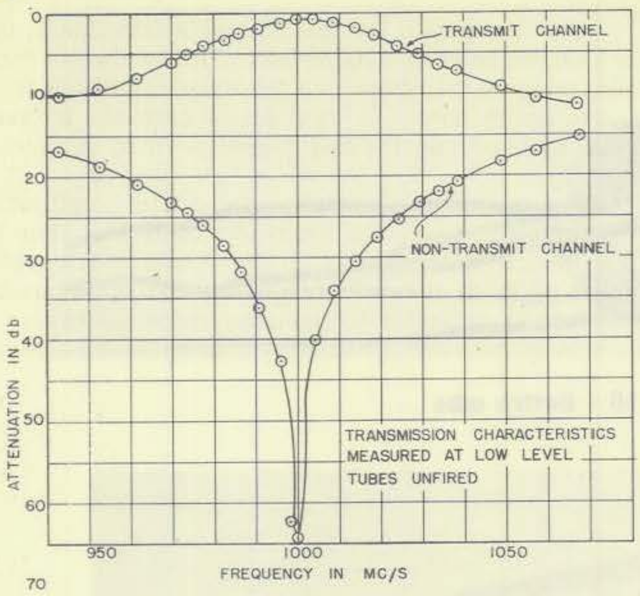

Fig. 7 - Transmission characteristics measured at low level tubes unfired

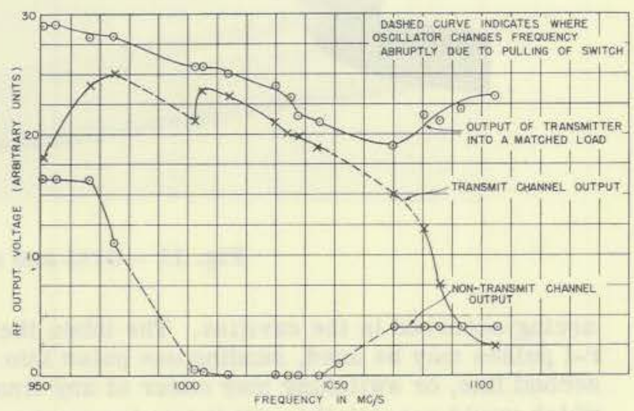

Fig. 8 - Transmission characteristics of switch when coupled to a transmitter oscillator.

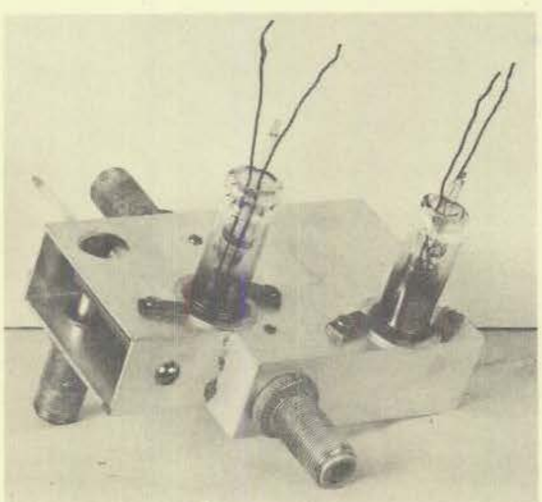

Fig. 9 - Complete r-f switch for 1000 Mc

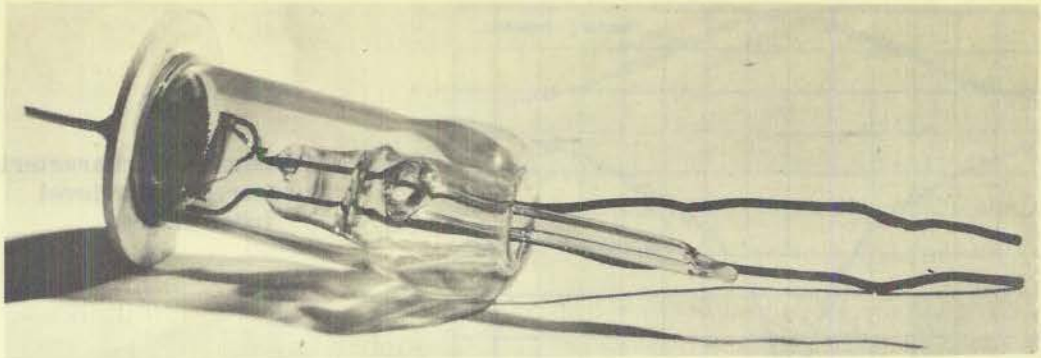

Fig. 10 - Switch tube

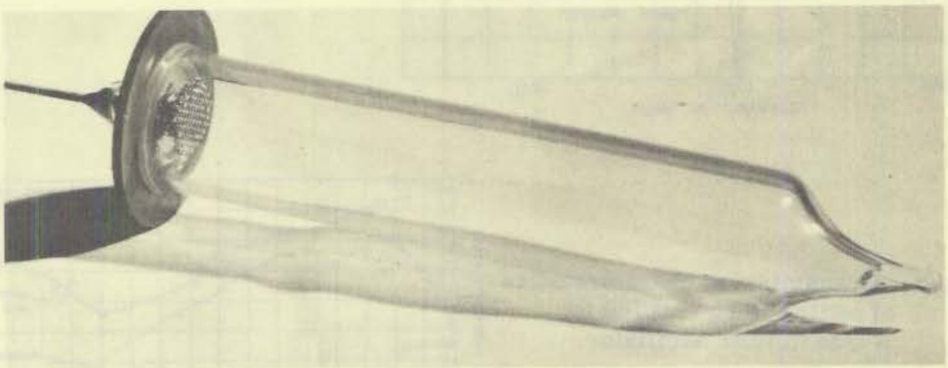

Fig. 11 - Grid and anode assembly

arcing occurred in the cavities. The tubes themselves did not fail due to arcing. Two r-f pulses may be used, sending one pulse into one line and switching the other into the second line, or switching may occur at any time during the passage of a single r-f pulse which would essentially split it into two parts.

* * *

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