May 29, 1956 R. B. NELSON ET AL 2,748,280

MAGNETRON AMPLIFIER

Filed July 25, 1952

Fig. 1.

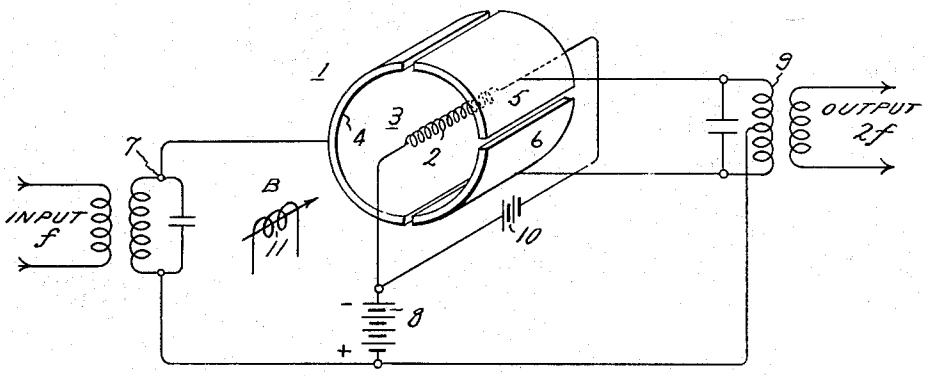


Fig. 2.

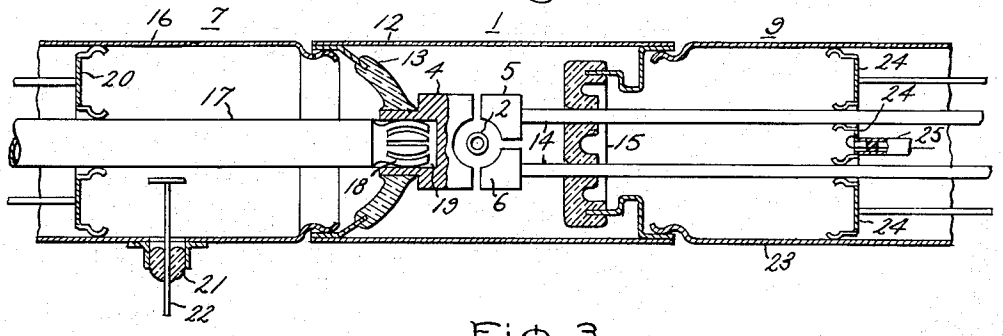
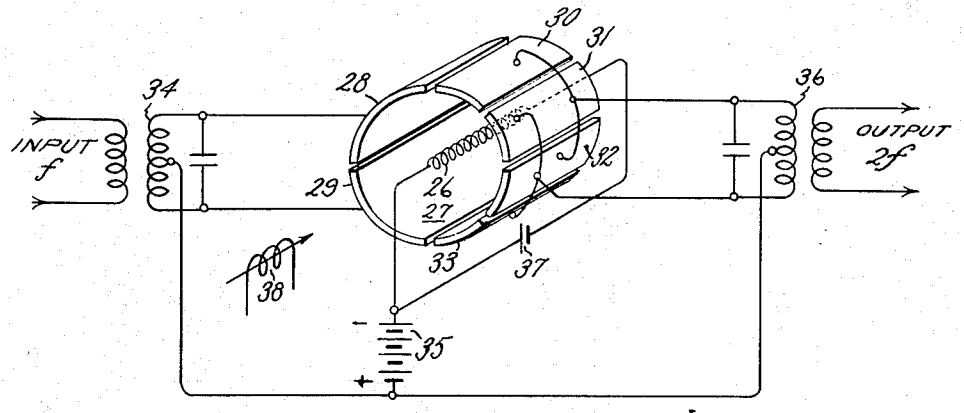


Fig. 3.



Inventors:
Richard B. Nelson,
Donald A. Wilbur,
by Paul A. Frank
Their Attorney.

United States Patent Office 2,748,280 Patented May 29, 1956

2,748,280

MAGNETRON AMPLIFIER

Richard B. Nelson, Mountain View, Calif., and Donald A. Wilbur, Albany, N. Y., assignors to General Electric Company, a corporation of New York

Application July 25, 1952, Serial No. 300,928

8 Claims. (Cl. 250—36)

This invention relates to frequency multiplying amplifiers and has particular reference to magnetron apparatus.

Discharge devices of the magnetron type have been extensively and successively employed as high frequency generators. Their ability to produce large amounts of power at relatively high efficiencies suggests their particular desirability as amplifying devices, and various attempts have been made to so utilize the magnetron type of discharge device in high frequency amplifying circuits. Accordingly, in traveling wave multivane magnetrons of the type having an anode assembly comprising a plurality of anode vanes or segments arranged in a circular array about a central cathode, input signals to be amplified have been applied to selected segments, and a power output circuit has been coupled to the other segments. In order to prevent loading of the input signal source, it is desirable in such magnetron amplifiers that input and output circuit coupling due to the geometry of the magnetron device discharge be minimized while still retaining the magnetron characteristics useful in amplifier arrangements.

Accordingly, a primary object of this invention is to provide a discharge device of the magnetron type for amplifying high frequency electromagnetic signals.

It is a further object of this invention to provide an improved magnetron amplifier in which loading of the input cricuit is minimized.

It is a still further object of this invention to provide a magnetron amplifier which also multiplies a frequency to be amplified.

In accordance with an exemplary embodiment of the invention described herein, a magnetron discharge device of the type having a plurality of spaced anode segments surrounding a centrally disposed cathode to define a cylindrical space charge chamber coaxial with the cathode has an input section comprising at least one anode vane or segment to which an input circuit for supplying input signals of a given frequency is coupled and an output section comprising a plurality of vanes or segments to which is coupled an output circuit for producing amplified signals at a desired integral harmonic or multiple of the input frequency. Each segment of the input section subtends an angle with respect to the cathode which is equal to the product of the desired multiple times the angle subtended by each of the segments of the output section. A radially directed static electric field and an axially directed static magnetic field are established in the space charge chamber to impart an average angular space charge velocity about the cathode slightly below the synchronous velocity required to maintain oscillation in the tuned circuits. This space charge is modulated by the applied input signal on the input section, in which the signal tends to drive the useful portion of the space charge at a higher than synchronous velocity. Energy is thus imparted to the space charge for maintaining excitation of the output section through interaction with the alternating electric field between the anode segment gaps. Since the circuit coupled to the input segments is not tuned to the output frequency, any voltages induced in the input circuit due to back-

modulation of the space charge by the output circuit are very small, thus minimizing back coupling. At the same time, the input signal has been both amplified in accordance with the amplitude modulation of the input signal and multiplied in frequency.

The features of the invention which are believed to be novel are described with particularity in the appended claims. The invention itself, however, both as to its method of operation together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 is a semi-schematic representation of a magnetron discharge device together with circuit connections in accordance with our invention; Fig. 2 is a sectional side view of the magnetron apparatus corresponding to Fig. 1; and Fig. 3 is a modification of the arrangement of Fig. 1.

Referring now to Fig. 1, a frequency doubling amplifier embodying our invention is illustrated. The magnetron 1 is typical of the multi-segment type of discharge device conventionally employed as a high frequency oscillator in so far as a plurality of spaced anode vanes or segments are arranged about an elongated cathode 2 to define between their inner surfaces a cylindrical space charge chamber 3 coaxial with the cathode. The input section of the anode assembly is a segment 4 having an inner surface subtsantially semi-cylindrical in form so as to subtend almost 180° of arc with respect to the space charge chamber axis. The output section is a pair of adjacent anode segments 5 and 6 which each subtend almost 90° of arc, the three segments being spaced from each other to provide small interaction gaps between them. An input circuit 7, schematically represented by a lumped capacitance and inductance circuit tuned to the frequency of the input signal f is connected between the input anode 4 and the cathode 2 through a direct voltage source such as a battery 8. The output segments 5 and 6 are connected to an output circuit 9 similarly schematically represented as in put circuit 7 and tuned to the doubled output frequency $2f$. The output and input circuits are respectively coupled to a suitable signal source and a load. Since the frequencies profitably employed in magnetron operation are in the very high or ultra-high frequency ranges, various tuned circuit structures employing distributed reactance may be utilized.

A high frequency neutral point of the output circuit 9, shown schematically as a center tap on its inductance element, is also connected to the cathode through the battery 8, thus establishing a uniform static radial electric field between the cathode and the anode assembly. To provide electrons for the magnetron space charge, the cathode is suitably connected to a source of heater current 10. When an axial static magnetic field, shown as established by a solenoid 11, is directed through the space charge chamber, the resulting space charge is given a generally rotating motion about the cathode. For purposes of illustration, a clockwise rotation is assumed. The synchronous angular velocity of the space charge is the same for either the input or output section, despite their different operating frequencies, since their respective anode segments are of appropriately different circumferential length. This velocity, which for a π mode traveling wave magnetron is $2\pi f$ where f is the input frequency, corresponds to that of a two-vane magnetron for the input section and of a four-vane magnetron for the output section.

When the voltage of the source 8 is raised to a value just less than that required for oscillation of either the input or output circuit, which value may be considered as the oscillation threshold, the velocity of the space charge is just less than that required for transfer of energy from the direct current source 8 to the high frequency sections. The driven input segment 4 becomes alternately

positive and negative at frequency f, thus increasing the velocity of the space charged during positive half cycles. This accelerated portion of the space charge then passes interaction gaps between the segments in phase with the fringing fields established by initial excitation of the output circuit at frequency $2f$, giving up energy and so assuming a greater diameter to define a space charge "spoke." The initial excitation may be assumed to be noise or random excitation in accordance with the prevailing concepts of conventional magnetron operation. Since the term "spoke" offers a simplified descriptive analysis of the magnetron amplifier operation and since such a configuration of space charge is believed to conform with the actual effect of the various interacting fields upon the magnetron space charge, use of this term is continued in the explanation.

While the input section at frequency f produces and drives only one spoke for each 360° rotation of the space charge, the output section at frequency $2f$ operates, because of its geometry, with two spokes for each rotation. The single driven spoke, accordingly, delivers pulses of energy to the output system at a rate equal to half the output frequency, which is sufficient to maintain excitation of the output circuit since the spoke is relatively narrow and not of a full half wave duration. The spoke may be considered, therefore, as having a high second harmonic content. The induced electric field at frequency $2f$ in the output system tends to react upon the space charge and modulate it at double frequency so as to increase the size of the driven spoke and to provide an an additional space charge spoke 180° displaced from the driven spoke. However, the current tending to be induced at the doubled frequency in the input circuit is cancelled out since the input circuit is tuned and operated at the fundamental frequency. The frequency doubling arrangement of the amplifier thus effectively isolates the input circuit.

Referring now to Fig. 2, magnetron apparatus corresponding to the arrangement schematically shown in Fig. 1 is illustrated. Here the magnetron **1** has a cylindrical metallic envelope **12** made of a non-magnetic material. Within the envelope are the cathode **2**, shown in end view, the input anode sgement **4** and the output segments **5** and **6**. Input segment **4** is a conducting block sealed around its periphery to a glass sealing ring **13** which is in turn sealed to one end of the envelope cylinder **12**. The output anode segments **5** and **6** are respectively connected to each of a pair of parallel conductors **14**. The conductors **14** are separately sealed through a glass sealing disk **15** at the other end of the envelope cylinder **12**.

The input circuit **7** is a tuned concentric conductor section having an outer conductor **16** of approximately the same diameter as the envelope **12** and conductively engaging the envelope at the end to which the input anode segment **4** is sealed. The inner tubular conductor **17** of the input circuit **7** suitably engages the exposed portion of the anode segment **4** as shown in the drawing. Spring fingers **18** at the end of the inner tubular conductor are biased due to their resiliency against the sides of a cylindrical bore **19** in the end of the anode segment **4** within which the inner conductor end is positioned. An annular short-circuiting plunger **20** is actually positioned along the length of the concentric conductor arrangement between the inner end and outer conductors to determine the transmission line section length and thus tune it to the desired input frequency. A concentric transmission line from the source of input signals is suitably coupled to the input circuit **7**. As shown in the drawing, the outer conductor of the input coupling transmission line **21** is connected to the outer conductor **16** of the tuned input section and the inner conductor **22** extends through an aperture in conductor **16** to be capacitively coupled to the inner conductor **17** of the tuned input section.

At the output end of the device **1**, the parallel conductors **14** are extended as external conductors to provide a tuned parallel conductor transmission line section therewith, this tuned section corresponding to the output tuned circuit **9** of Fig. 1. A cylindrical outer conductor **23**, of approximately the same diameter as the envelope cylinder **12**, is conductively coupled at one end to the output end of the envelope cylinder. A short-circuiting plunger **24** provides a short-circuiting termination between the parallel conductors, the axial position of the tuning plunger determining the tuning of the output circuit. The high frequency neutral point of the output circuit **9** is simultaneously coupled through the remaining portion of the plunger **24** to the series-connected outer cylinders **23**, **12**, and **16**. An output coupling means for coupling power from the output circuit to a desired load suitably takes the form of a concentric conductor transmission line **25** having its outer conductor connected to the slider **24** and its inner conductor extending therethrough to define an inductive loop.

As may be seen, the mechanical arrangement simplifies application of the anode voltage since the voltage supply need merely be connected between the cathode **2** and the envelope **12** of the magnetron. Since the outer cylinders **16** and **23** of the input and output circuit arrangements respectively are in conductive relation with the envelope **12**, both the input anode **4** and the output anodes **5** and **6** are maintained at the desired positive potential. The arrangement shown is both compact and relatively simple to maintain and adjust while providing for efficient operation as an amplifier. For example, a device of the nature described has been operated with a power gain of 100 at doubled frequency and with reasonable efficiency. Of course, it is obvious that other mechanical arrangements can be substituted since the principles of our invention are applicable to traveling wave magnetron amplifiers generally.

Referring now to Fig. 3, another magnetron arrangement embodying the invention is schematically shown in which the input circuit is balanced with respect to the cathode so that it need not be coupled thereto. This arrangement corresponds closely to that of Fig. 1 in so far as it is arranged for a frequency multiplying ratio of 2. Here again an electron emitting cathode **26** extends along a given axis with a plurality of anode segments surrounding the cathode to define between their inner surfaces a space charge cylinder **27** coaxial with the cathode. Two adjacent anode segments **28** and **29** define the input section and the remaining four segments **30**, **31**, **32**, and **33** define the output section. Since the amplifier is arranged as a doubler each of the input segments subtends twice the arc or angle with respect to the chamber axis as does each of the output segments. Hence with a total of 6 segments here involved the input segments each subtend substantially 90° of arc and the output segments each subtend substantially 45° of arc.

The input circuit **34**, schematically indicated, is tuned to the desired input frequency and its high frequency neutral point is connected to the cathode **26** through the anode voltage supply source **35**. The terminals of the input circuit are respectively coupled to the input electrodes **28** and **29** so that the input voltage appears between them. Output circuit **36**, also schematically represented, is tuned to twice the input frequency and its high frequency neutral point is also connected to the cathode through the anode voltage source **35**. The four output segments **30**, **31**, **32**, and **33** are connected for π mode operation, one of the output circuit terminals being connected to segments **30** and **32** and the other being connected to segments **31** and **33**. The cathode is suitably heated by a heating current source **37** and a magnetic field, schematically represented as provided by a solenoid **38**, is axially directed in the space charge chamber **27**.

As in the operation of the amplifier of Fig. 1, the anode voltage **35** is increased to a value just less than that required for oscillation. The application of an input signal across the input anode section causes excitation of the

output circuit at the doubled frequency. With the arrangement shown in Fig. 3, the synchronous speed of the electron space charge corresponds to that of a four-vane magnetron for the input system and to that of an eight-vane magnetron for the output system, assuming the usual π mode of operation. Accordingly, the input excitation will produce and drive two diametrically opposed space charge spokes. These will excite the output circuit even though they correspond to only half the usual number of spokes for an eight-vane magnetron since they are relatively narrow and hence do not cancel the double frequency excitation produced. The output anode section also produces two additional spokes, each displaced 90° from the driving spokes, but this back-modulation of the space charge does not load the input circuit **34**, since the input circuit is tuned to only one-half of the output frequency. Accordingly, back-excitation or reaction of the input section by a modulating space charge having four spokes per complete rotation is relatively small since the voltages produced by pairs of adjacent spokes tend to cancel out similarly as described in relation to the operation of the circuit of Fig. 1.

An analysis indicates that some reaction of the electron stream upon the input system is obtained. However, this reaction does not result in positive or resistive loading of the input circuit, but instead, results in excitation at the input frequency. The general effect therefore is to increase the effective input impedance of the input circuit. Since this is generally desirable and quite the opposite of the undesired effect obtained upon direct resistive loading, the impedance matching to the source of the input signals may be accordingly predetermined and is facilitated in many cases.

It will be understood that the invention is not limited to frequency doubling and that for use of higher multiplying ratios, the ratio of the arc subtended by each of the driving segments to each of the driven segments is accordingly increased.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that modifications may be employed without in any way departing from the spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A frequency multiplying amplifier comprising an electron discharge device of the magnetron type having an elongated electron emitting cathode and a plurality of spaced anode segments surrounding said cathode with their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith; an input circuit tuned to a given frequency coupled to an input anode section comprising at least one of said segments, an output circuit substantially independent of said input circuit tuned to an integral multiple of said frequency and coupled to an output anode section comprising other segments of said plurality of said segments, said at least one segment of said input section subtending an angle with said axis substantially equal to the product of said multiple times the angle subtended by each of the segments of said output section, and means for establishing an axially directed magnetic field and a radially electric field within said space charge chamber, said means being adjusted to maintain the amplifier slightly below the oscillation threshold.

2. A frequency multiplying amplifier comprising an electron discharge device of the magnetron type having an elongated cathode for supplying an electron space charge and a plurality of spaced anode segments surrounding said cathode and having their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith; an input circuit tuned to a given frequency coupled to an input anode section comprising at least one of said segments, an output circuit substantially independent of said input circuit tuned to an integral multiple of said frequency and coupled to an output anode section comprising other segments of said plurality of said segments, said at least one segment of said input section substending an angle with said axis substantially equal to the product of said multiple times the angle subtended by each of the segments of said output section, means for establishing an axially directed magnetic field within said chamber and means for applying a positive voltage to said anode segments with respect to said cathode whereby an average angular space charge velocity about the cathode is provided, said voltage being adjusted in intensity relative to said magnetic field to a value slightly below that required for maintenance of oscillations in either of said circuits, and means for coupling said input circuit to a signal source.

3. A frequency doubling amplifier comprising an electron discharge device of the magnetron type having an elongated electron emitting cathode, and a plurality of spaced anode segments surrounding said cathode and having their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith; an input circuit tuned to a given frequency coupled to an input anode section comprising at least one of said segments, an output circuit substantially independent of said input circuit tuned to a frequency and twice that of said given frequency coupled to an output anode section comprising other segments of said plurality of said segments, said at least one segment of said input section subtending an angle with said axis substantially twice the angle subtended by each of the segments of said output section, means for establishing an axially directed static magnetic field and a radially directed static electric field within said chamber, said fields being adjusted in relative intensity to a value slightly below that at which either of said circuits will oscillate, and means for coupling said input circuit to a signal source.

4. A frequency doubling amplifier comprising an electron discharge device of the magnetron type having an elongated electron emitting cathode, and a plurality of spaced anode segments surrounding said cathode and having their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith; an input circuit tuned to a given frequency coupled to an input anode section having a given number of said segments, an output circuit substantially independent of said input circuit tuned to a frequency twice that of said given frequency and coupled to an output anode section having a number of other segments of said plurality of said segments twice said given number, each segment of said input section subtending an angle with said axis substantially equal to twice the angle subtended by each of the segments of said output section, means for establishing an axially directed magnetic field within said chamber, means for applying a radially directed static electric field between said cathode and said anode segments, said electric field being adjusted in intensity relative to said magnetic field to a value slightly below that at which the amplifier oscillates, means for coupling said input circuit to a source of signals of the given frequency to be doubled, and means for coupling said output circuit to a load.

5. A frequency multiplier amplifier comprising a discharge device of the magnetron type containing an elongated electron emitting cathode and a plurality of spaced anode segments surrounding said cathode with their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith, an input circuit tuned to a given frequency coupled between one of said segments and said cathode, an output circuit substantially independent of said input circuit tuned to an integral multiple of said frequency and coupled to the other segments, said one segment subtending an angle with the axis substantially equal to the product of said multiple times the angle subtended by each of the other segments, means for establishing a radially directed electric field and an axially directed magnetic field within said space charge chamber,

said means being adjusted to maintain the amplifier slightly below the threshold of oscillation, and means for coupling said input circuit to a source of signals.

6. A frequency doubling amplifier comprising a discharge device of the magnetron type containing an elongated electron emitting cathode and three spaced anode segments surrounding said cathode with their inner surfaces defining a cylindrical space charge chamber coaxial therewith, an input circuit tuned to a given frequency coupled between one of said segments and said cathode, an output circuit substantially independent of said input circuit tuned to a frequency twice that of said given frequency and coupled to the other two segments, said one segment subtending substantially 180° of arc, each of the other segments subtending substantially 90° of arc, means establishing a radially directed electric field and an axially directed magnetic field within said space charge chamber for imparting a rotating space charge motion about the cathode, said means being adjusted to maintain the amplifier slightly below the threshold of oscillation, and means for coupling a source of signals to be amplified to said input circuit.

7. A frequency multiplying amplifier comprising a discharge device of the magnetron type containing an elongated electron emitting cathode and a plurality of spaced anode segments surrounding said cathode with their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith, an input circuit tuned to a given frequency coupled to two of said segments, an output circuit substantially independent of said input circuit tuned to a multiple of said input frequencies and coupled to other segments of said plurality of segments, each of said two segments subtending an angle with said axis substantially equal to the product of said multiple times the angle subtended by each of the other segments, means for establishing a radially directed electric field and an axially directed magnetic field within said space charge chamber, said means being adjusted to maintain the amplifier slightly below the threshold of oscillation, and means for coupling said input circuit to a source of signals to be amplified.

8. A frequency doubling amplifier comprising a discharge device of the magnetron type containing an elongated electron emitting cathode and a plurality of spaced anode segments surrounding said cathode with their inner surfaces defining a unitary cylindrical space charge chamber coaxial therewith, an input circuit tuned to a given frequency coupled between two of said plurality of said segments, an output circuit tuned to twice said input frequency coupled to four other segments of said plurality of segments, each of said two segments subtending an angle with said axis substantially equal to twice the angle subtended by each of said four segments, means for establishing a radially directed electric field and an axially directed magnetic field within said space charge chamber, said means being adjusted to maintain the amplifier slightly below the threshold of oscillation, and means for coupling said input circuit to a source of signals to be amplified.

References Cited in the file of this patent

UNITED STATES PATENTS

2,162,807	Fritz	June 20, 1939
2,166,210	Fritz	July 18, 1939
2,168,295	De Vries et al.	Aug. 1, 1939
2,168,296	De Vries et al.	Aug. 1, 1939
2,198,334	Fritz	Apr. 23, 1940