

Feb. 10, 1970

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 QUARTER-WAVE TRANSMISSION LINE RADIO FREQUENCY  
 VOLTAGE STEP-UP TRANSFORMER  
 Filed March 5, 1968

3,495,125

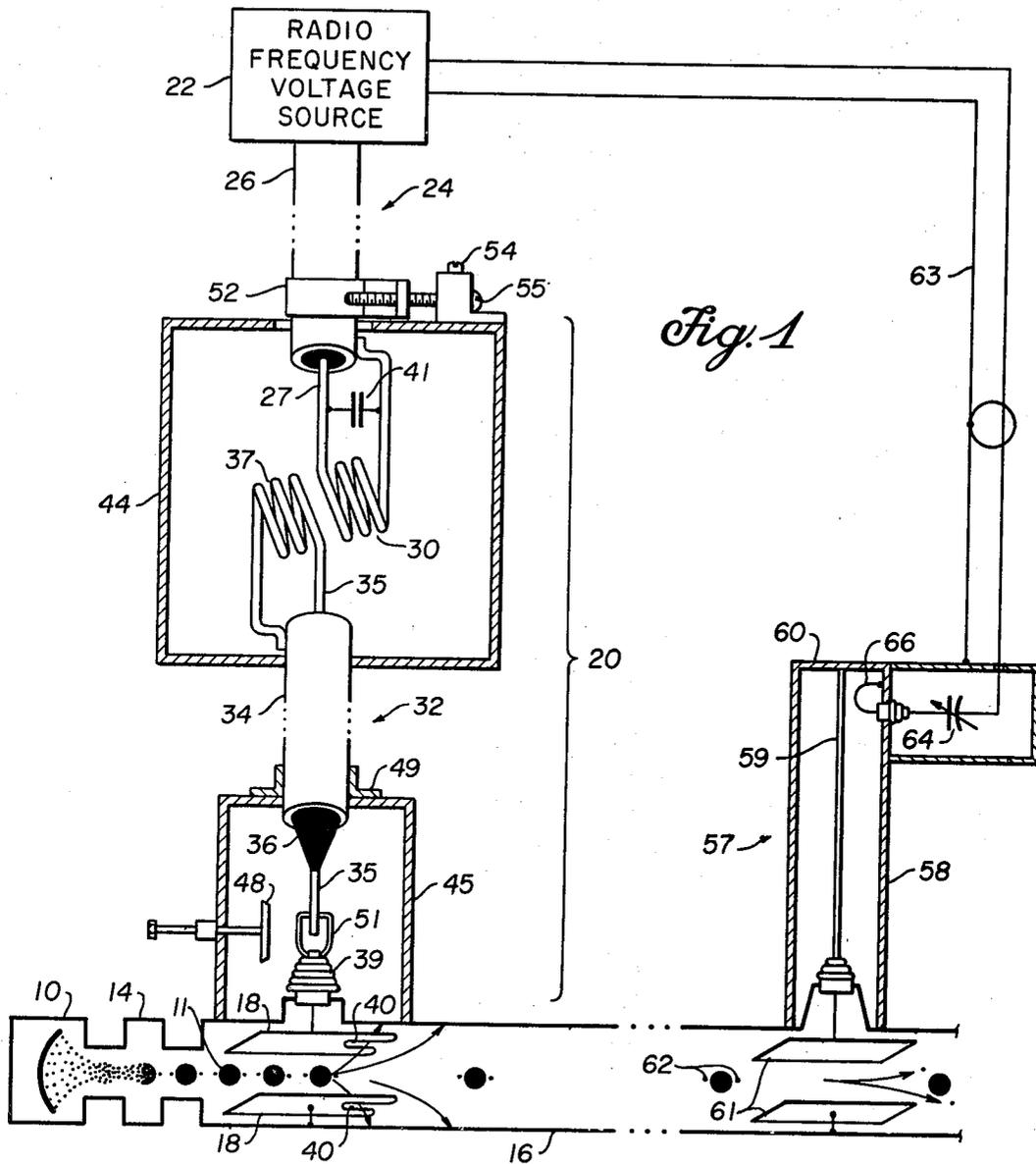


Fig. 1

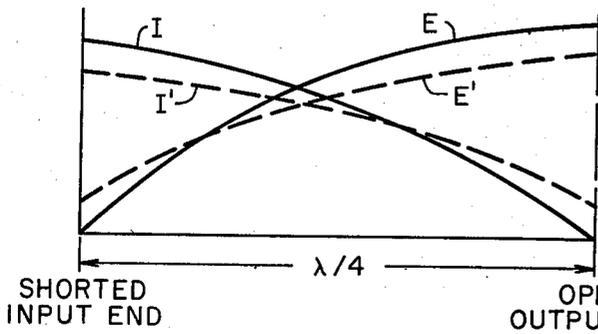


Fig. 2.

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**QUARTER-WAVE TRANSMISSION LINE RADIO  
FREQUENCY VOLTAGE STEP-UP TRANS-  
FORMER**

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Filed Mar. 5, 1968, Ser. No. 710,542

Int. Cl. H01j 29/70

U.S. Cl. 315—18

9 Claims

**ABSTRACT OF THE DISCLOSURE**

A quarter-wave transmission line having an open output end, and an input end inductively coupled to a resonant circuit by means of a small winding that also shorts the input end. Application of a radio frequency voltage to the resonant circuit produces large standing current and voltage waves in the line. The current wave is maximum at the shorted input end and zero at the output end. The voltage wave is zero at the input end and maximum at the output end, thereby stepping up the radio frequency voltage.

**BACKGROUND OF THE INVENTION**

This invention relates to radio frequency voltage step-up transformers, and more particularly, it relates to a quarter-wave transmission line that is inductively driven at its input end to produce a stepper up voltage at its output end.

The invention disclosed herein was made under, or in, the course of Contract No. AT(04-3)-400 with the United States Atomic Energy Commission.

One of the various uses for a radio frequency step-up transformer is to energize deflection plates for deflecting a charged particle beam, as in a charged particle accelerator. In the past, this has been done with standard lumped element radio frequency step-up transformers. However, for a high-voltage particle deflection system, such as required for a very high-energy linear accelerator when it is used for certain types of physics experiments requiring shortened beam pulses, the voltages obtainable with the standard lumped element transformers have been found insufficient to drive the deflection system. This is because the capacitance requisite in a lumped element transformer makes the turns ratio required for the voltage step-up impracticable to achieve. Quarter-wave transmission lines have heretofore been connected to be analogous to a lumped circuit autotransformer, and have been used as step-up transformers. However, impedance matching between a radio frequency source and the plates of a particle beam deflecting system becomes impracticable for the desired voltage ratios when this type of transformer is used.

**SUMMARY OF THE INVENTION**

In accordance with the present invention, step-up of a radio frequency voltage for application to a capacitive load may be accomplished with a quarter-wave transmission line having its input end substantially shorted with a coil having one turn or a small number of turns. The coil is coupled inductively to a resonant driving circuit which is energized with a radio frequency source. The driving circuit resonates at the frequency of the source, and accordingly produces very large oscillatory currents. These large currents create corresponding high intensity magnetic fields which are coupled to the small coil that is connected across the transmission line input. A standing current wave is thereby produced in the transmission line which is at a maximum value at the input end of the

transmission line and zero at the open output end of the line. Conversely, a standing voltage wave is created in the transmission line which is zero at the shorted input end and maximum at the open output end. Due to the very high intensity magnetic field present at the input end of the line, the standing current and voltage waves are of very great magnitude. The radio frequency voltage across the open output end thereby constitutes a large step-up of the voltage from the radio frequency source.

An object of the invention is to transduce a radio frequency voltage from a first level to a second level.

Another object of the invention is to simultaneously match a radio frequency voltage source to a load over a standard transmission line and to step up the source voltage to the load.

Another object of the invention is to drive a quarter-wave transmission line transformer with a resonant circuit to produce a very high radio frequency voltage.

Other objects and advantageous features of the invention will be apparent in a description of a specific embodiment thereof, given by way of example only, to enable one skilled in the art to readily practice the invention, and described herein after with reference to the accompanying drawing.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIGURE 1 is a diagrammatic illustration of a pair of radio frequency voltage step-up transmission line transformers according to the invention.

FIGURE 2 is a graphical illustration of voltage and current standing wave patterns of the transmission line transformers of FIGURE 1.

**DESCRIPTION OF AN EMBODIMENT**

The invention is generally useful for applying a high voltage to high impedance loads such as the plates of a charged particle beam deflection system, and in particular, in the deflection system of a high-energy, linear electron accelerator wherein it is used to selectively deflect electron bunches from one path to another, e.g., as for dumping undesired electron bunches or portions thereof near the electron injection point of the accelerator. This arrangement permits selective removal of bunches of electrons from the normal beam pulse to permit certain types of physics experiments to be carried out, especially time-of-flight experiments which require a series of pulses shorter than a normal beam pulse, and sometimes pulses comprised of only a single bunch of electrons. Such a deflection system is shown in FIGURE 1 of the drawings, wherein electrons emanating from an electron gun 10 are formed into electron bunches 11 by a prebuncher 14 of conventional design for injection into a linear accelerator beam tube 16. To increase the spacing of electron bunches as compared to those of a normal electron beam, a pair of deflection plates 18, disposed in opposing spaced, parallel relation across tube 16, are provided for periodically deflecting selected electron bunches from the usual axial path in tube 16, e.g., into the accelerator tube walls at an appropriate frequency. For a very high energy accelerator, a high deflection voltage is necessary to deflect the electron bunches, even at the injection end. This high voltage is obtained, in accord with the present invention, by means of a radio frequency transmission line voltage step-up transformer 20 which raises the voltage of a conventional radio frequency voltage source 22 to a level that is adequate to deflect the electron bunches 11 as desired. The radio frequency source voltage is applied to the transformer 20 over a coaxial transmission line 24 which is comprised of an outer conductor 26 and inner conductor 27. The transformer 20 is comprised of a primary winding 30 connected across the inner conductor 27 and the outer conductor 26. A secondary wind-

ing 37 is located coaxially adjacent to the winding 30, and is connected across an outer conductor 34 and inner conductor 35, separated by a solid dielectric 36, and together comprising transmission line 32, e.g., a coaxial transmission line section, having a length equivalent to one-quarter the wavelength of the source frequency. The windings 30 and 37 are positioned for critical inductive coupling therebetween. The lower end of the conductor 35 is fed through an insulator 39 and connected to the upper one of the plates 18. Each of the plates 18 has a slot 40 to provide clear passage for the electrons to the accelerator sides.

A capacitor 41 is connected across the primary winding 30. The capacitor 41 and winding 30 constitute a parallel resonant circuit across the output of the voltage source 22. The value of the capacitor 41 is chosen to make the parallel circuit resonant at the source frequency when critically coupled to the secondary winding 37. Thus, upon being supplied with energy from the source 22, very large oscillatory currents will circulate between the capacitor 41 and the winding 30 of the parallel resonant circuit. Since the winding 37 is comprised of only one, or at most a few, turns, it constitutes an effective low impedance or substantial short circuit across one end of the line 32. The other end of the line is connected to the upper one of the plates 18 and therefore constitutes an open end. As previously mentioned, a quarter-wave transmission line that is energized at its resonant frequency produces standing current and voltage waves. For a quarter-wave line that is shorted at one end and open at the other, the standing current wave has a maximum amplitude at the shorted end and is zero at the open output end, while the standing voltage wave is zero at the shorted end and has a maximum value across the open end. Standing current (I) and voltage (E) wave patterns for a quarter-wave transmission line shorted at one end and open at the other are shown in FIGURE 2.

In operation, the very large oscillatory currents produced in the winding 30 create a correspondingly large oscillatory magnetic field. This field is inductively coupled to the winding 37 to produce a correspondingly large current. This current is allowed to attain a maximum value, since it is introduced to the line 32 at its shorted end. With a maximum input current being introduced at the shorted end, a corresponding maximum output voltage is produced across the open output end across the high impedance load provided by deflection plates 18.

The described transformer has been found to be an efficient and effective means for attaining very high voltage step-up ratios at radio frequencies.

In practice, the inductance of the secondary winding 37, losses in the line 32, and a slight loading of the plates by collection of electrons will cause the current in the shorted input end to be slightly less than the theoretically maximum attainable current, and the voltage to be slightly more than zero. Consequently, there will be a slight current at the open output end and the voltage will be slightly less than the maximum theoretically attainable voltage. This condition is illustrated in FIGURE 2 by standing current and voltage waves  $I'$  and  $E'$ .

Generally, it will be found advisable to supply electromagnetic radiation shielding at critical points of the system. A conventional shield 44 may therefore be provided to enclose the loops 30 and 37, while another conventional shield 45 may be provided to enclose the connection of the conductor 35 to the upper plate 18.

An important feature of the present invention is that the step-up transformer 20 may be driven through a long standard 50-ohm. coaxial transmission line 24 without generating standing waves on the line. This feature is obtained by double-tuning the transformer 20. The winding 30 and capacitor 41 constitute a tuned primary circuit, while the winding 37 and line 32 constitute a tuned secondary circuit. By providing means, presently described for adjusting the mutual inductance between the

windings 30 and 37 and for tuning the secondary circuit, the input impedance of the transformer 20 may be adjusted to look like a 50-ohm. resistive termination to the source 22.

The mutual inductance between the coils 30 and 37 is adjustable by means of a collar 52 secured to the line 24. The collar, and therefore the line 24 and coil 30, may be moved by a screw 55 for adjusting the coupling between the coils 30 and 37. Once the adjustment is made, the coil 30 is locked in place with a set screw 54.

Fine tuning of the line 32 may be accomplished by varying an adjustable tuning plate 48. Additional fine tuning may be obtained by moving the conductor 35 with respect to a pair of sliding contacts 51 secured at the upper end of insulator 39. A collar 49 is integral with the shield 45 to maintain the line 32 in place once the line length is adjusted.

The maximum voltage attainable across the output of a radio frequency transformer according to the invention is a function of line breakdown voltage, load and line losses, and input power. For a constant input power, the output voltage of the transformer is maximized when load and line losses are minimized. Air dielectric lines can be constructed to give significantly lower line losses than can be obtained with solid dielectric lines. Accordingly, a quarter-wavelength air transmission line 57 is provided for energizing a pair of deflection plates 61 located within the accelerator 16 downstream of the plates 18. The line 57 comprises an outer conductor 58 in the form of a cylindrical housing and a rod-like inner conductor 59. The outer conductor surrounds the inner conductor at a constant radius, and has a solid end 60 which electrically connects the conductors 58 and 59. The end 60 shorts the upper end of line 57 and constitutes a single-turn coil. Deflecting voltages applied across the plates 61 may be used for sharpening the electron bunches 11 by deflecting residual electron bunches and random electrons 62, which appear at the leading and trailing edges of the selected electron bunches, for dumping into the side of the accelerator. Since the electron bunches have achieved relativistic velocities at this point in the accelerator, as opposed to the sub-relativistic velocities of the bunches as they pass between the plates 18, the voltages required across the plates 61 are substantially higher than those required across the plates 18. Even at these high voltages, the electrons 62 are only slightly deflected; however, it is adequate for sharpening the bunches 11 to the desired configuration. Since the electrons 62 are not sharply deflected, the slots 40 in the downstream edge of the plates 18 are not required in the plates 61. The quarter-wave transmission line 57 may be supplied with energy from the radio frequency voltage source 22 over a coaxial cable 63. The cable 63 is terminated with a series-resonant circuit comprising an adjustable capacitor 64 in series with a single-turn coil 66. The coil 66 is mounted within the air space of the line 57, at the upper end of the line, for inductive coupling to the single-turn coil constituted by the end 60.

In operation, large oscillatory currents are produced in the series-resonant circuit. This causes a correspondingly large oscillatory magnetic field to be generated in the proximity of the end 60 of the line 57. As with the line 32, large standing current and voltage waves are generated thereby in line 57. A standing current wave is produced that has a maximum value at end 60, and a corresponding standing voltage wave is produced that has a maximum value at the opposite open end of the line 57 across the plates 61. Since the losses and load of the air line 57 are very low, the voltage across the deflecting plates may be made correspondingly high using only low input driving power.

A system exemplifying the invention was constructed in which the radio frequency voltage source 22 was a 50-KW peak amplifier operated at an average power output of 300-2000 watts. The lines 24 and 32 were coaxial

cables having a diameter of 1½" and a solid dielectric with a voltage breakdown of 100 kv. The accelerator 16 was driven at a frequency of 2856 mHz. The voltage source 22 was operated at a frequency of 39.667 mHz. which caused an electric field across the plates 18 to interact with each group of 36 electron bunches in each beam pulse to dump 35 electron bunches into the accelerator walls and pass one electron bunch for acceleration over the length of the accelerator 16.

Capacitor 41 had a value of 200 picofarads.

The windings 30 and 37 were ¼" OD copper tubing.

The windings 30 and 37 were spaced apart ¾", and each had one turn with a radius of 2".

The line 24 was approximately 75 feet long.

The parallel resonant circuit consisting of the winding 30 and the capacitor 41 sustained oscillatory currents of 400-500 amps. This produced a voltage across the plates 18 of approximately 60 kv., giving a step-up ratio for the transformer 20 of 30-to-1.

The coaxial cable used in the lines 24 and 32 had a characteristic impedance of 50 ohms.

Line 32 had an electrical length of approximately 1.89 meters, and was selected to have a "Q" of approximately 30. This "Q" was found low enough to provide loss currents in the line 32 that are high, as compared with the current due to the incidental electron impingement on the plates 18. This stabilized the transformer 20 to prevent undue loading and to consequently enable operation of the transformer with desired phase stability.

While an embodiment of the invention has been shown and described, further embodiments or combinations of those described herein will be apparent to those skilled in the art without departing from the spirit of the invention or from the scope of the appended claims.

What I claim is:

1. A transformer for stepping up a voltage at a radio frequency from a first level to a second level, comprising:

- (a) a resonant circuit responsive to said voltage at said first level to resonate at said ratio frequency for producing large oscillatory currents and a corresponding large oscillatory magnetic field, said resonant circuit including a primary inductance winding;
- (b) a transmission line having an electrical length equivalent to one quarter-wavelength of an electrical wave at said radio frequency, said line having first and second ends, said first end being open;
- (c) a pair of deflection plates connected across said first end for deflecting selected portions of a charged

particle beam from a central path between said plate; and

(d) a secondary inductance winding across the second end of said transmission line, said inductance constituting a substantial short circuit across said second end, said secondary inductance being positioned with respect to said primary inductance for coupling said large magnetic field to said second end for producing a consequent corresponding large standing current wave having a maximum amplitude across said second end, and a corresponding large standing voltage wave having a maximum amplitude across said deflection plates at said first end.

2. A transformer according to claim 1, wherein said resonant circuit is a parallel resonant circuit.

3. A transformer according to claim 1, wherein said resonant circuit is a series resonant circuit.

4. A transformer according to claim 1, wherein said primary inductance is a winding having less than 10 turns, and said secondary inductance is a winding having less than 10 turns.

5. A transformer according to claim 1, wherein said transmission line comprises a quarter-wavelength of coaxial cable.

6. A transformer according to claim 1, wherein said transmission line is comprised of an inner conductor and an outer conductor separated by an air dielectric.

7. A transformer according to claim 1, wherein said transmission line is a length which is an odd multiple of a quarter-wavelength to provide an electric field at said first end at a frequency that is a corresponding multiple.

8. A transformer according to claim 1, wherein said transmission line includes means for adjusting the length of said line to critically coupled said primary and secondary inductances.

9. A transformer according to claim 1, wherein said plates have a central slot in one end to provide a clear path for particles deflected from said central path by said electric field.

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