

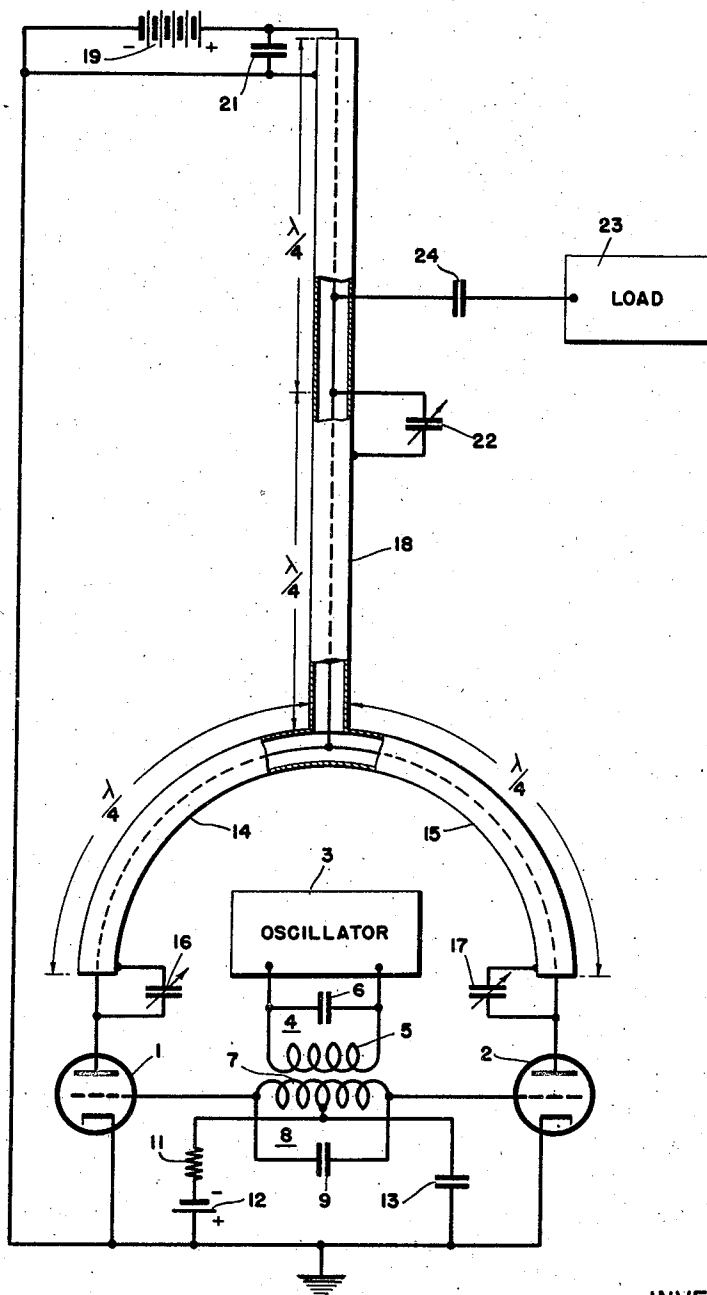
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FREQUENCY DOUBLER

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FREQUENCY DOUBLER

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This invention relates to frequency multipliers and has particular reference to devices which use resonant systems comprising transmission lines to develop ultra-high frequencies.

It is common practice to use frequency doublers which consist of a pair of vacuum tubes connected in push-push to a resonant circuit made up of lumped inductance and capacitance. Devices of this character have a number of inherent limitations. One of these is that the resonance of the tuned circuit is not as sharp as is sometimes desired. By reason of this resonance characteristic some difficulty is experienced in distinguishing between the fundamental frequency and its second harmonic. The frequency range at which devices of this character may be operated also is limited, particularly the highest frequency at which such a device will function satisfactorily.

When it is desired to develop ultra-high frequencies by means of apparatus which will multiply a lower frequency fundamental, advantage may be taken of the resonant properties of transmission lines. Such devices may be and frequently are used when operation in the ultra-high frequency range is desired. They have the advantage of considerably sharper resonance than a tuned circuit of lumped inductance and capacitance. For this reason it is considerably easier to separate the second harmonic frequency from the fundamental.

It, therefore, is an object of the present invention to provide a frequency multiplier which is capable of developing an ultra-high frequency and which embodies a novel arrangement of resonant transmission lines for the development of the multiplied frequency.

In accordance with the invention there is provided a frequency doubler which includes a resonant system comprising a pair of transmission lines having one terminal of each mutually connected. Each of the pair of transmission lines is of such a length that it has resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one quarter of a wave length at the doubled frequency. A third resonant transmission line also is employed and has one of its terminals connected to the mutually connected terminals of the pair of transmission lines. This third transmission line is of such a length that it has resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-half of a wave length at the doubled frequency. Additionally, there is provided

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means for impressing alternately upon the respective other terminals of the pair of transmission lines a series of voltage impulses at the fundamental frequency which is equal to one-half of the doubled frequency. A utilization circuit is coupled to the third transmission line.

More specifically, for impressing the voltage impulses upon the resonant system a current source may be connected to the pair of transmission lines through the space discharge paths of a pair of vacuum tubes. These tubes are rendered alternately conductive at the fundamental frequency under the control of their respective control grids which are excited at the fundamental frequency by means of an oscillator or other suitable alternating current device.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description, taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

The single figure of the accompanying drawing a circuit diagram of one embodiment of the invention.

Having reference now to the drawing, there is shown a pair of vacuum tubes 1 and 2, each of which comprises an anode, a cathode and a control grid. These tubes may be triodes, as illustrated, or, if desired, may be tubes of the multigrid type. The tubes are excited under the control of a source of fundamental frequency such as an oscillator 3. This oscillator or other frequency source may be entirely conventional. The output of the oscillator is connected to a parallel resonant circuit 4 comprising a coil 5 and a condenser 6. The coil 5 is inductively coupled to a coil 7 of another parallel resonant circuit 8 which, in addition, includes a condenser 9. The resonant circuits 4 and 8 are tuned to the fundamental frequency which it is desired to double.

The tubes 1 and 2 preferably are operated in the manner of a class C amplifier. For this purpose the control grids are negatively biased relative to their respective associated cathodes so that the tubes are conductive for short intervals occurring only at the voltage peaks of the exciting voltage wave impressed upon the control grids by the tuned circuit 8. The grid biasing is accomplished by connecting the midpoint of the coil 7 through a current limiting resistor 11 to the negative terminal of a battery 12. The positive terminal of this battery is connected to the grounded cathodes of the tubes 1 and 2. It

is to be understood that the battery 12 which is illustrated and described is indicative only of one source of biasing voltage. Obviously, other power supplies such as rectifier may be used for this purpose with equal facility. The grid-to-cathode circuits of the tubes 1 and 2 are bypassed for alternating currents by means of a condenser 13 connected between the grounded cathodes and the midpoint of the coil 7.

The anode of the tube 1 is connected to one terminal of a quarter-wave concentric transmission line 14. Similarly, the anode of the tube 2 is connected to another quarter-wave transmission line 15. The other terminals of these transmission lines are connected together so that there is in effect connected between the anodes of the tubes 1 and 2 a half-wave transmission line. The wave lengths referred to in connection with the transmission lines 14 and 15 are related to a frequency which is twice that of the oscillator 3. Adjustable condensers 16 and 17 are connected respectively between the inner and outer conductors of the transmission lines 14 and 15 at the terminals thereof which are connected to the tube anodes. These condensers are provided for the purpose of effectively adjusting the resonant properties of the transmission lines to correspond substantially with those of a quarter-wave transmission line at the doubled frequency. Theoretically, such an adjustable facility is not required. However, practically it is not always easy to form such a transmission line having the precise length required. In such a case the transmission line may be made to resonate at the desired frequency by means of a condenser such as 16 or 17.

At the junction point of the transmission lines 14 and 15 there is connected one terminal of a third concentric transmission line 18. The transmission line 18 is a half-wave line at the doubled frequency or it may be considered as a series connection of two quarter-wave lines. The other terminal of the transmission line 18 is connected to the positive terminal of a current source such as a battery 19. The negative terminal of this battery is connected to the grounded cathodes of the tubes 1 and 2. The terminal of the transmission line which is connected to the battery 19 is effectively short circuited for alternating currents by means of a condenser 21 connected between the inner and outer conductors of the transmission line. The battery 19 and its connection through the transmission lines to the vacuum tubes 1 and 2 thus serves as the source of space current for these tubes. It obviously is not essential that space current for the tubes be supplied through the whole, or even any part, of the transmission lines so long as the voltage impulses developed at the tube anodes are impressed upon the terminals of the lines 14 and 15.

An adjustable condenser 22 is connected between the inner and outer conductors of the transmission line 18 substantially at the midpoint thereof and serves to resonate this transmission line at the doubled frequency. In this manner the condenser 22 serves to compensate for slight deviations in the length of the transmission line 18 from one-half of a wave length at the doubled frequency. A load circuit 23 is capacitatively coupled to the transmission line 18 by means of a condenser 24 which is connected between the load circuit and the inner conductor of the transmission line.

The coupling between any load circuit and

the transmission line 18 should be relatively loose for the optimum performance of the system. This will be evident when it is considered that one of the major requirements of the coupling is that it have a minimum detrimental effect upon the resonance characteristic of the transmission line. Therefore, the value of the coupling condenser 24 will depend upon the point along the transmission line 18 to which it is connected. For example, if the coupling point be substantially the midpoint of the line, the condenser 24 should have a relatively small value inasmuch as such a point is one at which the maximum voltage of the standing wave is developed. At any other point along the line the voltage of the standing wave will be less than maximum and consequently, a coupling condenser having a somewhat greater value may be employed. The coupling between the load circuit and the transmission line 18 alternatively may be inductive, if desired, so long as the requirement of loose coupling is met. The inductive coupling should be of maximum looseness if the point of coupling is that at which the maximum current of the standing wave is developed. Such a point is, as will be seen, at either terminal of the line 18. If the point at which inductive coupling is made is not at either of the terminals of the transmission line, the current of the standing wave will be less than maximum and the looseness of the inductive coupling may be accordingly less than maximum.

Referring now to the operation of the apparatus, assume that it is desired to develop a frequency F by multiplication of a frequency $F/2$. In such a case the grids of the tubes 1 and 2 will be excited in opposite phase under the control of the oscillator 3 at a frequency $F/2$. Consequently, in every time interval equal to $2/F$ each of the tubes will be rendered conducting once. As the tubes are rendered conducting the current drawn from the source 19 through the impedance represented by the transmission lines 18 and 14 or 15 effects the development of a negative voltage at the tube anodes. The voltages developed at the anodes of the tubes 1 and 2 respectively are impressed upon the associated terminals of the quarter-wave transmission lines 14 and 15 respectively, for propagation to the other ends of these lines. Inasmuch as the voltages impressed upon the transmission lines 14 and 15 are 180° out of phase at the oscillator frequency, the wave energy propagated through these transmission lines will arrive at the junction point of the two quarter-wave lines 14 and 15 180° out of phase at the oscillator frequency or, considered at the doubled frequency which is twice that of the oscillator frequency, the propagated wave energy will be 360° out of phase.

In this manner there is impressed upon the terminal of the half-wave transmission line 18 which is connected to the junction point of the quarter-wave lines, voltages at twice the oscillator frequency, or in other words at the frequency F . This energy is transmitted to the other end of the half-wave line where it is reflected by the short circuiting condenser 21. In view of the well known fact that under the described conditions standing waves are produced in the respective transmission lines, it is convenient to couple the load circuit 23 to any desired fixed point on the half-wave line 18 and the voltage and current variations occurring at

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this point will represent the alternating wave energy propagated through the line.

It is desirable for the production of optimum results that the voltages impressed by the tubes 1 and 2 upon the quarter-wave lines 14 and 15 be relatively large. Whatever tubes are used, the current carrying capacities thereof are limited and also the current which may be drawn from a source such as the battery 19 also is limited in magnitude, and in the interest of economical operation it is desirable to maintain the magnitude of this current as small as possible. Therefore, in order to effect the development of substantial voltages at the anodes of the tubes 1 and 2, it is necessary that the effective impedance of the circuit by which current is supplied to these tubes be a maximum as presented to the tube anodes.

Accordingly, advantage is taken in the instant invention of the inherent impedance inverting characteristic of a quarter-wave transmission line. By effectively short circuiting the half-wave line 18 at the terminal which is connected to the battery 19, the impedance at this terminal has a minimum value. The impedance at the point at which the tuning condenser 22 is connected, being removed from the short circuited terminal by a distance equal to one-quarter of a wave length, therefore, has a maximum value. Similarly, at the junction point of the quarter-wave lines 14 and 15 the impedance has a minimum value. In the same manner the impedance at the anode-connected terminals of the quarter-wave lines has a maximum value, as desired. The tubes 1 and 2, therefore, are presented with a high impedance so that a given relatively small current flow will enable the development of a substantially large voltage for impression upon the quarter-wave lines.

Inasmuch as the impedance of the half-wave transmission line 18 at its midpoint is a maximum, the voltage of the standing wave at this point also is a maximum and the current of the wave is a minimum. Similarly, since the impedance of the line 18 is a minimum at its terminals, the voltage and current of the standing wave at these points are a minimum and a maximum respectively. The voltage and current of the wave at intermediate points will have corresponding intermediate values. As previously explained, the looseness of the coupling of the load 23 to the line 18 will depend upon the voltage or current value of the wave at the point of coupling, whether the coupling be capacitative or inductive. The greater the value of the voltage or current, the looser the coupling is required to be in order not to alter appreciably the resonance characteristic of the line.

The transmission line structure disclosed herein is in its simplest form to achieve the desired results. Obviously, the same results may be secured by more complicated transmission line structures having components which possess the same characteristics as those shown. For example, one or both of the quarter-wave lines 14 and 15 each may be replaced by a transmission line which has an effective length equal to three-quarters of a wave length at the doubled frequency, for example. It is known that a one-quarter wave line has substantially equivalent resonant properties to a three-quarter wave line. Similarly, the half-wave line 18 may be replaced with one having equivalent resonant properties such as a full wave line, for example.

While there has been described what, at pres-

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ent, is considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and therefore, it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In a frequency doubler, a resonant system comprising a pair of transmission lines having one terminal of each mutually connected, each of said transmission lines having resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-quarter of a wave length at a predetermined frequency, a third resonant transmission line having one terminal connected to the mutually connected terminals of said pair of transmission lines and having resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-half of a wave length at said predetermined frequency, means for alternately impressing upon the other terminals of said pair of transmission lines voltage impulses at a frequency equal to one-half of said predetermined frequency, and a utilization circuit coupled to said third transmission line.

2. In a frequency doubler, a resonant system comprising a pair of transmission lines having one terminal of each mutually connected, each of said transmission lines having resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-quarter of a wave length at a predetermined frequency, a third resonant transmission line having one terminal connected to the mutually connected terminals of said pair of transmission lines and having resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-half of a wave length at said predetermined frequency, a source of current having one terminal connected to said third transmission line, means for alternately coupling the other terminal of said current source to the other terminals of said pair of transmission lines at a frequency equal to one-half of said predetermined frequency, and a utilization circuit coupled to said third transmission line.

3. In a frequency doubler, a source of current, a pair of parallel conductive paths, means for alternately energizing said conductive paths at a predetermined frequency, a resonant impedance transformation device connecting said conductive paths and the other terminal of said current source, said impedance transformation device comprising a pair of transmission lines having one terminal of each connected respectively to said conductive paths and the other terminals connected together, each of said transmission lines having an effective length to produce an impedance inversion between the opposite terminals thereof, a third transmission line having one terminal connected to the mutually connected terminals of said pair of transmission lines and the other terminal connected to said current source and having an effective length to produce substantially the same impedance at the opposite terminals thereof, means for effectively short circuiting the terminal of said third transmission line connected to said current source for alternating current and a load circuit coupled to said third transmission line at a point suitably located with respect to the termi-

nals thereof to effect an impedance inversion between said point and said terminals.

4. A frequency doubler comprising, a pair of vacuum tubes each having an anode, a cathode and a control grid, means for impressing an exciting voltage wave having a predetermined frequency upon said control grids in opposite phase, a pair of transmission lines having one terminal of each connected respectively to said anodes and the other terminals connected together, each of said transmission lines having resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-quarter of a wave length at a frequency double that of said exciting voltage wave, a third resonant transmission line having one terminal connected to the mutually connected terminals of said pair of transmission lines and having resonant properties substantially equivalent to a resonant transmission line of an effective length equal to one-half of a wave length at said double frequency, a source of space current for said tubes having the terminals thereof connected respectively to the other terminal of said third transmission line and to said cathodes, and a load circuit coupled to said third transmission line.

5. A frequency doubler comprising, a source of alternating current having a predetermined frequency, a pair of vacuum tubes each having an anode, a cathode and a control grid, means coupled to said alternating current source for impressing an exciting voltage wave upon said control grids in opposite phase, means coupled to said control grids to effect current conduction in said tubes alternately only at the voltage peaks of said exciting wave, a first resonant transmission line having opposite terminals of one conductor thereof connected respectively to said anodes and having an effective length equal to an odd number of half wave lengths at a frequency double that of said alternating current source, a second resonant transmission line having one terminal of each of the conductors thereof connected respectively to corresponding conductors of said first transmission line at the midpoint of said first transmission line and having an effective length equal to one-half of a wave length at said double frequency, a source of space current for said tubes having the positive and negative terminals thereof connected respectively to the other terminal of one of the conductors of said second transmission line and to said cathodes, and a load circuit coupled to said second transmission line.

6. A frequency doubler comprising, a source of alternating current having a predetermined fre-

quency, a pair of vacuum tubes each having an anode, a cathode and a control grid, means coupled to said alternating current source for impressing an exciting voltage wave upon said control grids in opposite phase, biasing means coupled between said control grids and said cathodes to effect current conduction in said tubes alternatively only at the voltage peaks of said exciting wave, a first concentric transmission line having opposite terminals of one conductor thereof connected respectively to said anodes and having an effective length equal to one-half of a wave length at a frequency double that of said alternating current source, a second concentric transmission line having one terminal of each of the conductors thereof connected respectively to corresponding conductors of said first transmission line at the midpoint of said first transmission line and having an effective length equal to one-half of a wave length at said double frequency, a source of space current for said tubes having the positive and negative terminals thereof connected respectively to the other terminal of one of the conductors of said second transmission line and to said cathodes, and a load circuit coupled to said second transmission line.

7. A frequency doubler comprising, a source of alternating current having a predetermined frequency, a pair of vacuum tubes each having an anode, a cathode and a control grid, means coupled to said alternating current source for impressing an exciting voltage wave upon said control grids in opposite phase, a source of negative biasing voltage connected between said control grids and said cathodes and having a magnitude suitable to effect current conduction in said tubes alternately only at the voltage peaks of said exciting wave, a first concentric transmission line having opposite terminals of the central conductor thereof connected respectively to said anodes and having an effective length equal to one-half of a wave length at a frequency double that of said alternating current source, a second concentric transmission line having one terminal of each of the conductors thereof connected respectively to corresponding conductors of said first transmission line at the midpoint of said first transmission line and having an effective length equal to one-half of a wave length at said double frequency, a source of space current for said tubes having the positive and negative terminals thereof connected respectively to the other terminal of the central conductor of said second transmission line and to said cathodes, and a load circuit capacitatively coupled to said second transmission line.

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