

Aug. 5, 1958

J. R. PIERCE

2,846,613

BIFILAR HELIX COUPLING CONNECTIONS

Filed Oct. 23, 1953

2 Sheets-Sheet 1

FIG. 1B

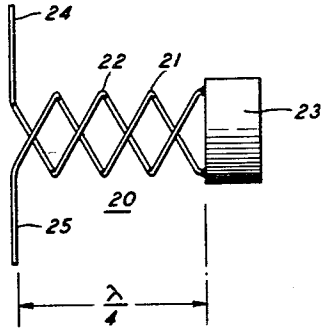


FIG. 1A

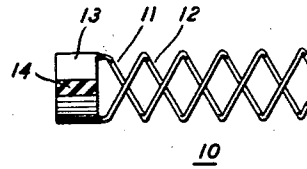


FIG. 2

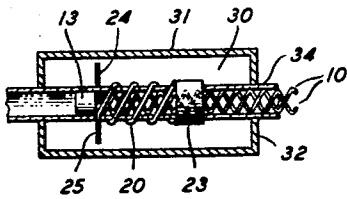


FIG. 4

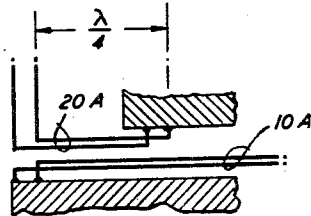
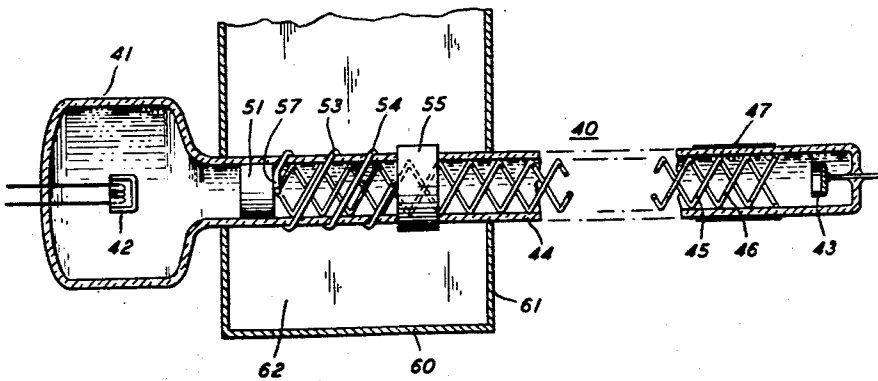


FIG. 3



INVENTOR
J. R. PIERCE
BY
A. J. Toraylin
ATTORNEY

Aug. 5, 1958

J. R. PIERCE

2,846,613

BIFILAR HELIX COUPLING CONNECTIONS

Filed Oct. 23, 1953

2 Sheets-Sheet 2

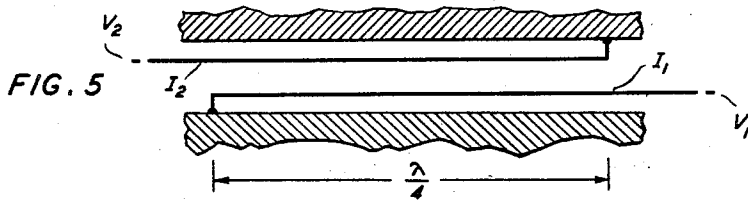


FIG. 6A

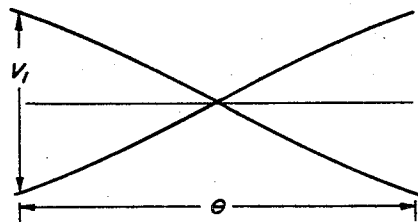


FIG. 6B

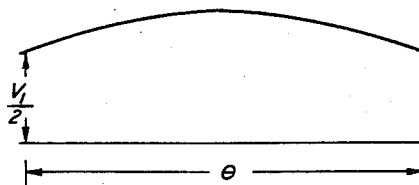


FIG. 7A

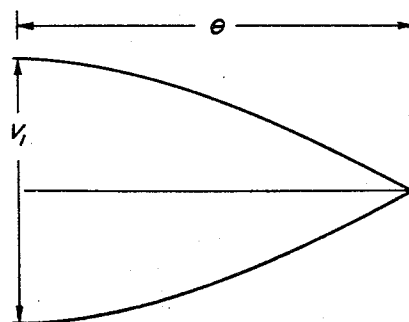
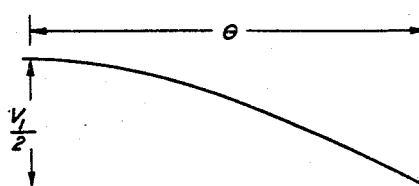


FIG. 7B



INVENTOR
J. R. PIERCE
BY
A. J. Torsiglieri
ATTORNEY

1

2,846,613

BIFILAR HELIX COUPLING CONNECTIONS

John R. Pierce, Berkeley Heights, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application October 23, 1953, Serial No. 387,832

10 Claims. (Cl. 315—3.6)

This invention relates to radio frequency coupling arrangements, and more particularly to arrangements for coupling to and from a bifilar helix which is operating as a coiled balanced line for propagating electromagnetic waves.

The term "bifilar helix" as used herein designates an arrangement comprising two interwound helices, the two helices of the arrangement having substantially the same pitch and diameter.

It has been found that a bifilar helix which is operated as a helically coiled balanced line (i. e., operated in the out-of-phase mode, wherein radio frequency potentials at corresponding points on adjacent turns of the two conductors differ in phase by approximately π radians) makes a highly efficient wave interaction circuit for incorporation in traveling wave tubes. In my copending application Serial No. 345,503, filed March 30, 1953, there are described several traveling wave tubes utilizing such a bifilar helix. It is characteristic of a bifilar helix that it can propagate in two distinct modes, the out-of-phase mode of interest herein, and an in-phase mode, in which, at corresponding points on adjacent turns of the two conductors, the radio frequency potentials are substantially in phase.

However, it has been difficult hitherto to couple efficiently over a wide band of frequencies to such a bifilar helix circuit operating in the out-of-phase mode. Such coupling is important in traveling wave tubes for introducing to the circuit electromagnetic waves to be amplified and, alternatively, for abstracting for utilization wave energy which has been developed on the circuit.

Accordingly, one object of the invention is to widen the operating frequency range and improve the efficiency of traveling wave tubes of this kind by providing an improved arrangement for coupling the tube interaction circuit to external wave guiding means.

In particular, it is desirable to have a coupling arrangement which requires no connections through the evacuated tube envelope and no elements of critical size or positioning inside the tube envelope.

In a coupling arrangement in accordance with the invention, at the end of the inner bifilar helix which is enclosed by the tube envelope and to which coupling is to be made, the ends of the two conductors forming this first bifilar helix are shorted together for radio frequencies as, for example, by a conductive ring. A second outer bifilar helix wound to substantially the same pitch as the first helix is positioned external to the tube envelope coaxial with and overlapping the end portion of the first helix. The second bifilar helix also is shorted together for radio frequencies but at the end of its overlapping region which is the more remote from the shorted end of the first helix. Additionally, the region of overlap of the two helices is adjusted to be approximately an odd integral number of quarter wavelengths of the operating wavelength. The external wave guiding means is coupled to the free ends of the two conductors forming the second bifilar helix.

2

For example, these two free ends may be connected to the two conductors of a two-conductor transmission line or, alternatively, to two antennas which are supported in a wave guide to excite or be excited by the electric vector in the wave guide. In the preferred embodiment to be described in detail the first helix is the interaction circuit in a backward wave oscillator, and the second helix couples to an external wave guide.

The invention will be better understood from the following more detailed description taken in conjunction with the accompanying drawings in which:

Figs. 1A and 1B show, respectively, the inner and outer bifilar helices which form after assembly a coupling arrangement in accordance with the invention;

Fig. 2 illustrates the manner in which a first bifilar helix is coupled to a rectangular wave guide by the use of a second bifilar helix in accordance with the invention;

Fig. 3 shows a backward wave oscillator of the bifilar helix type in which a coupling arrangement in accordance with the invention is utilized to abstract the oscillatory energy;

Figs. 4 and 5 are equivalent circuit representations which will be useful in describing the principles of the invention; and

Figs. 6A, 6B, 7A and 7B are voltage waveforms useful in an analysis of the coupling arrangement of the invention.

Referring now more particularly to the drawings, Figs. 1A and 1B show separately the two bifilar helices which are to be combined to form a coupling arrangement in accordance with the invention. Fig. 1A shows a bifilar helix 10 comprising a pair of helically interwound conductors 11 and 12 which are shorted together at one end for radio frequencies by a conductive ring 13. As will be further discussed below, for applications in which the two conductors 11 and 12 are to be maintained at different D. C. potentials the ring 13 may be split into two segments mutually insulated at D. C. but effectively electrically integral at radio frequencies. The free ends of the two conductors 11 and 12 may extend any desired length. Fig. 1B shows a bifilar helix 20 comprising two helically interwound conductors 21 and 22 which is wound to have a slightly larger diameter but the same pitch as the bifilar helix 10 whereby the two helices will be characterized by substantially the same axial wave phase velocity for waves traveling therealong. The conductors 21 and 22 are also shorted together at one end for radio frequencies by a conductive ring 23. At their unshorted or free ends, two conductors 21 and 22 are each extended laterally on opposite sides of the helix axis to form short straight antennas 24 and 25, respectively. The distance along each of the two conductors 21 and 22 from the point of antenna connection to its shorted end is made approximately an odd number of quarter wavelengths of the signal wavelength on the bifilar helix 20. Generally, as shown in Fig. 1B this distance will be a single quarter wavelength of the signal wavelength.

Fig. 2 shows the bifilar helices 10 and 20 assembled in coupling relation for providing energy transfers to and from the helix 10 inside the tube envelope 34 to a wave guide 30 of rectangular cross section. The helix 20 closely surrounds, external to the tube envelope, the helix 10 and shares a common axis therewith. The two helices are positioned relative to one another so that the shorted end of the inner helix 10 corresponds approximately to the quarter wavelength antenna connection points along the two conductors 21 and 22 forming the outer helix 20. This amounts to providing an overlap of approximately a quarter wavelength measured along either one of the bifilar helices. The electrical length of both the inner and outer helices will be the same (i. e., approximately a quarter wavelength) along this overlap region

3

since the two helices are of substantially the same pitch and have substantially equal diameters. The rectangular wave guide 30 has its wide walls 31 parallel to the common helix axis whereby two antennas 24 and 25 extend parallel to the narrow side walls 32 for coupling to the electric vector in the wave guide in opposite phase for providing a balanced mode on the bifilar helix.

A coupling arrangement of this kind can be represented by the equivalent transmission line circuit shown in Fig. 4. The outer helix 20 may be represented as a balanced pair line 20A which is excited at one end (the helix 20 being assumed to be the driving line) and maintained at a reference or ground potential at its opposite end. This is the case because the effect of shorting the ends of the two conductors forming the bifilar helix 20 is to maintain a radio frequency voltage null at such end. The inner helix 10 may be represented as a balanced pair line 10A which is at reference or ground potential at one end corresponding to the shorting of the two conductors forming it and which extends indefinitely at the other end. The two lines 10A and 20A are coupled over a quarter wavelength corresponding to the region of overlap of the two bifilar helices 10 and 20.

Now for purposes of analysis, consider one wire of each line and ground as forming a four-terminal network as shown in Fig. 5 in which the currents I_1 and I_2 at the terminals are related to the voltages V_1 and V_2 at the terminals by the usual four-terminal network equations. Because of the end-for-end symmetry, there are only two independent constants Y and N .

$$\begin{aligned} I_1 &= YV_1 + NV_2 \\ I_2 &= YV_2 + NV_1 \end{aligned} \quad (1) \quad (2)$$

It is now necessary to solve for the independent constants. This can be done by postulating two cases with known end conditions and solving for the values of the independent constants necessary to meet the known end conditions. The circuit shown in Fig. 5 without the end shorts may be regarded as a transmission system with two modes of propagation, one in which the wires act as a balanced pair of characteristic admittance M_p and the other in which they act as a single line of characteristic admittance M_c .

For our first case, we can combine these two modes so as to make voltages V_1 and V_2 of the four-terminal network equal. To do this we put an anti-symmetrical voltage V_1 on the balanced pair mode as shown in Fig. 6A and a symmetrical voltage

$$\frac{V_1}{2}$$

on the single line made as shown in Fig. 6B. From the usual transmission line equations, it is then found that

$$I_1 = \left(\frac{1}{2} jM_c \tan \frac{\theta}{2} - jM_p \cot \frac{\theta}{2} \right) V_1 \quad (3)$$

For our second case, we can assume that $V_2 = 0$. To do this, we put on the balanced pair voltages as shown in Fig. 7A and on the single line a voltage as shown in Fig. 7B. In this case, from the usual transmission line equations,

$$I_1 = V_1 (-\frac{1}{2} jM_c \cot \theta - jM_p \cot \theta) \quad (4)$$

From Equations 1 through 4 it is found that when θ is $\pi/2$, as where the section is a quarter wavelength long,

$$Y = 0$$

$$N = j \left(\frac{M_c}{2} - M_p \right)$$

Substituting these values in Equations 1 and 2, it is found that

$$\frac{I_1}{V_1} = \frac{V_2}{I_1} \left(\frac{M_c}{2} - M_p \right)^2$$

4

Accordingly, the section merely acts as a quarter-wave transformer of characteristic admittance.

$$\frac{M_c}{2} - M_p$$

Similarly for the case of particular interest shown in Fig. 2 in which two bifilar helices are coupled, there are corresponding mode characteristic admittances M_c and M_p associated with the driving of the outer helix in the balanced mode for inducing a balanced mode excitation of the inner helix.

Viewed in another aspect the outer helix may be considered as a reflectionless transducer for transferring energy from the outer helix to the inner helix.

Similarly, the inner helix may be operated as the driving line and the outer helix as the driven line.

Fig. 3 shows a backward wave oscillator 40 substantially of the kind described in my above-identified copending application and which is modified to incorporate a coupling arrangement in accordance with the present invention. An evacuated glass envelope 41 houses at opposite ends an electron source 42 for forming a cylindrical electron beam and a collector electrode 43 in target relation with the source 42. The electron flow is made parallel to the axis of the elongated tubular portion 44 of the glass envelope. The interaction circuit of the tube comprises the bifilar helix made up of the conductors 45 and 46. This helix is advantageously supported on the inner surface of the elongated portion of the tube envelope. At the downstream or collector end, the bifilar helix is terminated in its characteristic impedance by a resistive coating 47 designed to provide a substantially reflectionless termination over a wide frequency band. The resistive coating 47 is lossy material sprayed on the outer surface of the tube envelope to give large radio frequency dissipation without causing a low resistance contact between the two conductors of the helix. This makes it possible for the two conductors 45 and 46 to be maintained at different D-C. potentials for providing electrostatic focusing of the electron beam. For a broad band termination, the dissipation effect is increased gradually over a region corresponding to several turns of the helix.

For accelerating the electron flow, the two conductors 45 and 46 forming the circuit helix are each maintained at a positive potential with respect to the electron source by suitable lead-in conductors and voltage supplies not shown. Additionally for maintaining the electron flow in alignment, the two conductors are maintained at different D-C. potentials whereby there is established a time-constant spatially alternating longitudinal electrostatic field along the path of flow which provides a net radially inward force on the outer edge electrons of the hollow beam. In this way, the outer edge of the electron beam can be kept from spreading and good focusing achieved. The principles of electrostatic focusing of this kind are analyzed in a copending application Serial No. 364,242, filed June 26, 1953, by P. K. Tien.

In operation the electron beam current is made sufficiently high to initiate backward wave type oscillations, and the frequency of the oscillations is adjusted by control of the electron velocity. For oscillations of radian frequency ω , the beam accelerating voltage is adjusted to provide a beam velocity approximately equal to

$$\frac{\omega p}{\pi \left(1 - \frac{\omega d}{v} \right)}$$

where p is the separation between the two helical conductors 45 and 46, d is the diameter of the bifilar helix, and v is the velocity of the electromagnetic wave along the bifilar helix.

The oscillatory energy is abstracted for utilization from the upstream or electron source end of the bifilar helix into the rectangular wave guide 60 by way of a trans-

ducer of the kind shown in Fig. 2. To this end the two upstream ends of the conductors 45 and 46 are shorted for radio frequencies by means of the split ring 51. The ring 51 is split into two conductive sections which are insulated at D.-C. from one another by dielectric inserts (not here visible) so as to prevent a D.-C. short of the two conductors 45 and 46. However, the dielectric inserts are made sufficiently thin that at radio frequencies their presence has little effect. Additionally, a bifilar helix comprising the conductors 53 and 54 which are wound to substantially the same pitch as conductors 45 and 46 whereby the axial phase velocity of waves traveling on the outer helix will be substantially that of waves traveling on the inner helix is disposed around the glass envelope overlapping the end portion of the inner circuit helix for being in field coupling relation therewith. The ends of the two conductors 53 and 54 of the outer bifilar helix which are the more remote from the shorted ends of conductors 45 and 46 of the inner helix are themselves shorted for radio frequencies by the conductive ring 55. The outer bifilar helix is positioned relative to the inner bifilar helix so that along the common tube axis the unshorted ends of the conductors 53 and 54 correspond to the shorted ends of the conductors 45 and 46. Additionally, the length of the overlapping region of the outer bifilar helix is made approximately a quarter wavelength of the oscillatory wave on the outer helix, and where broad band operation is contemplated, one quarter the wavelength at the middle of the operating band. By making the wall thickness of the elongated portion of the glass envelope small, the length of the overlapping region of the inner helix will also be approximately one quarter wavelength. The free ends of the outer bifilar helix are connected to the antennas of which only one, shown as 57, is visible and which are simply straight lateral extensions of the conductors 53 and 54 as in the arrangement shown in Fig. 2. The antennas are enclosed in the rectangular wave guide 60 to couple to the electric vector thereof. To this end, the narrow side walls 61 of the wave guide are apertured for the passage of the tube envelope therethrough and the longitudinal axis of the wave guide is made perpendicular to the axis of the tube envelope and the orientation of the antennas is made parallel to the apertured side walls of the wave guide and perpendicular to the broad side walls 62 of the wave guide.

In operation, the oscillatory wave which is established on the inner bifilar helix sets up a quarter wave standing wave pattern on the outer bifilar helix and the wave energy is radiated by the antennas for propagation along the wave guide to utilization apparatus. The wave guide is closed at one end at a point which results in maximum coupling between the antennas and the wave guide and extends along its open end to utilization apparatus.

It can be appreciated that one of the great advantages of the coupling arrangement described is that it requires no critical dimensions for or adjustment of elements within the evacuated tube envelope. Rather, the various adjustments important can be made on the external bifilar helix which is outside the tube envelope and at atmospheric pressure. This is of considerable practical importance in the manufacture of the tubes.

It is to be understood that the above-described embodiment is merely illustrative of the general principles of the invention. Various modifications thereof and applications therefor can be devised by one skilled in the art without departing from the spirit and scope of the invention. In particular, the various helices may have sectional configurations other than circular and additionally the helices may be formed of ribbon or tape type conductors.

What is claimed is:

1. In combination, first and second bifilar helices each comprising a pair of helically interwound conductors of a given pitch, the second bifilar helix coaxial with and

surrounding the first bifilar helix whereby each helix includes an overlapping region, means for shorting for radio frequencies the two conductors of the first helix at one end of the overlapping region of said first helix, and means for shorting for radio frequencies the two conductors of the second helix at the end of the overlapping region of said second helix remote from the shorted end of the overlapping region of said first helix.

2. The combination of claim 1 characterized in that the overlapping region of each helix is approximately an integral odd number of quarter wavelengths of the middle of the operating band.

3. The combination of claim 1 characterized in that the overlapping region of each helix is approximately one quarter the wavelength of the middle of the operating band.

4. In a microwave transducer, inner and outer overlapping coaxial bifilar helices of approximately the same pitch, each comprising two helically interwound conductors, and separate means at opposite ends of the overlapping region of the two bifilar helices for maintaining one end of each of the two bifilar helices at a radio frequency voltage null.

5. The transducer of claim 4 further characterized in that the overlapping region of each helix is approximately a quarter the operating wavelength of the transducer.

6. In combination, inner and outer coaxial bifilar helices of approximately the same pitch, each comprising two helically interwound conductors and overlapping over a region approximately one quarter the operating wavelength, a conductive member shorting for radio frequencies the two conductors of the inner helix at one end of its overlapping region, a conductive member shorting for radio frequencies the two conductors of the outer helix at the end of its overlapping region remote from the shorted end of the two conductors of the inner helix, and a wave transmission line coupled to the unshorted end of the outer helix.

7. In combination, inner and outer coaxial bifilar helices of approximately the same pitch, each comprising two helically interwound conductors and overlapping over a region approximately one quarter the operating wavelength, a conductive member shorting for radio frequencies the two conductors of the inner helix at one end of its overlapping region, a conductive member shorting for radio frequencies the two conductors of the outer helix at the end of its overlapping region remote from the shorted end of the two conductors of the inner helix, a wave guiding member, and radiating means connected to the unshorted ends of the two conductors of the outer helix and positioned for coupling to the electric vector of the wave guiding member.

8. In combination, an electron source and a target defining a path of electron flow, a first bifilar helix comprising a first pair of helically interwound conductors disposed along the path of flow, dissipative means for making the target end of said helix substantially reflectionless, means for maintaining the source end of said helix at a voltage null, and means for abstracting wave energy from the source end of said bifilar helix comprising a second bifilar helix coaxial with and surrounding a source end portion of the first bifilar helix, and means for maintaining the second bifilar helix at a voltage null at a point spaced apart in the direction of electron flow from the electron source end of the first bifilar helix.

9. In combination, a traveling wave tube comprising means forming an electron beam, an interaction circuit for propagating an electromagnetic wave in field coupling relation with the electron beam including a first pair of helically interwound conductors for forming a first coiled balanced line, and means for maintaining a point of the first line at a radio frequency voltage null, and

7

means for effecting energy transfers with the interaction circuit of the traveling wave tube including a second coiled balanced line comprising a second pair of helically interwound conductors disposed coaxial with and surrounding a portion of said first line including the voltage null point, and means for maintaining the second line at a radio frequency voltage null at a point spaced apart from the point of voltage null on the first line approximately an odd number of quarter wavelengths of the propagating wave.

10. In combination, a traveling wave tube comprising an evacuated envelope, means within said envelope for forming an electron beam, an interaction circuit within said envelope for propagating an electromagnetic wave in field coupling relation with the electron beam including a first pair of helically interwound conductors for forming a first coiled balanced line, and means within said envelope for maintaining at least one end of the first coiled balanced line at a radio frequency voltage null, and means external to the envelope for effecting energy exchanges with the interaction circuit of the traveling wave tube including a second coiled balanced line com-

8

prising a second pair of helically interwound conductors disposed coaxial with and surrounding a portion of said first coiled balanced line including the voltage null point, and means for maintaining the second coiled balanced line at a radio frequency voltage null at a point spaced apart from the point of voltage null on the first coiled balanced line approximately a quarter the wave length of the propagating wave.

References Cited in the file of this patent

UNITED STATES PATENTS

1,970,315	Jones	Aug. 14, 1934
2,175,710	Usselman et al.	Oct. 10, 1939
2,189,309	Carlson et al.	Feb. 6, 1940
2,637,775	Lund	May 5, 1953
2,677,110	Amy	Apr. 27, 1954
2,699,519	Bruck	Jan. 11, 1955
2,708,727	Quate	May 17, 1955
2,758,283	Starner	Aug. 7, 1956

FOREIGN PATENTS

476,701	Great Britain	Dec. 14, 1937
---------	---------------	---------------