Dec. 20, 1966 H. J. WOLKSTEIN 3,293,482

PLURAL OUTPUT TRAVELING WAVE TUBE

Filed June 21, 1962 3 Sheets-Sheet 1

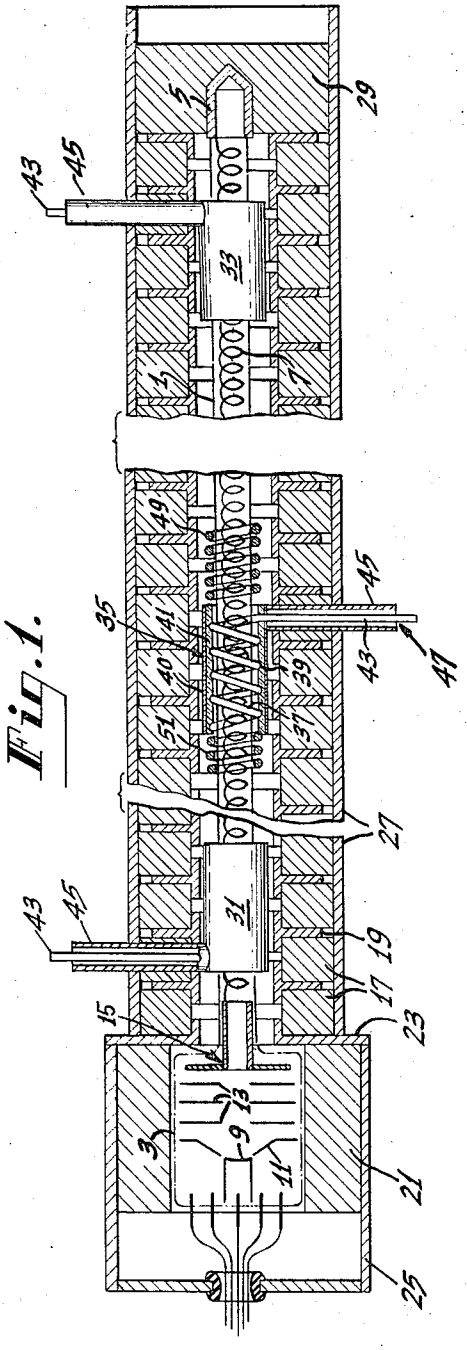


Fig. 1.

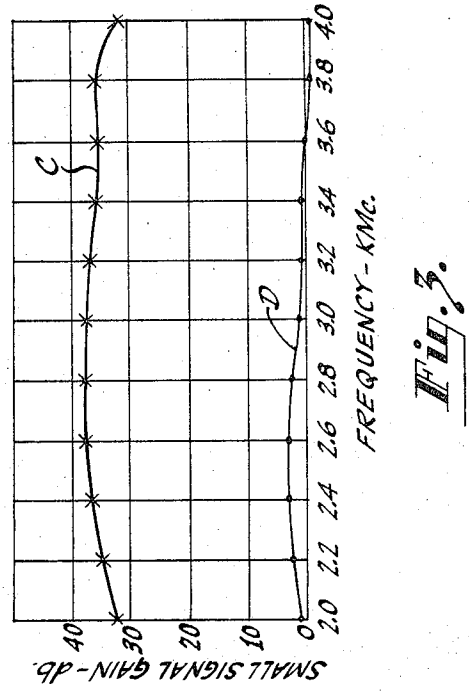


Fig. 3.

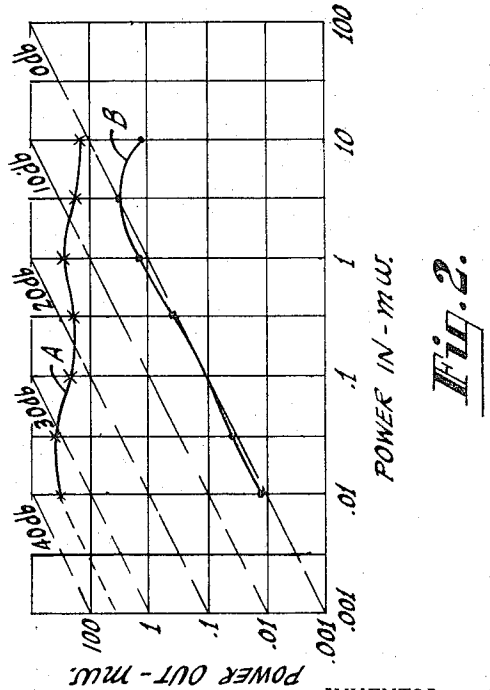


Fig. 2.

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Fig. 4.

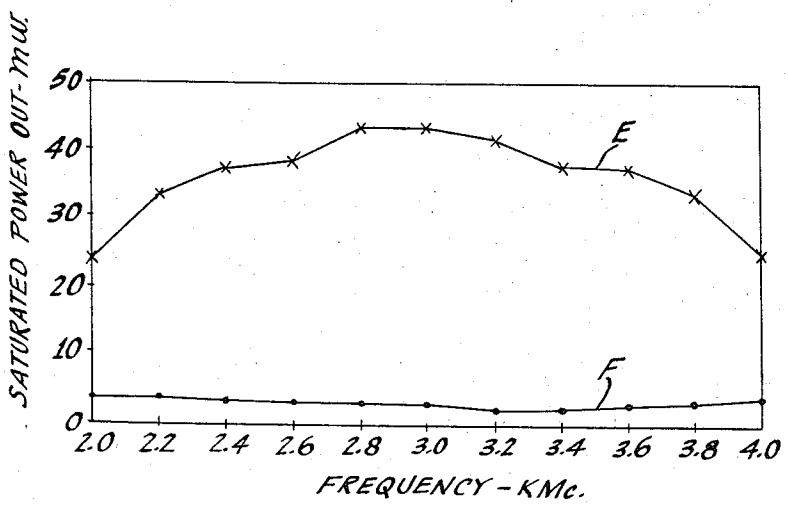
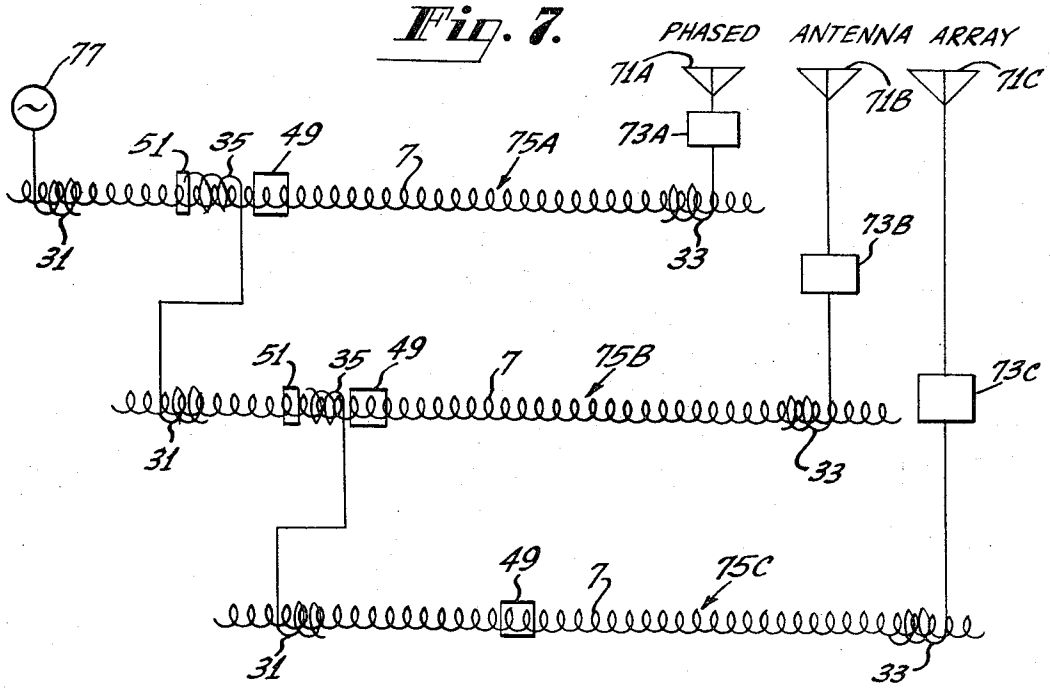


Fig. 7.



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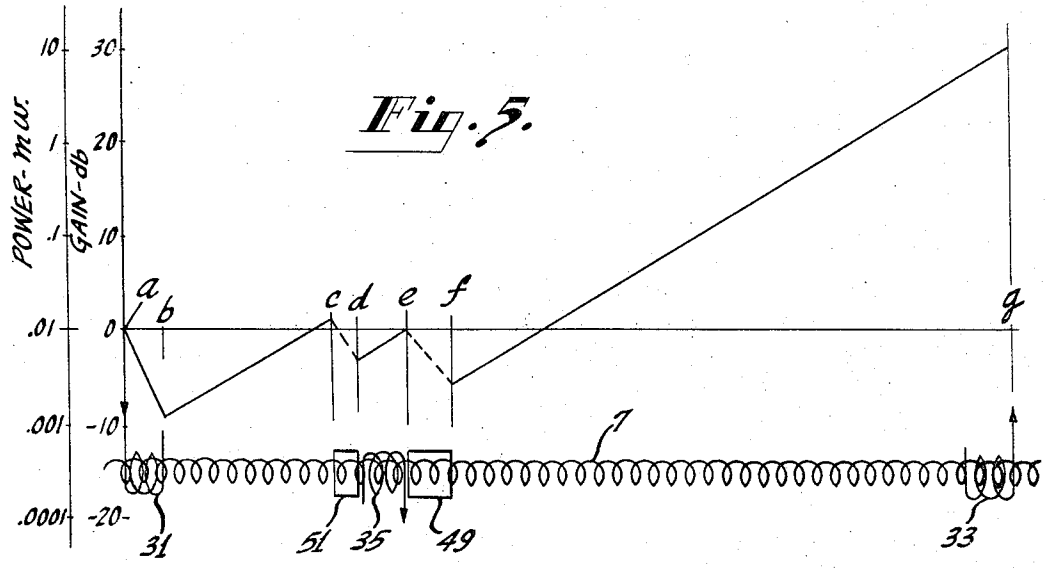


Fig. 5.

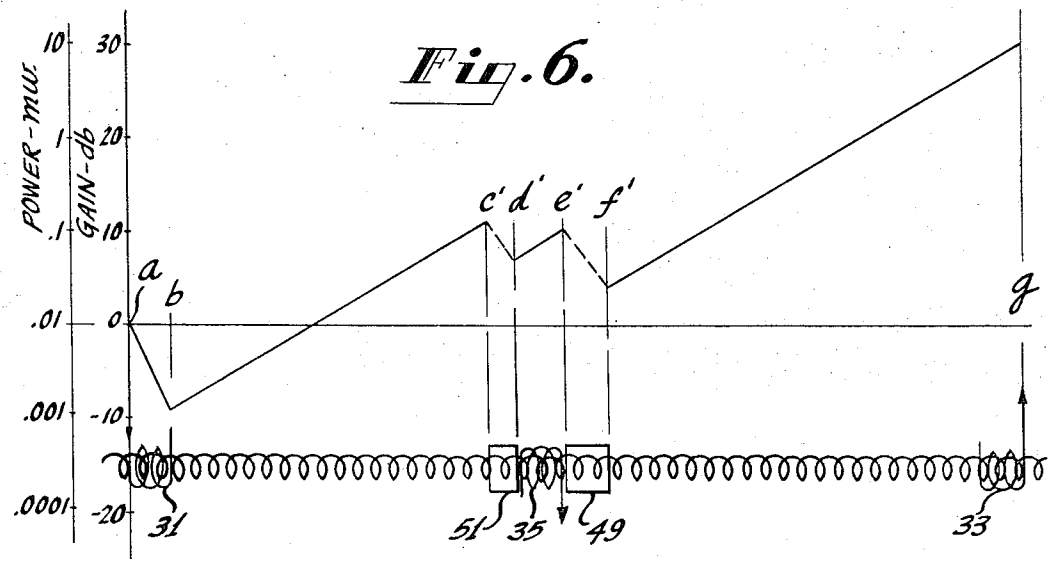


Fig. 6.

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PLURAL OUTPUT TRAVELING WAVE TUBE

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10 Claims. (Cl. 315—9)

The present invention relates to an improved traveling wave amplifier tube having, in addition to the usual high gain output coupler, an auxiliary coupler adapted to produce lower gain.

The provision of more than one output coupler in a traveling wave tube has been described in connection with FIG. 7 of Kompfner Patent No. 2,928,979, issued March 15, 1960. However, Kompfner's output couplers are all located near the collector end of the helix, in regions of high gain, and are graded in pitch, for the purpose of taking the power off the helix in stages.

An object of the present invention is to provide a traveling wave amplifier tube having an input coupler, a high gain output coupler; and an intermediate auxiliary output coupler having lower gain.

Another object of the invention is to provide RF isolation between the auxiliary coupler portion and the following portion of the tube helix, to prevent the auxiliary coupler from affecting the output from the high gain coupler.

Another object is to combine a plurality of plural coupler traveling wave tubes in a tandem-parallel system in which the input coupler of the first tube is coupled to a signal source, each tube except the last has an auxiliary output coupler coupled to the input coupler of the next tube, and the normal output couplers of all the tubes are coupled individually to an array of load elements, such as the antennas of a phased antenna array for search radar, for example.

In accordance with the invention, an auxiliary output coupler is coupled to the helix of a traveling wave tube in a region between the input coupler and the high gain output coupler. The portion of the tube helix coupled to the auxiliary output coupler is isolated from the portions on each side of that coupler by suitbale attenuators or helix gaps.

In the accompanying drawings:

FIG. 1 is an axial sectional view of a three-coupler traveling wave tube embodying the present invention;

FIG. 2 is a graph of the relation between power out and power in at a frequency of 3 kmc. for the two output couplers of a particular three-coupler tube similar to that shown in FIG. 1;

FIGS. 3 and 4 are graphs of the relation between small signal gain and saturated power out, respectively, and frequency for the two output couplers of a three-coupler tube;

FIG. 5 is a graph of the variation of power along the helix of a three-coupler tube similar to that shown in FIG. 1, in which the auxiliary coupler is located at a point of unity, or zero db, gain;

FIG. 6 is a graph similar to that of FIG. 5, for an auxiliary coupler located at a point of 10 db gain; and

FIG. 7 is a circuit in which a series of three coupler traveling wave tubes transmit an RF signal from a single source to a plurality of antennas of a phased antenna array.

The invention is illustrated in FIG. 1, for example, as applied to a periodic-permanent-magnet-focused traveling wave tube having a helix-type slow-wave structure and coupled-helix-type input and output couplers. The traveling wave tube comprises a conventional envelope made up of an elongated glass portion 1 joined at one end to an enlarged glass electron gun portion 3 and at the other end to a metal collector 5. The elongated envelope portion 1 contains an elongated metal helix 7 of uniform diameter and pitch. The gun portion 3 contains a conventional electron gun structure which may include a cathode 9, a beam forming electrode 11, one or more accelerating electrodes 13 and a drift tube electrode 15, adapted to project an electron beam axially through the helix 7 to the collector 5.

In order to focus or confine the beam, the tube may be coaxially positioned within a magnetic/focusing assembly comprising a stack of alternate ring magnets 17 and magnetic shims 19, with adjacent magnets 17 axially-polarized in opposite directions, surrounding the helix portion of the tube, and a cylindrical permanent magnet 21 surrounding the gun portion. A magnetic shim 23 serves as the common pole piece for the magnet 21 and the first ring magnet 17. Two tubular metal capsule members 25 and 27, attached to the shim 23, and a metal retainer plug 29 complete the focusing assembly.

The helix 7 is inductively coupled, through the glass envelope, to RF input and output couplers 31 and 33, respectively, which surround the envelope portion 1 near the ends of the helix, to introduce an RF signal to the helix and extract an amplified signal therefrom, respectively.

An auxiliary output coupler 35 is coupled to the helix 7 in a region between the input coupler 31 and the output coupler 33. The coupler 35, and also each of the couplers 31 and 33, may comprise a metal helix 37, supported in helical grooves 39 formed in the inner surface of an insulating sleeve 41, and having an extension 43 cooperating with a tubular metal conductor 45, which is connected to a metal casing 40 surrounding the insulating sleeve 41, to form a coaxial terminal 47. The coupling helix 37 and tube helix 7 have substantially the same phase velocity and are wound in opposite directions for maximum coupling therebetween. The conductor 45 passes loosely through one of the ring magnets 17. Another type of RF coupling means could be used instead of the coupled-helix type, as for example, a transverse waveguide coupled to an axial extension of the helix.

The portion of the helix 7 which is coupled to the auxiliary coupler 35 is isolated for RF currents from the portion of the helix 7 extending between the two output couplers 33 and 35 by a suitable RF attenuator 49. This attenuator 49 may be in the form of a resistive wire helix surrounding the glass envelope portion 1 adjacent to the auxiliary coupler 35 and coupled to the helix 7, so that the location of the attenuator (and the coupler 35) along the tube can be adjusted. On the other hand, if the location of the auxiliary coupler is pre-determined, the attenuator 49 may be in the form of a resistive coating or sleeve in contact with the helix 7 within the envelope. The function of the attenuator 49 is two-fold. It serves to prevent the extractioin of RF energy from the helix 7 by the auxiliary coupler 35 from affecting the normal high gain output from the output coupler 33, and also serves as the conventional attenuator to absorb amplified waves reflected back along the helix from the output termination and thereby prevent oscillations due to regeneration. In order to perform these functions, the attenuator is designed to absorb all of the RF energy reflected back along the helix at that point. This will usually require at least 30 db of cold attenuation (in the absence of the beam). Another alternative is to interrupt the helix 7 in this region and insert a drift tube in the gap between the helix sections to shield the beam path therein.

A second attenuator 51, which may be similar in kind to attenuator 48, is preferably coupled to the helix 7 on the other, or input, side of the auxiliary coupler 35, in order to isolate the input and auxiliary couplers for RF currents when the beam is cut-off. For some applications, such isolation may require as much as 40–60 db of cold

attenuation. In other applications, this attenuator may provide considerably less cold attenuation than attenuator 49. For example, attenuator 51 may provide less than 20 db of cold attenuation.

J. R. Pierce, in his book "Traveling-Wave Tubes," D. Van Nostrand Co., 1950, has shown that the RF voltage applied to the helix of a traveling wave tube in the presence of the electron beam sets up three waves therealong, namely an increasing wave, a decreasing wave and a neutral wave, with one-third of the input voltage associated with each wave. The overall gain of a tube with a uniform helix is:

$$G=A+BCN \text{ (db)} \quad (1)$$

where A is −9.54 db, the loss due to the fact that the voltage of the increasing or gain wave is only one-third of the applied voltage; B is 47.3, the shunt susceptance per unit length of helix; C is a gain parameter depending on circuit and beam impedance; and N is the helix length in wavelengths. Thus the gain can be written:

$$G=-9.54+47.3CN \text{ (db)} \quad (2)$$

The gain parameter C is given by:

$$C^3=(E^2/\beta^2P)(I_0/8V_0) \quad (3)$$

where P is the power flow in the circuit and E is the electric field associated with it which acts on the electron stream, $\beta=\omega/v$ is a phase constant corresponding to the electron velocity v, I_0 is the average electron convection current, and V_0 is the electron accelerating voltage corresponding to the velocity v. Since the gain parameter C is substantially a constant for a particular tube and set of operating conditions up to saturation, the gain in db is substantially a linear function of the distance along the helix. Thus a tube having a given helix length will have a given overall gain at the output coupler near the collector end of the helix, and a tube having a shorter helix will have a proportionately smaller overall gain. Similarly, a tube having an auxiliary output coupler located between the input and output couplers will have a shorter effective helix length and thus will produce lower gain at the auxiliary coupler than the usual output coupler.

FIG. 2 shows the variation of power output with power input from the two output couplers of an experimental traveling wave tube similar in construction to that shown in FIG. 1 at a frequency of 3 kmc. (kilo-megacycles). The diagonal dashed lines are constant gain curves. The upper curve A shows that the gain at the high gain output coupler 33 was about 35 db for power input up to about .01 mw. (milliwatt), beyond which the tube saturated and the gain fell off rapidly. The lower curve B shows that the gain at the auxiliary output coupler 35 was substantially zero db (unity gain) up to about 3 mw. input power.

FIG. 3 shows the variation of small signal gain with frequency for the two output couplers of the same tube as in FIG. 2. As shown, the gain of this tube for the high gain coupler 33, curve C, was fairly uniform over an octave range from 2 to 4 kmc., while the gain for the auxiliary coupler 35, curve D, varied between +4 and −1 db.

FIG. 4 shows the variation of saturated output power with frequency for the same tube as in FIG. 2. The output for the high gain coupler 33, curve E, varied between 24 and 44 mw., while the power from the auxiliary coupler 35, curve F, varied between 2.5 and 4 mw., over the range from 2 to 4 kmc.

FIG. 5 shows an example of the approximate distribution of the power of the growing wave on the helix 7 of a three-coupler tube constructed as in FIG. 1, for a power input of .01 mw. The gain in db is shown in FIG. 5 in addition to the power in mw., starting with 0 db gain at the input power of .01 mw. Assuming that all of the input power at point *a* is transferred to the helix by the input coupler 31, the power associated with the growing wave at the end of the input coupler 31 is shown at point *b* as 9.54 db below the input power, in accordance with Pierce's equations, (1) and (2) above. Actually the power at *b* will be somewhat higher than that shown because of the gain along the portion of helix 7 under the input coupler 31. Beyond point *b* the growing wave power increases exponentially (linearly on the logarithmic scale shown) due to the interaction between the beam and the growing wave, to a value at *c*, at the beginning of attenuator 51, depending on the location chosen for the auxiliary coupler 35 and associated attenuators 49 and 51. The hot attenuation (with the beam on) of the attenuator 51 reduces the power by about 4 db, for example, to the value shown at point *d*. Along the auxiliary coupler the power increases to point *e*. In the example shown in FIG. 5, the auxiliary coupler and the two attenuators are so located along the helix 7 that the power available at the auxiliary coupler will be approximately equal to the input power. In other words, the coupler 35 is located at the zero db or unity gain point *e* along the helix 7.

The attenuator 49 in FIG. 5 is designed to absorb all of the RF energy on the helix 7 at that point. The tube is designed to produce output power at the output coupler 33, point *g*, at about 30 db gain. This means that the cold attenuation of attenuator 49 must be greater than 30 db, in order to absorb amplified waves that are reflected back along the helix 7 from the output end thereof. Pierce has shown, in his book cited above, that the hot attenuation of a discontinuity in the helix of a traveling wave tube is about 6 db (from 5 to 7 db for $QC=.25$, as shown in Fig. 9.8 of the book). Thus, in FIG. 5, the growing wave power on the helix 7 at the beam exit end of the attenuator 49, point *f*, is shown as about 6 db below the power level at *c* entering the attenuator. This power at point *f* is excited by the bunched beam. Beyond point *f*, the growing wave power increases exponentially to the level of 10 mw. (30 db gain) at point *g*, in the example shown. If no RF energy is extracted from the helix 7 by the auxiliary coupler 35, the residual RF energy on the helix will be absorbed by attenuator 49. Therefore, whether or not any RF energy is extracted by the auxiliary coupler 35, the growing wave power on the helix at point *f* will be the same, and hence, the output to coupler 33 will also be the same. Thus, the normal output of the tube at coupler 33 is not affected by variation in output at coupler 35.

FIG. 6 is similar to FIG. 5, except that the auxiliary coupler 35 and attenuators 49 and 51 are positioned so that the coupler 35 is located at the 10 db gain point *e'* along the helix 7, in which case the auxiliary coupler output is .1 mw., for the same input power as in FIG. 5. The output at coupler 33 (point *g'*) is the same as in FIG. 5.

FIG. 7 shows a system for the distribution of RF energy in amplified form from a single RF source to a plurality of load elements. The system comprises three, for example, load elements 71A, 71B and 71C, in the form of a phased antenna array, for example, each coupled, either directly or through an intermediate amplifier and/or phase-shifter 73A, 73B, 73C, to the output coupler 33 of one of three traveling wave tubes 75A, 75B, and 75C. Each of tubes 75A and 75B is a three-coupler tube, as shown in FIG. 1, with a helix 7, input coupler 31, output coupler 33, auxiliary output coupler 35 located at the zero db gain point along the helix, and attenuators 49 and 51. Tube 75C may be a conventional two-coupler traveling wave tube similar to tubes 75A and 75B except for the omission of the auxiliary output coupler and the attenuator 51. Tube 75C includes an attenuator 49, for preventing oscillations due to reflected waves, located at such a point that the overall gain at coupler 33 is substantially the same as in tube 75A and 75B. An input source 77 is coupled to the input coupler 31 of tube 75A, and the auxiliary

coupler 35 of tube 75A is coupled to the input coupler 31 of tube 75B. Similarly, the auxiliary coupler of tube 75B is coupled to the input coupler 31 of tube 75C. The overall gain of each tube at the output coupler 33 may be 30 db, for example.

In the operation of the system of FIG. 7, an RF signal of given power applied to tube 75A from the single source 77 produces a signal of the same power at the auxiliary coupler 35 and a corresponding signal with 30 db gain at the output coupler 33 of that tube. The same is true of tube 75B. Thus, the power from a single source is applied equally to the input couplers of three tubes, and the output of each of the tubes is applied equally to each of three load elements. This system requires only one-third as much RF power input as a system in which each tube is coupled to a separate RF source. Moreover, it is easier to control the relative phases of the signals transmitted to the load elements, 71A, 71B and 71C, when derived from a single RF source, 77, as in FIG. 7, than in a system with separate RF sources.

Other applications for a three-coupler traveling wave tube as shown in FIG. 1 will be apparent to those skilled in the art. For example, such a tube could be used as a switch in a transmit-receive radar system with a common antenna for the transmitter and receiver by coupling the input coupler to the antenna and transmitter, coupling the high gain output coupler to the radar receiver, and coupling the auxiliary coupler through a pulse amplifier and shaper to one of the gun electrodes of the tube to cut-off the beam in the tube during the transmission of each radar pulse to the antenna and thereby protect the receiver.

I claim:

1. A traveling wave amplifier tube comprising:
(a) an electron gun and a collector spaced therefrom to establish an elongated electron beam path therebetween;
(b) an elongated slow-wave structure extending along and coupled to said path;
(c) RF input coupling means, coupled to the end of said structure nearest said gun, adapted to be coupled to a signal source to introduce a signal wave to said structure for traveling wave interaction with said beam;
(d) first RF output coupling means, coupled to the other end of said structure, for extracting a high gain amplified signal from said structure;
(e) second RF output coupling means, coupled to said structure in a region spaced from said first output coupling means for extracting a signal from said structure; and
(f) means for preventing the extraction of RF power from said structure by said second output coupling means from affecting the power output from said first output coupling means.

2. A traveling wave amplifier tube comprising:
(a) an electron gun and a collector spaced therefrom to establish an elongated electron beam path therebetween;
(b) an elongated slow-wave structure extending along and coupled to said path;
(c) RF input coupling means, coupled to the end of said structure nearest said gun, adapted to be coupled to a signal source to introduce a signal wave to said structure for traveling wave interaction with said beam;
(d) first RF output coupling means, coupled to the other end of said structure, for extracting a high gain amplified signal from said structure;
(e) second RF output coupling means, coupled to said structure in a region spaced from said first output coupling means for extracting a signal from said structure; and
(f) means effectively isolating for RF currents the portion of said structure coupled to said second output coupling means from the portion of said structure extending between said output coupling means.

3. A traveling wave amplifier tube comprising:
(a) an electron gun and a collector spaced therefrom to establish an elongated electron beam path therebetween;
(b) an elongated slow-wave structure extending along and coupled to said path;
(c) RF input coupling means, coupled to the end of said structure nearest said gun, adapted to be coupled to a signal source to introduce a signal wave to said structure for traveling wave interaction with said beam;
(d) first RF output coupling means, coupled to the other end of said structure, for extracting a high gain amplified signal from said structure;
(e) second RF output coupling means, coupled to said structure in a region spaced from said first output coupling means for extracting a signal from said structure; and
(f) attenuating means, associated with said structure beyond said second output coupling means, for absorbing all of the RF energy on said structure.

4. A traveling wave amplifier tube comprising:
(a) an electron gun and a collector spaced therefrom to establish an elongated electron beam path therebetween;
(b) an elongated slow-wave structure extending along and coupled to said path;
(c) RF input coupling means, coupled to the end of said structure nearest said gun, adapted to be coupled to a signal source to introduce a signal wave to said structure for traveling wave interaction with said beam;
(d) first RF output coupling means, coupled to the other end of said structure, for extracting a high gain amplified signal from said structure;
(e) second RF output coupling means, coupled to said structure in a region spaced from said first output coupling means for extracting a signal from said structure;
(f) first attenuating means, associated with said structure beyond said second output coupling means, for absorbing all of the RF energy on said structure; and
(g) second attenuating means, associated with said structure ahead of said second output coupling means, for absorbing part of the RF energy on said structure.

5. A traveling wave amplifier tube as in claim 4, wherein
(a) the overall gain at said first output coupling means is at least 30 db;
(b) the gain at said second output coupling means is substantially zero db;
(c) the cold attenuation provided by said first attenuating means is greater than said overall gain; and
(d) the cold attenuation provided by said second attenuating means is at least 10 db.

6. A traveling wave amplifier tube comprising:
(a) an electron gun and a collector spaced therefrom to establish an elongated electron beam path therebetween;
(b) an elongated slow-wave structure extending along and coupled to said path;
(c) RF input coupling means, coupled to the end of said structure nearest said gun, adapted to be coupled to a signal source to introduce a signal wave to said structure for traveling wave interaction with said beam;
(d) first RF output coupling means, coupled to the other end of said structure, for extracting a high gain amplified signal from said structure; and
(e) second output coupling means, coupled to said

structure in a region where the gain is substantially unity, for extracting an unamplified signal from said structure.

7. A traveling wave amplifier tube as in claim 6, further comprising attenuating means, associated with said structure beyond said second output coupling means, for absorbing all of the RF energy on said structure.

8. A traveling wave amplifier tube comprising:

(a) an elongated envelope;

(b) an electron gun and a collector in opposite ends of said envelope for establishing an elongated electron beam path therebetween;

(c) an elongated helix of uniform diameter and pitch within said envelope and coaxially surrounding said beam path;

(d) a helical input coupler coaxially surrounding said envelope and helix at the end of said helix nearest said gun;

(e) a first helical output coupler coaxially surrounding said envelope and helix at the other end of said helix;

(f) a second helical output coupler coaxially surrounding said envelope and helix in a region spaced from said first output coupler; and

(g) attenuating means, comprising a resistive helix coaxially surrounding said envelope and helix beyond said second output coupler, for absorbing all of the RF energy on said helix.

9. A traveling wave amplifier tube comprising:

(a) an elongated envelope;

(b) an electron gun and a collector in opposite ends of said envelope for establishing an elongated electron beam path therebetween;

(c) an elongated helix of uniform diameter and pitch within said envelope and coaxially surrounding said beam path;

(d) a helical input coupler coaxially surrounding said envelope and helix at the end of said helix nearest said gun;

(e) a first helical output coupler coaxially surrounding said envelope and helix at the other end of said helix;

(f) a second helical output coupler coaxially surrounding said envelope and helix in a region spaced from said first output coupler;

(g) first attenuating means, comprising a first resistive helix coaxially surrounding said envelope and helix beyond said second output coupler, for absorbing all of the RF energy on said helix; and

(h) second attenuating means, comprising a second resistive helix coaxially surrounding said envelope and helix ahead of said second output coupler, for absorbing part of the RF energy on said helix.

10. A system for transmitting RF energy from a single RF source to a number of load elements, comprising:

(a) a corresponding number of traveling wave amplifier tubes, each comprising:

(1) an electron gun and a collector determining an elongated beam path therebetween;

(2) an elongated slow wave structure extending along and coupled to said path; and

(3) RF input and output means coupled to opposite ends of said structure;

(b) means coupling said source to the input means of one of said tubes;

(c) means coupling the output means of each tube to one of said load elements;

(d) each of said tubes, except the last one, comprising an auxiliary RF output means coupled to the slow-wave structure of the tube at a point of zero db gain; and

(e) means coupling the auxiliary output means of each tube with the input means of the next tube.

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