July 5, 1955

L. M. FIELD

2,712,605

OSCILLATION GENERATOR

Filed Dec. 9, 1948

FIG. 1

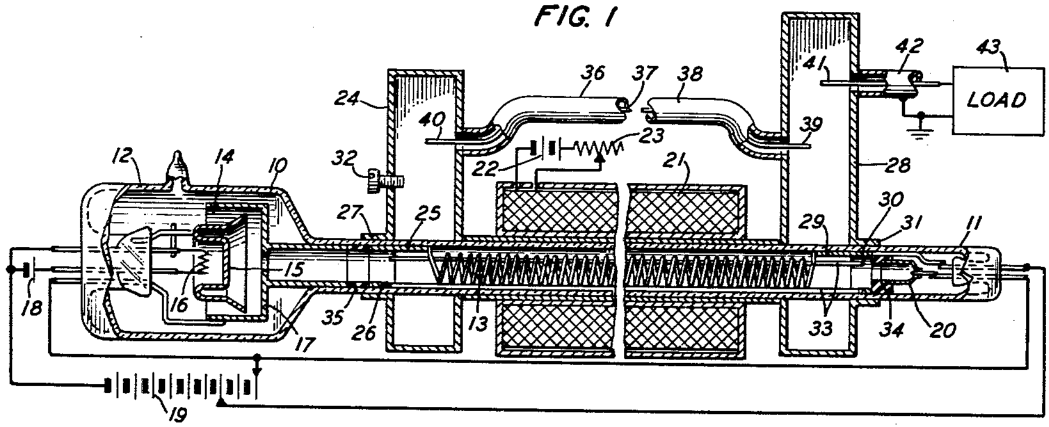


FIG. 2

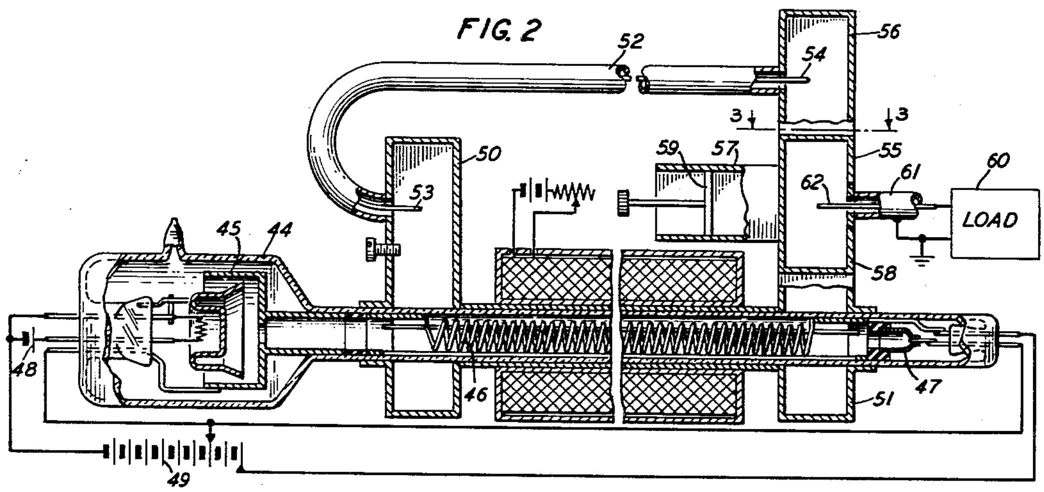


FIG. 4

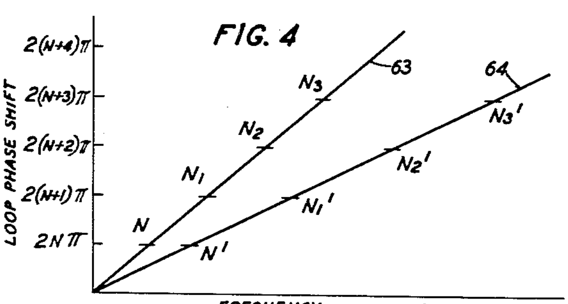
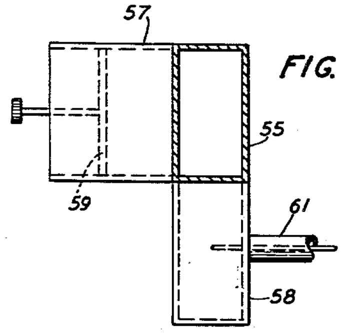


FIG. 3



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2,712,605
Patented July 5, 1955

2,712,605

OSCILLATION GENERATOR

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Application December 9, 1948, Serial No. 64,309
6 Claims. (Cl. 250—36)

This invention relates to means for generating high frequency electrical waves and more particularly to oscillation circuits utilizing traveling wave amplifying devices.

It is an object of the invention to provide new and improved methods of and means for generating high frequency electrical waves.

It is another object of the invention to provide a high frequency oscillation generator adapted to be readily adjustable over a wide range of frequencies.

There have been proposed electron beam amplifying devices wherein amplification is achieved by the interaction between the electron stream and a pure traveling wave, that is, a wave which progresses continually in a single direction without reflection, along an extended path. Such amplifying devices include a wave guide disposed along the path of the electron stream, the wave guide having an organization such that the traveling wave has electric field components in the direction of the electron stream and there is substantial equality between the speed of propagation of the wave in the direction of the stream and the speed of the electrons in the electron stream. The electron stream then reacts on the electric field of the traveling wave and the electric field reacts on the electron stream in a manner such that the wave increases in amplitude as it progresses along the path. Amplifying devices of this nature have been termed traveling wave amplifiers and have been described, for example, in copending application Serial No. 640,597, filed January 11, 1946 by J. R. Pierce, issued as United States Patent 2,636,948 on April 28, 1953, and copending application Serial No. 704,858, filed October 22, 1946 by J. R. Pierce, issued as United States Patent 2,602,148 on July 1, 1952.

The present invention contemplates novel circuit arrangements whereby traveling wave amplifying devices may be utilized to provide improved means for the generation of electrical oscillations, particularly oscillations of hyper and ultra-high frequency. The circuit arrangements include a high frequency energy feedback path connected between the output end and the input end of the wave guide incorporated in the traveling wave amplifying device. The loop thus formed may be repeatedly traversed by waves of proper frequency and phase characteristics, the amplifying action of the device being cumulative so that stable oscillations are generated. The frequency of the oscillations is primarily determined by the effective electrical length of the feedback path and one embodiment of the invention is concerned with methods of varying the length of the feedback path while the energy delivered to a load circuit remains unaffected.

The novel aspects of this invention are pointed out with particularity in the appended claims. The invention, together with further objects and the advantages thereof, may be better understood by reference to the following detailed description taken in connection with the accompanying drawing, in which:

Fig. 1 shows an embodiment of the invention illustrating the essential requirements of the circuit of the invention;

Fig. 2 shows an embodiment of the invention illustrating the use of a duplex balancer for adjusting the effective electrical length of the feedback path without affecting the energy delivered to a load;

Fig. 3 is a cross-sectional view of the duplex balancer of Fig. 2 taken along the line 3—3;

Fig. 4 is a graph useful in explaining the principles of operation of the circuits of the invention.

Referring now to Fig. 1, there is shown an illustrative embodiment of the circuit of invention employing a traveling wave amplifying device adapted for use at hyper and ultra-high frequencies. The arrangement shown comprises an electron beam tube **10** including an evacuated envelope having an elongated portion **11** and an enlarged electron-gun-containing portion **12**. The envelope is constituted of a low loss insulating material such as quartz or glass.

The discharge device **10** is provided with a source of electrons together with means for forming the electrons from the source into a concentrated stream directed axially through an elongated helix **13** disposed within the elongated portion **11** of the envelope. The illustrative combination includes a known type of electron gun **14** comprising a cathode **15**, a heater **16**, and a focussing electrode **17**. The heater **16** is supplied with energy from a source **18** and, together with the cathode **15**, is connected to the negative pole of a high potential source **19**. The focussing electrode **17** is biased to a suitable potential by the high potential source **19** and is of a configuration which provides field patterns adapted to accelerate and focus electrons from the cathode **15** into a concentrated stream. The electron stream so formed moves along an axial path through the helix **13** to a collector anode **20**, the helix and the collector anode being maintained at suitable positive potentials by the source **19**. The electron stream is further concentrated and guided along the axial path by a magnetic field formed by a coil **21** which is energized by a source **22** through a rheostat **23**. The strong magnetic field serves also to prevent the deviation of the electron stream from the desired path by outside magnetic influences.

The elongated helix **13** serves as a wave transmission path or wave guide along which high frequency waves may be propagated to interact with the electron stream flowing therethrough. In order to perform this function the dimensions of the helix must be such that the waves will be propagated in a mode having electric field components in the direction of the electron stream and at a speed along the axis of the helix of an order to which the electron stream may be accelerated by the use of moderate voltages. For accelerating voltages in the order of 1,500 to 2,000 volts, the helix may be wound with several turns per wavelength along the axis. The interaction between the electron stream and the traveling wave is cumulative and to insure an adequate interaction, the axial length of the helix may be of the order of thirty to forty wavelengths.

There are provided wave paths external to the amplifying device **10** for coupling waves or impulses to be amplified to the helix **13** and for transferring to load or other utilization circuits the amplified wave appearing at the output end of the helix. At the input end of the helix **13**, an input circuit or wave path is conventionally represented as a wave guide **24** of rectangular cross-section. The amplifying device **10** is inserted transversely through the input wave guide **24**, coupling between the guide and the helix **13** being achieved by means of an input coupling strip **25** conductively connected to the input end of the helix. There is provided a cylindrical metallic section **26** which supports the input coupling strip **25** and cooperates with a cylindrical metallic section **27**, conductively connected to the input wave guide 24, to effectively form an open circuited coaxial transmission line which has an electrical length in the order of one-fourth of the wavelength of the waves to be amplified. The transmission line thus formed acts as a low impedance path across the opening in the wall of the wave guide through which the envelope 11 is inserted and as a low impedance support point for the coupling strip 25. Similarly, at the output end of the helix the amplifying device 10 is inserted transversely through an output wave guide 28. An output coupling strip 29 is conductively connected to the helix 13 and is supported by a cylindrical metallic section 30 which cooperates with an external metallic section 31 attached to the output wave guide 28. In general, the couplings between the helix 13 and the input and output wave guides 24 and 28 may be proportioned in accordance with the considerations set forth in application Serial No. 705,181 filed October 23, 1946, by W. W. Mumford for optimum response over a wide range of operating frequencies. Necessary tuning of the external wave paths may be achieved by means such as a tuning screw 32 illustratively shown in connection with the input wave guide 24.

The helix 13 is supported by a series of non-conductive ceramic rods 33 which are disposed between the helix and the envelope 11 and which also cooperate with ceramic spacers 34 and 35 to maintain a longitudinal spaced relation between the focussing electrode 17, the input coupling strip support section 26, the output coupling strip support section 30, and the collector anode 20. The ceramic rods 33 are coated with a wave dissipative material in order to dissipate waves traveling along the helix 13 in a direction opposite to that of the electron stream, the dissipative material and the rods being organized in accordance with the considerations set forth in application Serial No. 704,198 filed October 22, 1946, by L. M. Field, and issued as United States Patent 2,575,383 on November 20, 1951.

There is provided in accordance with the invention a high frequency energy feedback path between the output wave guide 28 and the input wave guide 24, thus forming a novel circuit useful for the generation of high frequency electrical oscillations. The high frequency energy feedback path is conventionally represented as a coaxial transmission line 36 having an inner conductor 37 and an outer conductor 38. At the junction of the transmission line 36 with the output wave guide 28, the inner conductor 37 is extended into the interior of the wave guide to form a coupling probe 39, while at the junction with the input wave guide 24 the inner conductor is extended to form a coupling probe 40. Thus high frequency fields in the output circuit formed by the wave guide 28 will be communicated, at least in part, through the transmission line 36 to set up corresponding fields in the input circuit formed by the wave guide 24.

The effective electrical length of the transmission line 36 is a particularly important consideration in the practice of the invention. Accordingly, the transmission line is illustrated in a broken fashion to indicate an arbitrary length while the criteria which govern the determination of the length will be readily apparent from a subsequent discussion of the manner of operation of the illustrative embodiments of the invention.

Referring now to Fig. 2, there is shown a second illustrative embodiment of the invention, one particularly adapted to be readily tunable over a wide range of frequencies. The arrangement shown comprises an electron discharge device 44 including an electron gun 45, a helical wave transmission path 46, and a collector anode 47 and supplied by energy sources 48 and 49 similar to the arrangement of the traveling wave amplifier 10 of Fig. 1. There is similarly provided an input wave guide 50 and an output wave guide 51, coupled to the input and output ends of the helix 46 respectively, and a high frequency energy feedback path comprising a coaxial transmission line 52 and coupling probes 53 and 54, respectively.

The output wave guide 51 forms one arm of a duplex balancer 55 of which wave-guide sections 56, 57 and 58 form the remaining arms. The wave-guide section 56 forms an arm collinear with the output wave guide 51 and is coupled to the coaxial transmission line 52 by means of the coupling probe 54. The wave-guide section 57 forms a side arm of the duplex balancer and is provided with a plunger 59 for effectively varying the electrical length of the arm. The wave-guide section 58 also forms a side arm of the balancer and is coupled to a load 60 by means of a transmission line 61 and a probe 62. The physical arrangement of the duplex balancer may be more readily apparent from a consideration of Fig. 3 which is a cross-sectional view taken through the wave-guide section 56 in a direction indicated by the lines 3—3 of Fig. 2. For a discussion of the organization and manner of operation of duplex balancers generally, reference may be made to United States Patent 2,445,896 issued July 27, 1948, to W. A. Tyrrell, and to the section entitled "Balanced Duplexers" beginning on page 350 of the book, "Microwave Duplexers" by Smullen and Montgomery, of the Radiation Laboratories Series, published by McGraw-Hill Book Company, Inc. in 1948. For the purpose of this specification and the associated claims the term duplex balancer, used in the Tyrrell patent, will be employed to describe the device under discussion and will be understood to refer to the device comprising four wave transmission arms connected at a common junction point so as to provide substantial conjugacy between the two arms of each of two pairs as regards wave energy transmission over either arm toward the junction, whereby energy transmitted through one arm of a pair toward the junction is not coupled into the other (conjugate) arm of that pair and is divided equally between the arms of the other pair.

In operation, the output wave guide 51 is coupled to the helix 46 in an arrangement similar to the coupling between the helix 13 and the output wave guide 28 of Fig. 1 so that high frequency waves arriving at the output end of the helix generate waves of a dominant mode, i. e. TE_{10} waves, in the guide. Hence, in accordance with the principles of operation of duplex balancers, with such an excitation of the collinear arm formed by the wave guide 51 the side arm 57 acts as a series connection orb ranch in the electric plane while the output side arm 58 acts as a parallel connection or branch in the magnetic plane. The wave energy imparted to the output wave guide 51 by the helix 46 will then divide equally between the adjustable side arm 57 and the output side arm 58, the latter portion of the energy being conveyed to the load 60. The energy imparted to the adjustable side arm 57 is, however, reflected by the plunger 59 and returned to the junction where it will again be divided equally, this time between the collinear arms formed by the output wave guide 51 and the wave-guide section 56. The energy returned to the output wave guide 51 is dissipated along the helix 46 while a portion of the energy transmitted to the wave-guide section 56 is transmitted to the input wave guide 50.

It will thus be seen that by the employment of the duplex balancer 55 in the output circuit of the traveling wave tube, the effective electrical length of the feedback path may be varied at will while the energy imparted to a load or other utilization means remains unaffected.

The principles of operation of the circuits of the invention may be most readily appreciated while having an understanding of the significant attributes of the traveling wave amplifying devices utilized in those circuits. Briefly, the helix 13 of the illustrative device 10 of Fig. 1 acts as a wave guide for waves of proper frequencies, the waves propagating along the turns of the helix in a mode such that the electric field associated with the traveling wave has components in the direction of the electron stream. By reason of the fact that the wave travels along the circumference of the helix, the axial velocity of the wave is such that there is substantial equality between the speed of the electrons in the electron stream and the speed of propagation of the wave. Under such conditions the interaction between the electron stream and the wave increases the amplitude of the wave as it progresses along the helix.

A wave, in traveling over the helix from the input coupling strip **25** to the output coupling strip **29**, will, in the absence of the electron stream, undergo a change in phase determined solely by the geometry and electrical characteristics of the helical wave transmission path. However, in view of the electrodynamic aspects of the wave as it propagates along the helix in the presence of an electron stream, the total phase shift of the wave in traversing the helix in the presence of an electron stream is also dependent upon the velocity of the electrons. Thus for every electron stream velocity as determined by the potentials applied to the focussing electrode **17**, the helix **13**, and the collector anode **20**, there corresponds a value of phase shift experienced by a wave of a particular frequency in traversing the helix. Further, the total phase shift of the wave in traversing the helix will be a linear function of frequency, at least over restricted ranges of frequencies.

Referring again to the circuit of Fig. 1, it will be seen that by the introduction of the transmission line **36** between the output wave guide **28** and the input wave guide **24** there is formed a loop which may be traversed many times by certain electrical waves to build up oscillations of a desired amplitude. Thus, using the output coupling strip **29** as a reference point, the loop includes the output wave guide **28**, the coaxial transmission line **36**, the coupling between the output wave guide and the transmission line shown as the probe **39**, the input wave guide **24**, the coupling between the input wave guide and the coaxial transmission line shown as the probe **40**, the input coupling strip **25**, and the helix **13**. It is characteristic of the circuit elements of the loop that, like the helical wave transmission path, the phase shift experienced by a wave in traversing those elements is, at least for restricted ranges of frequency, a linear function of frequency. The total phase shift around the complete loop will be termed "loop phase shift" as distinct from the phase shift through the helix alone, which will be termed the "helix phase shift" utilizing the input and output coupling strips **25** and **29** as points of reference.

In the amplifying device **10**, voltages and currents of random frequency and phase distributions are always present in the helix **13** as random fluctuations over a wide band of frequencies. Over the bands of frequencies for which the output wave guide **28** will propagate these fluctuations as waves, certain of the waves will be in modes which may be imparted to the transmission line **36** by the coupling probe **39**. Such high frequency wave energy will thus be transmitted to the input wave guide **24** and further impressed upon the input coupling strip **25**. Thus waves corresponding to certain of those initiated at the output coupling strip **29** will be propagated along the helix **13** to be amplified by interaction with the electron stream.

Since the action just described takes place over wide bands of frequencies and phases, it will be seen that certain of the waves will experience a loop phase shift which is an integral multiple of 2π radians. That is, in traversing the loop from a reference point, in this case the output coupling strip **29**, some wave or waves will return to the reference point having a phase which differs from the starting phase by $2N\pi$ radians, where N is an integral number. Such waves will continue to traverse the loop, being increased in amplitude for each circuit by the action of the amplifying device until a limiting amplitude is reached, the limiting amplitude being dependent upon the voltage and current characteristics of the amplifying device. The waves thus generated are of characteristic frequency and amplitude suitable for utilization as electrical wave energy.

Referring now to Fig. 4, the operation of the illustrative embodiments of the invention may further be understood by a consideration of the circuit relationships as indicated in graphic form. There is shown the loop phase shift as a function of frequency, plotted as the ordinate and the abscissa respectively. A curve **63** indicates the loop phase shift as a straight line or linear function of frequency for a first loop length while a second curve **64** indicates the loop phase shift as a linear function of frequency for a second loop length. The points corresponding to phase shifts of integral multiples of 2π radians are the frequencies or modes at which oscillation may take place and are indicated as points N, N_1, N_2, and N_3 on curve **63** and as points N′, N'_1, N'_2, and N'_3, on curve **64**. It will now be apparent that the slope of the phase-frequency characteristic is determined by the effective electrical length of the loop so that, by proper choice of the electrical length of the feedback path, the frequency of various modes of oscillation characterized by the letters N, N_1, etc. may be determined as well as the frequency separation between the modes. In particular, the effective loop length may be varied by varying the length of the coaxial transmission line **36** in the embodiment of Fig. 1 and by adjusting the plunger **59** in the embodiment of Fig. 2.

The mode in which the circuit will normally oscillate is determined largely by the attenuation characteristics of the loop, taken either statically or dynamically. Thus there will be some narrow band of frequencies, in large part determined by the elements utilized for coupling between the input and output wave guides and the helix and between the input and output wave guides and the energy feedback path, at which the attenuation is a minimum. The system will then oscillate in the mode having a frequency most nearly coinciding with the frequency of minimum attenuation. Alternatively, where the attenuation around the loop is essentially uniform over several possible modes, the system will oscillate in the mode at which the amplification of the amplifying device is maximum.

The amount of energy imparted to the input wave guide or circuit is determined by the amount of coupling between the high frequency energy feedback path and the input and output circuits. In general, the amount of feedback energy necessary will be dictated by practical considerations such as, for example, the power requirements and the effective amplification of the amplifying device.

What is claimed is:

1. In oscillation apparatus, in combination, a traveling wave amplifier wherein amplification of high frequency waves is achieved through interaction between an electron stream and a high frequency electric field associated with the waves to be amplified over an extended distance along the transmission path of the wave, said traveling wave amplifier having an input circuit and an output circuit, a high frequency energy feedback circuit operatively connected to said input circuit, a load circuit, and means comprising a balanced, branched wave transmission network connected between said output circuit, said load circuit, and said feedback circuit, with the load circuit connected to an arm of the network which is conjugate to an arm of variable length controlling the electrical length of the energy feedback path, for effectively separating oscillation energies transmitted from the said output circuit to the said load circuit and to the said feedback circuit respectively.

2. Apparatus for generating high frequency electrical oscillations comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, wave transmission means disposed along said path whereby high frequency waves propagated over the said transmission means will interact relatively con-

tinuously with the said electron stream to produce amplification of the said waves, the said wave transmission means having an input end and an output end, and a four-arm duplex balancer, one arm of the duplex balplification of the said waves, the said wave transmission mission means, one arm being coupled to said input end of the wave transmission means, one arm being connected to a load circuit and one arm providing a reflecting circuit adjustable in electrical length.

3. Apparatus for generating high frequency electrical oscillations comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, wave transmission means disposed along said path whereby high frequency waves propagated over the said transmission means will interact relatively continuously with the said electron stream to produce amplification of the said waves, the said wave transmission means having an input end and an output end, and a four-arm duplex balancer coupled to said output end of the wave transmission means to provide a hybrid junction with two arms conjugate to each other connected to the input and output ends respectively of the wave transmission means and the two other arms conjugate to each other connected respectively to a load circuit and a reactive reflecting circuit which is adjustable in electrical length.

4. Apparatus for generating high frequency electrical oscillations comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, wave transmission means disposed along said path whereby high frequency waves propagated over the said transmission means will interact relatively continuously with the said electron stream to produce amplification of the said waves, the said wave transmission means having an input end and an output end, and a four-arm duplex balancer comprising four wave transmission arms connected at a common junction point so as to provide substantial conjugacy between the two arms of each of two pairs as regards wave energy transmission over either arm toward the junction, whereby energy transmitted through one arm of a pair toward the junction is not coupled into the other arm of that pair and is divided equally between the arms of the other pair, one arm of the duplex balancer being coupled to said output end of the wave transmission means, one arm being coupled to said input end of the wave transmission means, one arm being connected to a load circuit and one arm providing a reflecting circuit adjustable in electrical length.

5. Apparatus for generating high frequency electrical oscillations comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, wave transmission means disposed along said path whereby high frequency waves propagated over the said transmission means will interact relatively continuously with the said electron stream to produce amplification of the said waves, the said wave transmission means having an input end and an output end, and a four-arm balanced, branched wave transmission network coupled to said output end of the wave transmission means to provide a hybrid junction with two arms conjugate to each other connected to the input and output ends respectively of the wave transmission means and the two other arms conjugate to each other connected respectively to a load circuit and a reactive reflecting circuit which is adjustable in electrical length.

6. Apparatus for generating high frequency electrical oscillations comprising a source of electrons, means for forming electrons from said source into a stream along an extended path, wave transmission means disposed along said path whereby high frequency waves propagated over the said transmission means will interact relatively continuously with the said electron stream to produce amplification of the said waves, the said wave transmission means having an input end and an output end, and a four-arm duplex balancer comprising four wave transmission arms connected at a common junction point so as to provide substantial conjugacy between the two arms of each of two pairs as regards wave energy transmission over either arm toward the junction, whereby energy transmitted through one arm of a pair toward the junction is not coupled into the other arm of that pair and is divided equally between the arms of the other pair, two of said arms conjugate to each other being connected to the input and output ends respectively of the wave transmission means and the other two arms conjugate to each other being connected respectively to a load circuit and a reactive reflecting circuit which is adjustable in electrical length.

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