Oct. 1, 1946. J. W. CLARK 2,408,410

FREQUENCY CONVERTER

Filed June 19, 1941 2 Sheets-Sheet 1

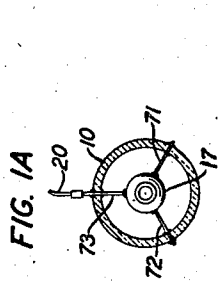


FIG. 1A

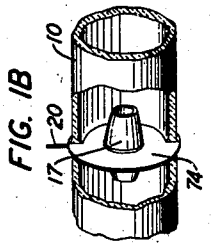


FIG. 1B

FIG. 1

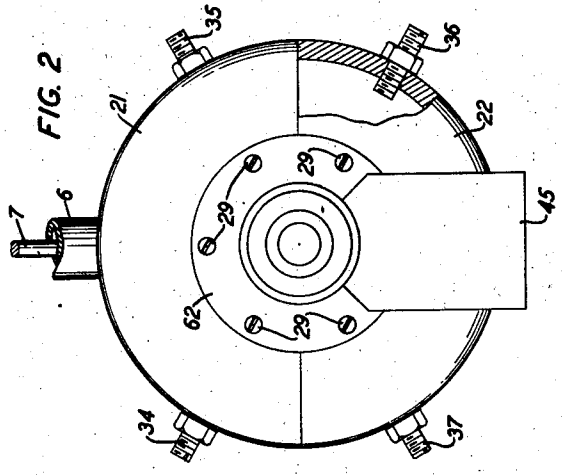


FIG. 2

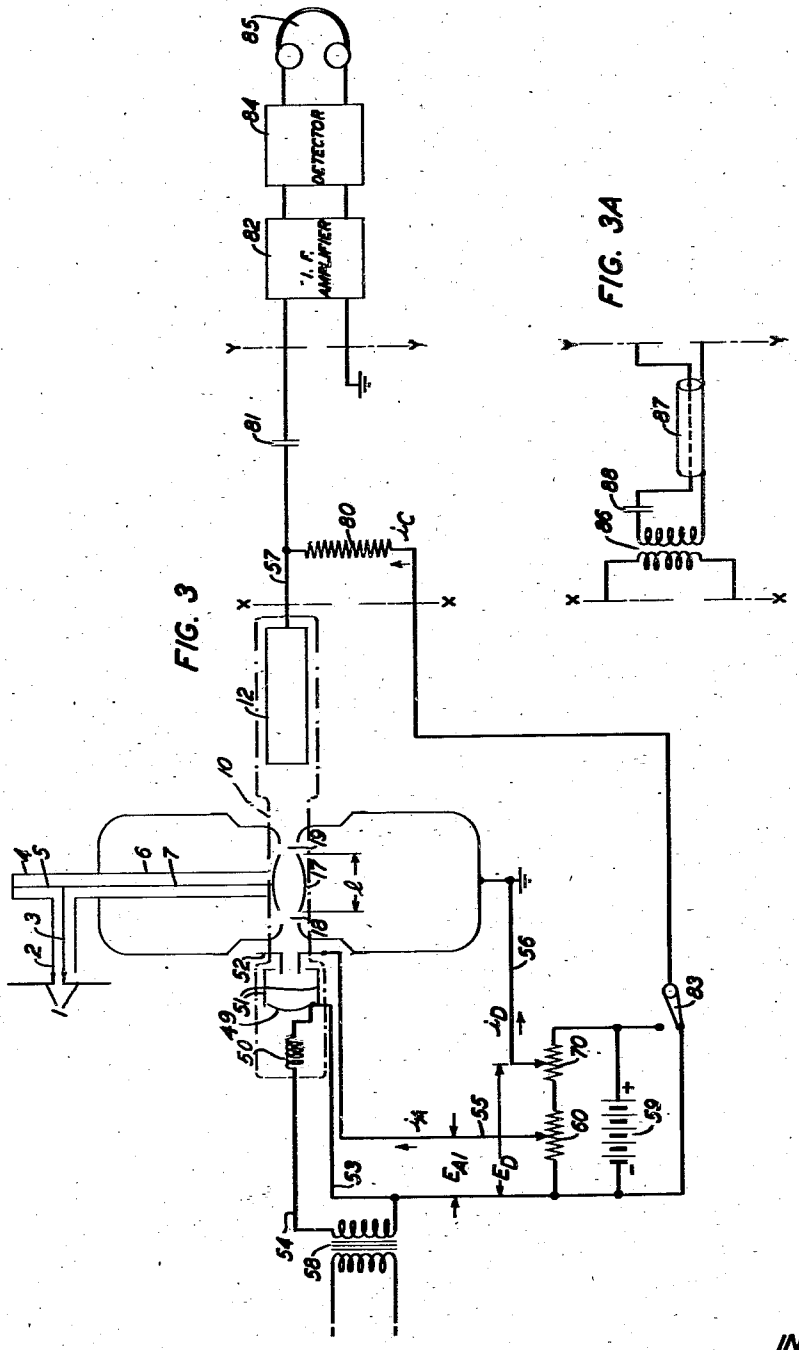
INVENTOR
J. W. CLARK

BY
Franklin Mohr
ATTORNEY

Oct. 1, 1946. J. W. CLARK 2,408,410

FREQUENCY CONVERTER

Filed June 19, 1941 2 Sheets-Sheet 2



INVENTOR
J. W. CLARK

BY
Franklin Mohr

ATTORNEY

Patented Oct. 1, 1946 2,408,410

UNITED STATES PATENT OFFICE

2,408,410

FREQUENCY CONVERTER

John W. Clark, Chatham, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 19, 1941, Serial No. 398,757

7 Claims. (Cl. 315—5)

1

This invention relates to modulating system for ultra-high frequency electromagnetic waves and currents and is particularly applicable to waves a few centimeters or less in wave-length. The invention relates more especially to a frequency converter, mixer, or first detector in a superheterodyne radio receiving system.

An object of the invention is to simplify the construction and operation of a superheterodyne radio receiver adapted for use in the ultra-high frequency range.

A feature of the invention is a compact means for introducing a received signal wave into the interior of a hollow resonator in an ultra-high frequency electron velocity variation type of oscillator to effect frequency conversion with no substantial disturbance to the normal operation of the oscillator and with high efficiency of conversion.

Another feature of the invention resides in impressing the received signal-modulated wave between the drift tube and the adjacent electrodes in a single cavity type of oscillator, effectively across the input and output gaps in parallel.

In accordance with the invention, the beating oscillator is of a type employing electron velocity variations, operated substantially in the normal manner, and provision is made for impressing the incoming signal modulated wave substantially simultaneously across the input and output gaps effectively in parallel. A velocity variation in accordance with the incoming wave is superposed upon the velocity variation due to the local oscillations. The velocity varied electron stream is then subjected to a conversion process to develop density variations. Any non-linearity in the conversion process will result in the appearance of modulation components, for example, sum and difference frequencies, in the density variations. To secure a relatively low intermediate frequency, the difference frequency component may be utilized. The modulation components may be developed at the collector electrode in various ways, as, for example, by operating the collector at a retarding potential adjusted to turn back the slower moving electrons. Alternately, the collector electrode may be operated at an electron accelerating potential or a substantially field-free drift space may be provided in which bunching of the electrons may take place in any suitable manner.

In the drawings:

Fig. 1 is a perspective view of an oscillator

2

modified in accordance with the invention, shown partially cut away;

Figs. 1A and 1B show alternative details which may be substituted in the arrangement of Fig. 1;

Fig. 2 is an end view of the structure of Fig. 1, shown partially cut away;

Fig. 3 is a schematic diagram of a superheterodyne radio receiver embodying the invention; and

Fig. 3A shows an alternative coupling arrangement which may be substituted for a portion of the circuit shown in Fig. 3.

Referring to the drawings, there is shown in Figs. 1 and 2 a resonant cavity oscillator of the electron velocity variation type such as is disclosed in application Serial No. 386,794 filed April 4, 1941, by A. E. Anderson and A. L. Samuel and assigned to the assignee of the present application. My oscillator structure herein disclosed includes certain modifications to accommodate the introduction of waves intercepted by a doublet antenna 1, or other means of intercepting ultra-high frequency power. The respective branches of the antenna or other interceptor are connected with the outer conductor 2 and inner conductor 3 of a suitable coaxial transmission line. The line 2, 3 preferably has two branches, one of which, comprising an outer conductor 4 and an inner conductor 5, is an adjustable tuning stub. The other branch, comprising an outer conductor 6 and an inner conductor 7, is fitted through an aperture in the semicylindrical casing section 21 of the Anderson-Samuel oscillator. Throughout the drawings the elements which are the same as corresponding elements in the Anderson-Samuel oscillator have been given the same reference numeral as in the drawings of the Anderson-Samuel application. The cylindrical insulating envelope 10 of the oscillator, for example, a glass tube, encloses an electron gun shown generally at 11, together with an electron collecting electrode or collector 12. Between the electron gun 11 and the collector 12 there are sealed into and through the walls of the envelope 10 a pair of disc members 13 and 14 formed respectively into protruding, approximately conical electrodes 15 and 16, coaxial with the electron gun and provided with aligned apertures at their respective apices for the passage therethrough of an electron stream or beam from the electron gun. A tube 17, referred to herein as the drift tube, is axially mounted between the electrodes 15 and 16 and has aligned apertures at its ends for the entrance and exit of the electron beam. The electrodes 15 and 16, in cooperation with the respective adjacent ends of the disc tube 17, form a pair

of gaps 18 and 19 which will be referred to respectively as the input gap and the output gap. The discs 13 and 14 and the drift tube 17 are preferably of highly conductive material, for example, copper. The discs 13 and 14 are hermetically sealed into and through the walls of the tube 10 by any suitable process or form of seal, for example, a copper-glass seal. The drift tube 17 has attached to it a conductive rod 20, by which it is supported in position and by means of which electrical contact may be made from the exterior of the envelope 10. The conductor 20 is sealed into and through the wall of the envelope 10 through a glass bead or other suitable hermetic seal. Alternatively, three supporting rods 71, 72 and 73 may be employed as shown in Fig. 1A, or the drift tube may be supported by a disc electrode 74 as shown in Fig. 1B. The inner conductor 7 is conductively connected to the drift tube 17 in any suitable manner as, for example, by means of the rod 20, or by one of the rods 71, 72 and 73 shown in Fig. 1A, or by connection to the disc electrode 74 of Fig. 1B. The outer conductor 6 is conductively connected to the casing 21 as by means of a snug frictional engagement or in other suitable manner.

The tuning stub comprising the outer conductor 4 and inner conductor 5 may be adjusted by means of an annular piston 8 of conductive material connected by rods or other suitable means with a knob 9.

In the oscillator, the discs 13 and 14 form a portion of the walls of the resonant chamber or cavity resonator together with the casing sections 21 and 22, which sections fit closely together and are provided with milled semiannular surfaces 23 and 24, respectively, which fits snugly inside the edges of the disc members 13 and 14. A pair of cylindrical collars 25 and 26 of magnetic material, provided with flanges 27 and 28, respectively, are placed over the tube 10 and against the outer surfaces of the respective disc members 13 and 14. On one side of the casing a ring 61 and screws 29 are provided so that when the screws are tightened the disc 13 and flange 27 are clamped securely between the ring 61 and surfaces 23 and 24 on the casing. A similar ring 62 and screws 29 are provided on the other side of the casing.

A plurality of plungers, in the form of screws 34, 35, 36 and 37, are threaded into the walls of the casing sections 21 and 22 for altering the size and shape of the resonant cavity for tuning purposes.

A permanent magnet 45 has pole-pieces extending perpendicular to the main body, the pole-pieces being milled out with cylindrical depressions at 46 and 47 to form a cradle to support the cylindrical collars 25 and 26, respectively. The tube assembly including the collars is held to the permanent magnet by the magnetic force and, in addition, the lower half section 22 of the casing may be secured to the middle portion of the permanent magnet by means of a screw 48. If desired, the magnet 45 may be attached to a base plate or other mounting in any suitable manner. A U-shaped magnet or one of other suitable shape may be used in place of the one illustrated, or an electromagnet may be substituted for the permanent magnet.

The electron gun 11 may be of the type disclosed in Figs. 3 and 4 of the Anderson-Samuel application, comprising a dished cathode 49 arranged to be heated by a heating element 50, as shown schematically in Fig. 3 herein. A shaping electrode 51 for forming the electrons emitted from the cathode 49 into a conical beam in cooperation with the shape of the cathode may be provided in the vicinity of the cathode as shown schematically in the figure. The electrode 51 is preferably electrically connected with the cathode. An accelerating electrode 52 serves to regulate the beam current and in conjunction with the shaping electrode 51 to focus the beam at approximately the center of the input gap 18. One side of the heating element 50 may be connected to the cathode within the tube 10 and brought out of the tube by means of the common lead 53. In that case, the lead 53, together with the remaining heater lead 54 and a lead 55 from the accelerating electrode 52 constitute the external connections from the electron gun. The remaining electrical connections to the oscillator comprise a lead 56 connected with the walls of the resonant chamber, which lead 56 may conveniently be grounded or connected with the mounting plate, and a lead 57 connected to the collector 12. The leads 53, 54, 55 and 57 are brought out through the walls of the tube 10 in suitable presses or seals.

The interconnections of the tube with suitable sources of biasing potential and heating current are shown schematically in Fig. 3. 58 is a power transformer or other source of suitable current for operating the heating element 50. The lead 53 is connected to the negative terminal of a biasing battery or other source of biasing potential 59. The lead 55 from the accelerating electrode 52 is connected to the variable contactor of a potentiometer 60, one of the two potentiometers 60 and 70 connected in shunt across the battery 59. The lead 56 from the resonator is connected to the variable contactor of the potentiometer 70 and may be grounded. If desired, the potentiometers 60 and 70 may be replaced by a single potentiometer with two contacts, either or both of which contacts may in some cases be fixed.

The head 57 from the collector 12 is connected to the common terminal of a resistor 80 and a condenser 81, the remaining terminal of the condenser being connected to one of the input terminals of an intermediate frequency amplifier 82. The remaining input terminal of the amplifier 82 is preferably grounded. The remaining terminal of the resistor 80 is connected to a point in the power supply circuit, for example, either to the negative or to the positive terminal of the battery 59. A switch 83 is shown in Fig. 3 whereby either of the latter two connections may be selected as desired. The output terminals of the intermediate frequency amplifier 82 are connected to the input terminals of a detector 84, which is connected to a suitable translating device such as a telephone receiver 85.

An alternative coupling arrangement for use between the collector 12 and the intermediate frequency amplifier 82 is shown in Fig. 3A and may be substituted for the portion of the circuit in Fig. 3 shown between the broken lines X and Y. In Fig. 3A, 86 is a transformer suitable for operation at the desired intermediate frequency, as, for example, a special air core transformer designed for 60 megacycles, or other convenient frequency. The secondary winding of the transformer is connected to a coaxial transmission line 87 through a coupling condenser 88. As the coaxial transmission line will usually be of relatively low impedance, say 70 ohms, the transformer 86 is preferably designed with a stepdown im-

pedance ratio to match the impedance of the collector circuit, which may be of the order of 6000 ohms.

In the operation of the system as shown in the figures, the oscillator functions to sustain electromagnetic waves of ultra-high frequency within the resonant cavity in substantially the same manner as described in the Anderson-Samuel application, to which reference may be made for a more complete description. The introduction of the coaxial transmission line 6, 7 into the resonating cavity has substantially no effect upon the mode of operation in the production of sustained oscillations. Since the conductors of the line are substantially radial they are approximately perpendicular to the lines of electrical intensity in the cavity, and, therefore, do not materially alter the configuration of the field. The main difference is a small change in the effective shape and volume of the cavity and a resultant difference in the resonating frequency, which may be allowed for in the design of the resonator. The function of the oscillator in the present arrangement is to establish a strong electric field of the resonant frequency across both the input gap 18 and the output gap 19. The antenna 1 is designed for the reception of a desired high frequency and the resonant frequency of the oscillator is preferably chosen to differ from the frequency to be received upon the antenna by an amount just equal to a desired intermediate frequency. The piston 8 is adjusted to resonate the line to the incoming frequency in known manner to impress a maximum alternating voltage upon the drift tube 17. The voltage thus applied is effectively in parallel between the drift tube and the electrodes 13 and 14, respectively.

Referring more specifically to the operation of the system as a modulator, frequency converter or first detector, it will be evident that the incoming signal waves and the locally generated waves are superimposed upon the input gap 18 and the output gap 19 in such manner as to simultaneously impress velocity variations upon the electrons passing through the gaps. It is known that velocity variations in an electron stream may be converted by various means into successions of density variations of the same stream at some point later traversed by the stream. It is also known that the process of conversion from velocity variations to density variations may be a non-linear one, so that modulation products such as sum and difference frequencies appear in the density variations so produced. In the present system, the conversion may be accomplished in at least two ways, either one of which may be selected by means of the switch 83. In accordance with one method, the switch 83 is placed in the lower position, as shown, so as to connect the collector 12 to the negative terminal of the battery 59, thereby placing the collector at substantially the same direct current potential as the cathode 49. The electrons, after passing the output gap 19, are in this case subjected to a strong retarding field. Having different velocities, the individual electrons possess different amounts of kinetic energy and are able to penetrate respectively different distances against the retarding field before being stopped and their motion reversed by the field. By proper adjustment of the initial velocity of the electron stream, it is possible to arrange matters so that the faster electrons strike the collector 12 while the slower electrons are turned back. The density variations above referred to are in this case effected by a sorting out of the electrons on the basis of their velocity, the faster electrons entering the collector. The process is analogous to rectification and in a similar manner, as in the use of a rectifier as a modulator or converter, sum and difference frequencies are produced in the resultant current. The difference frequency with respect to the incoming waves and the local oscillations is usually chosen as the intermediate frequency in order to take advantage of a relatively low frequency in the intermediate frequency amplifier. The modulation products in the collector circuit carry the original signal modulation as received at the antenna and the intermediate frequency component may be selected, and amplified, and subjected to a second detection to reproduce the original signals as in any superheterodyne radio receiving system. The intermediate frequency amplifier 82, detector 84 and translating device 85 are not shown in detail, as they may be of any suitable type.

When the switch 83 is placed in the upper position, the collector is connected to a positive portion of source 59, or other suitable potential to provide an electron accelerating effect in the space between the output gap 19 and the collector 12. All the electrons, in this case, are drawn to the collector but due to their unequal velocities they become somewhat grouped into bunches while traversing the distance between the output gap 19 and the collector 12. It is known that this process of bunching is generally a non-linear one. Consequently, modulation components appear in the density variations of the electron stream as it strikes the collector electrode 12, and an intermediate frequency component is impressed upon the coupling circuit with results similar to those described in the preceding case.

What is claimed is:

1. In a frequency converter, an oscillator comprising a resonating chamber for ultra-high frequency waves, a drift tube enclosed within said chamber, and said chamber walls and said drift tube having aligned apertures, means for directing a stream of electrons through said apertures whereby said electron stream is velocity varied by electromagnetic waves within said chamber, and means for adjusting the transit time of the electrons traversing said drift tube to initiate and sustain said oscillations; means for impressing between said drift tube and said chamber walls a wave having a frequency comparable to but different from the frequency of said oscillations whereby a second velocity variation is superposed upon said electron stream, and means non-linearly responsive to velocity variations of said electron stream, operative upon a doubly velocity-varied portion of the stream.

2. A system in accordance with claim 1 in which the non-linearly responsive means comprises means for sorting electrons on a basis of different electron velocities.

3. A system in accordance with claim 1 in which the non-linearly responsive means comprises means for converting velocity variations of the electron stream into electron density variations in the stream.

4. A system in accordance with claim 1 in which the non-linearly responsive means comprises means for grouping electrons into bunches in accordance with their differing velocities.

5. In a frequency converter, an oscillator comprising a resonating chamber for ultra-high frequency waves, a drift tube enclosed within said chamber, and said chamber walls and said drift

tube having aligned apertures, means for directing a stream of electrons through said apertures whereby said electron stream is velocity varied by electromagnetic oscillations within said chamber, and means for adjusting the transit time of the electrons traversing said drift tube to initiate and sustain said oscillations; a coaxial line for ultra-high frequency waves, said line extending radially through the wall of said chamber, the outer conductor of said line being conductively connected to the walls of said chamber and the inner conductor of said line being conductively connected to said drift tube, means for impressing upon said coaxial line waves having a frequency comparable to but different from the frequency of said oscillations and non-linearly operative means responsive to velocity variations of said electron stream.

6. In a frequency converter, a resonating chamber for ultra-high frequency waves, the wall of said chamber being apertured to admit an electron stream into the interior thereof, means to inject an electron stream through said aperture, a drift tube supported within said resonating chamber, said drift tube being arranged to surround said electron stream and to define together with the chamber wall a pair of gaps traversed by said electron stream, means cooperating with said drift tube, said chamber wall, and said electron stream for producing sustained electromagnetic oscillations within said resonating chamber at a resonant frequency thereof, a transmission line having concentric inner and outer conductors extending in a direction perpendicular to the lines of force of the electric field within said resonating chamber, said transmission line passing through the wall of said resonating chamber and extending through a substantial portion of the interior space of said resonating chamber, means

electrically connecting the outer conductor of said line to the wall of said resonating chamber, means electrically connecting the inner conductor of said line to said drift tube and an external wave source connected to said transmission line.

7. In a frequency converter, a resonating chamber for ultra-high frequency waves, the wall of said chamber being apertured to admit an electron stream into the interior thereof, means to inject an electron stream through said aperture, a drift tube supported within said resonating chamber, said drift tube being arranged to surround said electron stream and to define together with the chamber wall a pair of gaps traversed by said electron stream, means cooperating with said drift tube, said chamber wall, and said electron stream to produce sustained electromagnetic oscillations within said resonating chamber at a resonant frequency thereof, a transmission line having concentric inner and outer conductors extending in a direction substantially perpendicular to the lines of force of the electric field within said resonating chamber, said transmission line passing through the wall of said resonating chamber and extending through a substantial portion of the interior space of said resonating chamber, means electrically connecting the outer conductor of said line to the wall of said resonating chamber, means electrically connecting the inner conductor of said line to said drift tube, an external wave source connected to said transmission line and means for tuning said transmission line to the frequency of said external wave source to impress substantial potentials at the frequency of said external wave source across at least one of said gaps in superposition with potentials developed by said sustained electromagnetic oscillations.

JOHN W. CLARK.