June 26, 1951 S. RAMO 2,558,001

GENERATION OF ELECTROMAGNETIC WAVES BY DOPPLER EFFECTS

Original Filed March 15, 1945

Fig. 1.

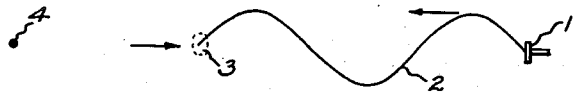


Fig. 2.

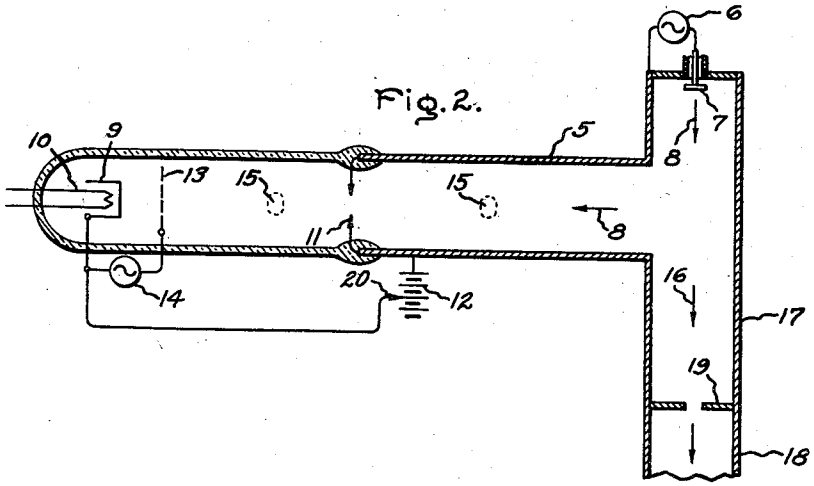


Fig. 3.

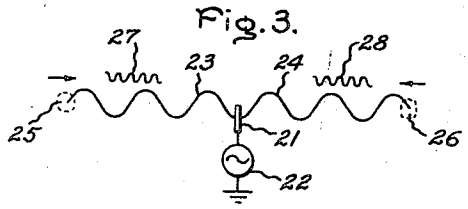
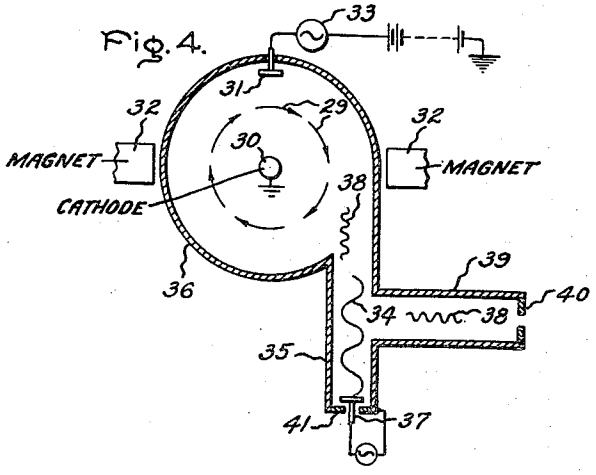


Fig. 4.



Inventor:
Simon Ramo,
by Harry R. Mayers
His Attorney.

Patented June 26, 1951

2,558,001

UNITED STATES PATENT OFFICE

2,558,001

GENERATION OF ELECTROMAGNETIC WAVES BY DOPPLER EFFECTS

Simon Ramo, Los Angeles, Calif., assignor to General Electric Company, a corporation of New York

Original application March 15, 1945, Serial No. 582,916. Divided and this application June 12, 1948, Serial No. 32,615

2 Claims. (Cl. 250—36)

1

This application is a division of my copending application, Serial No. 582,916, filed March 15, 1945. The present invention relates to the generation of electric waves and is concerned primarily with new and improved methods and means for generating waves of electric energy by the utilization of Doppler effects.

It is known that a source of waves moving with respect to an observer appears to that observer to have a frequency different from the emission frequency of this source by an amount dependent upon the velocity of the source relative to the observer. The frequency appears to be greater or less than the true value according to whether the distance between the source and observer is being diminished or lengthened. This is true for waves transmitted through a stationary medium and applies to electromagnetic waves, as well as sound and light waves. It is an object of my invention to utilize this principle for the generation of electromagnetic waves having extremely short wave lengths.

It is another object of my invention to provide new and improved means for converting electromagnetic waves of a given wave length to waves of a different wave length, either shorter or longer.

It is a still further object of my invention to provide new and improved methods and means for producing electromagnetic waves having a length of the order of one millimeter.

It is a further object of my invention to provide new and improved methods and means for producing extremely short waves at a minimum power loss.

It is a still further object of my invention to provide a new and improved system for producing frequency modulated high frequency waves.

It is a still further object of my invention to provide a new and improved system for producing frequency modulated high frequency waves which permits accurate control of the center frequency of the output waves.

It is a still further object of my invention to provide a new and improved method and means for producing frequency modulation of waves from sources of ultra high frequency waves which do not in themselves readily permit shifting of frequency.

It is a still further object of my invention to provide new and improved means and method for producing frequency modulated converted waves.

In its broad aspect, my invention consists in reflecting electromagnetic waves of a given frequency from a moving electric charge to produce another electromagnetic wave of a different frequency, the difference in frequency between the two waves being a function of the relative velocities of the moving charge and the incident electromagnetic wave. In another of its aspects, the invention contemplates production of extremely short waves by obtaining multiple reflections between moving charges and electromagnetic waves. In still another of its aspects, the invention consists in moving a modulated charge relative to a stationary wave transmitting system to produce an effect upon the output of the system which is a function of the movement of the charge.

2

For a better understanding of my invention, reference may be had to the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims. Fig. 1 of the drawing illustrates basically the interaction of moving charges and electromagnetic waves to produce other electromagnetic waves by Doppler effects; Fig. 2 illustrates schematically an ultra high frequency generator employing the principles of the basic illustration of Fig. 1; Fig. 3 shows a modification of the invention as applied to the source of moving charges; Fig. 4 illustrates apparatus for producing electromagnetic waves by the interaction of a rotating space charge and an electrowave.

In Fig. 1 there is shown a stationary source 1 which may be for example a probe or other type of electrode for producing an electromagnetic wave 2, the wave 2 being indicated as moving to the left in this figure. The numeral 3 represents a high speed electric charge moving in a direction opposite to that of the electromagnetic wave 2. I have discovered that the interaction of the electromagnetic waves 2 of a stationary source with a high speed charge 3 may be utilized to produce a Doppler effect for generating an additional electromagnetic wave. For maximum utilization of the theoretical possibilities of the effect, relatively high speed electrons may be used. The formula for describing the Doppler effects without making any approximations is as follows:

$$f' = \frac{1+B}{\sqrt{1-B^2}} f \qquad (1)$$

where f and f' are the frequencies observed by one moving with the source of waves and one who has a relative velocity with respect to the source, respectively.

$$B = \frac{v}{c}$$

where v is the relative velocity of the two observers and c is the velocity of light. The charge 3 may be for example a group of electrons, that is a region holding electric charge which is moving toward the source 1 with the velocity v, the source 1 being at rest and emitting an electromagnetic wave having a frequency as measured by a stationary observer as f_o. The frequency f_e which the electrons of the charge 3 see is

$$f_e=\frac{1+B}{\sqrt{1-B^2}}f_o \qquad (2)$$

Accordingly, the electrons of the charge 3 are caused to vibrate around their average position because of the electromagnetic forces of the incident waves 2, the frequency of such a vibration having the value f_e. In so vibrating, the electrons send out electromagnetic waves, these waves being a dispersion or reflection of the original impinging waves from the source 1, of course. To an imaginary observer, however, who moves with the charge 3, the waves appear as being emitted with a frequency f_e.

To an observer at the point 1, the waves emitted from the source 2 appear as waves received from a moving source, the frequency of the received reflected waves being

$$f_r=\frac{1+F}{\sqrt{1-B^2}}f_e \qquad (3)$$

When Equation 2 is combined with Equation 3, the resultant value of the reflected wave is

$$f_r=\frac{1+B}{1-B}f_o \qquad (4)$$

This is the value of the frequency of the reflected waves observed at the point 1. It is apparent that to another stationary observer, at the point 4, for example, who is behind the group of moving electrons 3, the sign of B is reversed and this observer will receive waves dispersed from the source 1 at the original frequency f_o, as well as waves generated by the vibrating electrons 3 due to the interaction between the electromagnetic waves 2 and the electrons 3. These newly generated waves have a frequency f_r' which is less than the frequency of waves from the source 1. Since, by the utilization of sufficiently high voltages in producing the high speed moving charge 3, it is possible to accelerate the electron charge to values at which B is close to unity, it is possible to obtain values of f_r which are substantially greater than f_o. For example, if a wave emitted by the source 1 has a wave length of the order of one centimeter, by the use of a voltage of approximately 300,000 volts one obtains high speed electrons having a value of B of approximately .8 and through the interaction of such high speed electrons with the one centimeter wave, a one millimeter wave is dispersed from the electron.

Fig. 2 illustrates diagrammatically apparatus for producing extremely short waves in the manner explained above. A dielectric wave guide 5 formed by suitable conductive enclosing walls is supplied with electromagnetic waves having a frequency f_o from a source 6 through any suitable coupling means, such as a probe 7, the waves being indicated by the arrows 8. A beam of electrons is emitted from an electron gun 9, the gun having the usual heating element 10, and is directed into the wave guide 5 through an iris or filter 11 used for reflecting the electromagnetic waves 8 to prevent their transmission through the open end of the wave guide 5.

The wave guide 5 functions likewise as the anode of a tube of which the gun 9 forms the cathode, accelerating potentials for electrons emitted from the gun 9 being supplied by a source of voltage, such as the battery 12. The electrons may be caused to enter the wave guide 5 as pulses of charge by the operation of a grid 13 and a high frequency modulating voltage 14. The most desirable frequency for the modulating voltage 14 from the point of view of efficiency of the electromagnetic wave generating system is a function of the dimensions and geometry of the wave guide, as well as the current density of the pulses of charge 15 and the accelerating voltage. It is apparent that, when many pulses exist in the wave guide at one time, a greater reflection of energy of the waves from the source 7 is obtained. It is important, however, that the wave guide 5 is not completely filled with a uniform space charge to prevent the medium within the guide from acting simply as a stationary medium of different dielectric constant. To this end, preferably the modulating voltage 14 is of a frequency high enough to insure variations in the electron beam before it travels the length of the guide. Stated in other words, the length of the guide 5 should be comparable with the length of the wave of the modulating source 14 if electrons having a velocity near the velocity of light are used.

As explained previously, because of the interaction of the electromagnetic forces of the impinging waves 8 on the electrons which form the pulse of high speed electric charge 15, these electrons are caused to vibrate around their average position and disperse an electromagnetic wave having a frequency f_r indicated by Equation 4. Such waves are indicated by the arrow 16. The generated waves 16 of very short wave length may be permitted to pass through the branch wave guide 17 to an output guide 18 through the action of any suitable filter 19 tuned to the frequency of waves 16, the function of the filter 19 being to reflect the electromagnetic waves 8 while permitting passage of the higher frequency electromagnetic waves 16.

Means are also provided for frequency modulating the newly generated waves 16 and comprise means, such as the movable potentiometer arm 20, for varying the accelerating potential applied to the pulses of charge which pass through the grid 13.

Another important feature of the system described is that because the electromagnetic waves 8 in passing through the wave guide 5 are either converted into waves of higher frequency when they impinge upon the moving charges 15 or are reflected off the relatively good conduction material constituting the iris or filter 11, very high efficiencies of operation may be obtained, the length of wave guide 5 in itself being a relatively high Q circuit, that is, a circuit whose ratio of stored energy to dissipated energy is large. The energy of the wave guide 5 is either converted into new waves by reflection of the moving charges or reflected from the iris 11 and stored in the high Q circuit, an extremely small amount of energy being dissipated in the enclosing structure.

In the schematic illustration of Fig. 3, there is shown a modification of the principle outlined in the discussion of Fig. 1. In this modification, a stationary source, such as the probe 21, excited by the high frequency generator 22, emits electromagnetic waves 23, 24 of a given fre-

quency. Two moving charge pulses **25, 26** of different velocity characteristics approaching the source **21** act as reflectors for the waves **23, 24** to produce waves of higher frequency. The reflected waves of higher frequency **27, 28**, in turn, impinge upon the moving charge pulses, or other charges of a beam of which the charges **25, 26** form a part, to produce other reflected waves having a still higher frequency. By such multiple reflection of waves between moving charges, waves of extremely high frequencies and very short wave lengths may be produced even though the pulses of moving charges **25, 26** have only moderate velocities.

Fig. 4 illustrates another modification of my invention in which electrons in a rotating space charge are used to create the moving reflector for incident electromagnetic waves. The rotating space charge **29** may be established, for example, within a magnetron having a centrally located cathode **30**, an anode **31**, and a magnetic system **32** for producing rotation of the electrons emitted by the cathode **30**. The electrons preferably are produced in pulses by the action of a source of modulating voltage **33** applied between the anode **31** and the cathode **30**. An input electromagnetic wave **34** is introduced into a wave guide section **35** connected to the magnetron tank **36** by any suitable input probe **37**. When the wave **34** impinges upon the high speed electrons **29** rotating in a direction opposite to the direction of motion of the wave **34**, this wave is reflected to produce an electromagnetic wave **38** of higher frequency and shorter wave length. The wave **38** may be supplied to any suitable utilization means through a branch wave guide **39**, filtering means **40** being utilized to permit passage of the wave **38** and reflection of the wave **34**. In the same manner, the filter **41** at the end of the wave guide **35** may be used to reflect a shorter wave length **38** to prevent leakage of energy of this frequency at the end of the wave guide **35**. It is understood of course that the filters **40, 41** are so placed with respect to the remaining portions of the wave guide structure that multiple reflections of both waves **34** and **38** within the wave guide system are prevented.

One of the advantages of the system of Fig. 4 is that relatively high efficiencies of operation may be obtained, since the electron beam **29** is maintained in rotation and a minimum number of electrons are collected by the anode **31**. In the ideal case of course no unidirectional currents are collected in the anode **31**. An alternative

form of the principle of the system of Fig. 4 may be utilized in an electronic tube of the Barkhausen-Kurz type in which multiple oscillation of electrons is obtained with a consequent reduction of the unidirectional current required for operation of the system.

Among the important uses of the system illustrated are to obtain minute differences in frequency, such as are required in frequency analyzers, as well as to obtain scanning frequencies for use in such analyzers. The principles of the systems of Figs. 1–4 may be employed likewise for investigation of all types of gaseous discharges, such as a lightning discharge, the impingement of an electromagnetic wave upon the discharge being effective to produce a new electromagnetic wave of different frequency.

While I have shown and described my invention as applied to particular systems embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention and I therefore aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A generator of ultra high frequency waves comprising means for establishing a rotating space charge, and means for impinging a beam of electromagnetic waves upon said charge to form by reflection therefrom electromagnetic waves having a frequency dependent on the relative velocity of said charge and said first waves.

2. An electromagnetic wave generator comprising a closed container, means for establishing a rotating space charge in said container, means for varying the instantaneous density of said space charge, means for reflecting an electromagnetic wave on said rotating charge to produce a reflected electromagnetic wave, and means whereby said reflected waves may be supplied to a utilization circuit.

SIMON RAMO.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,391,914	McElhannon	Jan. 1, 1946
2,409,991	Strobel	Oct. 22, 1946