

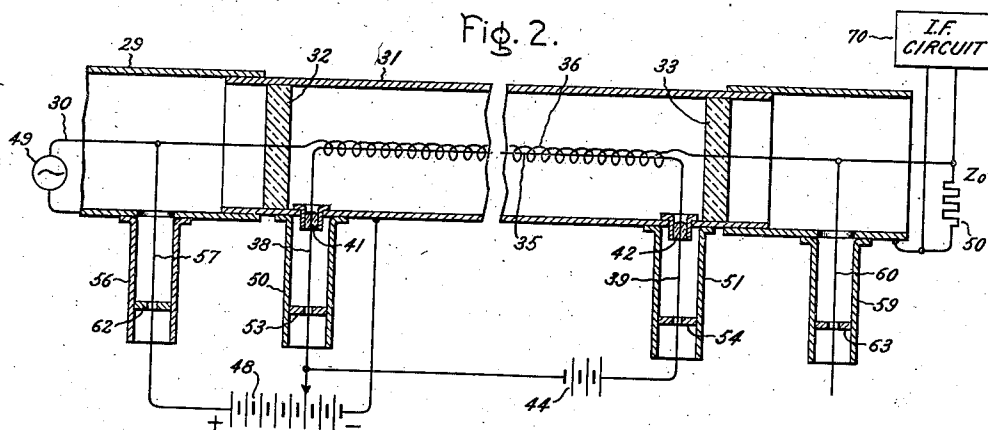
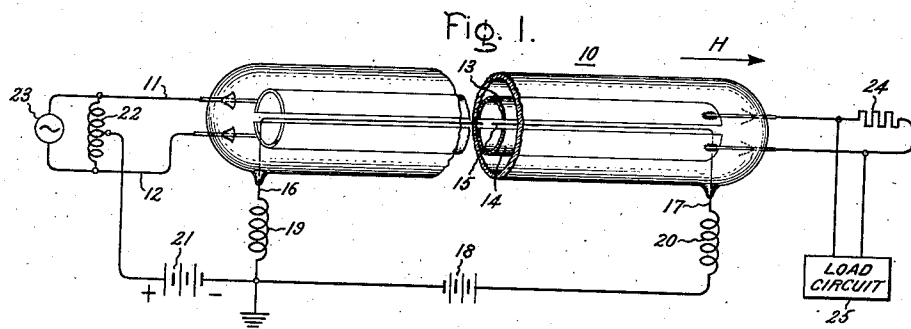
Aug. 27, 1946.

S. RAMO

2,406,635

METHOD FOR AMPLIFYING HIGH FREQUENCY SIGNALS

Filed March 27, 1942



Inventor:
Simon Ramo,
by *Harry E. Dunkley*
His Attorney.

UNITED STATES PATENT OFFICE

2,406,635

METHOD FOR AMPLIFYING HIGH-FREQUENCY SIGNALS

Simon Ramo, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application March 27, 1942, Serial No. 436,444

4 Claims. (Cl. 250-20)

1

The present invention relates to an improved method and means for obtaining amplification at ultra high frequencies.

It is well known that as one proceeds from relatively long wave lengths to wave lengths on the order of a few centimeters, the process of amplification with conventional amplifying devices becomes increasingly difficult, this being a result of unfavorable properties exhibited by such devices in the ultra high frequency range. It is a primary object of my present invention to provide an amplifying arrangement which is not adversely affected by increasing frequency and which is capable of being operated satisfactorily at even the shortest wave lengths.

In one of its aspects, the invention involves the use of a wave propagating system which has the attribute of negative attenuation. This property is realized by incorporating in the wave propagating structure an agency which imparts to the structure a negative conductance of appropriate value. As will be explained more fully in the following, this may be accomplished by the use in a particular manner of certain electronic devices which are of such configuration as to permit their integral incorporation in a wave propagating system. The nature of such devices and certain further requirements with respect to the termination of the wave propagating system will be described in detail in the ensuing description of the invention.

A further important aspect of the invention consists in the utilization of a negative conductance wave propagating system as an essentially self-contained superheterodyne converter for ultra-high frequency application.

The specific features desired to be protected herein are pointed out in the appended claims. The invention, itself, together with its further objects and advantages, may best be understood by reference to the following description taken in connection with the drawing, in which Fig. 1 represents a parallel conductor transmission line incorporating means for imparting negative conductance to the line, and Fig. 2 illustrates the use of such a line as a superheterodyne converter.

As is well known, the properties of a wave propagating system such as a coaxial conductor transmission line are determined by the distributed constants of the system, including its effective series resistance and inductance per unit length and further including its shunt capacitance and conductance per unit length. These factors serve to determine the wave prop-

2

agating characteristics of the line and in the usual case, act to produce attenuation of the propagated wave as it progresses along the line. The factor which determines the amount of such attenuation is ordinarily referred to as the attenuation constant and may be defined by the following approximate relationship:

$$a \text{ (attenuation constant)} = \frac{GZ_0}{2} + \frac{R}{2Z_0} \quad (1)$$

where G represents shunt conductance per unit length, R represents series resistance per unit length and Z_0 is the so-called characteristic impedance of the line. Neglecting losses

$$Z_0 = \sqrt{\frac{L}{C}}$$

The effect of the attenuation constant on the propagation of a particular aspect (say the voltage aspect) of a propagated wave may be expressed by the following relationship:

$$E_x = E_0 e^{-ax} \quad (2)$$

where E_x represents the value of voltage at an arbitrary point, x , along the line and E_0 represents voltage at the sending end of the line.

From this relationship it will be seen that as long as a is positive, the normal effect of attenuation is to reduce the amplitude of the propagated wave. It is equally apparent, however, that if a can be given a negative value, then the amplitude of the wave will increase rather than decrease with increasing distance from its source. Accordingly, if a wave propagating structure having negative attenuation is terminated in such a way as to prevent regenerative oscillations from occurring, a mechanism is provided by which useful amplification effects may be obtained. Moreover, such effects can be obtained with equal facility at even the highest frequencies by appropriate choice of the propagating system.

In accordance with the present invention, the concept of negative attenuation is realized in a practical way by the use of a propagating system which is characterized by a distributed negative conductance (see Equation 1, above) it being assumed that the absolute value of the conductance G is sufficient to outweigh the positive effect of the series resistance R of the propagating system involved. Specifically, negative conductance is obtained by the use of certain electronic devices which have heretofore been found usable as oscillators (and which therefore introduce the aspect of negative resistance) and which are of such structural form as to permit their effective

incorporation in a wave propagating system. The magnetron oscillator provides one example of such a device, while the Barkhausen-Kurz oscillator is another example.

Fig. 1 represents schematically an amplifying system which includes a split anode magnetron 10 incorporated in a transmission line having parallel conductors 11 and 12. The magnetron includes a pair of mutually spaced, semi-cylindrical anode members 13 and 14 which are respectively connected in series with the conductors 11 and 12 so as to be, in effect, continuations of them. Electrons are supplied to the space between the anode members by means of a cathode 15 having lead-in conductors 16 and 17 by which it may be supplied with heating current from a source 18. Choke coils 19 and 20 are connected in series with the cathode so as to isolate the source 18 from the high frequency system formed by the magnetron, and unidirectional potential is impressed between the cathode and the anode members 13 and 14 by means of a potential source 21 connected as shown. (The choke coil 22 allows the conductors 11 and 12 and the connected anode members to be at a common potential as far as D. C. potentials are concerned, while being effectively separated with respect to high frequency currents.) With a magnetic field established parallel to the axis of the magnetron as indicated by the arrow H, the magnetron assumes a negative resistance characteristic, which, with the parts in the relationship shown, appears as distributed negative conductance between the conductors of the transmission line. Because of the negative attenuation thus imparted to the section of the transmission line subtended by the magnetron, a signal-bearing wave propagated along the line, say from a source at 23, tends to increase in amplitude.

In order that the amplification effects thus realized may be usefully employed, the section of the transmission line formed by the anode members 13 and 14 should possess the same characteristic impedance as the remaining portions of the line, and the line should be terminated in its characteristic impedance so as to avoid reflection effects and a consequent tendency to regenerative oscillation. The first of these requirements may be adequately fulfilled by making the spacing of the conductors 11 and 12 somewhat less than the average spacing of the members 13 and 14 so as to offset the otherwise excessive capacitance attributable to the relatively larger area of the members. The requirement of proper termination of the line may be met by connecting between the extremities of the conductors 11 and 12 a resistance 24 the value of which is the same as that of the line impedance. In a practical case the resistance 24 may be made up in part of the input of a detector 25 or other device for converting the amplified wave received at 24 into a more usable form.

It is to be noted that the arrangement of Fig. 1 may be used, if desired, to amplify waves which simultaneously traverse the region of negative conductance in opposite directions. This requires that both extremities of the propagating system be terminated in the characteristic impedance of the system in order to prevent oscillations from being set up. When this condition is fulfilled, no mutual interference of the oppositely directed waves will occur provided sufficiently small signals are used.

Because of mechanical limitations it is not possible under all circumstances to provide a

propagating system which is electrically uniform throughout. For example, because of the need for providing filament wires, seals, leads for obtaining bias, etc., it is difficult to avoid introducing discontinuities into an arrangement such as that of Fig. 1, which discontinuities have a tendency to produce some reflection of incident waves. The effects of such discontinuities may be tuned out, or neutralized, for a particular frequency by the use of tuning means appropriately arranged with reference to the discontinuities in question. However, since available tuning means necessarily involve the use of reactance elements, their effects will obviously not be equally favorable for all possible frequencies. On the contrary, a tuning element which has the effect of preventing resonance at a particular frequency, may tend to promote resonance and self-sustained oscillations of the system at some other frequency. Whether oscillations actually occur at such other frequencies depends upon whether the system as a whole, including particularly the negative conductance element of the system, is in an operating condition which tends to favor the occurrence of oscillations at the frequency in question. In general, this is a factor which can be controlled by proper regulation of the operating conditions of the electronic device by which negative conductance is provided, so that oscillations at the unneutralized frequency can be obtained or avoided as desired.

The considerations stated in the foregoing paragraph may be employed for the attainment of useful objects by a construction of the character illustrated in Fig. 2, which represents the application of the invention to a superheterodyne converter in which the local oscillator and mixer are combined in a single agency.

In this case the wave propagating system comprises a coaxial conductor transmission line having an outer conductor 29 and an inner conductor 30. The central portion of the line is given a negative conductance characteristic by the use of a three-element electron discharge device in the nature of a Barkhausen-Kurz oscillator. This comprises a cylindrical evacuated metal envelope 31 which is closed at its extremities by means of sealed-in glass plugs 32 and 33. Within the tube there is provided a central filament 35 and a helically wound grid 36 which surrounds the filament. By means of lead-in connections carried through the plugs 32 and 33 the grid 36 is made electrically continuous with the inner transmission line conductor 30. The filament 35, on the other hand, is supplied with heating current by lead-in conductors 38 and 39 which are brought out through the wall of the cylindrical envelope 31 by lead-in seals 41 and 42. A battery 44 which is externally connected between the conductors 28 and 29 serves as an energizing source for the filament.

In the intended operation of the Barkhausen-Kurz tube the grid 36 is maintained at a positive potential with respect to the filament 35, whereas the anode, which consists of the wall of the metal envelope 31 is maintained at a relatively negative potential, these potentials being established by means of a battery 43. As is well known, this mode of connection imparts a negative resistance characteristic to the tube as a whole so that under certain conditions oscillations may be set up due to the gyrations of electrons in the interelectrode spaces. For present purposes, however, the negative resistance characteristic of the device is principally of interest in that it provides negative con-

5

ductance between the grid 36 and the anode-forming wall 31. As has been explained in connection with Fig. 1, this negative resistance permits amplification of a signal-bearing wave propagated along the transmission line (say, from a source 49) provided the line is terminated in its characteristic impedance Z_0 . Such a termination is indicated in the present case at 50.

As has been previously suggested, the necessity for including lead-in wires, seals, etc. in an arrangement such as that of Fig. 2 introduces electrical discontinuities into the system which tend to produce wave reflection and consequent resonance effects. Such discontinuities are introduced, for example, by the filament lead-in conductors 38 and 39 and by the glass sealing plugs 32 and 33. These discontinuities may be tuned out (i. e. effectively neutralized) by the use of compensating reactance elements properly arranged. For example, in connection with the conductors 38 and 39 neutralization may be accomplished by the use of stub transmission line sections formed by the combination of the conductors 38 and 39 and laterally extending metal tubes 50 and 51 which are respectively associated with the conductors. Slidable conductive plugs 53, 54 are provided in connection with each of the tubular members 50 and 51 for tuning purposes. While these plugs should be insulated from the filament lead-in conductors 38 and 39 as far as direct current flow is concerned, they may be assumed to be sufficiently capacitively coupled to these conductors to form adjustable short circuiting terminations for the respective stub lines with respect to high frequency currents.

Similar stub lines are provided in association with the plugs 32 and 33, one such line being formed by the combination of a transversely extending tube 56 and a concentrically arranged conductor 57, and the other by a similarly associated tube 59 and conductor 60. The conductor 57 may be incidentally employed as a terminal means for connecting the spiral grid 36 to the positive terminal of battery 48. Sliding tuners 62 and 63 are provided in connection with each of the stub lines just referred to.

By properly adjusting all the sliding tuning elements the wave propagating system may be caused to simulate a uniform line as far as waves of the particular frequency propagated by the signal source 49 are concerned. However, since the tuning devices are, in effect, reactance elements, complete tuning in the sense specified can be assured only for a relatively limited frequency band. Accordingly, with appropriate adjustment of the operating conditions of the tube there will be some frequency, materially displaced from that of the signal waves, at which reflection effects and self-sustained oscillations will occur as a result of the negative conductance characteristic of the tube 31.

Because of inevitable non-linearities in the system, the occurrence of strong self-sustained oscillations at a time when waves are being propagated down the transmission line from the signal source 49 will produce mixing of the signal and oscillatory frequencies with resultant superheterodyne action of the system as a whole. Accordingly, the signal received at the right-hand extremity of the propagating system will be not only of amplified character but will also contain side band components corresponding to the sum and difference frequencies of the signal and the locally generated oscillations.

6

The intermediate frequency side band may be abstracted by an appropriate circuit connected across the terminals of the transmission line as indicated at 70, this frequency component being thereafter further amplified or detected as desired.

While the invention has been described by reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without departing from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

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

1. In combination, a source of signal-bearing waves, a system for propagating waves derived from said source, said system including a pair of concentric transmission lines each including an outer tubular conductor and an inner conductor interconnected by an electronic discharge device incorporated in the said propagating system for giving it a negative attenuation characteristic whereby waves propagated by the system are amplified in intensity, said electronic discharge device including dielectric means for defining an evacuated region containing an electric discharge path, and means for terminating the system in such fashion as to minimize reflection of said signal-bearing waves, said last-named means including reactance components associated with said electronic discharge device which neutralize the reflection incident to the presence of said last-mentioned means and which cause said device to be self-oscillatory at a frequency different from the frequency of said signal-bearing waves, whereby the output of said device includes side-band components representing the sum and difference of said frequencies.

2. In a system for propagating electromagnetic waves, the combination comprising a pair of concentric transmission line sections each including an outer tubular conductor and an inner conductor, means for exciting one of said transmission line sections at signal wave frequency, electronic discharge means interconnecting said transmission line sections and comprising an outer tubular conductor in electrical contact with the first mentioned tubular conductors and a concentric inner conductor, said outer conductor and said inner conductor of said electronic discharge device constituting an anode and a cathode of an electric discharge path which in conjunction with a spaced grid produce distributed negative conductance whereby waves propagated by the system are amplified in intensity, means for terminating the other transmission line section to minimize reflection of signal-bearing waves, and reactance means which cause said device to be self-resonant for electromagnetic waves of a frequency different from the signal frequency and to serve both as a local oscillator and a mixer.

3. In a system for the propagation of electromagnetic waves, the combination comprising a pair of concentric transmission line sections each including an outer tubular conductor and an inner conductor, means for exciting one of said transmission line sections at signal frequency, means interconnecting said transmission line sections comprising an electronic discharge device including an outer tubular conductor of substantially the same diameter as the first mentioned tubular conductors and in electrical contact therewith and having a central inner con-

7

ductor and an electrostatic grid in spaced relation with respect to said outer tubular conductor and said inner conductor of said electronic discharge device which constitute respectively an anode and a cathode of an electric discharge path which produces a distributed negative conductance whereby waves propagated by the system are amplified in intensity, means for defining a localized region containing said electric discharge path and including dielectric members located near the extremities of the outer conductor of said electronic discharge device, tuning means associated with said inner conductor for neutralizing the reflections incident to said last mentioned means, and additional tuning means for rendering said device self-resonant for waves of a frequency different from the signal frequency and for causing said device to serve conjointly as a local oscillator and a mixer.

4. In a system for propagating waves derived from a source of signal-bearing waves having characteristics determined by the distributed con-

8

stants of component parts of the system, said system comprising a pair of concentric transmission line sections each including an outer tubular conductor and an inner conductor and comprising means for producing distributed negative conductance whereby waves propagated by the system are amplified in intensity, said last-mentioned means comprising an electronic discharge device, means intermediate said pair of transmission line sections for defining the region of said discharge device, and impedance means for terminating said system in such fashion as to minimize reflection of said signal-bearing waves and for neutralizing the reflection effects of said last-mentioned means, said impedance means including reactance components connected to said system and having a value such that said device oscillates at a frequency different from the frequency of said signal-bearing waves and serves conjointly as a local oscillator and mixer.

SIMON RAMO.