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AMPLITUDE LIMITERS FOR HIGH FREQUENCY RADIO SIGNALS

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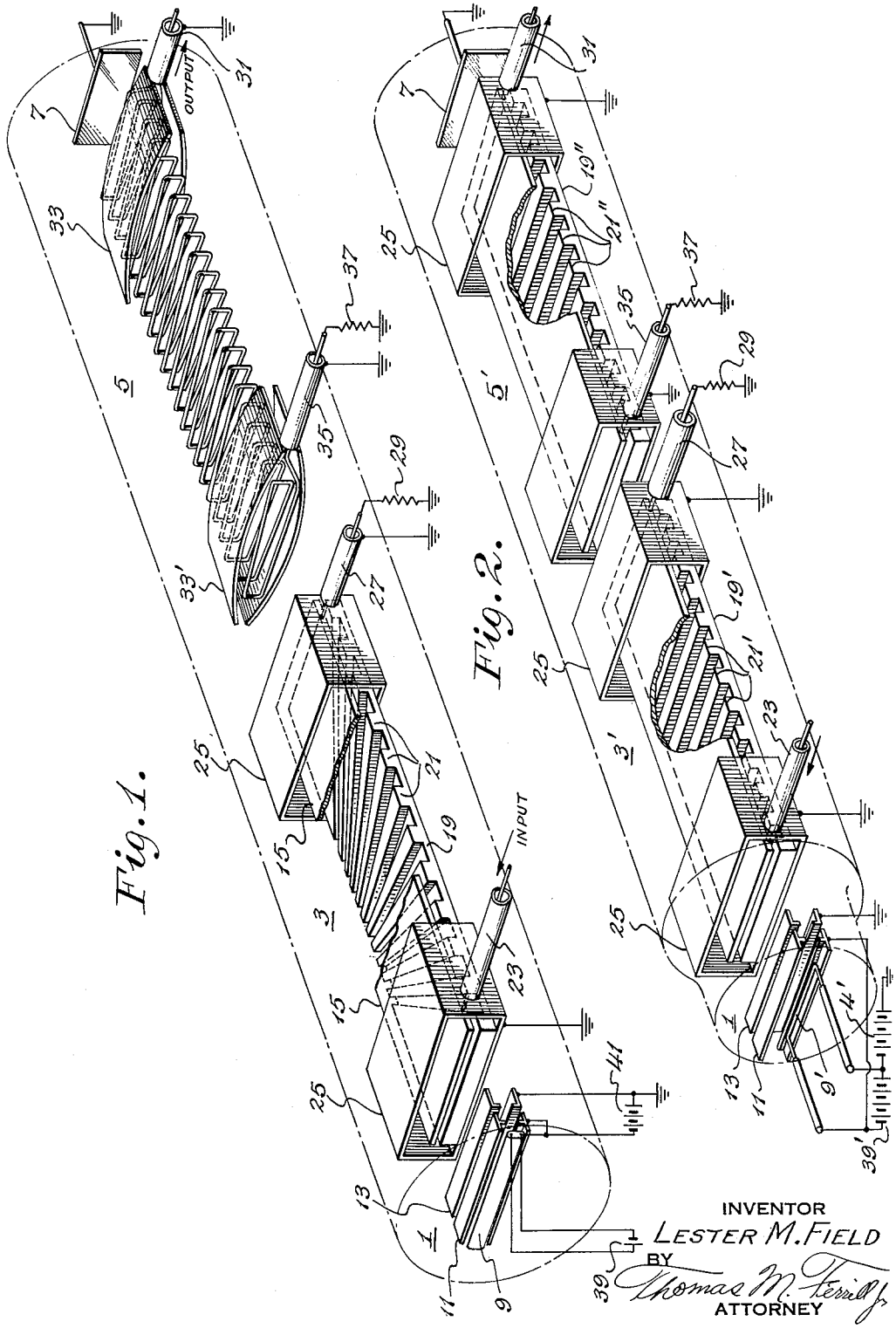


Fig. 1.

Fig. 2.

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AMPLITUDE LIMITERS FOR HIGH FREQUENCY RADIO SIGNALS

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This invention relates to improvements in amplitude limiters for high frequency radio signals, particularly microwaves, and its principal object is to provide devices having a frequency by frequency limiting action, whereby simultaneously present input signals or signal components of different frequencies are each individually limited to a predetermined output amplitude, regardless of the presence or the input amplitudes of the others. This action differs from that of prior limiters, which operate on the amplitude of the total signal, without reference to the frequencies of its components. An ordinary limiter will cause a strong input signal of one frequency to override and mask out a weak signal of another frequency. A frequency by frequency limiter will prevent any component from exceeding the limiting amplitude, but will not suppress relatively weaker components of other frequencies.

Frequency by frequency limiting could be obtained, or approximated, by using a large number of parallel channels, each comprising a narrow band pass filter and a separate limiter. Such an arrangement would be complex and cumbersome, and impractical, particularly if input signals throughout a relatively wide frequency range were to be accommodated.

According to the present invention, the desired type of limiting is effected in a special travelling wave tube by localized saturation of an electron beam wherein the geometric elements are selectively modulated, depending on the frequencies of the input signal components.

The invention will be described with reference to the accompanying drawings, wherein:

FIG. 1 is a perspective view of a preferred embodiment, and

FIG. 2 is a perspective view of a modification of the device of FIG. 1.

The tube shown in FIG. 1 includes an electron gun **1**, an input circuit **3** comprising a periodically loaded parallel plate transmission line, and an output circuit **5** which in the present example is a conductive helix. The gun **1** is arranged to project a beam of electrons through the circuits **3** and **5** in succession to a collector electrode **7**.

The electron gun is designed like a figure of lateral translation of a section of an ordinary gun of the type used to produce a pencil beam, as in a cathode ray oscilloscope tube. It includes a cathode **9**, a focusing electrode assembly **11**, and an anode or accelerator electrode **13**, all laterally extended as shown to produce a relatively wide thin ribbon shaped electron beam.

The input circuit **3** consists of upper and lower conductive plates **15** and **19** respectively, separated from each other to define a space conforming to the beam produced by the gun **1**. Periodic loading is effected by means of a series of equally spaced teeth **21** on one or both of the conductive plates; in this case, the lower one. The period, i.e. the tooth spacing, varies uniformly from a maximum value at one side of the structure to a minimum at the other. The teeth **21** may be formed by milling slots across the plate **19**. The slots should be of substantially equal and constant depths, and may be made of substantially the same width as the teeth between them.

Input connection to the line or circuit **3** is made by way of a coaxial transmission line **23** which has its inner conductor connected to the end of the plate **15** and its

outer conductor connected to a conductive shield **25**. The shield **25** surrounds both plates **15** and **19**, and is connected to the lower side of the plate **19**. It may extend throughout the length of the structure **3**, or cover only the end portion as shown. The other end of the line **3** is similarly coupled to a coaxial line **27** which is connected to a terminating resistor **29**. An alternative arrangement is to omit the line **27** and internally terminate the structure **3** at this end, for example by coating either or both of the members **15** and **19** with lossy material such as carbon.

The output helix **5** is of oblong cross section, with internal dimensions sufficient to accommodate the electron beam. It is longitudinally spaced from the end of the line **3** far enough to prevent any significant electromagnetic coupling between the structures **3** and **5**. Output connection to the end of the helix farther from the line **3** is made through a coaxial line **31** which has its inner conductor connected to the end of the helix conductor, and its outer conductor connected to a conductive shield **33** around the end of the helix. The shield **33** may consist of a pair of curved pieces facing each other and substantially enclosing the end portion of the helix, as shown.

The other end of the helix **5**, nearer the line **3**, may be terminated by means of a line **35** coupled to the helix like the line **31** and connected to a resistor **37**. As an alternative, this end of the helix may be terminated internally of the structure, for example by coating the shield **33'** with lossy material, and the line **35** may be omitted.

In the operation of the described system, the cathode is heated as by an external source **39** and it is connected together with the focussing electrode **11**, to the negative terminal of a high voltage D.-C. source **41**. The accelerator **13** and the collector **7**, as well as the lines **3** and **5**, may be connected to the positive terminal of the source **41**. This may be effected conveniently by way of a common ground connection, as shown.

Input signals which are to be limited are applied to the line **23**, and the output line **31** is connected to any suitable load or utilization means, not shown. As an example, the input signals may be provided by an antenna, and the amplitude limited output signals may be applied to a radio receiver.

The ribbon shaped electron stream travels with an average or D.-C. velocity u_0 which is a function of the potential of the source **41**. The input signals applied to the line **3** produce waves (i.e. varying electromagnetic fields) which travel in the same direction as the electrons, and have electric field components in the stream and directed along its path. As in an ordinary travelling wave tube, any such components that have a phase velocity approximately equal to the electron D.-C. velocity will exchange energy with the electrons, while other components, having different velocities, will not.

A periodic structure like the line **3** is dispersive, i.e. the phase velocity of a wave travelling on it depends on the frequency. The phase velocity at any given frequency is a function of the period, i.e. the spacing between adjacent teeth. Thus a signal or signal component of a certain frequency will produce waves having a phase velocity which varies with lateral position on the line, being relatively high where the tooth period is large, and low where the period is small.

If the input frequency is within a certain range, determined by the design and operating conditions, there will be a place where the phase velocity corresponds to the electron velocity, along a unique filamentary element of the beam. This one element of the beam will interact with, and be modulated by, the waves of that particular frequency. Input signals of other frequencies will likewise modulate other respective beam elements singularly, and have substantially no net interaction with

the beam except where the phase velocity equals the beam velocity.

The amount of such modulation of a beam element depends on the amplitude of the input signal which produces it, up to the point where the variation in beam density becomes equal to the average or D.-C. beam density. Beyond this point, further increase in amplitude of the input signal cannot increase the beam modulation significantly, and that particular beam element is saturated. However, saturation of one element does not affect any other elements, and the beam modulation is limited, frequency by frequency, to a value determined by its average current density.

The output helix 5 is designed in known manner to be substantially non-dispersive, i.e. the phase velocity is substantially equal to the electron velocity u_0 at all frequencies throughout the operating range. Any elements of the beam which have been modulated will induce corresponding waves that travel along the helix to its output end, where they are applied to the line 31 and conducted to the utilization means. Since the signals are supplied to the helix solely by way of the modulated electron beam, they are individually limited, like the beam modulations.

Some overall amplification may occur on the helix, because the waves produced on the helix by modulation of any one beam element will modulate the rest of the beam, and the helix will function substantially as an ordinary travelling wave amplifier which is supplied with signals that have been previously amplitude limited. It is necessary to make the helix 5 short enough, or of low enough gain, to prevent saturation of the entire beam by one or more such signals, but ordinarily this is not a very serious restriction.

The operating bandwidth of the device, and its discrimination, i.e. the degree of isolation between signals of nearly the same frequency, depend both on the design and the mode of operation of the periodically loaded line 3. The bandwidth will be proportional to the range of variation of the tooth period from one side of the line to the other. The discrimination will increase as the line is made wider, and also as it is made longer.

With one type of operation, which may be called the "fundamental" mode, the slots between the teeth 21 act like series inductive loads along the line, and the capacitances between the ends of the teeth and the conductor 15 are shunt loads. This makes the phase velocity decrease with increasing frequency over a certain range, and if the slots are made deep enough with respect to the tooth spacing, this range will include phase velocities corresponding to reasonably attainable electron velocities.

A second type of operation, called "space harmonic." depends principally upon the periodicity of the line, rather than upon loading effects. The teeth 21 provide alternate regions of high and low field intensities along the line, enabling relatively slow-moving electrons to interchange energy with fast-moving waves; instead of travelling with a particular phase front, an electron moves only the distance from one tooth to the next during the time a phase front moves over $N+1$ teeth, where N is any integer.

Suppose the electron happens to be in an accelerating field when it is in the strong field region over one tooth. Then, as the phase front moves on and the field reverses, the electron is moving into a weak field region between two teeth, so it is not decelerated as much as it was accelerated. As the following phase front catches up with the electron at the next tooth, the situation is the same as before, and the electron is accelerated. The overall effect is that the electron is subject to a pulsating unidirectional field, and interacts with it in substantially the same manner as if the phase fronts were actually travelling with the electron stream.

In the case of space harmonic operation, the phase velocity increases with increasing frequency, almost linearly throughout a wide range. The maximum phase velocity of the first space harmonic is one third the minimum phase velocity attained by the fundamental, so that the tooth spacings may be made considerably greater, for a given beam velocity and input frequency range. Furthermore, the slot depth is not critical, as it is in structures designed for fundamental operation.

Although the arrangement shown in FIG. 1 is preferred at present, numerous useful modifications thereof will be apparent to those skilled in the art. For example, the line 3 may be made with fins or teeth on both conductors, and such fins or teeth may be offset or interleaved to accentuate the longitudinal electric field components. The output circuit or line 5 may be another periodically loaded structure like the line 3, instead of the helix shown in FIG. 1.

The system of FIG. 1 distinguishes between signals of different frequencies, and acts on them individually, because the period of the input circuit 3, and hence its propagation characteristics, vary laterally of the direction of electron motion and wave propagation. A similar action can be obtained by making the velocities of the electrons vary as a function of their lateral positions in the beam instead of varying the period of the input circuit.

This may be accomplished as shown in FIG. 2, by using a modified electron gun 1' in which a filamentary cathode 9' has been substituted for the unipotential cathode 9 of FIG. 1. The filament 9' is designed to operate at a relatively high voltage, for example 200 volts, by making it of small diameter high resistance wire. The rest of the electron gun 1' may be like the corresponding elements in FIG. 1, or the focussing electrode 11 may be specially designed for cooperation with the filamentary cathode.

A D.-C. source 39' of suitable potential is connected to the filament 9' and has one of its terminals connected to the negative side of the high potential source 41. With the arrangement shown in FIG. 2, electrons emitted from the right side of the filament 9' will be accelerated to a velocity u_1 corresponding to the voltage of the source 41, while those emitted from the other side will reach a higher velocity u_2 corresponding to the sum of the voltages of the sources 41 and 39'. Since the IR drop is distributed along the filament 9', the electron velocity will vary across the beam, the velocity of each filamentary element of the beam being a function of its lateral position.

The input circuit 3' may be a periodic line similar to the line 3 of FIG. 1 except that its period does not vary laterally; the teeth 21' on the lower conductor 19' are parallel to each other.

The output circuit 5' in this case is substantially identical to the input circuit 3', comprising an upper conductor 15' and a lower conductor 19'' provided with uniformly spaced teeth 21''.

In the operation of the device of FIG. 2, input signals applied to the line 23 will produce waves on the line 3' with phase velocities that depend on their respective frequencies. The phase velocity for any particular frequency is the same at all lateral positions on the line 3'. Since the electron velocities vary across the beam, cumulative interaction between the beam and waves of a given frequency will occur only along a corresponding filamentary element of the beam, and frequency by frequency limiting is effected substantially as described in connection with the operation of the device of FIG. 1.

The output circuit 5' must also operate frequency by frequency, since the different elements of the beam have different velocities, and synchronization with waves of a given frequency can only occur along a respective beam element. Any beam elements which become saturated in the input circuit will remain so; no further amplification will take place in the output circuit. However, any beam elements carrying signals too weak for limiting in the

input circuit may be amplified further in the output circuit, up to the point where saturation may occur there. Thus the device of FIG. 2 works as a two-stage frequency by frequency limiter.

As in the system of FIG. 1, the dispersive lines or circuit elements may be modified in known ways, as by providing teeth on both upper and lower conductors, offset or interleaved if desired. Also dispersive helices or other known dispersive line structures may be substituted for the two conductor lines 3' and 5'.

Since many changes could be made in the above construction and many apparently widely different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An amplitude limiter for high frequency signals, including a dispersive wave conductor with opposed surfaces defining an interaction space of substantial extent transversely of the direction of wave propagation thereon, means adjacent one end of said wave conductor for producing a beam of electrons having a transverse cross section conforming substantially to said space, and projecting said electrons along said space in said direction of wave propagation with the velocity in each different filamentary element of said beam corresponding to the phase velocity of waves travelling on the corresponding element of said wave conductor at a different frequency; means for applying input signals which are to be limited to said one end of said wave conductor, and output coupling means spaced from the other end of said wave conductor in the path of said electron beam, and responsive to modulation of said beam by waves on said conductor to produce output signals similar to said input signals, each being individually limited in amplitude by the current density of the corresponding element of said beam.

2. A frequency by frequency limiter for microwave signals, including means for producing a stream of electrons comprised of contiguous filamentary elements constituting a substantially homogeneous sheet-like beam; input coupling means defining an interaction space in the path of said beam, and means for supplying input signals which are to be limited to said input coupling means to selectively modulate respective filamentary elements of said beam in accordance with the frequencies of said signals, the extent of such modulation being limited by the current density of said beam; and output coupling means in the path of said beam and spaced from said input coupling means and responsive to modulation of said beam to produce amplitude-limited output signals.

3. An amplitude limiter for high frequency signals, including a wave conductor which has the characteristic of carrying high frequency waves with phase velocities which depend on the frequencies of such waves, said conductor having a surface of substantial lateral extent transversely of the direction of wave propagation thereon, means adjacent one end of said conductor for producing a beam of electrons having a transverse cross section conforming substantially to said surface, and means for projecting said electrons along said surface in said direction of wave propagation with the velocity in each different filamentary element of said beam corresponding to the phase velocity of waves travelling on the corresponding element of said conductor at a different frequency which depends upon the lateral position of said element with respect to said conductor; means for applying input signals which are to be limited to said one end of said conductor, and means providing substantially reflectionless termination of the other end of said conductor; a second wave conductor spaced from said other end of said first conductor and in alignment with said first conductor and in interacting relationship with said electron beam, whereby modulation of any filamentary element of said beam by waves on said first conductor produces similar waves on said second conductor, said latter waves being limited in amplitude by the current density of said beam; and means coupled to said second wave conductor for transferring the amplitude-limited signals from said second wave conductor to a utilization device.

4. The invention set forth in claim 3, wherein said first mentioned wave conductor comprises a body of conductive material provided with a series of longitudinally spaced teeth oriented transversely thereof.

5. The invention set forth in claim 4, wherein the longitudinal spacing between said teeth varies according to transverse position on said first mentioned wave conductor.

6. The invention set forth in claim 3 wherein said first mentioned wave conductor comprises a conductive helix.

7. The invention set forth in claim 3, wherein said means for producing a beam of electrons and for projecting said electrons along said surface comprises an electron gun including a laterally extended cathode adapted to be excited by a voltage that is high enough to produce a substantial voltage gradient along said cathode, whereby the electrons in different filamentary elements of said beam have different velocities.

8. A frequency by frequency limiter for microwave signals, including a transmission line with opposed substantially parallel surfaces which are relatively wide compared to their separation from each other, said line being provided with transversely extending periodic loading elements, said elements being spaced apart longitudinally along said line, an electron gun adjacent one end of said line including laterally extended cathode and beam forming electrodes for producing a ribbon shaped beam of electrons and directing said beam along said line in the space between said surfaces with the velocity of said electrons, in terms of the number of loading elements traversed per unit of time, varying from a relatively low value at one side of said beam to a relatively high value at the other side, input coupling means at said end of said line for applying input signals which are to be limited to said line, and output coupling means adjacent the path of said beam beyond the end of said line where the beam emerges from the line, and responsive solely to modulation of said beam, to reproduce said input signals as limited by laterally localized saturation of said beam.

9. A frequency by frequency limiter for microwave signals, including a transmission line comprising two substantially parallel conductors which are relatively wide compared to their separation from each other, one of said conductors being provided with teeth oriented transversely thereof and extending toward the other of said conductors, said teeth being spaced apart longitudinally along said first conductor with the spacing varying from a relatively small value at one side of said conductor to a relatively large value at the other side of said conductor, an electron gun adjacent one end of said line including laterally extended cathode and beam forming electrodes for producing a ribbon shaped beam of electrons and directing said beam along said line in the space between said conductors, input coupling means at said end of said line for applying input signals which are to be limited to said line, to produce waves on said line travelling with phase velocities which correspond to the velocity of said beam only along filamentary elements of said beam whose lateral positions depend upon the frequencies of said signals, whereby modulation of said beam by said waves occurs only in said respective beam elements, the extent of such modulation being limited separately for each frequency by the current density of the respective beam element; and output coupling means adjacent the path of said beam beyond the end of said line where the beam emerges from the line, and responsive solely to modulation of said beam, to produce amplitude limited output signals.

No references cited.