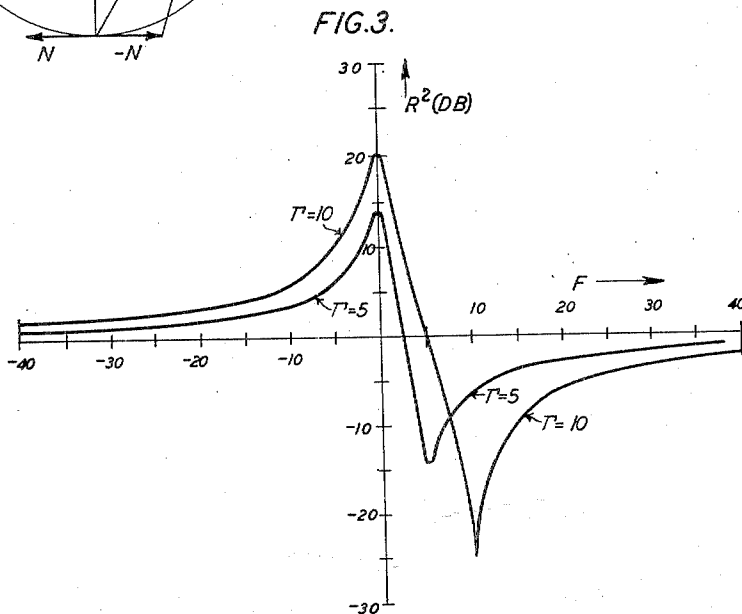
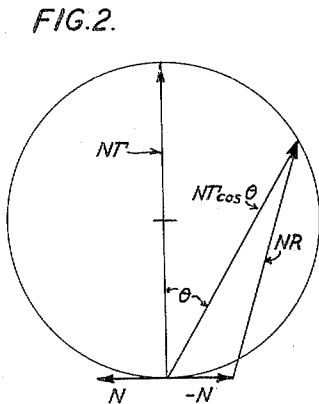
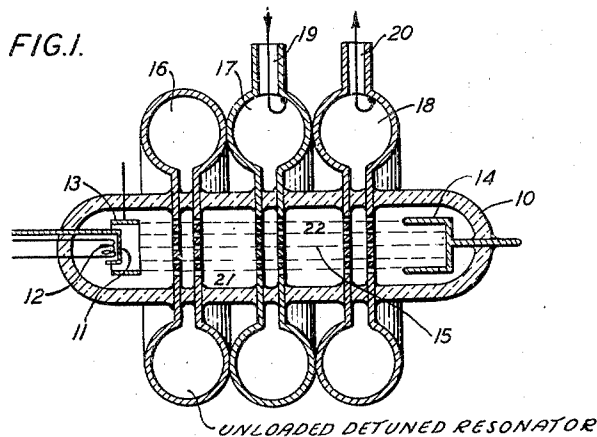


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ELECTRON VELOCITY VARIATION DEVICE
WITH NOISE REDUCING RESONATOR
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ELECTRON VELOCITY VARIATION DEVICE
WITH NOISE REDUCING RESONATORSloan D. Robertson, Red Bank, N. J., assignor to
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This invention relates to means for and a method of reducing noise producing currents in electron velocity variation devices, and more particularly to the use of a reactive cavity resonator coupled to the electron beam but not loaded nor otherwise coupled to any external circuit.

In the operation of electron velocity variation devices such as amplifiers and oscillators, undesired and unavoidable variations in the electron density in the electron beam are present. These density variations if periodic cause the induction of currents in cavity resonators coupled to the electron beam whenever the density variations of the beam occur with a frequency in the neighborhood of a resonant frequency of the cavity resonator. Random or non-periodic irregularities of the stream, also, particularly sudden density changes, are capable of inducing currents in cavity resonators of almost any frequency, since the irregular density changes contain frequency components distributed over a wide frequency band which will usually include the resonant frequency of a cavity resonator coupled to the beam. The currents induced in cavity resonators in such manner are termed noise currents because they are responsible for the production of unwanted noises in the final reproduction of audible signals carried by the electron velocity variation device. They are also responsible for disturbing effects in other types of signals including video signals.

The present invention is directed to means and method for causing the noise inducing density variations to occur in pairs separated by a critical interval of time or in opposing phases so that as a result the effect of one variation or of one impulse of a pair nullifies or greatly reduces the effect of the other variation or impulse of the same pair.

The invention is more fully described hereinafter in connection with the accompanying drawing in which:

Fig. 1 is a schematic representation of an electron velocity variation device embodying the invention; and

Figs. 2 and 3 are graphs useful in understanding the theory of operation of the invention.

Referring to Fig. 1, there is shown an electron velocity variation device having a vitreous envelope 10 enclosing a cathode 11 adjacent to a heater 12 and provided with a beam forming electrode 13 in the form of a short section of a metal tube. The electrodes 11, 12 and 13 are located at one end of the envelope 10 and at the other end of the envelope there is provided a collector electrode 14 consisting of a cup-shaped

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metal member mounted opposite the cathode and having its open end directed toward the cathode. The path of the electron beam from the cathode 11 to the collector 14 is indicated by a broken line 15. At intervals along the line 15 are mounted three cavity resonators 16, 17 and 18, of which the first resonator 16 is not loaded and has no input nor output connections. The next cavity resonator 17 is the input resonator for the device when used as an amplifier. The third resonator 18 is the output resonator. All of the resonators 16, 17 and 18 have electron permeable portions illustrated as grids in the path of the electron beam whereby each resonator is coupled to the beam for energy exchange reaction therewith. The resonator 17 has an input coaxial line coupler 19 and the resonator 18 has an output coaxial line coupler 20.

Except for the unloaded cavity resonator 16, the device shown in Fig. 1 is a conventional electron velocity variation amplifier. In the operation of the conventional portion of the device, an electromagnetic wave to be amplified and having approximately the frequency to which the cavity resonator 17 is resonant is impressed upon the resonator 17 through the coaxial coupler 19. In well-known manner, oscillations in the resonator 17 react with the electron beam in the path 15 to produce electron velocity variations of the beam as the latter passes through the field of the resonator. The portions of the path 15 between adjacent resonators constitute drift spaces 21 and 22, the former between the resonators 16 and 17 and the latter between the resonators 17 and 18. In the drift space 22, the velocity variations impressed upon the electron beam by the resonator 17 produce a bunching of the electrons of the beam whereby the electron density in the beam varies along the beam in accordance with the voltage variations impressed upon the beam by the resonator 17. The density variations constituting the electron bunches induce currents in the resonator 18 which are amplified replicas of the oscillations in the resonator 17.

In addition to the amplified replica currents in the resonator 18, there appear noise currents induced by the random and unavoidable electron density variations of the beam.

The purpose of the unloaded resonator 16 is to introduce a second set of random velocity variation and density variations in the electron beam which, in their inductive effect upon the output resonator 18 will annul each other or greatly reduce the resultant noise producing effect. Noise producing electron density variations in the elec-

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tron beam as it passes through the resonator 16 will induce currents which may be termed noise currents in the resonator 16 which in turn develop noise voltages across the gap in the same resonator and which in turn impress a noise velocity variation upon the electron beam. The drift action which occurs in the drift space 21 between the resonators 16 and 17 converts this velocity variation into an electron density variation. This density variation will induce noise currents in the resonator 17. Thus, there will be two components of noise currents in the resonator 17, namely, the noise which would be present even if the resonator 16 were absent induced in the resonator 17 directly by noise producing variations in the beam, and that due to noise induced in the resonator 16, amplified through the bunching action in the drift space 21 and inducing noise currents in resonator 17. It will be noted that noise reduction or cancellation can occur if the said two components in resonator 17 can be made equal in magnitude and opposite in phase. Any uncanceled residual noise components in the resonator 17 appear in amplified form in the resonator 18.

There is a 90-degree phase lag involved in the production of amplified noise variations in the resonator 16, inherent in the process of electron velocity variation. A given group of electrons in passing through the resonator 16 induces a current pulse in the resonator which results in a voltage maximum appearing at the gap and a new and more concentrated group of electrons forming 90 degrees out of phase with the original group.

To obtain a total of 180 degrees phase shift, an additional 90 degrees of phase lag is required. This additional phase lag may be obtained advantageously by using for the resonator 16 one which is tuned to a frequency considerably away from the resonant frequency of the resonators 17 and 18. In practice, an amount of detuning may be found which will give a maximum amount of noise reduction. While the theory given heretofore involving a phase difference of 180 degrees serves as a guide to understanding the operation of the invention, the invention is effective to reduce noise whether or not the theory given is the correct one. Although the simple theory would indicate that the greater the detuning of the resonator 16 the greater the noise reduction due to a closer approach to the 180-degree phase lag, a more exact analysis of the device given hereinafter shows that a minimum of noise is to be expected at a particular, more or less critical, value of detuning.

The phase relationships involved in the practice of the invention and in the more exact theory above-referred to are shown in Fig. 2 by means of a vector diagram. The vector N represents a typical noise producing electron group in the beam as it approaches the gap in the resonator 16. The larger vector NR represents the amplified noise current in the resonator 17 at the resonant frequency of the resonator 16. The modifying factor Γ is actually the product of several vectors as given by the equation

$$\Gamma = M_1^2 Z_1 g_1$$

where

M_1 is the modulation coefficient of the gap in resonator 16,

Z_1 is the impedance of the resonator 16, and

g_1 is the transconductance of the disc space 21.

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The noise current at any other frequency is given by the vector $NI \cos \theta$ and as the frequency gets farther from resonance, θ approaches 90 degrees. The resultant current in the resonator 17 is the vector sum of $NI \cos \theta$ and N, which resultant is shown in Fig. 2 as NR, which is the same thing as the vector difference of $NI \cos \theta$ and $-N$. It is evident from Fig. 2 that NR cannot be zero for any value of θ or Γ . The theory does, however, serve to show that there is a minimum value of NR for some specific value of θ which is almost 90 degrees and a maximum value of NR for some small negative value of θ .

From the geometry of Fig. 2

$$R^2 = 1 + \Gamma^2 \cos^2 \theta - \Gamma \sin 2\theta.$$

Differentiating this equation through with respect to θ and equating to zero the derivative of R with respect to θ , the condition for a maximum or minimum value is found to be

$$\tan 2\theta = -\frac{2}{\Gamma}$$

The smallest negative root of this equation gives the value of θ for maximum R^2 ; the smallest positive one, for minimum R^2 . Substituting these values back into the equation for R^2 gives,

$$R_{\min}^2 = 1 + \frac{1}{2}\Gamma^2 - \frac{1}{2}\Gamma\sqrt{\Gamma^2 + 4}$$

$$R_{\max}^2 = 1 + \frac{1}{2}\Gamma^2 + \frac{1}{2}\Gamma\sqrt{\Gamma^2 + 4}$$

For values of Γ increasing without limit, $R_{\min}^2$ approaches zero and $R_{\max}^2$ approaches infinity.

To make practical use of the foregoing analysis, it is necessary to determine the relation between θ and the frequency. This can be found in the following way. It is based upon the use of an approximate formula for the impedance of a resonant circuit for frequencies close to any one resonant frequency. This impedance may be expressed as

$$Z = \frac{\bar{X}}{j\Omega + \frac{1}{Q}}$$

In this expression X is the magnitude of the reactance of the circuit at resonance, j is the square root of minus one, Q is the ratio of reactance to resistance and

$$\Omega = \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}$$

Where

$\omega_0/2\pi$ is the resonant frequency and $\omega/2\pi$ the frequency at which Z is measured.

For values of ω sufficiently close to the value of ω_0 ,

$$\Omega = 2 \frac{\omega - \omega_0}{\omega_0}$$

In the expression for Z it will be noted that θ of Fig. 2 is the phase angle of the impedance vector Z, and that this angle is given by the expression

$$\tan \theta = Q\Omega$$

The expression $Q\Omega$ may be defined as a normalized frequency

$$F = Q\Omega$$

The value of F is zero at resonance and unity at any frequency where Z is the equal to 0.707 times its resonance value. In other words F is the frequency as measured in either direction from the

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resonant frequency in units of half the natural band width of the resonator. In terms of F

$$\tan \theta = F$$

$$|Z| = \frac{XQ}{\sqrt{1+F^2}}$$

also

$$R^2 = \frac{1+(F-\Gamma)^2}{1+F^2}$$

The latter expression for R^2 is plotted in Fig. 3 for two selected values of Γ . The ordinate is R^2 , which represents the noise current squared at the resonator 17, in terms of decibels above and below the noise currents due to the beam current at the resonator 17 with the resonator 16 far out of tune.

In interpreting the curves shown in Fig. 3, it should be noted that the typical noise value in a velocity variation tube is in the neighborhood of 30 to 35 decibels. To obtain a useful improvement over the typical noise figure, a reduction of at least 20 decibels due to noise cancellation would be required. This means a value of Γ at least as great as 10 and with this value of Γ , the frequency band over which noise cancellation is obtained, the region within which R^2 is 20 decibels or more, is a little less than one unit wide in terms of F . Thus, according to theory, the pass-band of the amplifier suffers some restriction due to the application of the noise cancellation device but it may be highly desirable under certain conditions to sacrifice some of the band width of the amplifier in order to secure an important reduction in noise.

It will be noted, that according to the theory, the noise currents are assumed to behave like pure sine waves so that the maximum of cancellation may be secured by critical adjustment of amplitude and phase. In the practical case, the cancellation may be somewhat less than would be expected according to the theory. However, an improvement in the noise figure may be expected even in the case of imperfect cancellation.

In practice, the amount of detuning required in the resonator 16 may best be determined experimentally by coupling a sensitive detector to the resonator 17 and varying the resonant frequency of the resonator 16 until a minimum of noise current is observed in the detector. This test is made in the absence of any signal input impressed upon the resonator 17. Tunable cavity resonators are known which are variable over a sufficient frequency range for the purpose of this test. When the correct amount of tuning is once determined, a cavity resonator of fixed resonant

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frequency of the required value may be used as resonator 16, or if desired, the resonator 16 may be provided with a trimming adjustment for fine tuning.

What is claimed is:

1. An electron velocity variation amplifier comprising means for projecting a beam of electrons along a particular path, a plurality of cavity resonators mounted along the path of said beam in the following order: the cavity resonator nearest the said means for projecting the beam being an unloaded resonator detuned from the operating frequency of the amplifier by a critical frequency difference, the next cavity resonator in order being an input resonator having an input coupling connected thereto and tuned to the operating frequency, and the next cavity resonator in order being an output device.

2. An amplifier comprising an electron beam source, a collector electrode, means adjacent said source for directing a beam from said source along a path extending to said collector electrode, input and output cavity resonators mounted along the path of said beam in energy transfer relation to the beam, input and output couplings respectively connected to said resonators, and an unloaded cavity resonator mounted along the path of said beam between said beam source and said input cavity resonator, said unloaded cavity resonator being tuned to a frequency differing by a critical amount from the resonant frequency of said input cavity resonator, to minimize noise effects in said input resonator due to electron density variations in the beam between the beam source and the input resonator.

3. An electron velocity variation amplifier comprising means for projecting a beam of electrons along a particular path, a plurality of cavity resonators mounted along the path of said beam in the following order: the cavity resonator nearest the said means for projecting the beam being an unloaded detuned resonator, the next cavity resonator in order being an input resonator having an input coupling connected thereto and tuned to the operating frequency, and the next cavity resonator in order being an output device.

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