April 21, 1959 G. E. BOGGS 2,883,527

STABILIZED NONLINEAR AMPLIFIERS

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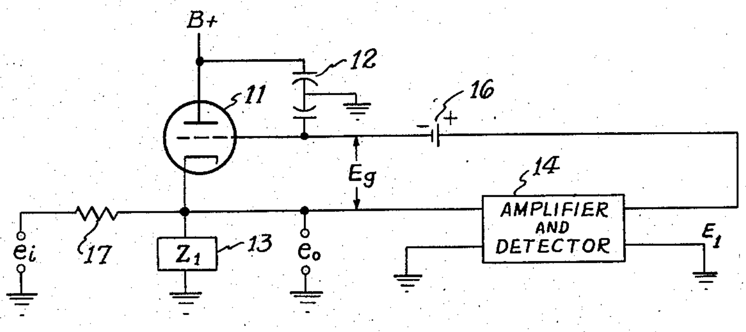

Fig. 1

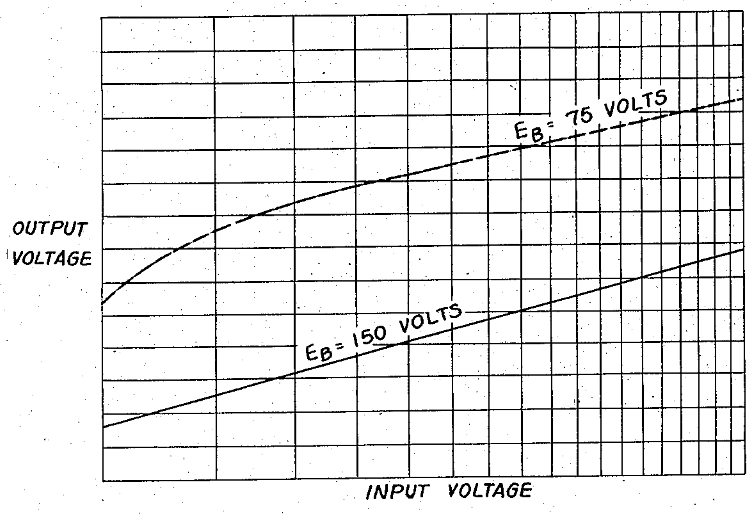

Fig. 2

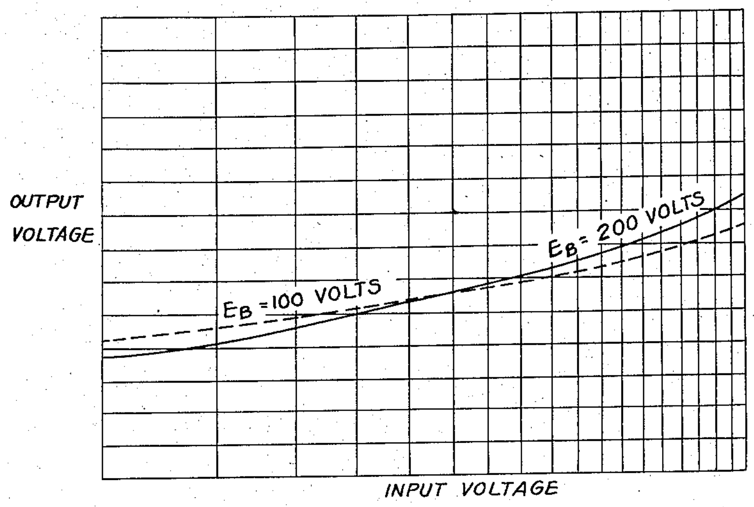

Fig. 3

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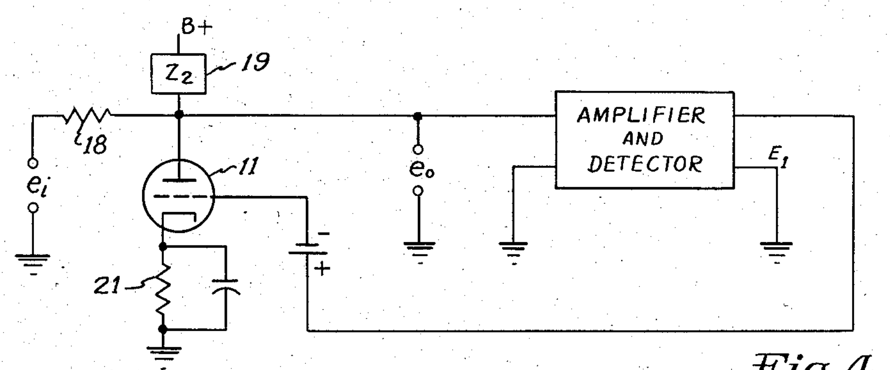

Fig. 4

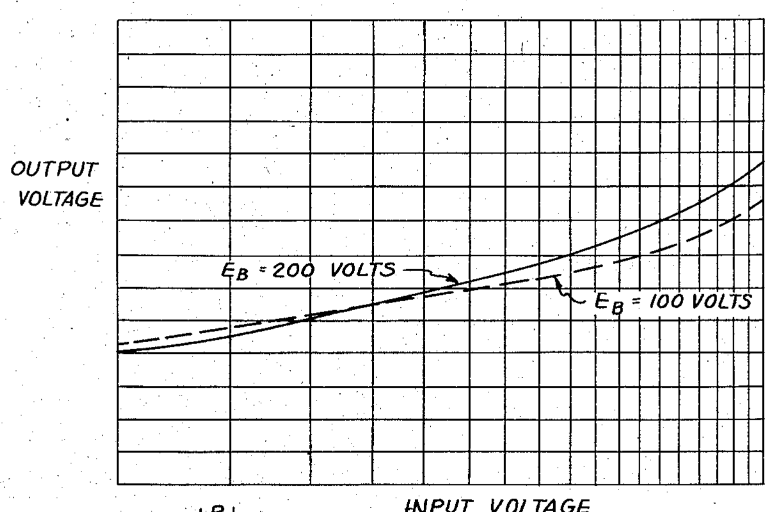

Fig. 5

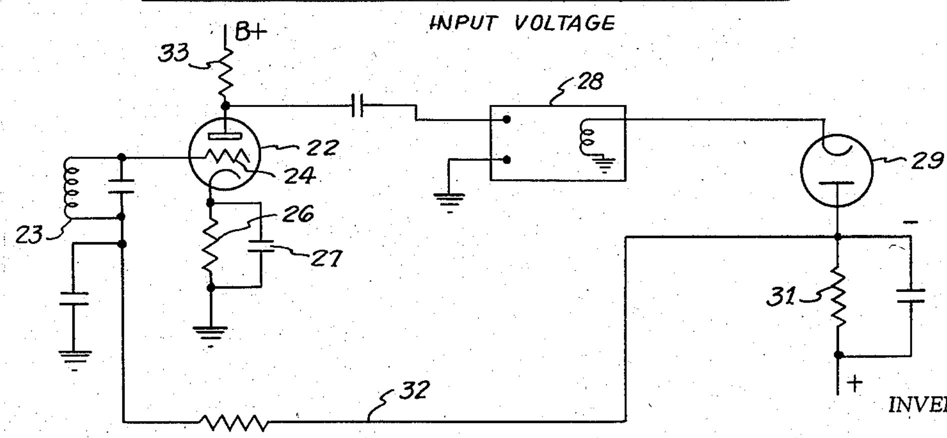

Fig. 6

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STABILIZED NONLINEAR AMPLIFIERS

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10 Claims. (Cl. 250—27)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment to me of any royalty thereon, in accordance with the provisions of 35 United States Code (1952), Section 266.

The present invention relates to a circuit employing an electron tube to produce an output voltage which is a nonlinear function of the input voltage and in particular to such a circuit in which direct-current degeneration is employed to stabilize the characteristics of the tube.

Stabilization of electron tubes in linear operation has been employed for many years in the prior art. Several methods have been used including the use of D.-C. degeneration. As far as is known, however, such a technique has not been used with a tube in a circuit having a nonlinear transfer characteristic because its use would tend to make the output linear with respect to the input, which is contrary to the desired result. The difficulty arises from the fact that D.-C. degeneration tends to stabilize the grid-to-plate transconductance of the tube regardless of the cause of the variation therein, while on the other hand it is necessary to vary this transconductance to provide the desired nonlinear transfer function. Therefore the problem is presented as to how it is possible to stabilize the transconductance with respect to certain undesired variations while varying the transconductance in accordance with desired variations.

It is therefore the primary object of the present invention to provide stabilization of electron tubes in circuits having nonlinear transfer characteristics by means of D.-C. degeneration without impairing the function of the tube as a nonlinear device.

Another object of the present invention is to provide for stabilization of electron tubes by means of D.-C. degeneration in circuits having nonlinear transfer characteristics by providing a method for distinguishing between variations in the grid-to-plate transconductance resulting from unwanted slowly varying signals on the one hand and the desired signal on the other hand.

It is another object of the present invention to provide for stabilization of electron tubes in circuits having nonlinear transfer characteristics by feeding back a D.-C. voltage to the input of the tube, which voltage is proportional to the magnitude of the envelope of the output signal.

Another object of the present invention is to provide D.-C. stabilization for an electron tube used as a variable nonlinear impedance.

Still another object of the invention is to provide D.-C. stabilization for an electron tube used as a nonlinear amplifier.

Another object of the present invention is to provide a stabilized precision nonlinear attenuator for A.-C. signals.

In accordance with the present invention, the required change in tube transconductance is achieved by a change in grid bias in accordance with the input signal. In order to achieve a stable device, the sensitivity of the tubes to variations arising from changes in all tube parameters and potentials may be reduced by the use of D.-C. degeneration. The grid control voltage is then increased by a factor K, defined as a stability factor in order to permit control of the required transconductance range. This is accomplished by inserting a large value of resistance in the cathode circuit of the tube thus producing negative D.-C. feedback. The output voltage of the tube is then amplified and rectified and the rectified signal voltage is applied to the grid of the tube. An A.-C. amplifier is used, this amplifier providing the means for differentiating between the input signal and the signals due to the aforementioned unwanted variations. The unwanted variations, since they are due to fluctuations in applied voltages, contact potentials, tube aging, etc., are relatively slow variations which show up as slowly varying D.-C. signals, and therefore are not passed by the amplifier. As a result the rectified signal is proportional to the envelope of the input signal and thereby the gain of the tube is varied in accordance with the input. If the gain of the amplifier is properly chosen, then the effect of D.-C. degeneration can be practically eliminated as regards the input signal.

Other uses and advantages of the invention will become apparent upon reference to the specification and drawings.

Figure 1 is a circuit diagram of one embodiment of the present invention in which an electron tube having a nonlinear transfer characteristic is employed as a variable impedance in a logarithmic attenuator.

Figure 2 is a graph on semilog paper of the output voltages of an unstabilized logarithmic attenuator when the plate voltage is varied.

Figure 3 is a graph on semilog paper of the output voltages of a stabilized logarithmic attenuator.

Figure 4 is a circuit diagram of a high impedance input logarithmic attenuator.

Figure 5 is a graph on semilog paper of the output voltages of a stabilized high impedance logarithmic attenuator.

Figure 6 is a circuit diagram of a stabilized nonlinear amplifier.

Referring to Figure 1, there is provided an electron tube **11** having its plate directly connected to a B+ supply and also connected to ground through the capacitor **12**. The cathode of the tube is connected to ground through the impedance **13**. The voltage developed across the impedance **13** is connected to the input of the amplifier and detector **14**. The output of the amplifier is applied to the grid of the tube **11** through the bias cell **16**. The input voltage is applied across the series-connected resistor **17** and cathode impedance **13**. The output of the system is taken across the cathode impedance **13**. In this circuit the tube **11** has a nonlinear transconductance transfer characteristic, the tube providing a nonlinear impedance in parallel with the cathode impedance **13**. In this particular circuit it is desired to produce an output voltage which varies logarithmically as the input voltage. To produce this effect, it can be shown that the grid-to-plate transconductance transfer characteristic of the tube must be approximately logarithmic with respect to the control grid voltage. In operation the input voltage is supplied across resistor **17** and impedance **13**, the output voltage being taken across the impedance **13**. This voltage is amplified and detected in the unit **14**, thereby providing a D.-C. output from the unit **14** which varies as a linear function of the envelope of the output voltage, the output voltage of the amplifier increasing as the envelope of the tube output voltage increases. The bias on the grid of the tube is determined by the voltage of the bias cell **16** and the output of the unit **14**, these two voltages being in opposition. This resulting bias fixes the point of operation of the tube along its transconductance curve.

In this circuit the tube is initially biased close to cutoff with zero signal. The A.-C. signal is applied to the tube across the cathode impedance **13** and thence to the amplifier and detector unit **14**. The rectified envelope voltage is then applied to the grid of the tube **11** and reduces the effective bias. Since the tube transconductance is greater at a lower bias, the tube acts as a variable impedance shunting the impedance **13**. The plate of the tube **11** is grounded for A.-C. voltages as a result of its connection to ground through the capacitor **12**.

For precision applications it is highly desirable to have an attenuator whose response is largely independent of supply voltages, contact potentials, tube aging, etc. Variations in these parameters will result in a proportional change in the transconductance of the tube which, if uncorrected, will produce errors in the output voltage. Therefore, it is necessary to provide some means for stabilizing the changes in transconductance due to these parameters. On the other hand, however, the attenuation characteristic of this device is achieved by changing the tube transconductance. It is well known that the sensitivity of the tube to variations arising from changes in all tube parameters and potentials may be reduced by the use of D.-C. degeneration. However, if the tube is made insensitive to the variations in all potentials, including the desired signal, it becomes relatively useless as a nonlinear device.

In the present invention this difficulty has been overcome by an increase in the loop gain of the system in order to provide sufficient control voltage to obtain the required transconductance range. The increased gain is provided in the A.-C. amplifier of unit **14**. In this way the relatively slow undesired variations are not accepted by the amplifier while the signal variations are amplified in order to provide the desired control range. In order to further illustrate the stabilizing action in this device consider the following: when D.-C. stabilization is applied to a tube, it can be shown that the sensitivity of the transconductance to changes in input voltage is reduced by a factor of approximately $1+g_mR_k$, where R_k is the D.-C. cathode resistance. It is possible to show that the transconductance may be represented as

$$g_m=f(E_1+\Sigma E) \qquad (1)$$

where ΣE is a voltage in series with E_1, the grid-to-ground voltage, and represents the effect, to a first approximation, of changes in perveance, the exponential term in Child's law and electrode voltages. Inserting a cathode resistor and increasing the grid-to-ground voltage E_1 by a factor of K in order to permit control of the required transconductance range results in the following representation:

$$g_m=f\left(\frac{KE_1+\sum E}{1+g_mR_k}\right) \qquad (2)$$

Inspection of Equation 2 reveals that the effect of variations in ΣE has been reduced by a constant K. Thus the sensitivity of the transconductance to all tube voltages except the input grid voltage has been reduced by a factor of K which is defined as a stability factor. Since Equation 2 is not of the same form as Equation 1 the transconductance transfer characteristic is of a slightly different form but this has been found to be a second order effect in most cases.

In order to obtain this D.-C. degeneration, a large cathode resistance must be employed. In one case, which will subsequently be described, the resistance employed was 10,000 ohms. The impedance **13** includes a cathode resistor, and depending upon the frequencies employed in the input, it may be necessary to use only a resistance in the cathode circuit. However, at radio frequencies the cathode-to-ground capacitance limits the magnitude of the cathode impedance. For this reason the cathode circuit should be resonant at the signal frequency, and in this case the cathode impedance will include the required inductance to obtain the resonant effect in addition to the cathode resistor necessary to provide D.-C. degeneration.

Referring to Figure 2, there is shown a curve of the attenuator output voltage at two different plate voltages on the tube **11** when stabilization is not employed. It will be noted that with a plate voltage of 150 volts the curve is a straight line, thereby indicating that the desired attenuator characteristic has been obtained. However, when the plate voltage is reduced by one-half to 75 volts, the curve is nonlinear over a portion thereof, and is greatly displaced from the curve obtained with 150 volts on the plate. The tube employed to obtain these curves was a 6BQ7.

Figure 3 is a curve of the output voltages when D.-C. degeneration is applied in the cathode circuit of the tube. In this case the cathode resistor has a value of 10,000 ohms. Again tube type 6BQ7 is employed. It will be noted that a variation in the curves with plate voltages of 200 volts and 100 volts is very small as compared with those obtained with the nonstabilized circuit. It will be noted, however, that the curves are no longer linear. This change in the characteristic of the tube is due to the use of a large cathode resistor in the circuit and may be anticipated from Equation 2. This characteristic of the stabilized attenuator will, in some cases, enable the designer to obtain the desired characteristic with a tube whose published transfer characteristic is not a sufficiently close approximation to the required relation. It appears that this property also limits the value of cathode resistance, since a substantial increase in cathode resistance beyond the value at which the desired response is obtained will cause the transfer characteristic of the device to deviate from the required law.

Figure 4 is a circuit diagram of a high impedance attenuator which is very similar to the low impedance attenuator shown in Figure 1. However, in this circuit the input voltage is applied to the plate circuit of the tube across the series circuit of resistors **18** and impedance **19**, the impedance **19** being connected in the plate circuit of the tube **11**. Again a large cathode resistor **21** is connected in the cathode circuit of the tube. The operation of this circuit is essentially the same as that of Figure 1, except that the input impedance to the device is high because of the plate resistance of the tube **11**. In this case it is the plate resistance characteristic of the tube which is important.

Referring to Figure 5, there is shown a graph of the output response of the circuit when the plate voltage is varied from 200 volts in the one case to 100 volts in the second case. The tube employed was again a 6BQ7 and the cathode resistance was 6800 ohms. Again the plots are not completely linear because the large cathode impedance has changed the characteristics of the tube.

Referring to Figure 6, there is shown another embodiment of the invention in which D.-C. degeneration is applied to an electron tube having nonlinear characteristics, which tube is used as an amplifier rather than a variable impedance. The amplifier **22** has in this case a logarithmic response to variations in grid bias. The input to the tube is applied across the tuned circuit **23** to the grid **24**. The resistor **26**, having a large value, is connected in the cathode circuit of the tube and is by-passed for alternating current by capacitor **27**. The output of the tube is capacitively coupled to the amplifier **28**. The output of the amplifier is rectified by the detector **29** and the feedback voltage is developed across the resistor **31**.

This voltage is applied to the grid 24 of the tube 22 over the line 32. As a result of the high impedance of the resistor 26, which causes the cathode of the tube 22 to be substantially positive with respect to ground, the resistor 31 is returned to a positive voltage which compensates for the voltage developed across the cathode resistor 26. The operation of this circuit with respect to D.-C. degeneration is the same as that of the devices of Figures 1 and 4. Slow variations in the voltage across the plate resistor 33 are not passed by the amplifier. Therefore the resistor 26 will stabilize the variation in transconductance due to the various factors previously mentioned. However, variations due to the input signal are amplified and passed by the amplifier 28, and a D.-C. signal which is proportional to the envelope of the output voltage is applied to the grid 24 of the tube. This will cause the transconductance of the tube to vary nonlinearly with the input voltage, thereby providing an output which is a nonlinear function of the input voltage.

The above circuits show that it is possible to stabilize the operation of a tube in nonlinear operation by means of D.-C. degeneration and an increase in loop gain. The use of an A.-C. amplifier permits discrimination between the undesired variation and the signal.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

What is claimed is:

1. A stabilized circuit for producing an electrical output which varies as a nonlinear function of an electrical input signal comprising variable electrical impedance means including a grid controlled electron tube having at least a plate, a control grid and cathode, said tube possessing a nonlinear control grid-to-plate transconductance characteristic over its operating range, said variable electrical impedance means also including direct current impedance means of an order of several thousand ohms coupled to the cathode of said tube for providing substantial direct current degeneration, means providing an alternating current signal by-pass around said D.-C. impedance means, means for applying an alternating current input signal to said variable electrical impedance means, means connecting the output from said variable electrical impedance means to a capacitively coupled alternating current amplifier, means coupled to said amplifier for rectifying at least a portion of the output thereof, and means for applying said rectified portion to the control grid of said tube.

2. A stabilized circuit for producing an electrical output which varies as a nonlinear function of an electrical input signal comprising a variable electrical impedance including a grid controlled electron tube having a plate, a control grid and a cathode, said tube possessing a nonlinear control grid-to-plate transconductance characteristic over its operating range, said variable electrical impedance also including a resistor connected in the cathode circuit of said tube for producing substantial direct current degeneration, said resistor being of an order of at least several thousand ohms, means providing an alternating current signal by-pass around said resistor, means for applying an alternating current input signal across at least a portion of said variable electrical impedance, means connecting the output from said varible electrical impedance to an alternating current amplifier circuit, said amplifier circuit including means for blocking direct current, means coupled to said amplifier circuit for rectifying the output thereof, and means for applying said rectified output to the control grid of said tube.

3. A stabilized circuit for producing an electrical output which varies as a nonlinear function of an electrical input signal comprising a variable electrical impedance including a grid controlled electron tube having a plate, a control grid and a cathode, said tube possessing a nonlinear control grid-to-plate transconductance characteristic over its operating range, plate supply means coupled to said tube, said variable electrical impedance including a relatively large resistor connected between said cathode and the negative terminal of said plate supply means for producing substantial direct current degeneration in said tube, means for applying an alternating current input signal across at least a portion of said variable electrical impedance, means providing an alternating current signal bypass around said resistor, means connecting the output from said variable electrical impedance to an alternating current amplifier circuit, said amplifier circuit including means for blocking direct current, means coupled to said amplifier circuit for rectifying the output thereof, and means for applying said rectified output to the control grid of said tube.

4. A circuit for producing an electrical output which varies as a nonlinear function of an input signal comprising an electron tube having at least three electrodes including a plate, a control grid and a cathode, said electron tube having a nonlinear control grid-to-plate transconductance characteristic over its operating range, an impedance including said electron tube across a portion of which an alternating current input signal is developed, means comprising a relatively large resistor connected in the cathode circuit of said tube for producing substantial direct current degeneration to stabilize said grid-to-plate transconductance, means providing an alternating current signal by-pass around said resistor, an alternating current amplifier having means to block direct current connected to receive the output from said impedance, means connected to the output of said amplifier to rectify the output thereof, and means for applying at least a portion of said rectified output to the grid of said tube.

5. A circuit as defined in claim 4 in which said electrical impedance comprises an alternating current potential divider having a fixed portion and a variable portion including said tube in series and in which said alternating current input signal is developed across said entire potential divider and in which the output therefrom is taken across said variable portion.

6. A circuit as defined in claim 5 in which the output from said potential divider is taken from the cathode of said tube.

7. A circuit as defined in claim 5 in which said variable portion includes a plate load impedance for said tube and in which the output from said potential divider is taken from the plate of said tube.

8. A circuit for producing an electrical output which varies as a nonlinear function of an input signal comprising an electron tube having at least a plate, a grid and a cathode, said electron tube having a nonlinear grid-to-plate transconductance characteristic over its operating range, means for applying an alternating current signal input to the grid of said tube, means comprising a relatively large resistor connected in the cathode circuit of said tube for producing substantial direct current degeneration to stabilize the grid-to-plate transconductance, means providing an alternating current signal by-pass around said resistor, an alternating current amplifier having means to block direct current connected to the output from said tube, means connected to the output of said amplifier to rectify the output thereof, and means for applying at least a portion of said rectified output to said grid.

9. A circuit for producing an electrical output which varies as a nonlinear function of an input signal comprising an electron tube having a plate, a control grid and a cathode, said electron tube having a nonlinear control grid-to-plate transconductance characteristic over its operating range, means for applying an alternating current signal input to the grid of said tube, a relatively large resistor connected in the cathode circuit of said tube for producing substantial direct current degeneration to

stabilize the grid-to-plate transconductance, additional impedance means coupled in said cathode circuit to by-pass said resistor for alternating current signal frequencies, an alternating current amplifier having means to block direct current connected to said plate to receive the output from said tube, means connected to the output of said amplifier to rectify the output thereof, and means for applying said rectified output to said grid.

10. A circuit as defined in claim 9 including bias means coupled to said grid to at least partially compensate for quiescent self-bias developed across said cathode resistor.

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