April 17, 1928. 1,666,738

R. V. L. HARTLEY

TRANSMISSION CIRCUIT

Filed Aug. 29. 1924

Fig. 1.

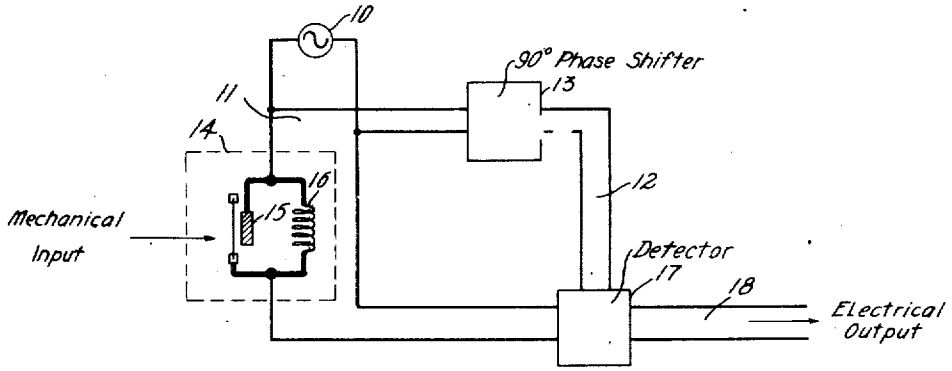
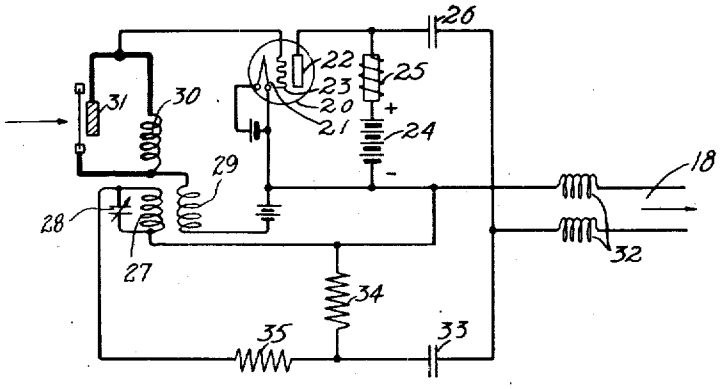


Fig. 2.



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UNITED STATES PATENT OFFICE.

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TRANSMISSION CIRCUIT.

Application filed August 29, 1924. Serial No. 734,861.

This invention relates to wave transmission, and more particularly to the conversion of mechanical waves into electrical waves.

Heretofore it has been common to employ transmitters of the mechanically variable resistance type, illustrated by the microphone, or of the mechanically variable reactance element type for converting mechanical waves, such as speech or sound waves, into electrical waves. Transmitters employing a mechanically variable resistance are in general more difficult to control, and produce more objectionable distortion than those employing a mechanically variable reactance element. On the other hand, the energy output from transmitters of the variable reactance type such, for example, as condenser transmitters, has been found to be insufficient for many purposes.

Objects of the present invention are to overcome the above difficulties; to provide efficient methods of and apparatus for converting mechanical waves, for example, speech or other sound waves, into electrical waves; to provide a substitute for a microphonic transmitter; and to provide a suitable transmitter for a substation in a signaling or wave transmission system.

In accordance with one aspect of the present invention a mechanical wave is converted into an electrical wave by mechanically controlling a variable reactance element to modulate the phase of a carrier wave in accordance with the mechanical wave, and detecting the resulting modulated wave by beating it with an unmodulated carrier wave in phase quadrature with the first mentioned carrier wave. The detected wave corresponds in character with the mechanical wave. The variable reactance for modulating the carrier wave may be a condenser transmitter, and is so associated with the carrier wave source as to not materially affect its frequency.

In one form of the invention, an amplifier of the space current type is so connected as to generate the carrier wave and at the same time produce the electrical wave corresponding to the mechanical wave by detection of the carrier wave modulated by the mechanical wave. Provision is made for decreasing the current fed from the output to the input circuits of the amplifier and for increasing the detecting efficiency of the amplifier.

These and other novel features and objects of the invention will be more clearly understood by reference to the following detailed description in view of the accompanying drawing, in which Fig. 1 is a schematic circuit diagram of one form of the invention, and Fig. 2 is a modification employing an amplifier of the space current type.

Referring to Fig. 1, the generator 10 supplies a carrier wave to the circuits 11 and 12. A phase shifter 13, of any suitable type, for shifting the phase of the carrier wave 90 degrees, is connected in one of the circuits 11 or 12, so that the carrier wave in one of these circuits is in phase quadrature with the wave in the other. The modulator 14 connected in circuit 11 may be of any suitable type for mechanically acting upon circuit 11 to vary the reactive component of the impedance through which the carrier wave is transmitted. In the form of circuit shown a condenser transmitter 15, of well-known type, is connected in parallel with inductance 16 to form therewith a resonant circuit, tuned substantially to the frequency of the carrier wave from source 10. Condenser 15 variably reactively or capacitively impedes the transmission of the carrier wave and thus varies its phase in accordance with the mechanical wave applied thereto. Circuits 11 and 12 are connected to the detecting device 17, of any well-known suitable type having a non-linear transmission characteristic, the output circuit or line 18 being provided for transmission of the detected wave.

It is to be noted that phase modulation produces a modulated wave which requires a somewhat more complicated detecting process than that required for detecting a modulated wave produced by amplitude modulation. In the case of an amplitude modulated wave, that is, a carrier wave whose amplitude is varied in accordance with a modulating wave, it is only necessary to beat together or produce a non-linear interaction between the side-bands and an unmodulated component of the original unmodulated carrier wave. In the case of phase modulation, however, it has been found that beating of the side-bands with an unmodulated com-

ponent of the original carrier wave produces no components of the signal frequency. This is apparently due to the fact that when the phase of a carrier wave is modulated, the unmodulated component has a different relation to the modulated side bands than in the case of amplitude modulation. For example, if the side bands are identical in the two cases, the unmodulated carrier component of the phase modulated carrier wave is in quadrature with the unmodulated carrier component of the amplitude modulated carrier wave.

That is, the product of this modulation may be represented by the expression: $M=K[\cos pt-k \sin pt \cos qt]$ whereas the product of amplitude modulation may be represented by the corresponding expression: $M=K[\sin pt+k \sin pt \cos qt]$ in each of which equations p and q represent the carrier and modulating frequencies, respectively, when multiplied by the operator 2Π; K sin pt and K cos pt represent the unmodulated carrier components; and K k sin pt cos qt represents the side band components. Comparing these expressions, it will be seen that they differ essentially only in that the phase of the unmodulated carrier of the first expression is displaced, relatively to its side bands, by 90 electrical degrees, as compared with the unmodulated carrier component in the second expression. If the carrier and side band components of the first expression are combined in a detector which obeys the square law, the reproduced signal waves resulting from the operations on the two side bands will be found to cancel each other. If the corresponding components of the second expression are similarly combined, the reproduced signal waves resulting from the operations on the two side bands will add to produce a resultant wave. A more detailed proof of the above relations may be found in applicant's copending application Serial No. 41,914, filed July 7, 1925, U. S. Patent No. 1,633,016.

This difficulty is overcome in the circuit of Fig. 1 by providing the circuit 12 supplying a carrier wave in phase quadrature with the unmodulated component of the carrier wave in circuit 11.

In the operation of Fig. 1, a high frequency carrier wave from source 10 is transmitted through circuit 11, the phase of the wave being modulated in accordance with speech or sound waves, or other mechanical variations impressed upon condenser 15. Modulated waves from circuit 11 together with the unmodulated carrier wave from circuit 12 in phase quadrature with the wave from circuit 11 are transmitted to detector 17. The resulting detected wave corresponding in wave form to the mechanical wave impressed on capacity 15, is transmitted to line 18. It will thus be seen that the circuit of Fig. 1 produces an electrical wave corresponding to an impressed mechanical wave, and is particularly useful as a telephone transmitter in a substation of a telephone or other wave transmission system. The quality of the detected wave produced by the method described is better than that produced in an ordinary microphonic transmitter by the same mechanical wave.

In Fig. 2, an electric wave amplifier 20 of the well-known space current type is provided with the cathode 21, anode 22 and the grid or control element 23. Grid 23 together with cathode 21 constitutes a pair of input terminals, and anode 22 together with cathode 21 constitutes a pair of output terminals for the amplifier. Space current from source 24 is supplied to the amplifier through choke coil 25 which prevents the transmission of alternating current from the output terminals of the amplifier through the source of direct current 24. Condenser 26 prevents the passage of direct current while presenting a path of low or negligible impedance to the passage of alternating current.

Inductance 27 of resonant circuit 27, 28 is coupled to inductance 29 to provide a feed-back circuit coupling the output and input terminals of the amplifier whereby a carrier wave current is generated, the frequency being determined by resonant circuit 27, 28. Inductance 30 and condenser transmitter 31 constitute a tuned circuit, preferably resonant to the frequency of the carrier wave generated in the amplifier, the inductance 30 being loosely coupled to inductance 27. Input resonant circuit 30, 31 is connected in series with inductance 29 so that the voltages across circuit 30, 31 and inductance 29 are in series. Owing to the loose coupling between inductances 27 and 30, insufficient energy is passed therebetween to support the generation of continuous oscillations.

When carrier waves are being generated in amplifier 20, current transmitted through inductance 27 is approximately 90 degrees out of phase with the voltage thereacross. The voltage induced in inductance 29 is displaced substantially 90 degrees from the current in inductance 27. It will, therefore, be seen that the voltage applied to the input terminals of the amplifier by inductance 29 is substantially in phase with or displaced 180 degrees from the voltage across the output terminals of the amplifier. Inductance 29 is so poled as to support the generation of continuous oscillations. The voltage across resonant circuit 30, 31 is displaced substantially 90 degrees from the voltage induced in inductance 29. That this is true is evident when it is considered that, although the voltages induced in inductances 29 and 30 from the inductance 27 are in the same phase, these voltages are differently

applied to the resonant circuit 30, 31. This circuit is in parallel resonant relation to the voltage induced in 29 and, therefore, constitutes a very large impedance for current due to this voltage; and in series resonant relation to the voltage induced in 30 and, therefore, constitutes a very much smaller impedance for the current due to this voltage. The voltage impressed on the grid from inductance 29, therefore, is substantially the same vectorily as the voltage induced in such inductance. The circulating current produced in series resonant circuit 30, 31 by the voltage induced in inductance 30 is in phase with such voltage, which is very small. However, the principal voltage impressed on the grid-filament results from the potential drop across the inductance 30 and due to such circulating current. This voltage is obviously in quadrature with the circulating current and, therefore, with the voltage induced in 30 and also with the voltage across inductance 29. Inductance element 29, therefore, may be looked upon as a source of carrier waves in phase quadrature with the carrier wave transmitted to inductance 30 from circuit 27, 28 which functions as a second source of carrier waves.

Mechanical vibrations, such as speech or other sound waves, are applied to condenser transmitter 31, thereby modulating the phase of the carrier wave transmitted from resonant circuit 30, 31. The resulting modulated waves are transmitted to the input terminals of the amplifier together with the unmodulated carrier wave from inductance 29. It will, therefore, be seen that the waves applied to the input terminals of the amplifier are in correct phase relation to produce a detected wave corresponding to the mechanical wave acting upon condenser 31. The non-linear transmission characteristic of amplifier 20 causes the waves impressed on the input terminals to beat together to produce a detected wave. The detected wave is transmitted from the output terminals of the amplifier through condenser 26 and high frequency choke coils 32 to line 18. Coils 32 are of low impedance to the detected wave and of high impedance to the carrier wave.

If the circuit 30, 31 is resonant at the carrier frequency, the phase variations will be proportional to the relative change in impedance that would occur if the frequency were similarly varied about a point of symmetry in the frequency-impedance curve which represents the character of the impedance as well as its absolute value. That is, variations would occur about the zero impedance point marking the mid-point of the transition portion of such curve between a relatively large inductive reactance and a relatively large capacitive reactance. The variation of phase is a maximum for this resonant condition, and is also a maximum when the resistance of the resonant circuit is minimum. The ultimate effect of this method of modulation, as is explained in applicant's copending application Serial No. 41,914, filed July 7, 1925, is to produce side bands which are equivalent to the side bands produced by amplitude modulation, although the resultant unmodulated carrier components are different in the two instances.

In the particular circuit disclosed there may be amplitude modulation as well as phase modulation but, by reason of the inherently unfavorable conditions, amplitude modulation will be relatively very small. That is, amplitude modulation results from a change in absolute value of impedance. Under the conditions specified for this circuit, the change of absolute value of impedance would be a minimum.

Condenser 33 prevents the transmission and consequent loss of the detected wave through the feed-back circuit in shunt to line 18, the condenser being of high impedance to the detected wave and of low impedance to the carrier wave. Resistance 34, or other suitable impedance, provides a path of low impedance for the carrier wave in shunt to the output terminals of the amplifier thereby increasing the detecting efficiency of the amplifier and at the same time reducing to a proper value the energy of the carrier current transmitted through the feed-back circuit. Resistance 35 still further reduces the energy transmitted through the feed-back circuit.

As ordinarily employed, the mechanical wave applied to condenser 31 is of relatively low frequency in comparison to the carrier wave generated in the amplifier, the detected wave transmitted to line 18 being also of low frequency corresponding to the wave applied to condenser 31. However, it is within the scope of the present invention to utilize other frequency relations. While a condenser transmitter has been disclosed as the modulating element for varying the phase of the carrier wave, it is obvious that any suitable variable reactive element, or phase modulating apparatus, might be employed for this purpose.

It should be noted that exact phase quadrature between the carrier wave from circuit 30, 31 and the carrier wave from inductance 29, Fig. 2, or between the carrier waves in circuits 11 and 12, Fig. 1, is not essential to the successful operation of the system. The reproduced or detected low frequency wave is substantially proportional to the cosine of twice the phase difference between the carrier waves, and so varies quite slowly with this difference in the neighborhood of 90 degrees.

While the invention has been described with specific reference to certain illustrative species, it is to be understood that the in-

vention may be carried out in various ways and be embodied in various forms as broadly defined in the appended claims.

What is claimed is:

1. The method of converting a mechanical wave into an electrical wave which comprises modulating the phase of a carrier wave in accordance with said mechanical wave, and producing the desired wave by beating together the resulting modulated wave and a carrier wave substantially in phase quadrature with said first-mentioned carrier wave.

2. The method of converting a mechanical wave into an electrical wave which comprises variably reactively impeding the transmission of a carrier wave in accordance with said mechanical wave, and producing the desired wave by beating together the resulting modulated wave and a carrier wave substantially in phase quadrature with said first-mentioned carrier wave.

3. In a telephone transmitter, the method of operation which comprises modulating the phase of a carrier wave in accordance with a mechanical wave, beating together the resulting modulated wave and a carrier wave substantially in phase quadrature with said first-mentioned wave, and transmitting from said transmitter at least a portion of the resulting detected wave.

4. In a telephone transmitter, the method of operation which comprises varying the phase of a carrier wave in accordance with a mechanical wave, detecting the resulting modulated wave by beating therewith a carrier wave substantially in phase quadrature with said first-mentioned carrier wave, and transmitting the resulting detected wave from the transmitter.

5. The method of converting a mechanical wave into an electrical wave which comprises separately transmitting two carrier wave currents substantially in phase quadrature with each other, modulating the phase of one of said currents in accordance with said mechanical wave, and beating together the resulting currents from the two phases to obtain the desired wave.

6. In apparatus for converting mechanical waves into electrical waves, the method of operation which comprises producing a high frequency carrier wave current, varying the phase of said wave in accordance with the instantaneous amplitudes of said mechanical waves, beating together the resulting modulated wave and an unmodulated carrier wave substantially in phase quadrature with said first-mentioned carrier wave, and transmitting the resulting detected wave from the apparatus.

7. The method of utilizing a space current device of the kind having an anode, a cathode and a control element, which comprises generating a carrier wave through the agency of said device, deriving from said carrier wave a second carrier wave substantially in phase quadrature with said first wave, modulating the phase of one of said carrier waves in accordance with a mechanical wave, beating the resulting modulated wave with said other carrier wave, and utilizing the resulting detected wave.

8. In a substation for an electrical wave transmission system, a pair of circuit elements, means for producing in said elements waves which are alike except relatively displaced in phase substantially 90 electrical degrees, one of said elements including means whereby it may be mechanically acted upon to modulate the phase of the wave therein in accordance with the wave to be transmitted from the substation, and means for beating the resulting modulated wave with the wave produced in the other element.

9. In a substation for an electrical wave transmission system, a pair of circuit elements, means for producing in said elements electrical waves which are alike except relatively displaced in phase substantially 90 electrical degrees, one of said elements including means whereby it may be mechanically acted upon to modulate the phase of the wave therein in accordance with the wave to be transmitted from the substation, means for beating the resulting modulated wave with the wave produced in the other element, and a pair of output terminals for transmitting from said substation the resulting detected wave.

10. In a substation for an electrical wave transmission system, a pair of circuit elements, means for producing in said elements electrical waves which are alike except relatively displaced in phase substantially 90 electrical degrees, one of said elements including means whereby it may be mechanically acted upon to modulate the phase of the wave therein in accordance with the wave to be transmitted from the substation, and a space current device connected to said circuits for beating the resulting modulated wave with the wave produced in the other element.

11. In a substation for an electrical wave transmission system, a pair of circuit elements, means for producing in said elements electrical waves alike except relatively displaced in phase substantially 90 electrical degrees, one of said elements including a condenser transmitter for modulating the phase of the wave therein in accordance with the wave to be transmitted from the substation, and means for beating the resulting modulated wave with the wave produced in the other element.

12. In apparatus for converting a mechanical wave into an electrical wave, an electrical wave amplifier having input terminals and output terminals, means coupling said output and input terminals

whereby a carrier wave is generated by said amplifier, said coupling means including means for modulating said carrier wave in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave, and means associated with said coupling means for decreasing the energy transmitted therethrough and for increasing the detecting efficiency of the amplifier.

13. In apparatus for converting a mechanical wave into an electrical wave, an electric wave amplifier having input terminals and output terminals, means coupling said output and input terminals whereby a carrier wave is generated by said amplifier, said coupling means including means for modulating said carrier wave in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave, and means for transmitting the detected wave separately from said carrier wave.

14. In apparatus for converting a mechanical wave into an electrical wave, an electrical wave amplifier having input terminals and output terminals, means coupling said output and input terminals whereby a carrier wave is generated by said amplifier, said coupling means including means for modulating said carrier wave in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave, and a resistance path in shunt to said coupling means for decreasing the energy transmitted therethrough and for increasing the detecting efficiency of the amplifier.

15. In apparatus for converting a mechanical wave into an electrical wave, an electrical wave amplifier having input terminals and output terminals, means coupling said output and input terminals whereby a carrier wave is generated by said amplifier, said coupling means including means for modulating said carrier wave in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave, and a path of relatively low impedance to said carrier wave in shunt to said coupling means for decreasing the energy transmitted therethrough and for increasing the detecting efficiency of the amplifier.

16. In apparatus for converting a mechanical wave into an electrical wave, an electrical wave amplifier having input terminals and output terminals, means coupling said output and input terminals whereby a carrier wave is generated by said amplifier, said coupling means including means for modulating said carrier wave in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave, and a path of relatively low impedance to said carrier wave and of high impedance to the detected wave in shunt to said coupling means for decreasing the energy transmitted therethrough and for increasing the detecting efficiency of the amplifier.

17. In apparatus for converting a mechanical wave into an electrical wave, an electrical wave amplifier having input terminals and output terminals, means coupling said output and input terminals whereby a carrier wave is generated by said amplifier, said coupling means including means for modulating said carrier wave in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave, and means associated with said coupling means for decreasing the energy transmitted therethrough and for increasing the detecting efficiency of the amplifier, said means including a resistance path in shunt to said coupling, and a resistance path in series therewith.

18. In apparatus for converting a mechanical wave into an electrical wave, an electrical wave amplifier having input and output terminals, means coupling said output and input terminals whereby two carrier waves substantially in phase quadrature with each other are generated by said amplifier and transmitted to said input terminals, said coupling means including means for modulating the phase of one of said carrier waves in accordance with said mechanical wave, and for transmitting the resulting modulated wave to said amplifier for detection to produce the desired electrical wave.

19. In apparatus for converting mechanical waves into electrical waves, an electrical wave generator, a circuit associated with said generator for deriving therefrom, an auxiliary wave substantially in phase quadrature with the generated wave, said circuit including means for varying the phase of the wave transmitted therefrom in accordance with said mechanical waves, said circuit being connected to apply the resulting modulated wave to said generator whereby detected waves corresponding to said mechanical waves are produced in the generator.

20. In apparatus for converting a mechanical wave into an electrical wave, an amplifier having an anode, a cathode and a control element, a frequency determining feed-back circuit coupling said anode and control element whereby a carrier wave is generated by said amplifier, means associated with said feed-back circuit for deriving from the generated wave a wave substantially in

phase quadrature therewith, said means including a modulator for varying the phase of the wave transmitted therethrough, and being arranged to apply the resulting modulated wave to said control element whereby a detected wave corresponding to said mechanical wave is produced in said amplifier.

21. In apparatus for converting a mechanical wave into an electrical wave, an amplifier having a pair of input terminals and a pair of output terminals, a resonant frequency determining circuit connected to said output terminals, an inductance connected to said input terminals and coupled to said resonant circuit whereby a carrier wave is generated by said amplifier, and a circuit substantially resonant to said carrier wave connected to said input terminals and loosely coupled to said output resonant circuit, said input resonant circuit including a variable reactance controlled by said mechanical wave for modulating a carrier wave transmitted therethrough, whereby a modulated wave is transmitted to said amplifier to produce the desired wave by detection.

22. In apparatus for converting a mechanical wave into an electrical wave, a source of two carrier waves substantially in phase quadrature with each other, a pair of circuits connected to said source, one for each of said waves, means for mechanically acting upon one of said circuits to vary in accordance with said mechanical wave the phase of the carrier wave transmitted therethrough, and means connected to said circuits for beating together the resulting waves thereby to produce the desired wave.

In witness whereof, I hereunto subscribe my name this 26th day of August A. D., 1924.

RALPH V. L. HARTLEY.

CERTIFICATE OF CORRECTION.

Patent No. 1, 666,738. Granted April 17, 1928, to

RALPH V. L. HARTLEY.

It is hereby certified that error appears in the above numbered patent requiring correction as follows: In the drawings Fig. 2, the diagonal line extending through the numeral 22, under the numeral 25, and terminating near the numeral 18, should not appear on the drawing; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 25th day of September, A. D. 1928.

M. J. Moore,
Acting Commissioner of Patents.

(Seal)

phase quadrature therewith, said means including a modulator for varying the phase of the wave transmitted therethrough, and being arranged to apply the resulting modulated wave to said control element whereby a detected wave corresponding to said mechanical wave is produced in said amplifier.

21. In apparatus for converting a mechanical wave into an electrical wave, an amplifier having a pair of input terminals and a pair of output terminals, a resonant frequency determining circuit connected to said output terminals, an inductance connected to said input terminals and coupled to said resonant circuit whereby a carrier wave is generated by said amplifier, and a circuit substantially resonant to said carrier wave connected to said input terminals and loosely coupled to said output resonant circuit, said input resonant circuit including a variable reactance controlled by said mechanical wave for modulating a carrier wave transmitted therethrough, whereby a modulated wave is transmitted to said amplifier to produce the desired wave by detection.

22. In apparatus for converting a mechanical wave into an electrical wave, a source of two carrier waves substantially in phase quadrature with each other, a pair of circuits connected to said source, one for each of said waves, means for mechanically acting upon one of said circuits to vary in accordance with said mechanical wave the phase of the carrier wave transmitted therethrough, and means connected to said circuits for beating together the resulting waves thereby to produce the desired wave.

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