Nov. 15, 1949 W. W. HANSEN 2,487,800

FREQUENCY MULTIPLIER AND STABILIZATION CAVITY RESONATOR APPARATUS

Filed Jan. 22, 1943 2 Sheets-Sheet 1

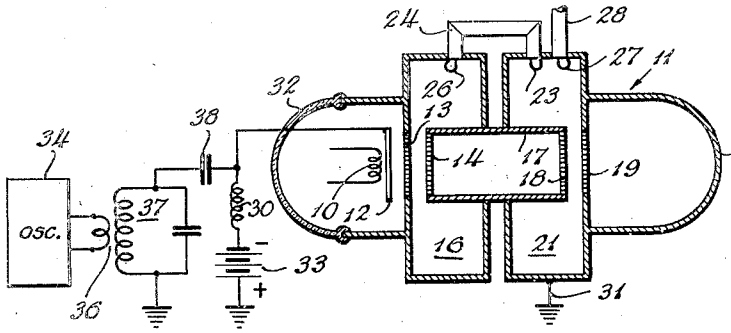


Fig. 1.

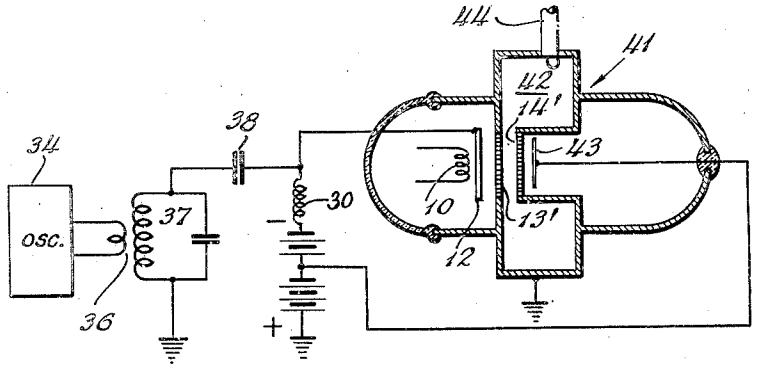


Fig. 2.

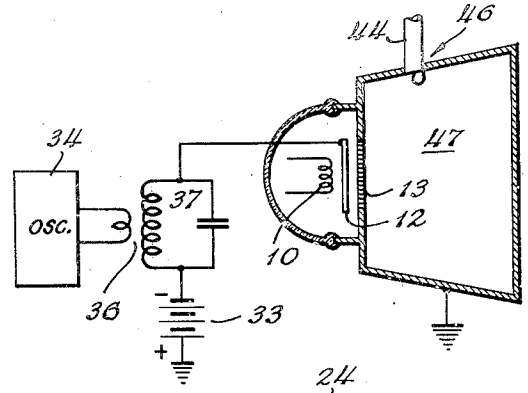


Fig. 3.

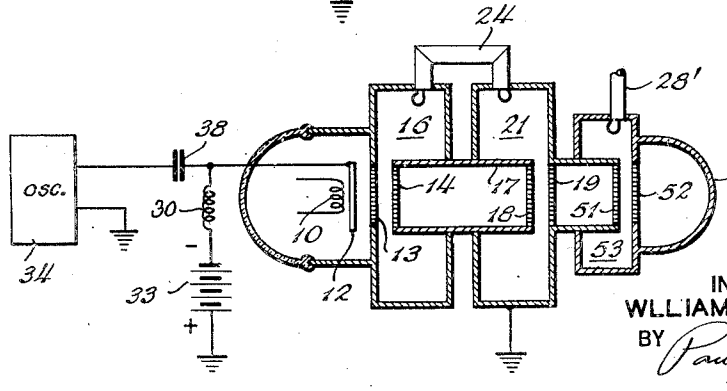


Fig. 4.

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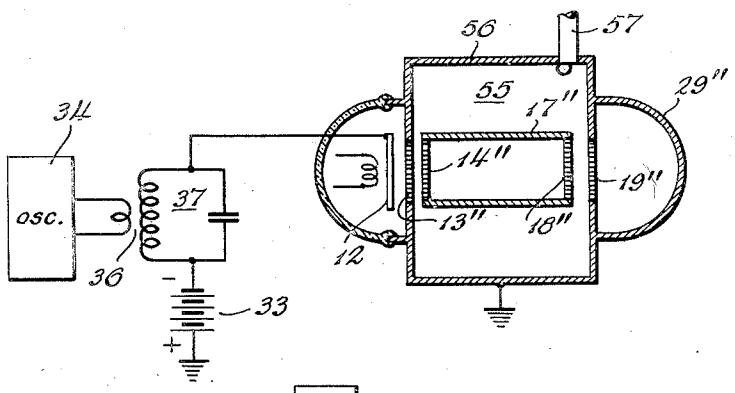


Fig. 5.

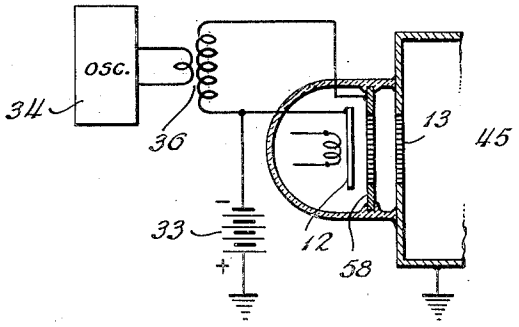


Fig. 6.

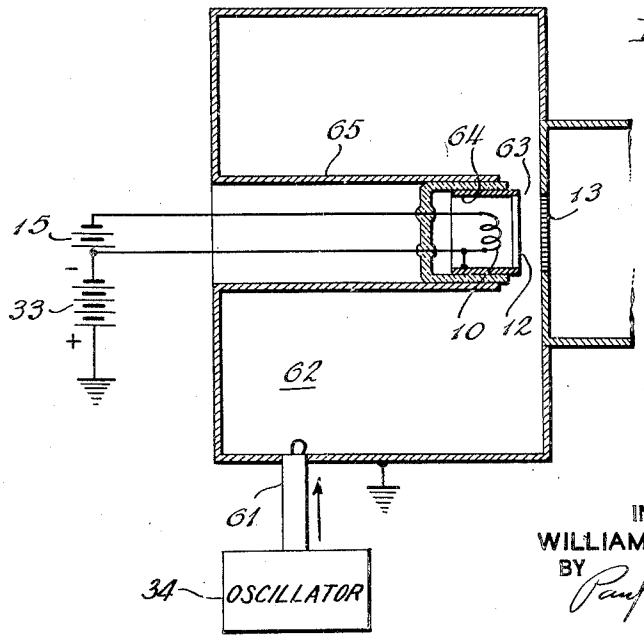


Fig. 7.

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Patented Nov. 15, 1949 2,487,800

UNITED STATES PATENT OFFICE

2,487,800

FREQUENCY MULTIPLIER AND STABILIZATION CAVITY RESONATOR APPARATUS

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Application January 22, 1943, Serial No. 473,254

9 Claims. (Cl. 315—6)

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The present invention is related to the art including frequency multipliers, especially for ultra high frequencies of the order of 10^8 cycles per second or higher.

The present device utilizes the principle of velocity variation or velocity modulation set forth in Varian Patent No. 2,242,275, issued May 20, 1941, but, as will be shown below, may be utilized with many other types of electron discharge devices. In this patent, an ultra high frequency oscillation generator is described in which an electron beam is acted upon by the high frequency field in a first or "buncher" hollow cavity resonator to produce periodic velocity variations of the electrons. These velocity-varied electrons are then projected through a field-free space in which the higher velocity electrons overtake the lower velocity electrons, producing recurrent bunching along the beam. This bunched beam is then projected through a second or "catcher" hollow cavity resonator, which abstracts energy from the beam at the operating ultra high frequency. A portion of this energy may be regeneratively fed back to sustain and maintain the velocity variations of the beam, if the device is to act as an oscillator and the remainder of the energy in the resonator is then available for use as desired. The electrons, after giving their energy to the "catcher" resonator, are suitably collected and returned to the cathode.

In devices of this type, the velocity varying or "buncher" resonator operates at and has the same resonant frequency as the energy pick-up or "catcher" resonator. It is often desirable to synchronize such an oscillator with a different source of high frequency energy. For example, sources of high frequency energy of several types producing frequencies of the order of several hundred megacycles per second are readily available, and it is often desirable to synchronize or "lock-in" an ultra high frequency oscillator of the above velocity-variation type with such a relatively low frequency oscillator; that is, to maintain a harmonic relation between these oscillators. By thus supplying relatively low frequency energy or medium frequency energy to the ultra high frequency oscillator and exciting or driving the oscillator in this way, larger amounts of ultra high frequency power, and improved frequency stabilization may be produced. The present invention provides apparatus for accomplishing this desirable purpose.

In the following, the term "relatively low frequency" is intended to designate a frequency of 300 megacycles per second or less, corresponding to wavelengths greater than one meter.

Accordingly, it is an object of the present invention to excite or drive an ultra high frequency velocity variation oscillator by means of a relatively low frequency wave.

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It is a further object of the present invention to stabilize the frequency of an ultra high frequency velocity variation oscillator from a relatively low frequency source of oscillations.

It is another object of the present invention to provide improved apparatus for producing ultra high frequency oscillations of a frequency harmonically related to that of a relatively low frequency source of oscillations.

Further objects and advantages will become apparent from the attached specification and drawings, wherein

Fig. 1 shows a schematic diagram of one form of driven high frequency oscillator according to the present invention.

Fig. 2 shows a schematic diagram of a modification of the apparatus of Fig. 1, and

Figs. 3–5 show schematic diagrams of further modifications of the device of Fig. 1, and

Figs. 6 and 7 show fragmentary views of modifications of portions of Figs. 1–5.

Referring to Fig. 1, reference numeral 11 refers to an ultra high frequency velocity variation oscillation generator of the type shown in the above-mentioned Varian Patent No. 2,242,275. This generator comprises a thermionic cathode 12 heated by filament 10 and acting as a source of electrons, which are projected under the influence of a battery 33 in the form of an electron beam through grids 13 and 14 forming a portion of the walls of a hollow resonant cavity or resonator 16 having a resonant frequency substantially the same as or close to the desired output frequency of the apparatus. Any high frequency alternating electromagnetic field existing within resonator 16 will produce recurrent velocity variations of the electrons passing between grids 13 and 14. The electrons then exiting from grid 14 pass through a field-free drift tube 17 whose length is so selected that, by the time these electrons arrive at the further grid 18, they are grouped to form recurrent bunches along the electron stream. Grids 18 and 19 form portions of the walls of a further energy pick-up or "catcher" resonator 21 and deliver high frequency energy at the operating frequency to the field within resonator 21. A portion of this energy is fed back to "buncher resonator" 16, as by way of a suitable coupling loop 23, connecting concentric transmission line 24, and coupling loop 26. A further coupling loop 27 and concentric transmission line 28 are provided, from which useful high frequency energy may be derived from resonator 21, for use wherever desired. The electrons passing through grid 19 are collected by a suitable collector electrode 29, which may form a part of the evacuated conductive housing of the device or may be a separate insulated electrode. Preferably, the evacuated housing is substantially completely metallic and grounded, as at 31, the cathode 12

being insulated therefrom by means of a suitable insulating seal 32 and operated at a high negative potential by means of battery 33 connected thereto through a radio frequency choke coil 30.

The circuit thus far described is essentially identical with that disclosed in the above-mentioned patent No. 2,242,275 and will operate as a self-sustained ultra high frequency oscillation generator to produce oscillations of the frequency to which resonators 16 and 21 are tuned. However, to stabilize the frequency output of this oscillator, and to increase the power output therefrom, it is desirable to excite or drive this oscillator from a further source of oscillations, which, according to the present invention, may be of a much lower frequency, for example, $\frac{1}{10}$ the frequency of the desired output frequency. Such a stabilizing frequency may be derived from a suitable oscillator 34 of any conventional type. As an illustrative example, the output of oscillator 34 may have a frequency of the order of 300 megacycles per second, and the resonators 16 and 21 may be tuned to a frequency of the order of 3000 megacycles per second (10 centimeters wavelength) whereby a 10 to 1 frequency multiplication may be obtained.

The output of oscillator 34 is coupled, as by means of a suitable radio frequency transformer 36, to a tuned circuit 37 connected between cathode 12 and grounded grid 13 through a high capacity blocking condenser 38. Accordingly, an alternating voltage of the frequency of oscillator 34 is thus impressed between cathode 12 and grid 13. Choke 30 prevents this voltage from being shortcircuited to ground through battery 33. Any other ways of impressing this voltage between cathode 12 and grid 13, such as shown in Figs. 3 and 4, may be used here, as described. This voltage produces a modulation of the electron stream flowing from cathode 12 at a frequency corresponding to that of oscillator 34. It has been discovered that such a modulation of the electron stream permits oscillator 11 to operate satisfactorily only at a frequency which is an exact harmonic of oscillator 34, when the resonant frequency of oscillator 11 is close to a harmonic of that of oscillator 34, by virtue of the phase relations existing between the relatively low frequency modulation of the electron stream caused by oscillator 34 and the high frequency variations produced by the field within resonator 16.

By the present arrangement, therefore, the frequency output of the oscillator 11, as derived by way of line 28, is accurately stabilized by that of oscillator 34. As is well known, oscillators of relatively low frequency, such as oscillator 34, are much more easily stabilized by well-known means such as quartz crystal devices, than the ultra high frequency oscillators of the type of oscillator 11. By the present circuit, therefore, the stability characteristics of oscillator 34 are transferred to oscillator 11, and a greatly improved frequency stabilization of the output of oscillator 11 is produced. Furthermore, by initially modulating the electron stream from cathode 12 before it enters the space between grids 13 and 14, the time required to build up oscillations in the oscillator 11 to a useful value is greatly reduced, and its power output is also increased.

Fig. 2 shows the application of the same principle to a slightly different type of velocity variation oscillator 41, known as the "reflex" type which is described more in detail in Varian et al. Patent No. 2,250,511, issued July 29, 1941, and especially with respect to Fig. 2 thereof. In this type of oscillator, the electron beam from cathode 12 is projected through the grids 13' and 14' of a single resonator 42 containing an alternating high frequency electromagnetic field, whereby velocity variations of the electrons of the beam are produced as in Fig. 1.

However, instead of providing a drift tube 17 and a further resonator 21 as in Fig. 1, the electron stream is caused to reverse its direction by means of a suitable reflecting electrode 43 having a potential substantially the same as or only slightly more positive than the potential of cathode 12. By properly spacing electrode 43 from grid 14', the electron beam is bunched as it re-enters resonator 42, and sustained oscillations are maintained within the resonator 42 whereby ultra high frequency energy may be supplied to an external utilization device by means of a suitable connecting line 44.

The oscillator 41 of Fig. 2 may be synchronized with and multiplies the frequency of the relatively low frequency oscillator 34 in much the same manner as in Fig. 1, by choosing the resonant frequency of resonator 42 close to a harmonic of the frequency of oscillator 34. Thus, the voltage output of oscillator 34 is impressed between cathode 12 and grounded grid 13' of oscillator 41 by way of transformer 36, tuned circuit 37 and coupling and blocking condenser 38, as in Fig. 1. The device of Fig. 2 will therefore operate in the same manner as that of Fig. 1, to produce an ultra high frequency output which is harmonically related to the relatively low frequency of oscillator 34, and which is stabilized by the oscillator 34.

Fig. 3 shows a further modification of the present invention in which the same principles are applied to yet another type of velocity variation oscillator 46 known as the "Monotron," which is described more fully in Hansen et al. Patent No. 2,269,456, issued January 13, 1942. In this type of oscillator, the electron beam from cathode 12 is projected into a hollow cavity resonator 47 through grid 13 by means of the accelerating voltage derived from battery 33. The transit time of the electron beam within the resonator 47 is selected and adjusted in accordance with the principles set forth in the above-mentioned Patent 2,269,456, to set up oscillations within the resonator 47. These oscillations may be fed to any suitable load device by means of a coupling line 44. The frequency stabilizing and multiplying features of Figs. 1 and 2 may also be applied to the oscillator 46 of Fig. 3, by impressing the relatively low frequency voltage derived from oscillator 34 between the cathode 12 and grid 13 of oscillator 46, whereby the output of oscillator 46 is again stabilized at a harmonic of the output of oscillator 34. It will be noted that a slightly different coupling for low frequency oscillator 34 is used. However, this is equivalent to and interchangeable with that of Figs. 1 and 2.

In addition to the frequency multiplication provided by the devices of Figs. 1, 2 and 3, an additional stage of multiplication may be incorporated in the device, in the manner shown in Fig. 4. Thus, in this figure, there is shown the same type of oscillating and frequency multiplying system as in Fig. 1. However, the electron beam passing through grid 19, instead of being collected by collector 29 as in Fig. 1 is passed through the grids 51 and 52 of a further resonator 53 whose resonant frequency is harmonically related to those of resonators 16 and 21. In this manner, as described more in detail in Hansen et al. Patent

2,281,935, issued May 5, 1942, the output ultra high frequency energy derived from resonator 53 by way of coupling line 28' will be harmonically related to the frequency of oscillations produced in resonators 16 and 21 which, as already discussed with respect to Fig. 1, is in turn harmonically related to the output of oscillator 34. In this way, a double frequency multiplication may be provided in a single device providing still higher frequencies while maintaining the same frequency stability.

Fig. 4 also shows a different form of coupling between oscillator 34 and cathode 12. In this instance, the output of the oscillator 34 has one terminal grounded and the other terminal connected directly to cathode 12 through a coupling and blocking condenser 38. The choke coil 30 in series with battery 33 prevents the alternating voltage on cathode 12 from being short-circuited to ground through battery 33. This coupling may be used interchangeably with the preceding couplings of Figs. 1 to 3.

Still another form of the present invention is shown in Fig. 5, where the same principle is shown applied to a velocity variation device of the type shown in Hansen et al. Patent No. 2,259,690, issued October 21, 1941, and termed a "floating kidney" device. In this device, the two resonators 16 and 21 of Fig. 1 are merged into a single resonant space 55, by suitably suspending the drift tube 17'' within an outer envelope 56. Electrons projected from cathode 12 are velocity varied as they pass between grids 13'' and 14'', become grouped during passage along drift tube 17, and give up ultra high frequency energy to the field of resonator 55 upon passage through grids 18'' and 19''.

The relatively low frequency wave from oscillator 34 is again impressed between cathode 12 and grounded entrance grid 13'' together with the accelerating voltage from battery 33, and the same type of operation ensues, to produce a frequency-multiplied and stabilized output at line 57.

In each of the preceding figures the relatively low frequency voltage has been applied between cathode 12 and the entrance grid 13, 13' or 13'' of the resonators of Figs. 1 to 5. Fig. 6 shows an alternative way of applying this relatively low frequency voltage, applicable with any of the electron beam devices of Figs. 1 to 5. In this figure, an added control grid 58 is inserted between the cathode 12 and the entrance grid 13, 13' or 13'' of any of the modifications of Figs. 1 to 5, and the relatively low frequency voltage from oscillator 34 is connected between cathode 12 and grid 58, as by way of transformer 36 or any other suitable connection. The principle of operation of the devices of Figs. 1 to 5, modified as in Fig. 6, is exactly the same as that already described, and will produce the same results.

Fig. 7 shows a further modification applicable to any of Figs. 1–5. Here the relatively low frequency energy from oscillator 34 is led through a concentric line or other conductor 61 to a resonant cavity 62 preferably tuned to the frequency of oscillator 34. Resonator 62 is formed to provide a relatively narrow gap 63, between cathode 12 and the entrance grid 13, 13' or 13'' of any of the resonators of Figs. 1–5. Cathode 12 is insulated from resonator 62 but is capacitively coupled thereto by way of sleeve 64 connecting cathode 12 with reentrant pole 65 of resonator 62 in a high frequency sense only, whereby the direct potential of battery 33 may be applied to cathode 12 despite the grounding of resonator 62 and without impairing the action of the resonator.

Resonator 62 operates functionally the same as tuned circuit 37, and the use of the modification of Fig. 7 with any of the devices of Figs. 1–5 will produce the same results already described above.

Thus, it will be seen that there has been provided an improved and novel apparatus for producing ultra high frequency energy having a frequency harmonically related to a relatively low control frequency and stabilized by the low frequency source.

As many changes could be made in the above construction and many apparently widely different embodiments of this 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. Ultra high frequency apparatus comprising means for producing a beam of electrons, means in said apparatus including a circuit having a predetermined resonant frequency for periodically varying the velocity of the electrons of said beam and for utilizing said velocity-varied electrons for producing oscillations, and means including means along the beam path for modulating on said beam before said velocity-variation for controlling said beam at a frequency substantially sub-harmonically related to said first-named frequency, whereby frequency stabilized energy harmonically related to said controlling frequency may be obtained.

2. Ultra high frequency apparatus comprising means for producing a beam of electrons, means including means along the path of said beam for varying said beam at a predetermined frequency, self-oscillating electron-beam-utilizing means along the path of said beam for producing oscillations at an operating frequency substantially harmonically related to said predetermined frequency, said self-oscillating means being energized by said varied beam, whereby frequency stabilized energy harmonically related to said predetermined frequency is produced.

3. Ultra high frequency apparatus comprising a cavity resonator having a pair of electron-permeable walls, a cathode on one side of said resonator, a reflector electrode on the other side of said resonator, means in said apparatus for projecting an electron stream from said cathode through said resonator by way of said electron-permeable walls toward said reflector electrode, said means comprising a source of accelerating potential between said cathode and said resonator, means coupled to said cathode and said resonator for varying said potential at a frequency substantially subharmonically related to the resonant frequency of said resonator, and means coupled to said resonator for extracting high frequency energy at a harmonic of said subharmonic frequency from said resonator.

4. High frequency apparatus comprising a cavity resonator having an electron-permeable wall, a cathode opposite said wall, a second cavity resonator having said wall as a portion thereof and capacitively coupled to said cathode, the resonant frequency of said second resonator being substantially subharmonically related to that of said first resonator, means coupled to said resonator for projecting an electron stream from said cathode through said second resonator and said wall, and into said first resonator, and means coupled with said apparatus for exciting

said second resonator at a frequency substantially subharmonically related to said first resonator resonant frequency, whereby energy may be taken from said first resonator at a harmonic of said exciting frequency.

5. A velocity modulation electron beam vacuum tube having a cathode, a control grid, a repeller electrode and a plurality of grids connected to a cavity resonator, a source of potential connected between said cathode and said resonator, a source of potential of lower value connected between said cathode and said repeller electrode, a source of high frequency energy connected to said grid, said source of high frequency energy being a sub-multiple of the resonant frequency of said resonator.

6. A velocity modulation vacuum tube having a cathode, a control grid, a repeller electrode, and a plurality of grids connected to a cavity resonator, a source of potential connected to said resonator and said repeller electrode, means connected with said source for adjusting the potential of the repeller electrode to a value less than that applied to said resonator, and a source of high frequency energy connected between said grid and another point of said vacuum tube, said resonator being tuned to a high harmonic of the frequency supplied by said source of high frequency energy.

7. The method of generating harmonics with a velocity modulation vacuum tube having a cathode, a control grid, a repeller electrode, and a cavity resonator, comprising applying a direct current potential between said cathode and said resonator, applying a direct current potential of lesser value between said cathode and said repeller electrode, and applying to said cathode high frequency energy which is a sub-multiple of the resonant frequency of said resonator.

8. The method of generating harmonics with a velocity modulation vacuum tube having a cathode, a control grid, a repeller electrode, and a plurality of grids connected to a cavity resonator, comprising applying a certain direct current potential between said cathode and said resonator, applying a direct current potential of lesser value than said certain direct current potential between said cathode and said repeller electrode, applying between said grid and said cathode high frequency energy, and adjusting said resonator to a frequency which is a higher harmonic of the high frequency energy applied to said grid.

9. A method of generating harmonics with a velocity modulation vacuum tube having a control grid, a repeller electrode, and a cavity resonator, comprising applying a direct current potential between the cathode of said tube and said resonator, applying a direct current potential of lesser value to said repeller electrode, applying between said grid and another electrode of said vacuum tube high frequency energy, and adjusting said resonator to a frequency which is a higher harmonic of the energy applied to said grid.

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