Sept. 15, 1936. J. J. LAMB 2,054,757

PIEZOELECTRIC FILTER

Filed Aug. 24, 1933 2 Sheets-Sheet 1

Fig. 1.

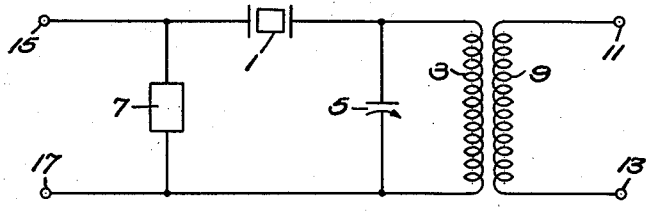


Fig. 2.

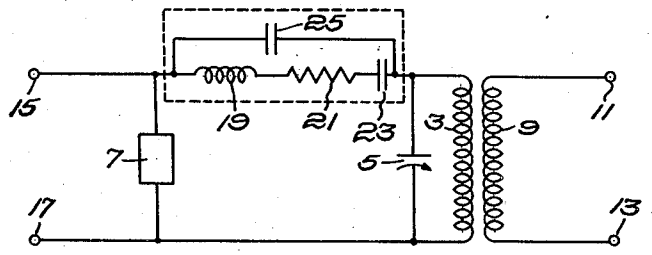
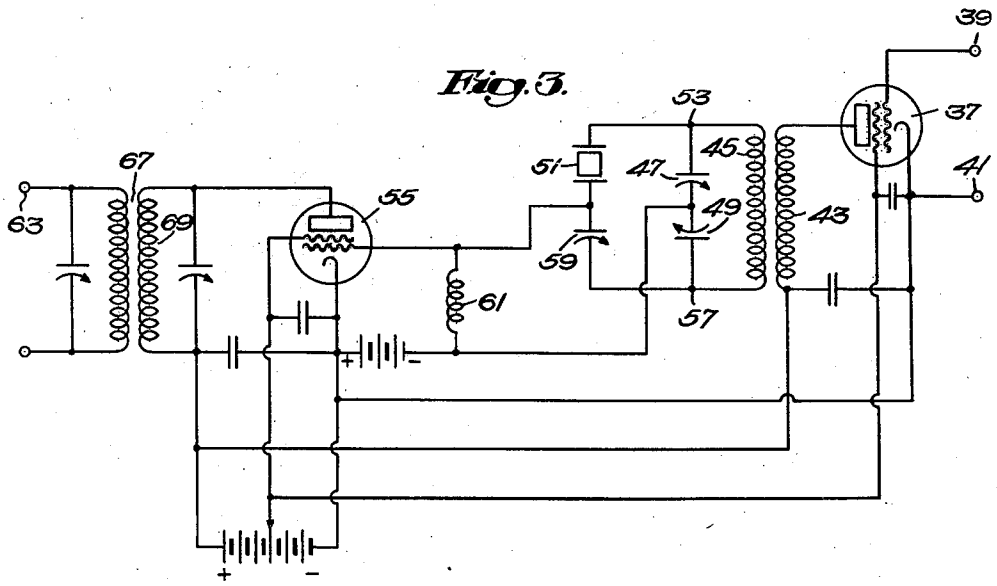


Fig. 3.



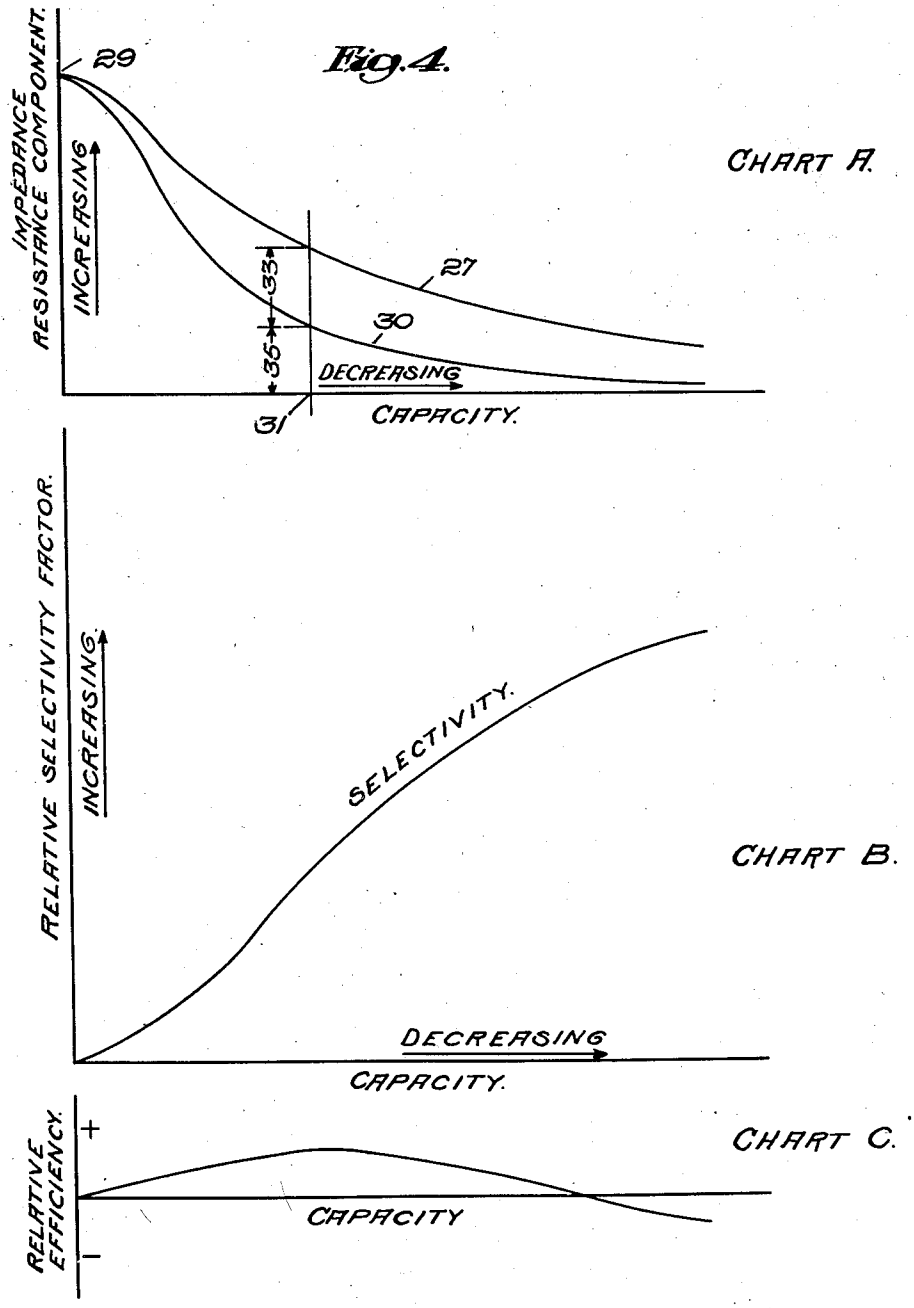
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Fig. 4.



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Patented Sept. 15, 1936 2,054,757

UNITED STATES PATENT OFFICE

2,054,757

PIEZOELECTRIC FILTER

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Application August 24, 1933, Serial No. 686,562

15 Claims. (Cl. 178—44)

My invention relates to electric wave signaling systems, and particularly to electric wave filters of the piezo-electric type for use in such systems.

The invention, which has among its objects the provision of varying and controlling the width of the frequency band passed by the filter and the suppression of undesired frequencies within the limits of this band, at the will of the operator, will be best understood from the following description when read in the light of the accompanying drawings.

In the drawings:—

Fig. 1 is a more or less idealistic schematic circuit diagram of a filter according to the invention;

Fig. 2 is an analytic schematic circuit diagram according to Fig. 1;

Fig. 3 is a schematic circuit diagram of one form of filter according to the invention for use with a vacuum tube amplifier; and

Fig. 4 is a chart illustrating graphically the relation between various factors involved in the operation of the filter.

It will be understood that the optimum selectivity of a wave signaling circuit is that which provides the minimum width of sensitive frequency band required for the needs of the particular type of communication. Heretofore selective piezo-electric type filters have been limited to a single fixed order of selectivity as determined by the design and construction of the filter. It has heretofore been impossible readily to adapt these filters to a wide variety of types of uses such as radiotelephone, high speed radiotelegraph, low speed radiotelegraph, and the like. The present invention is distinguished from piezo-electric type filters heretofore employed in that the degree of selectivity of the circuit is variable and completely controllable at the will of the operator.

Referring particularly to Fig. 1, which diagrammatically illustrates one more or less idealistic form of circuit according to the invention, a suitably mounted plate, bar, or other geometric form of piezo-electric substance 1, such as quartz, tourmaline or Rochelle salts of such dimensions as to have the resonant frequency desired, is connected in series with a parallel tuned circuit comprising an inductor 3 and a manually controlled variable capacitor 5, and also in series with a reactive circuit element 7 that has an appreciable inductive or capacitive reactance at the resonant frequency of the crystal substance, and has a low resistance and power factor at that frequency. The inductor 3 may be the secondary winding of a transformer, of which latter the primary winding 9 may be in the plate or grid circuit of a vacuum tube, or the terminals 11 and 13 may be otherwise suitably connected to constitute the input to the filter. In either case the terminals 15 and 17 may constitute the output terminals. The filter, however, will be operative with the terminals 15 and 17 constituting the input and the terminals 11 and 13 the output.

The circuit of Fig. 1 may be represented by the equivalent circuit shown by Fig. 2, in which the piezo-electric crystal is represented by an equivalent series network consisting of the inductance 19, resistance 21, and capacitance 23, a parallel capacitance 25 representing the capacitance of the piezo-electric substance dielectric between the electrodes. This network has a minimum impedance (maximum admittance) for an electric wave of frequency determined substantially by the values of the inductance 19 and capacitance 23, and has a maximum impedance (minimum admittance) for an electric wave of slightly higher frequency at which the series branch 19, 21, 23 is of inductive reactance resonating with the capacitance 25. These two frequencies for convenience are herein called the resonant frequency and the antiresonant frequency respectively of the piezo-electric crystal or network.

As is well known to those skilled in the art, the sharpness of resonance or selectivity at resonant frequency of a circuit containing inductance, capacitance and resistance in series is directly proportional to the reactance of either the inductive or capacitive branch and inversely proportional to the resistance. In the piezo-electric type of circuit the ratio of inductance to resistance is much greater than that obtainable with other resonant circuits of equal resonant frequency, and in consequence the selectivity of the piezo-electric circuit is considerably greater than that obtainable with other resonant circuits. In fact, the degree of selectivity provided by a piezo-electric resonator may be greater than can be utilized for most types of electric waves used in telecommunication, and hence it is highly desirable for such use to provide means for broadening the admittance band and controlling the width thereof; in other words, to provide means for varying the degree of selectivity of the circuit. This is accomplished in the circuits shown by Figs. 1 and 2 by varying the impedance of the parallel tuned circuit for an electric wave of the resonant frequency of the complete network, which frequency for convenience may be

called the characteristic frequency of the filter circuit.

Decreasing the selectivity to the extent desired could be accomplished by increasing the resistance of the series network, but the introduction of a non-reactive resistance in the piezo-electric circuit it is found results in such a waste of energy that the efficiency of the circuit is diminished to an undesirable extent. According to the present invention a controllable variable impedance is introduced in series with the piezo-electric network in such manner as to provide the desired degree of selectivity without to a material extent affecting the efficiency of the filter. This is accomplished by varying the parallel impedance of the parallel circuit comprising the capacitor 5 and inductor 3 connected in parallel. This parallel impedance it will be noted is the vector sum of ohmic resistance and reactance components, and it may be varied by varying either the value of the inductance or the value of the capacitance. When the variable element is the capacitance, the reactive component of the impedance of the parallel circuit is inductive in nature when the capacitance has a value less than that required for the resonant condition or characteristic frequency of the filter circuit, and is capacitive in nature when the capacitance has a value greater than that required for this resonant condition. At resonance the inductive and reactive components are equal and opposite, with the result that the reactance is zero and the impedance is purely resistive and is at its maximum value.

The utilization of this varying impedance having a reactive and resistive component to control selectivity may be better understood by reference to Fig. 4. This figure shows graphically the relation between the impedance and its inductive reactance component and resistance component when the value of the tuning capacitance is varied to make the circuit inductively reactive for a wave of frequency substantially the resonant frequency of the piezo-electric element. It also shows the variation in the selectivity factor of the filter circuit and the variation in its efficiency under these conditions. In the Charts A, B and C of Fig. 4 the abscissæ represent the capacity of the capacitor 5. In Chart A the curve 27 illustrates the decrease in impedance of the parallel circuit formed by the inductor 3 and capacitor 5 of Figs. 1 and 2 as the capacity of the capacitor 5 is decreased from that which causes an impedance value 29 corresponding to resonance of the circuit at the resonant frequency of the piezo-electric element. The curve 30 represents the resistance component of the impedance represented by the curve 27. Under these conditions at any value of capacity 31 the inductive reactance component of the impedance is represented by the value 33 and the resistance component of the impedance by the value 35. Hence when the impedance is varied by varying the capacity, as shown by this curve, the resistance component of the impedance is also varied. At the resonance point, as will be understood, and as shown by the curve, the impedance is wholly resistant. Chart B of Fig. 4 shows the effect of varying the impedance on the relative selectivity factor or sharpness of resonance of the filter. By comparing Chart A with Chart B it will be noted that the minimum relative selectivity factor occurs when the impedance is wholly resistive and the inductive reactance component of the impedance is zero. Chart C of Fig. 4 shows the relatively negligible effect on the relative efficiency of the circuit as the capacity is decreased to vary the impedance and the selectivity.

Fig. 3 illustrates one way of using the circuit above described as the variable selectivity filter in a vacuum tube amplifier. As illustrated, the vacuum tube 37, which herein is of the screen-grid type, is connected to the input terminals 39, 41 to receive electric waves in its grid circuit and transfer them in the usual manner to its plate circuit. As shown, the plate circuit of the tube contains the primary winding 43 of a transformer, the secondary winding 45 of which latter constitutes the inductance branch of the parallel tuned circuit associated with the filter network. A balanced, manually operated, variable condenser having the condenser halves 47, 49 constitutes the capacitance branch of this parallel tuned circuit. The piezo-electric crystal 51 in its electrode mounting is connected in series with one terminal 53 of the parallel tuned circuit and the control grid of a vacuum tube amplifier 55. The opposite terminal 57 of the parallel tuned circuit is also connected to the control grid of the vacuum tube 55 through a variable capacitance 59 in parallel with the crystal. The control grid of the vacuum tube 55 is further connected to the common rotor element of the balanced tuning condenser 47, 49 through a reactive circuit element 61, which latter preferably is inductive, or if desired may be a capacitor in parallel with a resistor so as to have appreciable reactance and substantially low resistance for a wave of the resonant frequency of the piezo-electric crystal. The vacuum tube 55 may be connected to the output terminals 63, 65 of the circuit through a transformer 67, the primary winding 69 of which is in the plate circuit of the vacuum tube.

The operation of the circuit shown by Fig. 3 is substantially the same as for the circuits shown by Figs. 1 and 2 hereinbefore described. The balanced condenser 47, 49 in connection with the piezo-electric crystal and variable condenser 59 form a bridge circuit energized by the potential across the secondary winding 45 of the input transformer of the filter, across which circuit the control grid circuit of the vacuum tube 55 is bridged. By adjusting the capacity of the condenser 59 the shunt capacitance, indicated by the capacitance 25 of Fig. 2, of the piezo-electric crystal can be modified within limits to make the anti-resonant frequency of the crystal network of suitable value to suppress a particularly undesirable electric wave of a frequency different from that of the frequency of the desired wave for which the piezo-electric element offers minimum impedance and which it is desired to transmit through the filter. It will be understood that the crystal has inductive reactance to a frequency higher than its resonant frequency and capacitive reactance to a lower frequency. Therefore the condenser 59 can be adjusted to modify this reactance to resonate with the reactance of the crystal through the circuit formed by the balanced tuning condenser 47, 49. In effect, from this particular aspect, this secures the same results as would be secured in the circuit shown by Fig. 2 if the capacitance 25 of that figure were variable.

As is well known in the art, the crystal is normally anti-resonant for a frequency approximately one-half percent higher than its resonant frequency. This results from the reactance of the shunt capacitance 25 of Fig. 2 resonating with the

inductive reactance of the crystal network slightly above the latter's resonant frequency. In the circuit arrangement of Fig. 3 this normal behavior is modified to shift the anti-resonant or rejection frequency to different values, either above or below resonance. Voltage is applied through the condenser capacitance **59** in anti-phase to the voltage operating on the crystal circuit. While it might be thought that capacitance **59** serves only to balance or neutralize the shunt capacitance **25** of the crystal, capacitance **59** does not serve simply to neutralize the effect of capacitance **25** and thus to prevent unselective transmission past the crystal. Rather, as capacitance **59** is varied from minimum to greater capacitance, the anti-phase voltage applied through it to the crystal serves to make the effective capacitive reactance **25** vary from its normal capacitive value, through zero, to a slightly minus capacitive value, when the effect is as if inductance were substituted for capacitance **25**. In the latter condition, the shunt reactance having changed sign, the complete crystal network is effectively in parallel resonance (or is anti-resonant) for a frequency below the crystal's resonant frequency. Thus, while having maximum response to the desired signal frequency, the circuit can be adjusted to reject an interfering signal of a frequency in the range from several kilocycles above to approximately the same amount below crystal resonance.

The above described operation of the circuit shown by Fig. 3 is particularly desirable in the heterodyne reception of radiotelegraphy. In this type of reception, where the incoming wave is modulated or heterodyned in detection subsequent to transmission through the filter, by a wave of suitably different frequency obtained from a local source, the most objectionable interference (other than that caused by an interfering wave of identically the same frequency as that of the desired signal) is caused by that of an interfering wave so differing in frequency from that of the desired signal as to cause an identical beat-note frequency with the wave from the local source. Since the modulating or heterodyning to obtain the desired beat-frequency note takes place in a detector subsequent to the piezo-electric filter in the receiver, the filter network can be adjusted to be anti-resonant for an electric wave differing in frequency from that of the desired wave so as to suppress such undesired wave and thereby prevent its causing this most undesirable type of interference.

It will be thus understood that the circuit shown by Fig. 3 provides for controlling the width of the acceptance pass band for desirable frequencies and at the same time provides for especial rejection of an undesirable wave within the limits of this band.

It will be understood that wide deviations may be made from the forms of the invention herein described without departing from the spirit of the invention.

I claim:

1. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, means for variably increasing the width of the band over a substantially wide range, and means for suppressing a selected frequency within the limits of the band being passed within said range.

2. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, and means comprising a circuit including a variable impedance in series with said crystal for increasing the width of the band over a substantially wide range at the will of the operator, and means for suppressing a selected frequency within the limits of the band being passed within said range.

3. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, an inductor and a capacitor connected in parallel circuit, which circuit is connected in series with said crystal, and means for making said parallel circuit inductively reactive or capacitively reactive at the will of the operator for varying the pass-band width over a substantially wide range greater than said minimum determined by said crystal.

4. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, means for variably increasing the width of the pass band, and means for suppressing a frequency within the limits of said band comprising a variable capacitor operatively connected in parallel with said crystal.

5. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, means for variably increasing the width of the pass band comprising means for introducing in series with said crystal a variable impedance having a variable resistance component, and means for suppressing a frequency within the limits of said band comprising a variable capacitor operatively connected in parallel with said crystal.

6. An electric wave filter having a bridge circuit one side of which comprises a pair of variable capacitors in series and the other side of which comprises a piezo-electric crystal and a variable capacitor in series, an inductor connected in parallel with said bridge circuit and constituting the input thereto, and means constituting a reactive load bridged across said circuit, whereby by varying said pair of variable capacitors the circuit comprising the same and said inductor may be made inductively reactive or capacitively reactive at the will of the operator for varying the pass-band width over a substantially wide range greater than the minimum determined by said crystal, and by varying said variable capacitor in series with said crystal a selected frequency within the limits of the band being passed may be suppressed.

7. An electric wave filter having a bridge circuit one side of which comprises a pair of variable capacitors in series and the other side of which comprises a piezo-electric crystal and a variable capacitor in series, an inductor connected in parallel with said bridge circuit, and means constituting an inductance bridged across said circuit, whereby by varying said pair of variable capacitors the circuit comprising the same and said inductor may be made inductively reactive or capacitively reactive at the will of the operator for varying the pass-band width over a substantially wide range greater than the minimum determined by said crystal, and by varying said variable capacitor in series with said crystal a selected frequency within the limits of the band being passed may be suppressed.

8. An electric wave receiving circuit having, in combination, a vacuum tube, a balanced vari-

able tuning condenser, a transformer having a primary winding in the plate circuit of said tube and a secondary winding in parallel with said tuning condenser, a piezo-electric crystal, a variable condenser, said crystal and last mentioned condenser being connected to form a series network also in parallel with said secondary winding and tuning condenser, a reactive load the opposite terminals of which are connected to the mid-point of said tuning condenser and to a point between said crystal and said variable condenser in series therewith respectively, and a vacuum tube amplifier having a control grid also connected to a point between said crystal and said variable condenser in series therewith.

9. An electric wave filter comprising an input circuit, an output circuit, circuit means comprising a piezo-electric substance for electro-mechanically coupling said input and output circuits including a variable impedance in series with said substance for varying the frequency band width of the filter, and means for applying to said circuit means a voltage of controllable phase and value for suppressing any selected frequency within said band.

10. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, means for increasing the width of the band over a substantially wide range at the will of the operator, and means for suppressing any selected frequency within said range comprising a variable reactance for applying to the crystal circuit a voltage of controllable phase and value.

11. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, means comprising a circuit including a variable impedance in series with said crystal for increasing the width of the band over a substantially wide range at the will of the operator, and means for suppressing any selected frequency within said range comprising a variable reactance for applying to the crystal circuit a voltage of controllable phase and value.

12. An electric wave filter of variable pass-band width having a piezo-electric crystal circuit for determining the minimum width of the frequency band passed by the filter, and means for applying to the crystal circuit voltages in anti-phase to the operating voltage on that circuit for varying the effective shunt capacitive reactance of the crystal through a range from its normal positive value to a negative value, whereby to adjust the crystal circuit to reject any selected interfering frequency in a range of frequencies from slightly above to slightly below resonance frequency of the crystal circuit.

13. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, an input circuit comprising an inductor and a capacitor connected in parallel circuit, which circuit is connected in series with said crystal, the capacity of said capacitor being variable for varying the impedance of said parallel circuit whereby to increase the width of said pass-band over a variable range greater than said minimum width determined by said crystal, and means for suppressing any selected frequency within said range comprising a variable reactance for applying to the crystal circuit a voltage of controllable phase and value.

14. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, means for variably increasing the width of said band at the will of the operator comprising means for introducing in series with said crystal a variable impedance having a variable resistance component, and means for suppressing any selected frequency within the band being passed comprising a variable reactance for applying to the crystal circuit a voltage of controllable phase and value.

15. An electric wave filter of variable pass-band width having a piezo-electric crystal for determining the minimum width of the frequency band passed by the filter, an inductor and a capacitor connected in parallel circuit, which circuit is connected in series with said crystal, the capacity of said capacitor being variable for varying the value of the impedance of said parallel circuit for varying the resistance component of said impedance whereby to increase the width of said pass-band over a variable range greater than said minimum width determined by said crystal, and means for suppressing any selected frequency within said range comprising a variable reactance for applying to the crystal circuit a voltage of controllable phase and value.

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