Oct. 11, 1949. W. P. MASON 2,484,636

MODULATION SYSTEM

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FIG. 1

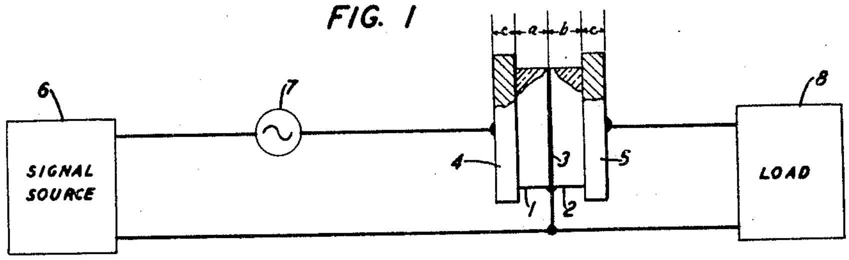


FIG. 2

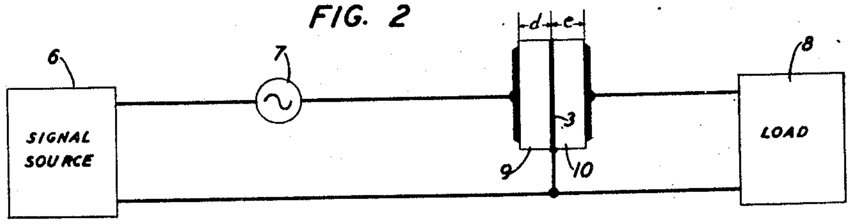
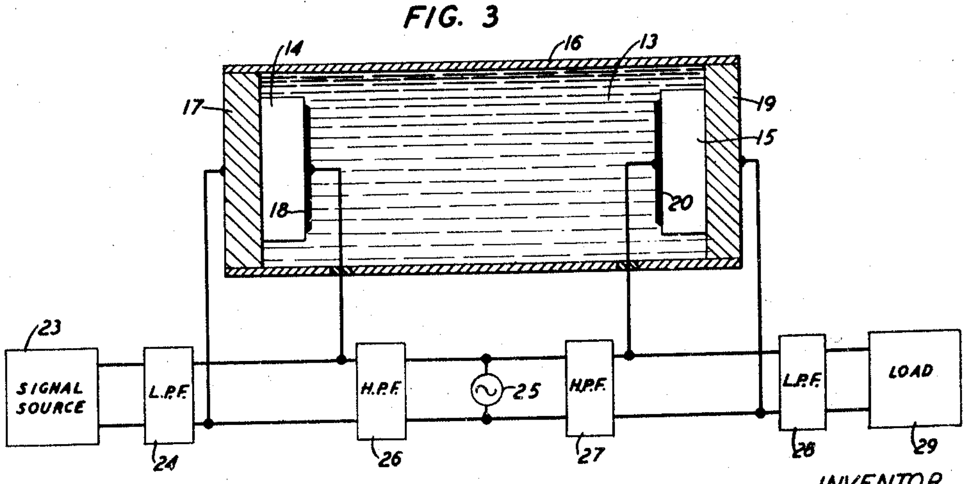


FIG. 3



INVENTOR
W. P. MASON
BY Ralph T. Holcomb
ATTORNEY

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MODULATION SYSTEM

Warren P. Mason, West Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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This invention relates to wave transmission and more particularly to a modulation system employing an electrostrictive element.

An object of the invention is to modify or modulate a carrier voltage in accordance with the signal to be transmitted. Another object is to delay the transmission of oscillations representing signal voltages. A further object is to reduce the cost of modulators and delay devices.

The modulation system in accordance with the present invention utilizes the electrostrictive property of an element which, preferably, is in the ferroelectric state. A plate cut from a Rochelle salt crystal, either of the ordinary or the heavy water type, or a plate made of fused barium titanate is a suitable electrostrictive modulation element because it has a large electrostrictive constant and is in the ferroelectric state over a temperature range which includes ordinary room temperature. For greatest electromechanical conversion efficiency the element is preferably dimensioned for mechanical resonance at the carrier frequency f. If Rochelle salt is used, the element may, for example, be an X-cut plate a half-wavelength in thickness at the frequency f, or a quarter-wave crystal backed by a metallic quarter-wave resonator. The carrier voltage and the signal voltage are impressed upon the element, producing therein, by virtue of the electrostrictive effect, modulated mechanical vibrations which may be utilized as desired.

In one embodiment these mechanical vibrations are converted into electrical oscillations by means of a suitable electromechanical converter, which may be a piezoelectric crystal, and fed to the load circuit. There is thus provided a comparatively simple and inexpensive modulator which requires no thermionic tubes.

In another embodiment an acoustic delay device is provided by interposing a low velocity medium between the modulation element and a similar element used as a demodulator. This medium may, for example, be a suitable liquid confined within a container. The time that the signal is delayed depends upon the distance between the modulator and the demodulator and the velocity of propagation within the medium. Thus, a very large delay may be obtained with a comparatively inexpensive device.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing, in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 is a schematic circuit of a modulation system in accordance with the invention employing a quarter-wave electrostrictive element with a quarter-wave backing plate;

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Fig. 2 shows a modification of the circuit of Fig. 1, using a half-wave element; and

Fig. 3 is a schematic circuit showing a delay device embodying the invention.

The embodiment of the modulation system in accordance with the invention shown in Fig. 1 comprises an electrostrictive modulation element 1 and a piezoelectric crystal element 2 mechanically coupled by a common electrode 3, two quarter-wave backing resonators 4 and 5, a source of signal voltage 6, a source of carrier voltage 7, and a load 8.

The modulation element 1 is made of material having a large electrostrictive constant and is operated at such a temperature that it is in the ferroelectric state. The element 1 may, for example, be a plate cut from a Rochelle salt crystal, either of the ordinary or the heavy water type, or a plate or disc made of polycrystalline barium titanate, $BaTiO_3$, fused into a ceramic state. Ordinary Rochelle salt is in the ferroelectric state over a temperature range of −18° C. to +24° C., heavy water Rochelle salt up to a temperature of 35° C., and barium titanate to 120° C. The element 1 is preferably dimensioned to be mechanically resonant at or near the carrier frequency f, in order to improve its efficiency as an electromechanical vibrator.

As shown in the modulating system of Fig. 1, the element 1 is an X-cut plate of Rochelle salt crystal with a thickness dimension a equal to a quarter-wavelength at the frequency f. In an X-cut plate the major faces are perpendicular to the X or electric axis of the crystal. The pick-up crystal element 2 makes use of the piezoelectric effect and is also resonant at the frequency f. It may, for example, be an L-cut Rochelle salt plate with a thickness dimension b equal to a quarter-wavelength at the frequency f. In an L-cut plate the X, Y and Z axes of the crystal all make equal angles with a perpendicular to a major face of the plate. The backing resonators 4 and 5 may be made of steel, with a thickness dimension c also equal to a quarter-wavelength at the frequency f.

The voltage from the signal source 6 and that from the carrier source 7 are applied to the modulation element 1 by connections to the electrode 3 and the backing resonator 4. The electrostrictive strain, which is proportional to the square of the applied voltage but is independent of its polarity, produces a modulated mechanical vibration in the element 1. This mechanical vibration may be utilized directly or it may be converted to electrical oscillations by means of an electromechanical converter such as the piezoelectric crystal element 2.

In Fig. 1 the mechanical vibrations of the element 1 are transmitted through the mechanical coupling of the common electrode 3 to the crystal 2. However, since the crystal 2 is tuned to the carrier frequency f the only important modulation products to which it responds are the two sidebands. By virtue of the piezoelectric property of the crystal 2, its vibration induces a corresponding voltage between its major faces. This voltage may be utilized by connecting a suitable load 8 between the backing resonator 5 and the electrode 3. The system of Fig. 1 thus provides a square-law modulator which will operate satisfactorily, for example, in the radio range.

The modulation system shown in Fig. 2 is similar to the one of Fig. 1 except that the quarter-wave crystals 1 and 2 are replaced, respectively, by the half-wave crystals 9 and 10 and the backing resonators 4 and 5 are omitted. Thus, for example, the modulation element 9 may be an X-cut plate of Rochelle salt crystal having a thickness d equal to a half-wavelength at the carrier frequency f and the pick-up crystal 10 may be an L-cut Rochelle salt plate with a thickness dimension e also equal to a half-wavelength at the frequency f.

In Fig. 3 the invention is applied to an acoustic delay device wherein a low velocity medium 13 is interposed between an electrostrictive modulation element 14 and a similar element 15 which serves as a demodulator. The medium 13, which is confined within the container 16, can be any liquid that will not dissolve the elements 14 and 15 and may, for example, be an oil, such as castor oil. As shown, the element 14 is a quarter-wave, X-cut Rochelle salt crystal plate securely attached to a quarter-wave backing resonator 17 and provided with an inner electrode 18. The assembly 17, 14, 18 is similar to the assembly 4, 1, 3 in Fig. 1. At the other end of the container 16 is a similar assembly comprising a crystal 15, a backing resonator 19 and an electrode 20. The resonators 17 and 19 also form the ends of the container 16.

The voltage from the signal source 23 is fed through a low-pass filter 24 and impressed upon the modulation crystal 14 by means of the connections to the resonator 17 and the electrode 18. Voltage from the carrier source 25 is fed through a high-pass filter 26 to the crystal 14. The filter 24 has its cut-off placed just above the highest component of the signal source 23 and the filter 26 has its cut-off somewhat below the carrier frequency f. By virtue of the electrostrictive effect there will be developed in the crystal 14 modulated mechanical vibrations which include the two sidebands and a component of twice the carrier frequency. These modulation products will be transmitted as compressional waves through the medium 13 to the receiving crystal 15, which will be set into corresponding mechanical vibrations. But carrier voltage from the source 25 is also fed through a high-pass filter 27, similar to the filter 26, to the crystal 15, which thus functions as a demodulator. The output voltage from the crystal 15 will include the demodulated components of the original signal and also the demodulated component of twice the carrier frequency, but this latter component is suppressed in the low-pass filter 28, similar to the filter 24, before the output is fed to a suitable load 29.

A carrier frequency is employed in the system of Fig. 3 in order to increase the efficiency and to avoid distortion of the signal due to the non-linear electrostrictive characteristic of the crystals 14 and 15.

By way of example, the signal source 23 in the delay device of Fig. 3 may have components up to 400 kilocycles per second and the frequency of the carrier 25 may be of the order of one to two megacycles. To get the highest efficiency the carrier source 25 should be capable of impressing a voltage of the order of 3,000 volts per centimeter of thickness on the modulation crystal 14. However, since a two-megacycle crystal is only about half a millimeter in thickness, in this example the carrier oscillator 25 would be required to provide only 150 volts, which is easily obtainable.

In the system of Fig. 3 the delay time is determined by the distance between the crystals 14 and 15 and the velocity of propagation of a compressional wave in the medium 13. Delays as great as 750 microseconds or more may be readily obtained. As a matter of comparison, to get a delay of 750 microseconds with electrical elements would require a network of 1,000 inductors and 1,000 capacitors. The saving in cost and space effected by use of the acoustic delay device of Fig. 3 is readily apparent.

What is claimed is:

1. In combination, an electrostrictive element in the ferroelectric state, a source of voltage of frequency f to be modulated, a source of modulating voltage, and means for impressing said voltages upon opposite faces of said element, said element being dimensioned for mechanical resonance at the frequency f whereby said voltages produce by electrostriction a modulated mechanical vibration in said element.

2. The combination in accordance with claim 1 in which said element comprises a Rochelle salt crystal plate.

3. The combination in accordance with claim 2 in which said Rochelle salt is of the heavy water type.

4. The combination in accordance with claim 2 in which said plate has its major faces perpendicular to the X axis of the crystal.

5. The combination in accordance with claim 4 in which said plate is approximately a half-wavelength in thickness at the frequency f.

6. The combination in accordance with claim 4 in which said plate is approximately a quarter-wavelength in thickness at the frequency f.

7. The combination in accordance with claim 6 which includes a backing resonator upon which said crystal plate is mounted, said resonator being approximately a quarter-wavelength in thickness at the frequency f.

8. The combination in accordance with claim 1 in which said element comprises barium titanate.

9. The combination in accordance with claim 8 in which said barium titanate is fused into the ceramic state.

10. The combination in accordance with claim 1 and means associated with said element for utilizing the mechanical vibration thereof.

11. The combination in accordance with claim 10 in which said vibration utilizing means comprise a medium having a low velocity for the propagation of compressional waves therein.

12. The combination in accordance with claim 11 in which said vibration utilizing means also

comprise a demodulator for modulated compressional waves, said medium being interposed between said element and said demodulator.

13. The combination in accordance with claim 10 in which said vibration utilizing means comprise an electromechanical converter for converting said mechanical vibration into an electrical oscillation.

14. The combination in accordance with claim 13 in which said converter comprises a piezoelectric crystal element.

15. The combination in accordance with claim 14 in which said crystal element is a plate of Rochelle salt so oriented that a perpendicular to its principal faces makes equal angles with the X, Y and Z axes.

16. A modulation system comprising an electrostrictive element in the ferroelectric state, an electromechanical converter, a source of voltage of frequency *f* to be modulated, a source of modulating voltage, and means for impressing said voltages upon opposite faces of said element, said element being dimensioned for resonance at the frequency *f* whereby said voltages produce by electrostriction a modulated mechanical vibration in said element, and said converter being physically coupled to said element whereby said mechanical vibrations are converted into electrical oscillations.

17. A system in accordance with claim 16 in which said converter is tuned to the frequency *f*.

18. A system in accordance with claim 16 in which said element comprises an X-cut plate of Rochelle salt and said converter comprises an L-

cut plate of Rochelle salt, each of said plates having a thickness approximately equal to a half-wavelength at the frequency *f*.

19. A delay device comprising an electrostrictive element in the ferroelectric state, a demodulator, a medium having a low velocity for the propagation of compressional waves therein interposed between said element and said demodulator, a source of carrier voltage, a source of signal voltage, and means for impressing said voltages upon opposite faces of said element, said element being dimensioned for mechanical resonance at the frequency of said carrier source whereby said voltages produce by electrostriction in said element a modulated mechanical vibration which is propagated through said medium to said demodulator and demodulated therein.

20. A delay device in accordance with claim 19 which includes a low-pass filter interposed between said signal source and said element and a high-pass filter interposed between said carrier source and said element.

WARREN P. MASON.

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