METHODOLOGICAL NOTES

Magnetostriction emmiters for lecture demonstrations on ultrasonics

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So far, only piezoelectric radiators have been used in lecture demonstrations to obtain ultrasound of frequency on the order of several megahertz. However, the vibrators of these radiators (quartz or piezoceramic plates) are relatively difficult to obtain, and the radiators themselves[1,2] are rather complicated to manufacture. We propose here magnetostriction radiators of quite simple construction, which produce ultrasound of frequency from 1 to 15 MHz and of intensity sufficient to perform practically all the known classroom experiments with ultrasound in this frequency band. A distinguishing feature of the radiators described below is that their vibrations are perpendicular to the direction of the variation of the change of the alternating magnetic field used to excite these vibrations. The vibrators are the easily available M400 NN ferrite rods (they can be bought in any radio store).

The vacuum-tube oscillator feeding the excitation bindings of the magnetostriction emitters ME (Fig. 1) uses two 6PZs triode-connected tubes in a push-pull circuit with capacitive feedback. The high-frequency choke CH_1 consists of 6–9 sections of 300–400 turns each (PÉL 0.25 wire); $R_1 = R_2 = 33$ kΩ; $C_1 = C_2 = 680$ pF, $C_3 = 10$–250 pF, $C_4 = 0.05$ μF. A single GU-29 tube can be used to increase the generator power. The generator is fed with alternating current from a step-up transformer rated 40–70 W, with output voltages 6.3, 300, 400, and 600 V (the latter voltage is not obligatory). A power transformer of practically any commercial receiver, with suitably connected windings (for example, in an autotransformer connection), can be used.

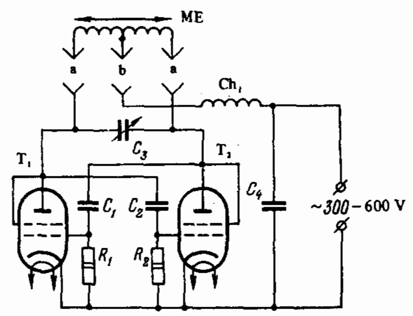

FIG. 1

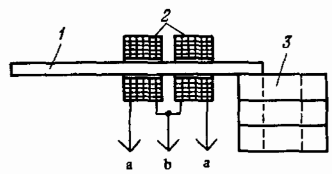

FIG. 2

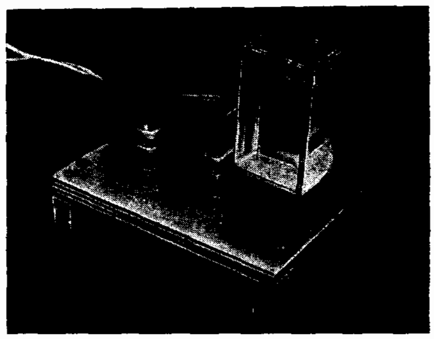

FIG. 3

The magnetostriction emitted used to obtain ultrasound with frequency on the order of 1 MHz consists of a ferrite vibrator 1, an excitation winding 2, and vibrator-magnetizing magnets 3 (Fig. 2). The vibrator was a flat ferrite rod type M400 NN, measuring $3 \times 20 \times 100$ mm. The rod vibrates in the direction of its thickness in such a way that when it is excited at the fundamental natural frequency half the wavelength (3 mm) of the ultrasound in the ferrite is spanned by the radiating planes of the vibrator. The vibrator need not be fastened to the form of the excitation coil. The exciting winding consists of two sections, each with 23–27 turns of PÉL 0.8–1.0 wire. The sections are wound in the same direction and are separated by a thin bakelite partition. The vibrator is magnetized by a stack of 3–6 annular ceramic magnets of 35 mm diameter and 7 mm thickness. The magnets should touch the vibrator. The overall view of the finished magnetostriction emitter with the cell placed on it is shown in Fig. 3.

To check the radiator it is necessary first, after swabbing the vibrator with alcohol, to place it inside the form of the excitation coil and to bring the vibrator-magnetizing magnet in contact with the end of the vibrator or with its lower radiating face. A drop of commercial petroleum oil or some other oil is placed on that part of the upper radiating plane which projects beyond the coil form, and the generator is tuned to resonance with the vibrator. Normal operation of the radiator is indicated by the characteristic "swelling" of the oil on the surface of the vibrator.

To obtain an ultrasound frequency higher than 1 MHz, it is necessary to assemble vibrators in accordance with the symmetrical scheme shown in Fig. 4: The ferrite vibrator 1 of the radiator is placed inside section 2 of the exciting winding and is magnetized from the end surfaces by permanent magnets 3. The vibrators of symmetrical radiators can be constructed with the flat M400 NN ferrite rod by grinding it with an abrasive. This simple operation makes it possible to obtain ferrite plates with thicknesses as low as 0.2 mm. The vibrator area is of no particular significance and is determined by the requirements imposed on the magnetostriction radiator. The vibrator should pass quite freely through the form of the excitation-coil sections. To magnetize the vibrators it is convenient to use annular ceramic magnets from the standard educational kit, which contains magnets of 10, 15, 20, 25, and 35 mm diameter and of 5 and 7 mm thickness. The mag-

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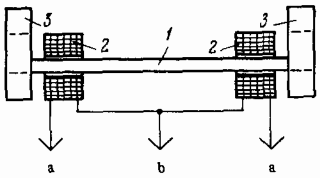

FIG. 4

nets should be so arranged that their field-intensity vectors have the same direction (parallel to the radiating plane of the vibrator). A different arrangement of the magnets relative to the vibrator is possible, but does not always lead to the best results. The excitation winding of the radiator consists of two identical sections wound in the same direction. The number of turns on the excitation winding and the optimum value of the magnetic field that polarizes the vibrator can be easily determined experimentally by bearing the following in mind: the higher the resonant frequency of the radiator (the smaller the vibrator dimensions), the weaker should be the field magnetizing the vibrator, and obviously the smaller the number of turns of the excitation winding. It must be borne in mind that the vibrators of the proposed magnetostriction radiators are best excited at their fundamental natural frequency; excitation of a ferrite vibrator at harmonics higher than the third is generally unadvisable, since the vibrator becomes rapidly heated and its operation becomes unstable (a drift of the resonant frequency is observed and it becomes necessary to retune the generator constantly).

By way of example we indicate briefly the principal data for a symmetrical magnetostriction radiator intended to produce in a liquid ultrasound of frequency on the order of 8 MHz. This radiator is assembled on a vinyl plastic frame and consists of a ferrite vibrator measuring 0.4 × 15 × 20 mm, excitation winding each having two sections of 3–4 turns of PÉL 0.6 wire, and two vibrator-magnetizing magnets of 10 mm diameter and 5 mm thickness.

The proposed magnetostriction radiators make it possible to perform the same experiments that are usually performed with piezoelectric radiators, for example to demonstrate a standing ultrasound wave in liquid, the reflection, refraction, interference, and diffraction of ultrasonic waves, radiation pressure, an ultrasonic fountain, diffraction of light by an ultrasonic wave, the chemical action of ultrasound, coagulation of hydrosols, etc.

In conclusion, notice should be taken of both the undisputed advantages of the magnetostriction radiators described here over the piezoelectric radiator (simplicity of construction, possibility of constructing vibrators with required parameters using widely available ferrite rods, etc.), as well as their essential shortcomings (difficulty of excitation of magnetostriction vibrators at harmonics of as high an order as, for example, in quartz vibrators, and the appreciable vibrator heating in comparison with piezoelectric ones). Incidentally, as indicated, these shortcomings should not discourage a very wide utilization of magnetostriction radiators, at least for teaching purposes.

The authors are grateful to R.-É. E. Shafir for great help with the construction of a number of radiators proposed in this note.

[1] Ya. S. Maksimov, Usp. Fiz. Nauk 50, 433 (1953).
[2] V. I. Krasnyuk, in: Primenenie ul'traakustiki k issledovaniyu veshchestva (Use of Ultrasonics in Material Research), No. 9, MOPI, 1964.

Interference of 3-cm radio waves in a plane-parallel dielectric layer

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If an electromagnetic linearly-polarized monochromatic plane wave is incident from air on a plane-parallel layer of a homogeneous absorbing dielectric with dielectric constant $\epsilon > 1$, then the intensities $I^{(t)}$ and $I^{(r)}$ of the waves transmitted and reflected from this layer respectively, are expressed in terms of the well known Airy formulas[1], which were derived with account taken of an infinite number of reflections from both boundaries of the layer:

$$I^{(t)}=\frac{I_0T^2}{(1-R^2)+4R\sin^2(\delta/2)}=I_0Q^2, \qquad (1)$$

$$I^{(r)}=\frac{I_0 4R\sin^2\delta/2}{(1-R)^2+4R\sin^2(\delta/2)}=I_0P^2. \qquad (2)$$

In these formulas, R and T are respectively the coefficients of reflection and transmission of the layer boundary and are connected by the relation $R + T = 1$, $\delta = (2\pi h/\lambda_0)\cos\theta$, where h is the thickness of the dielectric layer, λ_0 is the wavelength of the radiation in air, θ is the angle of refraction of the radiation at the layer boundary, and P and Q are the reflection and transmission coefficients of the layer as a whole. We confine ourselves henceforth to cases in which $\theta = 0$.

The value of $I^{(r)}$ is maximal when the layer of thickness h satisfies the conditions

$$h=\frac{1}{4}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{3}{4}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{5}{4}\frac{\lambda_0}{\sqrt{\varepsilon}}\ \text{etc.} \qquad (3)$$

$I^{(r)}$ vanishes when

$$h=\frac{1}{2}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{2}{2}\frac{\lambda_0}{\sqrt{\varepsilon}},\ \frac{3}{2}\frac{\lambda_0}{\sqrt{\varepsilon}}\ \text{etc.} \qquad (4)$$

As seen from (1), and also from the condition $I^{(t)} + I^{(r)} = 1$, $I^{(t)}$ is maximal if the conditions (4) are satisfied and minimal if conditions (3) are satisfied.

The wave incident on the layer interferes with the less intense wave reflected from the layer, as a result of which a system of standing waves superimposed on the traveling wave is produced in front of the layer. This spatial distribution of the intensity is characterized by the standing wave ratio (SWR), defined as the ratio of the maximum field amplitude A_{max} to the minimum