Band-pass Filter Based on Magnetoelectric Composite at Electromechanical Resonance

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Abstract— This paper focuses on the study of a prototype magnetoelectric filter at electromechanical resonance in the dual-phase structure The dual-phase structure consists of single-crystal nickel-zinc ferrite and piezoelectric lead-zirconate-titanate with dimensions of $24 \times 24 \times 2\,\mathrm{mm}^3$ and $30 \times 20 \times 2.25\,\mathrm{mm}^3$, correspondingly. The studied band-pass filter has the resonance frequency of 86.8 kHz and bandwidth of 2 kHz. Magnetoelectric voltage coefficient equals $0.47\,\mathrm{V/(cm \cdot Oe)}$ at resonance. The prototype magnetoelectric filter allows to adjust the amplitude of the gain-frequency characteristic within the limits of 10 dB.

1. INTRODUCTION

The present paper focuses on the study of spectrum of a prototype magnetoelectric (ME) filter at electromechanical resonance (EMR) in ferrite-piezoelectric structure. ME effect is characterized by an induced polarization in an applied magnetic field or by an induced magnetization in an applied electric field. In the EMR region, the magnetoelectric effect will allow to get a stronger ME interaction compared to the low-frequency region Theoretical estimates of ME coefficient at EMR in ME composites was reported recently [1, 2]. Experimental study of ME coupling in ferrite-piezoelectric bilayer at thickness shear mode was discussed in our earlier work [3–5]. In this work, we consider the longitudinal mode of EMR in a ferrite-piezoelectric bilayer. Longitudinal mode allows one to obtain much lower resonance frequencies than shear vibrations. This gives an opportunity to develop low-pass filtering devices. It should be noted that the characteristics of filters can be adjusted by means of dc magnetic field in a wide range of signal amplitudes Such tunable filter allows us to perform several radio engineering functions simultaneously. This filter in addition to the function of filtering can adjust the amplitude of the signal passing, also to make the power limiter either to execute a circuit of the modulator.

2. PROTOTYPE DESIGN

The design of studied filter prototype consists of solenoid coil with ME sample ME sample is a dual-phase structure consisting of a single-crystal $Zn_{0,2}Ni_{0,8}Fe_2O_4$ (NZFO) and piezoelectric lead zirconate-titanate (PZT). PZT and NZFO have dimensions of $24\times24\times2\,\mathrm{mm}^3$ and $30\times20\times2.25\,\mathrm{mm}^3$, correspondingly. The output voltage across the piezoelectric layer is measured by using the electrodes placed on planar surfaces of piezoelectric layer. Coupling at the interface is provided by gluing. Bilayer structure is formed so that the magnetoelastic resonance frequency in ferrite layer coincides with EMR frequency in the piezoelectric material. Frequencies of both resonances are about 86 kHz and primarily depend on linear dimensions. DC magnetic field H is necessary for magnetic layer to provide non-zero piezomagnetic coefficient and achieve the resonant characteristics.

3. MEASUREMENT SETUP

The measurements were carried out with used Agilent DSO-X 2002A oscilloscope. The measuring setup includes the signal generator, gaussmeter, electromagnet, and power supply as in Fig. 1. The output oscillations of signal generator are applied to the solenoid which produces the ac magnetic field of about 3 Oe. The ME output voltage induced by ME sample is measured by oscilloscope The electromagnet is used for bias magnetic field control. The value of bias field varies from 0 to 2000 Oe.

The measuring setup enabled measuring the frequency response of the filter as a function of bias magnetic field.

4. MEASUREMENT DATA

Figure 2 reveals the measuring data for prototype filter at frequencies from 70 to 100 kHz for bias field of 0, 170, and 1800 Oe. The peak output voltage is obtained at frequency of 87 kHz. Induced

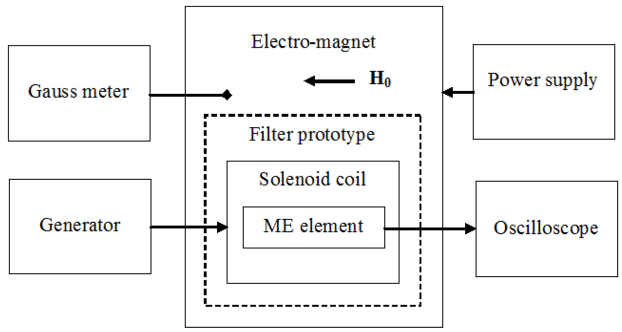

Figure 1: Measurement setup.

voltage equals 5 mV at 70 and 100 kHz and 2.46 V at 87 kHz for zero bias field. The bandwidth is about 2 kHz. Increasing bias field up to 170 Oe results in increased ME output of 12.62 V. The bandwidth remain equal to 2 kHz. It should be noted that signal amplitude variation is about 10 V. A further increase in bias field amplitude gives rise to an decrease in output voltage. Applying the bias field of 1800 Oe results in ME output of 1 V at EMR frequency. Signal amplitude variation is about 10 dB.

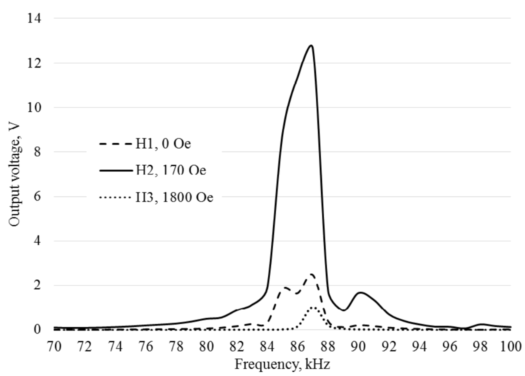

Figure 2: Output voltage vs. frequency of ME filter.

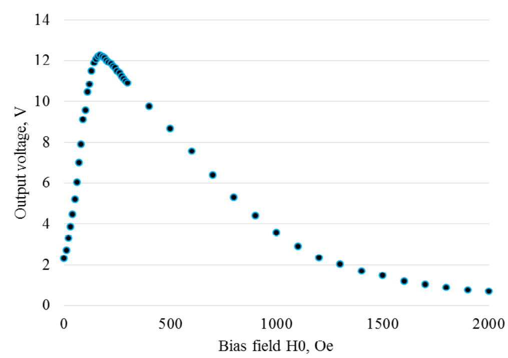

Figure 3: Output voltage vs. bias field of ME filter.

Figure 3 shows the bias magnetic field dependence of output voltage. The peak output voltage of 12.62 V is obtained at bias field of 170 Oe. Then the output voltage decreases. The curve shape is similar to the bias field dependence of magnetostriction for NZFO.

Based on the obtained results, one can estimate the ME voltage coefficient. The peak ME coefficient equals 0.47 V/(cm·Oe) at EMR frequency. The bias magnetic field dependence of output voltage in Fig. 3 suggests that the filter attenuation characteristic can be adjust by applying the appropriate bias magnetic field.

5. THEORETICAL APPROACH

ME effect in composites is known to be a product property of the magnetostrictive effect in a magnetic phase and the piezoelectric effect in a piezoelectric phase. A sharp increase in ME coupling strength is obtained in the vicinity of the electromechanical resonance (EMR) frequency because the ME effect in composites is due to mechanically coupled piezoelectric and magnetostrictive subsystems. Theoretical estimates of ME coupling in the EMR region were discussed recently [1]. The main parameters that determine ME coupling strength at EMR in composites are piezoelectric and piezomagnetic coefficients. Most ferromagnetic materials show the magnetostrictive effect, however, the linear piezomagnetic effect in these materials is not observed. Linearity in such materials is provided by applying the bias magnetic field and ac magnetic field with amplitude which is assumed to be small compared to bias field. Thus the magnetoelectric effect over a short range around this bias field can be approximated as a linear effect. We consider only the Joule magnetostriction that leads to a change of shape in the direction of the applied magnetic field, while maintaining a constant volume. Taking into account the expression for magnetoelastic free energy density for Joule magnetostriction leads to the following expression for the piezomagnetic coefficient q_{11} of a monodomain single-crystal ferrite:

$$q_{11} = 2b\mu_{11}M, \tag{1}$$

where μ_{11}, M, and b are permeability, magnetization, and magnetoelastic coefficient which only weakly depends on the external parameters. This equation can also be applicable to multidomain polycrystalline ferrite where one measures the averaged values of those quantities. Apparently, in this case one should replace magnetoelastic coefficient b with the effective coefficient b_{eff} which may vary with the change of the domain structure.

For a magnetically soft material, the value of magnetization vanishes in the absence of bias magnetic field. Eq. (1) shows that $q_{11} \approx 0$ for this case. Increasing applied magnetic field results in an increase in piezomagnetic coefficient. However, after this coefficient reaches a maximum, further increase of applied dc magnetic field leads to a decrease in piezomagnetic coefficient. As a result, the dependence of ME coefficient on bias magnetic field is a curve with one peak that is in agreement with data. Thus the transmission coefficient of the filter based on ME composite can be tuned by applying the appropriate bias magnetic field.

6. CONCLUSION

The frequency spectrum of the studied prototype of band-pass filter has the resonance pick at frequency 868 kHz, bandwidth equals 2 kHz for 0,7 level. Induced voltage equals 5 mV at 70 and100 kHz and 2.46 V at 87 kHz for zero bias field. The bandwidth is about 2 kHz. Increasing bias field up to 170 Oe results in increased ME output of 12.62 V. The bandwidth remain equal to 2 kHz. A further increase in bias field amplitude gives rise to an decrease in output voltage. Applying the bias field of 1800 Oe results in ME output of 1 V at EMR frequency. Signal amplitude variation is about 10 dB. At the EMR frequency ME voltage coefficient reached equals 047 V/(cm·Oe). The obtained results can be further used in practical applications.

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