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SAW FILTERS WITH FAN-SHAPED TRANSDUCERS

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The results of the study of frequency characteristics of SAW filters with multifinger fan-shaped transducers (FST) are presented. Practically useful relations determining the FST directivity diagram and the main filter characteristics dependent on FST layout and the distance between them are obtained.

One way to design SAW piezoelectric bandpass filters is to use multifinger fan-shaped transducers (FST). FST forms an acoustic field as a rather narrow acoustic beam whose intensity maximum moves along the aperture of the transducer when the exciting frequency is varied [1]. On frequencies corresponding to aperture edges, a rather sharp decrease of intensity of the acoustic beam is observed; this makes it possible to create bandpass filters with a high squareness ratio of the amplitude-frequency response (AFR). But to design such filters, it is necessary to know the influence of the SAW FST layout (the number of fingers, angles between them, aperture, etc.) on the main parameters of the frequency characteristics, such as the AFR squareness ratio, amplitude of AFR ripples in the passband, relative level of the signal in the attenuation band, etc.

A system consisting of two uniform biphase SAW FST on the surface of the isotropic piezoelectric substrate is under consideration. The layout of fingers in every FST, their numbering and phasing, as well as the systems of coordinates used for analysis are shown in Fig. 1. As a mathematical model of FST radiating, the model where every finger is considered as an elementary independent source of flat SAW propagating in a direction perpendicular to the finger is accepted. An acoustic field of FST radiation is formed as a sum of the waves from every elementary source.

Similarly, every finger of FST receiving is considered as an elementary source of an electric signal whose instantaneous value is proportional to the acoustic field averaged along the finger. The electric signal in the output of the filter is formed summarizing signals from every elementary source.

Applying the model, an acoustic wave radiated by one finger with number n being

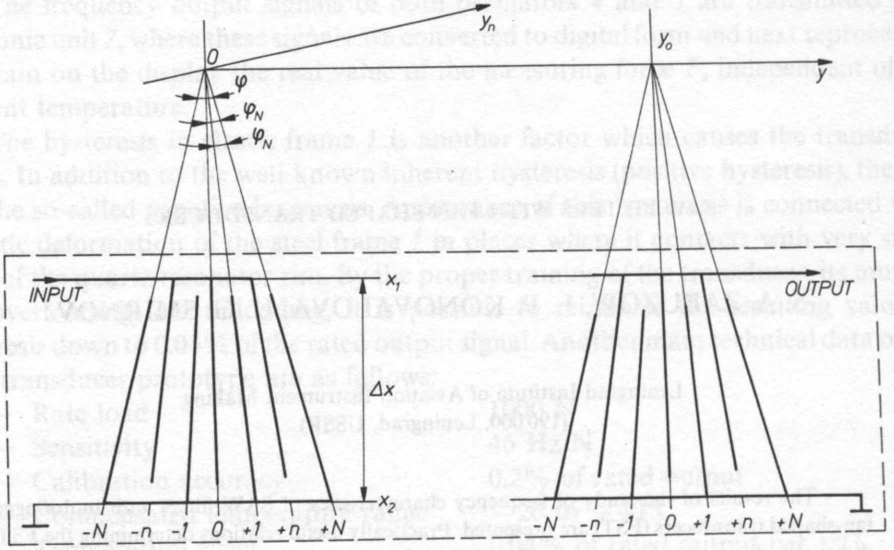

FIG. 1

fed with a harmonic signal with frequency f is described in the oordinates x, y by the following expression

$$a_n(x_n, y_n, t) = (-1)^n A_0 \exp j(2\pi f t - k x_n) \tag{1}$$

where A_0 and k – oscillation amplitude and wave number, respectively.

The instantaneous value of the acoustic field of radiating FST containing $2N+1$ fingers can be found transforming the coordinates x_n, y_n into x, y and summarizing the elementary waves.

$$a(x, y, t) = A_0 e^{j2\pi f t} \sum_{n=-N}^{+N} (-1)^n \exp[-jk(x \sin\varphi_n + y \cos\varphi_n)]. \tag{2}$$

The greatest value of the function $a(x, y, t)$ equals the sum of amplitudes of the elementary waves, i.e.,

$$a_{\max} = (2N+1) A_0 \tag{3}$$

can be seen in a point with the coordinates $y = 0$, $x = x_0$ only when the condition of synchronism is correct:

$$\sin\varphi_n = n \sin\varphi_1. \tag{4}$$

In accordance with it, FST angular dimensions must be chosen.

Normalized to the amplitude of the acoustic field of radiating FST, i.e. its directivity diagram, is determined with the formula

$$D(x, y) = \frac{1}{2N+1} \text{Mod} \sum_{n=-N}^{+N} (-1)^n \exp[-jk(x \sin\varphi_n + y \cos\varphi_n)]. \quad (5)$$

Near FST the axis Ox i.e., when $y \approx 0$ as well as with small angles (assuming $\cos\varphi_n \approx 1$),the relation (5), taking into account the condition of synchronism (4), is a sum of geometrical progression and can be written as

$$D(x, 0) = \frac{1}{2N+1} \frac{\cos\left(\frac{2N+1}{2} kx \sin\varphi_1\right)}{\cos {}^1/_2\, kx \sin\varphi_1}. \quad (6)$$

The relation (6) shows that as a result of interference of a great number of flat waves the acoustic field of radiating FST, gains the form of a rather narrow beam whose intensity maximum is seen along the line of synchronism, i.e., when

$$x = x_0 = \frac{\pi}{k \sin\varphi_1} = \frac{v}{2f \sin\varphi_1} \quad (7)$$

and shifts along the aperture when frequency is varied. The beam width at the level of 0.64 is equal to

$$\delta x = \frac{\lambda}{(2N+1)\sin\varphi_1} \approx \frac{\lambda}{\sin\varphi} \quad (8)$$

where λ and v–SAW wavelength and its phase velocity.

Frequency deviation corresponding to the beam shift of its width characterizes the frequency properties of FST and depends only on the number of fingers:

$$\delta f = \frac{2f}{2N+1} \approx \frac{f}{N} \quad (9)$$

The electric signal received by one finger of receiving FST is proportional to the value of the acoustic field averaged along the finger $a(x, y, t)(2)$, i.e.

$$u_m(t) = \frac{1}{x_2 - x_1} \int_{x_1}^{x_2} a(x, y(x), t)\,dx, \quad (10)$$

where

$$y(x) = y_0 + x \operatorname{tg}\varphi_m \quad (11)$$

– the equation of the straight line coinciding with the finger axis, m – rank number of the finger, x_1, x_2 – coordinates of the aperture's edges of receiving FST.

The electric signal of receiving FST containing $2N+1$ fingers can be found as the following sum:

$$u(t) = \sum_{m=-N}^{N} (-1)^m U_m(t) = Q(f) \exp(j\omega t). \quad (12)$$

As a result of integrating Eq. (11) and summarizing Eq. (12), the function $Q(f)$ is proportional to the complex voltage transmission coefficient of the filter:

$$Q(f)=\sum_{m=-N}^{+N}\sum_{m=-N}^{+N}(-1)^{n+m}\frac{\sin(\beta\pi f/f_0\gamma_{nm})}{\beta\pi f/f_0\gamma_{mn}}\times$$

$$\times\exp\left[j\pi\frac{f}{f_0}\left(\gamma_{nm}-M\sin^2\frac{\varphi_n}{2}\right)-j2\pi f\tau_0\right], \tag{13}$$

where

$$\gamma_{nm}=n+m\frac{\cos\varphi_n}{\cos\varphi_m};\quad \beta=\frac{\Delta x}{2x_0}\approx\frac{2\Delta f}{f_0};$$

$$f_0=\frac{v}{2x_0\sin\varphi_1};\quad x_0=\frac{x_2+x_1}{2};$$

$$\Delta x=x_2-x_1;\quad M=\frac{4y_0f_0}{v}=\frac{y_0}{\lambda_0};\quad \tau_0=\frac{y_0}{v},$$

In the formula (13) the following designations are found f_0 -frequency when the point of synchronism x_0 coincides with the center of aperture, λ_0 — SAW wavelength on frequency f_0, y_0 — the distance between the axes of symmetry of FST.

AFR and phase-frequency response PFR of the filter are respectively the absolute value and argument of the complex function $Q(f)$ and can be written as

$$K(f)=\sqrt{A^2+B^2},$$

$$\varphi_k(f)=2\pi f\tau-\operatorname{arctg}\frac{B}{A}, \tag{14}$$

where

$$A=\sum_{n=-N}^{+N}\sum_{m=-N}^{+N}(-1)^{n+m}\frac{\sin\beta\pi f/f_0\gamma_{nm}}{\beta\pi f/f_0\gamma_{nm}}\times$$

$$\times\cos\pi\frac{f}{f_0}\left(\gamma_{nm}-M\sin^2\frac{\varphi_n}{2}\right); \tag{15}$$

$$B=\sum_{n=-N}^{+N}\sum_{m=-N}^{+N}(-1)^{n+m}\frac{\sin\beta\pi f/f_0\gamma_{nm}}{\beta\pi f/f_0\gamma_{nm}}\times$$

$$\sin\pi\frac{f}{f_0}\left(\gamma_{nm}-M\sin^2\frac{\varphi_n}{2}\right).$$

Computation in accordance with Eqs. (14) and (15) show the following:

With small distances between FST axes of symmetry ($y_0 \ll y$) and small opening angles ($\varphi < 10°$), AFR and PFR actually do not depend on y_0 and φ. AFR shape is very close to rectangular and PFR shape – to straight. Actually, there are no AFR and PFR ripples in the filter's passband.

The transition coefficient in the passband is reversely proportional to frequency, and decreases proportionally to the square of frequency deviation outside the passband. The AFR slope on the edges of the passband is proportional to the number of fingers, that is in agreement with Eq. (9).

For example when $N = 20$ and $\varphi = 10°$, the passband $f/f_0 = 0.05$, and signal suppression with the frequency deviation of $2f$ reaches the level of 50 dB (0.3%). Such parameters whithout AFR and PFR ripples cannot be achieved in acoustic filters with apodized transducers having parallel fingers [2].

When the FST opening angle increases (i.e., when $\varphi > 10°$) signal suppression outside the filter's passband becomes worse. AFR and PFR ripples in the passband grow, the signal level in the suppression band increases.

With the distance y_0, between FST axes of symmetry increases, filter performance degrades. AFR and PFR ripples grow, signal suppression outside the passband decreases.

The filter's AFR close to rectangular is obtained only when the number of finger couples reaches a certain optimal value dependent on the relative bandwith in the FST aperture. When N is not great enough. AFR has a Gaussian line shape, and when N is too great i.e., when the FST opening angle is large, the AFR skew in the passband increases. If the FST aperture $\Delta x = 20\lambda$ and the relative passband $\Delta f/f_0 = 0.2$ then the optimal number of finger couples $N = 20 \ldots 25$.

An analysis of AFR and PFR SAW FST filters leads to the following conclusions:

– filters whose FST have a small opening angle lower than 10 and are placed as close to each other as possible, have the best performance;

– the AFR slope on the edges of the passband is determined by the number of finger couples in FST;

– the signal suppression level outside the passband and insertion losses in the passband are considerably dependent on the distance between FST.

References

[1] S. A. Zabuzov, U. G. Smirnov, *Radiosignal processing with acustoelectronic and acoustooptic devices*, Nauka Leningrad, 14, 1983 [Russ.].

[2] S. S. Karinsky, *SAW signal processing devices*, Sovetskoe radio Moskwa 1975 [Russ.].