Acoustoelectronic device of signal processing of antenna array for two angular coordinates

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Abstract. Acoustoelectronic device estimated at this work is quite competitive with other devices. It has small dimensions (0,005м×0,01м×0,03м), so it can be used in the complex signal processing systems in comparison with the digital systems which has larger dimensions. It is necessary to note that there are the parallel signal processing in such acoustoelectronic device. The main components of this device are the crystal of fused quartz and the thin film of ZnO. Using of thin films allows to operate in more super high frequencies. Promising enhancement of this device is increasing of operating frequency.

Keywords: acoustoelectronic device, spatial impulse characteristic, antenna array.

In this work there are some of topological and systemic variants of acoustoelectronic devices which can process signals of two-dimensional antenna arrays.

Acoustoelectronic devices with the scale-reradiated arrays (SRA) allow determining the direction of coherent acoustic and electromagnetic waves arrival simultaneously with antenna array (AA) in the real time. The modeling (in the reduced scale) of external wave fields in the processing medium (acoustic processor) takes place in such type of device [1].

In this work the possibility of SRA device application is considered for plane AA signal processing for two angular coordinates. It expands application field of these devices as diagram forming schema.

The spatial impulse characteristic (SIC) H($\bar{r}$,α, β, α',β') is the general characteristic determining the main factor of processing device, in particular spatial one, where are α,β and α'β' – are elevation and azimuth angles in objects area and respectively in images area (in processing medium of analogue processor). SIC is the response to monochromatic δ - generator placed in far zone of AA and is determined accurate to non-existent multiplier C in the following form:

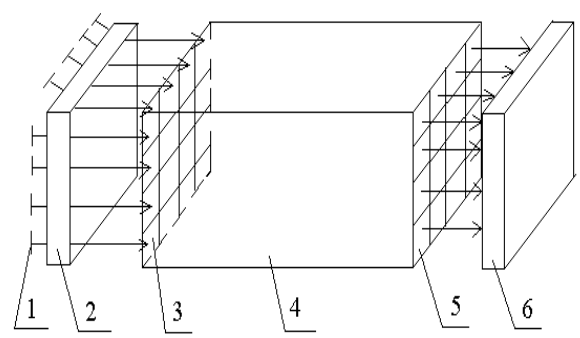
$$H(k,\alpha_o,\beta_o,\alpha'_o,\beta'_o) = C\int_{\bar{r}} P(k,\bar{r})V(k,\alpha_o,\beta_o,\bar{r})\times \times W(k,\alpha'_o,\beta'_o,\bar{r})d\bar{r} \quad (1)$$

where are P(k,$\bar{r}$) – function of aperture, V(k, α, β, $\bar{r}$) – function determining complex amplitude distribution of received signals, $W(k,\alpha',\beta',\bar{r})$ - seating function of acoustoelectronic device, $\bar{r}$ - radius-vector of point on AA aperture. As it is known, seating function should be choused equal to complex conjunct function of complex amplitude distribution on the receiving antenna in the frequency band of receiving signals when there is the implementation of algorithm of signals spatial processing.

So,

$$W(k,\alpha,\beta,\bar{r}) = V^*(k,\alpha,\beta,\bar{r}) \quad (2)$$

In the simplest case the reradiated array is placed on the one side of acoustic duct on an appropriate scale in the solid-state processor. The read-out array is placed on the opposite side of the duct [1] (pic.1).

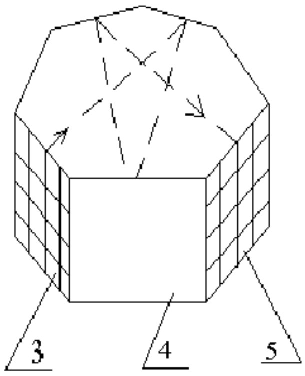


Pic.1. Acoustoelectronic device of signal processing of plane antenna array:

1 – plane AA; 2 – an amplifier; 3 - the reradiated array; 4 – acoustic duct; 5 - the read-out array; 6 – processing and indicating device.

The frequency and velocity scaling is used for decreasing of processor' dimensions, i.e. $m_\lambda = k/k, < 1$.

However, when the read-out array is located in far zone of the reradiated array, even in this case, there is the processor of the too large dimensions because of this location. To solve this problem one can use the polyhedron medium of duration (pic.2). Processor can be fulfilled in the form of polyhedron with piezoelectric transducers of reradiating and reading arrays for low frequency antenna array.



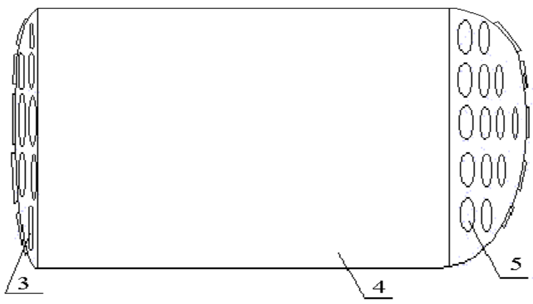
Pic.2. Polyhedron acoustoelectronic device of signal processing of plane antenna array:

3 – the reradiated array; 4 – the acoustic duct; 5 – the read-out array.

The square phase transparent can be used instead of lens to get focusing of reradiated wave. Such phase transparent is formed in the electrical circuits, for example, in multi-channel frequency changer. The number of formed channels is less than the number of AA elements in the device with "electrical lens" if the phase distribution is the function with stepped phase variation and argument deviation of support function from ideal one is no more than accepted value $|\Delta\varphi|$.

The second variant of decreasing of analog processor's dimensions is provision of focusing of reradiated acoustic wave on elements of read-out array. Focusing effect can be obtained by location of the reradiated and read-out arrays on spherical surface with determined law of transducers' placement (pic.3).

The topology of the device shown in picture 3 was calculated in this work.



Pic.3. Acoustoelectronic processor with spherical sides:

3 – the reradiated array;4 – the acoustic duct; 5 - the read-out array.

The topology of processor with focusing AA is determined. Its coordinates are found from equation *z(x,y)=z(x)z(y)*. In this case the location of elements is considered separately along axis *X*, *X′* and *Y,Y′*.

The support function of this device for coordinates of reradiated (x', z') and read-out (x_0',z_0') elements is determined as

$$W(x')=\exp(-jk'r'_H)=\exp\left\{-jk'\left[(x'-x'_0)^2+(z'-z'_0)^2\right]^{1/2}\right\} \quad (3)$$

We'll find such distribution laws of transducer elements to represent expression (3) in the form:

$$W(x')=\exp\left\{-jk'\left[r'_{H0}+\frac{kx\sin\alpha}{k'}\right]\right\} \quad (4)$$

what is respectively to the required characteristic (2) for the far zone of AA.

Now we transfer (4)

$$W(x')=\exp\left\{-jk'\left[r'_{H0}+\frac{k}{k'}\frac{D}{D'}f(x')\sin\alpha\right]\right\}= \quad (5)$$
$$\exp\{-jk'[r'_{H0}+f(x')\sin\alpha']\}$$

Where $\sin\alpha'=\mu\sin\alpha$, $\mu=\frac{kD}{k'D'}$, *f(x')* - function determining location of elements of reradiated array along axe X', where is $x'=\frac{D'}{D}x$, *D* and *D'* – apertures of AA and reradiated arrays.

There is the case sinα=0. According to (4) the elements of reradiated array can be located on circular arc with radius ρ' and the center in the place of read-out element's location where is *sinα=0*. When there are $x'_0|_{\sin\alpha=0}=0$, $z'_0|_{\sin\alpha=0}=\rho'$ then:

$$z'=\rho'-\left[(\rho')^2-(x')^2\right]^{1/2} \quad (6)$$

When (3) and (5) are equal and $x'_0=-z'_0 tg\alpha'$, $r'_{H0}=r'_H|_{x'=0}=z'_0/\cos\alpha'$ and there are only the first two expansion terms in power series then we can obtain:

$$z'_0=\frac{(x')^2-f^2(x')\sin^2\alpha'}{2f(x')tg\alpha'+\frac{(x')^2}{\rho'}-2x'tg\alpha'} \quad (7)$$

When dz'_0/dx' is equal to zero we obtain the differential equation of the first order:

$$\frac{d[f(x')]}{dx'}=\frac{f^2(x')\left[\frac{x'}{\rho'}\sin\alpha'\cos\alpha'-\sin^2\alpha'\right]+2x'f(x')-(x')^2}{f^2(x')\sin^2\alpha'+f(x')\left[\frac{(x')^2}{\rho'}\sin\alpha'\cos\alpha'-2x'\sin^2\alpha'\right]+(x')^2}$$

We take the new variable value $\chi'=\frac{x'}{\rho'}$

$$\frac{d[f(\rho'\chi')]}{d\chi'}= \quad (8)$$
$$\frac{\rho' f^2(\rho'\chi')\left[\chi'\sin\alpha'\cos\alpha'-\sin^2\alpha'\right]+2(\rho')^2\chi' f(\rho'\chi')-(\rho')^3(\chi')^2}{f^2(\rho'\chi')\sin^2\alpha'+\rho' f(\rho'\chi')\left[(\chi')^2\sin\alpha'\cos\alpha'-2\chi'\sin^2\alpha'\right]+(\rho'\chi')^2}$$

The solution of this equation is represented in the form:

$$f(\rho'\ )=a_1\chi'+a_2(\chi')^2+a_3(\chi')^3+... \quad (9)$$

From (8) and (9) we obtain the equation system:

$$\begin{cases} (a_1-\rho')\left[(\rho')^2 - a_1^2 \sin^2\alpha'\right] = 0 \\ a_2\left(\sin^2\alpha' - 2\right) + a_3 = 0 \\ 2a_2^2 \sin^2\alpha' - a_3\rho'\cos^2\alpha' = 0 \end{cases} \qquad (10)$$

We choose only the corns not depending from α': a_1=ρ', a_2=0, a_3=0.

Then *f(x')=x'*, elements of reradiated array must be located on circular arc (6) with the equal step along the axe X':

$$x' = \frac{D'}{D}x \qquad (11)$$

The coordinates of elements of reradiated array is determined as:

$$z_0' = \frac{(x')^2 - (x')^2\sin^2\alpha'}{2x'tg\alpha' + \frac{(x')^2}{\rho'} - 2x'tg\alpha'} = \rho'\cos^2\alpha'$$

$$x_0' = -z_0' tg\,\alpha' = -\rho'\sin\alpha'\cos\alpha' \qquad (12)$$

$$x_0' = \frac{\rho'}{2}\sin 2\alpha',\; z_0' = \frac{\rho'}{2}\left(1+\cos 2\alpha'\right)$$

$$\left(z_0' - \frac{\rho'}{2}\right)^2 + \left(x_0'\right)^2 = \left(\frac{\rho'}{2}\right)^2$$

The coordinates of elements of read-out array is satisfied to the circular equation with center ($\rho'/2$, 0) and radius $\rho'/2$.

According to (3) the support function of device with focusing array is determined as:

$$W(x') = \exp\Big\{\Big\{-jk'\Big\{(\rho')^2\cos^4\alpha' - 2\rho'\cos^2\alpha' +$$

$$+2\rho'\cos^2\alpha' \times \left[(\rho')^2 - (x')^2\right]^{1/2} + 2(\rho')^2 -$$

$$-2\rho'\left[(\rho')^2 - (x')^2\right]^{1/2} + (\rho')^2\sin\alpha'\cos^2\alpha' +$$

$$+2x'\rho'\sin\alpha'\cos\alpha'\Big\}^{1/2}\Big\}\Big\} \qquad (13)$$

We can write the support function as:

$$W(x') = \exp\Big\{-jk'\Big[(\rho'\cos\alpha' + x'\sin\alpha')^2 -$$

$$-2(\rho')^2\sin^2\alpha' \sum_{p=2}^{\infty}\frac{(-1)^P}{P!}\left(\frac{x'}{\rho!}\right)^{2P}\prod_{j=1}^{P}\left(\frac{3}{2}-j\right)\Big]^{1/2}\Big\} \qquad (14)$$

So, the support function is approximately equal:

$$W(x') \cong \exp\left[-jk'\left(\rho'\cos\alpha' + x'\sin\alpha'\right)\right] \qquad (15)$$

It is respectively to (5) and inaccuracy is less than |Δφ| if the following condition is fulfilled:

$$\rho' \ge \left[\frac{\pi}{|\Delta\varphi|}\frac{(D')^4}{64\lambda'}\sin\alpha' tg\,\alpha'\right]^{1/3} \qquad (16)$$

The device shown in picture 3 is the device with the scale-reradiated array. We use the velocity scaling in this work. The acoustic duct is fulfilled from fused quartz. The transducers are fulfilled in the form of low-aperture piezotransducers with using texturing films of ZnO for high and super high frequency range. Axis «C» is normally to substrate.

The central frequency of this device is equal 500 MHz; the bandwidth is determined by bandwidth of piezotransducers and is equal 175 MHz (35% of the central frequency). The dimensions of the device are 3x1x1cm. The width of the one transducer is determined by the central frequency and is equal 6,3 micrometers. The round form of the transducer was chosen for obtaining of axisymmetric directional characteristic of transducer. Diameter of the one reradiated area element is equal 0,3 mm; the distance between elements of reradiated array is equal 0,4 mm.

The read-out transducers have the round form too. Diameter of the one read-out area element is equal 0,8 mm; the distance between elements of read-out array is equal 1,2 mm. The elements of reradiated and read-out arrays are placed on spherical surfaces with radiuses of curvature 3,3 cm and 1,65 cm respectively. These elements are located on circular arcs. The number of reradiated array's elements is equal 7x7, the number of read-out array's elements is equal 6x6. Resolving ability of the device is equal 10°.

The film technology of piezotransducers' obtaining allows obtaining the texturing films of large and small squares on plane and curvilinear surfaces.

The results of thin films' sputtering were obtained for spherical surface of acoustic duct made of fused quartz with the following characteristics of texture perfection: texturing degree of crystal R_{002}≈100%, degree of axis off-orientation $|\sigma| \le \pm 8°$, the angle of slope of texture axis φ≤10°. The preliminary experimental obtained results of small-aperture transducers' creating show the availability of their using.

The experiments are spent with using of vacuum sputtering apparatus (type УВН) with magnetron sputtering system of zinc target on direct current in the mixture of argon and oxygen. The sputtering process is effected by constructing system parameters (form, target dimension, the distance between target and substrate) and the sputtering regime (velocity, pressure in the work camera, discharge power).

References:

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