## The SAW Recursive Filters and Dispersive Devices Using Multistrip Couplers

*B.N.Pirogov, A.S.Sokolov*
*Russia, S.-Petersburg State University of Telecommunications*
asfalcon@mail.ru

The technique of surface acoustic waves (SAW) have wide application in many branches of modern radio electronics: radar-locations, TV, communications etc. The most of strip filters is designed on the basis of transversal filters. The most distribution had been received by the SAW passband filters with the high characteristics. The such filters at most are not recursive. However it was necessary to design filters with the big number of transducer elements for the high quality filters (more than 1000). It is essentially complicated technology of manufacturing of these filters and raised their cost. Moreover the stopband signal level makes rather high size (-10…-20 dB). Producing filters with a lower level of stopband signal requires serious technological and economic expenses. The ability and necessity for miniaturization of existing units of electronics has appeared with the high speed development of technologies in microelectronics.

These lacks are eliminated by use of the SAW structures covered with a feedback, i.e. recursive filters[1]. Using a feedback in SAW filters allow essentially to simplify technology of manufacturing of multielement transducers (the number of elements decreases) to reduce spoilage percent at serial manufacturing and to increase reliability of devices.

The base block diagram of the SAW recursive filter is given at fig. 1.

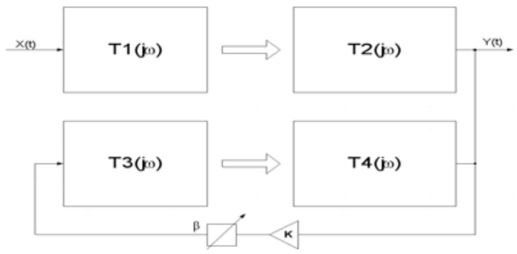


Figure 1.

Transfer function of the SAW recursive filters received with using the models of deltas – sources [2] looks like:

$$H(i\cdot w) = \frac{\frac{1}{N1}\cdot\sum_{n1=0}^{N1-1}(-1)^{n1}\cdot a_{n1}\cdot e^{-i\cdot w\cdot\frac{T1}{2}\cdot n1}}{1-K\cdot\frac{1}{N2}\cdot\sum_{n2=0}^{N2-1}(-1)^{n2}\cdot c_{n2}\cdot e^{-i\cdot w\cdot\frac{T2}{2}\cdot n2+\beta}} \qquad (1)$$

The analysis of base recursive structure of the filter was carried out. The method of deltas – functions was used.

Strong influence of transfer factor in a circuit of a feedback was revealed at the transfer function research of recursive structure by a method of the delta - analysis. This situation demands careful calculation of a feedback circuit transfer factor at designing. Comparative filter characteristics at different transfer factors are submitted on fig. 2. The number of elements of the transducers of a straight line and a feedback is equal 100.

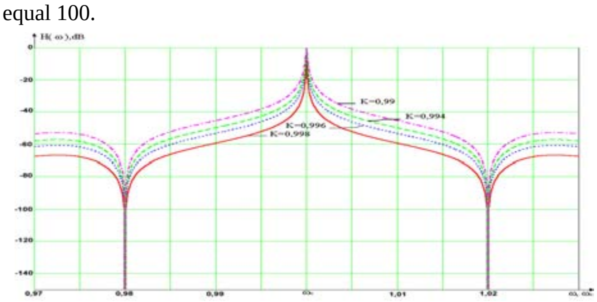

Figure 2.

The influence of phase shift in a feedback circuit to the AFC form was investigated. The central frequency of the filter is displaced aside low frequencies by entering a delay into a feedback circuit. At the same time the quality of the filter decreases and the stop band signal level raises.

Diagrams of dependence of frequency deviation and quality deviation of the filter by phase shift are submitted on fig. 3, 4, 5.

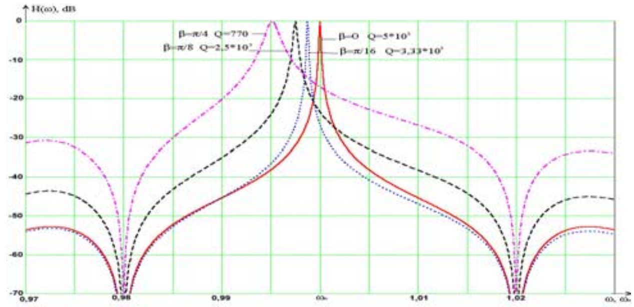

Figure 3.

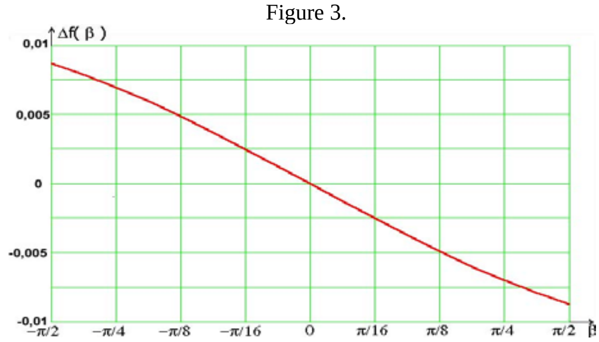


Figure 4.

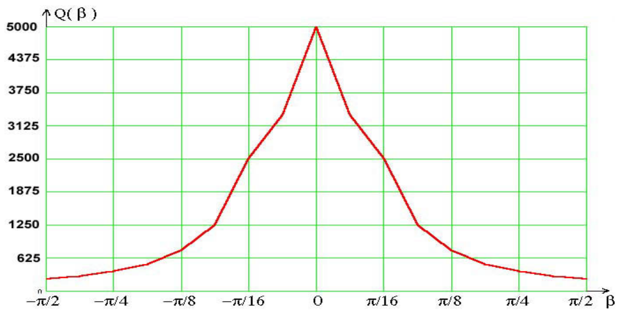


Figure 5.

But considering dependences of quality of the filter on a feedback circuit transfer factor it is possible to draw a conclusion that at sharing a phase-shifting circuit and the amplifier fine tuning of the central frequency of the filter is possible within the limits of 1 % (±0,5%).

The given property of recursive structures allows to low technology requirements by manufacture and to reduce interest of a spoilage.

The algorithm of bilinear z-transformation [3] widely used for a synthesis of the digital filters can be offered for the initial stage of designing of SAW recursive filters. This algorithm allows find the IIR filter coefficients using the analog filter - prototype for the given AFC.

At the analysis of an opportunity of application of analog filters - prototypes the following was revealed: only the 2 (Chebyshev 1&2) of 4 possible (Butterworth, Chebyshev 1&2 and elliptic) approximations is able to use in the SAW recursive filters so only this approximations gives a sing variable filter coefficients, that is necessary for designing biphase converters [3]. The use of other functions is complicated because of technological difficulties of manufacturing of structures on the received coefficients.

The received coefficients of numerator are apodization function of the converter of the filter in a direct part, and coefficients of a denominator - the converter in a feedback circuit.

For a synthesis of the strip filter with symmetric AFC application of calculation of coefficients of the filter in a range from 0 up to Wo is possible, that is as the filter-prototype the filter of high frequencies with the boundary frequency equal to average frequency of the synthesized strip filter gets out.

Using the given method calculation of the strip SAW recursive filter was made with the following parameters: Low Band Edge = 230 MHz, Upper Band Edge = 370 MHz, Stop Band Ripple = -40dB. The diagram of transfer function of the SAW recursive filter is submitted on Figure 6.

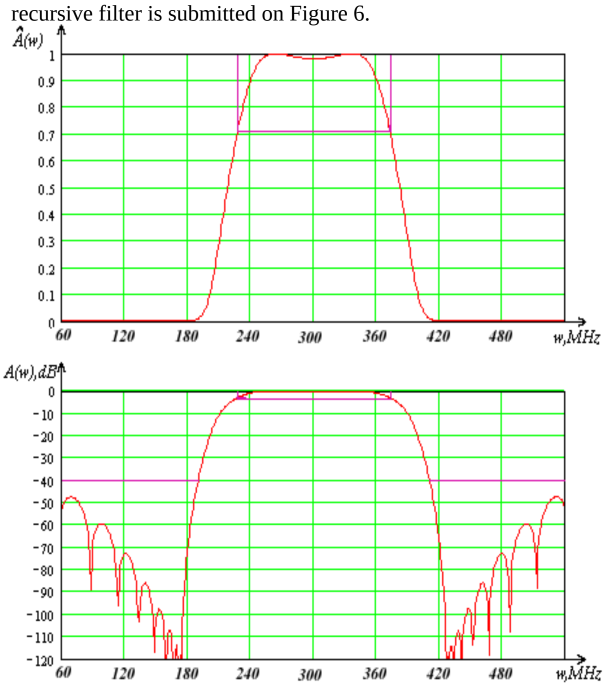


Figure 6.

After we have received the apodization coefficients we need to specify the received characteristic. The method of equivalent circuits can take advantage for this operation [4].

Also the ridge filters can be easily made using the SAW recursive circuits.

The multistrip couplers [5] can be used for a construction of the SAW recursive circuits. The design of such system is similar to not recursive circuits used now. Distances between electrodes in the top and bottom channels of multistrip coupler (*l1* and *l2* accordingly) can be taken constant. Thus average frequency of such filter is defined as:

$$f_o = Vs/|l2 - l1| \qquad (2),$$

where Vs is the SAW velocity. The complex frequency characteristic of this device is determined by a design of the multistrip coupler (as long and a difference of the periods in the top and bottom channels, and the width of the electrode). The single cell of the multistrip coupler equivalent circuit [6, 7] can be presented as an eight-pole submitted on fig.7.

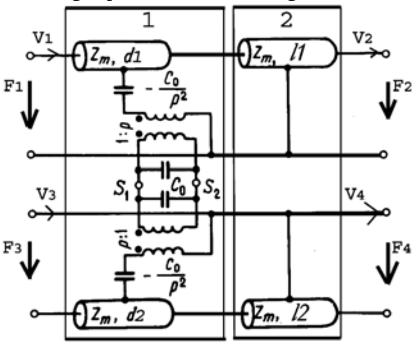


Figure 7.

Elements in the box 1 meet to a strip and elements in the box 2 meet to an interval between the strips of the elementary cell of the multistrip coupler; d1 and d2 are the strip widths in the top and bottom channels accordingly.

The matrix equation connecting entrance and target sizes looks like:

$$\begin{pmatrix} F1 \\ V1 \\ F3 \\ V3 \end{pmatrix} = \prod_{i=1}^{N} \left[ \begin{pmatrix} & A1_{4X4} & \end{pmatrix}_i \times \begin{pmatrix} & A2_{4x4} & \end{pmatrix}_i \right] \times \begin{pmatrix} F2 \\ V2 \\ F4 \\ V4 \end{pmatrix} \qquad (3),$$

when A1-matrix (4) is accorded to the strip, and A2-matrix (5) to the interval between the i and (i+1) strip.

$$A1 = \begin{pmatrix} a1_{1,1} - \frac{a1_{1,3} \cdot a1_{4,1}}{a1_{4,3} + a2_{4,3}} & a1_{1,2} - \frac{a1_{1,3} \cdot a1_{4,2}}{a1_{4,3} + a2_{4,3}} & -\frac{a1_{1,3} \cdot a2_{4,1}}{a1_{4,3} + a2_{4,3}} & -\frac{a1_{1,3} \cdot a2_{4,2}}{a1_{4,3} + a2_{4,3}} \\ a1_{2,1} - \frac{a1_{2,3} \cdot a1_{4,1}}{a1_{4,3} + a2_{4,3}} & a1_{2,2} - \frac{a1_{2,3} \cdot a1_{4,2}}{a1_{4,3} + a2_{4,3}} & -\frac{a1_{2,3} \cdot a2_{4,1}}{a1_{4,3} + a2_{4,3}} & -\frac{a1_{2,3} \cdot a2_{4,2}}{a1_{4,3} + a2_{4,3}} \\ -\frac{a2_{1,3} \cdot a1_{4,1}}{a1_{4,3} + a2_{4,3}} & -\frac{a2_{1,3} \cdot a1_{4,2}}{a1_{4,3} + a2_{4,3}} & a2_{1,1} - \frac{a2_{1,3} \cdot a2_{4,1}}{a1_{4,3} + a2_{4,3}} & a2_{1,2} - \frac{a2_{1,3} \cdot a2_{4,2}}{a1_{4,3} + a2_{4,3}} \\ -\frac{a2_{2,3} \cdot a1_{4,1}}{a1_{4,3} + a2_{4,3}} & -\frac{a2_{2,3} \cdot a1_{4,2}}{a1_{4,3} + a2_{4,3}} & a2_{2,1} - \frac{a2_{2,3} \cdot a2_{4,1}}{a1_{4,3} + a2_{4,3}} & a2_{2,2} - \frac{a2_{2,3} \cdot a2_{4,2}}{a1_{4,3} + a2_{4,3}} \end{pmatrix} \qquad (4),$$

$$A2 = \begin{pmatrix} \cos(\gamma) & jZ\sin(\gamma) & 0 & 0 \\ j\frac{\sin(\gamma)}{Z} & \cos(\gamma) & 0 & 0 \\ 0 & 0 & \cos(\gamma) & jZ\sin(\gamma) \\ 0 & 0 & j\frac{\sin(\gamma)}{Z} & \cos(\gamma) \end{pmatrix} \qquad (5),$$

when a1 and a2 are the matrixes of the equivalent circuits [4, 5, 6, 7, 8] of the part of the strip in the top and bottom channels accordingly, which looks like:

$$a1, a2 = \begin{pmatrix} \frac{\cos(\gamma) - S}{1 - S} & jZ\frac{\sin(\gamma) - 2g}{1 - S} & -\frac{\cos(\gamma) - 1}{1 - S} \cdot \Phi & 0 \\ j\frac{\sin(\gamma)}{(1 - S) \cdot Z} & a_{1,1} & -a_{2,1} \cdot \Phi & 0 \\ 0 & 0 & 1 & 0 \\ a_{2,3} & a_{1,3} & j\frac{\omega \cdot Co}{1 - S} & 1 \end{pmatrix} \qquad (6),$$

where: $\gamma = \frac{2\pi f \cdot d_x}{Vs}$, $\Phi^2 = \frac{k^2 \cdot Co \cdot Z \cdot Vs}{d_x}$,

$S = \frac{k^2 \cdot \sin(\gamma)}{\gamma}$, $g = \frac{k^2 \cdot (1 - \cos(\gamma))}{\gamma}$, $Z = \rho \cdot Vs$.

The boundary conditions for a final A -matrix (after all multiplying) are:

$$\frac{F1}{V1} = -Z, \quad \frac{F2}{V2} = Z, \quad \frac{F3}{V3} = -Z, \quad \frac{F4}{V4} = Z \qquad (7).$$

Solving the equation (3) with the boundary conditions (7) it is possible to find transfer functions:

$$T2(\omega) = \left|\frac{F2(j\omega)}{F1(j\omega)}\right|, T2(\omega) = \left|\frac{F2(j\omega)}{F1(j\omega)}\right|, T2(\omega) = \left|\frac{F2(j\omega)}{F1(j\omega)}\right| \qquad (8).$$

AFCs of multistrip coupler channels are represented on fig.8 (the difference of distances between the strips in the top and bottom channels is determined as Vs/fo, where fo=45MHz, Vs=3,45Km/sec ($LiNbO_3$), number of cells N=10).

Considered multistrip couplers can be used for the chirp device construction [8] with a high chirp rate. The difference (or a sum) of distances between the strips in the top and bottom channels changes according to the law of a formed or processable signal. The construction of a such chirp device with a multistrip coupler is represented on fig.9.

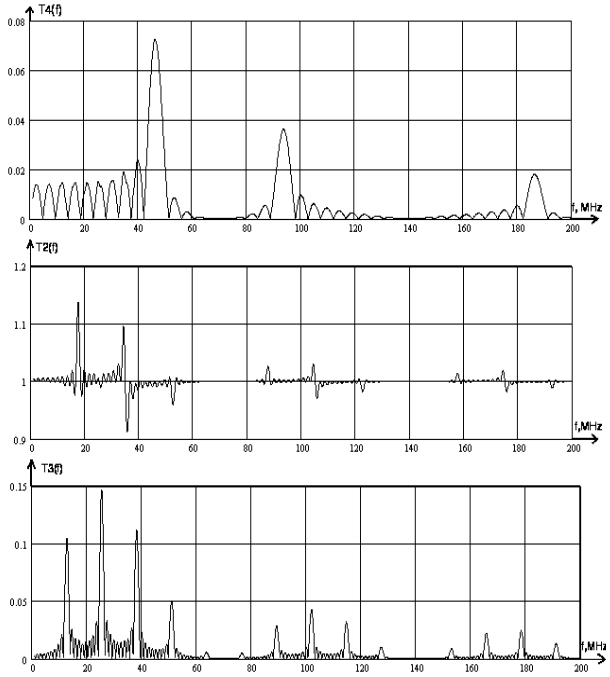


Figure 8.

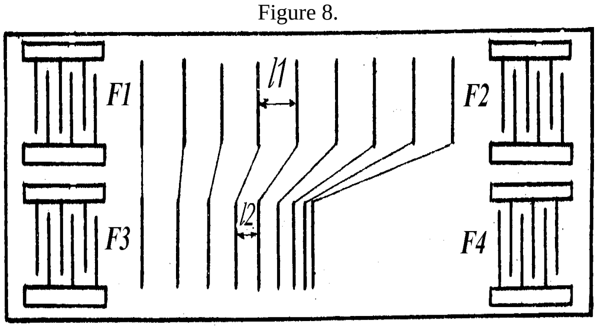


Figure 9.

AFC of multistrip coupler with the next parameters: the difference of distances between the strips in the top and bottom channels is changed according to chirp law (middle frequency fo=450MHz, bandwidth Δf=150MHz, duration ΔT=0,6µs, number of cells N=270) is given on fig.10.

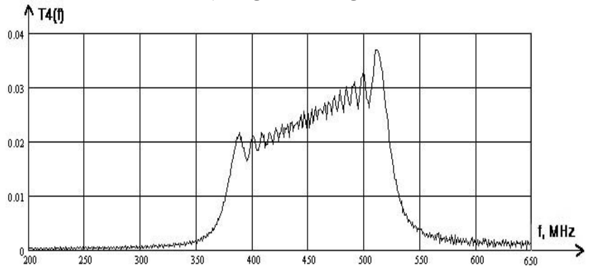


Figure 10.

AFC skew is cleaned by appropriate apodization of the multistrip coupler. However it is necessary to note, that energy transfer efficiency by formation of the complex signals essentially depends on relative width of an electrode (strip). Dependence of transfer efficiency on the relative strip width is represented on fig. 11 (λo=Vs/fo).

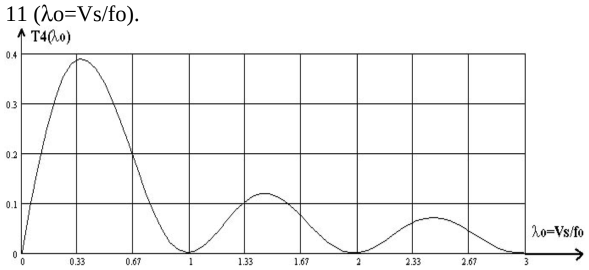


Figure 11.

On the other hand the relative strip width essentially influences to AFC cuts.

The considered method of construction, formation and processing of the complex signals with a high chirp rate allows essentially to simplify manufacturing techniques of these devices as the period of multistrip coupler in the top and bottom channels can be produced approximately identical to performance of a condition:

$$l1,\ l2 >> Vs/fo \qquad (9).$$

The way of a random choice of width of an interval according to the normal distribution in a such manner that the difference of distances between strips in the top and bottom channels changes according to the law of a formed or a processable signal can be offered for a reduction of an influence of the constant lattice period in the top channel to the AFC non-uniformity.

It is probably essential to lower technology requirements on manufacture of converters and to reduce the factor of a spoilage connected to the short circuits of the next electrodes designing the multistrip couplers for formation and processing of the chirp signals with a high chirp rate.

We have made the calculation of the chirp filter with the next parameters: fo=84 MHz, Δf=7MHz, duration ΔT=15µs. Number of cells of the MSC in such device is equal N=1260, that two time lower than the numbers of elements of the IDTs in the chirp device using just IDT. Relative strip width in the high channel is equal 0,5. Widths of the electrodes in the high and low channels of MSC are equal to 5µm, period of the решетки in the high channel is equal to 10µm (as ≈λ/4, λ=41µm (84MHz)),the width of the gap of the low channel is calculated according to chirp law (10). Apertures of high and low channels are choiced in accordance to the input and output IDT apertures, that equal to ≈60λ (in this case 2 mm).

$$(l1+l2)_i = \frac{V_0 \bullet \Delta t \bullet (f_0 + \frac{\Delta f}{2})}{\Delta f} \bullet \left( \sqrt{1 - \frac{2 \bullet \Delta f}{\Delta t \bullet (f_0 + \frac{\Delta f}{2})^2} \bullet i} - \sqrt{1 - \frac{2 \bullet \Delta f}{\Delta t \bullet (f_0 + \frac{\Delta f}{2})^2} \bullet (i+1)} \right) \quad (10),$$

where $i$ – is the current cell number.

Input IDT is acoustically connected to the 'F1' input of the MSC and the output IDT is acoustically connected to the 'F3' input of the MSC (we work with the sum of l1 & l2 periods) for a forming chirp signal. Also we can use the same structure for processing the chirp input signal (Input IDT is acoustically connected to the 'F2' input of the MSC and the output IDT is acoustically connected to the 'F4' input of the MSC).

Acoustic AFCs of the MSC are represented on fig. 12, 13 & 14.

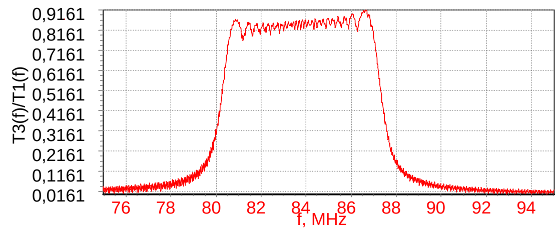


Figure 12

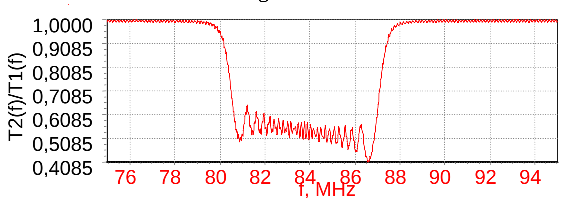


Figure 13

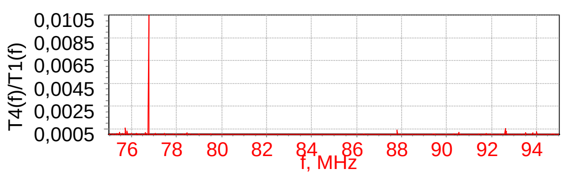


Figure 14

The chirp response according to the transfer characteristic T3(f)/T1(f) is represented on fig. 15.

To reduce the length of a strip (and its influence to the filter characteristics) on the middle channel, we shift channels so that their centers coincided.

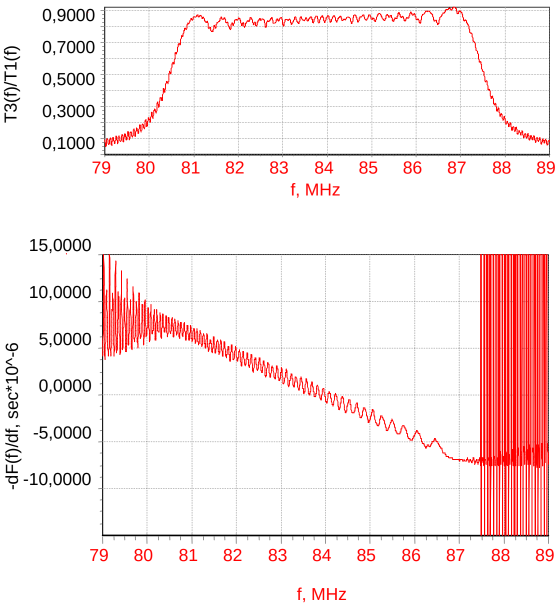


Figure 15.

Otherwise we can interleave cells of the low and high channels. Thus we can achieve essential reduction of the common converter length without deterioration of its characteristics.

AFC of the multistrip coupler processed the signal at the higher harmonics represented on fig.16. This figure shows potential ability to design devices processed with signal at higher harmonics.

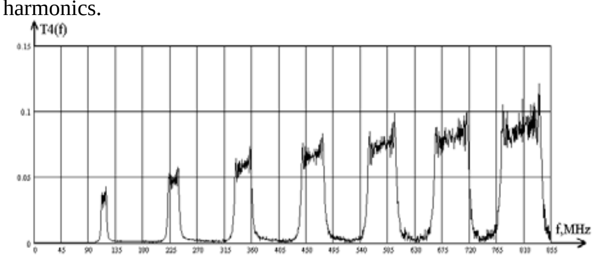


Figure 16.

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