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MULTI-BAND GRAPHIC EQUALISER BASED ON GYRATORS

Studies of the properties of human hearing have shown that the perception of loudness depends on both the frequency and intensity of sound. A person is able to compare the loudness of sounds of different frequencies. This allows us to construct so-called equal loudness curves (isophones). From them, it can be concluded that when the volume level is reduced, a person perceives sound components in the low and high frequencies of the sound range poorly, and at frequencies from 2 to 6 kHz, the ear is most sensitive to sounds. Therefore, it is with the help of an equalizer that sound correction is performed in accordance with equal volume curves. The purpose of this paper is to find a way to build an active eight-band equalizer to adjust the frequency response shape. This task can be solved in several ways. In the preliminary study, the three most common control principles were identified and analyzed, namely graphic equalizers based on an operational amplifier, bandpass filter signal addition, and an active filter with a feedback loop. Comparison of the latter with an equalizer based on an operational amplifier gave the following result: both have a uniform frequency response, but compared to the low-Q filters, the gyrator-based circuits have a higher quality, which gives an advantage to the operational amplifier-based equalizer because to obtain better quality factor and better stability of the EQ parameters based on the inclusion of a bandpass filter in the feedback loop, more complex filters that can accommodate two OPs and more elements must be used, which is not economical and will lead to an increase in size. It was also noticed that when adjusting the depth of control, the largest increase will be at the extreme positions of the slider, while at the middle positions, the slider has little effect on the depth, which is a big disadvantage. The same effect was observed for the developed scheme but with a smaller impact. But these effects are insignificant and can be ignored. The worst results are obtained with the equalizer with the addition of bandpass filter signals since it has frequency response fluctuations along the entire frequency axis at the middle positions of the sliders, and it also has the disadvantage of adjusting the frequency response in the attenuation direction, which is insignificant compared to the gain side. In order to increase the depth of control

in the attenuation direction, it is necessary to increase the quality factor of the filters, and this, in turn, will lead to an increase in frequency response fluctuations, so it is undesirable to use this scheme.
Key words: *graphic equalizer, operational amplifier, gyrator, Bexendahl, multiband equalizer.*

Семенов А. О., Стальченко О. В., Хльоба А. А., Пінаєв Б. О., Кристофоров А. В. Багатосмуговий графічний еквалайзер на основі гіраторів

Дослідження властивостей слуху людини виявили, що відчуття гучності залежить як від частоти, так і від інтенсивності звуку. Людина спроможна порівнювати по гучності звуки різної частоти. Це дозволяє побудувати так звані криві рівної гучності (ізофони). З них можна зробити висновок, що при зниженні рівня гучності людина погано сприймає складові звуку в області низьких і високих частот звукового діапазону, а на частотах від 2 до 6 кГц спостерігається найвища чутливість вуха до звуків. Тому саме за допомогою еквалайзера виконується корекція звуку відповідно до кривих рівної гучності. Метою даної роботи є знаходження шляху побудови активного восьми смугового еквалайзеру для регулювання форми АЧХ. Цю задачу можливо вирішити декількома способами. При попередньому дослідженні було виділено три найбільш розповсюджених принципи регулювання, по яким було проведено аналіз, це такі графічні еквалайзери на основі: диференціального підсилювача, складання сигналів смугових фільтрів, активний фільтр з колом зворотного зв'язку. Порівняння останнього з еквалайзером на основі диференціального підсилювача дало такий результат: в обох АЧХ є рівномірною, але в порівнянні з низькою добротністю фільтрів, контури основані на гіраторах мають вищу добротність, це надає перевагу в сторону еквалайзера побудованого на основі диференціального підсилювача, оскільки для здобуття кращої добротності та кращої стабільності параметрів еквалайзера на основі включення смугового фільтру в коло зворотного зв'язку потрібно використовувати більш складні фільтри, які можуть вміщувати два ОП та більшу кількість елементів, а це є не економічно та призведе до збільшення габаритів. Було помічено також, що при регулюванні глибини регулювання найбільший приріст буде на крайніх положеннях регулятора, тоді як при середніх положеннях, повзунок мало впливає на глибину, що є великим недоліком. Такий же ефект був помічений і для розробленої схеми але з меншим впливом. Але ці впливи незначні і ними можна знехтувати. Самі погані результати у еквалайзера з складанням сигналів смугових фільтрів, оскільки в ньому присутні коливання АЧХ по всій частотній осі при середніх положеннях повзунків, також в ньому є недолік регулювання АЧХ в сторону ослаблення, який є незначним у порівнянні з стороною підсилення. Для того, щоб збільшити глибину регулювання в сторону послаблення потрібно збільшувати добротність фільтрів, а це в свою чергу приведе до збільшення коливань АЧХ, тому таку схему використовувати небажано.
Ключові слова: *графічний еквалайзер, операційний підсилювач, гіратор, Бексендал, багатосмуговий еквалайзер.*

Formulation of the problem. At the present stage of the development of sound processing and reproduction technology, there is a significant increase in the interest of both consumers and developers in multi-band tone controllers – equalizers. Modern audio equipment and speaker systems can provide high-quality sound reproduction to the fullest extent only in a specially equipped room designed for listening to music. Most living spaces, especially small ones, are not suitable for this purpose. At any point in such rooms, there is such a phenomenon as interference (addition with different phases) of sound waves coming directly from speakers and reflected from walls, ceiling, floor, and furniture. At some frequencies, standing waves appear – voids and dips in sound intensity with an unevenness of up to 20 dB, which necessitates adjusting the frequency response of the audio system in certain frequency bands.

Insufficient soundproofing of the room results in listening to audio programs at a level significantly lower than the level at which they are generated (approximately 90 background). As a result, it is necessary to raise the volume level at frequencies below 200 and above 5000 Hz to preserve the timbre of the sound. The corresponding compensation introduced in volume controls is usually incomplete.

Frequency response control is also necessary for solving other tasks: correcting the sound of low-quality phonograms and equipment frequency response errors, compensating for age-related changes in hearing, and selecting timbre sounds to the listener's taste. Tone controls and equalizers are used for multi-band frequency response control.

Therefore, an eight-band equalizer that uses the differential amplifiers on which the gyrators are built as a filter is being developed and researched.

Analysis of recent research and publications. The first equalizers were quite simple devices. As a rule, it was a single knob that could be used to cut out a certain part of the high-frequency component. The first "serious" equalizer was invented by Peter Bexendahl [1]. His equalizer provided for separate control of low and high frequencies, with both gain and attenuation. The control remained in its middle position if equalization was not required. Subsequently, equalizer circuits experienced a rapid development that continues to this day [1].

Although the operational amplifier in its analog form is no longer a leading element in graphic equalizers, work is still underway to improve filters based on them, so in [2], the design of a graphic equalizer is being developed, and how to determine the target response is discussed. Much attention is paid to the cascade equalizer. In [3], the implementation of a Bode-type amplitude equalizer on differential amplifiers was proposed. Research is also underway to improve the method of developing a graphic equalizer using a neural network [4].

Although the topic under study is not new, a clear demonstration of the developed equalizer in the form of an article has not been found, so the results of the study of the eight-band graphic equalizer and its calculation will be demonstrated in a visual form below.

The purpose of the article: Develop a simple eight-band equalizer based on operational amplifiers, some of which act as a filter, namely, as a gyrator. To simulate and demonstrate the performance of the proposed circuit, to take the frequency response and frequency response of each band, and to provide the necessary calculations.

Presenting main material. To correct narrowband distortion, many bandpass tone controls (BTs) are used, which allow you to adjust the frequency response both in a narrow frequency band and in a wide frequency band (integrally). Typically, such BTs are a set of narrow-band filters with interleaved resonant frequencies located throughout the entire audio range on a logarithmic scale. It is convenient to raise or lower the gain of each filter by means of variable resistors with a linearly moving motor [5]. In this case, the resistors of all filters arranged in series on the front panel clearly characterize the set frequency response of the RT, which explains the popular name of multipole BTs – graphic correctors or graphic equalizers. The proposed circuit is shown in Figure 1.

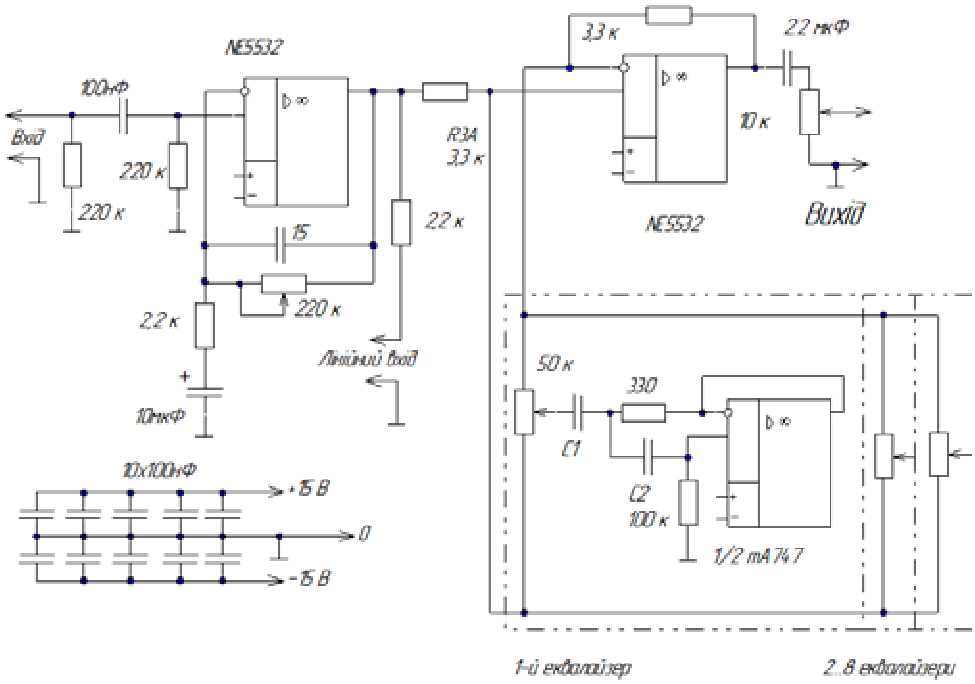


Fig. 1. Scheme of the graphic equalizer based on gyrators

The preamplifier is based on TL084CN, which has sensitivity control in the negative feedback circuit, and the gain can be adjusted within the range of 1…100 using a potentiometer (220 kΩ). A 15 pF capacitor prevents self-excitation at high frequencies. The output of the chip also provides a line output for connecting a mixing console. The equalizer is built on the same operational amplifier. Eight potentiometers are connected in parallel between the inverting and non-inverting inputs of the operational amplifier (OA). The following control principle is used. R-L links are connected between the potentiometer movers and ground, with inductances formed electrically. This scheme is known as a "gyrator" [6]. C1 is the capacitor "C" of the series oscillating circuit; C2, 330 Ohm, 100 kΩ resistors, and TL084CN simulate the "R-L" circuit. The 330 Ohm resistor (R_1) represents the series inductance loss, and the 100 kΩ resistor (R_2) represents the parallel inductance loss. The equivalent inductance is calculated using formula 1:

$$L = R_1 \cdot R_2 \cdot C\,, \qquad (1)$$

where R1, R2 are two loss resistances (in ohms); C is the capacitance of C2 (in nF). The inductance L is Henry's. Let's calculate the capacitances of the capacitors for the corresponding oscillating circuits using Thomson's formula. Thus, the resonant frequency of the oscillating circuit is determined by formula 2:

$$f = \frac{1}{2\pi\sqrt{LC}}\,. \qquad (2)$$

Whence the capacity will be equal (formula 3):

$$C = \frac{1}{4 \cdot \pi \cdot f^2 \cdot L}\ \text{[uF]}. \qquad (3)$$

The stage ends with a volume control. Let's calculate the 8-band graphic equalizer according to the above formulas. The control frequencies are selected according to Table 1, and the capacitance C_1 according to [5].

Table 1

Frequencies and gyratory capacities of the 8-band equalizer

f, Hz	**50**	**100**	**250**	**500**	**1000**	**2200**	**5000**	**12000**
C_1,uH	4,7	2,2	0,68	0,33	0,15	0,068	0,033	0,01
C_2, nF	68	33	18	10	5,1	2,2	1	0,51
L, H	2,244	1,089	0,594	0,33	0,1683	0,0726	0,033	0,01683

The circuit obtained for the simulation is shown in Figure 2. To build the model, we need to connect an oscillating circuit to the TL084CN, in which the R-C operational element plays the role of inductor. To make the model complete, you need to model an input buffer stage and eight such oscillating circuits that will accommodate eight operational amplifiers.

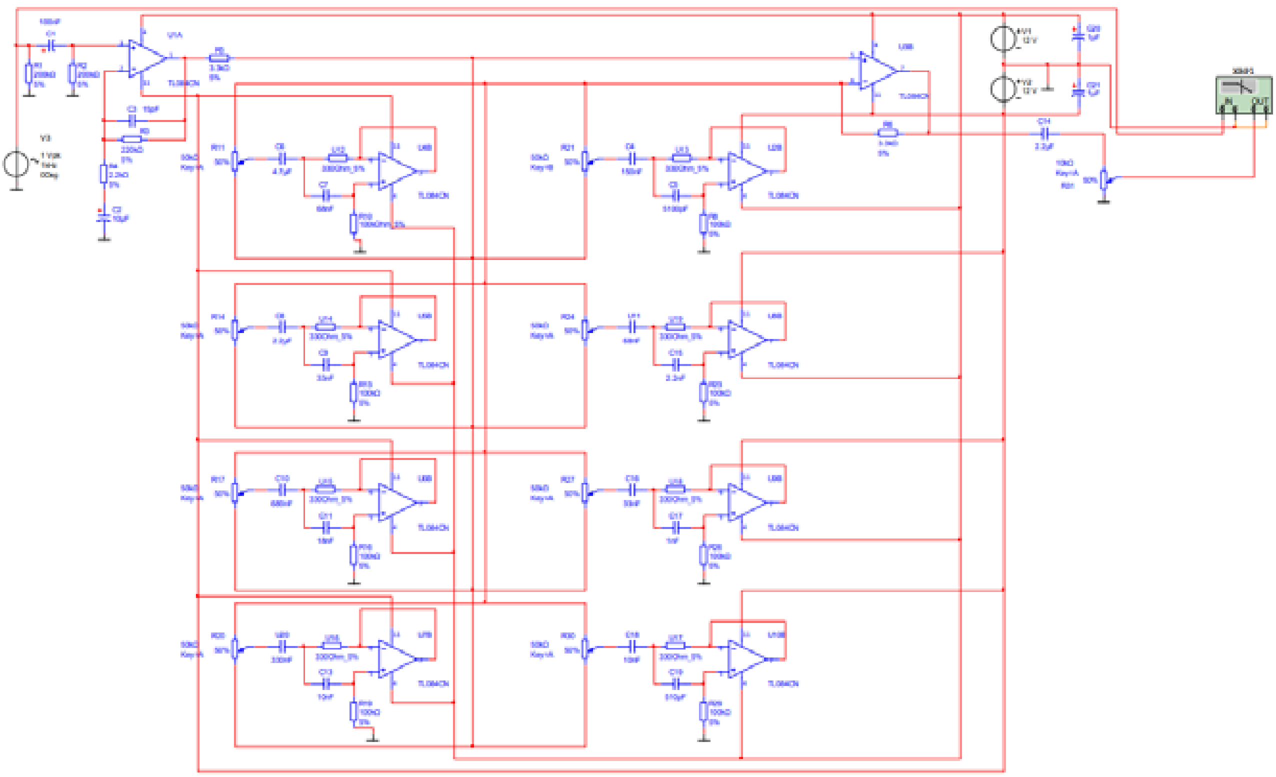


Fig. 2. The device circuit is prepared for modeling

To obtain the characteristics of each circuit, you will need to connect an explicit frequency response meter to each filter, connecting it between two points of the regulating resistance – the middle one, to which the capacitance is connected, and the other, which is connected to the non-inverting input of the op-amp. To obtain the overall characteristic, the input of the buffer stage and the input after the buffer stage (linear input) can be used as inputs.

First, let's check that all the circuits are working correctly. To do this, we will obtain the amplitude-frequency and phase-frequency characteristics of each circuit and examine them. They are shown in Figures 3 and 4. The overall frequency response and frequency response with the buffer stage connected to the input will look like Figure 5 (a, b).

The overall frequency response and frequency response of the equalizer without the buffer stage connected, i.e., when the signal is applied directly to the line input, will look like Figure 6 (a, b). To measure the depth of adjustment relative to the average level, we will change the slider position in one and the opposite direction for only one of the contours; this will be enough to see the depth of adjustment of each of the contours since they are identical. The results for the maximum and minimum positions, respectively, are shown in Figures 7 (a, b), 8 (a, b), and 9 (a, b).

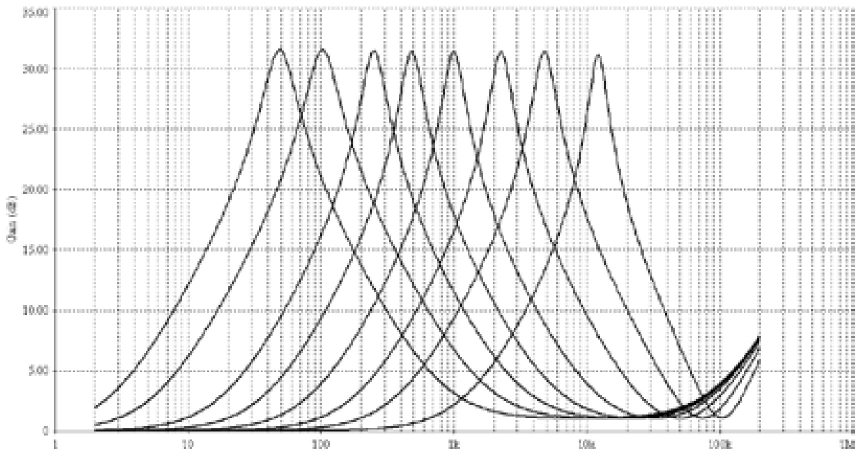


Fig. 3. Frequency response of all contours in one coordinate system

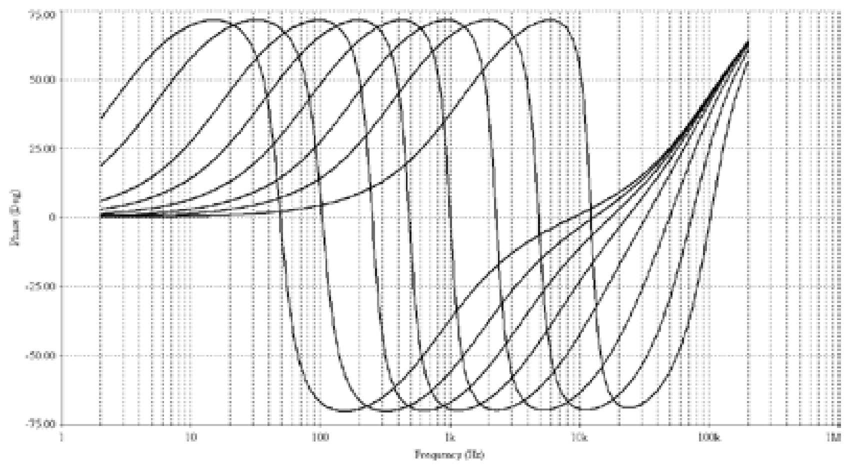
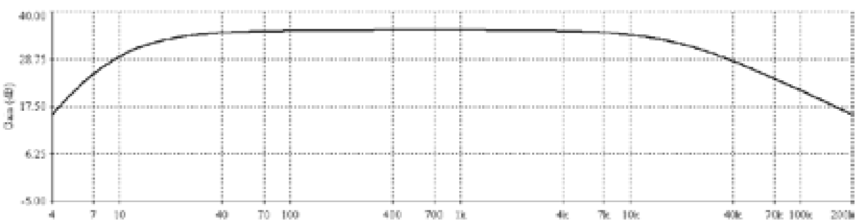
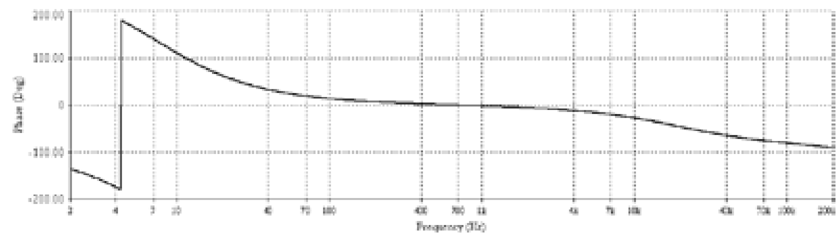


Fig. 4. Frequency response of all gyrator-based contours in one coordinate system

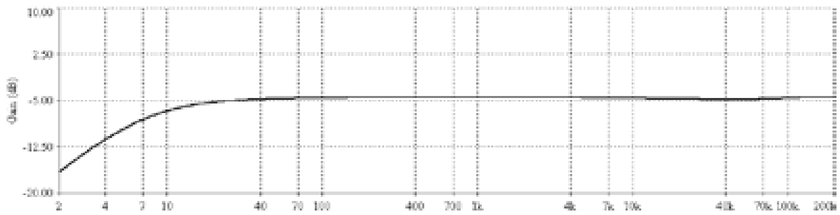


(a)

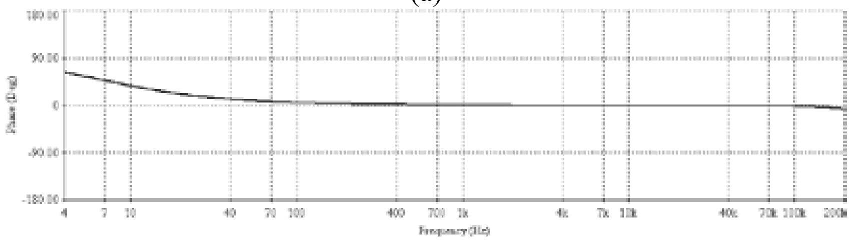


(б)

Fig. 5. General frequency response (a) and frequency response (b) of an equalizer based on a differential amplifier with a connected buffer stage

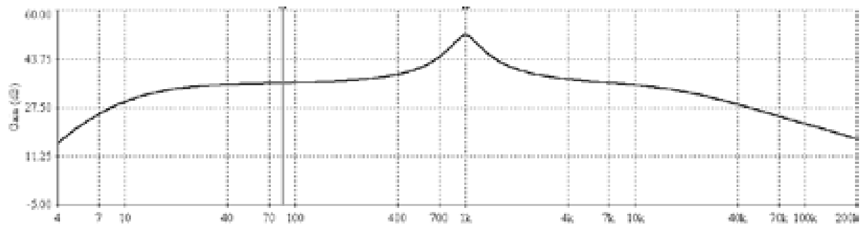


(a)

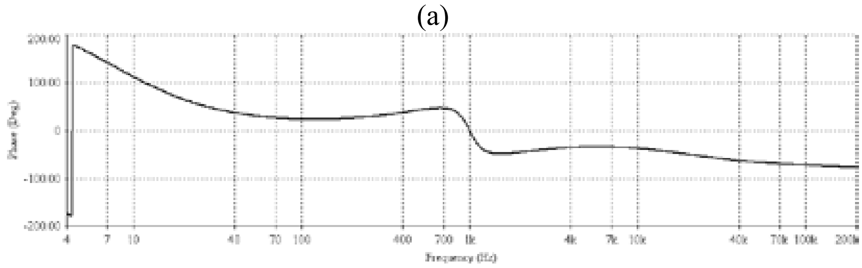


(б)

Fig. 6. General frequency response (a) and frequency response (b) of an equalizer based on a differential amplifier when a signal is applied to a line input



(a)



(б)

Fig. 7. Frequency response (a) and frequency response (b) of the equalizer at the maximum position of the slider of one of the circuits (1000 Hz)

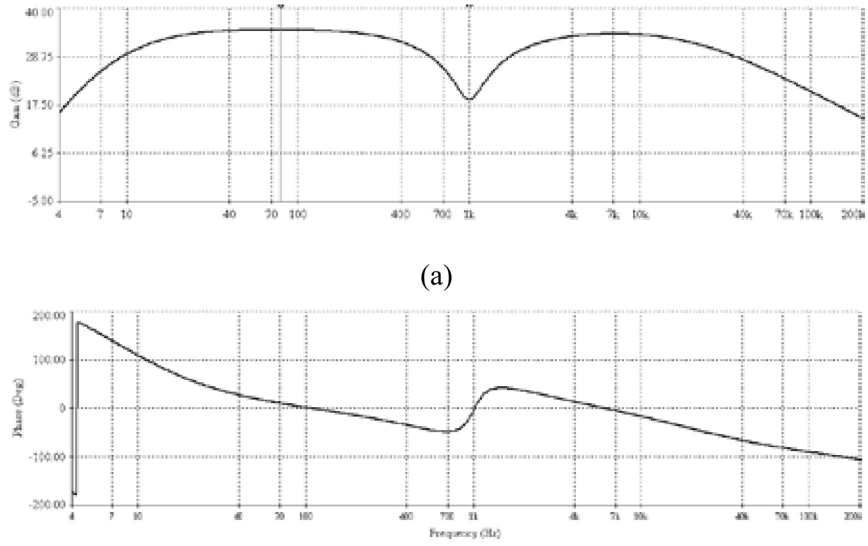
Bode Result	
x1	83.9305
y1	35.6946
x2	999.6596
y2	51.7943
dx	915.7292
dy	16.0997
1/dx	1.0920m
1/dy	62.1129m
min x	2.0000
max x	200.0000k
min y	976.6720m
max y	389.2133
offset x	0.0000
offset y	0.0000

(a)

Bode Result	
x1	78.9897
y1	35.0916
x2	999.6596
y2	18.7857
dx	920.6700
dy	-16.3059
1/dx	1.0862m
1/dy	-61.3275m
min x	2.0000
max x	200.0000k
min y	975.2993m
max y	56.8484
offset x	0.0000
offset y	0.0000

(б)

Fig. 8. Resulting values for the maximum (a) and minimum position of the slider of one of the contours (1000 Hz)



(a)

(б)

Fig. 9. The frequency response (a) and frequency response (b) of the equalizer at the minimum position of the slider of one of the circuits (1000 Hz)

Conclusions from this study and prospects for further research in this direction. The data obtained indicate that all circuits operate at the required frequencies, the gyrators were designed correctly, and all circuit frequencies have the correct geometric arrangement on the frequency axis. The quality factor is approximately the same and is $Q = \dfrac{997,35}{285,2} = 3,49$. This means that the control will be more accurate, and more oscillating circuits can be placed on the frequency axis.

As can be seen from Figures 7 and 8, the depth of adjustment of one circuit in the direction of signal amplification is 16.1 dB, and in the direction of attenuation -16.3 dB. The frequency range of the device is 50 Hz – 12 kHz, and the output voltage level is 2 V, the input impedance is not more than 240 kΩ, the output impedance is not more than 1 kΩ, the nonlinear distortion coefficient at the rated output power at a frequency of 1 kHz is not more than 0.4%. Comparing this result with the result obtained when constructing an equalizer based on the addition of bandpass filter signals [7], we can conclude that the construction based on a differential amplifier is much better; firstly, the quality factor of the circuits is higher, the frequency response is smoother, and the depth of adjustment in both directions is the same since the signals are not summed. The only advantage of the summation principle is a greater depth of control in the gain direction, but this can be realized in this method; it was necessary to set a greater depth of control, but this is not necessary since 16 dB is already quite sufficient. So, the advantage of building an equalizer on gyrators in comparison with building on the basis of summing the signals of bandpass filters is a significant uniformity of the frequency response and equal control depth relative to the average level.

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