

МИНИСТЕРСТВО ОБРАЗОВАНИЯ РОССИЙСКОЙ ФЕДЕРАЦИИ

Государственное образовательное учреждение
высшего профессионального образования
«КУЗБАССКИЙ ГОСУДАРСТВЕННЫЙ ТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»

Кафедра информационных и автоматизированных
производственных систем

ПРОТИВОПОДМЕННЫЕ АНАЛОГОВЫЕ ФИЛЬТРЫ БАТТЕРВОРТА

Методические указания к лабораторной работе по курсу
"Компьютерное управление" для студентов специальности 210200
"Автоматизация технологических процессов и производств
(в машиностроении)"

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Утверждены на заседании кафедры
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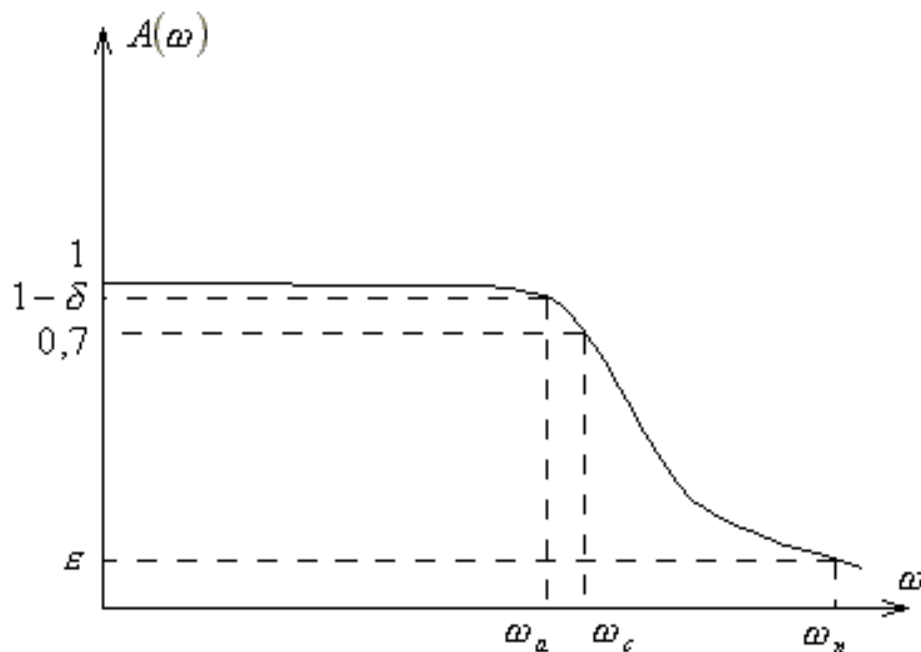
Кемерово 2003

1. ЦЕЛЬ РАБОТЫ

Цель работы – изучить противоположенные аналоговые фильтры низкой частоты Баттерворта и приобрести практические навыки по выбору их порядка и моделированию на натуральных и модельных временных рядах.

2. ОСНОВНЫЕ ТЕОРЕТИЧЕСКИЕ ПОЛОЖЕНИЯ

Амплитудная частотная характеристика $A(\omega)$ фильтров Баттерворта отличается от прямоугольной частотной характеристики идеального фильтра низкой частоты и приведена на рисунке.



Амплитудная частотная характеристика фильтров Баттерворта

ω_a, ω_n – граничные частоты, которые выделяют: полосу пропускания $(0; \omega_a)$; переходную полосу (ω_a, ω_n) ; полосу задерживания $(\omega_n, +\infty)$. Частоты ω_a и ω_n связаны с параметрами δ и ϵ , которые соответственно определяют максимальное ослабление в полосе пропускания и минимальное ослабление в полосе задерживания, т.е.

$$\left. \begin{aligned} 1 - \delta \leq A(\omega) \leq 1, \quad \omega \leq \omega_a \\ A(\omega) \leq \varepsilon, \quad \omega \geq \omega_n \end{aligned} \right\}. \quad (2.1)$$

При этом $\omega_n = k \cdot \omega_a$,

где k ($k > 1$) – коэффициент запаса.

Амплитудная частотная характеристика фильтров Баттерворта задается соотношением

$$A(\omega) = \frac{1}{\sqrt{1 + \omega^{2n}}}. \quad (2.2)$$

Прямоугольность $A(\omega)$ зависит от порядка n фильтра Баттерворта. Чем выше n , тем амплитудная частотная характеристика ближе к прямоугольной. Однако при этом усложняется схемная реализация фильтров Баттерворта. На практике показано, что при $n > 4$ обеспечивается приемлемая прямоугольность характеристики $A(\omega)$.

На основе выражений (2.1) получены соотношения по выбору порядка фильтров Баттерворта, обеспечивающих требуемые значения параметров δ и ε . В этом случае

$$n = \frac{\ln \eta}{2 \cdot \ln k}, \quad (2.3)$$

$$\text{где } \eta = \frac{(1 - \varepsilon^2)(1 - \delta)^2}{\varepsilon^2 \delta (2 - \delta)}, \quad (2.4)$$

где $\varepsilon, \delta \ll 1$.

Передаточные функции фильтров Баттерворта:

$$W_\phi(p) = \frac{1}{1 + a_1 p + a_2 p^2 + \dots + a_n p^n} \quad (2.5)$$

определяются через полюсы характеристического уравнения по выражению

$$W(p) = \frac{1}{(p - p_1)(p - p_2) \dots (p - p_n)}. \quad (2.6)$$

Полюсы передаточной функции фильтра Баттерворта p_1, p_2, \dots, p_n определяются по выражению

$$p_i = -\sin\left(\frac{2i-1}{2n} \cdot \pi\right) + j \cos\left(\frac{2i-1}{2n} \cdot \pi\right), \quad (2.7)$$

где $i = \overline{1, n}$.

Модули всех полюсов равны 1, а их аргументы $\varphi_i = \pi [n + (2i-1)] / 2n$.

При нечетном n $W_\Phi(p)$ имеет один вещественный корень и $(n-1)$ – комплексно-сопряженных корней, а при четном n все корни комплексно-сопряженные.

3. ПОРЯДОК ВЫПОЛНЕНИЯ РАБОТЫ

1. Ознакомиться с теорией построения амплитудных частотных характеристик фильтров низкой частоты Баттерворта, выбора их порядка, нахождения полюсов и получения на их основе передаточных функций.

2. Определить требуемый порядок фильтра Баттерворта n в соответствии с заданным вариантом по данным из табл. 3.1.

3. Построить амплитудные частотные характеристики $A(\omega)$ (2.2) для фильтров Баттерворта порядков $n-1$, n , $n+1$ в одних осях координат и провести сравнительный анализ о степени влияния порядка фильтра на прямоугольность $A(\omega)$.

4. Получить передаточные функции фильтров Баттерворта порядков $n-1$, n , $n+1$ по формуле нахождения полюсов (2.7) и формуле определения передаточных функций (2.6) и их алгоритмы фильтрации, используя правила непосредственного получения разностных уравнений по дифференциальным уравнениям или методы z - преобразования, используя общую подстановку вида

$$p = \frac{1 - z^{-1}}{\Delta t}. \quad (3.1)$$

Выбор шага дискретизации осуществить по наименьшей постоянной времени:

$$T_{\min} = -\frac{1}{p_{\max}}, \quad (3.2)$$

где p_{\max} – максимальный по модулю комплексно-сопряженный корень. При этом шаг дискретизации:

$$\Delta t = (0,1 \div 0,5) T_{\min}. \quad (3.3)$$

Таблица 3.1

Значения параметров фильтров Баттерворта

Вариант	Параметры		
	ε	δ	k
1	0,02	0,04	5
2	0,03	0,06	6
3	0,04	0,08	7
4	0,05	0,07	5
5	0,04	0,08	6
6	0,04	0,06	7
7	0,02	0,05	5
8	0,03	0,06	6
9	0,03	0,08	7
10	0,04	0,09	5
11	0,03	0,04	5
12	0,04	0,06	5
13	0,05	0,06	6
14	0,03	0,08	6
15	0,03	0,07	6
16	0,04	0,06	7
17	0,05	0,06	6
18	0,02	0,04	7
19	0,02	0,07	6
20	0,03	0,08	5

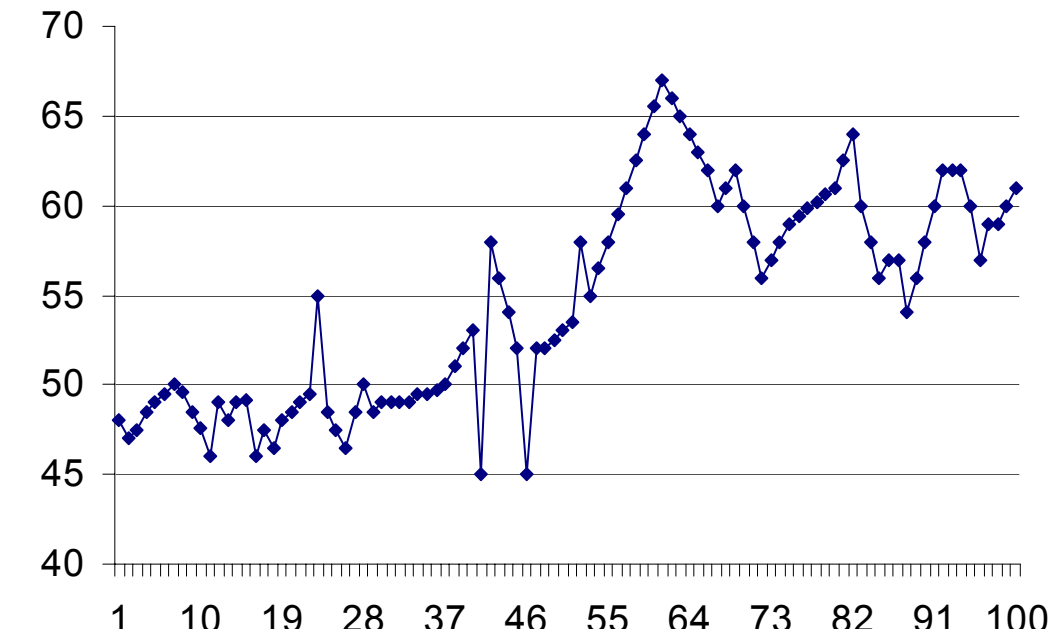
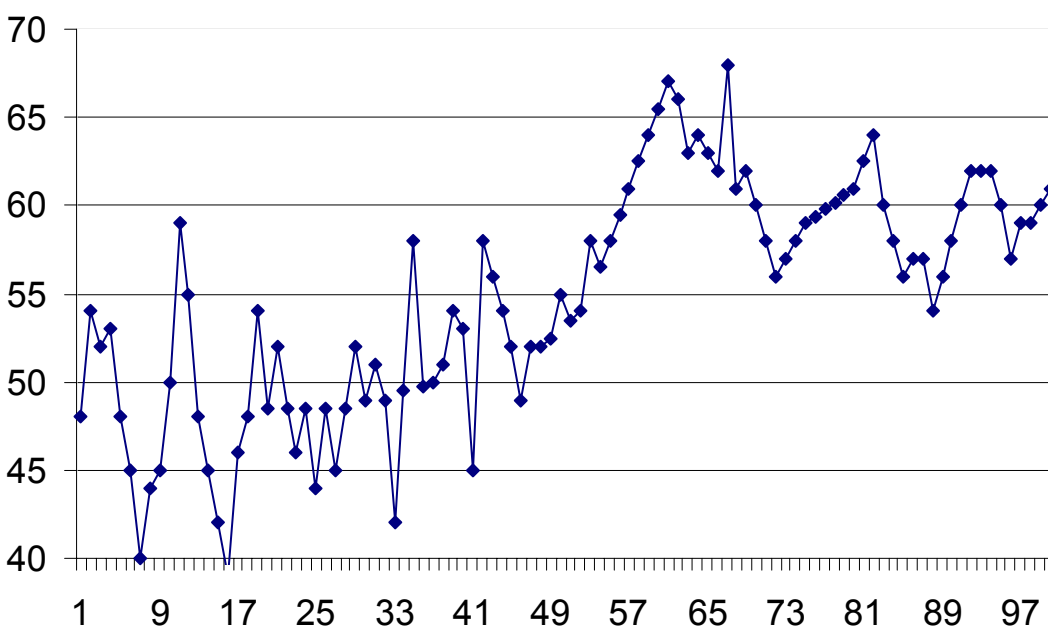
5. Отфильтровать значения натуральных сигналов, приведенные в табл. 3.2, фильтром Баттерворта порядка n и построить в одних координатах исходный и отфильтрованный сигналы и проанализировать результаты фильтрации.

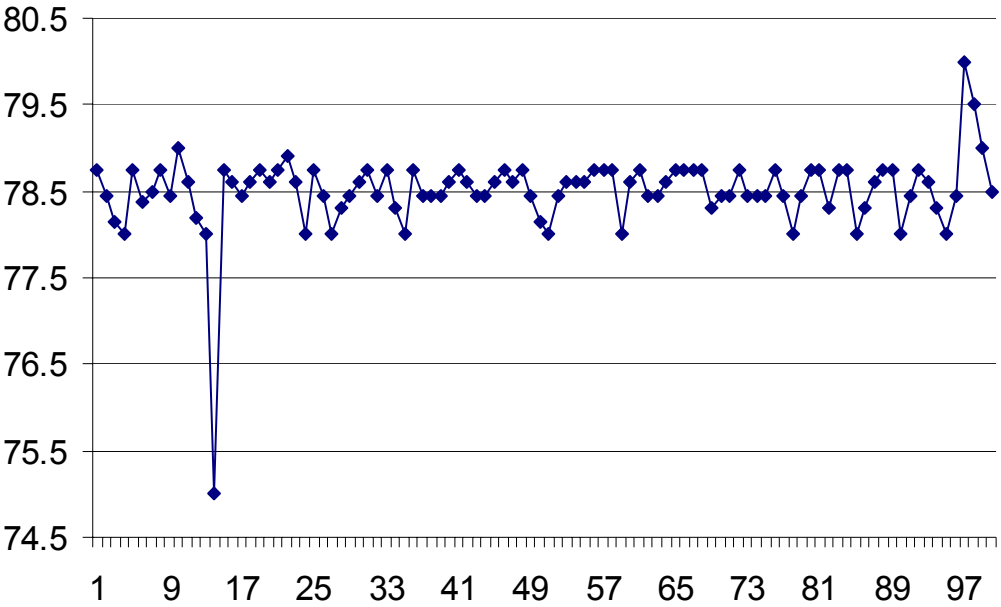
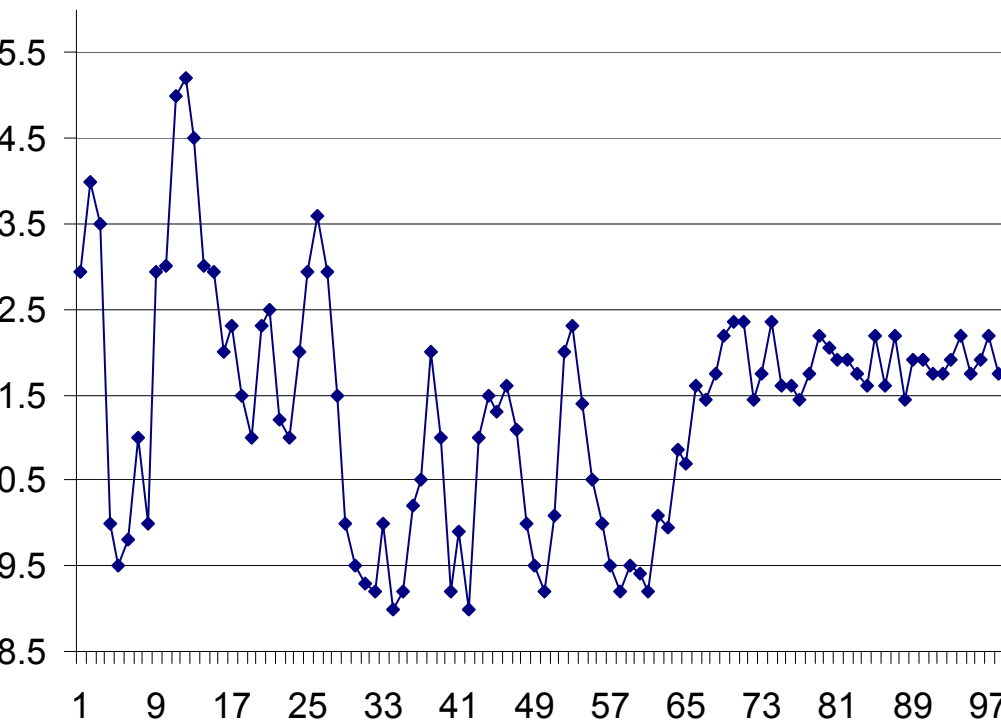
6. Оформить и защитить отчет по лабораторной работе.

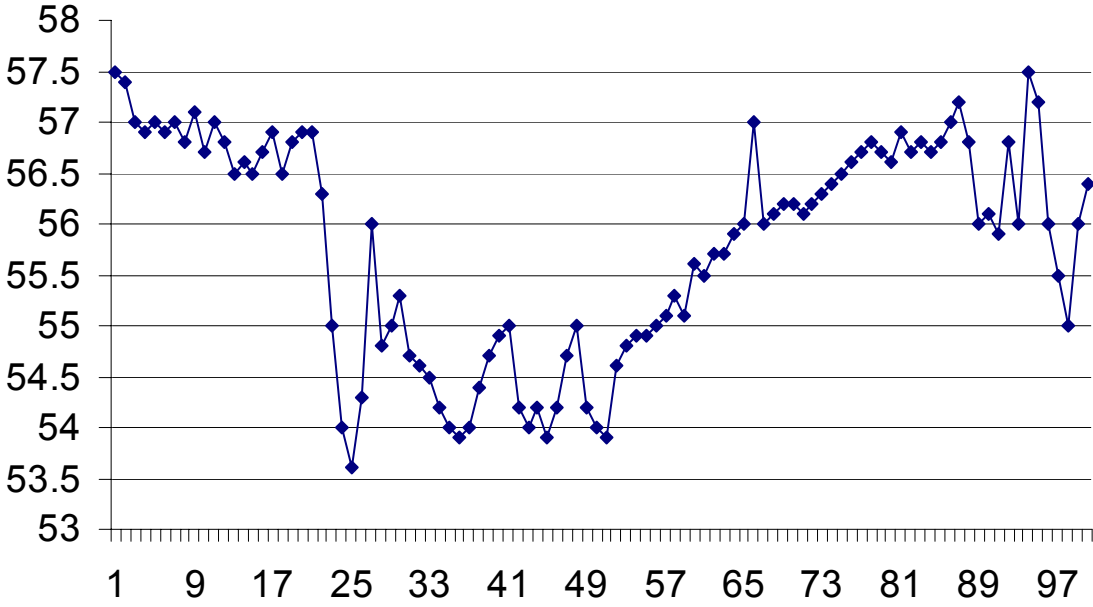
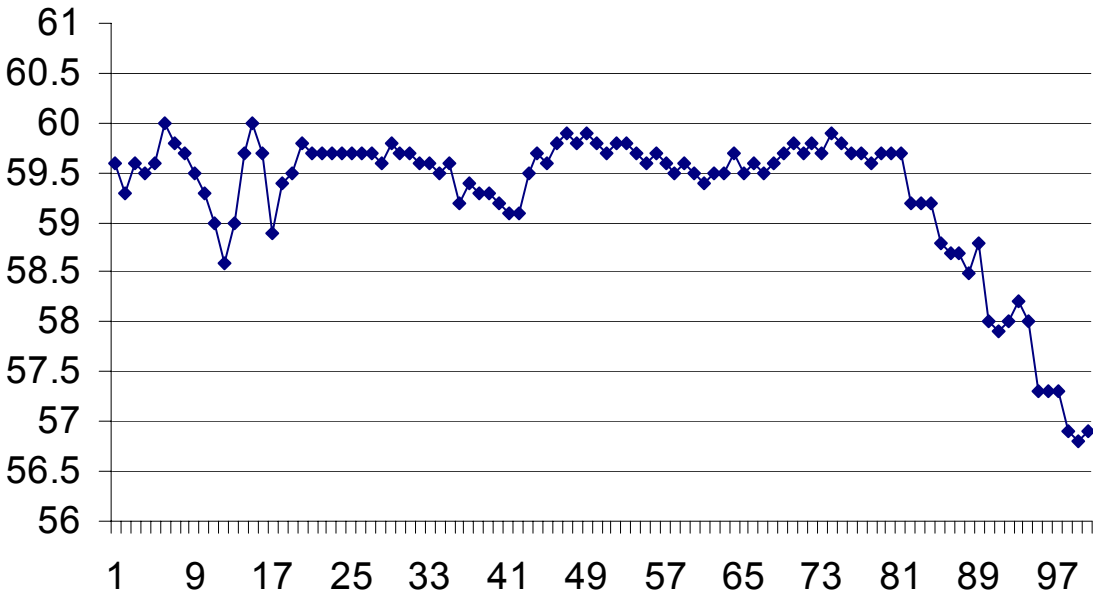
Таблица 3.2

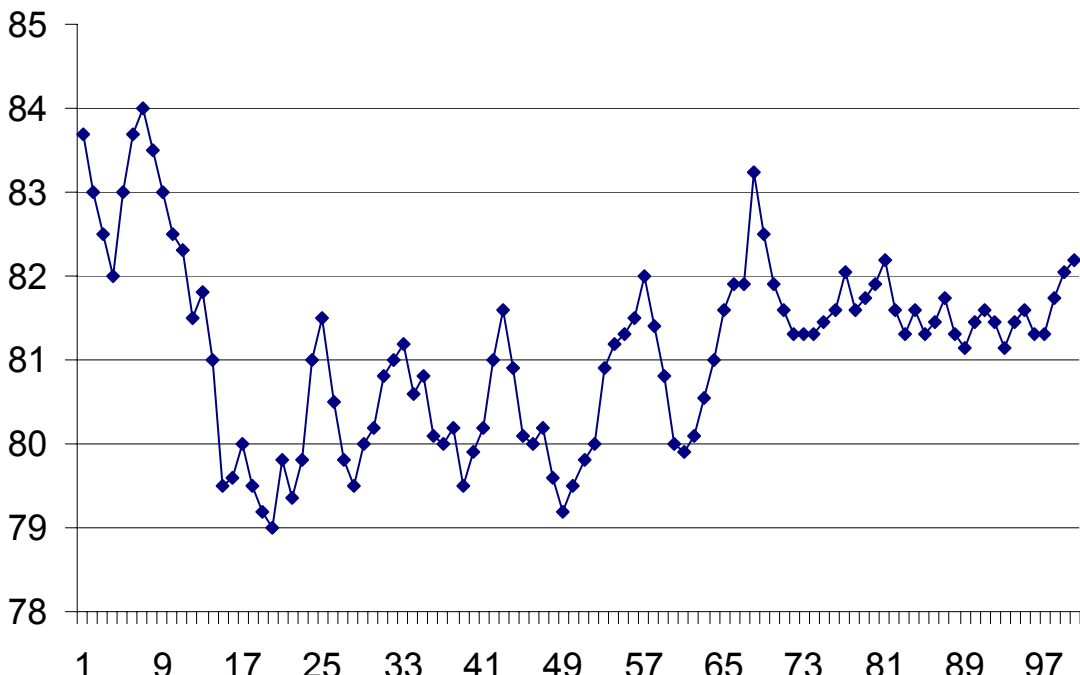
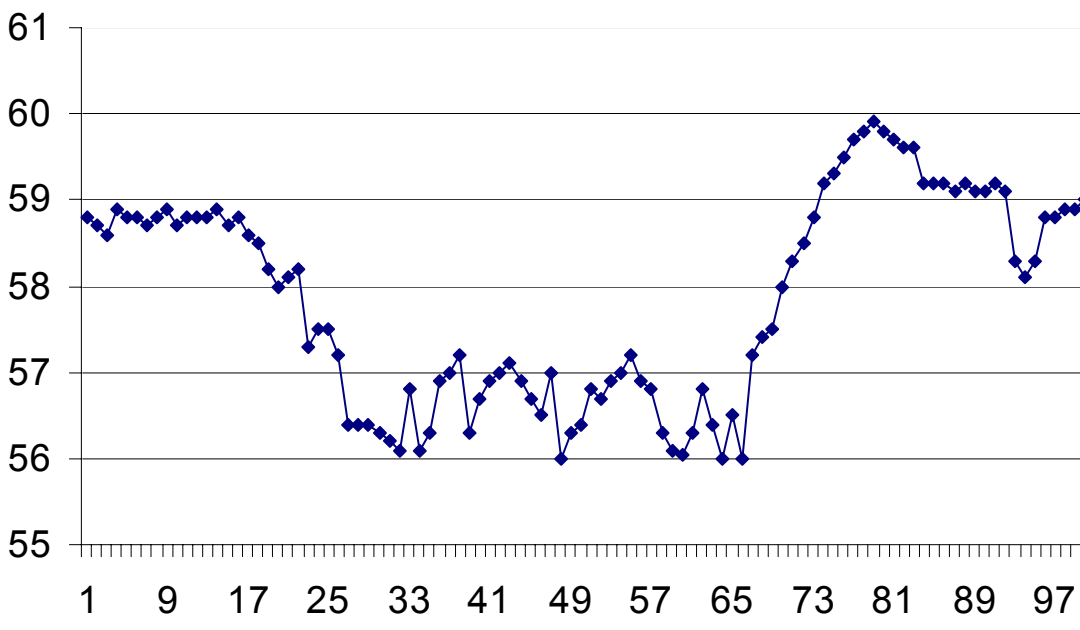
Натурные сигналы

Номер варианта	Сигналы
1	
2	

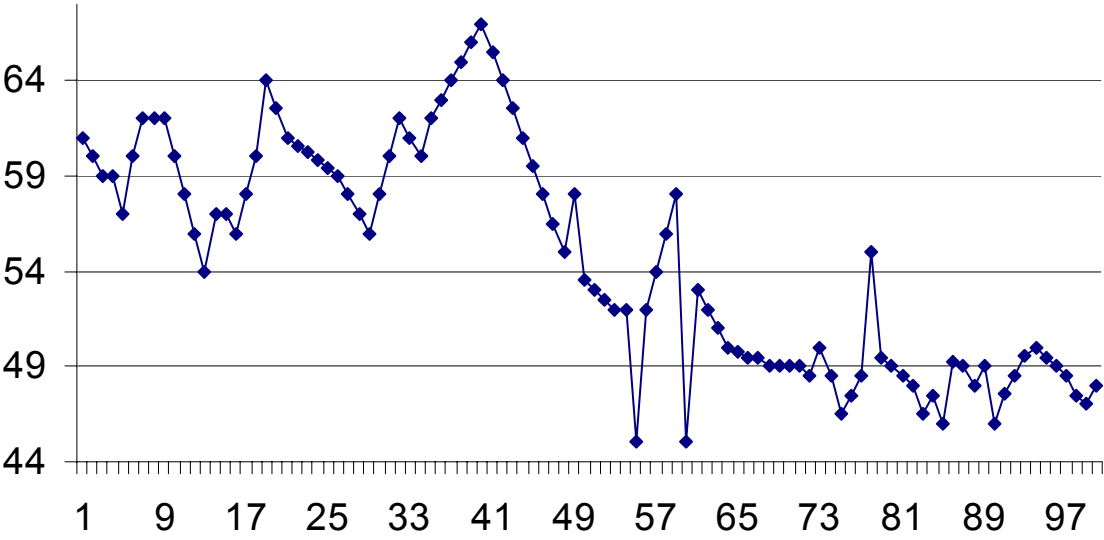
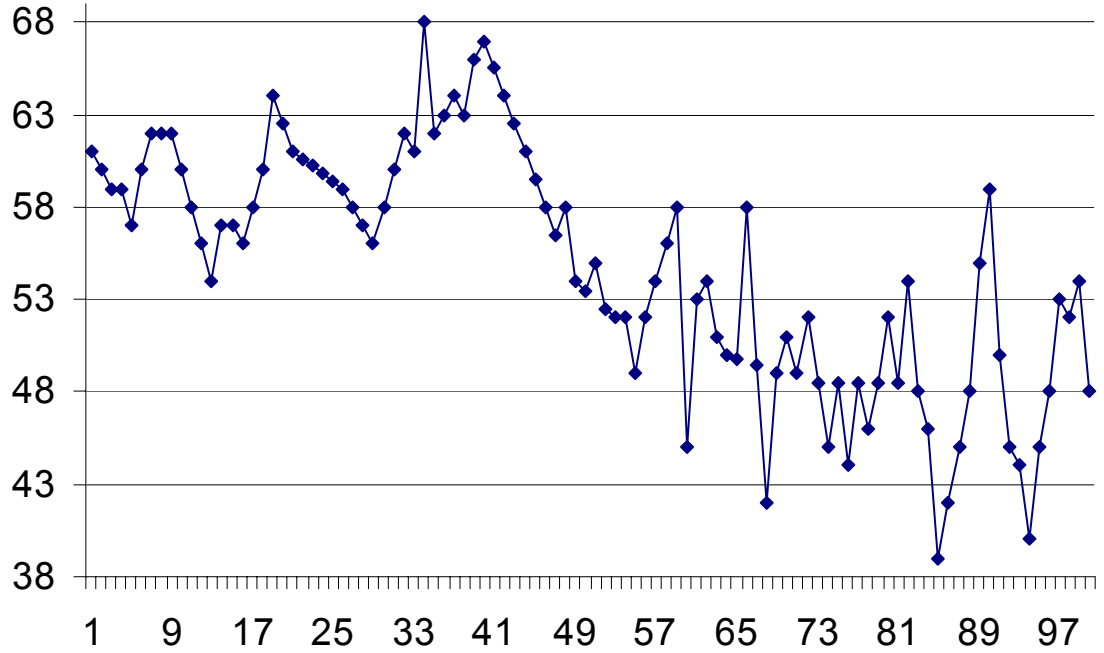
Номер варианта	Сигналы
3	 <p>The graph for variant 3 shows a signal starting at approximately 48, fluctuating between 45 and 50 until point 28. It then rises to a peak of about 67 at point 64, followed by a decline to around 54 at point 82, and finally rises again to approximately 61 at point 100. The y-axis ranges from 40 to 70 in increments of 5, and the x-axis is labeled from 1 to 100 in increments of 9.</p>
4	 <p>The graph for variant 4 shows a signal starting at approximately 48, fluctuating between 40 and 60 until point 41. It then rises to a peak of about 68 at point 65, followed by a decline to around 54 at point 89, and finally rises again to approximately 61 at point 97. The y-axis ranges from 40 to 70 in increments of 5, and the x-axis is labeled from 1 to 97 in increments of 8.</p>

Номер варианта	Сигналы
5	 <p>The graph for variant 5 shows a signal fluctuating around a mean value of approximately 78.5. The y-axis ranges from 74.5 to 80.5 with major ticks every 1.0 unit and minor ticks every 0.1 units. The x-axis ranges from 1 to 97 with major ticks every 8 units and minor ticks every 1 unit. The signal starts at approximately 78.8, drops to a minimum of 75.0 at x=13, and then rises to a maximum of approximately 80.0 at x=97.</p>
6	 <p>The graph for variant 6 shows a signal fluctuating between approximately 78.5 and 85.5. The y-axis ranges from 78.5 to 85.5 with major ticks every 1.0 unit and minor ticks every 0.1 units. The x-axis ranges from 1 to 97 with major ticks every 8 units and minor ticks every 1 unit. The signal starts at approximately 83.0, peaks at approximately 85.0 at x=13, and then fluctuates with several peaks and troughs, ending at approximately 81.5 at x=97.</p>

Номер варианта	Сигналы																												
7	 <p>Line graph for variant 7. The y-axis represents signal values from 53 to 58 in increments of 0.5. The x-axis represents points from 1 to 97 in increments of 8. The signal starts at approximately 57.5, fluctuates, and shows a significant dip around point 25 before rising back towards 57.</p> <table border="1"> <thead> <tr> <th>Point</th> <th>Signal Value</th> </tr> </thead> <tbody> <tr><td>1</td><td>57.5</td></tr> <tr><td>9</td><td>56.8</td></tr> <tr><td>17</td><td>56.8</td></tr> <tr><td>25</td><td>53.8</td></tr> <tr><td>33</td><td>54.5</td></tr> <tr><td>41</td><td>55.0</td></tr> <tr><td>49</td><td>54.5</td></tr> <tr><td>57</td><td>55.5</td></tr> <tr><td>65</td><td>57.0</td></tr> <tr><td>73</td><td>56.5</td></tr> <tr><td>81</td><td>56.8</td></tr> <tr><td>89</td><td>56.5</td></tr> <tr><td>97</td><td>56.0</td></tr> </tbody> </table>	Point	Signal Value	1	57.5	9	56.8	17	56.8	25	53.8	33	54.5	41	55.0	49	54.5	57	55.5	65	57.0	73	56.5	81	56.8	89	56.5	97	56.0
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73	56.5																												
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89	56.5																												
97	56.0																												
8	 <p>Line graph for variant 8. The y-axis represents signal values from 56 to 61 in increments of 0.5. The x-axis represents points from 1 to 97 in increments of 8. The signal starts at approximately 59.5, fluctuates, and shows a significant dip around point 15 before rising back towards 59.5.</p> <table border="1"> <thead> <tr> <th>Point</th> <th>Signal Value</th> </tr> </thead> <tbody> <tr><td>1</td><td>59.5</td></tr> <tr><td>9</td><td>59.5</td></tr> <tr><td>17</td><td>59.5</td></tr> <tr><td>25</td><td>59.5</td></tr> <tr><td>33</td><td>59.5</td></tr> <tr><td>41</td><td>59.5</td></tr> <tr><td>49</td><td>59.5</td></tr> <tr><td>57</td><td>59.5</td></tr> <tr><td>65</td><td>59.5</td></tr> <tr><td>73</td><td>59.5</td></tr> <tr><td>81</td><td>59.5</td></tr> <tr><td>89</td><td>58.5</td></tr> <tr><td>97</td><td>56.8</td></tr> </tbody> </table>	Point	Signal Value	1	59.5	9	59.5	17	59.5	25	59.5	33	59.5	41	59.5	49	59.5	57	59.5	65	59.5	73	59.5	81	59.5	89	58.5	97	56.8
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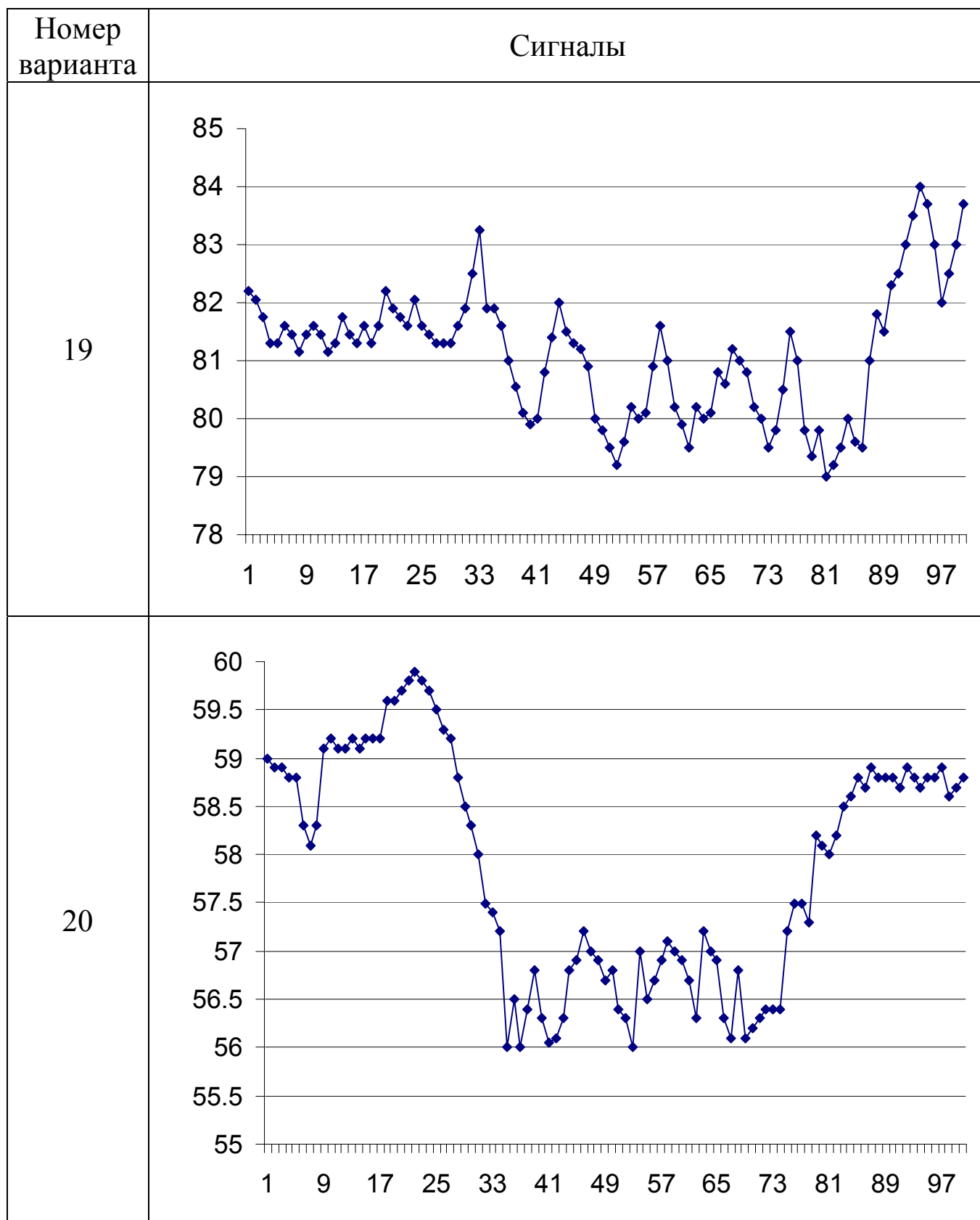
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9	 <p>Line graph for variant 9. The y-axis represents signal values from 78 to 85. The x-axis represents points from 1 to 97. The signal starts at approximately 83.7, drops to a minimum of 79.0 at point 20, and ends at 82.2 at point 97.</p> <table border="1"> <thead> <tr> <th>Point</th><th>Signal</th></tr> </thead> <tbody> <tr><td>1</td><td>83.7</td></tr> <tr><td>2</td><td>83.0</td></tr> <tr><td>3</td><td>82.5</td></tr> <tr><td>4</td><td>82.0</td></tr> <tr><td>5</td><td>83.0</td></tr> <tr><td>6</td><td>83.7</td></tr> <tr><td>7</td><td>84.0</td></tr> <tr><td>8</td><td>83.5</td></tr> <tr><td>9</td><td>83.0</td></tr> <tr><td>10</td><td>82.5</td></tr> <tr><td>11</td><td>82.3</td></tr> <tr><td>12</td><td>81.5</td></tr> <tr><td>13</td><td>81.8</td></tr> <tr><td>14</td><td>81.0</td></tr> <tr><td>15</td><td>79.5</td></tr> <tr><td>16</td><td>80.0</td></tr> <tr><td>17</td><td>79.5</td></tr> <tr><td>18</td><td>79.2</td></tr> <tr><td>19</td><td>79.0</td></tr> <tr><td>20</td><td>79.0</td></tr> <tr><td>21</td><td>79.8</td></tr> <tr><td>22</td><td>79.4</td></tr> <tr><td>23</td><td>79.8</td></tr> <tr><td>24</td><td>81.0</td></tr> <tr><td>25</td><td>81.5</td></tr> <tr><td>26</td><td>80.5</td></tr> <tr><td>27</td><td>79.5</td></tr> <tr><td>28</td><td>80.0</td></tr> <tr><td>29</td><td>80.2</td></tr> <tr><td>30</td><td>80.8</td></tr> <tr><td>31</td><td>81.0</td></tr> <tr><td>32</td><td>81.2</td></tr> <tr><td>33</td><td>80.6</td></tr> <tr><td>34</td><td>80.8</td></tr> <tr><td>35</td><td>80.0</td></tr> <tr><td>36</td><td>80.2</td></tr> <tr><td>37</td><td>80.0</td></tr> <tr><td>38</td><td>79.5</td></tr> <tr><td>39</td><td>80.0</td></tr> <tr><td>40</td><td>80.2</td></tr> <tr><td>41</td><td>81.0</td></tr> <tr><td>42</td><td>81.6</td></tr> <tr><td>43</td><td>80.9</td></tr> <tr><td>44</td><td>80.0</td></tr> <tr><td>45</td><td>80.2</td></tr> <tr><td>46</td><td>79.6</td></tr> <tr><td>47</td><td>79.2</td></tr> <tr><td>48</td><td>79.5</td></tr> <tr><td>49</td><td>80.0</td></tr> <tr><td>50</td><td>80.9</td></tr> <tr><td>51</td><td>81.2</td></tr> <tr><td>52</td><td>81.4</td></tr> <tr><td>53</td><td>81.5</td></tr> <tr><td>54</td><td>82.0</td></tr> <tr><td>55</td><td>81.4</td></tr> <tr><td>56</td><td>80.8</td></tr> <tr><td>57</td><td>80.0</td></tr> <tr><td>58</td><td>80.2</td></tr> <tr><td>59</td><td>80.5</td></tr> <tr><td>60</td><td>81.0</td></tr> <tr><td>61</td><td>81.6</td></tr> <tr><td>62</td><td>81.9</td></tr> <tr><td>63</td><td>81.9</td></tr> <tr><td>64</td><td>83.2</td></tr> <tr><td>65</td><td>82.5</td></tr> <tr><td>66</td><td>81.9</td></tr> <tr><td>67</td><td>81.6</td></tr> <tr><td>68</td><td>81.3</td></tr> <tr><td>69</td><td>81.3</td></tr> <tr><td>70</td><td>81.4</td></tr> <tr><td>71</td><td>81.5</td></tr> <tr><td>72</td><td>81.6</td></tr> <tr><td>73</td><td>81.5</td></tr> <tr><td>74</td><td>82.0</td></tr> <tr><td>75</td><td>81.6</td></tr> <tr><td>76</td><td>81.7</td></tr> <tr><td>77</td><td>81.8</td></tr> <tr><td>78</td><td>82.2</td></tr> <tr><td>79</td><td>81.6</td></tr> <tr><td>80</td><td>81.4</td></tr> <tr><td>81</td><td>81.6</td></tr> <tr><td>82</td><td>81.5</td></tr> <tr><td>83</td><td>81.4</td></tr> <tr><td>84</td><td>81.7</td></tr> <tr><td>85</td><td>81.4</td></tr> <tr><td>86</td><td>81.1</td></tr> <tr><td>87</td><td>81.5</td></tr> <tr><td>88</td><td>81.6</td></tr> <tr><td>89</td><td>81.5</td></tr> <tr><td>90</td><td>81.2</td></tr> <tr><td>91</td><td>81.6</td></tr> <tr><td>92</td><td>81.4</td></tr> <tr><td>93</td><td>81.6</td></tr> <tr><td>94</td><td>81.3</td></tr> <tr><td>95</td><td>81.4</td></tr> <tr><td>96</td><td>81.8</td></tr> <tr><td>97</td><td>82.2</td></tr> </tbody> </table>	Point	Signal	1	83.7	2	83.0	3	82.5	4	82.0	5	83.0	6	83.7	7	84.0	8	83.5	9	83.0	10	82.5	11	82.3	12	81.5	13	81.8	14	81.0	15	79.5	16	80.0	17	79.5	18	79.2	19	79.0	20	79.0	21	79.8	22	79.4	23	79.8	24	81.0	25	81.5	26	80.5	27	79.5	28	80.0	29	80.2	30	80.8	31	81.0	32	81.2	33	80.6	34	80.8	35	80.0	36	80.2	37	80.0	38	79.5	39	80.0	40	80.2	41	81.0	42	81.6	43	80.9	44	80.0	45	80.2	46	79.6	47	79.2	48	79.5	49	80.0	50	80.9	51	81.2	52	81.4	53	81.5	54	82.0	55	81.4	56	80.8	57	80.0	58	80.2	59	80.5	60	81.0	61	81.6	62	81.9	63	81.9	64	83.2	65	82.5	66	81.9	67	81.6	68	81.3	69	81.3	70	81.4	71	81.5	72	81.6	73	81.5	74	82.0	75	81.6	76	81.7	77	81.8	78	82.2	79	81.6	80	81.4	81	81.6	82	81.5	83	81.4	84	81.7	85	81.4	86	81.1	87	81.5	88	81.6	89	81.5	90	81.2	91	81.6	92	81.4	93	81.6	94	81.3	95	81.4	96	81.8	97	82.2
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11	<p>Line graph for variant 11. The y-axis represents signal values from 79 to 84 in increments of 0.5. The x-axis represents points from 1 to 97 in increments of 8. The signal starts at 82.1, fluctuates between 81.5 and 83.1, and has a sharp dip to 79.4 at point 67 before rising back to 83.0 at point 75 and continuing to fluctuate between 81.5 and 83.0.</p>
12	<p>Line graph for variant 12. The y-axis represents signal values from 52 to 72 in increments of 2. The x-axis represents points from 1 to 97 in increments of 8. The signal starts at 59, rises to 64.5 at point 7, fluctuates between 60 and 71, and has a sharp dip to 53 at point 63 before rising back to 68 at point 75 and continuing to fluctuate between 64 and 71.</p>

Номер варианта	Сигналы
13	 <p>The graph for variant 13 shows a signal fluctuating between 44 and 64 over 97 points. The y-axis has major ticks at 44, 49, 54, 59, and 64. The x-axis has major ticks at 1, 9, 17, 25, 33, 41, 49, 57, 65, 73, 81, 89, and 97. The signal starts at approximately 61, peaks at 64 around point 20, and then generally trends downwards with significant fluctuations, ending at approximately 48.</p>
14	 <p>The graph for variant 14 shows a signal fluctuating between 38 and 68 over 97 points. The y-axis has major ticks at 38, 43, 48, 53, 58, 63, and 68. The x-axis has major ticks at 1, 9, 17, 25, 33, 41, 49, 57, 65, 73, 81, 89, and 97. The signal starts at approximately 61, peaks at 68 around point 33, and then generally trends downwards with significant fluctuations, ending at approximately 48.</p>

Номер варианта	Сигналы
15	<p>Line graph for variant 15. The y-axis ranges from 74 to 81. The x-axis ranges from 1 to 97. The signal starts at approximately 78.5, peaks at 80 at point 5, and then fluctuates around 78.5. A sharp drop occurs at point 87, reaching a minimum of 75, before rising back to approximately 78.5 by point 97.</p>
16	<p>Line graph for variant 16. The y-axis ranges from 78 to 86. The x-axis ranges from 1 to 97. The signal starts at approximately 82, fluctuates between 81 and 82.5 until point 37, then drops to a minimum of approximately 79.2 at point 57. It then rises to a peak of approximately 85.2 at point 89, before dropping to approximately 80 at point 97.</p>

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17	<p>Line graph for variant 17. The y-axis represents signal values from 53 to 58. The x-axis represents 100 points. The signal starts at approximately 56.4, drops to 55.0, peaks at 57.5, and then fluctuates between 53.6 and 57.5.</p> <table border="1"> <thead> <tr> <th>Point</th> <th>Signal</th> </tr> </thead> <tbody> <tr><td>1</td><td>56.4</td></tr> <tr><td>2</td><td>56.0</td></tr> <tr><td>3</td><td>55.0</td></tr> <tr><td>4</td><td>55.5</td></tr> <tr><td>5</td><td>56.0</td></tr> <tr><td>6</td><td>57.2</td></tr> <tr><td>7</td><td>57.5</td></tr> <tr><td>8</td><td>56.0</td></tr> <tr><td>9</td><td>56.8</td></tr> <tr><td>10</td><td>55.9</td></tr> <tr><td>11</td><td>56.0</td></tr> <tr><td>12</td><td>56.8</td></tr> <tr><td>13</td><td>57.2</td></tr> <tr><td>14</td><td>57.0</td></tr> <tr><td>15</td><td>56.8</td></tr> <tr><td>16</td><td>56.7</td></tr> <tr><td>17</td><td>56.8</td></tr> <tr><td>18</td><td>56.8</td></tr> <tr><td>19</td><td>56.8</td></tr> <tr><td>20</td><td>56.6</td></tr> <tr><td>21</td><td>56.8</td></tr> <tr><td>22</td><td>56.7</td></tr> <tr><td>23</td><td>56.6</td></tr> <tr><td>24</td><td>56.5</td></tr> <tr><td>25</td><td>56.4</td></tr> <tr><td>26</td><td>56.2</td></tr> <tr><td>27</td><td>56.2</td></tr> <tr><td>28</td><td>56.2</td></tr> <tr><td>29</td><td>56.1</td></tr> <tr><td>30</td><td>56.0</td></tr> <tr><td>31</td><td>57.0</td></tr> <tr><td>32</td><td>56.0</td></tr> <tr><td>33</td><td>55.9</td></tr> <tr><td>34</td><td>55.7</td></tr> <tr><td>35</td><td>55.5</td></tr> <tr><td>36</td><td>55.6</td></tr> <tr><td>37</td><td>55.1</td></tr> <tr><td>38</td><td>55.3</td></tr> <tr><td>39</td><td>54.2</td></tr> <tr><td>40</td><td>54.8</td></tr> <tr><td>41</td><td>55.1</td></tr> <tr><td>42</td><td>55.0</td></tr> <tr><td>43</td><td>54.9</td></tr> <tr><td>44</td><td>54.8</td></tr> <tr><td>45</td><td>54.6</td></tr> <tr><td>46</td><td>54.8</td></tr> <tr><td>47</td><td>54.7</td></tr> <tr><td>48</td><td>53.9</td></tr> <tr><td>49</td><td>54.2</td></tr> <tr><td>50</td><td>55.0</td></tr> <tr><td>51</td><td>54.7</td></tr> <tr><td>52</td><td>53.9</td></tr> <tr><td>53</td><td>54.2</td></tr> <tr><td>54</td><td>54.0</td></tr> <tr><td>55</td><td>55.0</td></tr> <tr><td>56</td><td>54.2</td></tr> <tr><td>57</td><td>54.2</td></tr> <tr><td>58</td><td>54.0</td></tr> <tr><td>59</td><td>55.0</td></tr> <tr><td>60</td><td>54.9</td></tr> <tr><td>61</td><td>54.4</td></tr> <tr><td>62</td><td>54.0</td></tr> <tr><td>63</td><td>54.0</td></tr> <tr><td>64</td><td>54.4</td></tr> <tr><td>65</td><td>54.5</td></tr> <tr><td>66</td><td>54.6</td></tr> <tr><td>67</td><td>54.7</td></tr> <tr><td>68</td><td>55.3</td></tr> <tr><td>69</td><td>55.0</td></tr> <tr><td>70</td><td>54.8</td></tr> <tr><td>71</td><td>56.0</td></tr> <tr><td>72</td><td>54.3</td></tr> <tr><td>73</td><td>53.6</td></tr> <tr><td>74</td><td>54.0</td></tr> <tr><td>75</td><td>55.0</td></tr> <tr><td>76</td><td>56.3</td></tr> <tr><td>77</td><td>56.9</td></tr> <tr><td>78</td><td>56.8</td></tr> <tr><td>79</td><td>56.5</td></tr> <tr><td>80</td><td>56.8</td></tr> <tr><td>81</td><td>56.5</td></tr> <tr><td>82</td><td>56.5</td></tr> <tr><td>83</td><td>56.5</td></tr> <tr><td>84</td><td>56.5</td></tr> <tr><td>85</td><td>56.5</td></tr> <tr><td>86</td><td>56.5</td></tr> <tr><td>87</td><td>56.5</td></tr> <tr><td>88</td><td>56.5</td></tr> <tr><td>89</td><td>56.5</td></tr> <tr><td>90</td><td>56.5</td></tr> <tr><td>91</td><td>56.5</td></tr> <tr><td>92</td><td>56.5</td></tr> <tr><td>93</td><td>56.5</td></tr> <tr><td>94</td><td>56.5</td></tr> <tr><td>95</td><td>56.5</td></tr> <tr><td>96</td><td>56.5</td></tr> <tr><td>97</td><td>56.5</td></tr> <tr><td>98</td><td>56.5</td></tr> <tr><td>99</td><td>56.5</td></tr> <tr><td>100</td><td>56.5</td></tr> </tbody> </table>	Point	Signal	1	56.4	2	56.0	3	55.0	4	55.5	5	56.0	6	57.2	7	57.5	8	56.0	9	56.8	10	55.9	11	56.0	12	56.8	13	57.2	14	57.0	15	56.8	16	56.7	17	56.8	18	56.8	19	56.8	20	56.6	21	56.8	22	56.7	23	56.6	24	56.5	25	56.4	26	56.2	27	56.2	28	56.2	29	56.1	30	56.0	31	57.0	32	56.0	33	55.9	34	55.7	35	55.5	36	55.6	37	55.1	38	55.3	39	54.2	40	54.8	41	55.1	42	55.0	43	54.9	44	54.8	45	54.6	46	54.8	47	54.7	48	53.9	49	54.2	50	55.0	51	54.7	52	53.9	53	54.2	54	54.0	55	55.0	56	54.2	57	54.2	58	54.0	59	55.0	60	54.9	61	54.4	62	54.0	63	54.0	64	54.4	65	54.5	66	54.6	67	54.7	68	55.3	69	55.0	70	54.8	71	56.0	72	54.3	73	53.6	74	54.0	75	55.0	76	56.3	77	56.9	78	56.8	79	56.5	80	56.8	81	56.5	82	56.5	83	56.5	84	56.5	85	56.5	86	56.5	87	56.5	88	56.5	89	56.5	90	56.5	91	56.5	92	56.5	93	56.5	94	56.5	95	56.5	96	56.5	97	56.5	98	56.5	99	56.5	100	56.5
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4. КОНТРОЛЬНЫЕ ВОПРОСЫ

1. Назначение противоподменных аналоговых фильтров низких частот.
2. На какие три полосы делят граничные частоты ось частот и от чего они зависят?
3. На что влияет порядок фильтра Баттерворта?
4. Основное отличие реальной амплитудной частотной характеристики фильтров низких частот от идеальной.
5. На что влияет значение коэффициента k ?
6. Основное отличие фильтров Баттерворта от других фильтров низких частот.

5. СПИСОК РЕКОМЕНДУЕМОЙ ЛИТЕРАТУРЫ

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Составители
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Виктор Иванович Штефан

**ПРОТИВОПОДМЕННЫЕ АНАЛОГОВЫЕ ФИЛЬТРЫ
БАТТЕРВОРТА**

Методические указания к лабораторной работе по курсу "Компьютерное управление" для студентов специальности 210200 "Автоматизация технологических процессов и производств (в машиностроении)"

Редактор Е.Л.Наркевич

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