Filter for Data Transmission using 4B3T Coding

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Abstract: - In the design of analogue filters for the pre-processing of digital signals the filter parameters need to be chosen with respect to the spectral components of the signal being filtered. An incorrect choice can lead to a faulty processing or evaluation of the original signal. The paper points out the connection between the choice of cut-off frequency and the shape of the spectrum of processed signal. The design of a new type of filter for data transmission with 4B3T coding is shown. A computer simulation of the chosen filter is performed and the filter spectra prior and subsequent to filtering are compared.

Key-Words: - Filters, spectrum, rejection of higher harmonic waveforms

1 Introduction

In analogue filtering it is assumed that the desired signal is composed primarily of a single sinusoidal component or a range of non-critical sinusoidal components. There are many applications, however, that involve data filtering. Previous assumptions no longer apply, and the designer must adopt new techniques for a successful filter design. Data transmission is best done differentially, so that common mode components can be eliminated. This is not to say that data transmission cannot be done in a single-ended manner, through metallic cable or some data channel, etc.

In data transmission it is necessary to know well the signal spectrum and to consider which harmonic components can be suppressed. Based on this knowledge, the nature of the filter and its properties can be chosen appropriately. These problems will be discussed below.

2 Harmonic Analysis of Data

The harmonic analysis of signal is generally known. More complex waveforms are composed of many harmonics, generally an infinite number of harmonics. These harmonics form the final waveform when added together. Any continuous-time, T-periodic waveform x(t) can be described mathematically as a Fourier series of individual sine waves. The general form of the Fourier series is

$$x(t) = \frac{a_0}{2} + \sum_{\mathbf{k}=1}^{\infty} \left(a_{\mathbf{k}} \cos(\mathbf{k}\omega_0 t) + b_{\mathbf{k}} \sin(\mathbf{k}\omega_0 t) \right) \ , \quad (1)$$

where

$$\omega_0 = \frac{2\pi}{T} (\mathrm{rad\,.s^{-1}}) \cdot$$

The Fourier series of a square wave is

$$x(t) = \sin(\omega_0 t) + \frac{\sin(3\omega_0 t)}{3} + \frac{\sin(5\omega_0 t)}{5} + ... + \frac{\sin(N\omega_0 t)}{N} . (2)$$

As given above, this means that a square wave is an infinite series of odd harmonics, summed together to create the square shape. Obviously, if a square wave is to be transmitted without distortion, all of the harmonics - up to infinity - must be transmitted.

3 Line Coding

In the strictest sense, block codes make use of look-up tables to perform conversion from binary bits in a two-level system to X-nary bits in an X-level system. Using a multi-level line code has the effect of reducing the transmit spectrum of the transceiver by a factor dependent on the line code used. 4B3T coding converts 4 binary bits to 3 ternary bauds (in this case 3-level). For 4B3T the effective transmission rate is reduced from 160kbit/s to 120kbaud/s (i.e. 160·(3/4)).

For each direction of transmission the line code is a Modified Monitoring State Code mapping 4 bits into 3 ternary symbols with level "+", "-" or "0" (4B3T). The level "+" is usually the voltage level +2V, "-" -2V and "0" 0V. Details of the coding scheme are given in Table 1. Note that the numbers in the columns for each of the 4 alphabets S1…S4 give the numbers of the alphabet to be used for the coding of the next block of 4 bits. The bits and symbols standing left are those transmitted or received first.

Table 1: 4B3T Coding Table [6]

	S1	S2	S3	S4
0001	0 - + 1	0 - + 2	0 - + 3	0 - + 4
0111	- 0 + 1	- 0 + 2	- 0 + 3	- 0 + 4
0100	- + 0 1	- + 0 2	- + 0 3	- + 0 4
0010	+ - 0 1	+ - 0 2	+ - 0 3	+ - 0 4
1011	+ 0 - 1	+ 0 - 2	+ 0 - 3	+ 0 - 4
1110	0 + - 1	0 + - 2	0 + - 3	0 + - 4
1001	+ - + 2	+ - + 3	+ - + 4	- - - 1
0011	0 0 + 2	0 0 + 3	0 0 + 4	- - 0 2
1101	0 + 0 2	0 + 0 3	0 + 0 4	- 0 - 2
1000	+ 0 0 2	+ 0 0 3	+ 0 0 4	0 - - 2
0110	- + + 2	- + + 3	- - + 2	- - + 3
1010	+ + - 2	+ + - 3	+ - - 2	+ - - 3
1111	+ + 0 3	0 0 - 1	0 0 - 2	0 0 - 3
0000	+ 0 + 3	0 - 0 1	0 - 0 2	0 - 0 3
0101	0 + + 3	- 0 0 1	- 0 0 2	- 0 0 3
1100	+ + + 4	- + - 1	- + - 2	- + - 3

4 Design of second-order lowpass filter

For application in practice it was necessary to design a filter that can process digital signals in 4B3T coding. When choosing the basic filter configuration we start from special structures that make use of the second-generation current conveyor (CCII) [1].

The initial general connection is given in Fig. 1. It is an autonomous circuit with the characteristic equation

$$Y_1Y_3 + Y_3Y_2 + Y_2Y_4 = 0. \qquad (3)$$

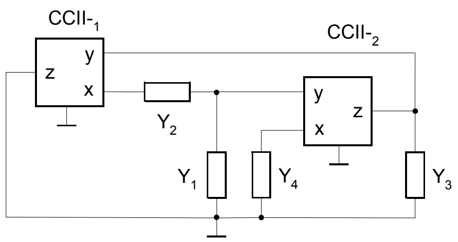


Fig. 1. Autonomous circuit with CCII-

Choosing $Y_1 = sC_1$, $Y_2 = G_1$, $Y_3 = sC_2$, $Y_4 = G_2$, the characteristic equation of autonomous system will be given by the relation

$$Q(s) = s^2C_1C_2 + sC_2G_1 + G_1G_2 = 0\,. \qquad (4)$$

This configuration is suitable for various types of filter such as Lowpass Filter, Highpass Filter, Bandpass Filter, and Notch Filter in the voltage mode or Lowpass Filter, Highpass Filter, and Bandpass Filter in the current mode. An analysis and the design of individual filter types can be found in [5], [8].

Our attention will now focus on the filter of the type of lowpass filter in the voltage mode whose concrete circuit is shown in Fig. 2. Instead of the two current conveyors CCII- the EL2082C [3] devices are used as active elements. Using an external control voltage, these circuits enable setting the current transfer $c(I_z=cI_x)$. If the transfers c_1 and c_2 of conveyors CCII-$_1$ and CCII-$_2$, respectively, are included in the circuit design relations, we can derive the following equation

$$K_u(s) = \frac{c_2G_1G_2}{s^2C_1C_2 + sC_2G_1 + c_2G_1G_2}\,,$$
$$Q_p = \frac{c_2G_2}{\omega_pC_2}\,,\quad \omega_p = \sqrt{\frac{c_2G_1G_2}{C_1C_2}}\,. \qquad (5)$$

Controlling the current gain c_2 of conveyor CCII- will simultaneously affect the position of cut-off frequency and the quality of filter. A change in the magnitude of parameter c_2 has a greater effect on filter quality than on shifting the cut-off frequency, the latter being proportional “only” to the second root of the magnitude of this parameter.

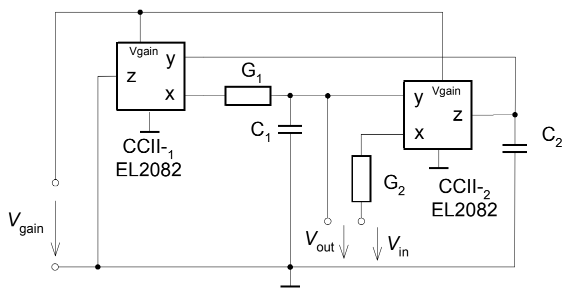


Fig. 2. Lowpass filter based on autonomous circuit

The filter was designed for the Chebyshev approximation (3 dB) and cut-off frequency f_0 = 200 kHz, i.e. $C_1 = C_2$ = 2 nF and $1/G_1 = 293.5\ \Omega$, $1/G_2 = 74.5\ \Omega$. The required cut-off frequency tunability is provided for by changing the control voltage V_{gain}.

The magnitude frequency characteristics of this filter in dependence on control voltage V_{gain} are given in Fig. 3.

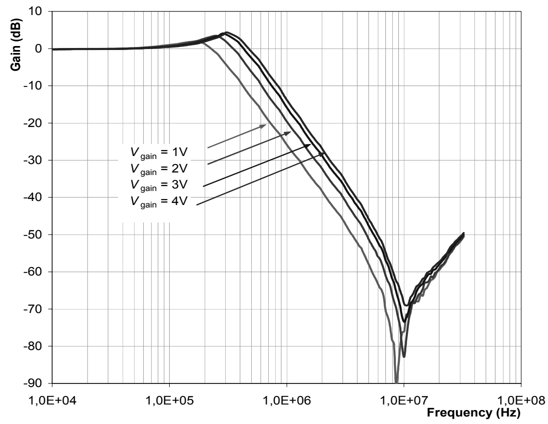


Fig. 3. Measured magnitude frequency characteristics of lowpass filter, with the effect of control voltage V_{gain}

It is evident from Fig. 3 that the cut-off frequency is in this case tuneable in a range from 284 kHz to 651 kHz. This is of importance for the final precision tuning of cut-off frequency when transmitting a digital signal on the basis of signal spectrum with 4B3T coding.

5 Filtering Data of 4B3T coding signal

Lowpass data filtering affects the harmonic content of the waveform because, by definition, it eliminates higher-order harmonics. Interfering frequencies must be much higher in frequency than the fundamental frequency. If the system requires that third, fifth, or even higher harmonics must be passed, the 3 dB cut-off frequency must be 3, 5, 7 or more times the fundamental frequency. Note that there is a significant attenuation of the 5th and 7th harmonics as well, which produces rounding in the final waveform [4]. The Fourier synthesis allows the user to play with the Fourier harmonics such that the appropriate shape of the waveform is obtained. An imperfect waveform may be acceptable to the designer - it depends on the timing of the leading and the trailing edge of the waveform. Eliminating the harmonics results in rounding the edges, and therefore delaying the leading and trailing edges of the digital signal. The residual ripple in the high and low sections of the waveform must not trigger logic-level changes at the next digital stage. Of more importance, however, is that the harmonics that are passed are not delayed. An early or late harmonic can change the timing of data. The shape of the waveform must be preserved.

In the case of signals with 4B3T coding, altogether three voltage levels are used, usually +2V, -2V and 0V. An example of such a signal and its spectrum is given in Fig. 4.

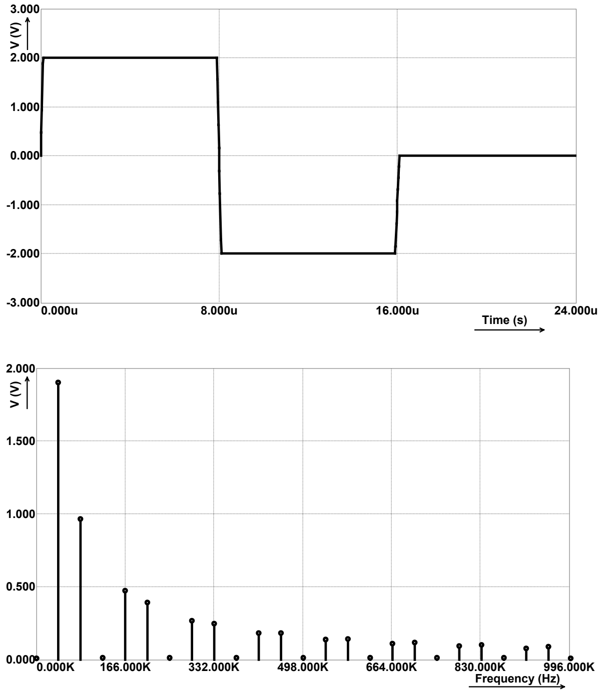


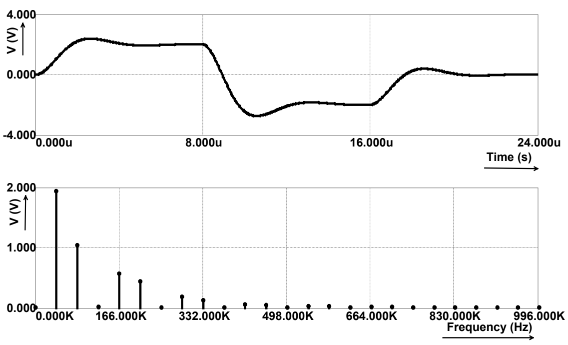
Fig. 4. Waveform of simulated 4B3T signal, and its spectrum

As can be seen, the 3rd, 6th, 9th, 12th, ... harmonics are zero. In the design of the filter it is therefore necessary to consider the type of coding and to choose the filter parameters accordingly.

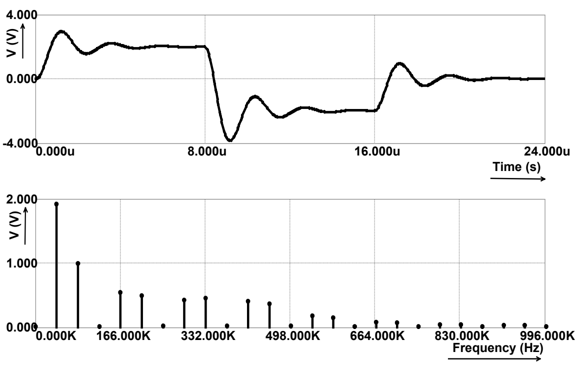
One of the designer's jobs is to select a 3 dB cut-off frequency that eliminates interference, but does not adversely affect system performance by attenuating harmonics that are crucial to system timing. The designer also has to insure that all of the harmonics are phase shifted by the same amount, and arrive at the output of the filter at the same time. In the design it is also necessary to take into consideration the different properties of individual types of approximation.

In our case, the Chebyshev approximation with 3-dB ripple was chosen, which compared with the frequently used Butterworth approximation has a steeper magnitude frequency characteristic. With this approximation, the ripple of pass-band transmission will contribute to enhancing the harmonics just below the cut-off frequency (4, 5) and thus to a more precise signal detection in subsequent processing. Using the Chebyshev approximation has, of course, a major effect on changes in the phase of the signal being filtered. In our case, this fact is to no detriment but if another type of signal were used, in which the phase must be preserved, it would be of advantage to use another type of approximation.

Based on the above filter design, the simulation of digital signal transmission with 4B3T coding was performed. The suitability of using the chosen approximation was confirmed, and the possibility of fine-tuning the filter cut-off frequency proved to be highly significant for filter implementation. Fig. 5 gives the output signal spectra for V_{gain}= 0.5V and V_{gain} = 2V.



a)



b)

Fig. 5. Filtered 4B3T coding signal and its spectrum a) V_{gain}=0.5V, $f_o \approx$ 284kHz, b) V_{gain}=2V, $f_o \approx$ 651kHz.

6 Conclusion

In telecommunication technology, filter design requires a different approach than is usual in analog signal filtering. The knowledge of both the properties of individual filter types and their approximations and of the type of signal coding is necessary. On the basis of this knowledge and that of the signal spectrum the design proper of the filter must be adapted. This holds in particular for the choice of cut-off frequency, which sometimes tends to be difficult in digital signals. It is proposed in the paper to employ a filter with current conveyors, which enable realizing the filter in both the voltage and the current mode and can thus be used with advantage as universal blocks in telecommunication applications.

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