Rene HARTANSKY

Slovak University of Technology

doi:10.15199/48.2016.02.11

Analysis of the general digital signals for EMC purpose

***Abstract**. In the paper discussed and the comparison of two digital signals. The rising and falling edge of the first signal has the same. The spectrum of this signal is well known from the various literatures. The different rising and falling times has the second signal, what represents a general technical digital signal. This paper provides calculation of spectra of such a signal. Presented paper also contains the calculation of the radiation interferences of the current loop fed with the both analysed signals. Based on the obtained results the thesis is formulated, enabling to reduce radiation of the device when it is processing general digital signal.*

***Streszczenie.** W artykule przeanalizowano i porównano dwa sygnały cyfrowe. Pierwszy sygnał opisany jest takim samym czasem narastania i opadania zbocza impulsu. Charakterystyka widmowa takiego sygnału jest znana z literatury. Drugi z sygnałów charakteryzuje się różnymi czasami narastania i opadania zbocza, co reprezentuje sygnały cyfrowe spotykane w praktyce. Artykuł przedstawia metodę wyznaczania widma takiego sygnału. W artykule zamieszczono także obliczenia zaburzeń promieniowanych przez pętlę prądową wytwarzanych przez oba rodzaje sygnałów. Na podstawie otrzymanych wyników zaproponowano rozwiązanie, umożliwiające zmniejszenie zaburzeń promieniowanych przez sygnał cyfrowy. (**Analiza podstawowych sygnałów cyfrowych do celów EMC**).*

Keywords: digital signal, spectrum of digital signal, radiation interference, rise edge, fall edge.
Słowa kluczowe: sygnał cyfrowy, widmo sygnału cyfrowego, zakłócenia promieniowane, zbocze narastające, zbocze opadające.

Introduction

In engineering practice, we often meet with digital signals working devices. The problem of digital signal equipment is wide frequencies band hence the high level of electromagnetic interference. Calculation of digital signal harmonic frequencies and digital equipment radiation interference is well documented in [1]. For convenience in the literature there are the frequency spectrum calculations only of the idealized digital signals. It is such a signal that the time rising and falling edge of the same. Such a signal is symmetrical around the y axis and the solution of Fourier series will contain only one type of Fourier coefficients. In the calculating general digital signal frequency spectrum, we must take into account absence signal symmetry. In this case exist coefficients a_n and b_n Fourier series. It is believed that the shape of the spectrum and also radiation interference (EMI) of the general digital signals will be other than that of the idealized digital signal.

Digital signal spectrum

When calculating the spectrum of digital signal we have to assume the following:

- the signal is periodic;
- the signal frequency limited;
- the signal has two discontinuities per one period.

Based on such assumptions it is possible to reduce the signal into Fourier series:

(1) $$f(t) = a_0 + \sum_{n=1}^{\infty} \{a_n \cos(n\omega t) + b_n \sin(n\omega t)\}$$

where a_n a b_n are Fourier coefficients, which can be calculated the following way:

(2) $$a_0 = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)dt$$

(3) $$b_n = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\sin(n\omega t)dt$$

(4) $$a_n = \frac{2}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\cos(n\omega t)dt$$

Spectrum of idealized digital signal

Let assume the shape of the digital signal as it is shown in Fig.1 and let: $t_i = t_k$.

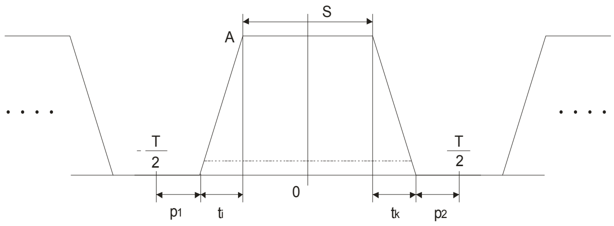

Fig.1. Digital signal

Signal is symmetrical around the *y* axis. By [1] coefficients b_n = 0 and coefficients a_n are:

(5) $$a_n = \frac{2AS}{T}\frac{\sin X_S}{X_S}\frac{\sin X_f}{X_f} \qquad \begin{cases} X_S = \dfrac{n\pi S}{T} \\ X_f = \dfrac{n\pi t_i}{T} \end{cases}$$

From (5) follows that higher harmonic frequencies in the spectrum of the ideal digital signal follow: *sin*(*x*)/*x* function. The spectral envelope is shown in Fig.2. It has two important breaks. The first one is dependent from the width *S* of the digital signal. And the second one depends on the pulse rising/falling time. From Fig.2 we can see that spectral width is rising with decreasing rising (falling) time.

Based on this fact, we can assume that EMI caused by the digital signal is strongly dependent on t_i.

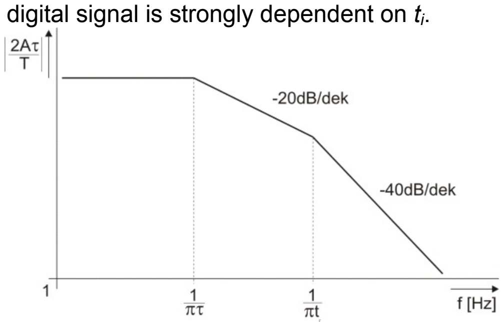

Fig. 2. The envelope of the ideal digital signal

Spectrum of real digital signal

In this section we will assume that $t_i \neq t_k$. The solution of such a case is not present in the literature. Therefore we will indicate the solution in the following sections. Based on Fig.1 it is possible to write:

(6) $$p_1 + t_i = p_2 + t_k$$

With respect to Fig.1 and (4) holds:

(7)
$$a_n = \frac{2}{S + t_i + t_k + p_1 + p_2}\left\{ \int_{-S/2-t_i-p_1}^{-s/2-t_i} -A\cos(n\omega t)dt + \int_{-S/2-t_i}^{-S/2}\left(\frac{2A}{t_i}t + \frac{A(S+t_i)}{t_i}\right)\cos(n\omega t)dt + \int_{-S/2}^{S/2} A\cos(n\omega t)dt + \int_{S/2}^{-S/2+t_k}\left(-\frac{2A}{t_k}t + \frac{A(S+t_k)}{t_k}\right)\cos(n\omega t)dt + \int_{S/2+t_k}^{S/2+t_k+p_2} -A\cos(n\omega t)dt \right\}$$

By solving (7) and result simplified we get coefficients a_n:

(8)
$$a_n = -\frac{AT}{n^2\pi^2 t_i t_k}\left\{(-t_i - t_k)\cos\left(\frac{n\pi S}{T}\right) + t_k\cos\left(\frac{2n\pi(S/2+t_i)}{T}\right) + t_i\cos\left(\frac{2n\pi(S/2+t_k)}{T}\right)\right\}$$

Similarly we can calculate coefficients b_n from:

(9)
$$b_n = \frac{2}{S + t_i + t_k + p_1 + p_2}\left\{ \int_{-S/2-t_i-p_1}^{-s/2-t_i} -A\sin(n\omega t)dt + \int_{-S/2-t_i}^{-S/2}\left(\frac{2A}{t_i}t + \frac{A(S+t_i)}{t_i}\right)\sin(n\omega t)dt + \int_{-S/2}^{S/2} A\sin(n\omega t)dt + \int_{S/2}^{-S/2+t_k}\left(-\frac{2A}{t_k}t + \frac{A(S+t_k)}{t_k}\right)\sin(n\omega t)dt + \int_{S/2+t_k}^{S/2+t_k+p_2} -A\sin(n\omega t)dt \right\}$$

And by solving (9) and result simplified we get coefficients b_n:

(10)
$$b_n = -\frac{AT}{n^2\pi^2 t_i t_k}\left\{(t_i - t_k)\sin\left(\frac{n\pi S}{T}\right) + t_k\sin\left(\frac{2n\pi(S/2+t_i)}{T}\right) + t_i\sin\left(\frac{2n\pi(S/2+t_k)}{T}\right)\right\}$$

Spectral coefficients of a real (technical) digital signal (8) and (9) have substantially more complex analytical form than for the ideal digital signal. From the first glance it is not possible to say how will look the spectral envelope of a real digital signal and how such signal will influence EMI.

Analytical results

Using the system *Mathematica* we had calculated the individual harmonics of the ideal digital signal with the following parameters: The amplitude *A=15*, the rising and falling edge $t_i = t_k = 0.01$, period *T=1*, duration of level *H S=2*. The coefficients a_n are shown in Fig.3.

The line connecting the peaks of the individual harmonics has the shape of broken line. The first break is not shown on the graph (the parameter S is very large). The second brake is in the vicinity of radial frequency $1/\pi t_i$ = 31.8. The calculations confirmed the predicted theoretical outcomes but it didn't bring any new findings.

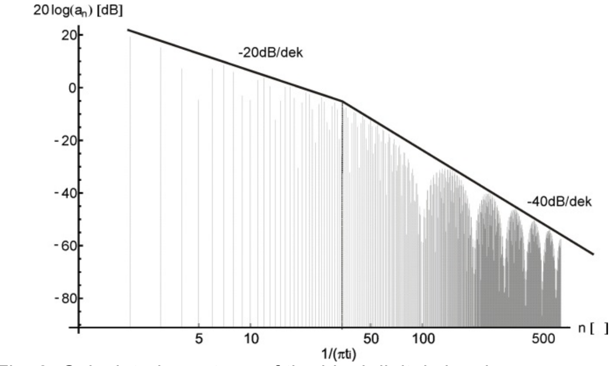

Fig. 3. Calculated spectrum of the ideal digital signal.

Much more interesting is the calculation of the spectrum of a real (technical) digital signal. Such signal also contains coefficients a_n and b_n [2]. The amplitude A_n of its magnitude spectrum is determined as:

(11) $$A_n = \sqrt{a_n^2 + b_n^2}$$

For the analysis we used the signal with the following parameters: the amplitude *A=15*, the rising edge $t_i = 0.001$, the falling edge $t_k = 0.01$, period $T = 1$, duration of level *H* $S = 0.2$. In Fig.4 is shown an amplitude spectrum of a real digital signal. Its spectral envelope is falling with 20dB/decade a and contains the second break at radial frequency $1/\pi t$, where $t = \min\{t_i, t_k\}$.

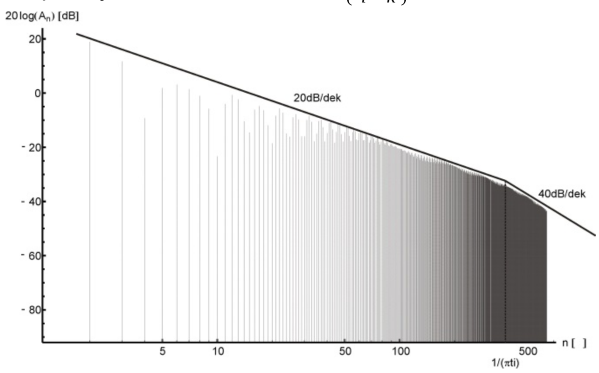

Fig. 4. Calculated spectrum of a real digital signal for ti=0.001.

The first break is not visible due to the signal parameters. By comparing Fig.3 and Fig.4 we can see that the second break has shifted toward higher frequencies and thus a real digital signal has a significantly higher bandwidth. E.g. for 500th harmonics the spectral level of the real digital signal has risen by 14db. The analyzed real signal had the falling/rising edge ratio: $t_k / t_i = 10$.

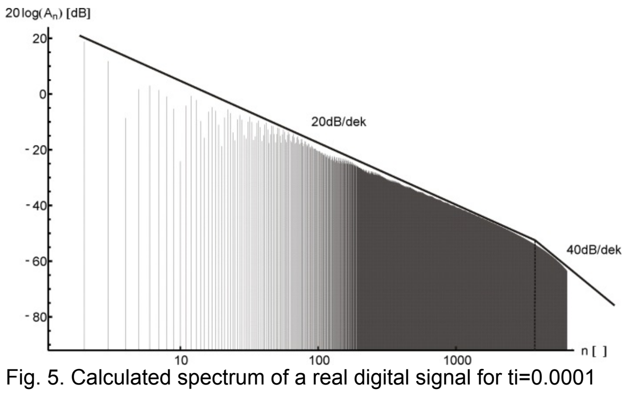

Fig. 5. Calculated spectrum of a real digital signal for ti=0.0001

Let’s do the similar analysis of the amplitude spectrum for signal with: $t_k / t_i = 100$. We will use (8), (10) and (11).

Calculated spectrum is in Fig.5. It contains two breaks. By comparing to Fig.4 we can see that this time the spectrum has at 500th harmonics the level increased by 17dB. This fact has made EMI even worse [4], [5].

EMI of digital signal devices

Let assume that the digital signal loads the loop. Then the loop radiation based on (1) will be following:

$$|E_\Phi| = \left| \frac{Z_0 k^2}{4\pi} \frac{\overbrace{\pi R^2}^{S} I_0 \sin\Theta}{r}\left(1+\frac{1}{jkr}\right)e^{-jkr}\right| = \left|\frac{Z_0 k^2}{4\pi}\frac{S I_0 \sin\frac{\pi}{2}}{r}\left(1+\frac{1}{jkr}\right)e^{-jkr}\right| = \frac{Z_0 \frac{4\pi^2}{\lambda^2}}{4\pi}\frac{S I_0}{r} = \frac{\mu_0 \pi f^2}{c}\frac{S I_0}{r} = const\cdot f^2 \qquad (12)$$

where Z_0 - is wave impedance of free space; r - is the distance between the loop and the observation point; S - is the loop area; k - is the wave number; f - is frequency.

Electric field with respect to frequency expressed in dB is:

$$|E_\Phi|_{dB} = 20\log(const\cdot f^2) = 20\log(const) + 40\log(f) \to 40dB/dek \qquad (13)$$

In Fig.6 the dashed line (rising with +40dB/decade) represent EMI radiation from the electrical loop depending on frequency [3]. The dots line represents EMI radiation from the electrical loop fed with the digital signal. It can be observed that the maximal value of EMI depends on the second break on the spectral envelope of the digital signal. If we take into account the results from the previous section, with the ratio: $t_k / t_i = 10$ the EMI radiation has risen by 14dB. In case of $t_k / t_i = 100$ the EMI radiation has risen by 17dB.

From the previous analysis follows: if we want to decrease the EMI radiation of a digital device, we have to increase the time of the shorter edge of the signal so it is equal to longer edge.

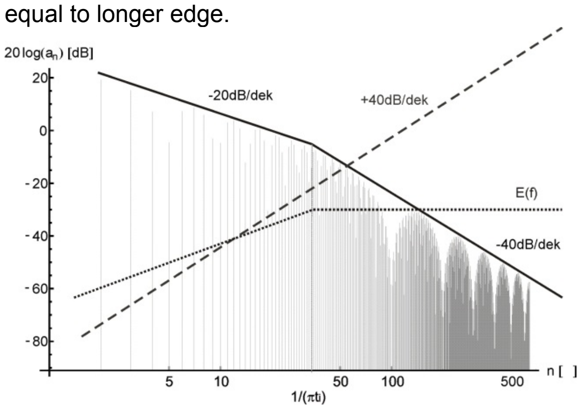

Fig. 6. EMI radiation of digital signal.

Using of slower digital circuits does not necessarily fulfill this condition. In this case the edge will be slower, but the ratio t_k / t_i does not have to be equal 1. From to point of the decreasing EMI radiation it is better to use simple RC filters placed at the output of a digital circuit, as it is shown in Fig.7. The time constant of the RC filter has to be chosen so the both edges of the digital signal are lengthened.

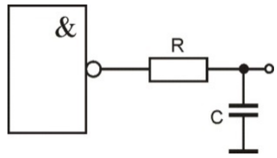

Fig. 7. RC filter on output of digital IC.

Conclusion

In this paper we analyzed the spectrum of a real digital signal. In such signal rising and falling edges are not equal. We had calculated the envelope of the amplitude spectrum, based on which we found out that the second break on the spectral envelope depends on the shorter of the signal edges. The level of the EMI radiation also depends on the duration of the shorter edge. In order to decrease EMI radiation it is necessary to prolong the shorter of the signal edges. This can be achieved by adding simple hardware. The use of slower IC is not in this case recommended, since also the slower IC can have different rising and falling edges.

Acknowledgment

This work was supported by the projects VEGA 1/0431/15, APVV-14-0076.

***Authors**: assoc. prof. Ing. PhD. René Harťanský, Institute of Electrical Engineering, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, ul. Ilkovičova 3, 812 19 Bratislava, E-mail: rene.hartansky@stuba.sk*

REFERENCES

[1] Harťanský, R., Maga, D.,Ješko, V. EMC in mechatronic systems. Trenčín: TnUAD, 2000, ISBN 80-88914-22-1

[2] Rakús, M., Radzyner R. *Signal & Systems. Experiments with Emona TIMS*: Vol S1 - Fundamentals of Signals & Systems. Emona Instruments Pty Ltd, Australia, 2011.

[3] Maršálka, L. *Complex electromagnetic sensor structure analysis by numerical modeling*. In EQ-2014 : In the framework of International Forum "Education Quality - 2014". Proceedings. April 23, 2014, Izhevsk, Russia. s. 260-263.

[4] Hallon, J., Bittera, M. *Directivity of capacitive clamp for EFT pulses injection*. Radioelektronika 2014 : Proceedings of 24th International Conference. Bratislava, Slovak Republic, April 15-16, 2014. Bratislava: FEI STU, 2014, s. 225-228.

[5] Bittera, M., Smieško, V. *Directivity Error of Broadband Antennas at EMI Measurement*. In Przeglad elektrotechniczny. Vol. 88, Iss. 6 (2012), s.61-63.

[6] Božek, P., Turygin, Y. Measurement of the operating parameters and numerical analysis of the mechanical subsystem. (http://www.measurement.sk/2014/Bozek.pdf) *Measurement Science Review*. Vol. 14, No. 4 (2014), online, pp. 198-203.