Resonance and Time-Delay Annihilation with Bandpass NGD Active Circuit
(Invited paper)

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Abstract

This paper introduces an annihilation method of resonance by using bandpass (BP) negative group delay (NGD) active circuit. The NGD annihilation principle is analytically developed with the resonance effect transfer function (RETF) parametrized by variable coefficient. The NGD canonical parameters are formulated as a function of the RETF ones. The proposed method feasibility is illustrated by frequency and time domain numerical applications, which shows attenuation and time-delay of RLC-resonant circuit annihilation.

1. Introduction

An unfamiliar circuit theory states that certain electronic circuits can operate with negative group delay (NGD) [1-2]. Like the filter behavior, different types as low-pass (LP) and bandpass (BP) NGD function were classified [1-2]. One of NGD function promising applications in electromagnetic compatibility (EMC) engineering is the improvement of distorted signal integrity [3-5] and delay cancellation [6-9] based on innovative equalization technique of perturbation transfer function (TF). Different studies highlight the feasibility of cancellation of electrical interconnect [6-7], cable [8] and wireless propagation [9] delay with LP- and BP-NGD functions.

More importantly, it was recently investigated an EMC application particular case of NGD equalization. that the BP-NGD circuits can effectively be applied to EMC problems to reduce the resonance effect in the electronic systems [10-11]. The proposed NGD method can be combined to the time-reversal (TR) technique to minimize the undesirable EMC effects [12]. The general concept of this NGD method of resonance annihilation is reported in the present paper.

2. Analytical approach of resonance annihilation with BP-NGD function

The analytical approach of the BP-NGD function-based method of resonance annihilation is developed in the present section.

2.1 Principle of NGD resonance annihilation

The basic principle of the resonance annihilation NGD method is illustrated by Fig. 1. The resonant system, which can be identified from TR [12], is represented by transfer function (TF) $T(s)=V_{out}(s)/V_{in}(s)$ with the Laplace variable versus angular frequency $s=j\omega=j2\pi f$. Due to the EMC issues as resonance dispersion, the output signal undergoes undesirable degradation. The resonant effect implies the time-domain (TD) dispersion of output v_{out} compared to input signal v_{in}.

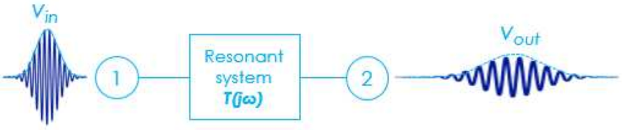

Figure 1. Resonant system and input/output signals.

This RETF is characterized by its center frequency $f_0=\omega_0/(2\pi)$ over the bandwidth $\Delta f=\Delta\omega/(2\pi)$. By taking the real positive parameters T_r and ζ, the resonant degradation can be canonically formulated as:

$$T(s)=\frac{T_r\omega_0^2}{s^2+\zeta\omega_0 s+\omega_0^2}. \qquad (1)$$

At ω_0, we take $T_0=T(\omega_0)=|T(j\omega_0)|$ and group delay (GD) $t_0=GD(\omega_0)=-\partial\arg[T(j\omega)]/\partial\omega|_{\omega=\omega_0}$. The resonant effect is explained by the "concave" behavior of magnitude and GD of Figs. 2(a) and 2(b), respectively.

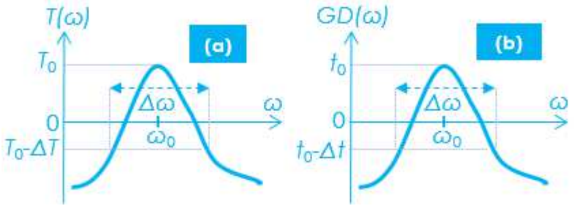

Figure 2. RETF (a) magnitude and (b) GD behaviors.

Based on the magnitude concave behavior, the resonance effect can be assumed by the associated differential magnitude $T_{0dB} - \Delta T_{dB} = \left| T_{dB}\left[j(\omega_0 \pm \Delta\omega/2) \right] \right|$ and GD $t_0 - \Delta t = GD(\omega_0 \pm \Delta\omega/2)$.

2.2 Design formula of BP-NGD parameters

After introduction of NGD annihilator, we expect to generate output well correlated to the input $v_{ngd} = T_n(v_{out}) \approx v_{in}$. The design solution consisting in cascading the RETF and NGD circuit is proposed in Fig. 3. Under the good matching condition, the total system TF can be ideally written as $T_t(s) = T(s)T_n(s)$. The annihilation is equivalent to generate $T_t(\omega) \approx 1$ and $GD_t(\omega) \approx 0$ in the frequency band around ω_0.

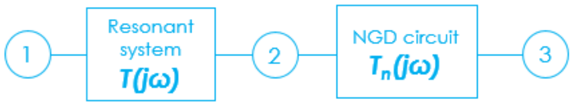

Figure 3. Cascaded resonant and NGD system.

We remind that the BP-NGD magnitude and GD known with canonical TF:

$$T_n(s) = \frac{T_{n_0}(s^2 + \omega_1 s + \omega_0^2)}{s^2 + \omega_2 s + \omega_0^2} \qquad (2)$$

with positive parameters T_{n0}, ω_1, and ω_2, present generally typical "convex" behaviors as sketched in Fig. 4(a) and in Fig. 4(b), respectively.

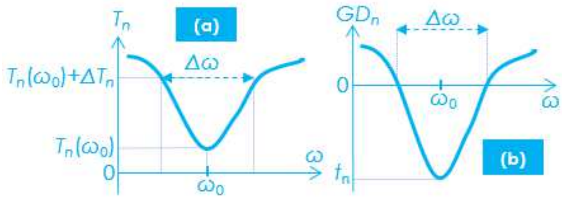

Figure 4. BP-NGD (a) magnitude and (b) GD behavior.

Emphatically, to annihilate the resonance effect, at ω_0, we can design a BP-NGD circuit with minimal gain $T_n(\omega_0) = \left| T_n(j\omega_0) \right|$ and GD $GD_n(\omega_0) = t_n$ by the expressions:

$$T_n(\omega_0) = \frac{T_{n_0}\omega_1}{\omega_2} \qquad (3)$$

$$GD_n(\omega_0) = \frac{2(\omega_1 - \omega_2)}{\omega_1 \omega_2}. \qquad (4)$$

After synthesis by solving the equations $T_n(\omega_0) = 1/T_r$ and $GD_n(\omega_0) = -t_0$, we must determine the NGD bandwidth $\Delta\omega = \omega_c - \omega_0^2/\omega_c$, which is linked to the NGD higher cut-off frequency ω_c. Consequently, the NGD TF parameters ω_1 and ω_2 can be synthesized from the relations:

$$\omega_2 = \frac{(\omega_c^2 - \omega_0^2)\left[\sqrt{16\omega_c^2 + (\omega_c^2 - \omega_0^2)^2 t_0^2} + t_0(\omega_0^2 - \omega_c^2) \right]}{4\omega_c^2} \qquad (5)$$

$$\omega_1 = \frac{2\omega_2}{2 - \omega_2 t_0} \qquad (6)$$

It can be emphasized that $\omega_1 < \omega_2$.

To verify the effectiveness of the established theoretical approach, an application case will be examined in the following section.

3. Application result

A circuit simulation was run in the ADS® environment to verify the feasibility of the resonance effect annihilation method. The resonant system is defined with the resonant frequency f_0=1 GHz, frequency band Δf=0.2 GHz, attenuation T_0=-5 dB and coefficient ζ=0.1. The schematic of the associated proof of concept (POC) composed of combined resonant and NGD circuits is presented in Fig. 5.

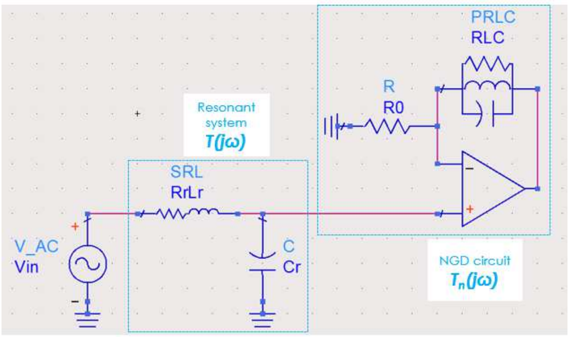

Figure 5. POC of combined resonant and NGD circuit.

3.1 Frequency domain illustration

The frequency domain simulation of our resonant, NGD and whole circuit was carried out from 0.7 GHz to 1.3 GHz. The resonance effect is assumed with attenuation variation of about 15 dB.

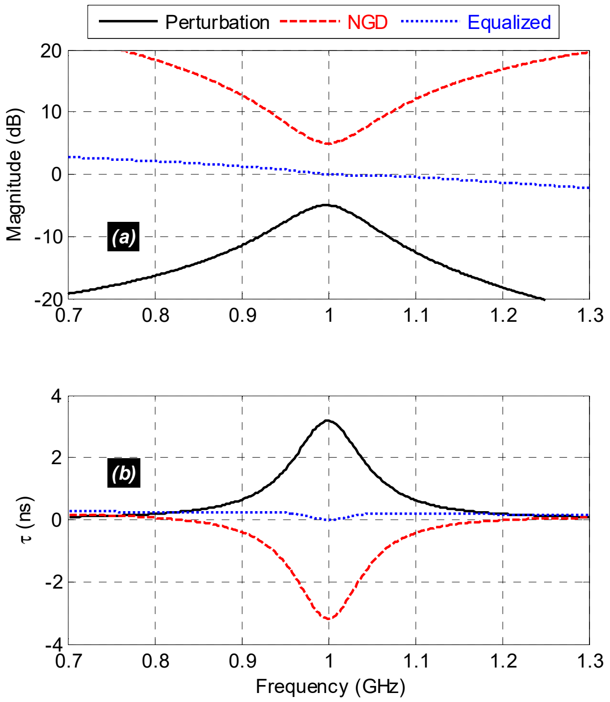

Figure 6. Resonant circuit (solid line), NGD (dashed line) and annihilated (dotted line): (a) magnitude and (b) GD frequency responses.

The computed results showing the relevance of the BP-NGD annihilation effect is confirmed by Figs. 6. In these plots, the RETF responses are shown in solid line, the BP-NGD responses in dashed line and the whole system ones are in dotted lines. We can see that the signal propagation average delay at f_0 can reach 3.18 ns. The synthesized NGD parameters are around T_{n0}=5 dB, f_1=0.094 GHz and f_2=1.55 GHz. The annihilation effect is represented by the overall TF T_t with magnitude changing from -2.2 to 2.7 dB and the GD varies between only 0.1 ps to 0.25 ns in the whole frequency range. As expected, the annihilated TF of the whole system is close to unity.

3.2 Time-domain illustration

In addition to the previous frequency domain analysis, a data sequence of three pulse train signal was considered as input test signal. This data sequence was modulated by 1 V amplitude modulating since carrier with 1 GHz frequency. The input signal spectrum belongs also to the NGD bandwidth. The test signal is analytically defined by raised cosine with 10 ns period. The transient analysis is performed in 60 ns duration the time window.

Fig. 7(a) and Fig. 7(b) show the plots of the original and degraded signals v_1 and v_2.

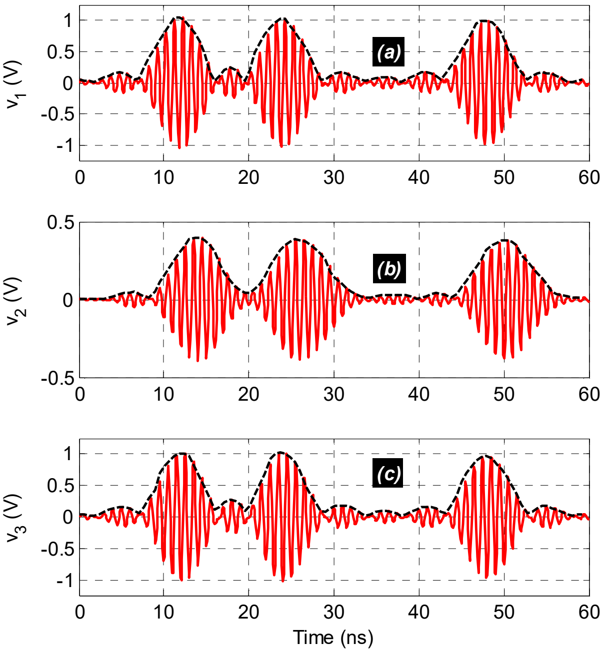

Figure 7. Transient plot results with data sequence input signal v_1.

It can be seen that v_2 presents wider time width pulse, which is susceptible to generate interferences. This resonance effect is correctly annihilated by referring to signal v_3 shown in Fig. 7(c). The associated signal envelopes are plotted in Figs. 8. The second lobes of raised cosine signals disappear for v_2. Similar to the results shown in previous paragraph, the original and annihilated signals v_1 and v_3 present a highly correlated aspect with correlation coefficient close to unity.

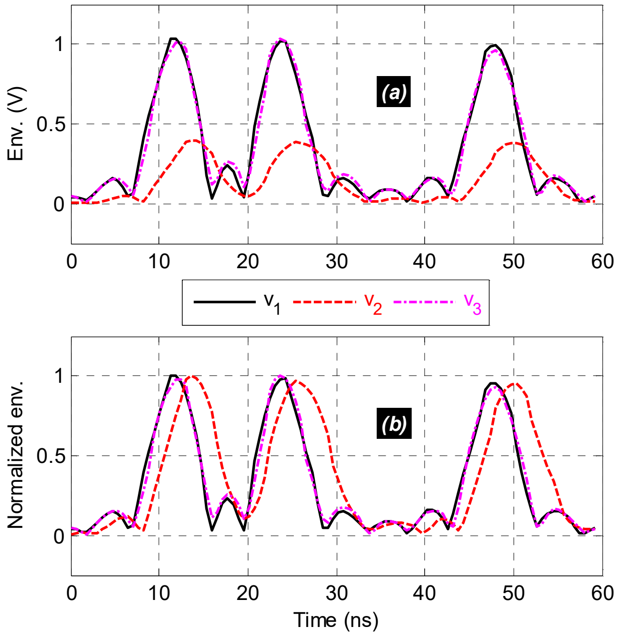

Figure 8. Envelope (a) natural and (b) normal plot results with data sequence input signal v_1.

4. Conclusion

A resonance annihilation method with BP-NGD function is investigated. The basic principle is introduced with numerical application. The method is expected to be developed for the EMC application with hybrid combination of time-reversal technique.

5. Acknowledgements

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