RF RESONANT CAVITY NGD-EQUALIZATION WITH OPPOSITE DELAY METHOD

B. Ravelo*, M. Guerin, F. Haddad**, W. Rahajandraibe**, T. Gu*, F. Wan*, G. Fontagalland*****

*NUIST, Nanjing, Jiangsu 210044, China
**AMU, CNRS, University of Toulon, IM2NP UMR7334, Marseille, France
***Federal University of Campina Grande, Applied EM and Microwave Lab., Campina Grande/PB, 58429, Brazil
Email: blaise.ravelo@yahoo.fr

Keywords: Negative group delay (NGD), resonance equalization, EMC application, signal integrity (SI), cavity.

Abstract
The resonance effect issue is regularly found in EMC engineering. Different experimental methods were proposed to alleviate this EMC issue. This paper describes an original method of negative group delay (NGD) equalization of electromagnetic (EM) cavity effect. The bandpass (BP) NGD design as an unfamiliar engineering is analytically formulated. The proposed method feasibility is shown with 42×28×3.8 cm-size cavity simulation by using RLC-series network-based BP-NGD active circuit. By means of about -4 ns NGD value at 0.644 MHz centre frequency, resonance effect reduction with 1-dB flatness is discussed. The comparison between the NGD and time-reversal methods is under study.

1 Introduction
Time reversal (TR) was popularly used as a method for acoustic and EM signal processing [1-3]. It is reversing in time (t→-t) system's response signals. TR was efficiently exploited as EMC solutions to treat and to localize disturbances and resonance of EM effect [2-3]. But TR requires expensive and time cost 1-D, 2-D and 3-D full wave simulations. The NGD engineering seems a prominent solution against the EMC and signal integrity (SI) issues. We would like to develop an alternative method of opposite delay based on bandpass (BP) type NGD-equalization [4-6]. Reduction of resonant cavity effect remains a hot topic for EMC engineers [7-9]. In the present paper, by means of group delay (GD) opposite, an equalization of EM cavity resonant perturbation is introduced.

2 EM cavity resonance equalization NGD-method
Fig. 1 illustrates the scenario of EM cavity NGD-equalization under study.

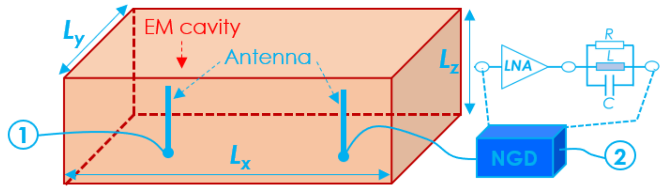

Fig. 1: Configuration of NGD equalized EM cavity.

This rectangular enclosure can be modelled by $R_cL_cC_c$-resonant network with eigen mode resonance frequency:

$$f_{mnp}=c/2\sqrt{(m/L_x)^2+(n/L_y)^2+(p/L_z)^2} \quad (1)$$

with light speed c and (m,n,p) are mode indexes [7-9]. We recall that for 2-port circuit having reference impedance R_0=50 Ω, modelled by $\omega=2\pi f$ frequency dependent S-parameters:

$$[S_c(j\omega)]=\begin{bmatrix} S_{11c}(j\omega) & S_{12c}(j\omega) \\ S_{21c}(j\omega) & S_{22c}(j\omega) \end{bmatrix} \quad (2)$$

the GD is defined by:

$$GD_c(\omega)=-\partial\varphi_c(\omega)/\partial\omega \quad (3)$$

where $\varphi_c(\omega)=\arg[S_{21c}(j\omega)]$ is the transmission phase with GD. To reduce the resonance effect, we proceed from the opposite of signal delay induced by the cavity GD given by:

$$GD_c(f_{110})=2R_0R_cC_c/(R_0+2R_c) \quad (4)$$

We remark that this delay is naturally positive. The NGD equalization principle is analytically formulated by $S_{21c}(j\omega)\times S_{21n}(j\omega)\approx 1$ by denoting the NGD circuit transmission coefficient $S_{21n}(j\omega)$. For this reason, the NGD active circuit is designed with low-noise amplifier (LNA) cascaded to the EM cavity as depicted in Fig. 1 to generate the opposite delay.

3 NGD specifications and synthesis equations
Thanks to the analogy between GD and magnitude behaviors, an innovative theory stating different types of NGD circuits [10]. The BP-NGD specifications as center frequency f_n, cut-off frequencies $f_{1,2}$ and values $t_n=GD(f_n)<0$ which must be negative are based on magnitude and GD diagrams as illustrated by Figs. 2. Similar to classical RF ones, the NGD circuits are also characterized by insertion and reflections losses as $S_{11n}(f_n)=A$ and $S_{22n}(f_n)=B$.

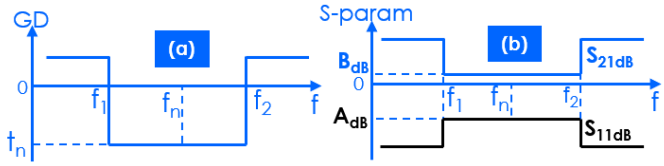

Fig. 2: NGD ideal specifications: (a) GD and (b) S-parameters.

The BP-NGD equalizer design methodology is organized by following steps:

- ❑ <u>Step 1</u>: Definition of EM cavity resonance effect (center frequency, bandwidth, peak of magnitude)
- ❑ <u>Step 2</u>: EM cavity delay modelling [7-9]
- ❑ <u>Step 3</u>: BP-NGD topology identification [10]

- ❑ Step 4: Formulation of BP-NGD equalizer synthesis equation by considering the opposite delay represented by NGD value t_n=-$GD_c(f_{110})$ and return loss A:

$$R = 2R_0 A/(1-A) \quad (5)$$

$$C = -t_n(1-A)/(4R_0A^2) \quad (6)$$

$$L = -A^2R_0/\left[\pi^2 f_{110}^2 t_n(1-A)\right] \quad (7)$$

To get overall transmission coefficients close to unity, we can choose the amplifier gain by the equation:

$$g \approx S_{21c}(f_{110})/(1-A) \quad (8)$$

It is noteworthy that for EM cavity and NGD equalizer matching, a LNA with neglected return and isolation loss is considered.

- ❑ Step 5: Proof of concept (POC) design and design of BP-NGD circuit parameters
- ❑ Step 6: Validation

As POC for further understanding, a resonant RLC model perturbation is described in the next section.

3 EM cavity NGD-equalized results

As POC, we consider the EM cavity with size L_x×L_y×L_z×=42×28×3.8 cm. The equivalent model (R_c=47 kΩ, L_c=930 pH, C_c=65 pF, C_{a1}=180 fF, C_{a2}=280 fF, n_1=1, n_2=0.7) [9] including the NGD-equalizer designed in ADS® schematic environment is sketched by Fig. 3.

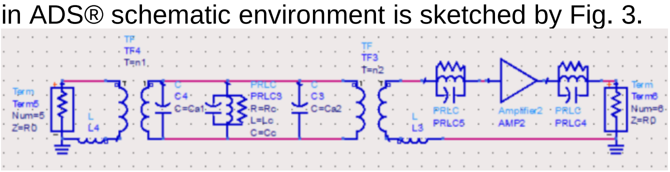

Fig. 3: ADS® design of NGD equalized EM cavity.

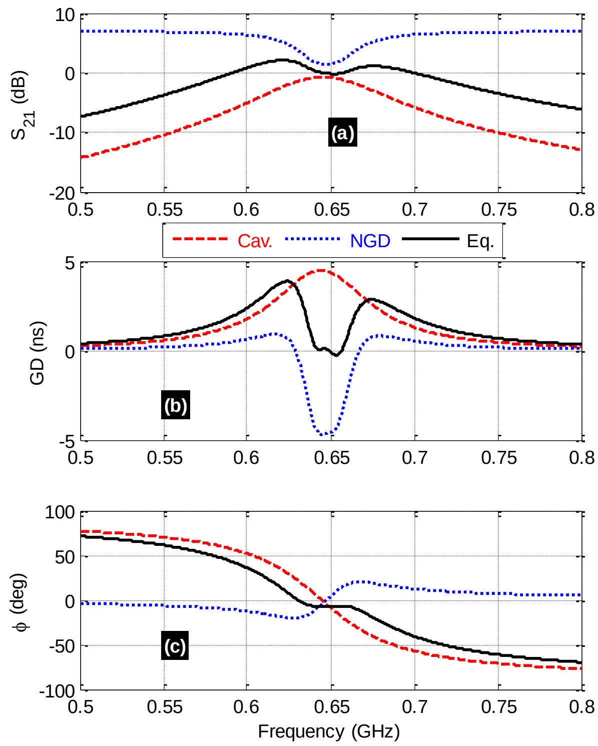

Fig. 4: (a) Magnitudes, (b) GD and (c) phases of cavity, NGD and equalized structures.

The considered EM cavity resonance frequency is about f_{110}≈0.644 GHz. By means of formulas (2)-(5) and by targeting reflection coefficient A=-10 dB and further optimization, two-cell NGD circuit was designed with parameters R=46.3 Ω, L=454 pH, C=133 pF and g=7 dB. Figs. 4 represent the EM cavity (red dashed "Cav." line), NGD (blue dotted "NGD" line) and equalized (black solid "Eq." line) structures transmission coefficient magnitudes, GDs and phases simulated from 0.5 to 0.8 GHz. The opposite delay can be seen with GD diagram of Fig. 4(b) with flat GD≈-4.6 ns under 0.5 ns variation from f_a=0.639 GHz to f_b=0.657 GHz. As expected, significant resonance reduction effect is found from f_a to f_b showing reduction of EM cavity GD from 4 ns to less than 1 ns and also magnitude flatness 0.3 dB variation. Moreover, the equalized structure operates with flat transmission phase as illustrated by Fig. 4(c).

4 Conclusion

An original method of EM cavity NGD equalization for EMC application is studied. The BP-NGD circuit design is introduced. The method feasibility is discussed with interesting simulation results. Comparison of the NGD-equalization effectiveness and TR method is expected in the future of the present research work.

References

[1] B. Fall, F. Elbahhar, M. Heddebaut, A. Rivenq, "Time-Reversal UWB positioning beacon for railway application", 2012 Int. Conf. IPIN, pp. 1-8, (2012).

[2] V. S. Asadchy, M. S. Mirmoosa, A. Díaz-Rubio, S. Fan, S. A. Tretyakov, "Tutorial on Electromagnetic Nonreciprocity and its Origins", Proc. IEEE, vol. 108, pp. 1684-1727, (2020).

[3] Z. Wang, S. He, Q. Li, B. Liu, R. Razzaghi, M. Paolone, Y. Xie, M. Rubinstein, F. Rachidi, "A Full-Scale Experimental Validation of Electromagnetic Time Reversal Applied to Locate Disturbances in Overhead Power Distribution Lines," IEEE TEMC, vol. 60, pp. 1562-1570, (2018).

[4] B. Ravelo, S. Lalléchère, W. Rahajandraibe, and F. Wan, "Electromagnetic Cavity Resonance Equalization with Bandpass Negative Group Delay," IEEE TEMC, vol. 63, pp. 1248-1257, (2021).

[5] B. Ravelo, F. Wan, J. Nebhen, W. Rahajandraibe, S. Lalléchère, "Resonance Effect Reduction with Bandpass Negative Group Delay Fully Passive Function," IEEE CAS II: Express Briefs, vol. 68, pp. 2364-2368, (2021).

[6] B. Ravelo, F. Wan, M. Guerin, W. Rahajandraibe, G. Fontagalland, G. Chan, "Resonance and Time-Delay Annihilation with Bandpass NGD Active Circuit (Invited)", Proc. 2022 3rd URSI AT-AP-RASC, pp. 1-4, (2022).

[7] O. Maurice, Elements of Theory for Electromagnetic Compatibility and Systems. Aix en Provence, France: Bookelis, (2017).

[8] O. Maurice, A. Reineix, P. Hoffmann, B. Pecqueux, and P. Pouliguen, "A formalism to compute the electromagnetic compatibility of complex networks," Adv. Appl. Sci. Res., vol. 2, pp. 439–448, (2011).

[9] S. Leman, B. Demoulin, O. Maurice, M. Cauterman, P. Hoffmann, "New approaches in electromagnetic compatibility: Use of the circuit approach to solve large EMC problems," C. R. Physique, vol. 10, pp. 70–82, (2009).

[10] B. Ravelo, "Similitude between the NGD function and filter gain behaviours," Int. J. Circ. Theor. Appl., 42, 10, Oct. 2014, pp. 1016-1032.