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Design of 3.6-GHz 5G NGD passive circuit

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Abstract/Résumé

This paper introduces a design of bandpass NGD circuit with 3.6-GHz centre frequency. The NGD passive topology consists of parallel resistance associated with an open-ended microstrip stub. The S-matrix and group delay (GD) model of the topology are established. A microstrip proof of concept is designed and simulated to validate the theoretical approach. The simulated circuit operates with -0.34 ns NGD around 3.6 GHz centre frequency over 0.32 GHz bandwidth and only 3 dB attenuation loss. This NGD circuit can be useful for the improvement of phase linearity and GD equalization of future 5G microwave devices.

1 Introduction

The 5G technology is a promising solution for the future RF/microwave system [1]. However, the system may suffer from the data synchronisation in order to satisfy the master word target wireless connection "anything, anywhere and anytime". In this context, the design of electronic and power systems will require enhanced works [2]. The future 5G device performances depend on the delays between the multiple transmitter (Tx) and receiver (Rx) positions. To reduce the delay effect, we propose an innovative solution based on the bandpass (BP) negative group delay (NGD) function [3-5]. Because of the unfamiliarity of RF/microwave design engineers and also research communities to this fascinating function, it would be necessary to have a brief recall on its functioning with a simple topology. For this reason, the present paper introduces a design of a BP NGD cell with 3.6 GHz centre frequency.

2 Design method of NGD circuit

This section describes the theoretical approach of the BP NGD circuit.

2.1 Topological description and S-matrix modelling

Fig. 1 represents the topology of NGD passive two-port circuit. It is composed of a parallel resistance R ended by an lossless open-ended stub TL(Z,τ_0) which is defined by characteristic impedance Z and delay τ_0. Acting as a symmetric passive circuit, the equivalent S-matrix must be written as S_{11}=S_{22} and S_{12}=S_{21}.

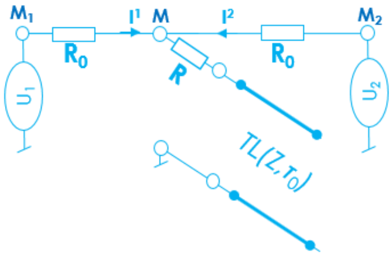

Figure 1: NGD passive circuit

By denoting the reference impedance R_0=50 Ω and the angular frequency variable ω, the S-matrix model of this circuit can be written as:

$$\begin{cases} S_{11}(j\omega) = \dfrac{-jR_0\tan(\omega\tau_0)}{2Z+(2R+R_0)\tan(\omega\tau_0)} \\ S_{21}(j\omega) = \dfrac{2(Z+R)\tan(\omega\tau_0)}{2Z+(2R+R_0)\tan(\omega\tau_0)} \end{cases} \quad (1)$$

The associated group delay (GD) model is defined by:

$$GD(\omega) = \frac{-\partial\arg\left[S_{21}(j\omega)\right]}{\partial\omega} \quad (2)$$

It can be derived from the transmission coefficient given in (1) that:

$$GD(\omega) = \frac{R_0 Z\tau_0\left[1+\tan^2(\omega\tau_0)\right]\left[2Z^2-R(2R+R_0)\tan^2(\omega\tau_0)\right]}{\left[Z^2+R^2\tan^2(\omega\tau_0)\right]\left[2Z^2+(2R+R_0)^2\tan^2(\omega\tau_0)\right]} \quad (3)$$

2.2 NGD analysis and synthesis

The NGD analysis consists in proving that the proposed topology is capable to operate as a bandpass NGD function. Doing this, we intuitively have the NGD centre frequency:

$$f_0 = \omega_0 / (2\pi) = 0.25 / \tau_0 \tag{4}$$

At this frequency, the S-parameters and GD established in (1) and (2) become, respectively:

$$\begin{cases} \left|S_{11}(j\omega_0)\right| = R_0 / (2R + R_0) \\ \left|S_{21}(j\omega_0)\right| = 2R / (2R + R_0) \end{cases} \tag{5}$$

$$GD(\omega_0) = -R_0 Z \tau_0 / \left[R(R_0 + 2R)\right] \tag{6}$$

The associated NGD bandwidth is given by:

$$\Delta f = \left\{ \frac{\omega_0}{\pi} - \frac{2}{\tau_0} \arctan\left[\frac{Z\sqrt{2}}{\sqrt{R(R_0 + 2R)}} \right] \right\} \tag{7}$$

The NGD design equation can be established from the desired NGD centre frequency, NGD value and return loss *a*, by solving the system of equations:

$$\begin{cases} S_{11}(f_0) = a \\ GD(f_0) = -t \end{cases} \tag{8}$$

Therefore, we have:

$$\begin{cases} \tau_0 = 0.25 / f_0 \\ R = 0.5 R_0 (1 - a) / a \\ Z = 0.5 R_0 (1 - a)\, t / a^2 \tau_0 \end{cases} \tag{9}$$

3 Validation results

A proof of concept and comparison between the model and microstrip simulation is discussed in this section to validate the previous BP NGD theory.

3.1 POC description

Table 1 addresses the desired NGD specifications to design the 5G NGD POC. By using design equations (9), we obtain the NGD parameters of Table 1.

Specifications	Designation	f_0	t	a
	Value	3.6 GHz	0.34 ns	10 dB
NGD ideal parameters	Designation	τ_0	R	Z
	Value	69 ps	60 Ω	1 kΩ

Table 1: NGD specifications and calculated parameters

A microstrip circuit illustrated in Fig. 2(a) was designed and simulated to validate more concretely the modelled S-parameters. The dielectric substrate with thickness *h* is Cu metallized with physical width *d*, length *d* and thickness *x*. Fig. 2(b) shows the 3D design of the NGD circuit POC constituted by a resistor *R*, open-ended TL(*w*,*d*) and access line $TL_a(w_a,d_a)$. After calculations and slight optimization, the specifications of the Kapton substrate and the NGD POC physical parameters are indicated in Table 2.

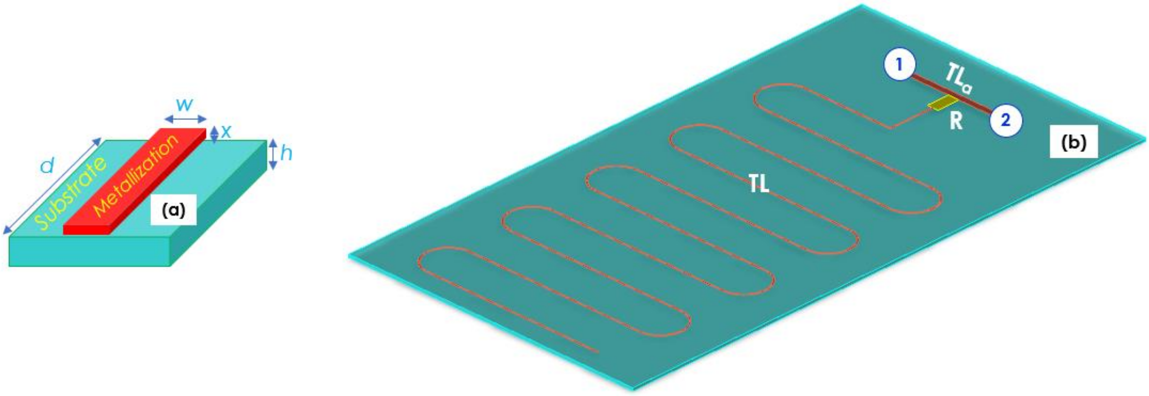

Figure 2: (a) Microstrip design and (b) NGD circuit POC 3D design

Substrate	ε_r	tan(δ)	x	h	σ
	3.3	0.002	17 µm	125 µm	58 MS/s
NGD POC	w	d	w_a	d_a	R
	62 µm	23.4 cm	277 µm	2 mm	60 Ω

Table 2: Specifications of the NGD microstrip circuit

3.2 Discussion on NGD results

As an ideal model, Matlab calculations of equations (1) and (3) have been realized. Then, the distributed microstrip circuit introduced in Fig. 2(b) was simulated with the commercial tool ADS® from Keysight Technologies® schematic simulation. Figs. 3 display the compared results from calculations (“Calc.”) and ADS® simulations (“Simu.”). As expected theoretically, bandpass NGD function is observed as depicted in Fig. 3(a). Table 3 summarizes the differences between the calculated and simulated results.

Characteristics	f_0	$GD(f_0)$	Δf	$S_{21}(f_0)$	S_{21} (f_0)
Ideal	3.6 GHz	-0.34 ns	327 MHz	-3.025 dB	-10.63 dB
Simu.	3.599 GHz	-0.298 ns	172 MHz	-2.35 dB	-12.67 dB

Table 3: Characteristic of ideal and simulated NGD POCs

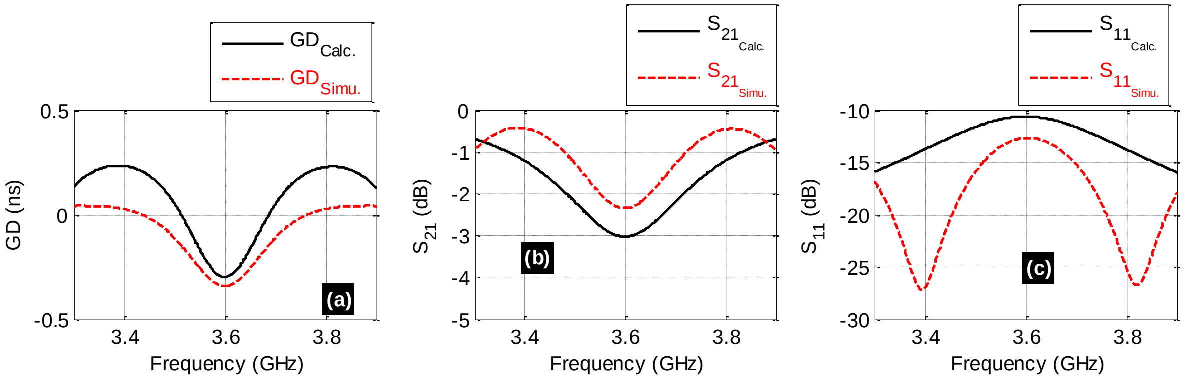

Figure 3: Calculated and simulated (a) GD, (b) S_{21} and (c) S_{11} of 3.6 GHz 5G NGD circuit

4 Conclusion

A pedagogical BP NGD theory is investigated. The NGD circuit is constituted by a shunt parallel resistor ended by an open-ended stub. The NGD analysis and synthesis equations have been established from the S-matrix equivalent model. The feasibility of the NGD theory was verified with design of ideal and microstrip POCs. As expected, BP NGD responses operating around the 5G frequency 3.6 GHz were obtained and discussed. This innovative NGD function can be a potential solution for future 5G networks (Fig. 4) [6]. An example of wireless sensor (WS) scenario and NGD delay effect reduction [7] is illustrated in Fig. 5.

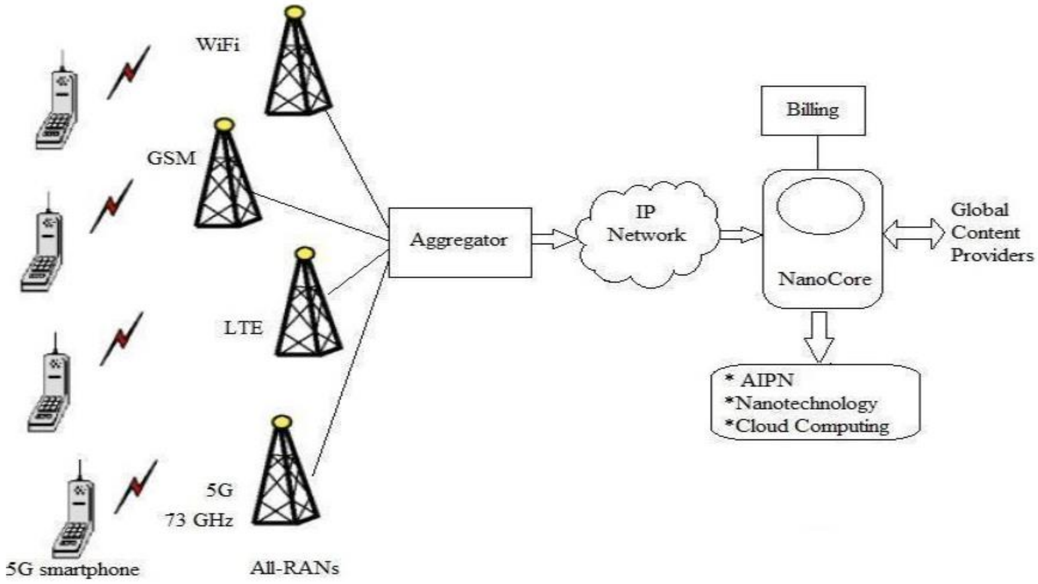

Figure 4: Network Architecture for 5G [6]

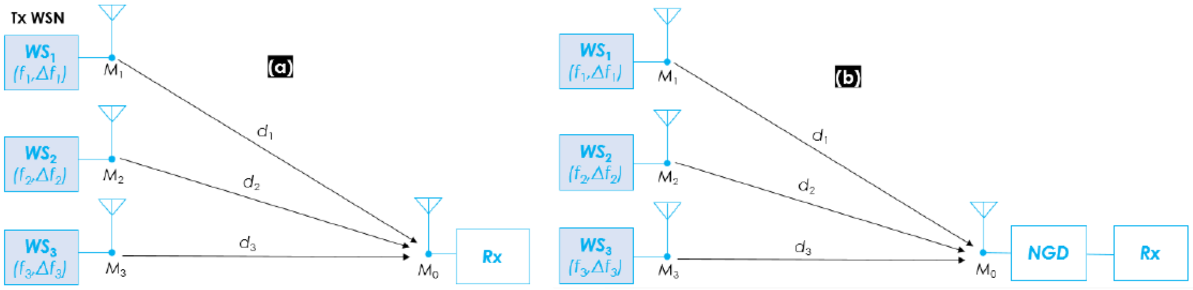

Figure 5: Configuration NGD delay reduction [7]

References

[1] V. Tikhvinskiy et al., “Experimental test results of EMC between 5G and Radio relay links in millimeter band”, in proc. EMC Europe 2019, Barcelona, Spain, 2-6 Sept. 2019, pp. 220-225.

[2] Q. Yu, “The era of 5G and its impacts on EMC Design and Testing”, in proc. IEEE Int. Symp. On EMC, SI/PI, Washington, DC, 2017.

[3] B. Ravelo, “Theory and Design of Analogue and Numerical Elementary NGD Circuits: Theoretical Characterization of Analogue and Numerical NGD Circuits”, LAP Lambert Academic Publishing, Germany, 2012.

[4] B. Ravelo, “Negative Group Delay Devices: From concept to applications”, IET Materials, Circuit and Devices Series 43, Publisher Michael Faraday House, UK, 2018.

[5] B. Ravelo, “On the low-pass, high-pass, bandpass and stop-band NGD RF passive circuits”, URSI Radio Science Bulletin, Vol. 2017, No. 363, Dec. 2017, pp. 10-27.

[6] S. Arunachalam, S. Kumar, H. Kshatriya and M. Patil, “Analyzing 5G: Prospects of Future Technological Advancements in Mobile, International Conference on Innovative and Advanced Technologies in Engineering”, IOSR Journal of Engineering, pp. 6-11.

[7] F. Wan, N. Li, W. Rahajandraibe and B. Ravelo, “Reduction Technique of Differential Propagation Delay with Negative Group Delay Function”, Accepted for communication, IEEE EuCAP 2020, Copenhagen, Denmark, 15-20 March 2020, pp. 1-5.