32nd URSI GASS, Montreal, 19–26 August 2017

Design of a Dispersion-Switchable Phaser for Chirping Modulation

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Abstract

This paper presents a new switchable reflective phaser (which is a component providing arbitrary dispersive group delay response) for the first time. It is used for chirping modulation in real-time analog signal processing. Time-domain signals are modulated with two different dispersive group delay responses in correspondence to two different switch states. To efficiently design this new component with two different states, we transfer these two circuits into a single symmetrical filter network by applying odd/even-mode analysis, and subsequently apply the classic filter approaches. A design example is provided to illustrate the design approach. The result is in a good agreement with the prescribed response.

1 Introduction

Real-time analog signal processing (R-ASP), which is defined to realize a specific operation by processing the signal in their pristine analog form and in real time, may be an alternative or a complement to dominantly digital radio schemes, especially at millimeter-wave and terahertz frequencies, where digital signal processing solution is inefficient [1].

Phaser, as the core of an R-ASP system, provides an arbitrarily prescribed dispersive group delay response to achieve some specific performance [1]. phasers are in great demand for processing ultra-fast pulses, e.g. spectrum analysis [2–4]. Several approaches based on network synthesis have been proposed in [5–15].

Modulation technology plays a crucial role in wireless communication environments. Typical digital technologies are suffering from poor performance at high frequencies for broadband signals. Considering their inability to meet the exploding throughput and reliability demand for next-generation wireless networks, a dispersion code multiple access (DCMA) scheme has been introduced in [16]. The bit-error-rate (BER) performance of a DCMA system is further investigated in [17].

This paper proposes a new switchable reflective-network phaser that is applicable to a chirping modulation system.

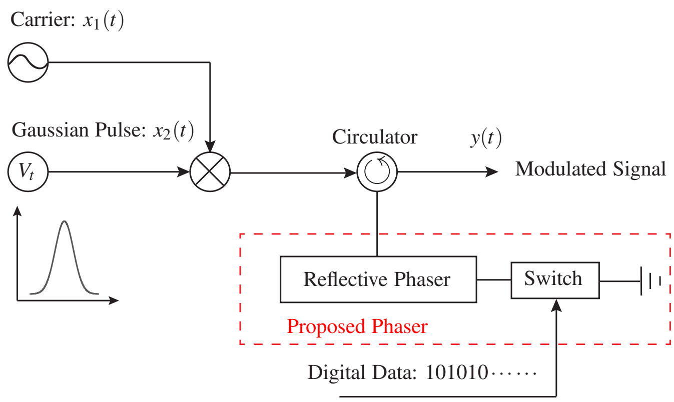

Figure 1. Chirping Modulation System with the proposed switchable phaser.

Time-domain signals are modulated with two different dispersive group delay responses in correspondence to two different switch states. To efficiently design this new component with two different states, we transfer these two circuits into a single symmetrical filter network by applying odd/even-mode analysis, and subsequently apply the classic filter approaches.

2 Principle

The chirping modulation system with the proposed switchable phaser is shown in Fig. 1. A carrier signal, $x_1(t)$, is firstly mixed with a Gaussian pulse, $x_2(t)$, to limit the spectrum bandwidth of the input signal. This input signal is then injected into the proposed switchable reflective phaser through a circulator which transforms the reflective one-port device into a two-port transmission-type device. The reflective phaser is terminated with a switch, which is fully controlled by the digital input data, e.g. $'1'$ corresponding to a open state and $'0'$ corresponding to a short state. Then if one properly designs the reflective phaser, its reflection responses for the two states, open and short, may exhibit a big difference, which finally leads to two differently modulated signals in the output $y(t)$. Therefore, how to efficiently design the reflective phaser for two switchable states is the main focus and most challenging part of the modulation system.

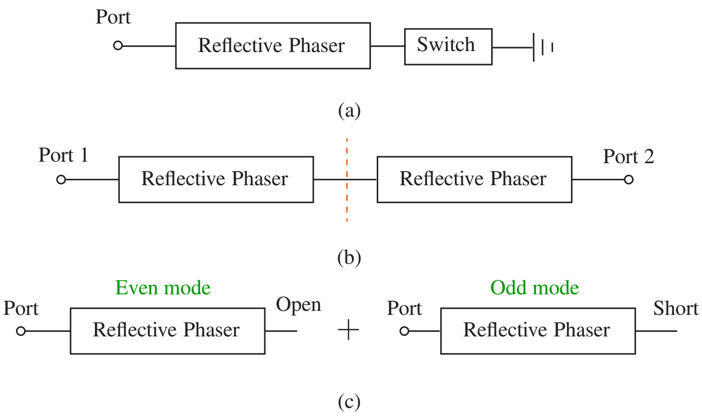

Figure 2. Transformation of the switchable reflective phaser into a two-port symmetrical filter network. (a) The switchable phaser; (b) Two equivalent circuits corresponding to the two switched states; (c) Two-port symmetrical filter network.

In this work, we are mainly focused on a lossless passive realization of the reflective phaser. In this case, the reflection magnitude is unity for both open and short states. Thus, we design the reflective phaser for two different dispersive group delay responses. Thus, the input pulse will be chirped in different fashions when the reflective phaser is terminated in two different states. This exactly corresponds to a chirping-modulation operation.

To efficiently design the reflective phaser with two dispersion/chirping states, we propose here a simple approach. Figure 2(a) shows the reflective phaser with a switchable termination. Instead of directly designing two differently terminated reflective phasers, we transform it into a symmetrical two-port network in Fig. 2(b). This symmetrical network can be split into two halves using even/odd-mode analysis. The even mode and odd mode correspond to an open and short terminations at the symmetrical plane, respectively, as shown in Fig. 2(c), which exactly correspond to the reflective phaser with two termination states.

Assume the reflection responses of the reflective phaser with open and short terminations are S_e and S_o, respectively, one may compute the required scattering parameters of the transformed two-port network in Fig. 2(b) as

$$S_{11} = \frac{S_e + S_o}{2} \tag{1a}$$

$$S_{21} = \frac{S_e - S_o}{2} \tag{1b}$$

where S_{11}, S_{21} are reflection coefficient and transmission coefficient of the two-port network,respectively. It can be proved that the two-port network is lossless and passive as long as S_e and S_o are both lossless.

Since S_e and S_o should provide arbitrarily prescribed dispersions, the transformed two-port network may exhibit independent magnitude and phase responses according to (1).

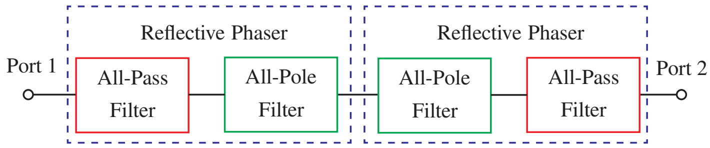

Figure 3. Realization of the two-port network in Fig. 2(b).

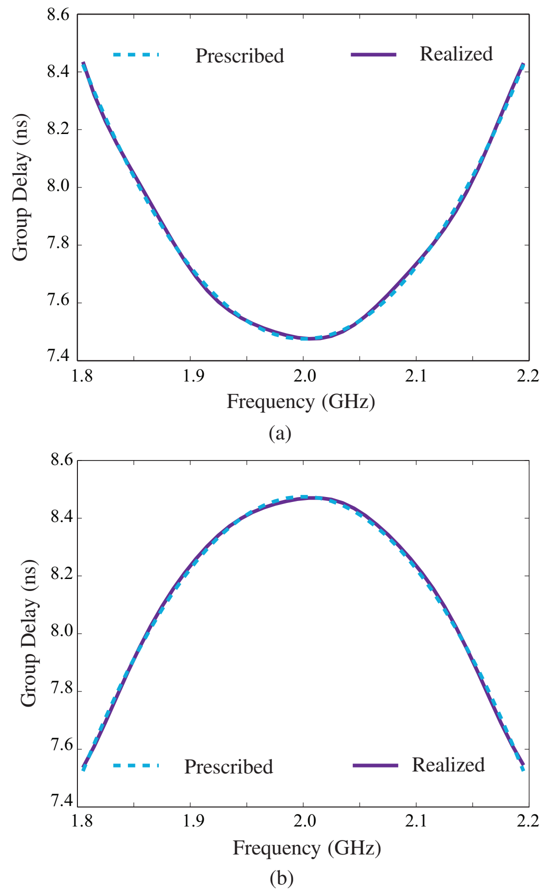

Figure 4. Specified and realized group delay responses of the reflective phaser with (a) open state and (b) short state.

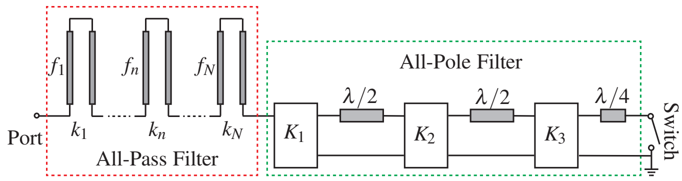

Figure 5. Implementation of the reflective phaser in Fig. 3.

One possible implementation is to combine an all-pole filter and an all-pass filter networks, as shown in Fig. 3, where the all-pole filter controls the magnitude response and all-pass filter controls the phase response.

3 Design Example

To illustrate the proposed approach, one considers an example with the specified group delay responses within the frequency from 1.8 GHz to 2.2 GHz, as shown in Fig. 4, where two complementary responses, concave and convex shapes, are prescribed to represent two different states. The implemented circuit is shown in Fig. 5, where N cascaded C-sections acts as the all-pass filter while a K-inverter-coupled half-wavelength-resonator network represent the all-pole filter. The computed parameters are $N = 5$, $k_1 = 0.35$, $k_2 = 0.094$, $k_3 = 0.271$, $k_4 = 0.215$, $k_5 = 0.029$, $f_1 = 0.43$ GHz, $f_2 = 1.638$ GHz, $f_3 = 0.368$ GHz, $f_4 = 1.707$ GHz, $f_5 = 1.538$ GHz, $K_1 = 0.906$, $K_2 = 0.469$, $K_3 = 0.327$. The realized responses are shown in Fig. 4, which well follow the prescribed ones.

4 Conclusion

A new switchable reflective phaser has been presented in this paper. The switchable phaser can be synthesized using a symmetric two-port circuit according to odd/even mode analysis. A circuit implementation is provided to illustrate the proposed method. The switchable phaser is potentially applicable to the chirping modulation in real-time analog signal processing.

5 Acknowledgements

This work is supported by National Natural Science Foundation of China (61401191), Guangdong Natural Science Funds for Distinguished Young Scholar (2015A030306032, S2013050014223), Shenzhen Science and Technology Innovation Committee funds (KQJSCX20160226193445650, JCYJ20150331101823678, KQCX2015033110182368, JCYJ20 160301113918121, JSGG20160427105120572), and Shenzhen Development and Reform Commission funds ([2015]944).

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