Synthesis of Phasers for Real-Time Analog Signal Processing

(*Invited Paper*)

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Abstract

Different synthesis techniques associated with different types of phasers are reviewed. Both material- and network-based synthesis are discussed. In the network synthesis, all phasers have closed-form synthesis techniques, except the coupled C-section phasers which require optimization techniques, all the others have.

1. Introduction

Radio analog signal processing (R-ASP), inspired by ultra-fast optics and surface acoustics wave signal processing [1], [2], has attracted increasing attention recently due to the exploding demand of high-efficiency and high-speed communication. Conventional digital signal processor (DSP) suffer from high power consumption due to signal sampling, and narrow bandwidth due to A/D and D/A limitations. The main R-ASP applications pertain to instrumentation [3]-[10], radar [11]-[13], sensors [14]-[16] and communications [17]-[21]. Overviews of R-ASP are provided in [22]-[24].

The core of a R-ASP system is a phaser [24], which is a component exhibiting an arbitrary group delay response versus frequency. An pulse passed through a phaser with linear group delay gets its spectral information mapped onto time, which is phenomenon often used for real-time Fourier transformation [6]-[9]. Two frequency-modulated pulses, passing through a phaser with step-case group delay [15], separates themselves in the output, which is often used as spectrum sniffer [16]. Therefore, the group delay response of the phaser should be arbitrarily controlled according to different applications.

Phasers can be implemented in several technologies. These technologies may be mainly divided into two categories: reflection-type and transmission-type. Reflection-type phasers usually exhibit simpler configuration and are therefore easier to synthesize. However, they are one-port devices, and therefore require a circulator or a hybrid coupler to become two-port devices [25]-[27]. Transmision-type phasers are inherently two-port devices, but their synthesis is more complicated [28]-[34]. A comparison of transmission-type and reflection-type phasers in terms of system resolution was reported in [35]. This paper overviews currently existing synthesis techniques for these types of phasers .

2. Phaser Synthesis

Phasers may be realized using two distinct aproaches: material (sub-wavelenth and periodic cells) and network (distrubuted and non-periodic, typically half-wavelength cells). A typical example for the material case is the CRLH phaser [11], [13], [19]. In this case, the group delay is controlled by adjusting the equivlent inductance and capacitance of the artificial transmission line sections. However, the resulting charactersitics are only limited to hyperbolic group delay functions, due to the dispersion limitation of CRLH transmission lines. An extensive review of CRLH metamaterial based phasers may be found in [22]. Network-based phasers feature more degrees of freedom and best achieve quasi arbitrary group delay responses. They can be divided into reflection-type and transmission type phasers, and further divided into bandpass-type and allpass-type phasers. Different synthesis techniques are required for different phasers, as will be discussed next.

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Reflection-type bandpass phasers may be realized by Bragg-grating type structures [25], [26]. Although they are two-port devices, one port is terminated by a matched load and only the other port is used. The group delay response of this type of phaser is typically controlled by chirping the spatial pattern of a periodically loaded quasi-TEM transmission line [25]. A approximate design formulas are usually employed in the synthesis. In these phasers, periodic structures are used to produce a stopband in the transmission direction or passband in the reflection direction. Therefore, the overall length tends to be rather large. Moreover, the group delay and magnitude for these phasers are usually accompanied by strong parasitic ripples.

Reflection-type allpass phasers are one-port devices realized by casacading direct-coupled resonators [27],[36]. They are synthesized either directly in the bandpass domain [36] or indirectly in the lowpass domain [27]. Direct bandpass-domain synthesis requires optimization whereas indirect lowpass-domain synthesis have closed-form formulas. In the latter case, the original group delay synthesis problem is transformed into a Hurwitz polynomial generation problem, which is quite easy to solve using the recurrence formula provided in [37].

Transmission-type bandpass phasers are realized by cross-coupled filter configurations and synthesized using the closed-form formulas provided in [28]. The difficulty is to separately control the magnitude and group delay (or phase) in a specified frequency band. The synthesis method in [28] employs a para-conjugate polynomial in the numerator of the transfer function (which is unnessary in general [38]) so as to determine the magnitude of the transfer function whereas the phase is exclusively controled by the denominator.

Transmission-type allpass phasers are realized by casacading C- and D-sections [31]-[34], [39]. If these sections are loosely coupled, the total group delay response can be synthesized by closed-form formulas [33],[34]. Although the synthesis is quite simple and fast, the resulting device may be insufficiently compact. This issue is addressed by tightly coupling the sections in which case a global optimization, e.g. genetic algorithm [31] or space mapping technique [39], is required. The genetic algorithm used in [31] is very time consuming whereas the space mapping technique used in [39] is quite efficient.

3. Conclusion

This paper has reviewed the main synthesis technques for phasers. Both material- and network-based synthesis were introduced.

4. References

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