Commensurate and Non Commensurate Lines for Group Delay Engineering

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Abstract—An experimental demonstration of a non commensurate group delay line is presented using all-pass C section networks is presented. A quasi-arbitrary group delay response can be obtained by allowing C sections with different length and properly adjusting the number of C sections in the design. The proposed C-section networks are suitable for analog signal processing of broad bandwidth (a few gigahertz bandwidth) signals, where relatively low group-delay values (up to a few nanoseconds) are required.

Index Terms—All-pass C sections, Commensurate lines, Group delay engineering, Non commensurate networks.

I. INTRODUCTION

The recent emergence of Ultra-wide-band (UWB) systems with emphasis on enhanced spectral efficiencies and related research in Cognitive radio (CR) systems where spectrum sharing and utilization is of utmost importance has made real time monitoring of Radio Frequency (RF) environment of paramount interest. Digital techniques are generally preferred due to high flexibility, integration, low cost and strong reliability. However the use of digital techniques at very high frequencies suffers from poor performance, excessively costly AD/DA converters and high power consumption. At millimeter wave and Sub-tera hertz frequencies analog systems are needed for real time signal processing.

The core of an analog real-time signal processor is a dispersive structure. An ideal dispersive structure should provide a flat magnitude response with smooth and continuous group delay profile within frequency range of operation [1]. All pass microwave C sections have these properties.

In a dispersive structure, the group velocity is a function of frequency, which results in a frequency-dependent group delay. Consequently, a wide-band signal traveling along such a structure experiences time spreading since its different spectral components travel with different group velocities and are, therefore, temporally rearranged. By exploiting this temporal rearrangement, the various spectral components of a wideband signal can be directly mapped onto time domain and can then be processed in real time for various applications [1].

There are many techniques to attain dispersion at microwave frequencies. Major techniques available are Surface acoustic wave device, Magnetostatic wave devices, Reflection type structures, chirped microstrip lines etc. [1] Extensively discusses these techniques.

This report is organized as follow. Section II presents group delay engineering using a cascaded microwave C section. Section III discusses about the theory of multi-conductor commensurate and non commensurate lines. Section IV & V presents experiments and their results respectively. Section VI provides conclusion.

II. GROUP DELAY ENGINEERED CASCADE MICROWAVE C SECTIONS.

The transfer function of an all-pass network is defined by

\[ S_{21}(p) = \frac{D(-p)}{D(p)} \]  

(1)

Where \( p = \sigma + j\omega \) is the complex frequency variable and \( D(p) \) is a strict Hurwitz polynomial. At real frequencies \( p = j\omega \), \( |S_{21}(j\omega)|^2 = S_{21}(p)S_{21}(-p) = 1 \) so that the amplitude response is unity at all frequencies, that is why it is called the all-pass network. However, there will be phase shift and group delay produced by an all pass network. At real frequencies Equation (1) can be expressed as

\[ S_{21}(j\omega) = e^{i\phi_{21}(\omega)} \]  

(2)

The phase shift is then given by

\[ \phi_{21}(j\omega) = -j \ln(S_{21}(j\omega)) \]  

(3)

And group delay \( \tau_d \) is given by

\[ \tau_d = -\frac{d\phi_{21}(\omega)}{d\omega} \]  

(4)

If all poles and zeros of an all-pass network are located along the \( \sigma \)-axis, such a network is said to consist of C type sections.
Figure 1: Characteristics of a single section C type all pass networks: (a) Pole Zero Diagram. (b) Group Delay response.

There are many ways to implement a typical C section in a Microstrip or a Strip-line configuration. A typical microstrip-line configuration is shown in figure 2.

The transfer function (S21) of such a section is given by

\[ S_{21}(\theta) = \frac{\sqrt{1+k} \cos \theta - j\sqrt{1-k} \sin \theta}{\sqrt{1+k} \cos \theta + j\sqrt{1-k} \sin \theta} \]  

(5)

Where \( \theta = \beta l \) with \( l = \lambda/4 \) [1].

The group delay is then given by [1]

\[ \tau(\theta) = -\frac{d \phi_{S_{21}}(\omega)}{d \omega} = \frac{2a}{a^2 + (1-a^2) \cos^2 \theta} \frac{d \theta}{d \omega} \]  

(6)

Where \( a = \frac{\sqrt{1-k}}{\sqrt{1+k}} \)

The group delay response depends strongly on the coupling coefficient \( k \) which in term depends on the spacing between adjacent lines.

A coupled line all pass networks can be then used to implement various group delay responses. For this purpose a series of series of individual all pass filtering sections with different parameters are cascaded to realize a wide range of group delay characteristics. A desired group delay response can be achieved by superposition of various group delay functions provided by coupled line all pass networks.

III. THEORY OF MULTI-SECTION LINES

The theory for coupled line implementation for commensurate and non-commensurate lines is described in detail in [1]. The basic idea is to use a commensurate and non-commensurate coupled line N-port networks and then convert it into a 2 port network. The theory of this is given in [1]. [1] Uses strip line configuration for physical implementation of group delayed commensurate and non-commensurate lines. This work uses Microstrip line configuration for physical implementation of group delayed lines. With the use of microstrip line configuration, since the fields are in air as well as in the dielectric substrate so an effective Zin is attained by using [3].

**Figure 3:** Principle of group-delay engineering using cascaded all-pass network sections (for positive chirp) [1].

**Figure 4:** A typical coupled line C section.

Where \( Z_{i1} \) is the effective input image impedance. This is given by

\[ Z_{i1} = \sqrt{Z_{0e}Z_{0o}} \]  

(7)

This means for matching purposes, the effective impedance offered by the C line section should be 50Ω. This is attained by calculating even-odd mode impedance of microstrip line so that the effective image impedance \( Z_{i1} \) offered by the C section is 50 Ω.

[3] Provides with the theory for evaluation of even mode impedance \( Z_{0e} \) and odd mode impedance \( Z_{0o} \). A Matlab script...
was implemented based on [3] to calculate $Z_{oe}$ and $Z_{oo}$ for different spacing and width to attain $Z_i=50\,\Omega$ effectively.

IV. EXPERIMENTS

In the following designs, the width $w$ of the lines, the $w'$ width of the end connecting transmission line sections, the gap $s$ between them, the substrate thickness $h$, and the substrate permittivity $\varepsilon_r$ are assumed to be fixed, and are equal for all the lines. These parameters were calculated using [3] and may be tweaked as needed.

Using [3] as a design guide, various design implementations were simulated in Agilent Design Software (ADS). Various design configurations were created using ADS and Matlab and an optimum width of metal track which gives a 50ohm match was then calculated. The optimum width thus calculated comes as 1mm. Next width was kept fixed and an optimum spacing between C sections was obtained. This spacing is 5mm.

Few of the geometries thus implemented are shown in Figure 5.

![Figure 5: Few of the geometries implemented.](image)

V. RESULTS

The design geometries were fabricated on Avalon AD 600 with $\varepsilon_r=6.15$ and thickness $h=30\,\text{mil}$. The geometries were calculated using Matlab and [3].

The measurement was done on Agilent Network Analyzer and the results are shown in figure 4.

Due to matching issues, a constant offset is observed between the simulated and measured results. Also due to $S_{11} > -20\,\text{dB}$ there are undulations observed in group delay plot. This can be attributed to the fact that the design is more sensitive to variations due to large $\varepsilon_r$ and small thickness $h$.

![Figure 6: Results. 6(a) Commensurate Section. 6(b) Non-commensurate section I. 6(c) 50 Ohm line. 6(d) Non-commensurate Section II.](image)

VI. CONCLUSION

Group delay engineered commensurate and Non-Commensurate All-pass C section networks are successfully implemented for linear and quasi linear group delay response using Microstrip line. Bandwidth obtained is sufficiently large.
The proposed C-section networks are suitable for analog signal processing of broad bandwidth (a few gigahertz of bandwidth) signals, where relatively low group-delay values (up to a few nanoseconds) are required.

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