SYNTHESIS OF DELAY FILTERS

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ABSTRACT

A procedure is proposed for the design of delay filters. Both minimum phase and non-minimum-phase cases are included. Design examples show that the agreements between the results obtained by theory and experiment are excellent.

INTRODUCTION

As linearization architecture, feed forward technique for power amplifiers has been used for decades [1]. In this technique, error signals (third order inter-modulation products) are extracted, amplified and used for the cancellation of the delayed main line distorted signals [2]. Especially, with recent "smart" digitally controlled attenuators, phase shifters and multi-loop cancellations, the third order intermodulation can be controlled to be -65dBc [3]. Therefore, it has been adopted widely in the wireless industries, and migration to other systems such as satellite communication systems, is ongoing [2].

The ever increasing demands of high quality feed forward power amplifiers in wireless communication systems have stimulated the authors' reconsideration of the delay lines used in this technique. They are bulky and dissipative, and could consume 30 percent output power of the amplifiers.

The delay lines used in the amplifiers can be replaced by delay filters which have been studied as a class of filters for decades [4]. Due to the resonant properties of filters, conventional design will end up with either too many sections or poor phase linearity. This makes it difficult to meet the requirement of high quality linear power amplifiers.

Filters with concerns on both amplitude and group delay have been reported by Rhodes [5]-[7], Atia and Williams [8]. In these works, some theories and techniques are established for the synthesis of linear phase filters in which internal phase equalizers are realized by additional degrees of freedom of filters, i.e., nonadjacent couplings [9]. Great improvement can be achieved for the phase linearity by these techniques.

Due to its time delay purpose, the absolute group delay and phase linearity (or group delay flatness) are the most important parameters for a delay filter. The amplitude property in the interested band is kept as close to equiripple as possible, while it is not so important in the stop band. These requirements lead to the development of a design procedure which can be summarized as follows.

FORMULATION

A. Minimum Phase Case Denoting the poles of a Chebyshev transfer function as σ_k+jx_k in the complex plane [10], the group delay of a coupled line Chebyshev response band pass filter can be written as

$$T_d(f) = \frac{\sin(\frac{\pi}{2}\frac{\omega}{\omega_0})}{4f_0\sin(\frac{\pi}{2}\frac{\Delta\omega}{2\omega_0})}\sum_{k=1}^{n}\frac{\sigma_k}{\sigma_k^2+(x-x_k)^2} \qquad (1)$$

where n is the order of the filter, ω_0 is the center angular frequency, ω_1 and ω_2 are the upper and lower band edges.

An empirical expression of (1) at mid band for 0.01dB ripples is

$$T_d(f_0) = \frac{1.375 + 0.821n + 0.008n^2}{4f_0}\alpha \qquad (2)$$

where $T_d(f_0)$ is in ns, Δf is in GHz.

The order of the filter needed is determined by

$$n \geq 1.674 + 1.16[T_d(f_0)4f_0/\alpha] \\ 0.009[T_d(f_0)4f_0/\alpha]^2 \qquad (3)$$

Phase linearity referred to the midband group delay can be approximated by

$$\Delta\phi_{lin} \approx 120[T_d(f_a) - T_d(f_0)]\,|f_a - f_0| \qquad (4)$$

where f_a is the bandedge of the required linear phase region. It should not be close to the band edges of the filter. $\Delta\phi_{lin}$ is in degree.

Phase linearity referred to the mean value of group delay in the interested band can be approximated by

$$\Delta\phi_{p-p} \approx 35.6[T_d(f_a) - T_d(f_0)]\,|f_a - f_0| \qquad (5)$$

Given group delay, phase linearity (or delay flatness) and frequencies , (1) - (5) can be used for the determination of the order and bandwidth of Chebyshev response coupled line filters. Traditional synthesis techniques can then be applied.

B. Non-minimum Phase Case Due to its superior group delay properties, even degree generalized interdigital filters are preferred for delay filters. The low-pass prototype network [5] is shown in Fig. 1. The generalized interdigital filter [6] can be obtained through the frequency transformation. The physical view of an eight degree generalized interdigital filter is shown in Fig. 2.

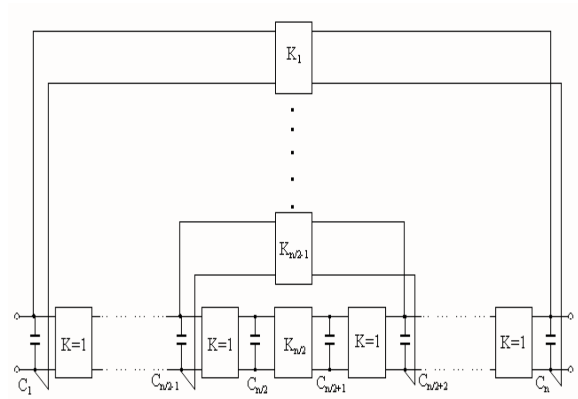

Fig.1. The symmetrical even-degree non-minimum phase low pass prototype network

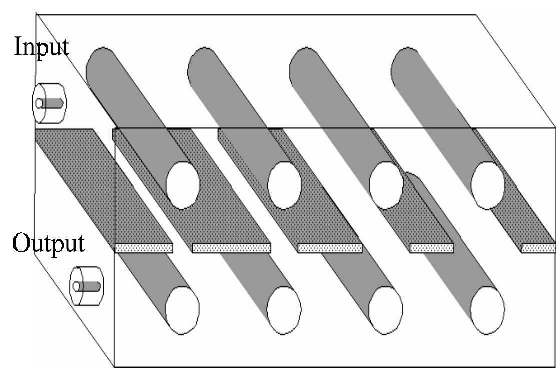

Fig.2 Physical view of the generalized interdigital filter

Extensive optimized design data (equi-ripple passband amplitude and constant group delay in the sense of least squares) for the low-pass prototype can be found in Cloete's work [11].

For the fully cross coupled, 0.01dB ripples, optimized group delay generalized interdigital filter, the mean group delay can by found to be

$$T_{avg} = \frac{2.93 + 1.253n + 0.006n^2}{4f_0}\alpha \qquad (6)$$

where the deviation of the group delay from the mean value is less than 0.1ns over 90 percent passband.

The order (even) of the filter can be obtained by

$$n \geq 2.333 + 0.776\,[T_{avg}4f_0/\alpha] - 0.002\,[T_{avg}4f_0/\alpha]^2 \qquad (7)$$

Finally, the design procedure in [6] and the curves in [12] can be used to evaluate the electrical values and the physical dimensions in Fig. 2, respectively.

DESIGN EXAMPLES

The specifications of a PCS band delay filter is as following

Group Delay: 8ns
Phase Linearity: ±1 Deg. (p-p)
Center Frequency: 1960MHz
Bandwidth: 120MHz

The equalized bandwidth of (6) is 90 percent of the bandwidth of the filter. Therefore, the bandwidth of the filter should be at least 120/0.9 = 133MHz. With this bandwidth, the order of the filter can be found to be 6 by (7). Substitute the order of the filter and group delay in (6), the accurate bandwidth of the filter can be found to be 191MHz. This means that the delay of the filter will be 8ns over 191×0.9= 172MHz if the group delay is optimized and the ripples are kept 0.01dB.

Fig. 3 and Fig. 4 show the responses of the synthesized filter. The measured results are shown in Fig. 5 and Fig. 6. Excellent agreements are obtained.

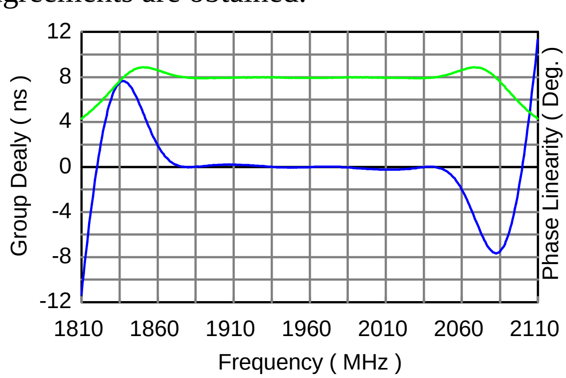

Fig. 3. Group delay and phase linearity of the delay filter

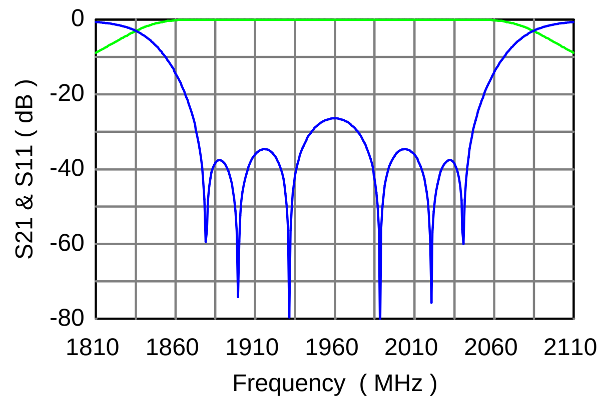

Fig. 4. Inseration loss and return loss of the delay filter

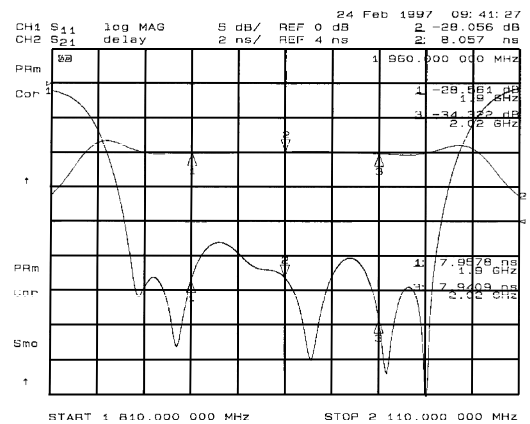

Fig. 5. Measured group delay and return loss of the delay filter

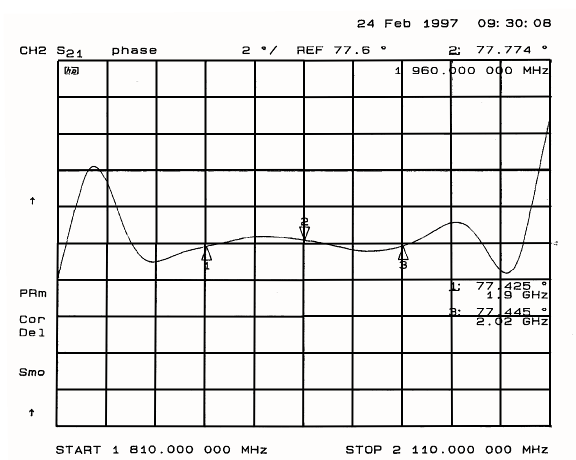

Fig. 6. Measured phase linearity of the delay filter

Another 16ns delay filter with the same specifications as above has been synthesized.

The responses of the theory and measurement are shown in Fig. 7 - Fig. 9.

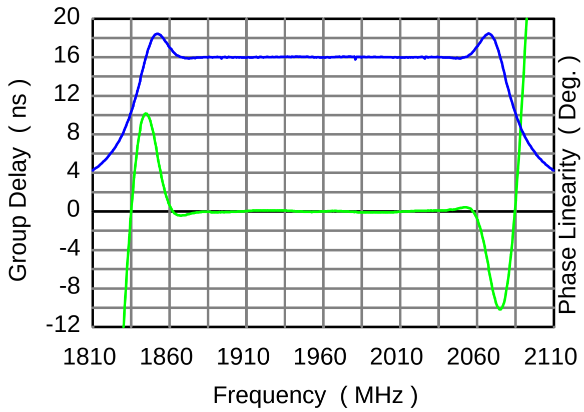

Fig. 7. Group delay and phase linearity of the delay filter

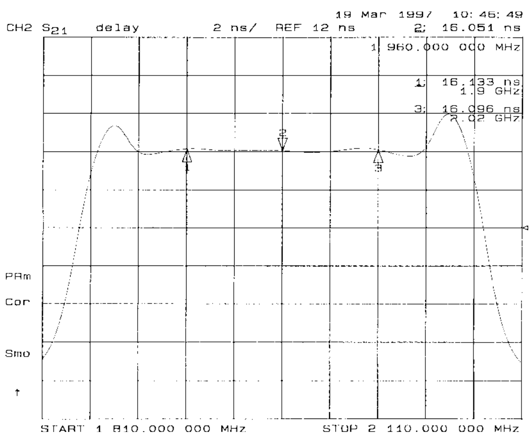

Fig. 8. Measured group delay of the delay filter

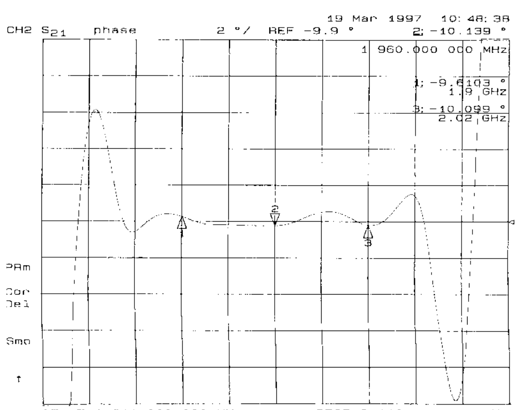

Fig. 9. Measured phase linearity of the delay filter

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