Spectral Estimation Techniques for Faster TLM Analysis

(Channabasappa Eswarappa and Wolfgang J.R. Hoefer)

The time domain numerical methods such as the Transmission Line Matrix (TLM) and Finite Difference-Time Domain (FD-TD) methods require a very large computer CPU time and memory. The shorter the input excitation pulse, the larger is the time required to reach the convergence. Also the narrow band structures such as filters require a larger number of iterations to converge because of multiple reflections. Recently, the spectral estimation techniques have been applied in conjunction with time domain numerical methods to reduce the CPU time. The idea is to predict the future time samples from the past time samples, or, to estimate the transfer functions from the knowledge of a lesser number of time samples. We have applied Prony's, autoregressive (AR), and autoregressive moving average (ARMA) models for various kinds of microwave structures.

1. Prony's Method:

In this method, a signal in the time domain is represented as a sum of complex exponentials representing damped sine waves:

$$u(n\Delta t) = \sum_{k=1}^{p} A_k e^{j\phi_k} e^{(\alpha_k + j2\pi f_k) n\Delta t}, n = 1, 2, \ldots, N \qquad (1)$$

where A_k is the modal amplitude, ϕ_k is the modal phase, α_k is the damping factor in seconds^{-1}, f_k is the resonant frequency in Hertz of the mode, p is the order of the model (equal to twice the number of resonant modes). From the knowledge of these modal parameters, the time and frequency responses of the given signal can be computed using the analytical equations.

We have applied the above method to a five-section microstrip interdigital filter shown in Fig. 1. The first 30,000 TLM time samples of the output port response of the filter were sampled at a rate of 1 in 200 to obtain 150 samples for Prony's method. The modes computed using Prony's method using these samples are given in Table 1. Fig. 2 shows the insertion loss of the filter computed using these modal parameters without using the regular discrete Fourier transform. To get the same order of convergence, the discrete Fourier tranform requires 150,000 time steps. Therefore the savings in CPU time is five times.

2. AR and ARMA Techniques

a. AR Technique

An AR process for the time series u(n), u(n-1),...., u(n-M) satisfies the following difference equation:

$$u(n) + a_1 u(n-1) + a_2 u(n-2) + \ldots + a_M u(n-M) = v(n) \qquad (2)$$

where a_k are called the AR parameters, M is the order of the model and $v(n)$ is a white noise process. In the AR model the system is treated as an all-pole model, and it has an infinite impulse response (IIR). The AR parameters can be estimated using the Yule-Walker equations which make use of the autocorrelation functions of the data samples.The AR parameters can also be obtained by applying Least-Squares solutions. This technique does not require the autocorrelation functions.

b. ARMA Technique

The input and output time signals [x_k] and [y_k] of any discrete linear system are related by the following linear difference equation:

$$y_k = \sum_{n=0}^{L} b_n x_{k-n} - \sum_{n=1}^{L} a_n y_{k-n} \quad (3)$$

where L is the order of the system. The transfer function of this discrete model (digital filter) can be computed from the ARMA coefficients [a_k] and [b_k].

We have used the pure order recursive least-squares ladder algorithm to estimate the ARMA coefficients. This algorithm requires only the auto- and cross-variances of the input and output data sequences. The ARMA model is derived through a two-channel AR predictor. The parameters of this two-channel AR predictor are obtained from the ladder reflection matrices using Levinson-type recursion.

The above AR and ARMA techniques have been applied to a three-section Ka-band (WR 28) waveguide bandpass filter. The filter was excited with a cosine modulated Gaussian pulse. The response obtained at the output port of the filter is shown in Fig. 3. First the TLM time responses are sampled at the rate of 1 in 100 . It was found that 100 TLM samples (that means 10,000 iterations) are needed to estimate 50 AR parameters using the linear least-squares solution to the system of equations formed by (2). For ARMA modeling, 200 samples were required. The insertion loss computed using AR, ARMA and the discrete Fourier transform (DFT) of 50,000 original TLM samples have been plotted in Fig. 4.

The details of this project are reported in the following papers:

[1] C. Eswarappa and W.J.R. Hoefer, “Application of autoregressive (AR) spectral estimation technique for faster TLM analysis of microwave structures”, in 1994 IEEE MTT-S Digest, San Diego, CA, May 23-27, 1994.IEEE AP-S Digest, Seattle, WA, June 19-24, 1994.

[2] C. Eswarappa and W.J.R. Hoefer, “Characterization of microwave structures using ARMA system identification and TLM method”, in 1994

[3] C. Eswarappa and W.J.R. Hoefer, “Fast S-parameter computation of a microstrip interdigital filter using TLM, Prony’s and digital filtering techniques”, to be submitted for publication in the International Journal of Numerical Modeling.

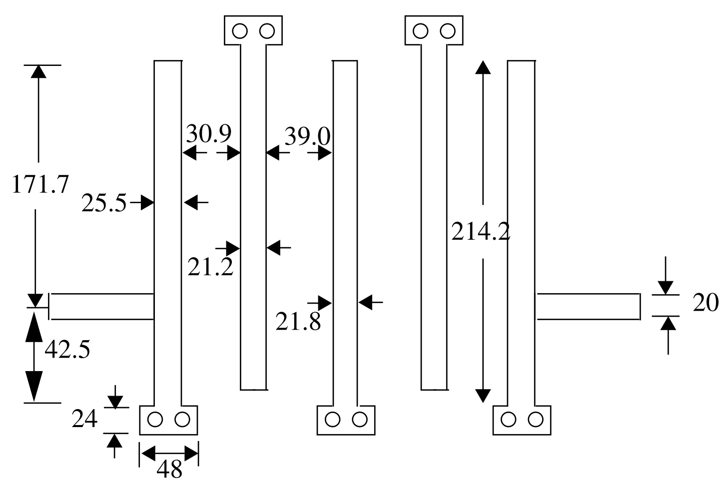

Fig.1: A microstrip interdigital filter (all dimensions are in mils).
substrate thickness = 15 mils, dielectric constant = 9.8.

Mode Number	Frequency [GHz]	Damping Factor	Amplitude	Phase [rad]
1	4.5017	-0.0173	0.06697	-1.3477
2	4.6547	-0.0402	0.2439	1.987
3	4.7461	-0.0265	0.1826	-1.0789
4	4.8487	-0.0060	0.22389	2.1024
5	4.8776	-0.3044	0.22022	-1.2484

Table 1:Modal parameters obtained by Prony's method for the microstrip filter.

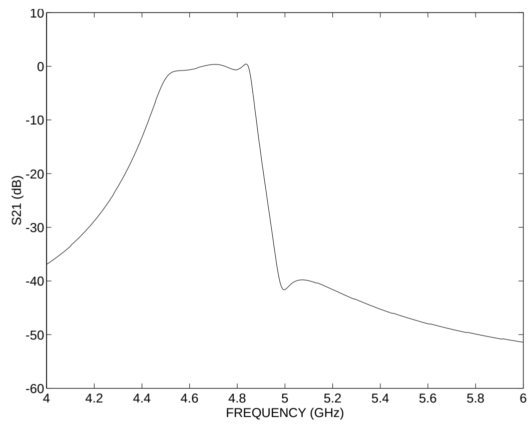

Fig. 2: Insertion loss of the microstrip filter computed by using the Prony-analytica equation without using discrete Fourier transform.

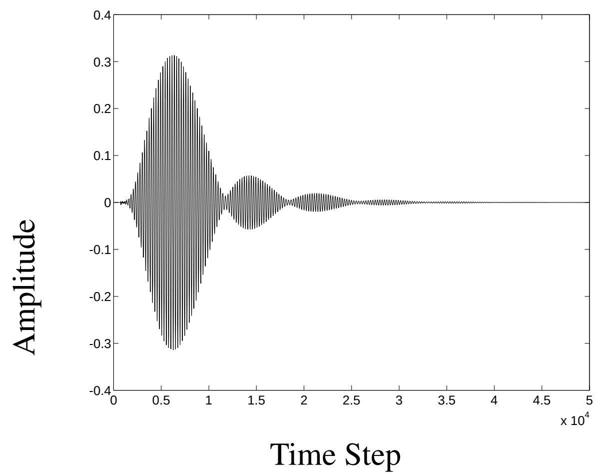

Fig. 3: Transmitted wave obtained at the output port of the Ka-band waveguide bandpass filter using the TLM method.

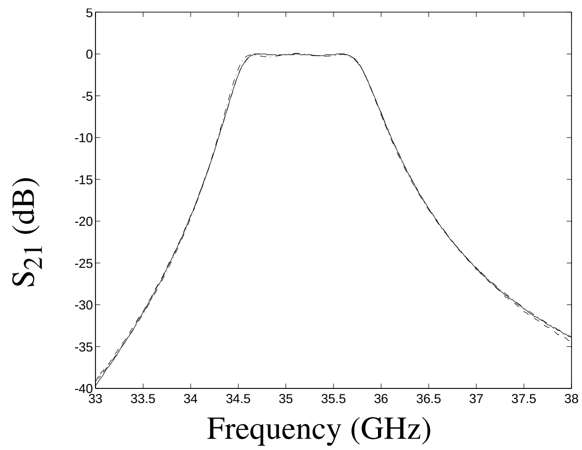

Fig. 4: Comparison of S21 of the filter obtained by (TLM + AR), (TLM + ARMA) and (TLM + DFT) method: - TLM+AR, - - TLM, -.- TLM+ARMA.