A Comprehensive System Based UWB Antenna Optimizer

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ABSTRACT

This is a revolutionary method which overcomes many of the antenna system analysis problems associated with UWB communication. By using this method, the antenna system is analyzed from the viewpoint of antenna to antenna transfer function, which makes it possible to consider the transmitting antenna and receiving antenna as a complete unit rather than individual element. The refined formulation of transfer function in rational polynomial can identify the poles and zeros of antenna system, which also make it possible to devise the antenna system together with filter circuit or signal processing so as to simplify the overall design of communication system.

INTRODUCTION

The imminent widespread commercial deployment of ultra-wideband systems has sparked renewed interest in the subject of ultra-wideband antenna. When using the very narrow pulses (in the order of 1 to 10 nanoseconds) over a bandwidth of several giga-hertz (complying with FCC power mask for UWB communicating), any part of system is correlated and should be considered together. The antenna system not only acts as transducer and receiver but also serves as significant pulse/power shaping filter. Thus, an analysis method that could give a comprehensive evaluation of antenna and as well as facilitate the integrated design with other component will give rise to significant simplicity of overall system. In this paper, the rational transfer function is used to analyze the UWB antenna together with the system as a whole.

Rational transfer function is an innovative attempt to represent the overall performance of antenna system. By the employment of transfer function, the thorny problem on the incapacity of conventional parameters (such as return loss, gain, radiation patterns) for characterizing antenna working over the ultra-wide operating band is readily solved. Transfer function reflects a synthesized effect by taking into account the impedance matching, gain, popularization matching, and the distance between antennas. The main design objectives of the UWB antenna such as effective isotropic radiated power (EIRP) and pulse fidelity can be derived from the transfer function. In existing literatures, several authors have proposed transfer function definitions that are associated with the antenna system, which are either based on the concept of signal flow charts [1] or two port networks [2].

A rational transfer function is a form of transfer function in Lapalce domain consisting of numerator polynomials and denominator polynomials, whose coefficients can be determined by fitting simulation result. The overall performance of antenna can be characterized by a simple rational transfer function which yields the feasibility to combine the antenna with other components in the communication system rather than an independent part as in conventional design. The perspective of antenna is not confined to a transmitting or receiving element, it also performs a significant portion of the filtering required for the system. With rational transfer function of antenna, the pulse shaping, EIRP stabilizing or integrated design with circuitry will not be challenges any more. These can be readily solved in a general way of filter design which results in simplification and enhancement of overall system.

Another key advantage of this method is the application of model-based method [3] to reduce the time taken to compute the transfer function at each selected frequency over an ultra-wide band. In this method, only a few parameters at relatively large frequency intervals are directly computed using method of moment (MoM). These parameters are then used to interpolate the other parameters at the intermediate frequencies approximated by a rational polynomial.

AN ANALYSIS METHOD USING RATIONAL TRANSFER FUNCTION

In general, rational transfer function is defined as complex valued rational polynomials over a concerned frequency range. The derivation of rational function is based on model based parameter estimation method (MBPE). MBPE is a numerical process used to circumvent the requirement of obtaining all samples of desired quantities from calculated or measured data instead of using an order reduction, physical based approximation of sampled data called a fitting model. In this case, the rational polynomial is chosen as fitting model and parameters are estimated by a curve fitting technique based on simulation result from MoM calculation. The complete process consist of two main steps:

1) MOM method is used to calculate the transfer function

A MATLAB code [4] is implemented to calculate the transfer function of antenna system by MoM relying on Rao-Wilton-Glisson (RWG) edge element [5]. The overall simulation of antenna system includes two parts: transmitting antenna and receiving antenna which may or may not be identical. The effect of the interaction of these two parts can be numerically represented by the ratio of received voltage to the input voltage that constitutes the antenna-to-antenna transfer function. MOM calculation is not optimal because of the enormous computation time. In order to solve this problem, in this method, only small portion of transfer function is calculated directly at certain frequencies, the others can be interpolated by using a rational polynomial at the intermediate frequencies.

2) Curve fitting method is used to derive the rational transfer function

A rational polynomial given by (1) is used for transfer function fitting model.

$$H(\omega) = \frac{\sum_{k=0}^{m} a_k s^k}{\sum_{k=0}^{n} b_k s^k} \qquad (1)$$

The transfer function model $H(\omega)$ is evaluated along complex frequency domain s= $j\omega$. The a_k and b_k are the coefficient of numerator and denominator polynomial with orders, m and n respectively. The estimation of coefficients is a process of curve fitting to minimize the error between the analytic model and available data as possible over a chosen frequency band. The error between the modeling value in (1) and the simulation value h_i at selected i^{th} frequency ω_i can be written as (assuming b_n =1):

$$e_i = \sum_{k=0}^{m} a_k (j\omega_i)^k - h_i \left[\sum_{k=0}^{n-1} b_k (j\omega_i)^k + (j\omega_i)^n \right] \qquad (2)$$

Note that an error vector can be developed by expanding the summations in (2), the generic form (2') can be expressed by vector-matrix under the assumption that the number of sampled frequency set to L:

$$\{E\} = [P]\{A\} - [T]\{B\} - \{W\} \qquad (2')$$

$$where:$$

$$[P] = \begin{bmatrix} 1 & j\omega_1 & \dots & (j\omega_1)^m \\ 1 & j\omega_2 & \dots & (j\omega_2)^m \\ \vdots & \vdots & \vdots & \vdots \\ 1 & j\omega_L & \dots & (j\omega_L)^m \end{bmatrix}$$

$$[T]=\begin{bmatrix} h_1 & h_1(j\omega_1) & \dots & h_1(j\omega_1)^{n-1} \\ h_2 & h_2(j\omega_2) & \dots & h_2(j\omega_2)^{n-1} \\ \vdots & \vdots & \vdots & \vdots \\ h_L & h_L(j\omega_L) & \dots & h_L(j\omega_L)^{n-1} \end{bmatrix}$$

$$\{A\}=\begin{Bmatrix} a_0 \\ a_1 \\ \vdots \\ a_m \end{Bmatrix},\{B\}=\begin{Bmatrix} b_0 \\ b_1 \\ \vdots \\ b_{n-1} \end{Bmatrix},\quad \{C\}=\begin{Bmatrix} h_1(j\omega_1)^n \\ h_2(j\omega_2)^n \\ \vdots \\ h_L(j\omega_L)^n \end{Bmatrix}$$

To identify the approximation, error criterion should be defined first. In this paper the most familiar square error criterion is chosen:

$$J=\sum_{i=1}^{L} e_i^* e_i = \{E^*\}^T\{E\} \qquad (3)$$

$$\begin{aligned} &where: L = number\ of\ sampled\ frequency \\ &\quad * \quad denotes\ complex\ conjugates \\ &\quad T \quad denotes\ transpose \end{aligned}$$

With the ideal value of a_k and b_k, the J should be at it's minimum point where the derivatives of J with respect *{A}* and *{B}* should equal to zero according to necessary condition.

$$\frac{\partial J}{\partial A}=0; \qquad \frac{\partial J}{\partial B}=0 \qquad (4)$$

Therefore, a set of linear equations can be obtained and the coefficients can be identified by the solutions. However, these linear equations are generally ill-conditioned resulting in the difficulty to resolve. In order to circumvent this problem, the rational function is re-formulated in terms of orthogonal polynomials as depicted in [6] at length. Once the orthogonal polynomials coefficients are known, the coefficients in (1) can be transformed from orthogonal ones easily [7]. Hence, the rational function can be obtained and the poles and zeros of the transfer function can be determined by solving for the roots of the both the numerator and characteristic polynomials.

EXPERIMENTAL RESULT AND ANALYSIS

As mentioned before, the investigated antenna system is firstly modeled by Method of Moment with MATLAB. The frequency range is chosen as UWB operating band from 3.1GHz ~ 10.6GHz. The transfer function is calculated at each sampled frequency. To examine efficiency and accuracy of the proposed rational transfer function method for solving antenna problems over wide frequency band, a numerical example of a well known antenna is considered.

Bowtie antenna

This is a simple model of bowtie antenna with height and apex angle equals *h=10xm* and $\alpha=90°$ (Fig.1). In this case, the rational function with order *N=M=7* is used. This implies 15 transfer function points (number of samples=M+N+1) are needed to fit the rational polynomial. In Fig.2 and 3, the numerical data obtained using rational function is compared with the exact solution calculated by MoM.

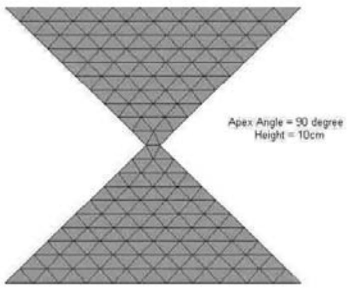

Fig.1 Meshed model of bowtie antenna

The results show good agreement. It was also found that the method is significantly faster than the applying the ordinary MoM solution, for example, in order to represent the transfer function in UWB band, it needs at least 45 points for bowtie antenna, but only small portion of sampled transfer function (15 points) is calculated by this method, as a result, the speed is accelerated by 3 (45/15) times faster. The number of frequency samples for which the quantity of interest must be obtained is dependent on the structure and bandwidth under investigation

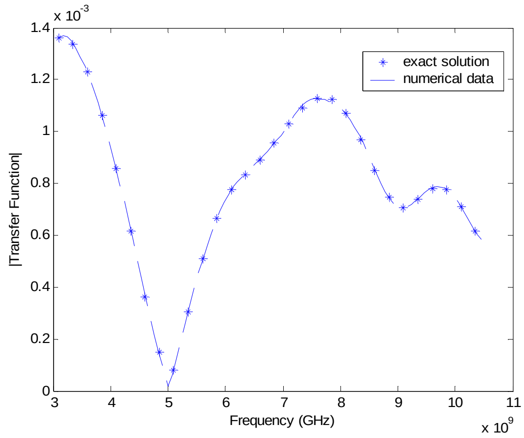

Fig.3 Magnitude of rational transfer function

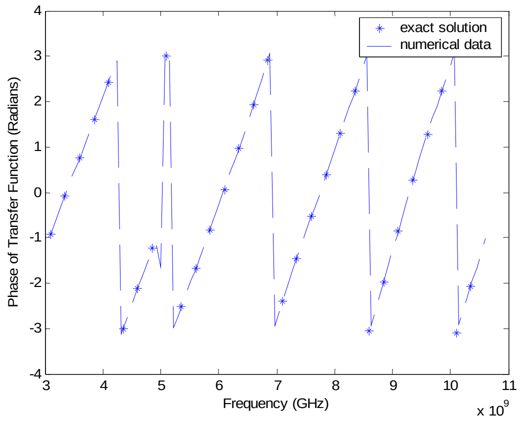

Fig.4 phase of rational transfer function

CONCLUSION

A fast and efficient method for UWB antenna system analysis -rational transfer function has been discussed in this paper, which can characterize the overall antenna system. And with the rational transfer function, poles/zeros can be identified and the integrated design with other parts of the communication system can be constructed. Furthermore, for some specific requirement of UWB communication system such as EIRP, the bandwidth under consideration is not restricted to operating band in order to investigate the interference with other communication systems, the extrapolation of transfer function can speed up the solution of this problem.

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