TIME DOMAIN ANALYSIS AND DETECTION OF DISCONTINUITIES IN ELECTROMAGNETIC CIRCUITS USING A MULTIDIMENSIONAL MUSIC ALGORITHM

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1. INTRODUCTION

In this paper, we apply a multidimensional MUSIC algorithm [1,2] (MDM) to detection of discontinuities included in electromagnetic circuits (device under test, DUT). The MDM is the superresolution methods of spatial spectrum estimation and is an extension of the eigenvector subspace approach, MUSIC algorithm [3]. The MDM may detects the discontinuities (reflection points) using narrower frequency bandwidth than that of a Fast Fourier Transform (FFT) method. At first, we explain the MDM briefly. Then, we show the experimental results and compare the bandwidths required to detect the discontinuities by the MDM and the conventional FFT equipped in the network analyzer system, HP8510B.

2. Multidimensional Method (MDM)

Data obtained by the HP8510B network analyzer system are frequency characteristics of reflection or transmission at sampling frequencies. Furthermore, reflected waves from discontinuities are the unmodulated sinusoidal ones generated by the same sweep oscillator. Therefore, they are completely correlated, a condition referred to as coherent. The MUSIC algorithm does not work properly in a coherent or highly correlated signal environments. In this paper, we apply MDM, which overcomes such coherent signal environments, for estimating discontinuities in DUT and reflection coefficients. The covariance matrix, **R**, which is computed from data measured in the coherent signal environments, has only one unique signal eigenvalue and the other noise ones which are as large as the thermal noise power. Now, $\mathbf{E}_N$ denotes a matrix composed of eigenvectors corresponding to noise eigenvalues of **R**. In the coherent signal environment, $\mathbf{E}_N$ is orthogonal to the linear combination of the mode column vectors and is not orthogonal to the individual mode vectors which give a position of the discontinuities in DUT. In the MDM, the discontinuities are detected by searching the peak position of Pmusic given by

$$\mathrm{Pmusic} = \left\{ \min_{\mathbf{C}} \frac{\mathbf{C}^H\mathbf{A}^H\mathbf{E}_N\mathbf{E}_N{}^H\mathbf{A}\mathbf{C}}{\mathbf{C}^H\mathbf{A}^H\mathbf{A}\mathbf{C}} \right\}^{-1}, \qquad (1)$$

where $\mathbf{A}=[\mathbf{a}(t_1), \mathbf{a}(t_2), \cdots, \mathbf{a}(t_D)]$. $\mathbf{a}(t_i)$ ($i=1, 2, \cdots, D$, where D denotes the estimated number of discontinuities and the number of the dimensions in MDM) denotes the mode column vector, t_i an estimated round-trip time between a reference point and a reflection point, **C** a column vector formed from complex linear combining constants, and ^{H} a complex conjugate transpose, respectively. Equation (1) implies that for each reflection point, t_i is obtained by taking the minimum of the term in braces over all possible values of **C**. The solution of the equation (1) can be computed as the minimum root of the following quadratic equation in λ.

$$\det\{\mathbf{A}^H\mathbf{E}_N\mathbf{E}_N{}^H\mathbf{A} - \lambda\ \mathbf{A}^H\mathbf{A}\} = 0. \qquad (2)$$

Then, the equation (1) is rewritten as

$$\text{Pmusic} = \{\text{min root of } \lambda \text{ in the equation (2)}\}^{-1}. \qquad (3)$$

When we apply the MDM to the data in the ideal coherent signal environment, Pmusic exhibits sharp peaks indicating coherent reflection pairs.

3. Experimental results and estimation of the discontinuities in DUT

Fig.1 shows the configuration of the measurement system. We used the HP9816 desktop computer as a system controller which measures and stores the data of reflection characteristics of the DUTs. The stored datas were sent to the desktop super-mini computer "HP9020B" and were used for the estimation of the discontinuities. In our experiments, we measured two DUTs. At the first measurement, we used a semi-rigid coaxial cable of about 16cm which terminates with a dummy. Fig.2 shows the FFT results given by the time domain analysis of the HP8510B with the narrowest bandwidth to resolve the two reflection points. A horizontal axis denotes the round-trip time corresponding to the two reflection points. From this figure, it is apparent that there are two reflection points at t_1=0.0nsec and t_2=1.618nsec. The minimum frequency bandwidth which is needed to detect the two distinct reflection points is 1.5GHz. Then, Fig.3 shows the results of the MDM (two dimensional search). In this figure the horizontal axis denotes the first reflection position t_1, and the vertical axis shows the second reflection point t_2 (dotted line) and logarithm scale of Pmusic (solid line). Furthermore, three values of N which denotes the dimension of **R** are used in the estimation. In this case we measured 685 data sets to compute the covariance matrix **R** which is averaged by them. Table 1 shows the minimum bandwidth with which the reflection points are estimated. From Figs.2 , 3 and table 1, it is clear that MDM permits the estimation of the reflection position with only about 1/25 of the bandwidth of the FFT analysis.

For the second measurement we used another semi-rigid coaxial cable of about 25cm which includes another discontinuity other than two connection ports. Also, it terminates with the dummy. Fig.4 shows the HP8510B FFT analysis result for the DUT. It is seen from this figure that there are three reflection points at t_1=0.05nsec, t_2=2.31nsec and t_3=2.61nsec. In this case the estimation is done by using the frequency bandwidth of 6GHz (10-16GHz). Using the three dimensional MDM, we find three reflecting points with the frequency bandwidth of 0.36GHz (10-10.36GHz). 999 measurement data sets were used to compute the covariance matrix **R**. Fig.5 shows the result of the MDM estimation. One more line which denotes the third reflection point t_3 is drawn in this figure, comparing with Fig.3. Now we find the only one peak of Pmusic and three reflection points at t_1=0.05nsec, t_2=2.35nsec and t_3=2.76nsec. This result presents the fact that MDM is useful to estimate discontinuities in DUT as the bearing estimation in a correlation signal environment. Compared with the FFT analysis of the HP8510B shown in Fig.4, the MDM needs only 1/17 of the frequency bandwidth for the estimation.

4. Conclusion and Summary

In this paper we have presented that the MDM is useful for the estimation of discontinuity positions in the DUT as for the bearing estimation in the coherent signal environment and that the MDM estimation needs narrower frequency bandwidth than that of the FFT analysis. Furthermore, if we eliminate causes of the estimation errors, the MDM gives more superior estimation performances.

Acknowledgment

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References

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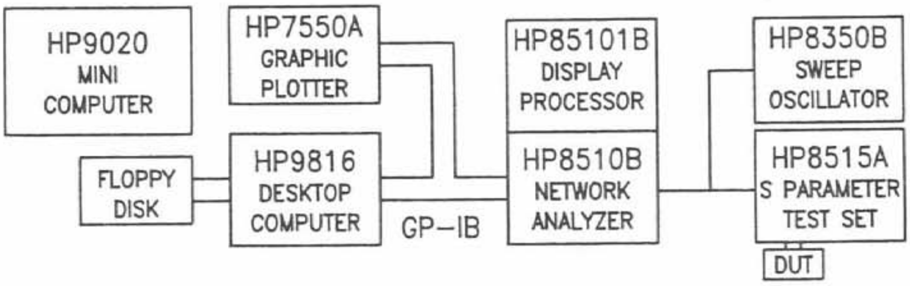

Fig.1-Configuration of the measuring system.

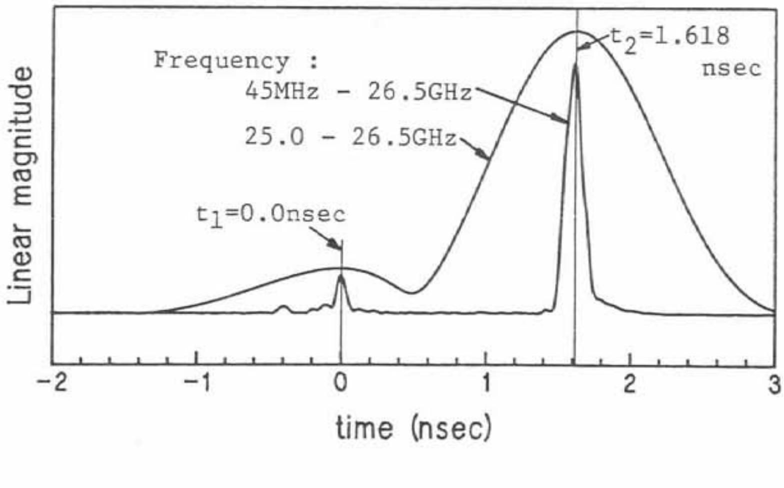

Fig.2-FFT analysis for the case of two reflection points.

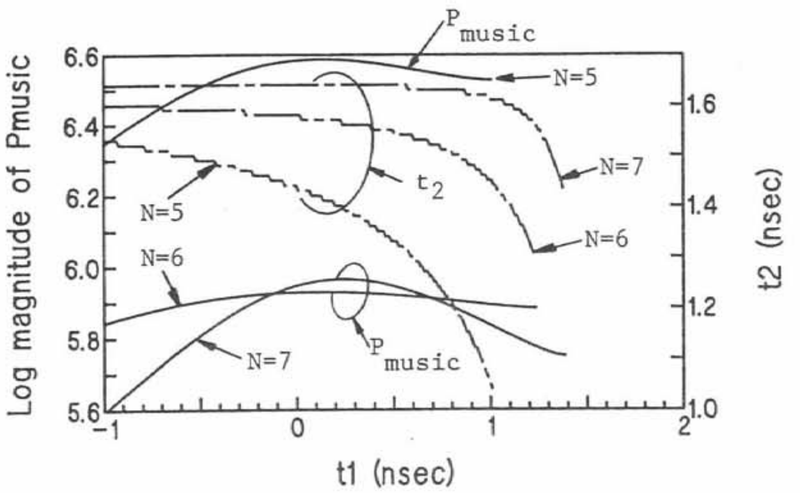

Fig.3-MDM analysis for two dimensional case.

Table 1-Required frequency bandwidth for the estimation.

N	Required Bandwidth	Estimated Reflection points
7	78MHz(26.1-26.178GHz)	(0.24, 1.64)
6	65MHz(26.1-26.165GHz)	(0.11, 1.57)
5	60MHz(26.1-26.160GHz)	(0.11, 1.42)

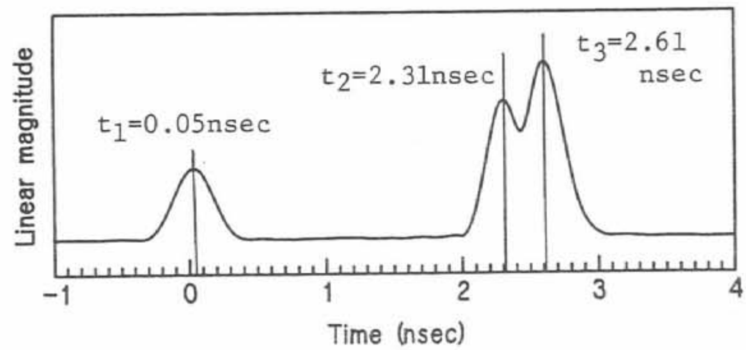

Fig.4- FFT analysis for the case of three reflection points.
Frequency bandwidth : 6GHz (10-16GHz).

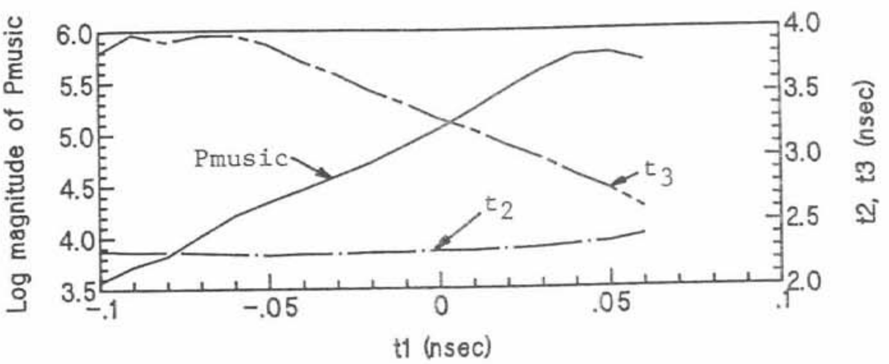

Fig.5- MDM analysis for three dimensional case.
Frequency bandwidth : 0.36GHz (10-10.36GHz), estimated reflection points : t1=0.05nsec, t2=2.35nsec, and t3=2.76nsec.