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# Comparison of Antenna Poles Extracted From Radiated and Scattered Fields

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**Abstract**—This paper presents a new approach of antenna characterization by applying Singularity Expansion Method to Radar Cross Section Measurements. Poles extracted from the radiated field are compared to poles extracted from the scattered field of a dipole antenna. The scattered field is simulated for three different load conditions. Poles extracted from the scattered field of the dipole antenna in matched condition seem to be the closest to those extracted from the radiated field.

**Index Terms**— Complex Natural Resonance, Matrix Pencil, Radiated field, Scattered field, Singularity Expansion Method

## I. INTRODUCTION

Since many years, the Singularity Expansion Method (SEM) [1], introduced by C. E. Baum in 1971, is studied to be applied to target identification. In fact, SEM represents a solution of an electromagnetic problem in terms of singularities (poles). Since singularities are independent of the direction of the incoming wave, it makes this method useful for scatter identification. More recently, this method has been applied in both time and frequency domains to model antenna effective length, in order to fully describe the antenna pattern, directivity and gain using only a few set of parameters (poles, also known as Complex Natural Resonances, and residues) [2] [3]. Another way to characterize antennas is to use Radar Cross Section (RCS) measurements [4]. This allows avoiding disturbing feeding cable and is very useful especially for small antennas. The main idea of this paper is to apply SEM post processing to RCS measurements to take advantages of these two methods. To verify this approach, the first step is to compare poles extracted in radiation condition to those extracted in scattering condition.

In section II, we briefly describe the SEM theory and Matrix Pencil algorithm. In sections III and IV, poles extracted from the scattered field of a dipole antenna and a bowtie antenna are presented and compared to those extracted from the radiated field of the same antennas in a given direction.

## II. SEM THEORY

SEM allows modeling the late time response of an antenna as

$$y_k \approx \sum_{n=1}^N R_n e^{s_n k}, \quad (1)$$

where  $N$  is the number of poles,  $k = 0, 1, \dots, K - 1$ ,  $K$  is the number of sampled data ( $K > 2N$ ),  $R_n$  are the residues and  $s_n$  are the poles ( $s_n = \sigma_n \pm j\omega_n$  with  $\sigma_n$  the damping coefficient and  $\omega_n$  the resonant pulsation). There are several

methods to extract poles and residues like Prony [5] and Matrix Pencil [6] in time domain and Cauchy [7] in frequency domain. These methods have different noise sensitivity and have already been compared applied on noisy antenna responses [8-9]. Matrix Pencil is more computational and gives the best results in presence of noise. Poles and residues are extracted here with the Matrix Pencil method using the Total Least Square approach based on a Singular Value Decomposition.

## III. APPLICATION ON DIPOLE ANTENNA FIELDS

A  $L = 33.75$  mm long dipole is simulated using CST Microwave Studio (MWS) [10] between 1 and 20 GHz. Its diameter is  $D = 1.12$  mm ( $L/D \approx 30$ ).

### A. Radiated Field

Matrix Pencil method is first applied on the radiated field of the dipole antenna. Results are presented in Fig. 1.

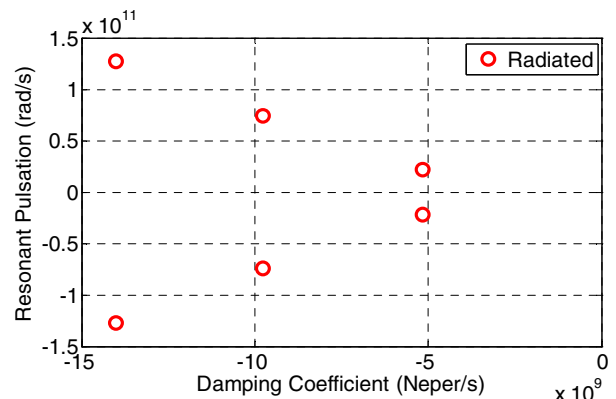


Figure 1. Poles extracted from radiated field in complex plane.

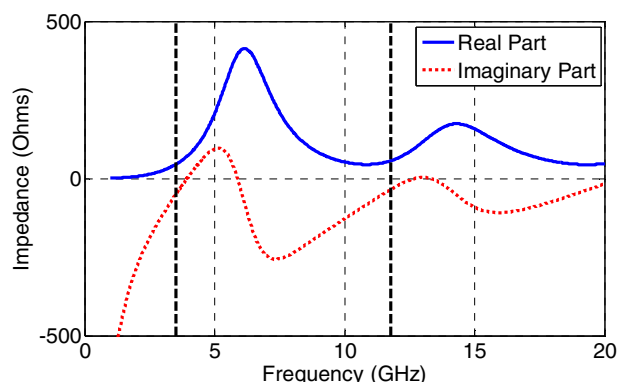


Figure 2. Impedance of the dipole antenna.

Resonant pulsations correspond to  $\lambda/2$ ,  $3\lambda/2$  and  $5\lambda/2$  resonances of the dipole antenna. Resonant pulsations of the two first poles are represented with a black dashed line on the impedance of the dipole antenna in Fig. 2. They correspond to the natural resonances of the dipole antenna. Using these poles, the late time of the radiated field is reconstructed and compared to the simulated one in Fig. 3. The reconstructed and simulated fields are very close (Normalized Mean Square Error (NMSE) fewer than 2 %). A 6 poles set is enough to accurately model the late time of the radiated field.

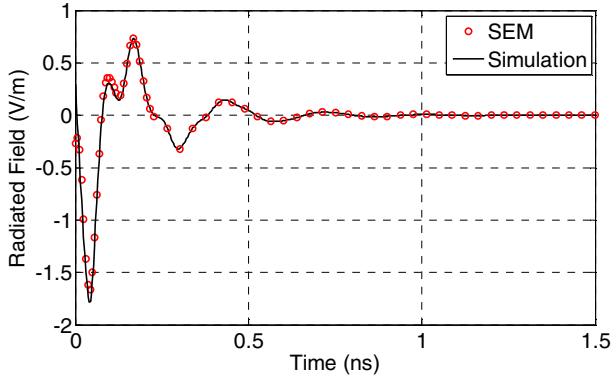


Figure 3. Electric field radiated by the dipole antenna in time domain.

### B. Scattered Fields

In this part, the Matrix Pencil algorithm is applied on the scattered field of the dipole antenna. Three different load conditions are simulated: short-circuited, open-circuited and matched. The matched case corresponds to a real load of  $73 \Omega$ . Scattered fields obtained in these three conditions are presented in Fig. 4.

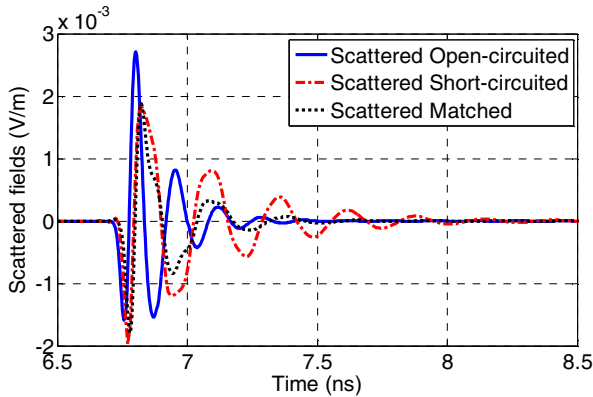


Figure 4. Electric field scattered by the dipole antenna in time domain.

The scattered field of the short-circuited dipole antenna takes more time to damp than the two other configurations. One reason could be the higher Q of the short-circuited dipole antenna in comparison to the open-circuited one. Matrix Pencil is applied on the late time of these responses. Poles extracted are presented in Fig. 5 and compared to those extracted from radiated field. For all cases, only three pairs of poles are extracted and Normalized Mean Square Error (NMSE) between the simulated field and the reconstructed field are less than 6 %.

Poles extracted from the short-circuited condition have almost same resonant pulsations than those from matched condition but damping coefficients are significantly different (from 3 to  $5 \cdot 10^9$  Neper/s) because a part of the energy is absorbed by the load. Moreover, as we can see in Fig. 4, the field in the short-circuited case is the slowest to damp, so damping coefficient are lower. On the other hand, resonant pulsations in the open-circuited case are higher than for the two other cases (around  $15 \cdot 10^9$  rad/s higher). In fact, in this case, the two parts of the dipole antenna are not connected and can be seen as two close small dipole antennas with some coupling effects between them. Poles extracted from radiated field and from scattered field are now compared. For poles extracted from the short-circuited condition, resonant pulsations are almost the same than from radiation condition (difference of 1 to  $3 \cdot 10^9$  rad/s according to the pole) but damping coefficients are significantly lower (up to  $5 \cdot 10^9$  Neper/s for the third pole). We can see that poles extracted from the matched case are very close to those extracted in radiation condition. In fact, resonant pulsations are almost the same and errors on damping coefficients are only from 0.5 to  $1.4 \cdot 10^9$  Neper/s.

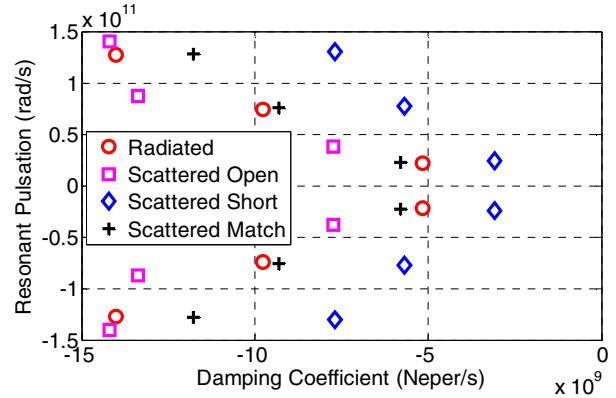


Figure 5. Poles extracted from fields scattered by the dipole antenna in complex plane compared to those obtained from radiated field.

## IV. APPLICATION ON BOWTIE ANTENNA FIELDS

We now consider a broadband bowtie antenna, simulated using CST MWS between 1 and 20 GHz. Its length is 33.7 mm and the flare angle is  $45^\circ$ .

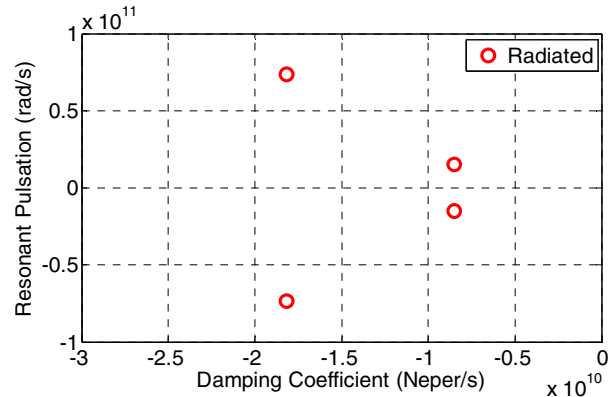


Figure 6. Poles extracted from field radiated by a bowtie antenna in complex plane.

### A. Radiated Field

Poles are first extracted from the field radiated by the bowtie antenna in the boresight direction. Results are presented in Fig. 6. Two pairs of poles are extracted from the radiated field. They correspond to resonances of the bowtie antenna. Resonant pulsations of bowtie antenna poles are represented with a black dashed line on the impedance of the bowtie antenna in Fig. 7. For the second pole, the imaginary part of the impedance is very close to zero. For the first pole, the imaginary part of the impedance is around -85 Ohms. At this frequency, the bowtie antenna is not well matched ( $S_{11} = -4$  dB), this can explain that the pole is less accurate. The late time of the field radiated by the bowtie antenna is then reconstructed using this set of poles. Results are presented in Fig. 8. The field is very well reconstructed and the NMSE is around 6%.

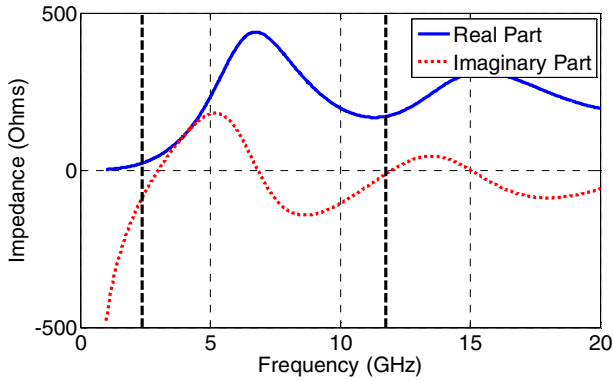


Figure 7. Impedance of the bowtie antenna.

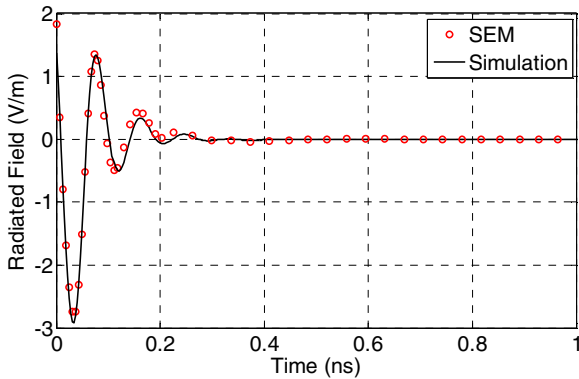


Figure 8. Electric field radiated by the bowtie antenna in time domain.

### B. Scattered Fields

In this part, the bowtie antenna is excited by a plane wave and the scattered field is computed. Three load conditions are simulated: short-circuited, open-circuited and matched. The matched case corresponds to a real load of  $200 \Omega$ . Results are presented in Fig. 9. As for the dipole antenna, the behavior of the scattered field is close when the bowtie is short-circuited or matched. Period seems to be similar but the scattered field damps more quickly for the matched case. For the open-circuited case, period seems to be around two times larger than the two other cases. Poles are extracted from these three scattered fields and results are presented in Fig. 10.

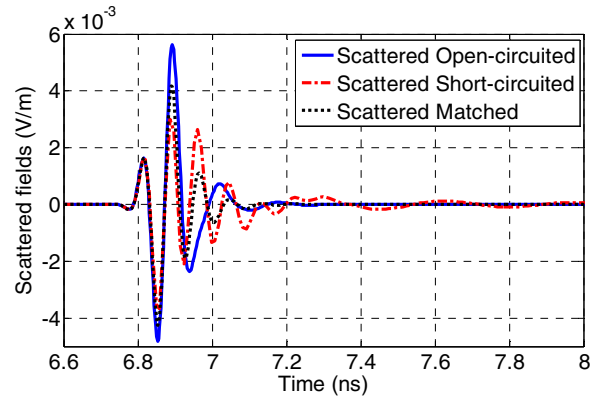


Figure 9. Electric fields scattered by the bowtie antenna in time domain.

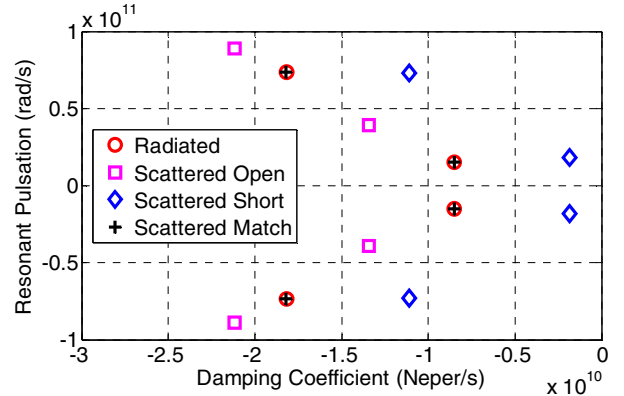


Figure 10. Poles extracted from fields scattered by the bowtie antenna in complex plane compared to those obtained from radiated field.

For the three cases, the NMSE of the reconstructed field is under 10% so each 4-poles set are enough to accurately model associated scattered field. Like for the dipole antenna, poles extracted for open-circuited case have higher resonant pulsations than for the two other cases (around 2.5 times higher). For the short-circuited case, resonant pulsations are identical to those extracted for matched case but damping coefficients are lower (around 0.6 Neper/s lower). Poles extracted from scattered field in matched condition and from radiated field match very well. The behavior of poles regarding the load condition is similar to the dipole antenna case.

## V. CONCLUSION AND PERSPECTIVES

Poles are only due to the antenna characteristics [1], so for the same load conditions, poles should be the same whatever the scattered or radiated field; only residues should be modified. In radiation condition, antennas are simulated using a matched lumped port. It explains that poles are very close when extracted from the radiated field and the scattered field in matched case.

We have shown that, for a matched dipole antenna and a match bowtie antenna, it is possible to obtain same poles from radiated field and scattered field. This constitutes a first step of a process to obtain radiation pattern and S parameters of an antenna, using poles extracted from scattered field. To our knowledge, this is the first comparison between antenna poles extracted from radiated and scattered fields.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] C. E. Baum, "On the singularity expansion method for the solution of electromagnetic interaction problems," EMP Interaction Note 8, Air Force Weapons Laboratory, Kirkland AFB, New Mexico, Dec. 1971.
- [2] S. Licul and W. A. Davis, "Unified frequency and time-domain antenna modeling and characterization," IEEE Transactions on Antenna and Propagation, vol. 53, No 9, pp. 2882–2888, Sep. 2005.
- [3] C. Marchais, B. Uguen, A. Sharaiha, G. L. Ray and L. Le Coq, "Compact characterisation of ultra wideband antenna responses from frequency measurements," IET, Microwaves, Antennas & Propagation, vol. 5, Issue: 6, pp. 671-675, 2011.
- [4] W. Wiesbeck and E. Heidrich, "Wide-band multiport antenna characterization by polarimetric RCS measurements," IEEE Transactions on Antennas and Propagation, vol. 46, pp 341-350, Mar. 1998.
- [5] R. Prony, "Essai expérimental et analytique sur les lois de la dilatabilité de fluides élastiques et sur celles de la force expansive de la vapeur d'alcool", *Journal de l'école polytechnique*, vol. 1, No 22, pp. 24-80, 1795.
- [6] Y. Hua and T. K. Sarkar, "Matrix pencil method for estimating parameters of exponentially damped/undamped sinusoids in noise," IEEE Transactions on Acoustics, Speech and Signal Processing, vol. 38, pp. 814-824, May. 1990.
- [7] A. L. Cauchy, "Sur la formule de Lagrange relative à l'interpolation", *Analyse Algébrique*, Paris, 1821.
- [8] F. Sarrazin, A. Sharaiha, P. Pouliguen, J. Chauveau, S. Collardey and P. Potier, "Comparison between matrix pencil and Prony methods applied on noisy antenna responses," Loughborough Antennas and Propagation Conference, pp 1-4, Nov. 2011.
- [9] F. Sarrazin, A. Sharaiha, P. Pouliguen, P. Potier and J. Chauveau, "Analysis of two methods of poles extraction for antenna characterization," Antennas and Propagation Society international symposium, pp 1-2, July 2012.
- [10] CST MicroWaves Studio, 3D Electromagnetic Field Simulation software, [www.cst.com](http://www.cst.com).