Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Antenna Design Using Characteristic Modes and Related Techniques.

Comments and Questions on the EuCAP presentation on, “Scattering Analysis for Arbitrarily Shaped bodies using Characteristic Modes,” by Y. Chen in the EuCAP’16 Special Session on *Theory and Application of Characteristic Modes,* convened on Monday, April 11, 2016

I found the above presentation by Chen interesting because it is perhaps the only one in the Special session that dealt with the topic of Characteristic Modes (CMs) for dielectric bodies. The author made some very interesting points in this paper. He used the standard eigenvalue equation:

$[X]\,\{J_n\} = \lambda_n\,[R]\,\{J_n\}$, where [R] and [X] are the Hermetian parts of the MoM matrix [Z].

for deriving the CMs, though unlike the case of PECs, the original MoM matrix [Z] was obtained by using the PMCHWT formulation, typically used for dielectric objects.

The author made the following observations in his presentation about the CMs for dielectric bodies that he derived by using the above approach:

1. *Cannot predict the resonant frequencies*
2. *Do not yield reasonable modal currents and fields*
3. *No application of CMs found in the literature for dielectric bodies for the past 38 years since they were introduced by Chang and Harrington in their classic paper in 1977*
4. *In contrast to the dielectric case, the CM formulation for the PEC case finds plenty of antenna applications*

While I do not dispute the main points of the above observations, I have strong doubts about the correctness of the explanation he went on to provide in his presentation in an attempt to “explain the reason why the old formulation cannot give the true modes,” as he put it.

He argued, for instance, that the CMs are “exterior modes” that are counterparts of the waveguide modes (interior modes) for closed region problems, and he showed some pictures of the modes of a rectangular waveguide on the left side of the page, together with CMs for a rectangular plate in the right side of the same slide.

He failed to recognize that there are ***fundamental*** differences between the cavity modes of a closed body and the CMs for open objects. The difference stems from the fact that the interior cavity modes are true resonances at “real” frequencies (eigenvalues are real), and under ideal conditions (PEC walls), the modes can exist inside a ***closed*** cavity with the excitation tending to 0 in the limit exactly at resonance. In contrast to the closed cavities, open objects can never have true resonances at real frequencies, and all the eigenvalues of the MoM matrix [Z] must be complex. So, unlike the closed cavity case, the fields must be identically zero

in the absence of excitation regardless of the frequency. What Harrington and Garbacz did was that they introduced an auxiliary equation in terms of R and X, which did have real eigenvalues and whose eigenvectors were defined as the CMs. However, the CMs are not like cavity modes, they are not the eigenmodes of the MoM matrix, and they can never exist without excitations at any frequency, resonance or otherwise. Where most people including Chen have gone wrong is they thought CMs are real modes (eigensolutions) of open objects, which they are not because they are not derived from the MoM matrix [Z]. For some open region PEC geometries, e.g., thin wires, the complex resonant frequencies do have a highly dominant real part, and the CMs do resemble resonance “modes” but that’s more of an exception than it is a rule.

It is worthwhile mentioning here that the topic of complex resonances of open structures is a well-researched subject and the credit goes to Carl Baum, who introduced the concept of the “Singularity Expansion Method,” or SEM, as it is known more popularly. I submit that the CM group could learn a lot by going through the seminal works of Baum, thereby helping themselves to rid of many misconceptions about CM.

The Chen paper argues that the CMs are useful for PEC structures, but not for dielectrics, unless a modified approach to generating the CM’s are used for the latter. It then goes on to propose a different eigenvalue equation which can be used to generate solutions that maximize the ratio of the radiated power to stored energy. While that equation is correct as it stands, it has no direct relationship with resonances or eigenmodes, or CMs for that matter, though it does provide a way to choose the weights of certain distributions to lower the Q of an antenna. But the point is that those distributions need not be CMs, and one is free to choose another convenient set of basis functions with which to represent the current distribution on an antenna.

The paper also mentions the CMs for two antenna problems, namely a CP-type Microstrip patch antenna (MPA)--as an example of a PEC antenna structure (ignoring the dielectric substrate, we guess)--and a cylindrical-shape Dielectric Resonator Antenna (DRA) which obviously falls in the category of a dielectric antenna. Interestingly, both of these examples have one thing in common. Their “true” resonant frequencies, though complex, have real parts that dominate. Furthermore, we can calculate these frequencies very simply by using the “cavity model” for the MPA, and the resonance model for a dielectric cylinder of finite height by taking advantage of the fact the relative permittivity of the DRA is very high (38 in Chen’s paper) which helps to substantially confine the fields inside the DRA. An important consequence of this that they both have strong resemblance to “closed cavity’ type of problems which do have natural modes. So while the Chen paper argues that we should use CMs to figure out how to excite an MPA in the CP mode, and that we should use a patch geometry with 4 slots of certain shapes to excite two CM modes, nothing can be further from the truth. It has been well known for years that we can excite an MPA in the CP mode either by using a ‘single’ probe feed—appropriately located—or by using two orthogonal linear pol feeds with appropriate phase difference. It is not necessary to introduce strange-shaped slots in the patch and try to figure out how to excite the CMs. What is also interesting to note is that in the figure that was presented in the talk the recommended locations of the CM excitations didn’t appear to coincide with the maxima of the CM distributions, as per recommendations of Newman; furthermore, to-date no one has come up with a systematic way to excite the CMs, and the recipe provided by Newman doesn’t work for a complex geometry anyhow. The bottom line is that for this example it is much more convenient, and straightforward, to work with the well-known cavity modes of the MPA, rather than with CMs.

Interestingly, the same is also true for the second example in the paper, namely the DRA, whose theory is very well developed in terms of the cavity modes of the DR that are easy to derive and we can just follow the recipe provided in countless papers and books to do the design. Nothing is gained by switching to the CM approach for this case either, which the author proposes to do without comparing with the legacy designs to point out the advantages of the CM approach over legacy designs, if any.

Finally, in the last part of the paper, the author discusses scattering (as opposed to radiation) from dielectric bodies and shows how one can use CMs for the problem. But, as we have already pointed out, the SEM is a well-established technique for solving open region problems and the author does not provide a clue as to why it would be advantageous to use CM method over the SEM. What we see instead from the paper, that the CM approach would require a very large number of ‘modes’; it is not clear what would we gain by using the approach proposed by the author rather than the legacy method, which has been well established for decades.

Submitted by “curious” CM group member