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FEKO

Comprehensive Electromagnetic Solutions

Characteristic Mode Analysis for Antenna Placement

FEKO's Characteristic Mode Analysis capability is instrumental in HF antenna placement and pattern synthesis.

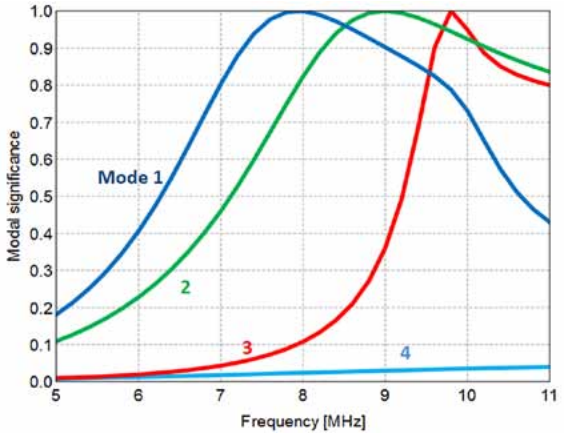
Introduction

Antenna design for high-frequency (HF) communications on a small aircraft is challenging because the antennas will always be much smaller than the wavelength. However, this disadvantage can be turned into an advantage. In the HF band the wavelengths and the aircraft size have the same order of magnitude, so through judicious antenna placement the aircraft body can be excited in such a way that the radiation pattern and the bandwidth are improved.

A small jet aircraft

Strategy

Characteristic mode analysis (CMA) [1, 2] provides insight into the radiating current modes that fit naturally on a given geometry [3]. The graph on the right shows the modal significances of the first four modes. At the frequencies of interest, only the first three can radiate significantly. Knowledge of the modal currents is instrumental in choosing the antenna locations for optimal coupling to the modes. CMA also provides insight in the modal radiation patterns. Given multiple antennas and multiple modes, this enables choosing antenna excitations to synthesize a desired antenna pattern [4]. The bottom image shows the modal currents and the modal radiation patterns for modes 1, 2 and 3 at 9 MHz.



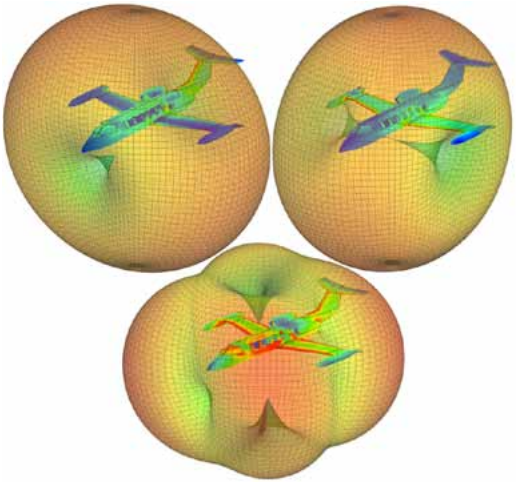
The modal significances of the first four modes

CMA reveals that strong modal currents flow in the leading edges of the wing and the vertical part of the stabilizer. Therefore, to take advantage of the modes, three notch antennas are placed in those edges (see figure on next page).

This placement has a direct benefit: the effective antenna sizes become larger since they include part of the aircraft. Matching for a useable bandwidth with reasonable component tolerance therefore becomes feasible.

The other important benefit is that CMA makes pattern synthesis possible. After the antennas have been placed, another characteristic mode analysis provides the coupling coefficients between ports and modes. Knowing those coefficients, it is possible to devise how to excite linear combinations of characteristic modes, and hence a linear combination of known modal radiation patterns, through a suitable combination of port excitations.

Suppose the goal for long-distance communications is to achieve



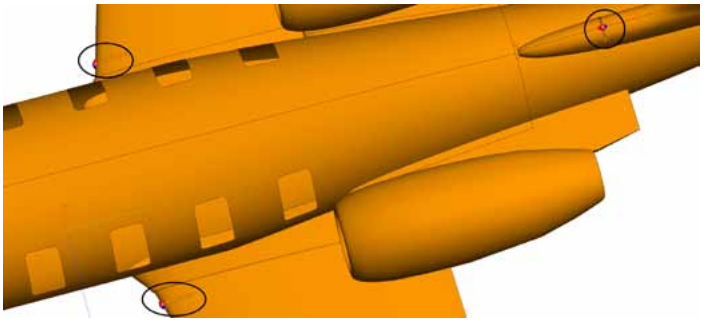
The modal currents and modal radiation patterns at 9 MHz

a gain pattern better than -13 dB in all azimuth directions (to any airport or other aircraft) and better than -3 dB in the forward direction (toward the destination). The sum of modes 1 and 2 (blue line in the bottom graph) does not achieve the goal, and neither does mode 3 by itself (green line). Insight into the modal patterns, however, naturally suggests the idea to excite modes 1 plus 2, and add mode 3 at smaller amplitude, for example 0.25. The red line in the bottom graph shows that the goal has been met.

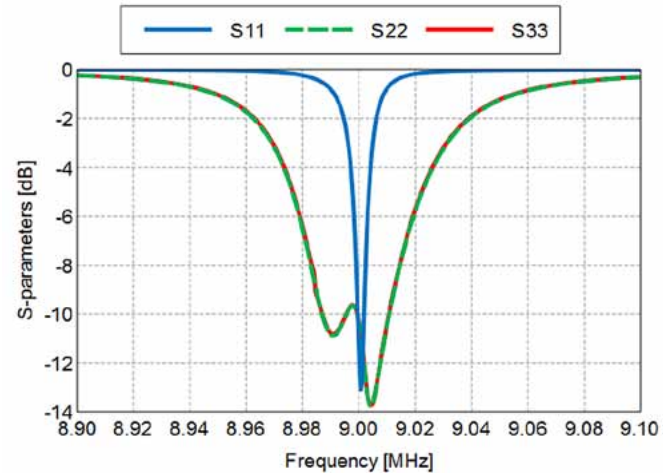
Since modal excitation coefficients link modes to port excitations, the synthesis of a desired antenna pattern is a deterministic process.

Conclusion

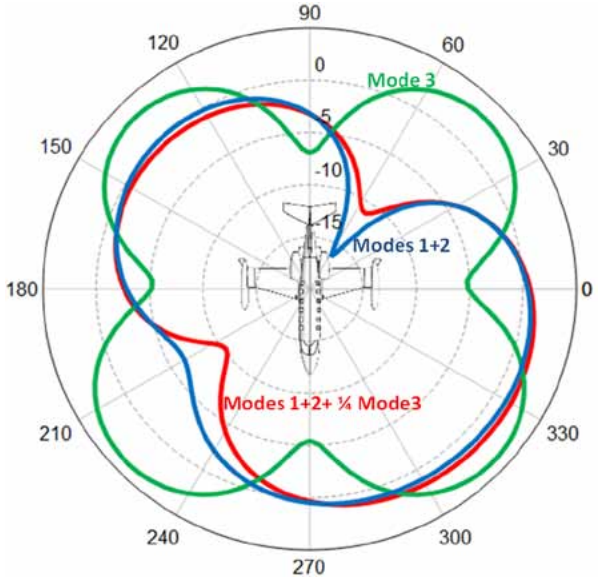
Characteristic mode analysis enables antenna placement in locations to take advantage of desired modes (or to avoid undesired ones), and enables deterministic synthesis of a desired antenna pattern.



Placement of the three notch antennas



The bandwidth after matching is sufficient for practical usage



Synthesizing antenna patterns by exciting modal radiation patterns

References

[1] R.F. Harrington and J.R. Mautz, "The Theory of Characteristic Modes for Conducting Bodies," IEEE Trans. Antennas Propagat., vol. 19, no. 5, pp. 622-628, 1971.

[2] R.F. Harrington and J.R. Mautz, "Computation of Characteristic Modes for Conducting Bodies," IEEE Trans. Antennas Propagat., vol. 19, no. 5, pp. 629-639, 1971.

[3] M. Cabedo-Fabrés et al., "The Theory of Characteristic Modes Revisited: A Contribution to the Design of Antennas for Modern Applications," IEEE Antennas and Propagation Magazine, Vol. 49, No. 5, October 2007.

[4] Y. Chen and C-F Wang, "Electrically Small UAV Antenna Design Using Characteristic Modes," IEEE Trans. Antennas Propagat., Vol. 62, no. 2, pp. 535-545, February 2014.