Application Sheet

FEKO

Comprehensive Electromagnetic Solutions

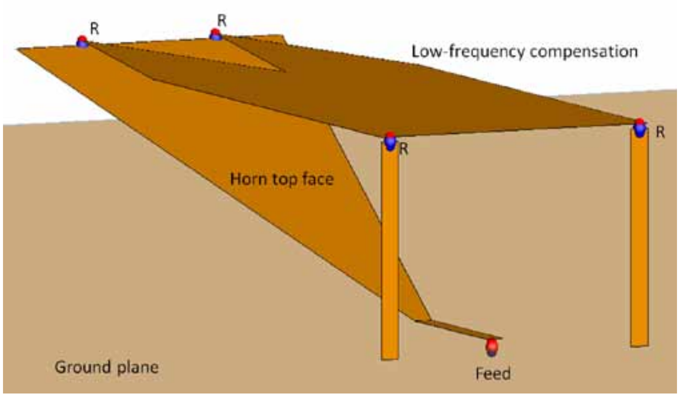
Characteristic Mode Analysis for Ultra-Wideband Antenna Design

FEKO's Characteristic Mode Analysis capability is used to improve an ultra-wideband antenna.

Introduction

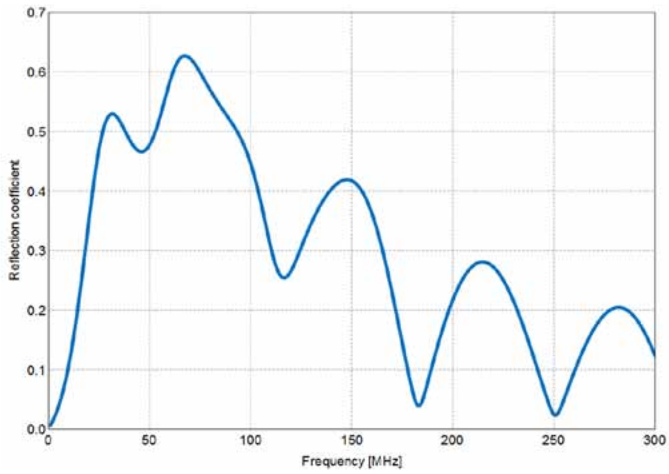
The starting point for this Ultra-Wideband Antenna design is a transverse electromagnetic (TEM) horn. It is essentially a horn antenna without sidewalls, so it supports the TEM mode and has no low-frequency cut-off. Still, at low frequencies, where the horn is much smaller than a wavelength, the horn will approach, electromagnetically, a dipole with a large reflection coefficient and a poor directivity.

A big improvement at low frequencies is achieved with a well-designed low-frequency compensation [1], shown conceptually in the figure at the top right. Provided the electric and magnetic dipole moments of the structure are balanced and the correct resistor values are chosen, the antenna pattern will even point "forward" at the low-frequency end. Also, the reflection coefficient will be low there.



A TEM horn with with low-frequency compensation
Length 2.4 m, width 0.8 m, height 0.6 m

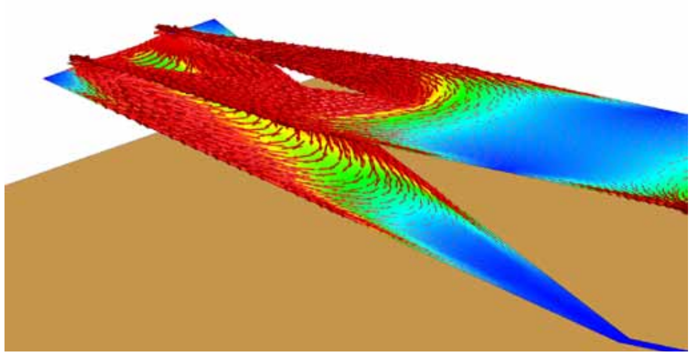
The resulting reflection coefficient is shown in the figure to the right. At frequencies of a few hundred MHz and above, the signal "sees" only the horn and has a low reflection coefficient and a high forward directivity. At the lowest frequencies the low-frequency compensation ensures a low reflection coefficient and a forward pattern. The challenge at this point is to improve the antenna at intermediate frequencies, roughly from 50 to 150 MHz.



The reflection coefficient as a function of frequency

Strategy

In order to improve performance at intermediate frequencies, one can inspect total currents and fields or only the fields, but ideas for improvements don't suggest themselves easily. Characteristic mode analysis (CMA) [2, 3] provides new insights, as it produces the radiating current modes that fit naturally on a given geometry. An inspection of several characteristic modes at 68 MHz reveals one that radiates well in the forward direction (it has a high modal significance) but is poorly coupled to the port (it has a low excitation coefficient). The figure to the right shows shows its modal currents.

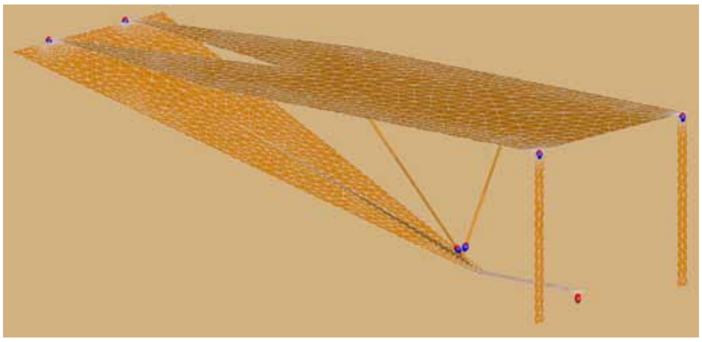


The modal currents of mode 4 at 68 MH

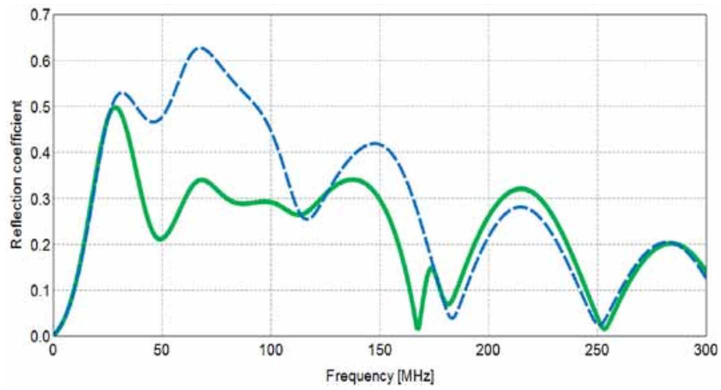
This insight in the modal currents suggests a topology change that might not have been obvious otherwise. We use wires with band-pass filters to provide an additional low-impedance path between source currents and modal currents as shown in the figure on the right. These increase the coupling between the port and the mode of interest.

The figure on the middle-right shows shows the “before“ and “after“ reflection coefficients. Note that the result has improved at intermediate frequencies without sacrificing performance at low or high frequencies, where the wires with band pass filters have practically no effect.

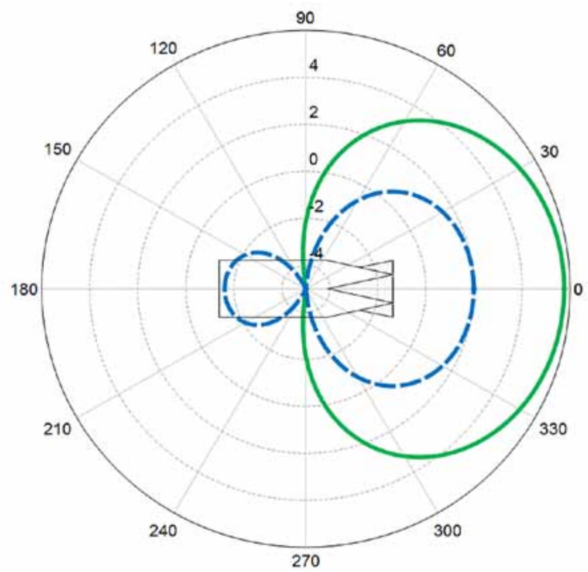
The figure at the bottom shows shows the “before“ and “after“ realised-gain patterns at 68 MHz. The power density in the “forward“ direction has improved by almost 4 dB while it has gone down in the “backward“ direction. Hence, in addition to achieving a lower reflection coefficient we achieved a better “forward“ directivity.



The topology change to improve the performance at intermediate frequencies



The improved reflection coefficient (green solid line) compared with the results before the modification (blue dotted line)



Improved azimuth realised-gain pattern (green solid line) in dB, compared with results before the modification (blue dotted line)

Conclusion

Characteristic mode analysis provides insights that would be difficult to obtain with other methods. In antenna design, these insights suggest modifications that would not have been obvious otherwise.

References

[1] M. H. Vogel, “Design of the Low-Frequency Compensation of an Extreme-Bandwidth TEM Horn and Lens IRA,” in Ultra-Wideband Short-Pulse Electromagnetics 3, edited by C. E. Baum, L. Carin and A. P. Stone, ISBN 0-306-45593-5, New York, NY, Plenum Press, 1997, pp. 97-105.

[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.