Test case #4 – RCS behavior of a “chaff cloud” of falling PEC wires

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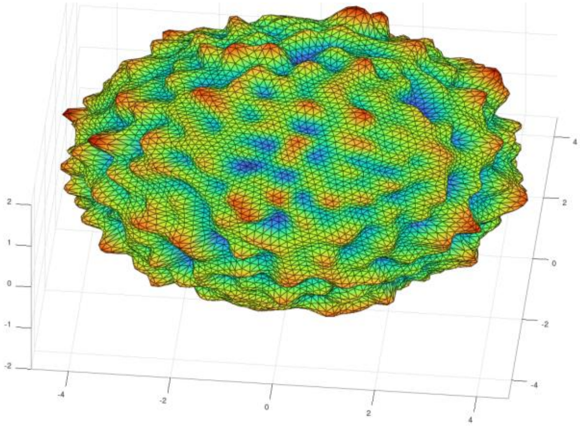
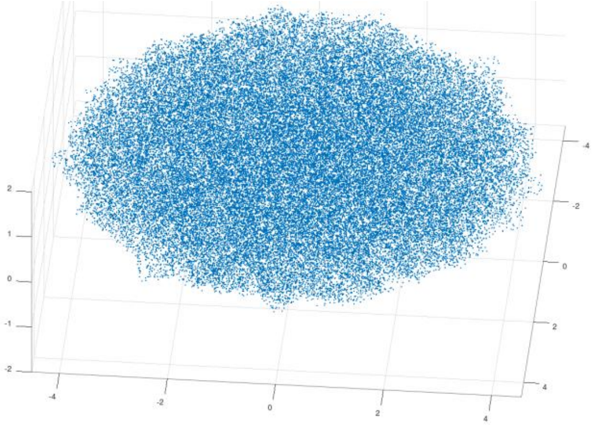
1 – Geometrical and electrical description

This test case deals with various Radar Cross Section (RCS) properties of a “cloud” of falling thin PEC wire segments (half a wavelength in length), notionally similar to a generic “chaff” radar decoy.

A fixed density of wire segments is initially spread uniformly inside an irregular (“bumped”) and flattened ellipsoidal volume, approximately 9 x 9 x 3 m (the “cloud”). The outer boundary of the cloud has deliberately been “bumped” randomly in order to mitigate hypothetical RCS effects which may possibly arise in the special situation of a smooth and regular cloud boundary.





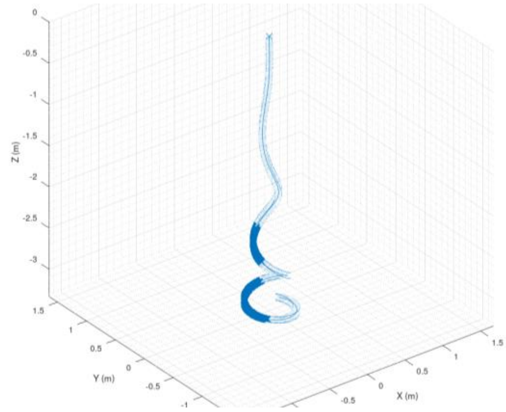
We make the following assumptions about the wires:

- length: exactly 15 mm long (which is very close to ½ wavelength at 10 GHz)
- thickness: infinitely thin (1D line segments) or, wherever needed, their radii can be set to 0.1 mm
- material: perfect electric conductor (PEC) behavior or, wherever needed, the complex impedance should be set very close to zero (*e.g.* R = 0, L = 0, C = 10^{20}…)
- electrically disconnected (in the unlikely event of a collision and/or if this may lead to computation problems (*e.g.* division by zero, loss of accuracy…) participants are allowed to disconnect them manually (by applying a slight shift or by discarding one of them entirely)
- orientations: randomly tilted away from the vertical, inside a 60° half-angle conical sector around the Z-axis

Each wire follows a slowly falling motion (speed ~20 cm/sec) according (and tangentially) to a single template swirling trajectory, progressively transitioning from vertical to horizontal.

This template trajectory is mirrored (alternately left-handed and right-handed) for every second wire.

Each wire’s starting position along the trajectory is determined by its initial (random) tilt.



All “chaff cloud” configurations to be evaluated in the following RCS case studies are provided as sets of geometry definition files, to be freely chosen between two available formats (whichever seems least inconvenient):

- “POINTS”: simple columnar ASCII files listing the 6 coordinates of each wire’s end points
  X1 Y1 Z1 X2 Y2 Z2 (unit: meter)

- “IGES”: standard CAD definition files of the wire segments in IGES format (unit: millimiter) which should be readily importable into most 3D CAD / meshing software tools

2 – Computational parameters

The participants shall compute the time-harmonic full-polar complex far-field scattering coefficients (either bistatic or monostatic) for several configurations of the “chaff cloud”, with the phase reference at origin (0,0,0).

The EM wave illumination, observation and polarization directions are defined with the usual spherical angles and polarization coordinate system in accordance with ISO-80000-2 (summarized on the figure below).

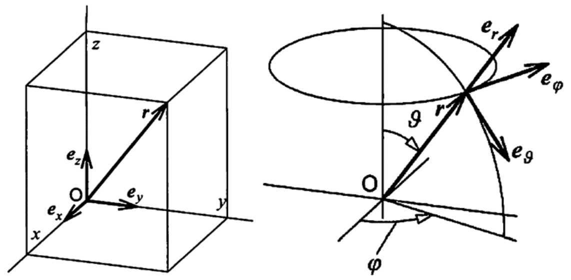
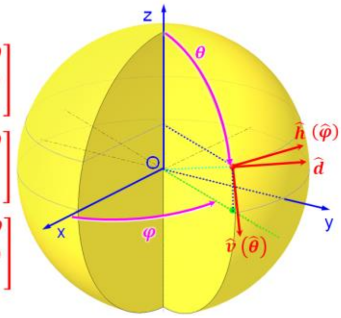


Figure 3 — Right-handed spherical coordinate system

$$\hat{d} = \begin{bmatrix} \sin\theta \cdot \cos\varphi \\ \sin\theta \cdot \sin\varphi \\ \cos\theta \end{bmatrix} \quad \hat{h} = \begin{bmatrix} -\sin\varphi \\ \cos\varphi \\ 0 \end{bmatrix} \quad \hat{v} = \begin{bmatrix} \cos\theta \cdot \cos\varphi \\ \cos\theta \cdot \sin\varphi \\ -\sin\theta \end{bmatrix}$$



For all sub-cases, in order to compute the required full-polar scattering, the “chaff cloud” will be successively illuminated with two plane waves incident from $x = +\infty$ (in other words $\theta_{inc} = 90°$ and $\varphi_{inc} = 0°$):

- the first one will be polarized horizontally (electric field parallel to Y)
- the second one will be polarized vertically (electric field parallel to Z)

The participants shall provide results for at least the first two of the three following case studies.

- **sub-case 1** – effect of “chaff density” on RCS (ZIP bundle of geometry files suffixed “_SUBCASE1”)
    - 5 configurations of the “chaff cloud” (starting position for 5 wire densities)
        - density 4^3 = 64 wires / m^3 (6 872 wires)
        - density 5^3 = 125 wires / m^3 (13 480 wires)
        - density 6^3 = 216 wires / m^3 (23 214 wires)
        - density 8^3 = 512 wires / m^3 (54 958 wires)
        - density 10^3 = 1000 wires / m^3 (107 606 wires)
    - the carrier frequency is fixed at 10 GHz
    - the bistatic far-field observation is swept across 7201 directions in the XY plane
        - $\theta_{obs} = 90°$
        - $\varphi_{obs} = -180° : 0.05° : 180°$
    - suggested result format: a set of 5 ASCII files (one per density) with 7201 lines and 9 columns
      φ_{obs} $\mathrm{Re}(VV)$ $\mathrm{Im}(VV)$ $\mathrm{Re}(VH)$ $\mathrm{Im}(VH)$ $\mathrm{Re}(HV)$ $\mathrm{Im}(HV)$ $\mathrm{Re}(HH)$ $\mathrm{Im}(HH)$
- **sub-case 2** – frequency dependence or “chaff bandwidth” (geometry file suffixed “_SUBCASE2”)
    - configuration of the “chaff cloud”: starting position for density 5^3 = 125 wires / m^3 (13 480 wires)
    - the carrier frequency is swept between 9 GHz and 11 GHz @ 10 MHz (201 steps)
    - the bistatic far-field observation is swept across 7201 directions in the XY plane
        - $\theta_{obs} = 90°$
        - $\varphi_{obs} = -180° : 0.05° : 180°$
    - suggested result format: a single ASCII file with 7201 × 201 lines and 10 columns
      $freq$ φ_{obs} $\mathrm{Re}(VV)$ $\mathrm{Im}(VV)$ $\mathrm{Re}(VH)$ $\mathrm{Im}(VH)$ $\mathrm{Re}(HV)$ $\mathrm{Im}(HV)$ $\mathrm{Re}(HH)$ $\mathrm{Im}(HH)$
- **sub-case 3** – time-varying RCS or “chaff fluctuations” (ZIP bundle of geometry files suffixed “_SUBCASE3”)
    - 501 time steps of the lowest-density “chaff cloud” (density 4^3 = 64 wires / m^3, 6 872 wires) (corresponding to a 50 Hz sampling of wire positions during a 10 seconds time interval)
    - the carrier frequency is fixed at 10 GHz
    - single monostatic far-field observation direction
    - suggested result format: a single ASCII file with 501 lines and 8 columns
      $\mathrm{Re}(VV)$ $\mathrm{Im}(VV)$ $\mathrm{Re}(VH)$ $\mathrm{Im}(VH)$ $\mathrm{Re}(HV)$ $\mathrm{Im}(HV)$ $\mathrm{Re}(HH)$ $\mathrm{Im}(HH)$

Participants shall specify which time-harmonic convention they have used in their computations (by default, the $e^{-i \cdot \omega \cdot t}$ convention will be assumed) and briefly report about the computation method they chose, mesh size, number of unknowns, computational resource usage (CPU time, memory, also detailing computer specs).

Participants are – of course – also encouraged to use (and document) any computational strategy and/or approximations allowing them to reduce the computation resource needs.