PC 04 – KBC

For task 1, you can obtain 4 credits.

In the task, we are going to model a **wire monopole** as an on-body antenna on the back of an adult man. The back is approximated by a three-layer phantom consisting of a skin (*skin_t* = 2 mm), a fat (*fat_t* = 10 mm) and a muscle (*muscle_t* = 28 mm). Electric parameters of the layers are given in Tab. 1.

The antenna is represented by a quarter-wavelength monopole. The monopole consists of a coaxial cable with the characteristic impedance Z_0 = 50 Ω, a circular reflector and a wired arm created from the central conductor of the coaxial cable (see Figure 1).

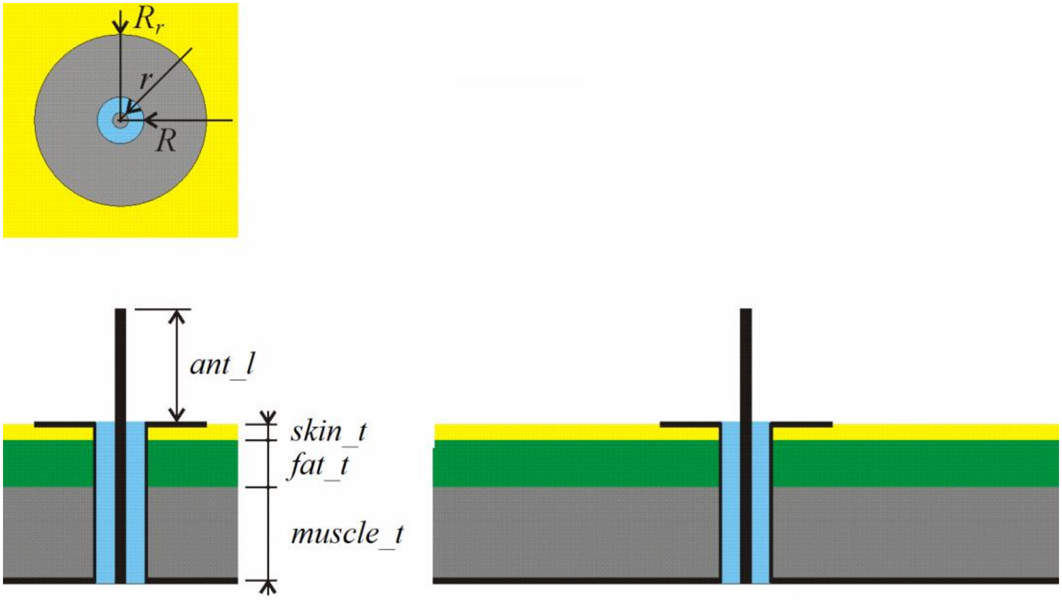

Figure 1 Layered phantoms and structure of quarter-wavelength monopole.

	f_{c1} = 2.45 GHz		f_{c2} = 5.8 GHz	
	ε_r [–]	σ [S/m]	ε_r [–]	σ [S/m]
Skin	38.0	1.46	35.1	3.72
Fat	5.3	0.10	5.0	0.29
Muscle	54.4	1.74	48.5	4.96

Table 1 Electrical parameters of layered phantom at 2.45 GHz and 5.8 GHz.

Coaxial cable. Radius of the inner conductor is r = 0.5 mm, radius of the outer conductor R equals to 1.8 mm and relative permittivity ε_r of dielectrics is 2.4. Losses in dielectrics can be neglected. Conductors are perfectly electrically conductive (PEC).

Monopole. The length *ant_l* of the monopole should be $\lambda_0/4$ and the width of the monopole equals r of the coaxial cable. The radius of the reflector is R_r = *ant_l* = $\lambda_0/4$. Here, λ_0 is the wavelength in vacuum at the central frequency f_c. Both the monopole and the reflector are PEC. The monopole is located in the center of the back.

Back. The back is represented by a square box with the horizontal size *phantom_w* = 100 mm. The thickness equals to the sum of the skin thickness, the fat thickness and the muscle thickness. Above the skin, the 100mm thick air layer is considered. All outer sides of the air box and the phantom are set to *Radiation*.

Channel. Two identical monopoles are located in the axis of the box at a distance of *ant_d* = 150 mm. The transmission properties of the transmission channel correspond to the transfer function between the excitation wave ports of the antennas.

Task 1

Dimensions of the monopole should be computed for the central frequency f_{c1} = 2.45 GHz, and parameters of the phantom should be set accordingly. Transmission between antennas 150 mm apart should be evaluated in the frequency range of 2-3 GHz.

Task 2 (optional)

Adjust the length of the monopoles and the parameters of the individual layers of the phantom for the central frequency f_{c2} = 5.8 GHz. Evaluate the transmission between the monopoles in the frequency band of 4.8-6.8 GHz.

How to do it …

1. In a new HFSS project, create a model of the layered phantom using three boxes (Draw → Box). The size of the box Skin is *phantom_w* × *phantom_w* × *skin_t*. The monopole will be placed in the center of the coordination system, the arm in the direction of the +*Z* axis, the feeding coaxial in the direction of the –*Z* axis. Therefore, the Position of the Skin is [-*phantom_w*/2, -*phantom_w*/2, 0], Xsize and Ysize = *phantom_w*, and Zsize is -*skin_t*.
2. Create the other two phantom layers (Fat and Muscle) and Air layer by copying the Skin. Edit the parameters of the new boxes:

Name	Position	Zsize
Fat	[-*phantom_w*/2, -*phantom_w*/2, -*skin_t*]	-*fat_t*
Muscle	[-*phantom_w*/2, -*phantom_w*/2, -*skin_t*-*fat_t*]	-*muscle_t*
Air	[-*phantom_w*/2, -*phantom_w*/2, 0]	100 mm

3. Assign material properties to the created objects (Skin, Fat, Muscle) according to Table 1. Check the Air is assigned to the vacuum. Display the Air as a wireframe.
4. The model of the antenna consists of two cylinders, one for the dielectric (Ant_diel) and the other for the inner conductor (Ant_wire), and one circle for the reflector (Reflector).

   Start by drawing the dielectric of the coax Ant_diel (Center Position = [0mm, 0mm, 0mm]; Radius = 1.8 mm; Height = -*skin_t*-*fat_t*-*muscle_t*). Create and assign a new material *Ant_diel* with ε_r = 2.4 to the Ant_diel.

   Select the longitudinal surface of the shell (Edit → Selection Mode → Faces), which will represent the shielding of the coaxial cable, and assign it to the boundary condition PEC (HFSS → Boundaries → Assign → Perfect E).

   Insert the Ant_diel into the phantom layers.

Create the Ant_wire (Center Position = [0mm, 0mm, *ant_l*]; Radius = 0.5 mm; Height = -(*ant_l*+skin_t+*fat_t*+*muscle_t*). The variable *ant_l* denotes the length of the arm and should be $\lambda_0/4$. Change the material to PEC. Insert the Ant_wire into the Ant_diel and Air.

Create the Reflector as a sheet structure (Draw → Circle) centered at the origin of coordinates [0, 0, 0] with a radius of *ant_l*. Create a hole in the Reflector using the Ant_diel. Assign a PEC boundary condition to the Reflector.

5. Create a wave port at the antenna input (HFSS → Excitation → Assign → Port → Wave Port). Define a new integration line between the inner and outer conductor of the coaxial cable.

6. The antenna has to be placed in free space. Select all outer surfaces of the phantom layers and the Air and set the Radiation boundary condition on these surfaces (HFSS → Boundaries → Assign → Radiation).

7. Set a new analysis at the single solution frequency of 2.45 GHz with Maximum Number of Passes of 3. Leave the other settings unchanged. In the Frequency Sweep dialog, set the frequency sweeping for 21 points in the band of 2-3GHz. Before running the analysis, perform validation check on design setup (HFSS → Validation Check). Run the analysis.

8. Verify the characteristic impedance Z_0 of the coaxial cable and the resonance of the antenna at the desired frequency.

   Display the 3D gain pattern of the antenna at 2.45 GHz (HFSS → Results → Create Far Fields Report → 3D Polar Plot → Y: dB(GainTotal)). The calculation of field strengths in the far region has to be defined (Radiation → Insert Far Field Setup → Infinite Sphere).

   The analysis of the antenna is complete and the model can be modified to calculate the transmission between two antennas.

9. The antennas should be separated by *ant_d* = 150 mm. Make a copy of the project for further editing. Adjust the size of the phantom layers and the Air in the direction of the +*Y* axis to *phantom_w*+*ant_d*.

   Create a copy of the antenna at a distance of *ant_d* in the direction of the +*Y* axis. Select all antenna objects (Ant_wire, Ant_diel, Reflector) and copy them along line *Y* axis (Edit → Duplicate → Along Line, start point = [0, 0, 0], end point = [0, *ant_d*, 0], Total Number = 2). The object boundary conditions and wave port should be preserved by copying. Insert the newly created objects into the phantom layers.

10. Perform validation check on the model and run the analysis. Note the total computation time (Setup1 → Profile → Elapsed time). With increasing *ant_d*, the computation time increases analogously.

    Symmetry boundaries enable us to model only part of a structure, which reduces the size or complexity of our design (results from one half are symmetrically copied to the other). As the numerical model is symmetric along the *YZ* plane, we can exploit this symmetry.

    Since our antenna model has a vertical plane of symmetry and the E-field is tangential to the surface, a Perfect H boundary should be applied to the faces along the symmetry plane as illustrated in Figure 2.

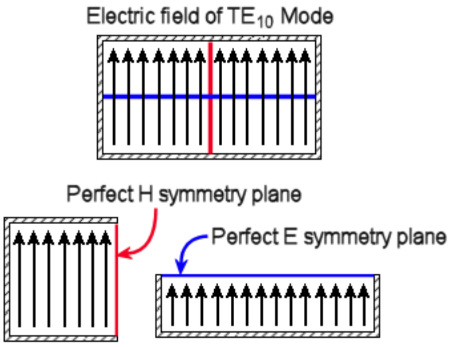

Figure 2 Electric field and symmetry planes.

11. Make a copy of the project for further editing. Create a half-symmetry model using a box filling half space of the model in the direction of the –*X* axis:
    Position = [0, -*phantom_w*/2, -*skin_t*-*fat_t*-*muscle_t*]
    Xsize = -*phantom_w*/2
    Ysize = *phantom_w*+*ant_d*
    Zsize = *skin_t*+*fat_t*+*muscle_t*+100mm

    From all model objects (Ctrl+A) subtract the created box.

    Check the boundary conditions and wave ports are preserved after subtracting the objects.

    Change the grid plane to *YZ* and create a rectangle SymmetryH (Draw → Rectangle). The position of the SymmetryH is [0, -*phantom_w*/2, -*skin_t*-*fat_t*-*muscle_t*], Ysize = *phantom_w*+*ant_d* and Zsize = *skin_t*+*fat_t*+*muscle_t*+100mm. After the operation, set the grid plane back to *XY*.

    Select the SymmetryH and assigned it to the *Perfect H Symmetry* (HFSS → Boundaries → Assign → Symmetry) with *Port Impedance Multiplier* of 0.5.

    Perform validation check on the model and run the analysis. Evaluate the percentage time savings of the half-symmetry model. Thanks to the saving of computational time, the accuracy of the analysis can be increased by using a higher number of iteration steps (by refining the discretization mesh).

12. Compare the S_{11} and the characteristic impedance Z_0 of the coaxial cable with the ones reached by modeling the full-size model. Display the E field distribution on the surface of the SymmetryH (HFSS → Fields → Plot Fields → E → Mag_E or Vector_E) in a logarithmic scale (Modify → Scale → Log). Display the time change of the plotted E field (Field Overlays → E Field → Mag_E1 → Animate).

13. Optional: Make a copy of the project and modify the appropriate variables to analyze the transmission between the antennas in the frequency band of 4.8-6.8 GHz.

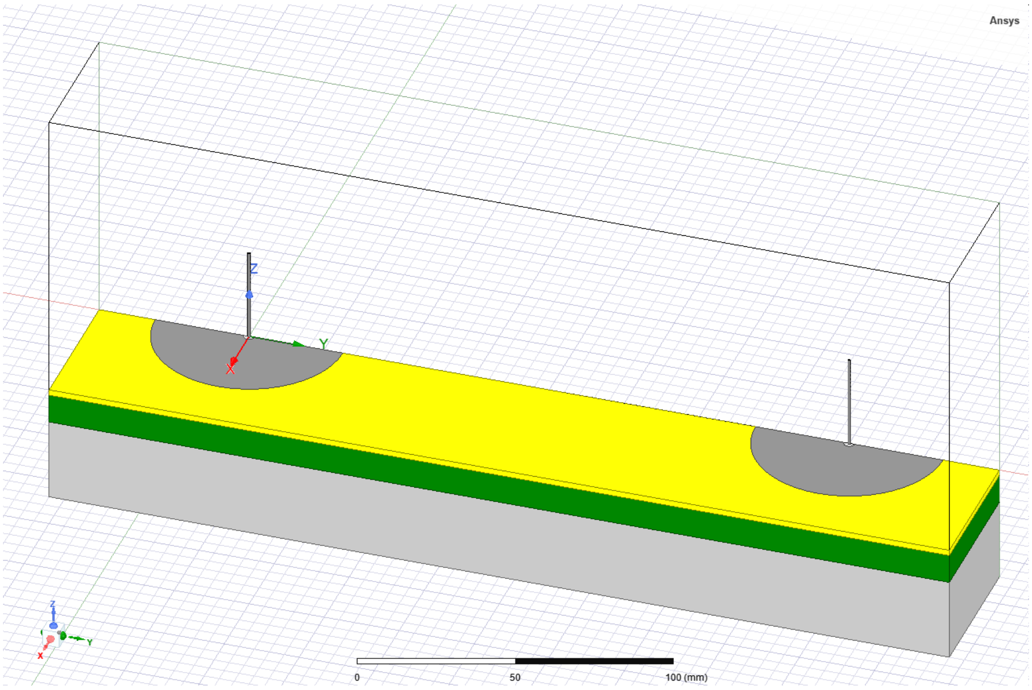

Figure 3 Numerical half-symmetry model of layered phantom and monopoles in HFSS.