PC 05 – KBC

For task 1 and 2, you can obtain 2 credits.

In the task, we are going to model **a slot dipole** 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 bow-tie slot dipole designed on the top metallic layer of the dielectric substrate ARLON AD450 (ε_r = 4.5, tan δ = 0.0035, *sub_t* = 60 mil). The bottom metallic layer of the substrate is etched. The dipole is fed by a coplanar waveguide (CPW) with the characteristic impedance Z_0 = 50 Ω (see Figure 1). The antenna is operating at the frequency f_c = 2.45 GHz.

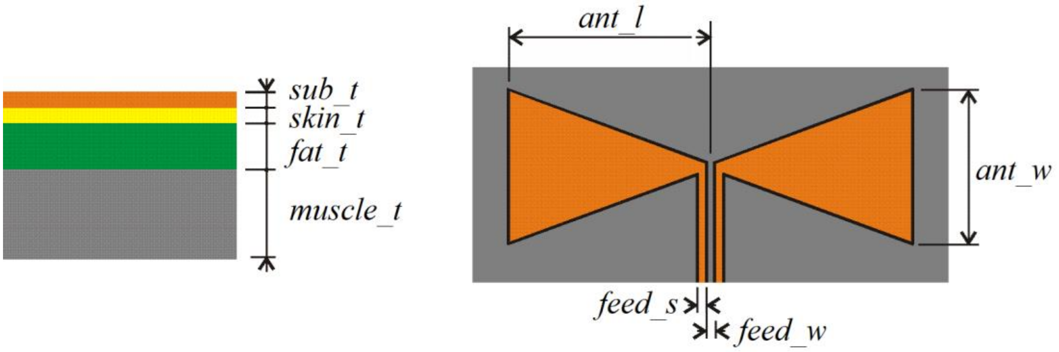

Figure 1 Layered phantoms and structure of bow-tie slot dipole.

	ε_r [–]	σ [S/m]
Skin	38.0	1.46
Fat	5.3	0.10
Muscle	54.4	1.74

Table 1 Electrical parameters of layered phantom at 2.45 GHz.

Coplanar waveguide. Using the on-line coplanar waveguide calculator verify that the characteristic impedance Z_0 is approaching 50 Ω for the ground plane spacing *feed_s* = 0.2 mm and the trace width *feed_w* = 0.9 mm.

Dipole. The size of the arm is *ant_l* = 19 mm and *ant_w* = 24 mm. In free space, the length *ant_l* of the arm should be $\lambda_0/4$. Here, λ_0 is the wavelength in vacuum at the central frequency f_c. The maximum width *ant_w* is adjusted depending on the required operation bandwidth. The minimum width *ant_w* equals to the ground plane spacing of the CPW. The ground plane of the dipole is perfectly electrically conductive (PEC).

Back. The back is represented by a rectangle box with the horizontal XY size of *phantom_x* × *phantom_y* = 60 mm × 40 mm. The thickness equals to the sum of the skin thickness, the fat thickness and the muscle thickness. Above the skin, the 40mm thick air layer is considered. All outer surfaces of the air box and the phantom are set to *Radiation*.

Propagation. The electric field distribution along a plane above the phantom surface obtained from the simulation can be fitted to the formula E [dB] = E_0 [dB] – βd representing exponential attenuation, where E_0 is the electric field at the distance d = 0 mm measured from the center of the antenna and β is the attenuation rate of the field.

Task 1

Create a numerical model of the slot dipole placed on the layered phantom. Use a wave port to excite the antenna. At the 2.45 GHz frequency, evaluate the reflection coefficient and radiation pattern of the antenna and the characteristic impedance Z_0 of the CPW.

Task 2

At the 2.45 GHz frequency, evaluate the variation of the perpendicular electric field component E_z 1 mm above the skin surface. The power of source should be 1 W. Fit the variation of the E_z to the propagation model $E_z = E_0 - \beta d$. The distance d measured from the center of the antenna varies from 20 mm to 120 mm.

Task 3 (optional)

Evaluate the input reflection coefficient and 3D radiation pattern of the antenna and the characteristic impedance Z_0 of the CPW at the resonance frequency of the antenna placed in free space. Compare the parameters of the antenna in free space with the ones of the antenna placed on the phantom.

How to do it …

1. In a new HFSS project, create the substrate and the phantom layers in the direction of the –Z axis and the air box in the direction of the +Z axis. The size of the Substrate is *phantom_x* × *phantom_y* × *sub_t*. Assign material properties to the created objects (Air, Substrate, Skin, Fat, Muscle). The steps are identical to the previous exercise.

   Creating a half-symmetry model is highly recommended then a full model.

   The *Radiation* boundary condition should be set on all outer surfaces.
   In case of the half-symmetry model, set also the *Symmetry* boundary condition.

2. The dipole is located in the top metallic layer of the substrate. Create the Metallization as a sheet structure (Draw → Rectangle) over the entire upper surface of the Substrate and assign the *Perfect E* boundary condition.

3. Create the shape of the right arm of the dipole and a part of the CPW. The related poly-line Dipole (Draw → Line) is defined by the following points:

x:	*y*:
feed_w/2+*feed_s*	-*phantom_y*/2
feed_w/2+*feed_s*	-*feed_s*/2
ant_l	-*ant_w*/2
ant_l	*ant_w*/2
feed_w/2	*feed_s*/2
feed_w/2	-*phantom_y*/2
feed_w/2+*feed_s*	-*phantom_y*/2

In case of the full model, create the second arm by mirroring (Edit → Duplicate → Mirror) the Dipole in the direction of the –X axis according to the point [0, 0, 0].

Subtract the Dipole from the Metallization. Check the boundary condition *Perfect E* is preserved after subtracting the objects.

4. Create a wave port at the input of the CPW using a rectangle Port. The Xsize and Zsize is 7 mm and 6 mm, respectively. The Port should be centered with the CPW trace. Leave the default port settings.

5. Set a new analysis at the Single Solution Frequency of 2.45 GHz with Maximum Number of Passes of 8. Leave the other settings unchanged. Set the frequency sweeping for 21 points in the band of 1.4-3.4 GHz. Perform validation check on design setup and run the analysis.

6. Verify the characteristic impedance Z_0 of the CPW and that the antenna resonates at the desired frequency. Display the 3D gain pattern of the antenna at 2.45 GHz.

7. Make a copy of the project for further evaluation the antenna parameters in free space.

   The E_z component will be evaluated in the direction of the +Y axis. Increase the Ysize of the corresponding layers (Air, Skin, Fat, Muscle) by 100 mm.

   Make sure the Air is touching the Skin. Check the assignment of the radiation boundary condition.

   The component E_z will be plotted along a Line. Create the Line (Draw → Line) with a start point [0 ,0 ,-*sub_t*+1mm] and an end point [0 ,120mm ,-*sub_t*+1mm].

   Check the source value of the port is 1 W (HFSS → Fields → Edit Sources), perform validation check on design setup, disable the frequency sweep and run the analysis.

   Display the E_z variation along the Line. First define the calculation of the near field along a line (Radiation → Insert Near Field Setup → Line → OK). Then define a new result:

   HFSS → Results → Create Near Fields Report → Rectangular Plot
   Solution:Setup1:LastAdaptive
   Primary Sweep:NormalizedDistance
   X:NormalizedDistance*(Phantom_y/2+100mm)
   Y:dB(NearEZ)

   For the distance d from 20 mm to 120 mm, fit the variation of the E_z to the propagation model E_z [dB] = E_0 [dB] – βd. The plotted data can be exported (Results → Near E Plot 1 (right mouse click) → Export).

8. To evaluate the antenna parameters in free space, change the materials of the phantom layers to the vacuum. The analysis should be performed for 47 frequency points in the range of 1.4 GHz to 6.0 GHz. Find the resonant frequency of the antenna.

   The 3D gain pattern should be evaluated at the resonant frequency (Solution: Setup1:Sweep, Families → a frequency close to resonance should be chosen).

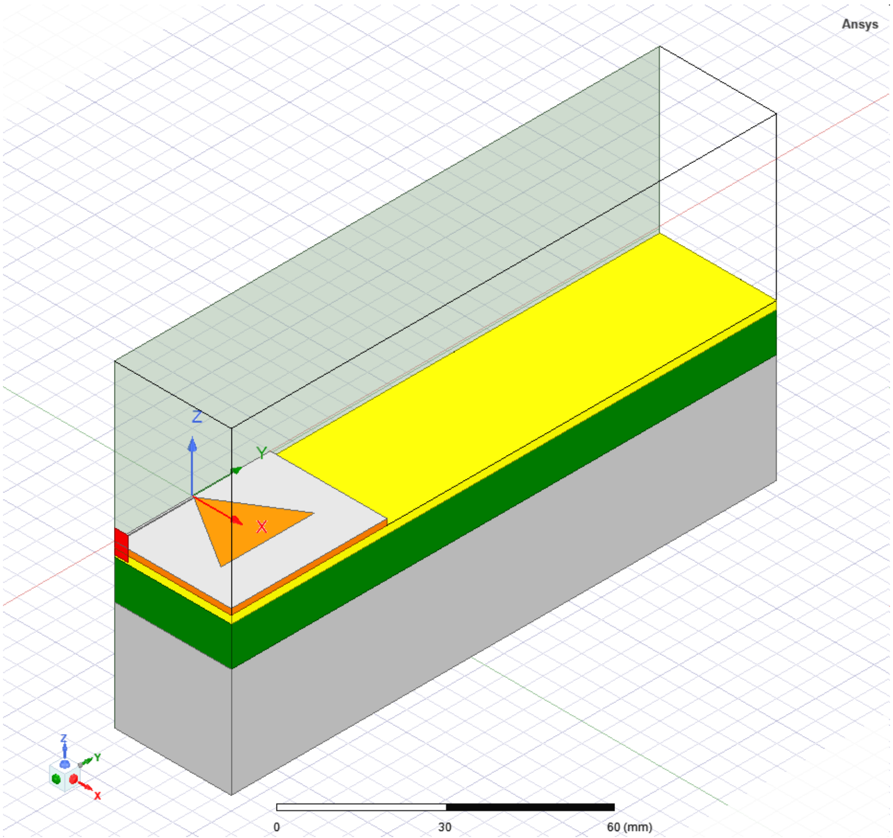

Figure 2 Numerical half-symmetry model of layered phantom and bow-tie slot dipole in HFSS.