

# WIPL-D Pro CAD Modelling Tutorial – Cavity Resonator Filters

## Introduction

This application note represents a **step-by-step guide how to model cavity filters in WIPL-D Pro CAD.**

## Cavity Resonator Filter

The filter modeling will be presented using a 6-cavities resonator filter structure as illustrated in Figure 1 where the final appearance of the filter is shown. In Figure 2 a cross-section of the filter is presented with important details of the interior exposed.

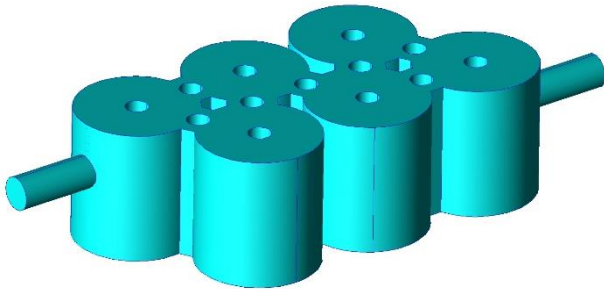


Figure 1. 6-cavities resonator filter

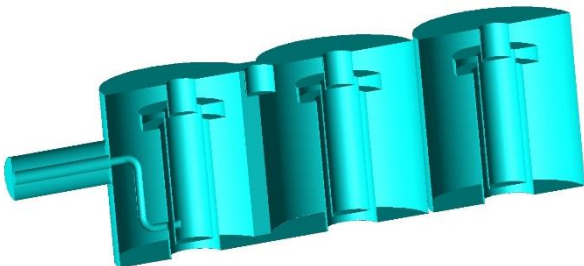


Figure 2. 6-cavities resonator filter cross section

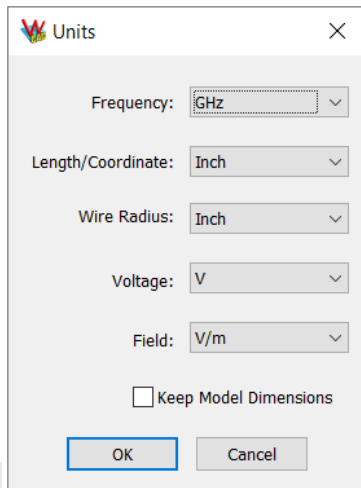






Figure 3. Setting units in WIPL-D Pro CAD

Obviously, the first step of the modeling is to start WIPL-D Pro CAD program, either by double clicking WIPL-D Pro CAD desktop

icon or by choosing **File, WIPL-D Pro CAD** from the WIPL-D Pro interface. When WIPL-D Pro CAD opens, click  or **File, New**.

Next use **Configure, Units** or . Set the units as in Figure 3. It can be seen that lengths, coordinates, and wire radii will be represented using Inches, which is very suitable for users in USA and UK.

## Modeling Single Cavity

The cavities are modeled as simple cylinders. Only two symbol variables, Ch and Cr, are required to define a cylinder (see Figure 4; the rest of the symbols from the figure will be explained later). The symbolic variables are created in the Symbols table via icon  or **Edit, Symbols**. New symbols are added by choosing **Add** button. After the variables are defined, we create a cylinder objects by using Cylinder icon  or using menu shortcut **Construct, Solid, Cylinder**. Its parameters are:

Position X,Y: (0,0); Radius: Cr; Height: Ch

The structure (Body1) looks like below.

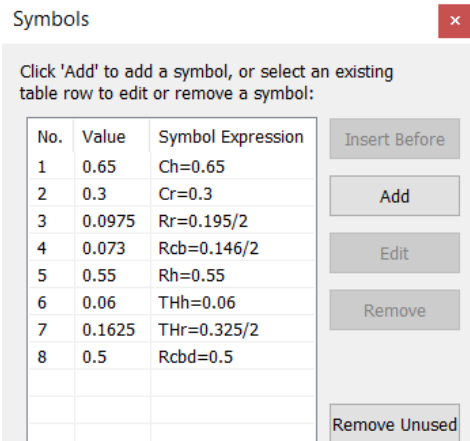
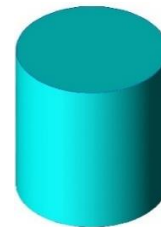




Figure 4. Cylinder object which will serve as cavity, with symbols needed for its definition

Next step is to add symbols necessary to define an interior of the cavity: Rr, Rcb, Rh, THh, THr, Rcbd. The Symbols table should look as presented in Figure 4.

The easiest way to create interior of the cavity is using the sweep command. It requires the definition of two wire bodies. The first one is a simple wire loop of arbitrary radius (but we can

use  $R_r$  here, for example). The loop is created by using icon  or **Construct, Curve, Loop**. Wire radius (arbitrary since used for sweep) can be set to zero. Its parameters are:

Position X,Y: (0,0); Radius:  $R_r$  (resulting in Wire1)

Next, we create a segmented wire by using wire polyline primitive (click  or **Construct, Curve, Polyline**). The nodes of the wire are (again, leave zero for a value of the radius):

$(R_r,0,0)$ ,  $(R_r,0,R_h-T_Hh)$ ,  $(T_Hr,0,R_h-T_Hh)$ ,  $(T_Hr,0,R_h)$ ,  $(R_{cb},0,R_h)$ ,  $(R_{cb},0,R_h-T_Hh)$ ,  $(R_{cb},0,R_h-R_{cbd})$

After the last vertex press Shift+Enter to complete entering vertices. As the result Wire2 is created.

Entering coordinates of multiple consecutive nodes might be tiresome. Alternatively, creation of Wire2 can be executed by editing the WCM file using an appropriate editor, say Notepad. This file is a core of the WIPL-D Pro CAD project, and is completely ASCII based. The commands section lists all of the actions performed to obtain the model. So, for the particular case of drawing Wire2, user can create the starting two nodes, close project, open WCM file from Notepad and then use repeatedly Copy/Paste/Edit to add the remaining nodes.

The two wire loops should like this:



Figure 5. Two wire loops that will be swept



To sweep wire polyline (Wire2) along wire circle (Wire1), select Wire2 first, click  or **Modify, Sweep, Normal** and then choose Wire1. The result of this operation is Body2. Select both wires and delete them. Body2 cross section is shown below in Figure 6.






Figure 6. Result of sweep command

Now we need to add two Circle objects to make Body2 into a closed object. Circles are created as primitives by using  or **Construct, Surface, Circle**. The parameters are:

Position X,Y: (0,0); Radius:  $R_r$  (Body3)

Position X,Y: (0,0); Radius:  $R_{cb}$  (Body4)

The bodies created this way are Body3 and Body4. Move Body4 along z coordinate to the bottom of the cavity insert by using  or **Modify, Transformation, Translate Body**. Translation should be  $R_h-R_{cbd}$  along z coordinate.

Now select Body2, Body3, Body4 and unite them (click  or **Modify, Boolean, Unite**). The result is Body5. Last step is to remove the insert from the cavity. Select Body5, then use subtract (click  or **Modify, Boolean, Subtract**), and then select Body1. Result of this step is single object named Body6. Interior of the cavity should look like in the Figure 7 (half of the cavity shown):

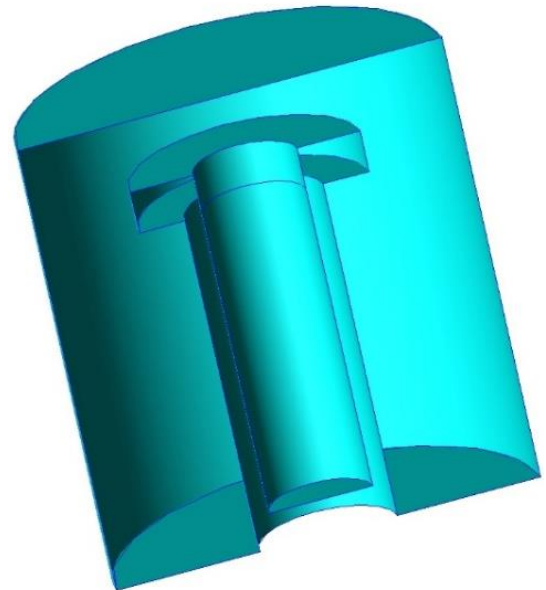




Figure 7. Interior of single cavity

## Multiplying Cavity

By using the model of the single cell, we can easily create model with 6 cells. We need additional symbol for spacing between cavities  $C_s$  (Symbols table via icon  or **Edit, Symbols**).

	Symbol	Value
8	0.5	$R_{cbd}=0.5$
9	0.62	$C_s=0.62$

Figure 8. Adding symbol  $C_s$

Next step is to select Body6 created in the previous step and to perform multiple copy operation (click  or **Modify, Copy, Multiple Copy**). Use the parameters as in the Figure 9 - one copy translated for:

$(C_s/2, -C_s*\sin(\pi(1)/3),0)$

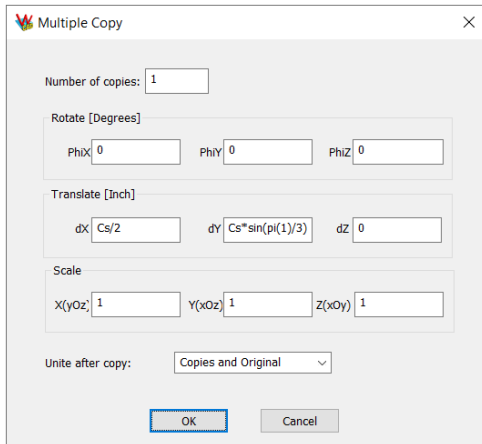


Figure 9. Using multiple copy to get the second cavity

The result of this operation is Body7. Select Body7 and perform the following copy – 2 copies translated for:

(Cs,0,0)

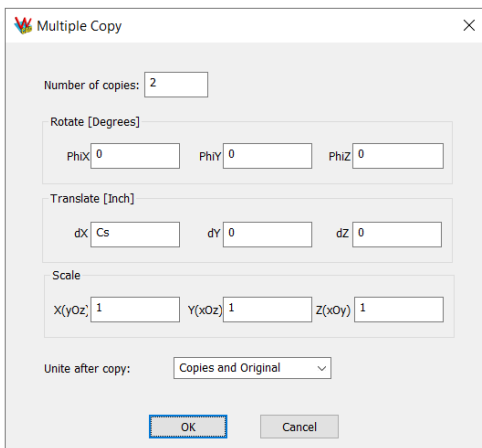


Figure 10. Using multiple copy to get cavities #3-#6

The result of this is Body8, shown below.

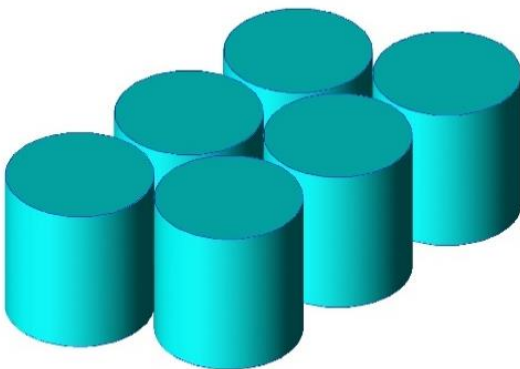


Figure 11. 6 cavities obtained by multiple copy

### Modeling Coupling between Cells

After modelling the cells, we need to add coupling between cell #1 to cell #2, between #2 and #3 etc. This is a direct signal path. We also create two additional cross-couplings between cavities

#1 and #3, and #4 and #6. In this step we only need symbol which controls the width of the coupling Cc and one auxiliary symbol that helps to define a cuboid which performs the coupling (symbol is named aux1).

9	0.62	Cs=0.62	
10	0.236	Cc=0.236	
11	0.034...	aux1=Cs/2-(Cr^2-(Cc/2)^2)^0.5	Remove Unused

Figure 12. Adding symbol Cc and one auxiliary symbol

After that we create a cuboid element (or **Construct, Solid, Cuboid**) with the following parameters:

First node coordinates X,Y: (-aux1,-Cc/2); Second node coordinates X,Y: (aux1,Cc/2); Height:Ch

This body is named **Body9**. Next step is to translate this body along X axis for Cs/2 (select Body9 then click or **Modify, Transformation, Translate Body**).

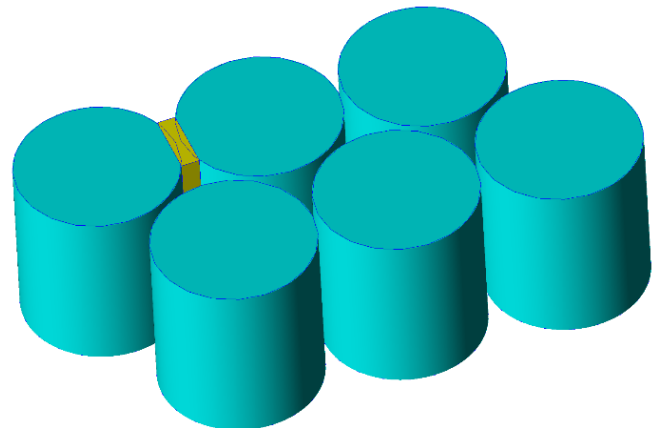
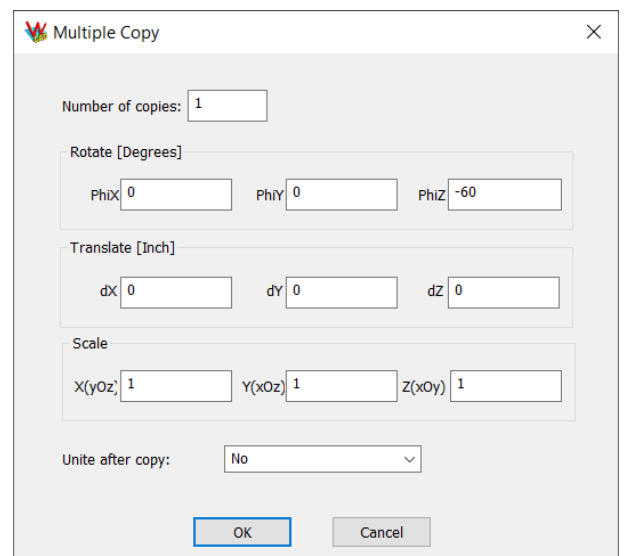
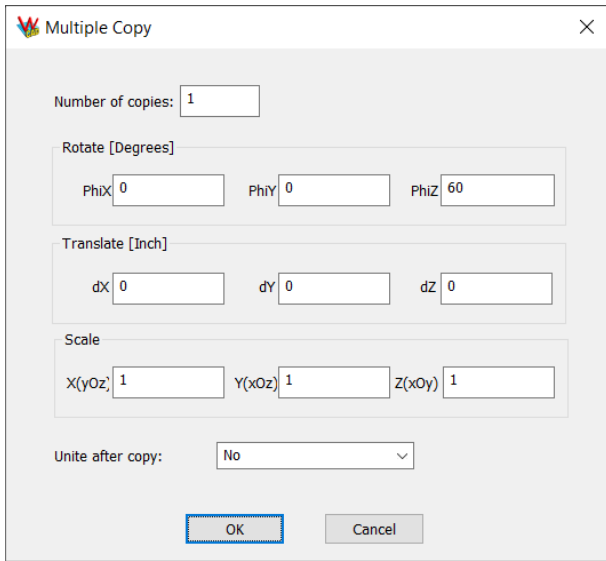



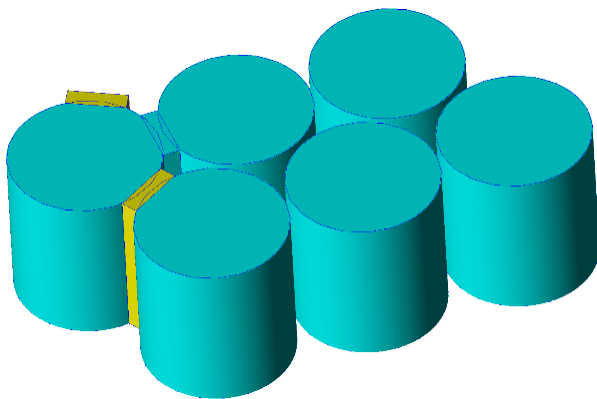
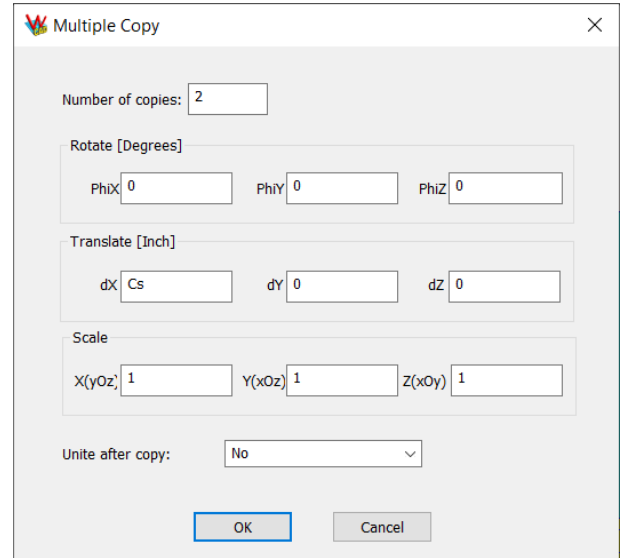
Figure 13. Positioning the first coupling element

Next, we copy this body to create two additional coupling bodies. The easiest way to create them is to copy Body9 and rotate it around z for -60 and 60 degrees by using or **Modify, Copy, Multiple Copy** as in the figure below.






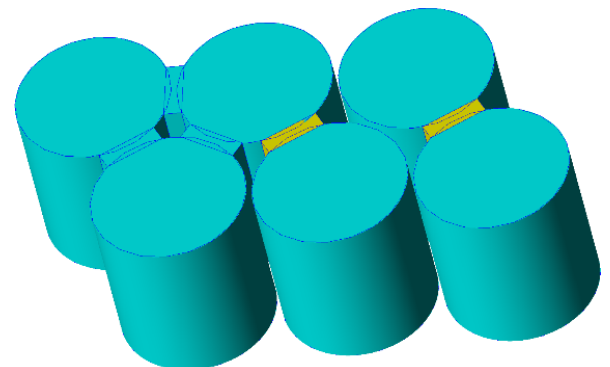
- copy Body9\_1 (by using  or **Modify, Copy, Multiple Copy**) two times and move for Cs along x



**Figure 14. Using multiple copy to create two additional coupling elements rotated by 60 degrees**

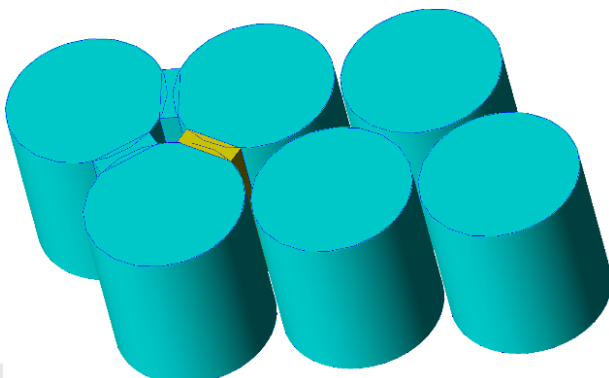
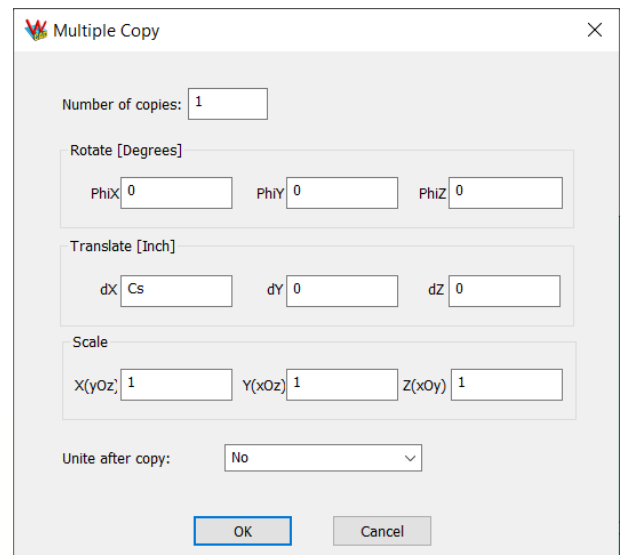
Newly created objects are marked as Body9\_1 and Body9\_2 which indicates they originate from Body9. The body rotated for -60 degrees (Body9\_1) is in the proper location while the body created with 60 degrees (Body9\_2) should be translated (select Body9\_2 then click  or **Modify, Transformation, Translate Body**) for:

$$Cs/2, -Cs*\sin(\pi(1)/3)$$



**Figure 16. Using multiple copy for additional coupling elements**

- copy Body9\_2 (by using  or **Modify, Copy, Multiple Copy**) once and move for Cs along x



**Figure 15. Positioning the third coupling element**

The easiest way to create the remaining coupling elements is to copy the 3 we already have:

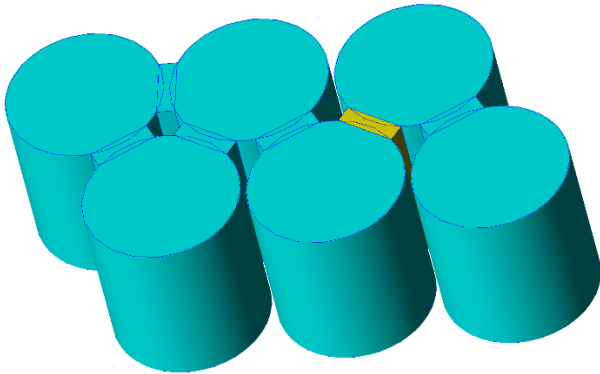


Figure 17. Using multiple copy for additional coupling elements

- copy Body9 (by using  or **Modify, Copy, Multiple Copy**) once and move for:

$$1.5*Cs, -Cs*\sin(\pi(1)/3)$$

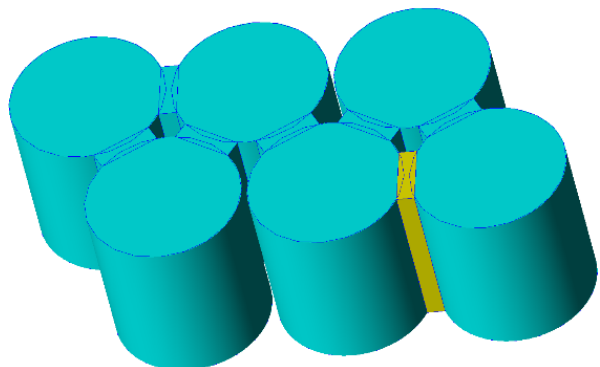
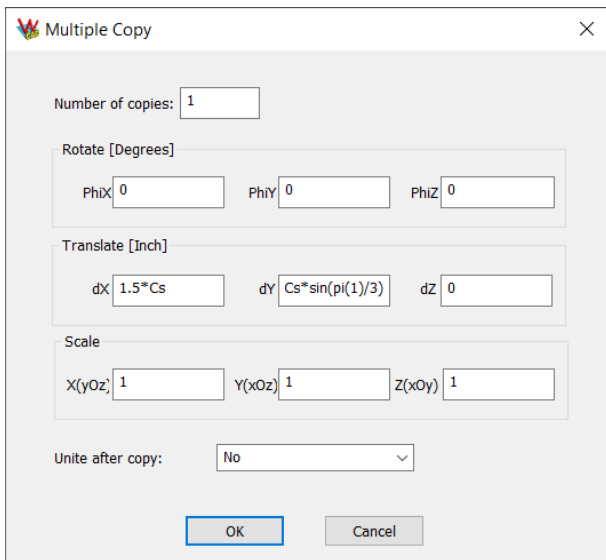





Figure 18. Using multiple copy for additional coupling elements

With all the coupling elements in place, unite them into a single body. Select Body9, Body9\_3, Body9\_2\_1, Body9\_1\_2, Body9\_1\_1, Body9\_2, Body9\_1 (hold Ctrl while selecting multiple bodies or use Shift and select first and last body) and unite them via  or **Modify, Boolean, Unite**. The resulting body is named **Body10**.

To properly connect the coupling elements and cavities, we will use Imprint manipulation. Select Body10, click  or use **Modify, Boolean, Imprint** and then select Body8. The last step is to use Unite Simplify operation to eliminate all obsolete parts between the cavities and couplings. Select Body8 and Body10 and then click  or use **Modify, Boolean, Unite Simplify**. This results in **Body11**, as shown in the following figure.

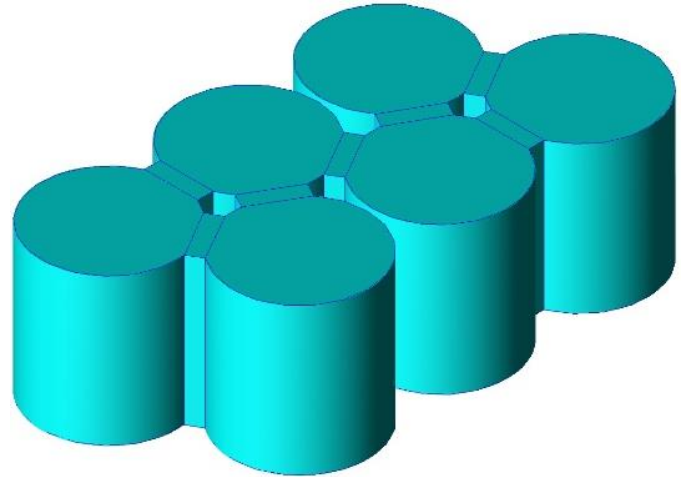



Figure 19. 6 cavities connected with coupling elements


## Assembling Tuning Screws

In this step, we model the tuning screws as cylinders. We have two kinds of screws, the ones that tune the resonance of the cavity and the screws that tune the coupling between cavities. First set of screws has radius **RTr** while the second one has **ITr**. First set has 6 screws and their length is controlled with symbols R1d, R2d,..., R6d while the second set has 7 screws: C12d, C13d, C23d, C34d, C45d, C46d, C56d.

The first step is to create appropriate symbols by going to Symbols table via icon  or **Edit, Symbols**.

12	0.056	RTr=0.112/2
13	0.056	ITr=0.112/2
14	0.125	R1d=0.125
15	0.125	R2d=0.125
16	0.125	R3d=0.125
17	0.125	R4d=0.125
18	0.125	R5d=0.125
19	0.125	R6d=0.125
20	0.55	C12d=0.55
21	0.1	C13d=0.1
22	0.4	C23d=0.4
23	0.35	C34d=0.35
24	0.4	C45d=0.4
25	0.55	C56d=0.55
26	0.1	C46d=0.1

Figure 20. Symbols required for geometry of the screws

Next, create 13 cylinder objects by using Cylinder icon  or **Construct, Solid, Cylinder**.

The locations and dimensions of cylinders are:

Position X,Y: (0,0); Radius: RTr; Height:-R1d

Position X,Y: (Cs/2,-Cs\*sin(pi(1)/3)); Radius: RTr; Height:-R2d

Position X,Y: (Cs,0); Radius: RTr; Height:-R3d

Position X,Y: (1.5\*Cs,-Cs\*sin(pi(1)/3)); Radius: RTr; Height:-R4d

Position X,Y: (2\*Cs,0); Radius: RTr; Height:-R5d

Position X,Y: (2.5\*Cs,-Cs\*sin(pi(1)/3)); Radius: RTr; Height:-R6d

Position X,Y: (Cs/4,-Cs/2\*sin(pi(1)/3)); Radius: ITr; Height:-C12d

Position X,Y: (Cs/2,0); Radius: ITr; Height:-C13d

Position X,Y: (0.75\*Cs,-Cs/2\*sin(pi(1)/3)); Radius: ITr; Height:-C23d




Position X,Y: (1.25\*Cs,-Cs/2\*sin(pi(1)/3)); Radius: ITr; Height:-C34d

Position X,Y: (1.75\*Cs,-Cs/2\*sin(pi(1)/3)); Radius: ITr; Height:-C45d

Position X,Y: (2\*Cs,-Cs\*sin(pi(1)/3)); Radius: ITr; Height:-C46d

Position X,Y: (2.25\*Cs,-Cs/2\*sin(pi(1)/3)); Radius: ITr; Height:-C56d

The tiresome work can be done by editing the WCM file in Notepad directly, as explained previously.

Unite the 13 bodies created (select Body12, Body13,...,Body24 and then click  or **Modify, Boolean, Unite**). Translate them for Ch along z (select Body25 then click  or **Modify, Transformation, Translate Body**) and as final step we subtract body comprising all 13 screws from the body comprising all 6 cavities. Select Body25, then click  or **Modify, Boolean, Subtract**, then select **Body 11**. The structure looks like in the figure below. The resulting body is named Body26.

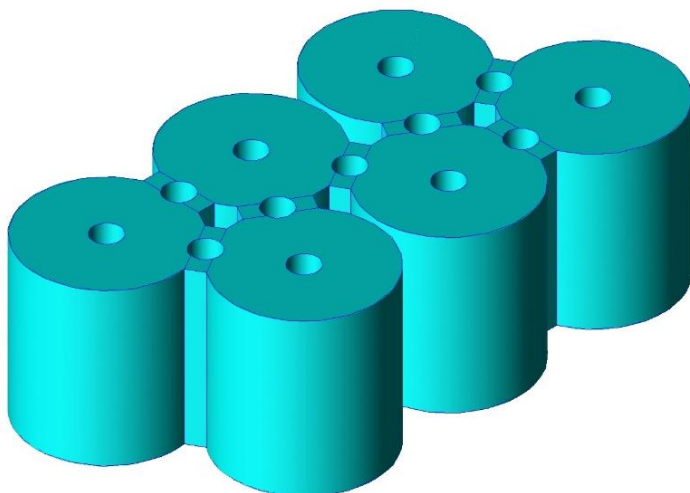


Figure 21. 6 coupled cavities with tuning screws

## Feeding Mechanism

This section is an explanation how to add a feeding mechanism. It consists of curved wire that connects one end of feeding port(s) and the inner wall of first (or last) cavity as shown in Figure 22.

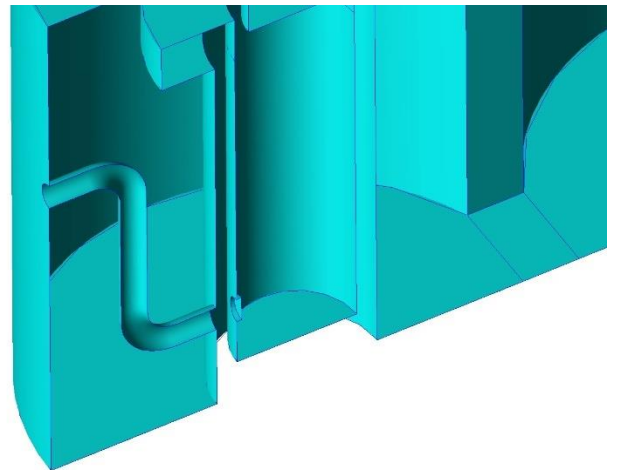




Figure 22. Feeding mechanism


The following set of symbols: Ph, TWr, L1, L2, TWc, TWh is needed as in the following figure (open Symbols table by clicking icon  or **Edit, Symbols**).

27	0.4	Ph=0.4
28	0.016	TWr=0.032/2
29	0.0525	L1=0.0525
30	0.080...	L2=0.08065
31	0.05	TWc=0.1/2
32	0.125	TWh=0.125

Figure 23. Required symbols for feeding mechanism

The easiest way is to create a wire shape that corresponds to the geometry and use Sweep manipulation. Wire shape consists of several wires. First segment uses Line primitive, invoked via  or **Construct, Curve, Line**. Wire radius can be left as zero and vertices coordinates should be.

(-L1,0,TWc) (0,0,TWc)


This yields Wire3. Next segment is arc created by using elliptic arc primitive:  or draw, Curve, Elliptic Arc. Its parameters should be:

XY position of center (0,0)

Major Axis (TWc,0)

Minor Axis: TWc

Start and end angle: 0 to 90 degrees

This result in Wire4, which should be rotated around x for 90 degrees via Rotate Body manipulation:  or **Modify, Transformation, Rotate Body**.

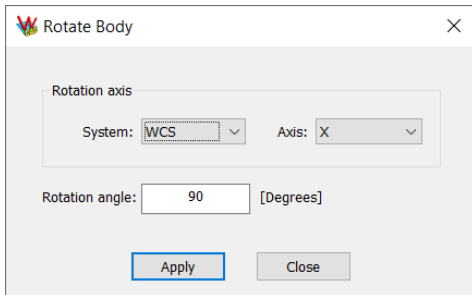




Figure 24. Rotate arch for 90 degrees around X axis

Next segment is again straight line  or **Construct, Curve, Line**:

$$(TWc,0,0) \quad (TWc,0,-(Ph-TWh-2*TWc))$$

Body created is named Wire5. The next segment is again arc that can be obtained by using multiple copy command of the previously created object, Wire4. Select Wire4 and either click  or **Modify, Copy, Multiple Copy**:

Translation vector (dZ cannot be read from the figure below) is:

$$(2*TWc, 0, -(Ph-TWh-2*TWc))$$

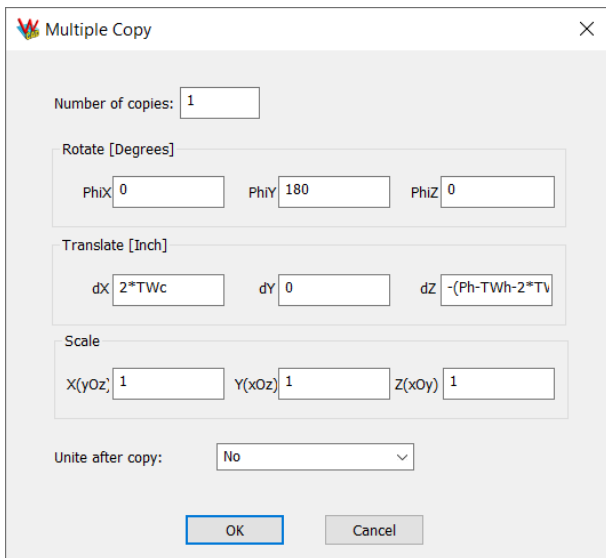





Figure 25. Multiple copy used to get another curve of the wire profile



The result is Wire4\_1. Last segment is again straight wire  or **Construct, Curve, Line**:


$$(2*TWc,0,-(Ph-TWh-2*TWc)-TWc) \quad (2*TWc+L2,0,-(Ph-TWh-2*TWc)-TWc)$$

All five wires can be united into a single body (Wire3, Wire4, Wire4\_1, Wire5, Wire6). Select them by using Shift or Ctrl. Click  or **Modify, Boolean, Unite**. Resulting body is Wire7.

Now we need a simple circle object that will be used to sweep along Wire7 and create a curved wire profile. Circle is created by using Circle primitive  or **Draw, Surface, Circle**:

X,Y position (0,0) Radius: TWr

This creates Body27 which should be rotated ( or **Modify, Transformation, Rotate Body**) around Y for 90 degrees and then translated ( or **Modify, Transformation, Translate Body**) for: (-L1, 0, TWc)

Now select Body27, click  or **Modify, Sweep, Normal** and then click Wire7. The result is Body28 as in the following figure.

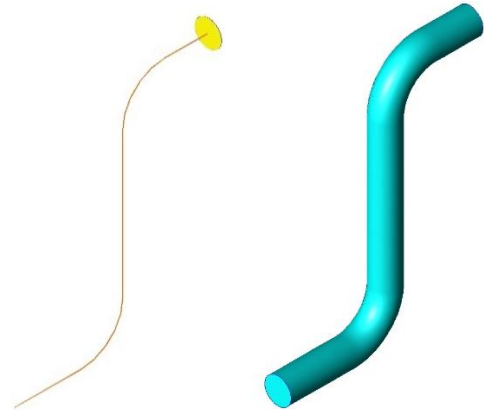




Figure 26. Before and after the sweep

Now we can delete Wire7 and Body27 as they are not required anymore and translate Body28 for Ph-TWc along Z axis by using  or **Modify, Transformation, Translate Body**. We can use multiple copy now to obtain a feeder at the second port (last cavity). Use  or **Modify, Copy, Multiple Copy**:

Translation vector is:

$$(2.5*Cs+Cr-L1, -Cs*\sin(\pi(1)/3), 0)$$

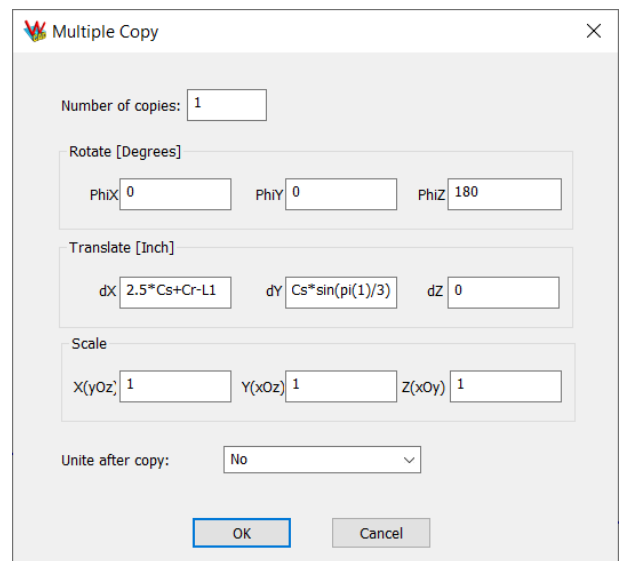


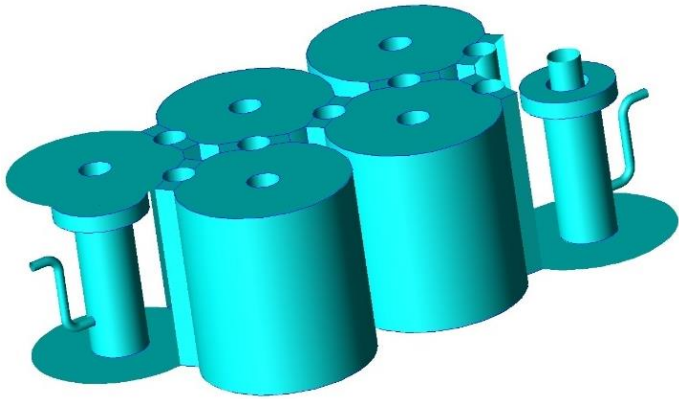


Figure 27. Using multiple copy for the second feeder

The first feeder (Body28) needs to be placed in the adequate position via  or **Modify, Transformation, Translate Body** for:

$$(-(Cr-L1), 0, 0)$$

At the end, select Body28 and Body28\_1. Click  or **Modify, Boolean, Subtract** and choose Body26. End result is Body29 as in the following image.




**Figure 28.** The structure after adding feeds (certain surfaces are hidden to enable inspection of interior)

### Adding Coaxial Ports

The final section explains adding Teflon coax port (mounted onto the last and first cavity). Again, this requires a couple of symbols defining port radii, position, Er of the material used: PL, POr, PIr, Er.



ID	VALUE	UNIT
33	0.3881	PL=0.3881
34	0.081	POr=0.162/2
35	0.025	PIr=0.05/2
36	2.2	Er=2.2

**Figure 29.** Remaining symbols for coaxial ports

The SMA ports are created as 2 cylinders ( or **Construct, Solid, Cylinder**):

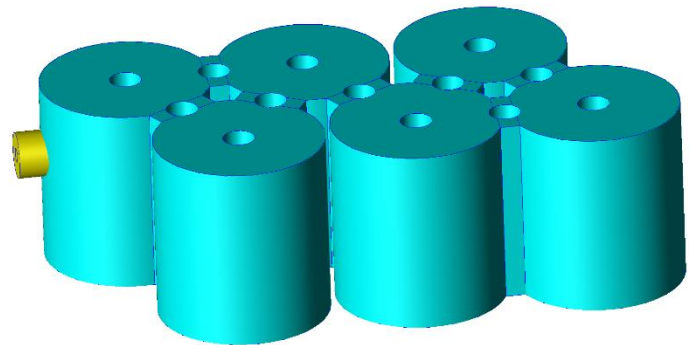
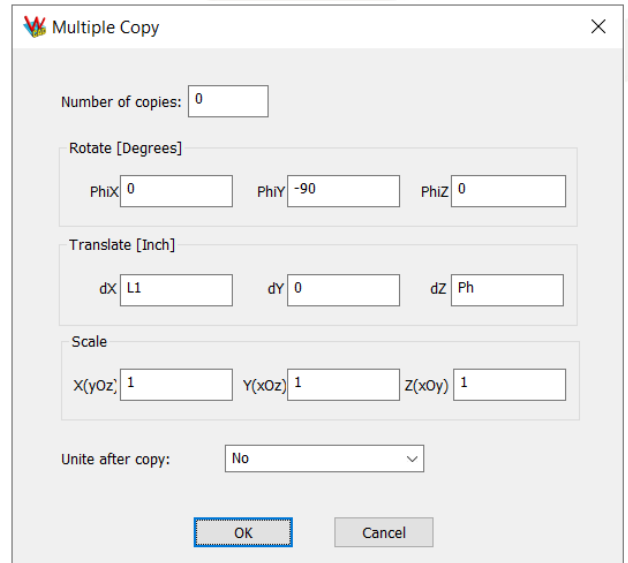
XY position:(0,0) Radius: PIr Height:PL+L1 (Body30)

XY position:(0,0) Radius: POr Height:PL+L1 (Body31)



Body30 and Body31 should be united ( or **Modify, Boolean, Unite**) which results in Body32. After this, we need to trim the part of the coax cable so that it can fit the cylindrical surface of the cavity. The easiest way is to create a cylinder of the same radius as original cavity and subtract it from the coax cable. We can position the coax cable (Body32) to the right spot by using Multiple Copy which allows simultaneous rotation and translation ( or **Modify, Copy, Multiple Copy**):

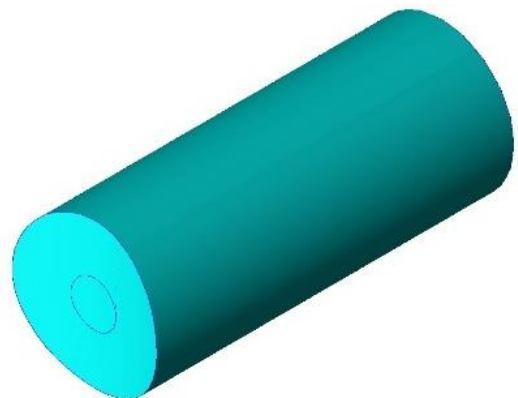
Translation vector is (with rotation for -90 around Y):

(L1, 0, Ph)




**Figure 30.** Positioning coax cable

Now we draw cylinder (XY position (Cr,0), Radius:Cr, Height:Ch, Body33,  or **Construct, Solid, Cylinder**). Select Body33, choose  or **Modify, Boolean, Subtract** and select Body32 (coax cable). We obtain a trimmed coax cable (Body34).



**Figure 31.** Trimmed coax cable

Now we need to copy the port to the end of the cavity. Select Body34 and click  or **Modify, Copy, Multiple Copy**. Use the parameters from the following figure.

Translation vector is (with rotation for 180 around Z):

$(2.5 * Cs + Cr, -Cs * \sin(\pi(1)/3), 0)$



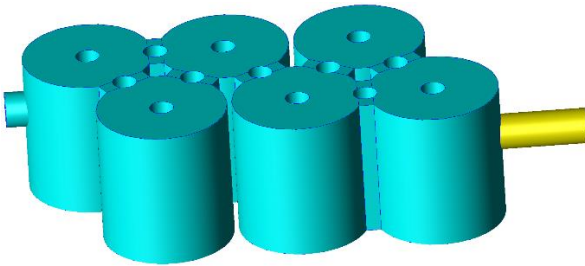
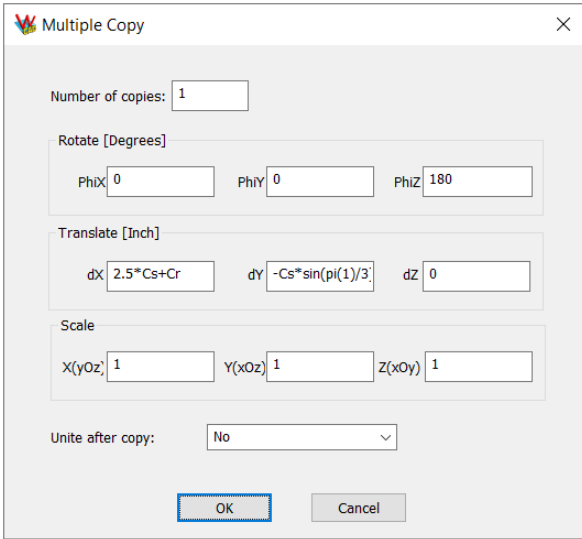


Figure 32. Creating a second port

The first port should now be translated to its position. Again select Body34 and translate for  $-Cr$  along X axis (or **Modify, Transformation, Translate Body**).

We now have completed the geometry we need to model the filter. Select all bodies: Body29, Body34, Body34\_1 and unite them (or **Modify, Boolean, Unite**).

Next, we need to define a new domain for Teflon in the Domains table (or **Edit, Domains**). Click **Add** and add a second domain with real part of electrical permittivity equal to symbol  $\epsilon_r$ .

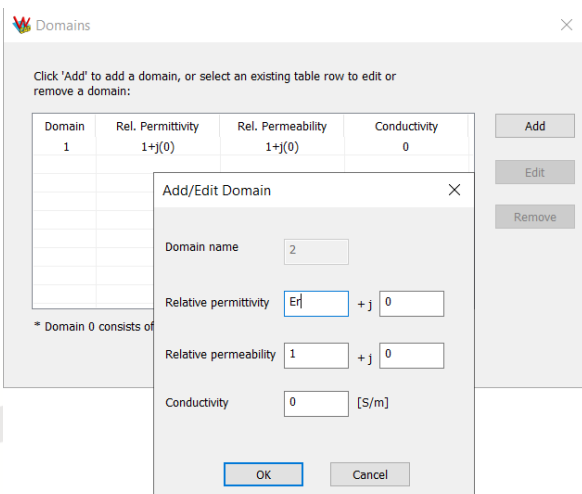


Figure 33. Creating new domain for Teflon

Now select Body35. In the subtree, select two regions between inner and outer coax. Right click and choose **Set Domain Spec**. Set the domain to #2.

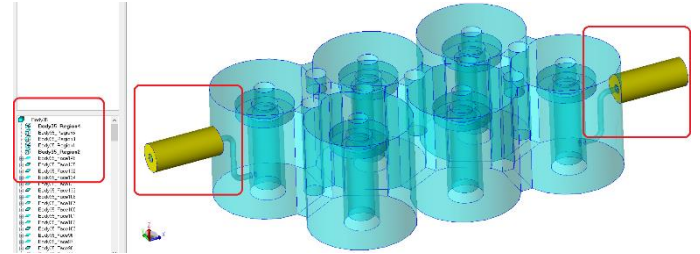


Figure 34. Assigning domain to regions

In the same way, the interior of the cavity should be set to belong to domain of free space (#1).

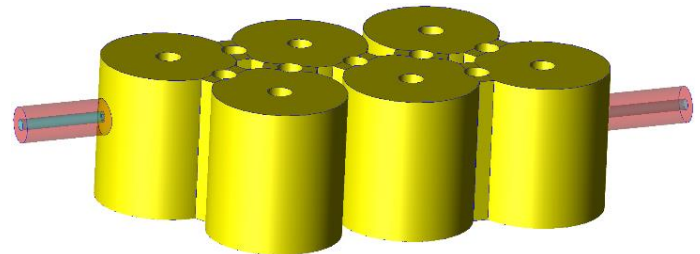


Figure 35. Assigning domain internal region

After this, we need two faces on the outer surface of the coax as in the Figure 36.

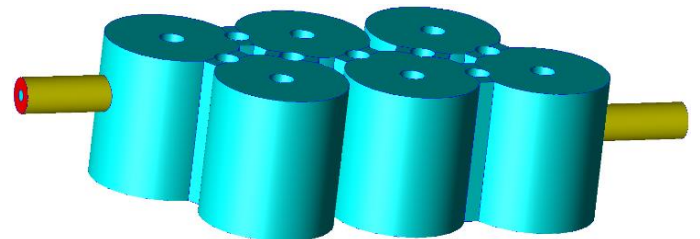


Figure 36. Setting outer surface of the coax as metallic

After this right click and choose **Set Domain** or go to **Modify, Set Properties, Set Domain**. Thicken the **Composite metallic boundary** check box.

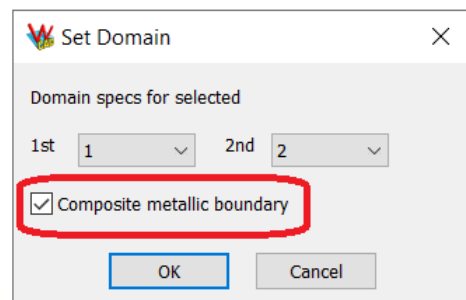
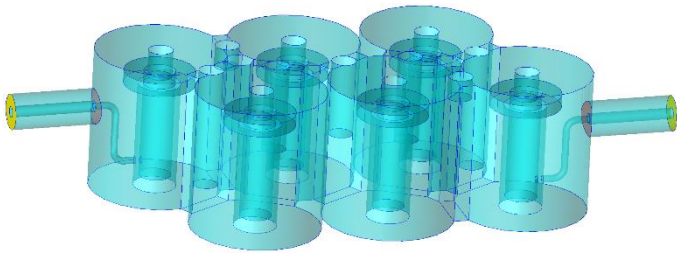


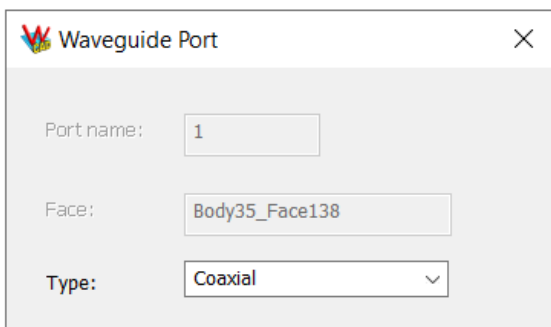
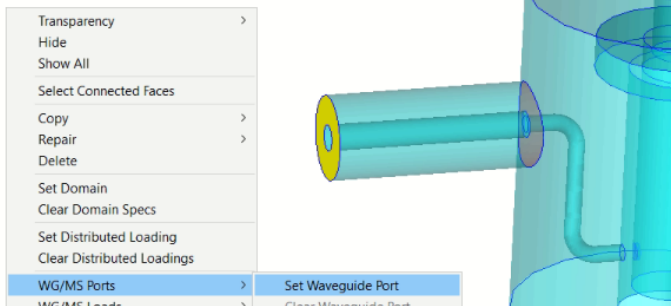
Figure 37. Setting outer surface of the coax as metallic

The ports should be set to the two faces as shown below.



**WSMB data:**

- Ch=0.65
- Cr=0.3
- Rr=0.195/2
- Rcb=0.146/2
- Rh=0.55
- THh=0.06
- THr=0.325/2
- Rcbd=0.5
- Cs=0.62
- Cc=0.236
- $aux1=Cs/2-(Cr^2-(Cc/2)^2)^{0.5}$
- RTr=0.112/2
- ITr=0.112/2
- R1d=0.125
- R2d=0.125
- R3d=0.125
- R4d=0.125
- R5d=0.125
- R6d=0.125
- C12d=0.55
- C13d=0.1
- C23d=0.4
- C34d=0.35
- C45d=0.4
- C56d=0.55
- C46d=0.1
- Ph=0.4
- TWr=0.032/2
- L1=0.0525
- L2=0.08065
- TWc=0.1/2
- TWh=0.125
- PL=0.3881
- POr=0.162/2
- PIr=0.05/2
- Er=2.2



**Figure 38. Defining port**

The filter requires tuning or optimization by changing the parameters of the tuning screws until the desired performance is achieved. For initial results it can be simulated around 3 GHz. Instruction how to efficiently perform filter tuning/optimization please refer to the application note [Cavity Filter Design and Optimization](#).

At the very end, in case a user needs a shortcut to obtain complete filter model, the project can be made in seconds using the procedure described next.

Make new project and save under arbitrary name. Set units as explained at the start of the tutorial. Save and close. Paste the symbol definitions to the WSMB file (in Notepad) and commands to the WCM file. The list with actions should be pasted into the block named "commands" which is the last block in WCM file. Save changes in Notepad and re-open project. Note that WSMB file requires an empty line at the end of file.

**WCM data:**

```

DrawCylinder "Body1" (0,0,0) Cr Ch-(0)
DrawLoop "Wire1" (0,0,0) Rr 0 1
DrawPolyline "Wire2" "points" {(Rr,0.000000,0.000000) ,
(Rr,0.000000,Rh-THh) , (THr,0.000000,Rh-THh) ,
(THr,0.000000,Rh) , (Rcb,0.000000,Rh) , (Rcb,0.000000,Rh-THh) ,
(Rcb,0.000000,Rh-Rcbd)} 0 1
Sweep "Body2" "normal" "Wire2" "Wire1" "UseDrawDir"
Delete {"Wire1","Wire2"} "no"
DrawCircle "Body3" (0,0,0) Rr
DrawCircle "Body4" (0,0,0) Rcb
Translate "Body4" (0, 0, Rh-Rcbd)
Unite "Body5" {"Body2","Body3","Body4"}
Subtract "Body6" {"Body5","Body1"}
MultipleCopy "Body6" 1 (0, 0, 0) (Cs/2, -Cs*sin(pi(1)/3), 0) (1, 1, 1) "Copies and Original"
MultipleCopy "Body7" 2 (0, 0, 0) (Cs, 0, 0) (1, 1, 1) "Copies and Original"
DrawCuboid "Body9" (-aux1,-Cc/2,0) (aux1,Cc/2,0) Ch-(0)
Translate "Body9" (Cs/2, 0, 0)
MultipleCopy "Body9" 1 (0, 0, -60) (0, 0, 0) (1, 1, 1) "No"
MultipleCopy "Body9" 1 (0, 0, 60) (0, 0, 0) (1, 1, 1) "No"
Translate "Body9_2" (Cs/2, -Cs*sin(pi(1)/3), 0)
MultipleCopy "Body9_1" 2 (0, 0, 0) (Cs, 0, 0) (1, 1, 1) "No"
MultipleCopy "Body9_2" 1 (0, 0, 0) (Cs, 0, 0) (1, 1, 1) "No"
MultipleCopy "Body9" 1 (0, 0, 0) (1.5*Cs, -Cs*sin(pi(1)/3), 0) (1, 1, 1) "No"
Unite "Body10" {"Body9","Body9_3","Body9_2_1","Body9_1_2","Body9_1_1","Body9_2","Body9_1"}
Imprint {"Body10","Body8"}
UniteSimplify "Body11" {"Body8","Body10"}
DrawCylinder "Body12" (0,0,0) RTr -R1d-(0)
DrawCylinder "Body13" (Cs/2,-Cs*sin(pi(1)/3),0) RTr -R2d-(0)
DrawCylinder "Body14" (Cs,0,0) RTr -R3d-(0)
DrawCylinder "Body15" (1.5*Cs,-Cs*sin(pi(1)/3),0) RTr -R4d-(0)
DrawCylinder "Body16" (2*Cs,0,0) RTr -R5d-(0)
DrawCylinder "Body17" (2.5*Cs,-Cs*sin(pi(1)/3),0) RTr -R6d-(0)
DrawCylinder "Body18" (Cs/4,-Cs/2*sin(pi(1)/3),0) ITr -C12d-(0)

```

```

DrawCylinder "Body19" (Cs/2,0,0) ITr -C13d-(0)
DrawCylinder "Body20" (0.75*Cs,-Cs/2*sin(pi(1)/3),0) ITr -C23d-(0)
DrawCylinder "Body21" (1.25*Cs,-Cs/2*sin(pi(1)/3),0) ITr -C34d-(0)
DrawCylinder "Body22" (1.75*Cs,-Cs/2*sin(pi(1)/3),0) ITr -C45d-(0)
DrawCylinder "Body23" (2*Cs,-Cs*sin(pi(1)/3),0) ITr -C46d-(0)
DrawCylinder "Body24" (2.25*Cs,-Cs/2*sin(pi(1)/3),0) ITr -C56d-(0)
Unite "Body25" {"Body12","Body24","Body23","Body22","Body21","Body20","Body19","Body18","Body17","Body16","Body15","Body14","Body13"}
Translate "Body25" (0, 0, Ch)
Subtract "Body26" {"Body25","Body11"}
DrawLine "Wire3" (-L1,0,TWc) (0,0,TWc) 0 1
DrawEllipticArc "Wire4" (0,0,0) (TWc,0,0) TWc 0 90 0 1
Rotate "Wire4" 90 "WCS" "X"
DrawLine "Wire5" (TWc,0,0) (TWc,0,-(Ph-TWh-2*TWc)) 0 1
MultipleCopy "Wire4" 1 (0, 180, 0) (2*TWc, 0, -(Ph-TWh-2*TWc)) (1, 1, 1) "No"
DrawLine "Wire6" (2*TWc,0,-(Ph-TWh-2*TWc)-TWc) (2*TWc+L2,0,-(Ph-TWh-2*TWc)-TWc) 0 1
Unite "Wire7" {"Wire3","Wire6","Wire4_1","Wire5","Wire4"}
DrawCircle "Body27" (0,0,0) TWr
Rotate "Body27" 90 "WCS" "Y"
Translate "Body27" (-L1, 0, TWc)
Sweep "Body28" "normal" "Body27" "Wire7" "UseDrawDir"
Delete {"Body27","Wire7"} "no"
Translate "Body28" (0, 0, Ph-TWc)
MultipleCopy "Body28" 1 (0, 0, 180) (2.5*Cs+Cr-L1, -Cs*sin(pi(1)/3), 0) (1, 1, 1) "No"
Translate "Body28" (-Cr-L1), 0, 0)
Subtract "Body29" {"Body28","Body28_1","Body26"}
DrawCylinder "Body30" (0,0,0) PIR PL+L1-(0)
DrawCylinder "Body31" (0,0,0) POR PL+L1-(0)
Unite "Body32" {"Body30","Body31"}
MultipleCopy "Body32" 0 (0, -90, 0) (L1, 0, Ph) (1, 1, 1) "No"
DrawCylinder "Body33" (Cr,0,0) Cr Ch-(0)
Subtract "Body34" {"Body33","Body32"}

```

```
MultipleCopy "Body34" 1 (0, 0, 180) (2.5*Cs+Cr, -Cs*sin(pi(1)/3),  
0) (1, 1, 1) "No"
```

```
Translate "Body34" (-Cr, 0, 0)
```

```
Unite "Body35" {"Body29","Body34","Body34_1"}
```

```
DefineDomain "2" {"Er"=Er, "Ei"=0, "Mr"=1, "Mi"=0, "Sigma"=0,  
"Ro"=1000}
```

```
SetDomain {"Body35_Region1","Body35_Region5"} "D_2"
```

```
SetDomain "Body35_Region4" "D_1"
```

```
SetDomain {"Body35_Face42","Body35_Face149"} "M_1_2"
```

```
DefineWaveguidePort "1" "Body35_Face148" "Coaxial"  
"Default" 0 ("Linear",1,0) {(1,0) , (1,0) , (1,0) , (1,0) , (1,0) , (1,0) ,  
(1,0)} (0,0,0,0,0,0,0)
```

```
DefineWaveguidePort "2" "Body35_Face41" "Coaxial" "Default"  
0 ("Linear",1,0) {(1,0) , (1,0) , (1,0) , (1,0) , (1,0) , (1,0) , (1,0)}  
(0,0,0,0,0,0,0)
```