

Splash Plate Reflector Antenna Design Guide

This paper presents the procedure for the design of splash plate reflector antenna. It contains theoretical consideration and foundation, as well as procedure for design in the WIPL-D software suite.

Splash plate reflector antenna consists of two parts:

- Feeding cylindrical waveguide (feeder),
- Splash plate sub-reflector and main parabolic reflector (reflectors).

The design procedure is approximately divided into two steps, each corresponding to the design of single part. After a theoretical consideration, the description of the modeling in WIPL-D is provided for each step.

1. Design of Feeder

For splash plate reflector, the feeding antenna is most often chosen to have large beam-width. In our case we will use open-end cylindrical waveguide (CWG).

The feeder design procedure consists of design of CWG, according to the specified central operating frequency, and adding choke to the CWG aperture edge to suppress backward radiation. The details are explained in the following section.

1.1. Design of CWG

CWG is excited by a probe and typical cross-section illustration is shown in Fig. 1.

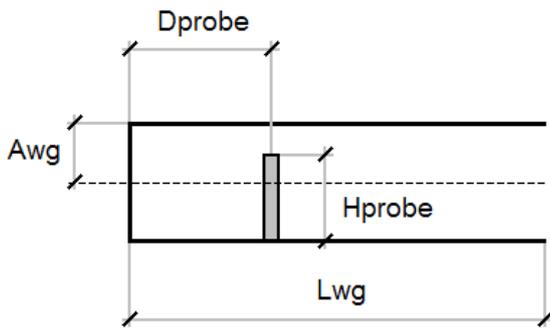


Fig. 1. CWG Cross Section

Design of CWG consists of adopting values for:

A_{wg} – waveguide radius,

L_{wg} – waveguide length (it must be large enough to allow propagation of the dominant mode only, usually half of the wavelength from probe to CWG aperture is sufficient),

H_{probe} – probe height (this should be set according to the wavelength in air or in the waveguide dielectric),

D_{probe} – probe to back wall distance (this should be set to quarter of the wavelength).

The fundamental mode propagating through a cylindrical waveguide is TE₁₁ mode. The next mode is TM₁₀. Cut off frequencies for TE₁₁ and TM₁₀ modes are:

$$F_c(TE_{11}) = 0.293 \frac{c}{A_{wg}} \quad (1)$$

$$F_c(TM_{10}) = 0.383 \frac{c}{A_{wg}} \quad (2)$$

where c is the speed of light and A_{wg} is the radius of the cylindrical waveguide. The optimum operating frequency F_0 is chosen to be geometrical mean value of two cut off frequencies:

$$F_0 = \sqrt{F_c(TE_{11})F_c(TM_{10})} = 0.335 \frac{c}{A_{wg}} \quad (3)$$

Since $c = 10^8 \frac{m}{s}$ from (3) we obtain the radius of the cylindrical waveguide for given operating frequency:

$$A_{wg}[mm] = \frac{100}{F_0[GHz]} \quad (4)$$

At the operating frequency F_0 the wavelength in free space WLO and in the waveguide $WLwg$ are given with:

$$WLO = \frac{c}{F_0} \Rightarrow WLO = \frac{300}{F_0[GHz]} \quad (5)$$

$$WLwg = \frac{WLO}{\sqrt{1 - \left(\frac{F_c(TE_{11})}{F_0}\right)^2}} \quad (6)$$

$$\Rightarrow WLwg = \frac{619}{F_0[GHz]}$$

Waveguide length is chosen in such a manner that higher order modes completely vanish before the aperture. The sufficient length is:

$$L_{wg}[mm] = \frac{3}{4} WLwg[mm] \quad (7)$$

The distance of the probe from the back wall should be:

$$D_{probe}[mm] = \frac{1}{4} WLwg[mm] \quad (8)$$

The probe length should be:

$$H_{probe}[mm] = \frac{1}{4} WLO[mm] \quad (9)$$

The dimensioning of the waveguide is completed with setting the above mentioned variables.

To suppress back radiation a choke is added to the CWG aperture edge. CWG with the choke looks like in Fig. 2.

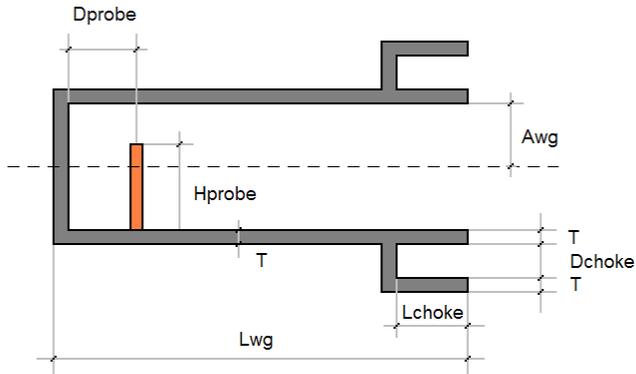


Fig. 2. Cross section of CWG with choke

The choke length should be:

$$L_{choke}[mm] = \frac{WLO[mm]}{4} \quad (10)$$

while the choke width Dchoke is taken to be equal to metallic wall thickness T.

1.2. Modeling of Feeder in WIPL-D

The complete CWG feeder can be made of one BoR (body of revolution) object, two Circle objects and single wire. The cross section with the indicated objects can be seen in Fig. 3.

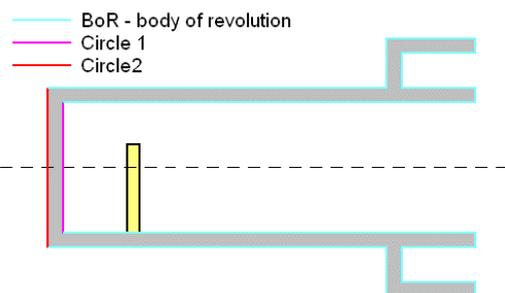


Fig. 3. Objects in WIPL-D mode

Since the feeder has two symmetry planes, both can be used to reduce the analysis time. There are two feeder models:

- Cylindrical waveguide feeder 1 – the model uses one symmetry plane. Only half of the model is built, and it is suitable for calculation of both radiation pattern and input impedance.
- Cylindrical waveguide feeder 2 – the model uses two symmetry planes. Only quarter of the model is built, and it is suitable for calculation of radiation pattern. It is not suitable for calculation of input impedance, because CWG is excited by a dipole instead by a probe. The deembedding procedure is required to obtain the proper return loss.

In the Symbols table, we define all the design parameters mentioned in the theoretical consideration and all the relevant coordinates needed to build the model. The Symbols table can be

inspected by clicking  in the WIPL-D Pro.

Symbols numbered 1-5 define the design parameters of the feeder:

F0 – Reference frequency (25.5 GHz by default),

BW – 10 dB beam-width (122 deg by default),

T – Metallic wall thickness (1 mm by default),

Zfeed – Shift constant (0 by default). By changing *Zfeed*, one moves the feeder along z-axis for the specified length,

N – Number of segments for polygonal approximation of the cylinder (4 by default).

Symbols numbered 6-18 define auxiliary values needed for calculation. The parameter of interest is:

Ceq – Equivalent radius factor. Since the cylinder curvature is approximated by a polygon, design radius *Awg* should be taken in the model multiplied by *Ceq*, to compensate for polygonal approximation of the cylinder curvature. *Ceq* is chosen in such a way that cross section of cylinder (polygon) has the same surface as the circle with Radius *Awg*.

Symbols numbered 19-43 define *p* and *z* coordinates of the BoR object.

Modification of the models is simple. Starting from either Cylindrical waveguide feeder 1 or 2, it is possible to obtain:

- CH without metal thickness – by deleting from (R10,Z10) to (R12,Z12) in the BoR object and by completely deleting Circle #2 object.
- CH without choke – by deleting from (R6,Z6) to (R10,Z10) in the BoR object.

To run simulation, click . After the simulation is done, to inspect YZS click , and for radiation pattern click .

2. Design of Sub-reflector and Reflector

2.1. Splash Plate Sub-reflector

The cross section of the splash plate sub-reflector is given in Fig. 4. A cylindrical bump is added to the center of the splash plate to prevent radiation of the EM wave back to the CWG.

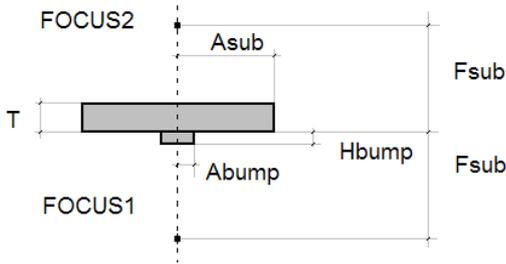


Fig. 4. Cross section of splash plate sub-reflector

The splash plate is completely determined with the following parameters:

A_{sub} – Radius of the splash plate,

T – Splash plate thickness,

A_{bump} – Radius of the bump, and

H_{bump} – Height of the bump.

Hypothetical focuses are added to the splash plate reflector. When the phase center of the CWG feeder is placed in Focus #1, the reflected wave field radiates towards the parabolic reflector as if the source was placed in Focus #2.

Focal distance F_{sub} is related to the half beam-width HBW of CWG feeder as:

$$F_{sub} = \frac{A_{sub}}{\tan\left(\frac{\pi}{180} HBW\right)} \quad (11)$$

2.2. Parabolic Reflector

The cross section of the parabolic reflector is given in Fig. 5.

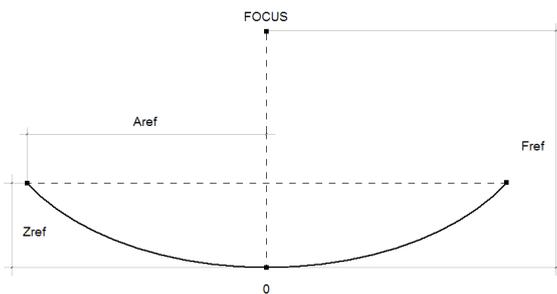


Fig. 5. Cross section of parabolic reflector

The parabola is completely determined with the following parameters:

F_{ref} – focal distance of the parabola,

A_{ref} – radius of the parabola,

Z_{ref} – the height of the parabola edge.

Z_{ref} is related to other parameters as:

$$Z_{ref} = \frac{A_{ref}^2}{4F_{ref}} \quad (12)$$

The Focus #2 of the splash plate should be put in the focus of the parabola.

2.3. Splash Plate Sub-reflector and Parabolic Reflector

The cross section of the reflector and sub-reflector is shown in Fig. 6.

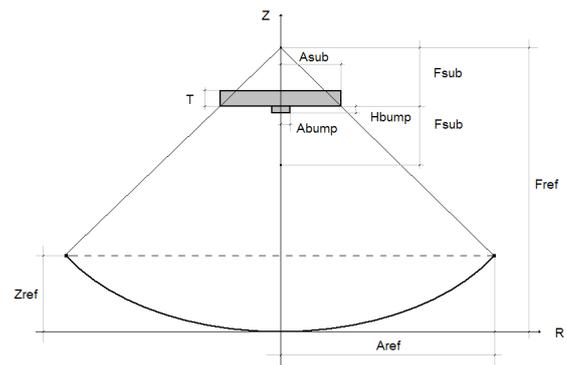


Fig. 6. Reflector and sub-reflector cross section

The geometry of the reflectors is chosen to satisfy the following conditions:

- Focus #2 of the splash plate should be placed in the focus of the parabola.
- The line which is tangential to the edge of the parabola and goes through the focus, should also be tangential to the edge of splash plate.

The parameters of the reflectors specified by the designer are: A_{ref} , F_{ref} , and A_{sub} .

2.4. Building Model of Reflectors in WIPL-D

The splash plate sub-reflector and parabolic reflector are built using one Rflct., one BoR and one Circle object in WIPL-D Pro.

There are two reflector and sub reflector projects:

- Splash plate reflector 1 (one symmetry plane used – half model) and
- Splash plate reflector 2 (two symmetry planes – quarter model).

Symbols numbered 1-7 are defined by the user and specify referent frequency and geometry of the reflectors:

$F0$ – Reference frequency (25.5 GHz by default),

T – Metal thickness (1 mm by default),

A_{ref} – radius of the parabolic reflector (150 mm by default),

F_{ref} – focal distance of the parabolic reflector (112.5 mm by default),

A_{sub} – radius of the splash plate sub-reflector (26 mm by default),

$Abump$ – radius of the sub-reflector bump (3 mm by default),

$Hbump$ – height of the sub-reflector bump (2 mm by default).

Symbols numbered 7-10 stand for:

$Nref$ – Number of segments per quarter of circumference for parabolic reflector. $Nref$ should be even integer larger than $NrefE$ estimated in symbol #11. The estimation of $NrefE$ is made using the criterion that maximum size of the reflector patch is no larger than 1.5 wavelength at the referent frequency $F0$.

$Nsub$ – Number of segments per quarter of circumference for splash plate reflector. $Nsub$ should be even integer larger than $NsubE$ estimated in symbol #12. The estimation of $NsubE$ is made using the criterion that maximum size of the sub-reflector patch

is no larger than $\frac{\pi}{4}\lambda$ at the referent frequency $F0$.

HBW – Half beam-width of the CWG feeder radiation pattern in order to have 10 dB space taper at the edge of the sub-reflector. BW from the model CWG should be equal to $2HBW$.

$Fsub$ – Focal distance of the sub-reflector.

Symbols numbered 13-15 are additional symbols for the geometry definition and positioning, as well as auxiliary symbols.

What is left to do is to import the feeder into the project with reflector. There are two projects of the complete antenna:

- Splash plate reflector with cylindrical waveguide feeder 1 (one symmetry plane - half model) – suitable for calculation of both radiation pattern and input impedance.
- Splash plate reflector with cylindrical waveguide feeder 2 (two symmetry planes – quarter model) – suitable for calculation of radiation pattern only. The deembedding procedure must be applied to obtain proper return loss.

To import use option Edit/Structure/Import. After the import, move the feeder phase center to splash plate Focus #1 by specifying $Z_{feed} = Fref - 2Fsub$ in the Symbols table.

The final model with one symmetry plane (Splash plate reflector with cylindrical waveguide feeder 1) is shown in Fig. 7.

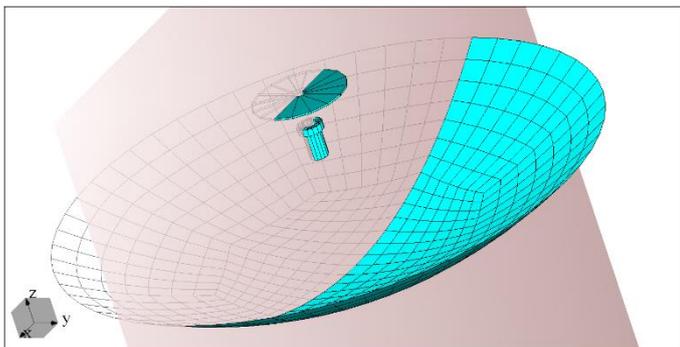


Fig. 7. Model of splash plate reflector with cylindrical waveguide feeder in WIPL-D Pro

The Default analysis parameters are:

- Frequency range: 25.5 GHz (set in Edit/Frequency),
- Radiation pattern: $\phi=0, 90$ and $-90^\circ \leq \theta \leq 90^\circ$ at 361 points (can be modified in Edit/Output Results/Radiation)

After the analysis, the radiation patterns in 3D, E and H plane are shown in Fig. 8. The model requires only 2,825 unknowns to be simulated in WIPL-D Pro. Simulation time at the everyday inexpensive work PC (CPU: Intel i7-7700K@3.60 GHz) is under 3 seconds per frequency point.

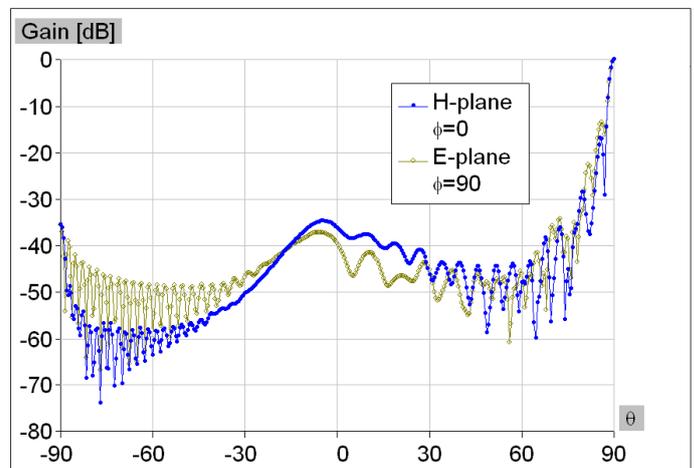
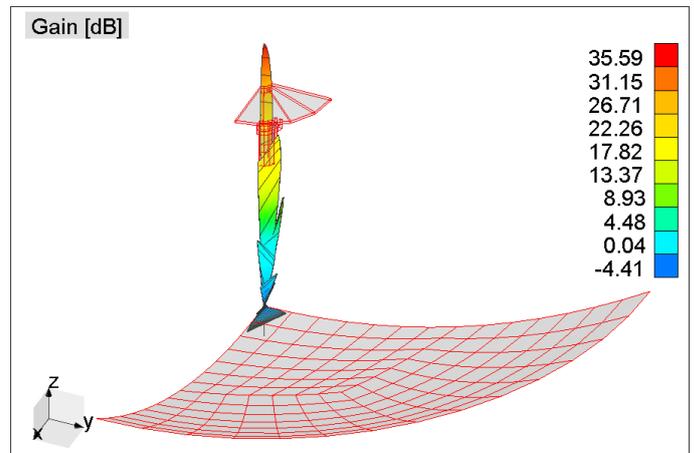


Fig. 8. Radiation pattern

Simple modification of the model is possible. To obtain:

- CWG with splash plate – remove parabolic reflector by deleting Rflct. object.
- CWG feeder – remove parabolic reflector by deleting Rflct. object, and remove the splash plate by deleting BoR and Circle objects.

For the models described in this application note, please contact WIPL-D support team.