
ASAP and FDTD Solutions

Breault Research Organization has engaged in a partnership with Lumerical, an innovative technology company based in Vancouver, Canada. This collaboration grants optical engineers access to a broad range of design and analysis tasks previously considered inaccessible.

As a result of this partnership, users will be able to readily share the enormous resources of a full-vector Maxwell solver with the power and flexibility of ASAP to accomplish system-level analyses in such applications as micro-optics, optical audio and video devices, projection systems, bio-optics instrumentation, and more.

The ASAP PRO edition from Breault Research Organization, Inc. supports finite-difference, time-domain (FDTD) simulations via field distribution import from FDTD Solutions™ by Lumerical. It also calculates and stores detailed history information for every ray that is traced, allowing more detailed analysis of problem paths through your system.

If you are interested in taking advantage of this integrated approach, you must own licensed copies of *both* ASAP PRO and FDTD Solutions.

Please note: There is no support for the transfer of geometric entities between the two programs. Creation of the micro-geometry and subsequent propagation of the field must be performed within the FDTD Solutions environment completely independent of ASAP.

This document provides an overview of the feature as well as an illustrated example to demonstrate its implementation. The following files are referenced in the included example:

dvd_lumerical.inr (ASAP script file)
dvd_ASAP.fsp (FDTD Solutions script file)

ASAP-FDTD Solutions interoperability commands in ASAP

Interoperability between ASAP 2005 and FDTD Solutions is restricted to exchange of complex field information. A new import/export command, CVF, was added to the ASAP 2005 kernel for this purpose. This command serves two functions:

- Writes information contained in an ASAP *.DAT to FDTD Solutions input field format *.FLD.
- Reads *.FLD files of FDTD Solutions and converts the information into a *.DAT file compatible with ASAP.

CVF (Complex Vector Field)

Syntax

```
CVF EXPORT format [ dist_filespec [ exch_filespec ] ]
      IMPORT      [ exch_filespec [ dist_filespec ] ]
```

Remarks

- **EXPORT** or **IMPORT** indicates the direction of data exchange, from or to ASAP, respectively.
- *format* indicates the manner of data exchange. Currently, only LUMERICAL is supported.
- *dist_filespec* optionally specifies a distribution file native to ASAP by either name or unit number; the filename may have a three-letter extension; if a filename is provided without an extension, .dat is assumed; if neither a name nor a unit number is provided, the bro029.dat file is used by default; preexisting files are overwritten on output.
- *exch_filespec* optionally specifies a file for data exchange by name; the filename may have a three-letter extension; if a filename is provided without an extension, .fld is assumed; if no filename is provided, cvf.fld is assumed.

Typically in ASAP, a CVF EXPORT command is used to export a field sampled using the FIELD command. The FIELD command must precede the use of a CVF command. We therefore need to specify both the area over which the field is to be calculated by using a WINDOW command, and set spatial resolution by using a PIXELS command to avoid phase ambiguities. Autoscaling the WINDOW is not recommended.

NOTE: WINDOW dimensions may have a profound impact on the run times of *FDTD Solutions*.

The following example script excerpts illustrate a generic application of the CVF command.

```
:
FIELD ENERGY YX a a' d d' PIXELS n
RETURN
CVF EXPORT LUMERICAL "bro029.dat" "in_field.fld"
$IO
:
```

NOTE: At this point, the ASAP task must be temporarily suspended. The simulation continues after we make a manual transition to FDTD Solutions. When we have completed the FDTD Solutions portion of the task, the simulation resumes in ASAP by first importing the processed field then performing a Fourier decomposition.

```
:  
CVF IMPORT LUMERICAL "out_field.fld" "outgoing.dat"  
POLARIZ X  
DECOMPOSE "outgoing.dat" DIRECTION m a a'  
:
```

- Fourier decomposition depends upon WINDOW size, PIXELS resolution and FTSIZE set during the previous FIELD calculation and cannot be altered as part of the DECOMPOSE.
- The DECOMPOSE command Fourier transforms only one component of the field at a time; for example, to decompose properly a vector field propagating mostly in the Z-direction.

```
RAYS 0  
POLARIZ X; DECOMPOSE ...  
POLARIZ Y; DECOMPOSE ...
```

Support Note

BRO provides technical support for issues related only to ASAP at support@breault.com.

All inquiries related to the functionality of FDTD Solutions should be directed to Lumerical at support@lumerical.com.

ASAP-FDTD Solutions interoperability commands in FDTD Solutions

Interoperability between ASAP 2005 and *FDTD Solutions* is restricted to exchange of complex field information. A new source type called ASAP Source has been added to *FDTD Solutions* for this purpose. As well, several scripting commands have been added. The purpose of the ASAP Source and scripting commands is to:

- Import field data from ASAP 2005 in the *.fld format to be used as a source in *FDTD Solutions*
- Export field data from FDTD Solutions in the *.fld format for use as a source in ASAP

ASAP Source

ASAP sources are used to import electric field data produced with ASAP ray-tracing design environment. The ASAP source allows the user to input field profile data produced by ASAP as a radiation source within the three-dimensional FDTD Solutions design environment. ASAP sources are only available in 3D simulations. For details on all the parameters of the ASAP sources, please consult the *FDTD Solutions Reference Guide*.

Scripting Commands

The following scripting commands are available for exporting and importing data to the *.fld file format:

Command	Description
<code>asapexport("monitorname");</code>	Exports the desired monitor to a file for interfacing with ASAP 2005. These files are called fld files. The monitor must be a frequency power or a frequency profile monitor. By default, the first frequency point is exported.
<code>asapexport("monitorname", f);</code>	Exports the specified frequency point.
<code>asapexport("monitorname", f, "filename");</code>	Exports to the specified "filename" without opening a file browser window.
<code>asapimport("sourcename");</code>	Imports a file in the BRO/Lumerical interface format to the desired source.
<code>asapimport("sourcename", "filename");</code>	Imports a specified file in the BRO/Lumerical interface format to the desired source without opening a file browser window.
<code>asapload;</code>	Load data from an fld file. After loading, you can get data using <code>getasapdata</code>
<code>asapload("filename");</code>	Loads data from an fld file called "filename" without opening a file browser window.
<code>getasapdata("data");</code>	After loading an asapfile with <code>asapload</code> , you can extract any desired data. Data can be <ul style="list-style-type: none"> • Ex, Ey, Ez, Hx, Hy, Hz, x, y, z • power, frequency, wavelength, index For example the commands <code>asapload("testfile");</code> <code>Ex = getasapdata("Ex");</code> <code>x = getasapdata("x");</code> <code>y = getasapdata("y");</code> <code>image(x,y,pinch(real(Ex)));</code> Can be used to image the real part of the electric field in an fld file containing data over a surface in the x-y plane.

For more details on using the scripting environment, please consult the *FDTD Solutions Reference Guide* and the examples in the *FDTD Solutions Getting Started*.

Support Note

All inquiries related to the functionality of FDTD Solutions should be directed to Lumerical at support@lumerical.com. BRO provides technical support for issues related only to ASAP at support@breault.com.

Example: Simulation of a DVD system

The following example illustrates the interoperability feature now available with ASAP 2005 and *FDTD Solutions*. Its purpose is to present methodologies employed in exercising the interoperability feature.

This example is an end-to-end simulation of a generic DVD player. The macroscopic optical system is modeled in ASAP 2005, while the microscopic DVD pit is modeled by *FDTD Solutions*.

NOTE: Familiarity with both ASAP 2005 and FDTD Solutions is recommended for working through this example.

The macroscopic optical system as modeled in ASAP is comprised of a beamsplitter and two focusing elements, which deliver the output of a laser diode source to the DVD disk. The return beam is collected and routed by reflection in a cube beamsplitter through a focusing optic to a signal detector. *FDTD Solutions* facilitates interaction of the incident field with a microscopic surface 'bump' measuring 320 nm (W) × 120 nm (H) × 8 μm (L). See Figures 1 and 2.

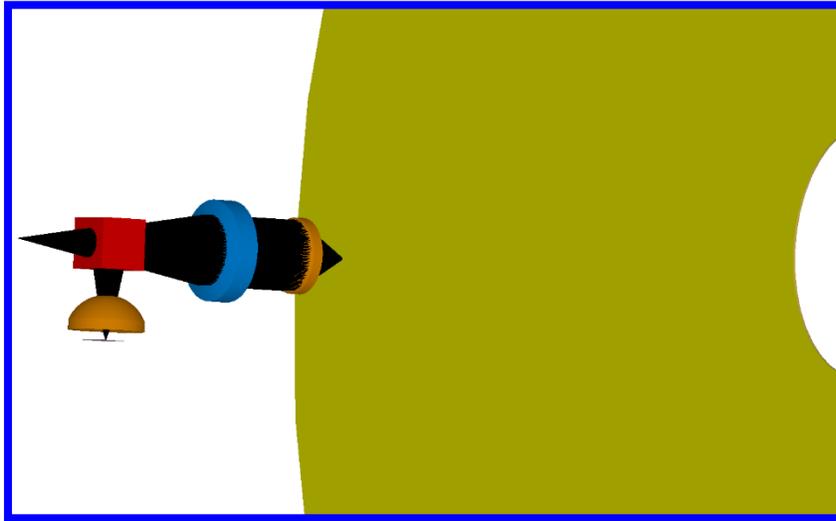


Figure 1. Macroscopic optical system to be modeled with ASAP

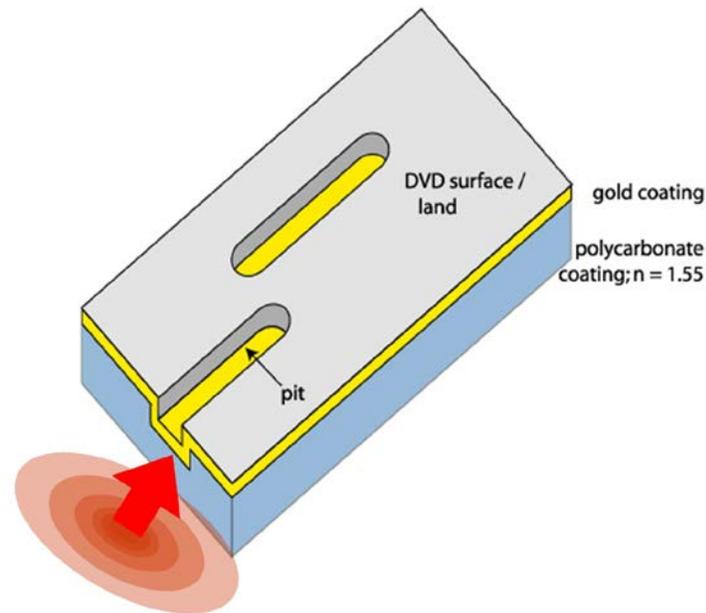


Figure 2. Microscopic optical system to be modeled with FDTD Solutions.

The illumination is from the backside, where the pit appears as a “bump”.

This example is separated into three steps:

Step	Purpose	Product
<u>1</u>	Model the macroscopic optical system that delivers the output of a laser diode source to the a focused spot at the surface of the DVD disk	ASAP 2005
<u>2</u>	Model the interaction of the focused beam with <ol style="list-style-type: none"> a sub-wavelength metal DVD pit a flat, metal DVD surface and 	<i>FDTD Solutions</i>
<u>3</u>	Model each reflected beam through the optical collection system to a detector surface. Calculate the signal modulation depth due to the presence of the sub-wavelength DVD pit.	ASAP 2005

Step 1: Macroscopic beam delivery to the DVD surface

The macroscopic optical system, shown previously in Figure 1, as modeled in ASAP, is comprised of a beamsplitter and two focusing elements, which deliver the output of a laser diode source to the DVD disk. The return beam is collected and routed by reflection in a cube beamsplitter through a focusing optic to a signal detector.

The script that generates this optical system is `dvd_lumerical.inr`. After setting up the optical system model in ASAP, the source is traced to a dummy plane located in close proximity to the DVD surface as shown in Figure 3. Note that no microscopic DVD surface features are included in the ASAP model. A FIELD calculation stores the complex vector electric field in a `cincoming.dat` file, which is then exported to *FDTD Solutions* file format using the CVF command. The file is saved as `cincoming.fld`. The energy distribution at the dummy plane 140 nm above the landing is shown in Figure 4. Note that WINDOW dimensions, PIXELS setting and location of the dummy plane may require iteration in order to arrive at the conditions suitable for an accurate FDTD simulation. In this case, a $4\mu\text{m} \times 4\mu\text{m}$ WINDOW insures all the focused energy is captured within the window. A choice of PIXELS 101 provides spatial resolution necessary to avoid phase ambiguities. After completed the export operation, the ASAP session is suspended and the user switches to *FDTD Solutions* to continue the simulation.

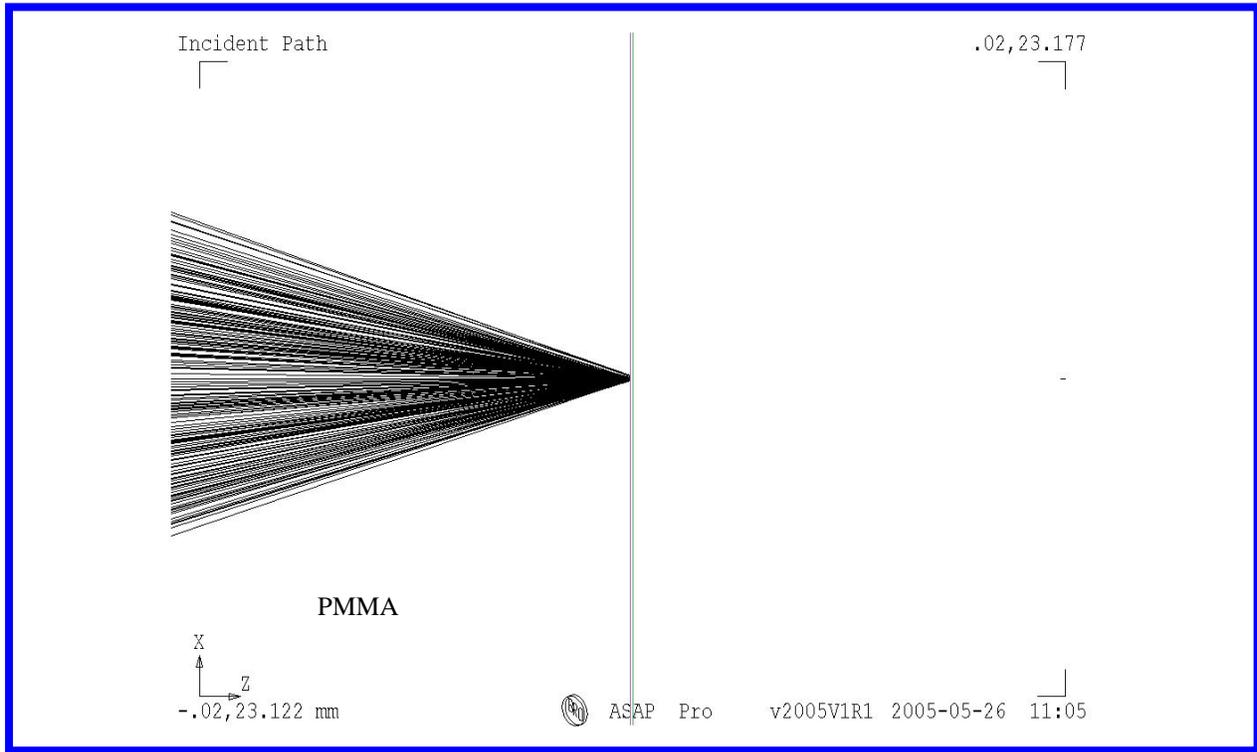


Figure 3. Dummy plane 140 nm above the DVD land surface, where the focused beam is recorded with ASAP

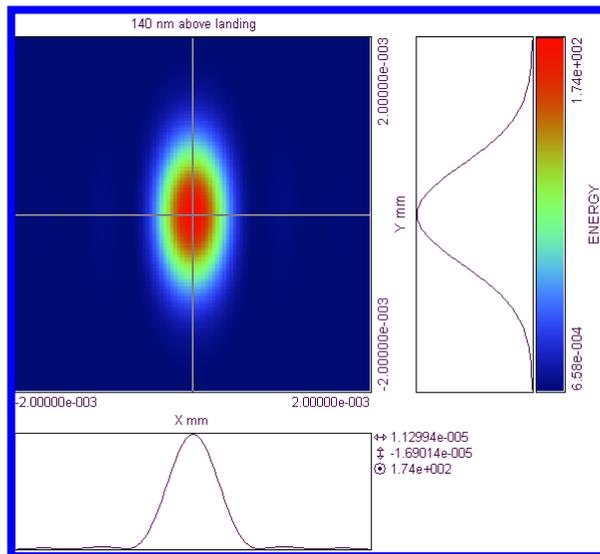


Figure 4. Energy distribution at the dummy plane as recorded with ASAP

We proceed by constructing the DVD surface and assigning optical properties to the geometry in FDTD Solutions.

Step 2: Modeling the sub-wavelength features of the DVD surface

For the second step of the problem, open *FDTD Solutions*. Open the example file `dvd ASAP . fsp`. This file can be found in the default examples directory and is used in one of the advanced examples of the *FDTD Solutions Getting Started* manual.

The geometry consists of a landing and a ‘bump’ as shown in Figure 5. The optical properties of the entire structure are defined by a NIR dispersive model for gold immersed in PMMA.

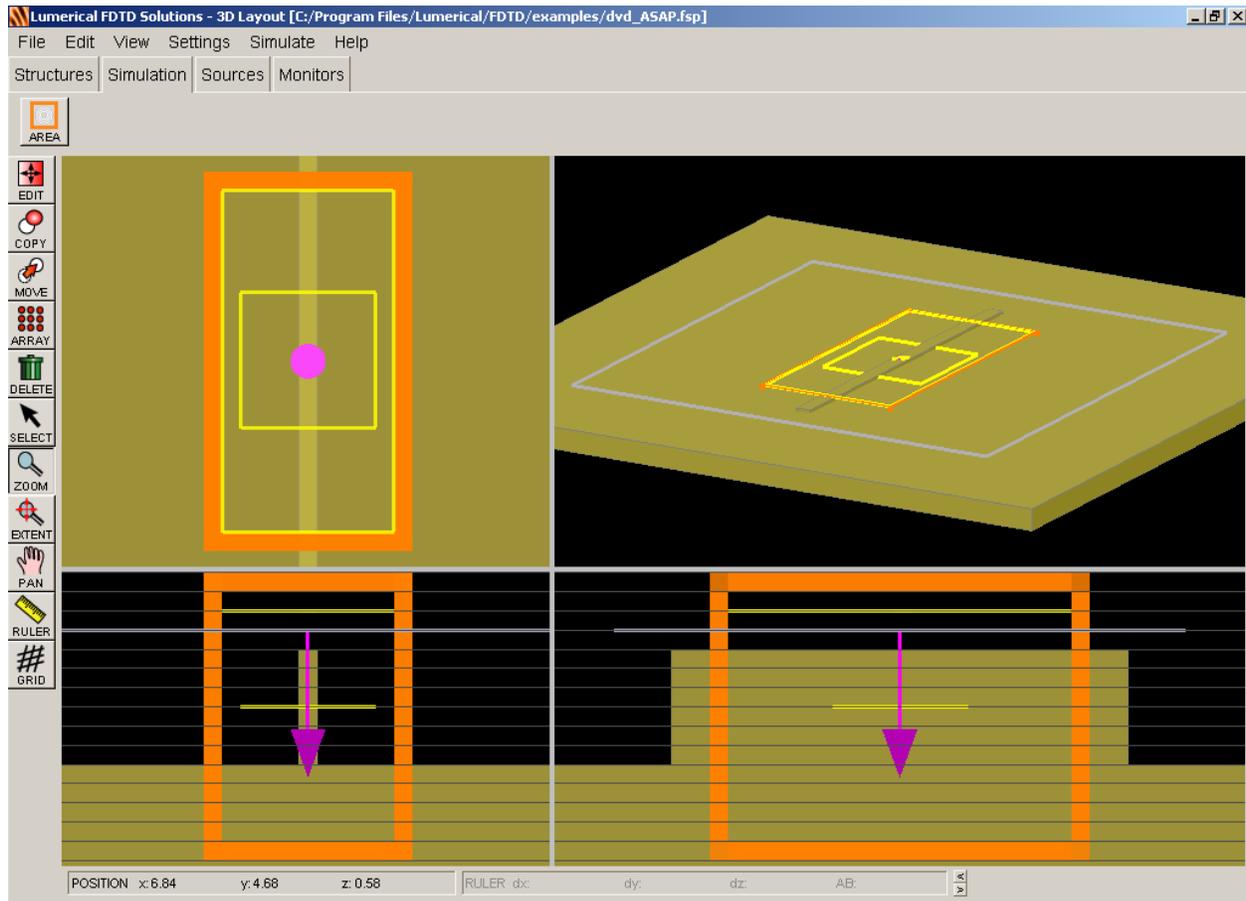


Figure 5. Sub-wavelength DVD pit or “bump”, drawn in the CAD Layout Editor of FDTD Solutions

The source (grey box with purple arrow), the reflection monitor (yellow rectangle), and relevant geometry are enclosed in a simulation volume (orange cubic volume). The choice of source insertion point and simulation volume dimensions serve to minimize calculation time, while preserving the necessary attributes to accurately model the physics.

NOTE: *FDTD Solutions* does not allow the source and monitor planes to be co-located therefore the monitor plane (and thus the plane from which the result is exported back to ASAP) and the source injection plane must be separated by at least 1 grid spacing (20 nm in this case).

The following steps show how to setup, run and analyze the simulations of the sub-wavelength DVD pit, as well as export the resulting data back to an `fld` file to be re-imported into ASAP.

2a. Set up the material properties

1. If you are in analysis mode (the Analysis window is open), open the SIMULATION menu and select SWITCH TO LAYOUT EDITOR.
2. Select the STRUCTURES tab and make sure that the DVD bump has the following dimensions.

property	value
x position	0 μm
x span	0.32 μm
y position	0 μm
y span	8 μm
z min	-0.12 μm
z max	0 μm

3. In this example, the wavelength is 650 nm. We want to make sure that both the DVD bump and the gold substrate use the following material properties. Note that you can set them both by selecting both objects and editing their group properties.

property	value
material	Au (gold) :: VIS 400-750nm

2b. Load the field data into the ASAP Source

- If there is not already an ASAP source, create one by clicking the **ASAP** button on the SOURCES tab.
- Open the property edit window of the ASAP source, which is shown in Figure 6.

Edit: ASAP Source (ASAP data has not been imported)

General | Frequency/Wavelength

name: Source1

injection axis: x-axis

direction: Forward

amplitude: 1

ASAP Settings

ASAP x (microns):

ASAP y (microns):

ASAP z (microns):

ASAP index:

ASAP power:

ASAP wavelength (microns):

Read ASAP Source

plot current fields

plot: E intensity

Plot Current Field

use global source settings

Center and Span

x (microns): 0.05

y (microns): 0

z (microns): 0

x span (microns): 0

y span (microns): 15.3

z span (microns): 10

Min and Max

x min (microns): 0.05

x max (microns): 0.05

y min (microns): -7.65

y max (microns): 7.65

z min (microns): -5

z max (microns): 5

OK Cancel

Figure 6. Property edit window of an ASAP source in FDTD Solutions

- Click the **Read ASAP Source** button and choose the file `cincoming.fld`, which was created from the data in `cincoming.dat` with the ASAP command CVF.

- Try plotting the current field by clicking **Plot Current Field**, you will see the same plot as Figure 7.

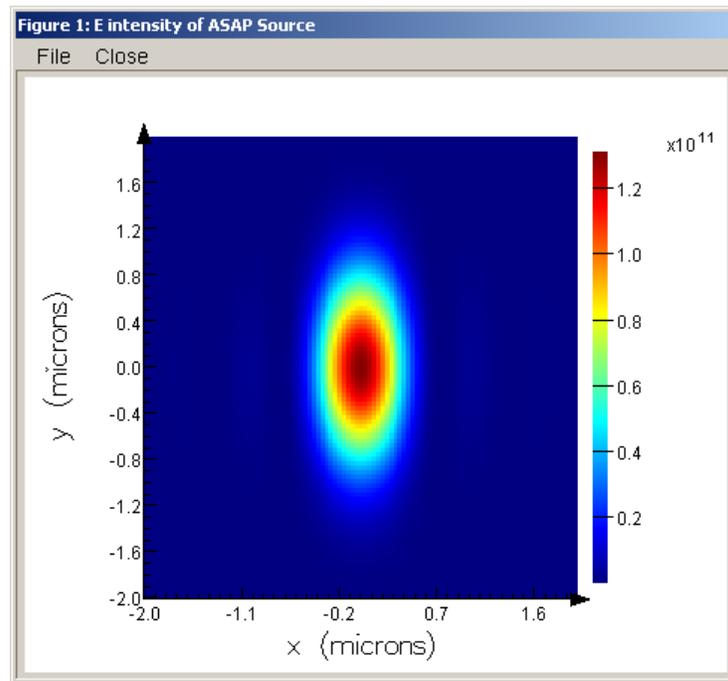


Figure 7. The electric field intensity imported from ASAP to FDTD Solutions

Notice that this spot has an **x** span of approximately 1 μm and a **y** span of approximately 2 μm . For this spot configuration, the track length is in the **y** direction, and the track width is in the **x** direction.

- Set the following properties of the ASAP source:

property	value
name	asap
x	0 μm
y	0 μm
z	0.02 μm
direction	Backward

- Verify that the ASAP source is defined to operate at a wavelength of 650 nm by selecting the **FREQUENCY/WAVELENGTH** tab of the ASAP source. This wavelength is the same as the wavelength defined in the file `cincoming.fld` when it was exported from ASAP. You can change this wavelength if you like, but it is automatically set when you load the data.
- On the **FREQUENCY/WAVELENGTH** tab, you will notice from the SIGNAL VS TIME plot that the simulation is not long enough and truncates the source signal. To correct this, select **SET TIME DOMAIN**. Change the pulselength property to 3 fs and the offset to 6 fs.
- Click **OK** to accept all the source changes.

2c. Modify the simulation region

We imported a field from ASAP that covers a $4 \times 4 \mu\text{m}^2$ region. However, the spot is smaller than this. It is sufficient to simulate a region of approximately $3 \times 6 \mu\text{m}^2$.

- Edit the FDTD Simulation region and set the following properties:

property	value
x span	3 μm
y span	6 μm
simulation time	25 fs

- On the **Advanced Options** tab, make sure that the “meshing refinement” property is set to 0. For most materials it is desirable to average their physical properties near interfaces but for metals, such as gold, this is not always desirable. You can disable this feature by setting a value of zero for the “meshing refinement”.

Notice that the ASAP source is larger than the simulation region. The simulation will use only the portion of the ASAP source that is within the simulation.

2d. Verify the frequency monitor

Edit the properties of the field monitor. You will notice that this monitor has changed to record data at a frequency of 461.219 THz because the **USE SOURCE LIMITS** checkbox is on. In wavelength, this is 650nm. This is the desired frequency of operation with the ASAP source.

2e. Run the simulation

Run the simulation, which will take from 2 to 15 minutes, depending on the speed of your computer.

2f. Analyze the data

Plot the **E_y** electric field component versus time, you will see the plot shown in Figure 8.

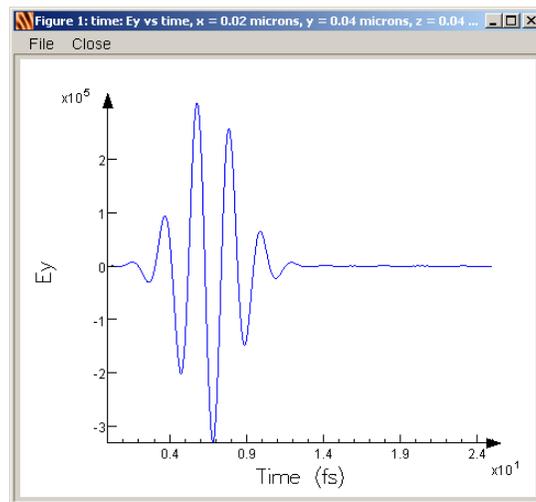


Figure 8. Electric field component E_y as a function of time

You can see that the signal is short and decays quickly. The simulation has been run for long enough to collect all the data.

Plot the E_y intensity in the near field from the monitor called *reflection*, and it should look like Figure 9.

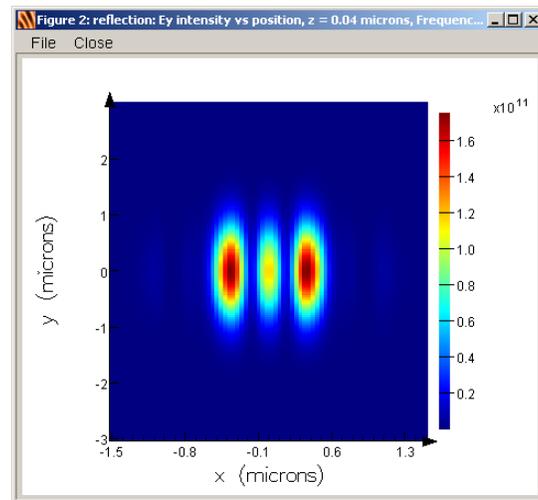


Figure 9. Electric field component E_y at a single frequency/wavelength as a function of position in the near field

Use the far field projection to plot the electric field intensity in the far field, it will look like Figure 10.

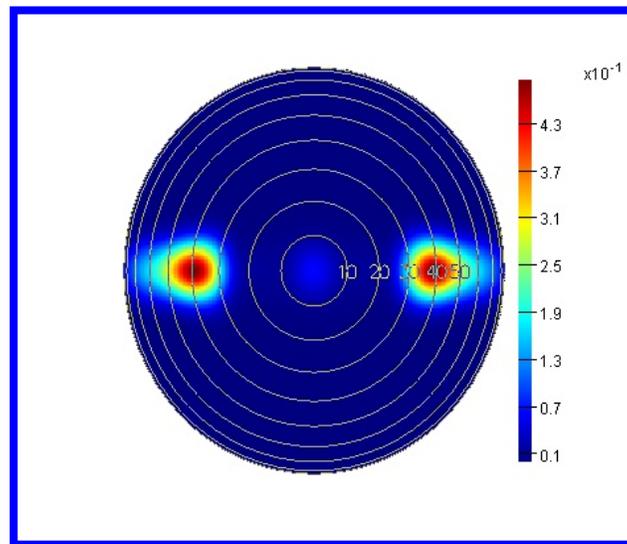


Figure 10. Electric field intensity at a single frequency/wavelength as a function of angle in the far field

2g. Export the results back to ASAP

To bring the reflected signal back into ASAP where it can be used to optimize the collection optics, you will need to save the data contained in the *reflection* monitor back to an *.fld file. This can be achieved by a single scripting command.

- If you cannot see the scripting prompt, use the **VIEW** menu and select **VIEW SCRIPT PROMPT**
- From the script prompt type the following command
`asapexport("reflection");`

A file chooser window will appear that will allow you to select a name for your data. Choose `coutgoing.fld` and save the file. There are a variety of optional arguments for importing and exporting ASAP files using the two scripting commands `asapexport` and `asapimport`. Please refer to the *FDTD Solutions Reference Guide* for details.

2h. Rerun the simulation with no bump

To compare the modulation with and without the bump, you will need to rerun the simulation without the presence of the bump.

- From the **FILE** menu, choose **SAVE AS** and save the file as `dvd_ASAP_blank.fsp`
- From the **SIMULATE** menu, choose **SWITCH TO LAYOUT EDITOR** and click **OK** when prompted.
- Rerun the simulation.
- From the script prompt type the following command:
`asapexport("reflection");`

When the file chooser appears, select the filename `cboutgoing.fld`.

You can now import the data from `coutgoing.fld` and `cboutgoing.fld` into ASAP.

Step 3: Modeling the reflected beam to the detector

The return beam is collected and routed by reflection in a cube beamsplitter through a focusing optic to a signal detector.

The resulting *.fld files created in Step 2 can now read into ASAP by invoking a CVF command with the IMPORT option.

The imported field is converted to traceable rays by means of a directional decomposition, namely DECOMPOSE DIRECTION. Since the source originates inside the PMMA material, the IMMERSE command must precede DECOMPOSE DIRECTION. Note also that the DECOMPOSE DIRECTION command operates on only one polarization component at a time. Therefore, a POLARIZ command must precede decomposition of the x -, y - and z -components of the field.

A brief section of ASAP script, `dvd_lumerical.inr`, is shown in Figure 11 as an example of the import of the *FDTD Solutions* file. Here, a limiting cone angle has been specified to match the solid angle subtended by the collection optics. The minus sign on the DIRECTION option indicates the direction of propagation. Also, the sources must be IMMERSEd and shifted to the appropriate location since geometries in ASAP and *FDTD Solutions* are completely independent of one another.

```

:
CVF IMPORT LUMERICAL RFL_FIELD.FLD RFL_FIELD.DAT
RETURN

RAYS 0
DIUG=20      ??HALF-ANGLE SUBTENDED BY COLLECTION LENS
IMMERSE PMMA
POLARIZ X 1 0
DECOMPOSE RFL_FIELD.DAT -DIRECTION 0.99 (DIUG)
POLARIZ Y 1 0
DECOMPOSE RFL_FIELD.DAT -DIRECTION 0.99 (DIUG)
RAYSET
SHIFT Z 23.14986    ??SHIFT TO GLOBAL XYZ POSITION
RETURN
:

```

Figure 11. Excerpt from ASAP script showing how to import data from fld file created by FDTD Solutions

NOTE: ASAP does not propagate evanescent fields as part of its Gaussian Beam Decomposition method. As a result, it is not necessary in this case to decompose and attempt to trace the z -polarized field component, since this field component would propagate perpendicular to the optical axis.

The dvd_lumerical.inr script file calculates the signal at the detector with the bump (coutgoing.fld) and without the bump (cboutgoing.fld). The results of the ENERGY at the detector are shown below. Diffraction due to the presence of the bump scatters a significant portion of the incident energy out of the reflected beam that arrives at the detector surface. Results of the ENERGY at the detector are shown in the table below. Diffraction that is due to the presence of the bump has scattered a significant portion of the incident energy out of the reflected beam. As a result, the peak irradiance and the total energy at the signal detector is reduced by approximately 30 times in the presence of the bump.

	Blank DVD surface (no bump)	DVD surface with bump
ENERGY MAX	10.35034	0.3779390
ENERGY INTEGRAL	0.4438739E-04	0.1522924E-05

Results at the signal detector are plotted in Figures 12 and 13.

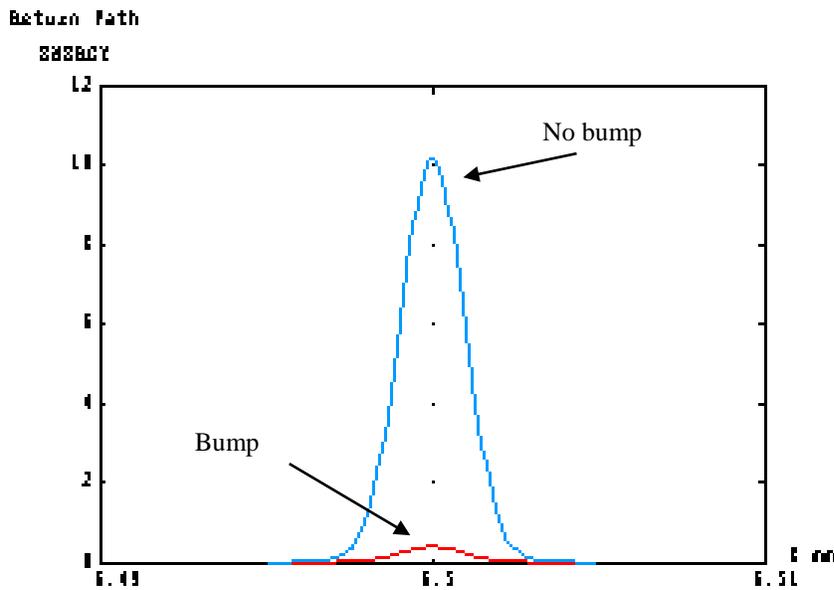


Figure 12. Cross-section of irradiance at the detector, without and with the bump.

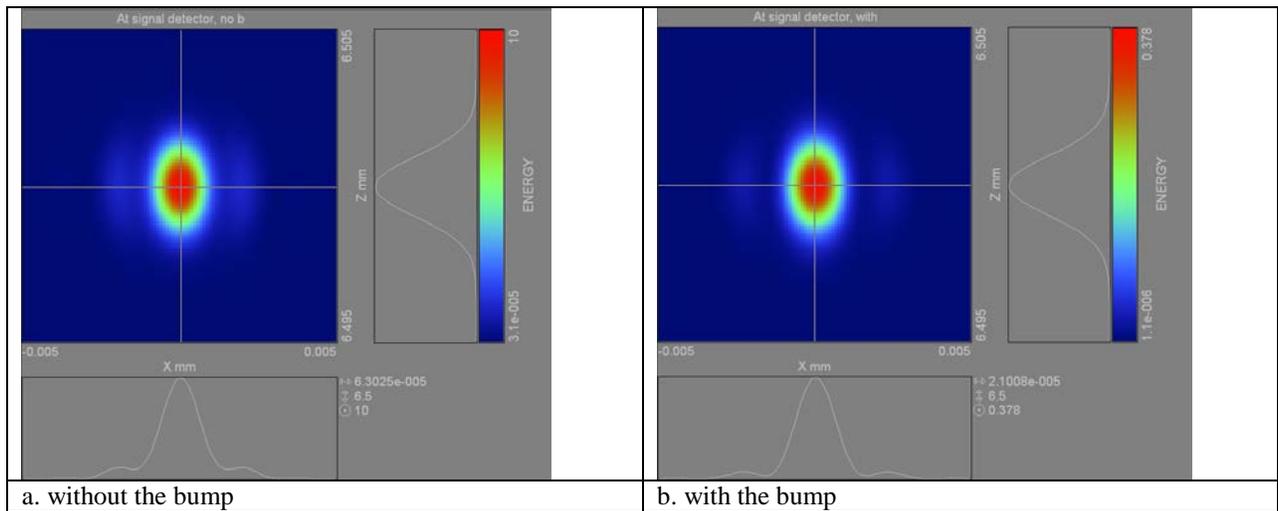


Figure 13. Irradiance patterns at the detector, without and with the bump

You can optimize the shape and size of the DVD bump using *FDTD Solutions*, as well as to optimize the beam delivery and collection optics using ASAP.

- For optimization in *FDTD Solutions*, please see the related DVD Examples in the *FDTD Solutions Getting Started* manual.