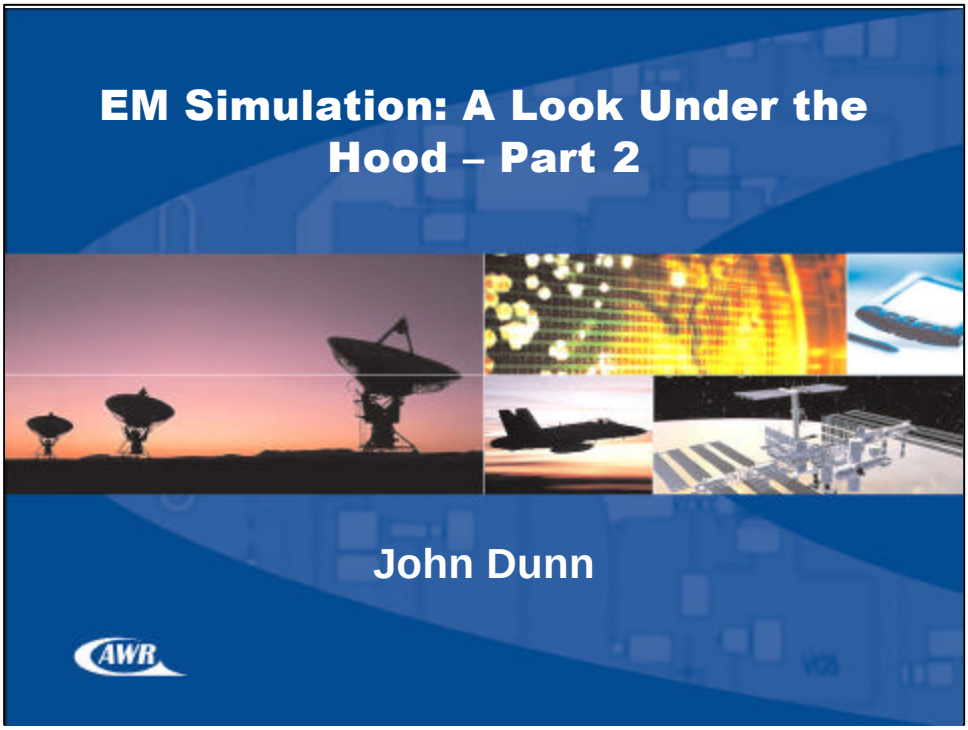

Summary:

In this webinar, we continue our investigation into the inner workings of electromagnetic simulators - specifically EMSight, the moment method simulator built into Microwave Office. Emphasis will be placed on fundamental concepts essential for successful simulations. Topics covered in the webinar are: the importance of the simulation box size, and the proper use of boundary conditions.

This webinar was originally given on February 3, 2006.

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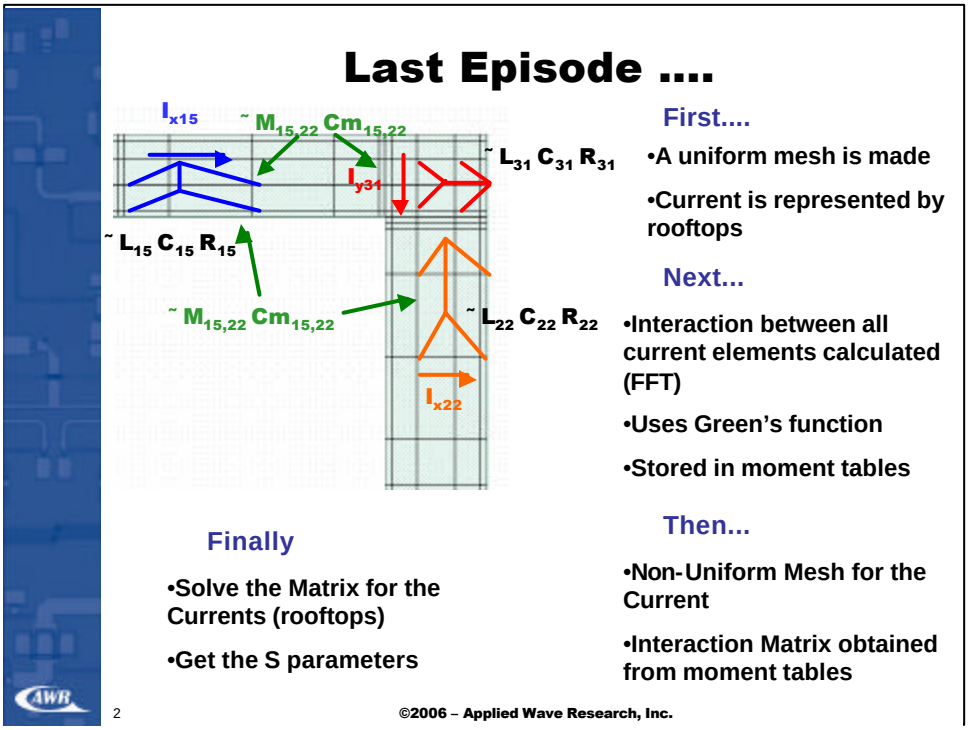
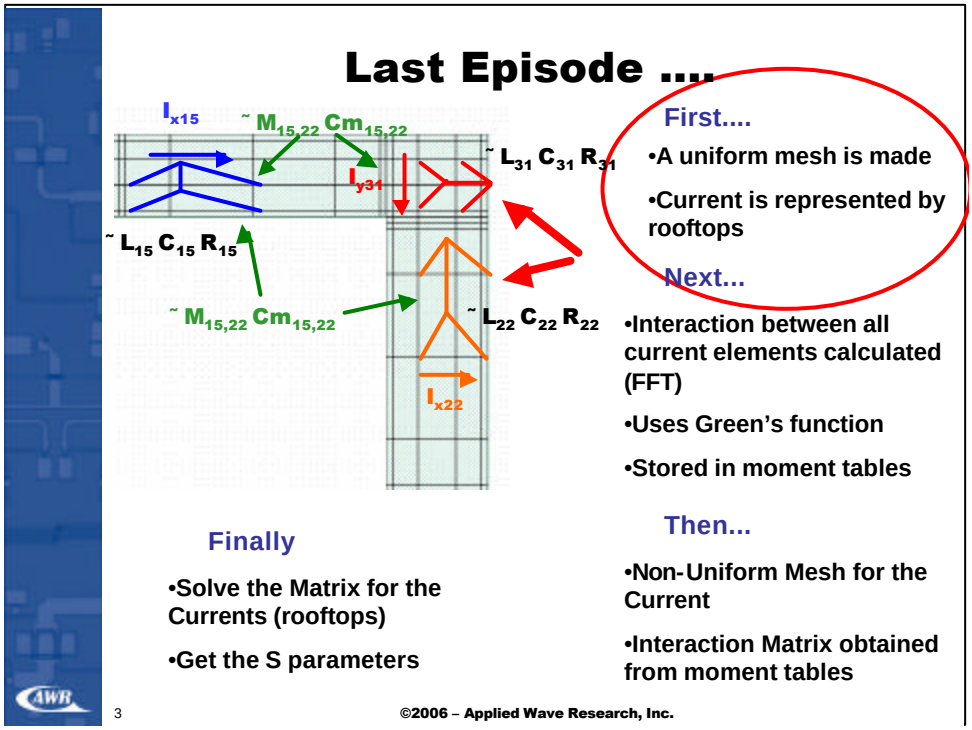


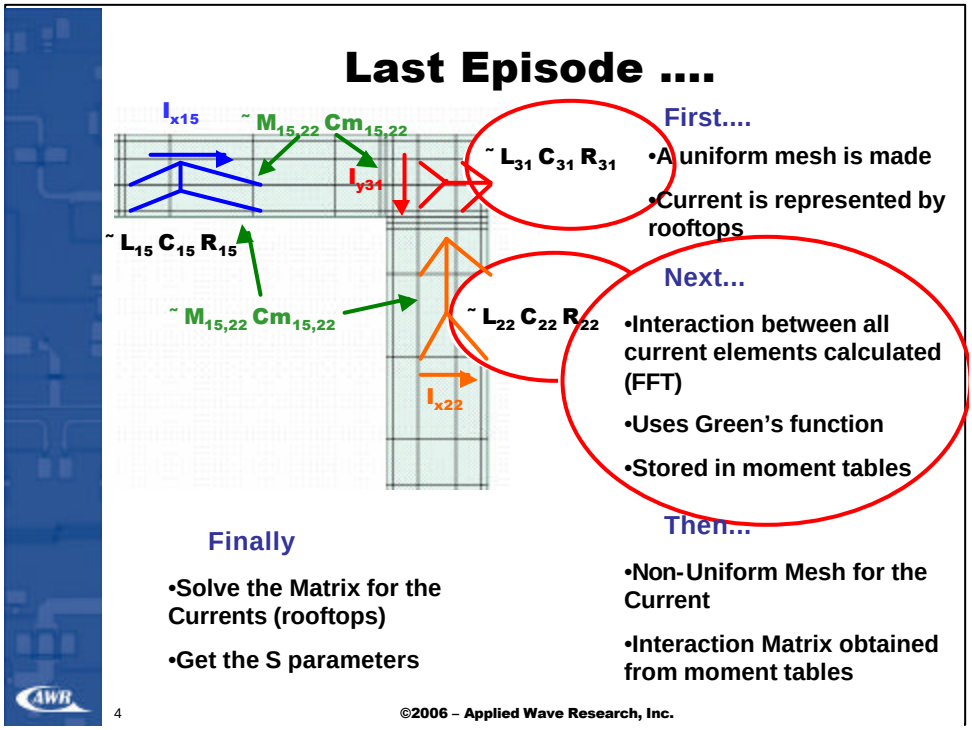
In the previous webinar, EM1, we discussed how a moment method code works. Specifically, we went into detail about how EMSight works, the built-in electromagnetic simulator in Microwave Office.

The essential points of the simulator are quickly reviewed. Details are given in the previous webinar.



The object of the simulation is to solve for the unknown currents on the conductors. In order to do, the conductors are meshed with a uniform mesh. The currents are approximated as "rooftops". A rooftop is an approximation to a current distribution, in which the current goes from 0 to maximal value in a linear fashion, and then back to 0. This takes place over two cells of the mesh. Each elemental mesh is therefore half a rooftop. Both x and y directed currents can exist, and therefore there are also x and y directed rooftops. Some examples are shown in the figure.

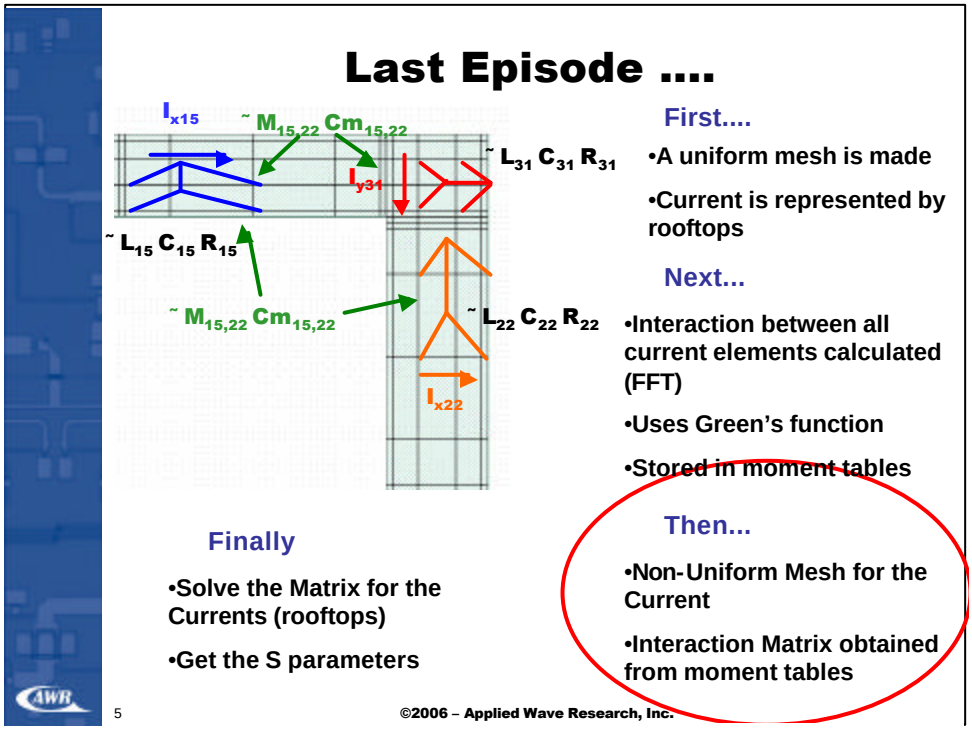
Notice that the rooftops shown are not all the same size. This is because a non-uniform mesh is normally used; it is constructed by combining the elemental mesh rooftops in the appropriate manner.



The objective is to find the (complex) height of the rooftop. The current is then known in the approximate rooftop basis, and S parameters for the structure can be determined. The height is a complex number as there are typically phase differences between the rooftops.

The interactions between the rooftops are required. This interaction is found by using a Green's function. (George Green was a 19th century English mathematician – it's not the color green.) Since the rooftops represent currents, the interaction between them can conceptually be represented by self and mutual inductances. In addition, the currents are changing, and there is associated charge build-up. (A fundamental law of physics says you cannot create charge – so, if you have current changing with distance, you must have charge buildup.) Therefore, we also have self and mutual capacitances. The Green's function is the tool that allows these values to be calculated. The interaction between all elementary cells are then stored in a moment table.

An advanced point is that the Green's function also calculates delay between two elements. In this sense, the circuit interaction analogy is not quite accurate, as simple elements cannot easily incorporate delay. Therefore, the Green's function is even more general than a circuit analogy.

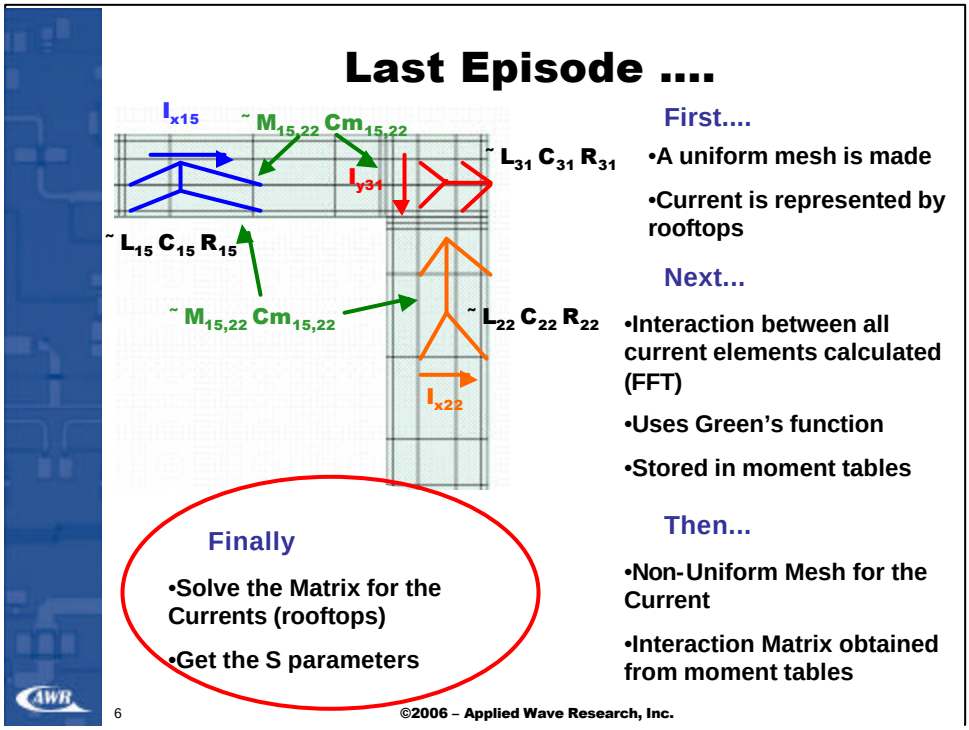


A mentioned before, the current is usually represented by non-uniform sized rooftops, which are calculated by combining the elemental rooftops stored in the moment tables. This is done for two reasons:

•The number of resulting rooftops will be smaller, which results in a smaller matrix, and a faster solve time.

•More rooftops can be used where the current is changing rapidly, for example at discontinuities like bends. In regions where the lines are straight, few rooftops are used. By default, the computer uses "reasonable" assumptions to make the non-uniform mesh. For example, it normally edge meshes lines, in which a small mesh is placed near the line's edge to give more accurate results.

The matrix representing the interaction between all the rooftops is assembled.



Once the matrix is assembled, the matrix equation can be solved for the complex heights of the rooftops. Ports have to be attached to get a non-zero solution. Otherwise, the answer is that no current is excited.

Since the currents are known for the given excitation, the S parameters at the ports can be determined.

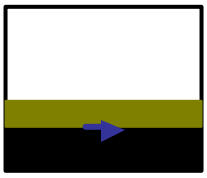
Green's Function

Gives Interaction Between Elements

- Dielectrics, ground planes,...
- Includes delay

In a Box (EMSight, Sonnet)

or not ... (Zeland – IE3D)



Must Have for EMSight

- Rectangular Box – Flat top, bottom, and sides
- Homogeneous, planar, dielectrics
- Infinitely Thin Horizontal conductors, or...
- Vertical Vias (Constant Current)

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A few more points are reviewed regarding the Green's function.

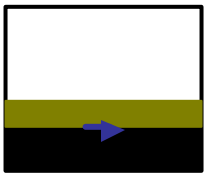
Green's Function

Gives Interaction Between Elements

- Dielectrics, ground planes,...
- Includes delay

In a Box (EMSight, Sonnet)

or not ... (Zeland – IE3D)



Must Have for EMSight

- Rectangular Box – Flat top, bottom, and sides
- Homogeneous, planar, dielectrics
- Infinitely Thin Horizontal conductors, or...
- Vertical Vias (Constant Current)

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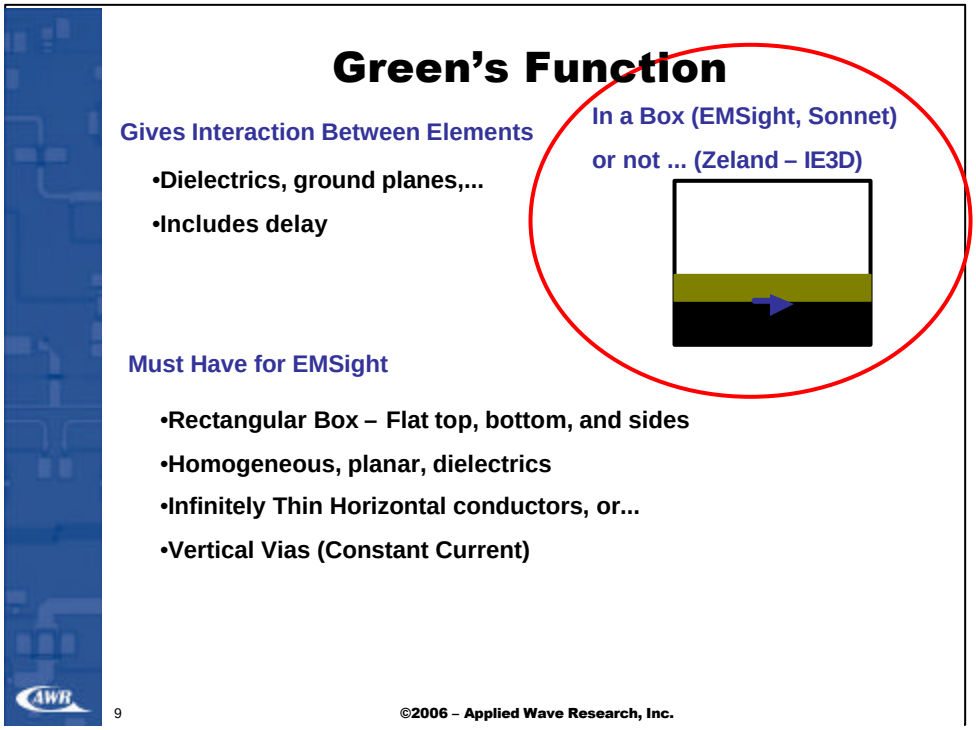
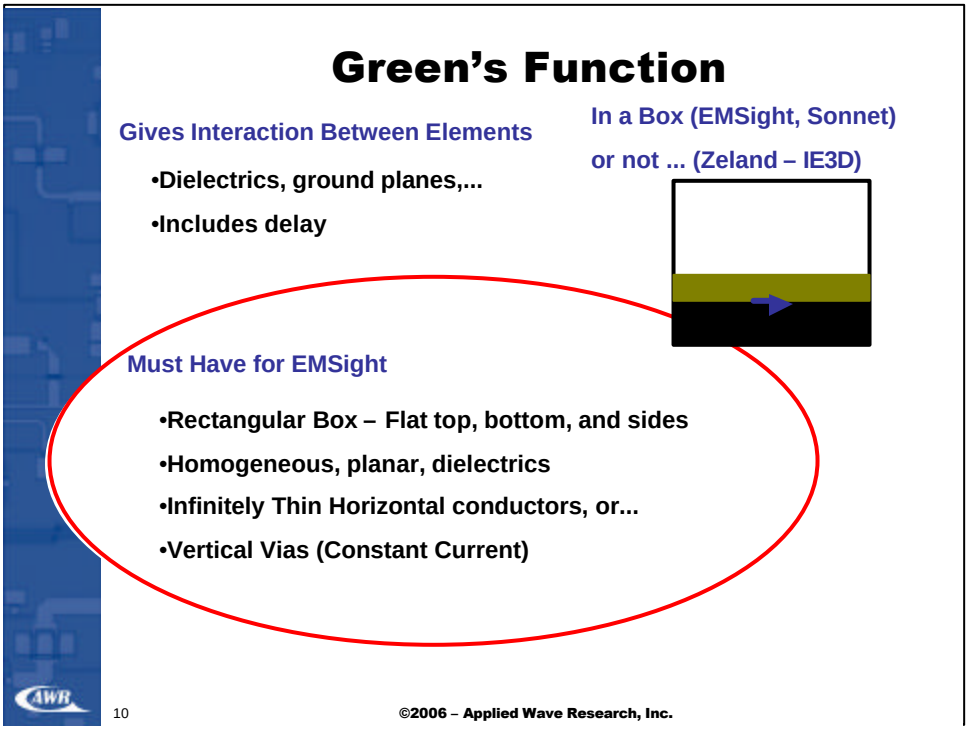
The Green's function is aware of the complete electrical environment in which the circuit's conductors reside. For example, it knows about all the dielectric layers, and the ground planes. As mentioned before, it includes delay effects between elements.



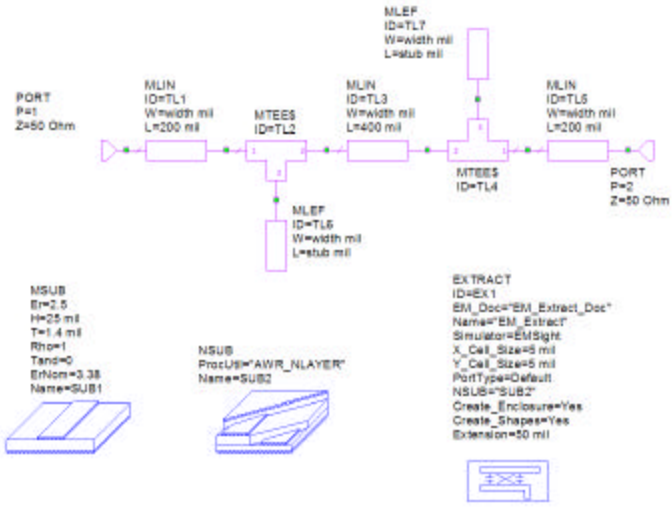
However, not all geometries have known Green's functions. EM simulators using moment methods require flat, homogeneous, layers. Ground planes must cover the entire plane, and be parallel to the dielectric layers. Some simulators like EMSight, and Sonnet are in a box. The box must be rectangular, with vertical walls, and flat roof. Other simulators do not require a box – for example, IE3D from Zeeland. In this case the dielectrics extend infinitely in the horizontal directions.



Moment method simulators typically also have other restrictions. Although strictly not forbidden by the moment method, restrictions are made in the interests of coding efficiency, and following realistic usage models. For example, EMSight only allows infinitely thin conductors. (However, thick conductors can be approximated by stacking conductors and uniting them with vias.) EMSight can model vertical currents for vias, but assumes a constant current. Usually, this is not a problem as vias are electrically very short, and are connecting two conductors. If needed, a via can be made to go through several layers of dielectric. In this way, the current on the via can change.

Extraction to the EM Socket

It's Powerful and Easy....but Beware!



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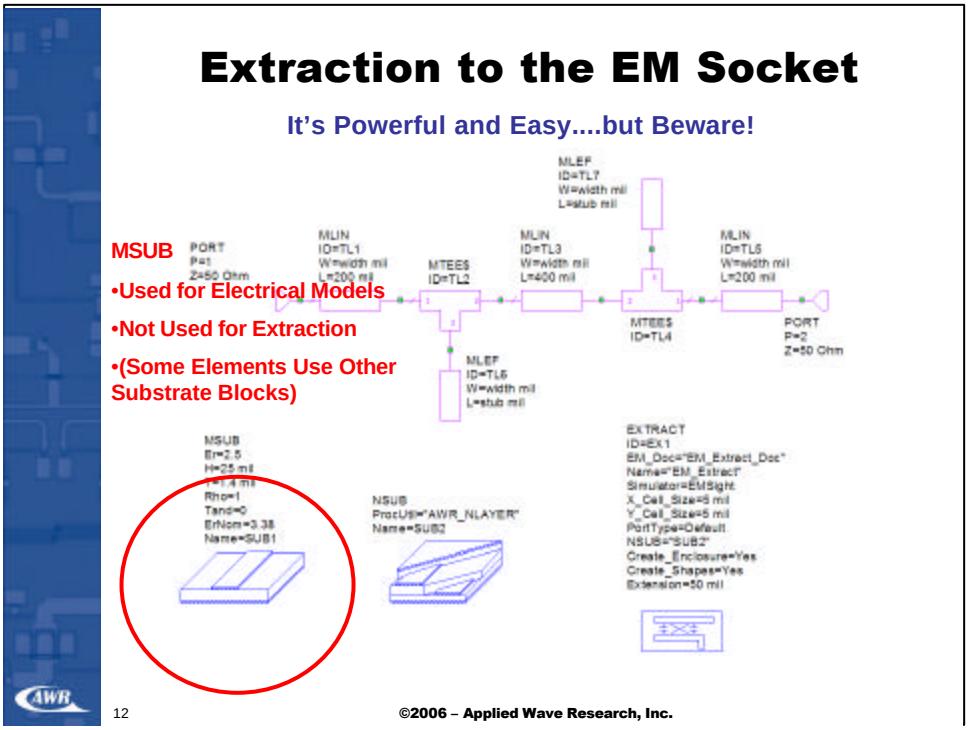
In this webinar, we continue our discussion by looking at the EM Socket, and extraction. Extraction is the process of sending a schematic layout out to an EM simulator. Once simulated, the results are automatically brought back into the circuit simulator.

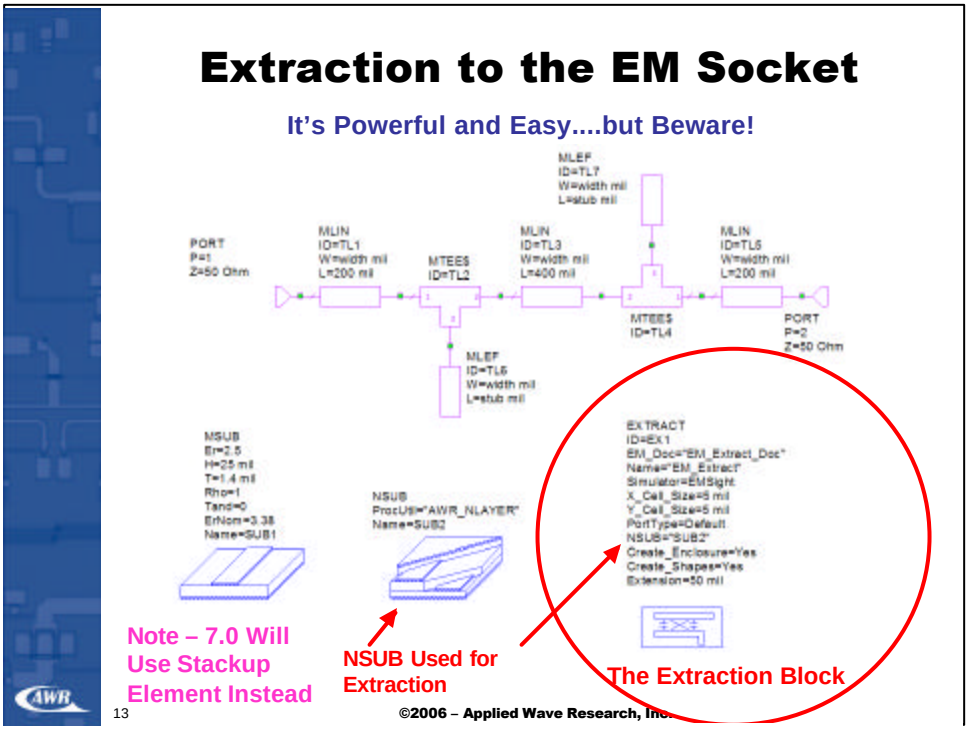
Extraction is a powerful tool. However, care must be taken when using it, as it almost "too easy", and mistakes can be made.



A schematic of a filter is shown. The designer wishes to send the schematic layout to the EM socket, and simulate using EMSight.

The first thing to understand is the control and substrate blocks in the schematic. The circled object is the MSUB element. This element describes a single layer substrate with ground plane, used for microwave circuit elements.

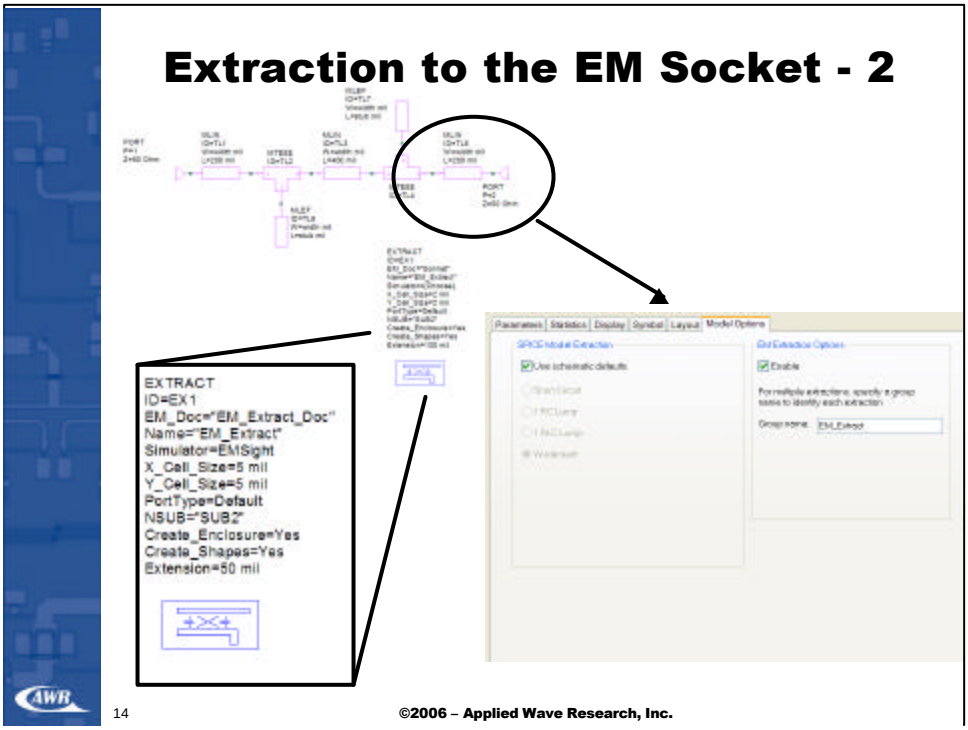
For example, MLIN microstrip line models use this element. Note that It is not used by the extraction block at all.



The extraction block uses the NSUB element, shown here. A common source of error is to confuse the use of the MSUB element, and the NSUB element.

Note – in MW0 7.0 an element called STACKUP will be used instead of NSUB will be used to control the extraction. MSUB and NSUB will still be used for electrical models.

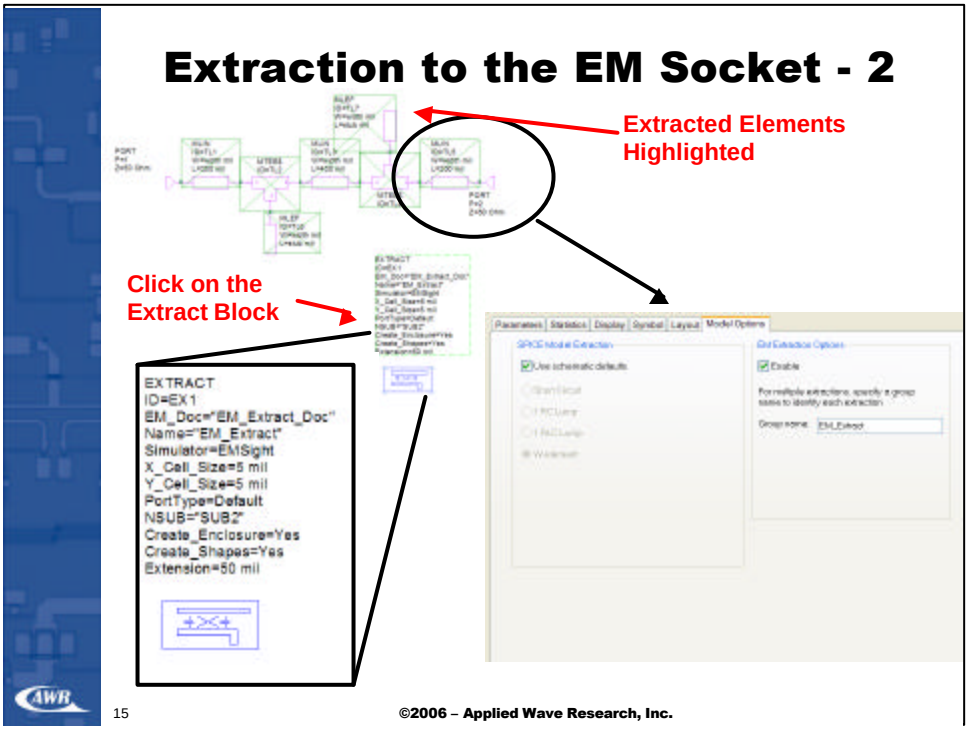
The extraction block determines what parts of the layout are sent to the EM socket.. Various options can also be set in the extraction block.



The slide shows how the layout of an element is selected for extraction. The properties menu can be viewed by right clicking on the element and selecting Properties. The model options tab/page is shown. The EM Extraction Options have been enabled. There is a field for the Group Name – it defaults to the name “EM_Extract”.

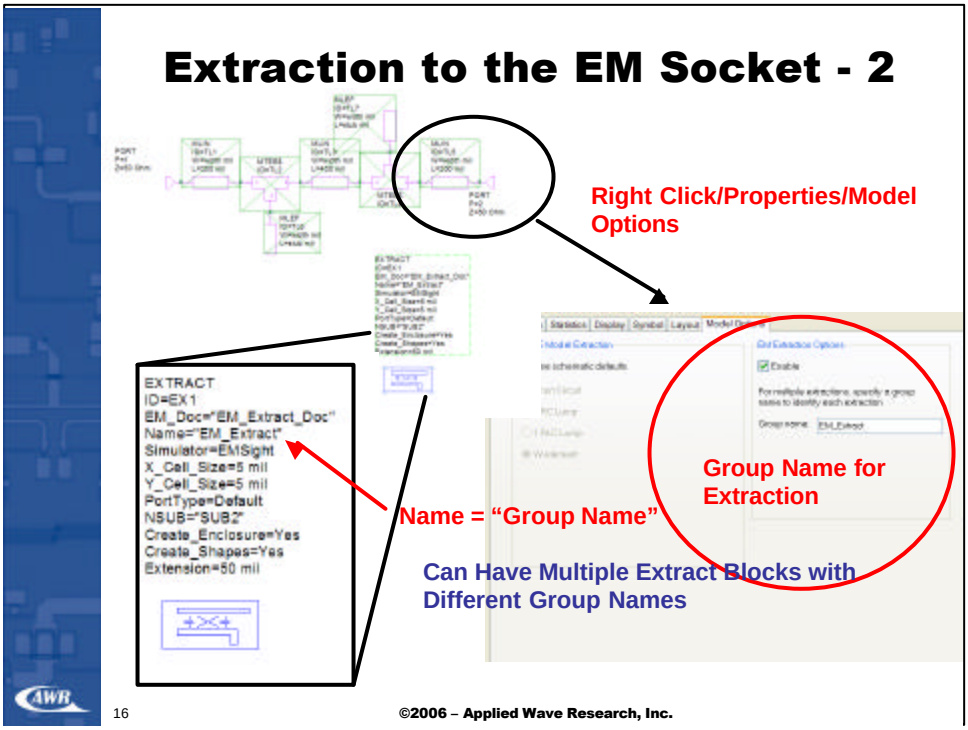
The settings for the Extraction block are shown enlarged on the left, for easier viewing. Note the field Name, here set to “EM_Extract”. This extraction block will extract all elements in the schematic (or subcircuits) with their extraction field enabled, and the Group Name of “EM_Extract”.

It is possible to have multiple extraction blocks on the same schematic, each selecting different extraction elements with different extraction names.

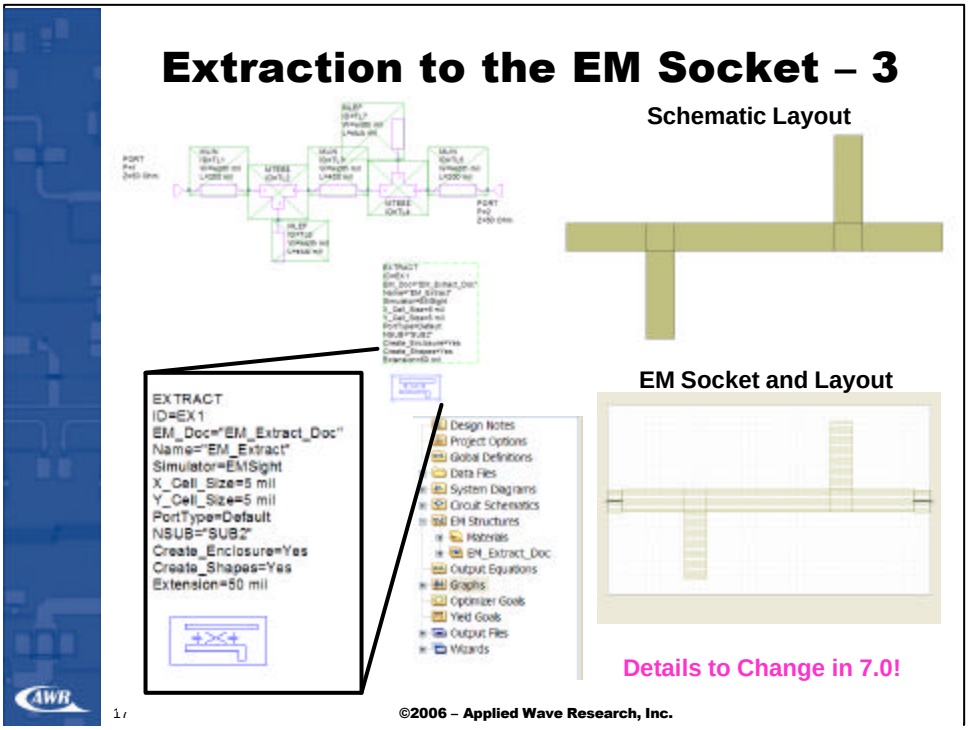


The extraction block is selected by clicking on it. The elements to be extracted then have a green X over them, indicating they will be extracted.

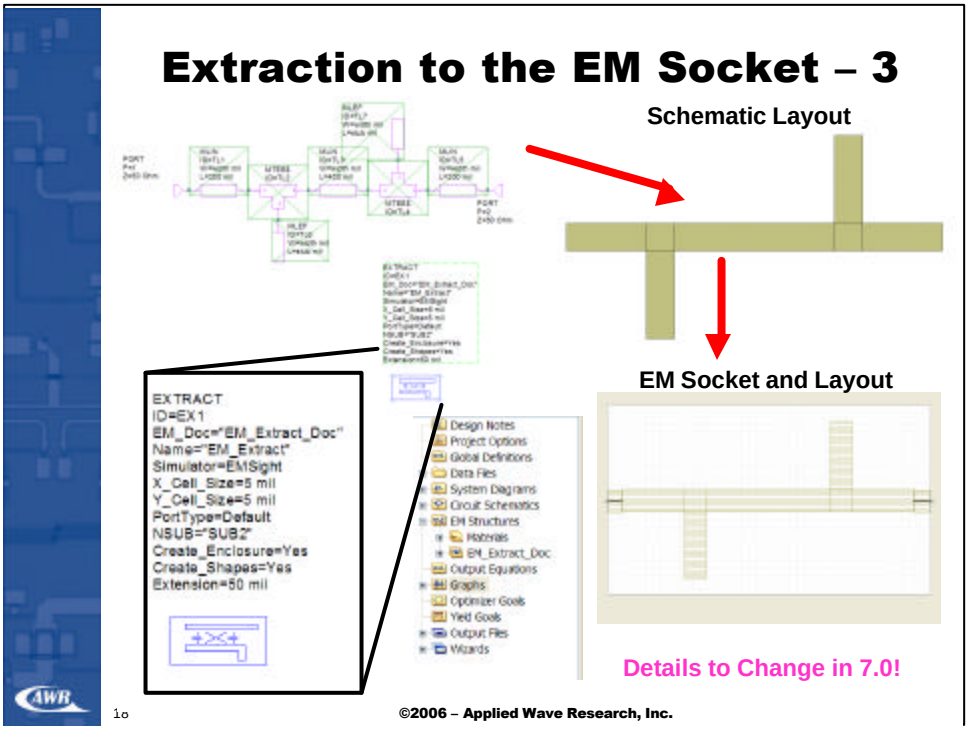
Note that the multiple elements were enabled for extraction by selecting them all, and then right clicking for the Properties tab. This avoids the need to enable extraction for each element individually.



This slide highlights the fields for the Group Name for extraction in the element and the Extraction block.

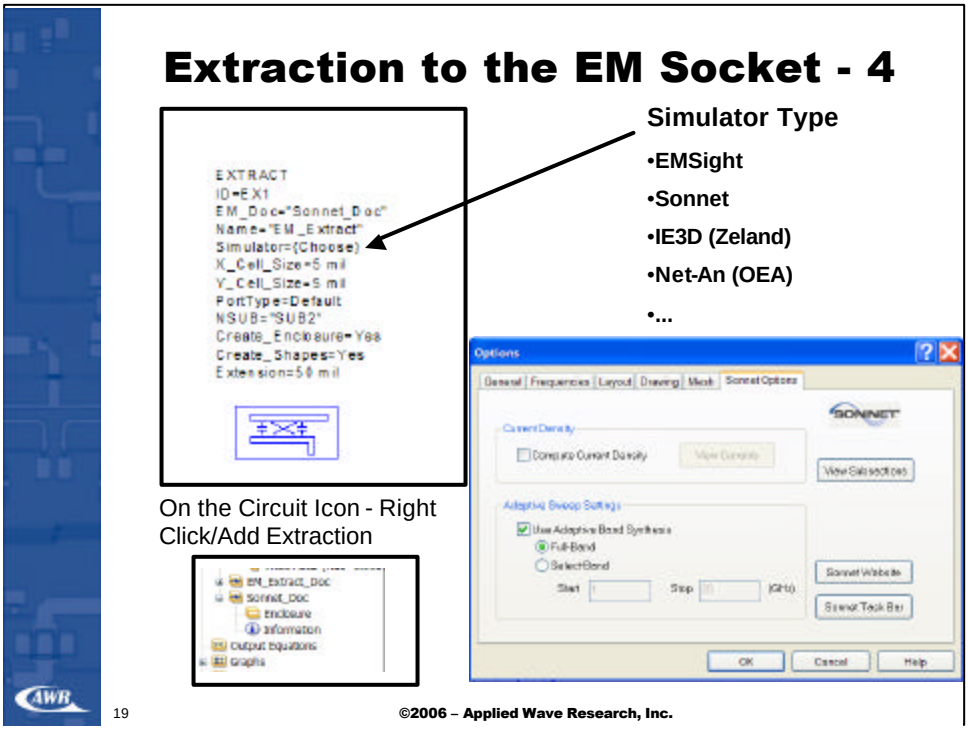


The flow of how the extraction is carried out is shown in this slide.



The desired elements to be extracted have been enabled, as previously discussed. The schematic layout of the selected elements is then sent to the EM Socket. In this example, the entire double stub filter is sent to EMSight.

Note that some of the details of this process will change in version 7.0, although the philosophy remains the same.



The extraction block also controls the type of simulator the EM socket will use. A variety of different EM simulators are supported by the socket, including:

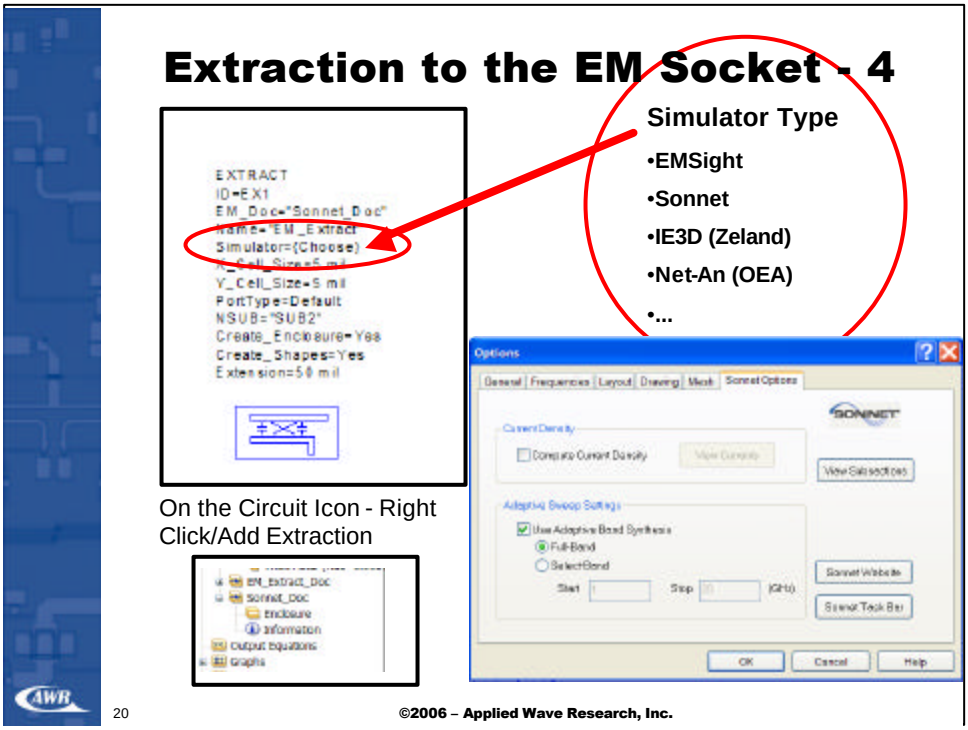
•EM Sight – the internal simulator in MWO.

•Sonnet.

•IE3D from Zeland Software.

•Net-An from OEA.

A complete list of supported products can be found at the AWR website: www.appwave.com, and going to the sales/alliance/partners/EM page – http://www.appwave.com/sales/alliance/partners/EM/.

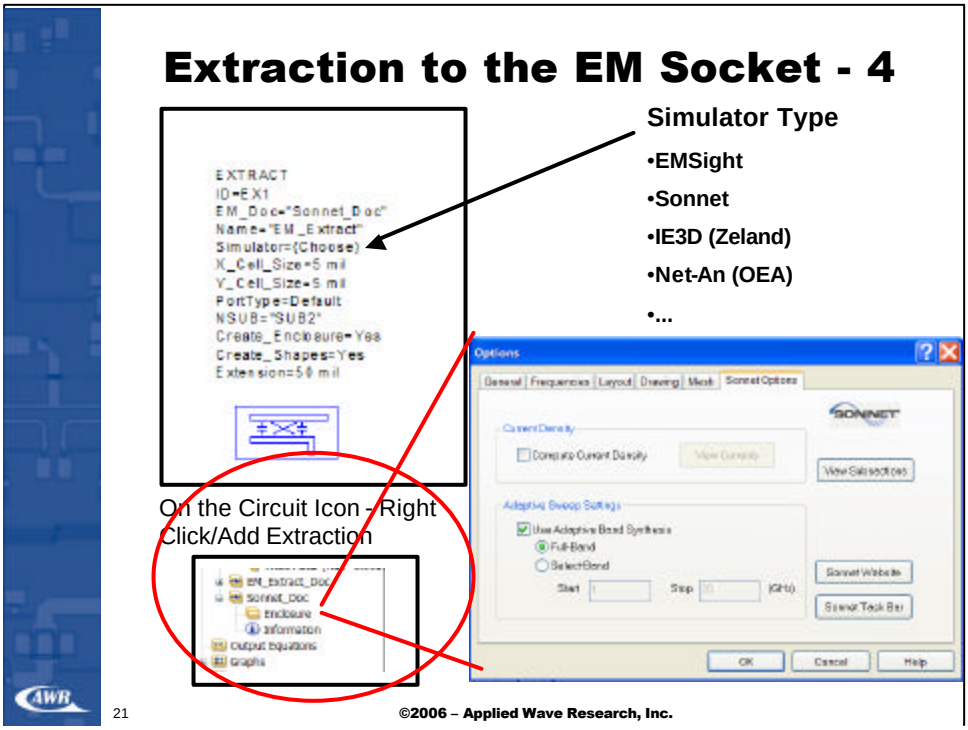


The field Simulator in the extraction block sets the simulator type. It can be selected in 2 different ways:

•Clicking over the Choose field – will give a few choices, including EMSight.

•If you don't see your choice, you can leave the field set to Choose. Then, go to the schematic icon on the project browser, and right click to select Add Extraction. A menu will come up allowing you to select the simulator you need.

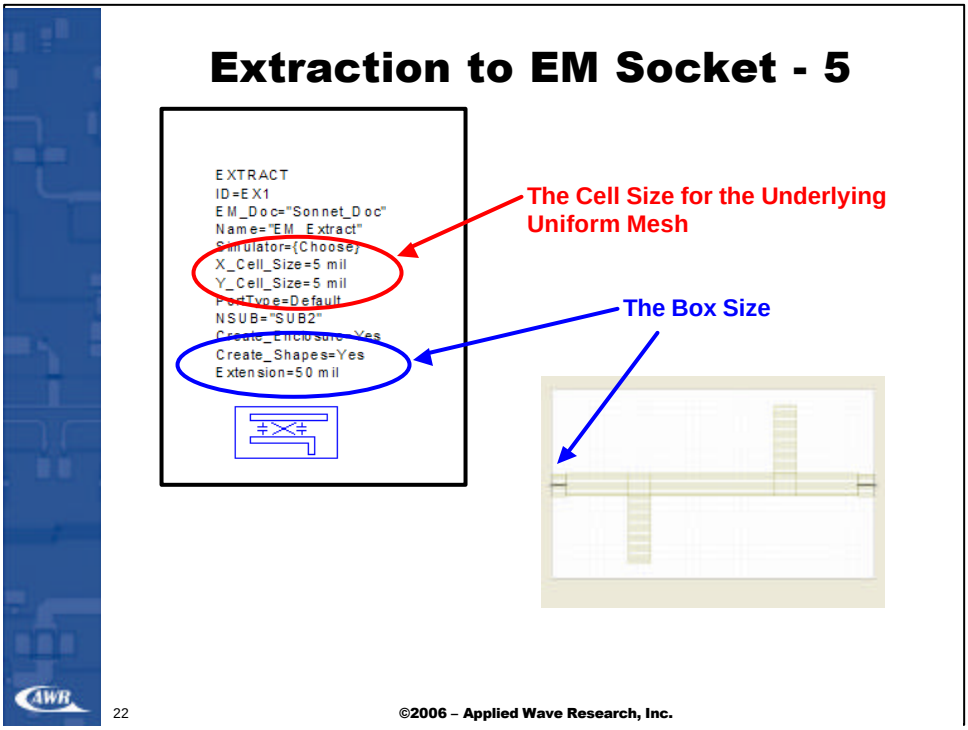
Note that you need a license for the simulator you are using.



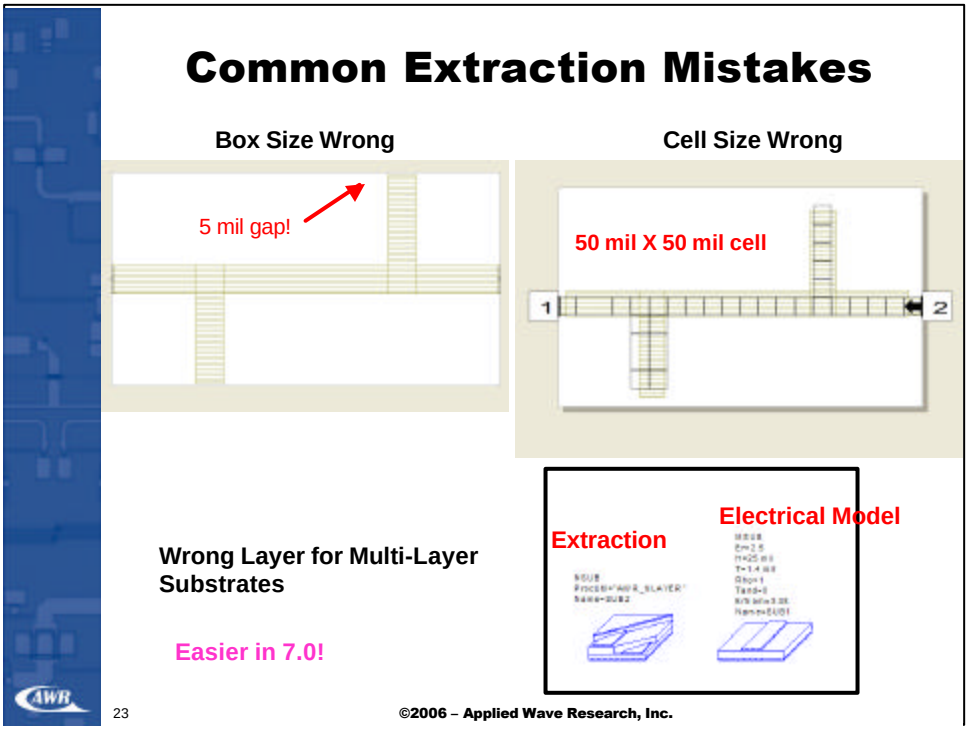
The Extraction will make a new EM Document in the EM Structures area of the Project Browser. The name of the Document is controlled by the EM_Doc field in the Extraction Block.

It is important to check the EM Document to make sure the settings are correct, at least when starting to work on a new group of simulations. The most common errors occur with Extraction because the designer has never bothered to make sure the settings are reasonable.

The EM Socket controls the settings going to the simulator. In this example, the Sonnet options can be seen. To get this menu, right click on the EM Document (here Sonnet_Doc) and select Options.

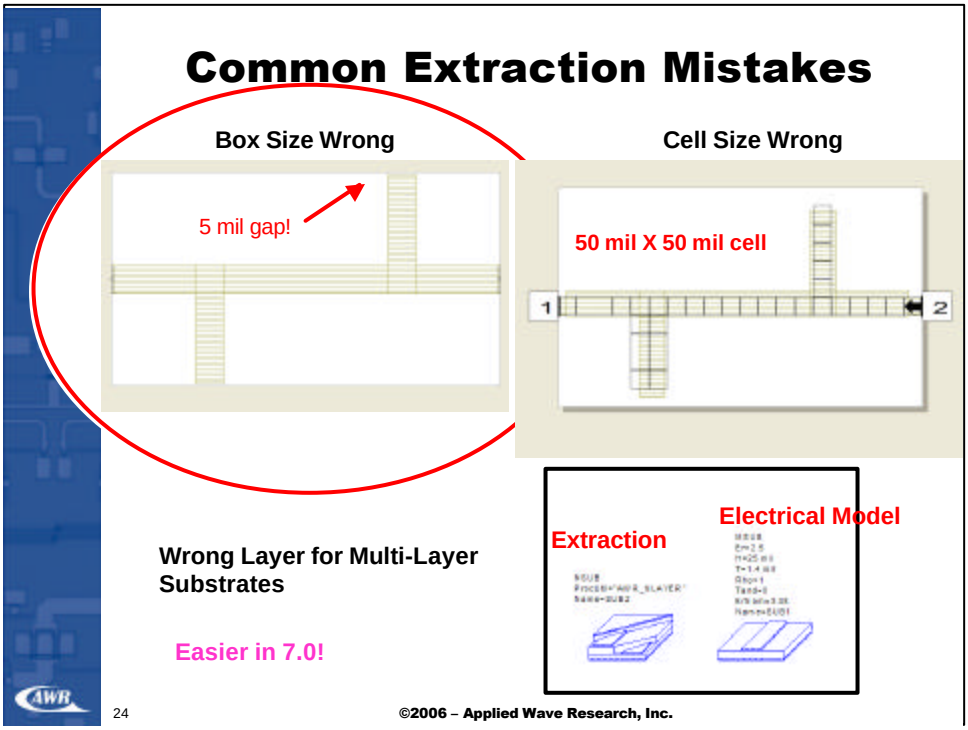


The Extraction Block controls the size of the uniform mesh, and the size of the box. This is the most common source of error in Extraction.

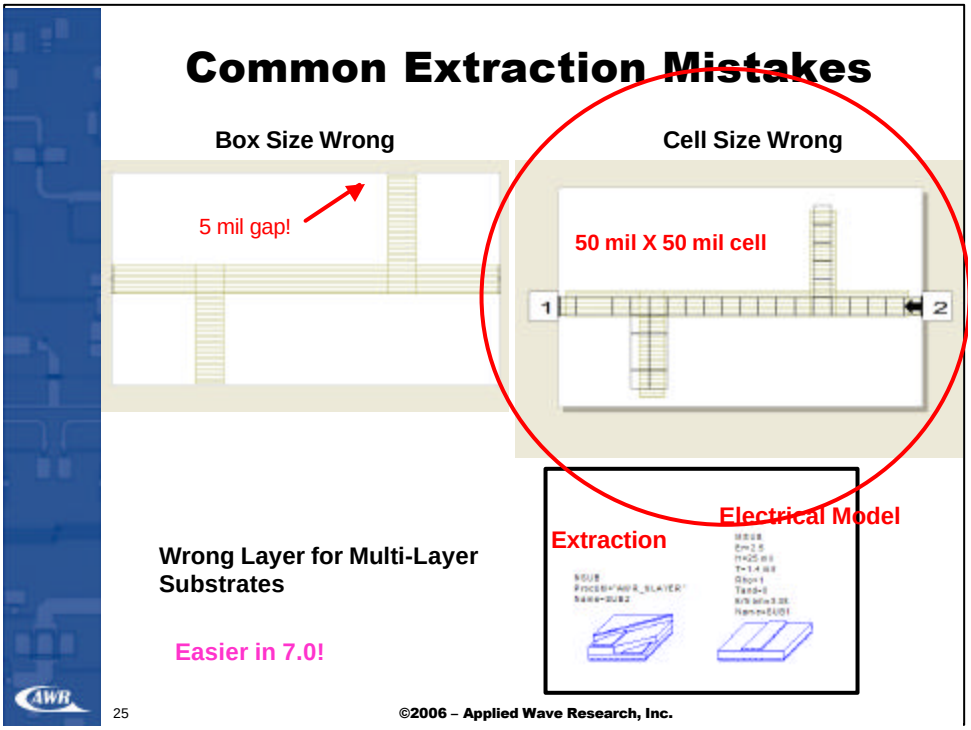


This slide shows the three most common extraction errors. Notice for all these errors, the problem is apparent once the EM document layout is examined.

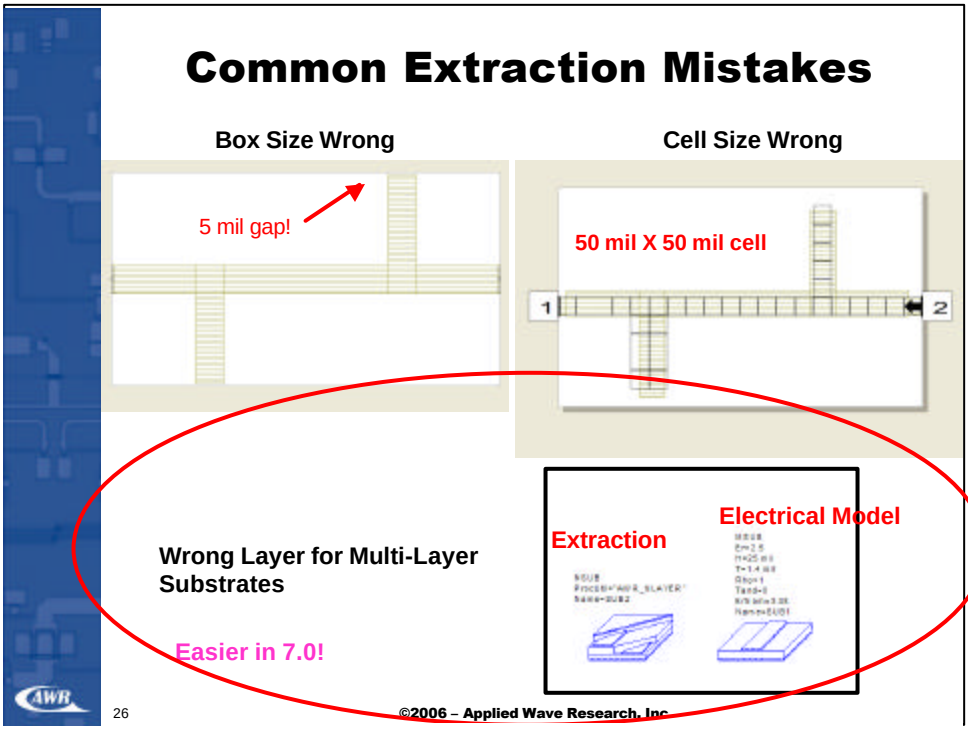
Note – Do not confuse the EM Layout with the Schematic Layout.



It is a common problem to set the box size to low. In this slide, the box size leaves only a 5 mil gap with the end of the stub. Clearly this is too close, and will lead to erroneous results



The cell size must be appropriate to the problem being simulated. Conductor widths should be integer numbers of fundamental cell lengths. In this slide, the fundamental cell size of 50X50 mils is to large for the 70 mil line. Only 1 cell wide can be drawn, making the simulation inaccurate. There are too few cells, and the width of the line will be simulated as 50 mils.



The third most common error is drawing on the wrong metal layer. This is because there are a variety of settings which must be correct before the metal layer mapping is correct. The settings include:

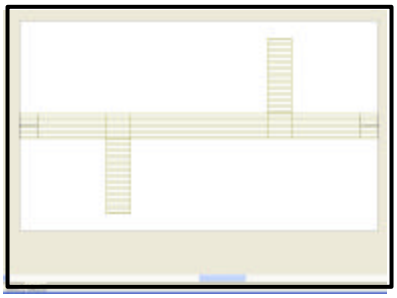
- EM Mapping Layers.
- NSUB Layers.
- LPF layer mappings.

It is beyond the scope of this webinar to go into the details. Please see the Signal Integrity webinar given on November 3, 2005. It is available in the Knowledge Base – article number: 170771.

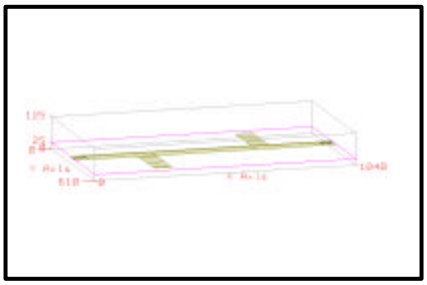
In version 7.0, the details of the layer mappings will change.

So … Always Check

Look At the EM Layout in the EM Socket!



2D EM View



3D EM View

Details to Change in 7.0!

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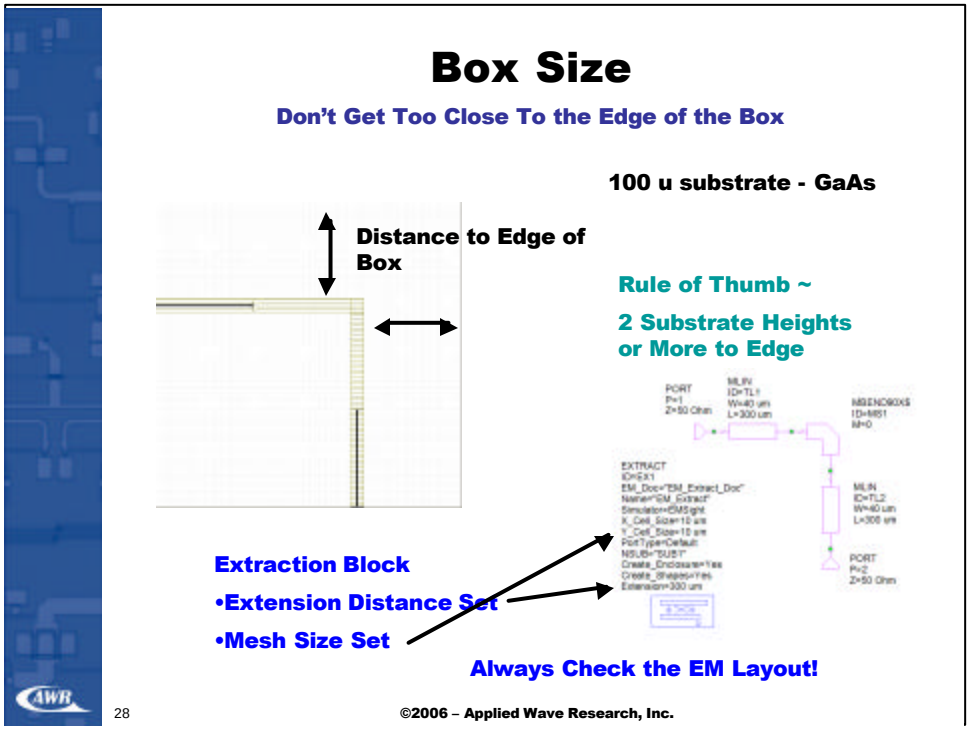
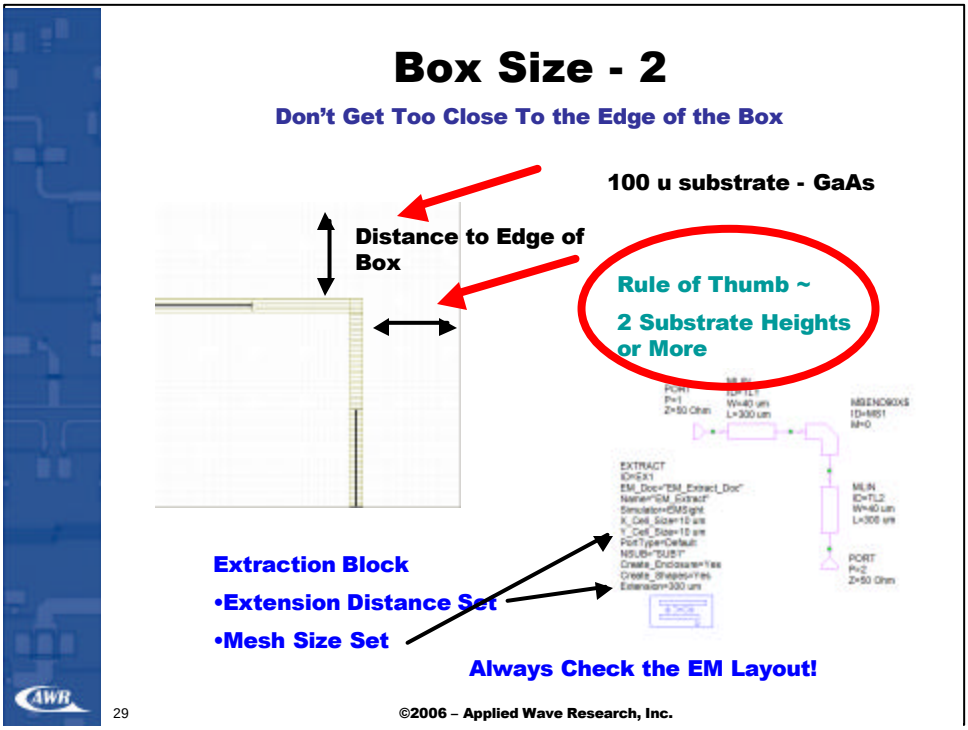
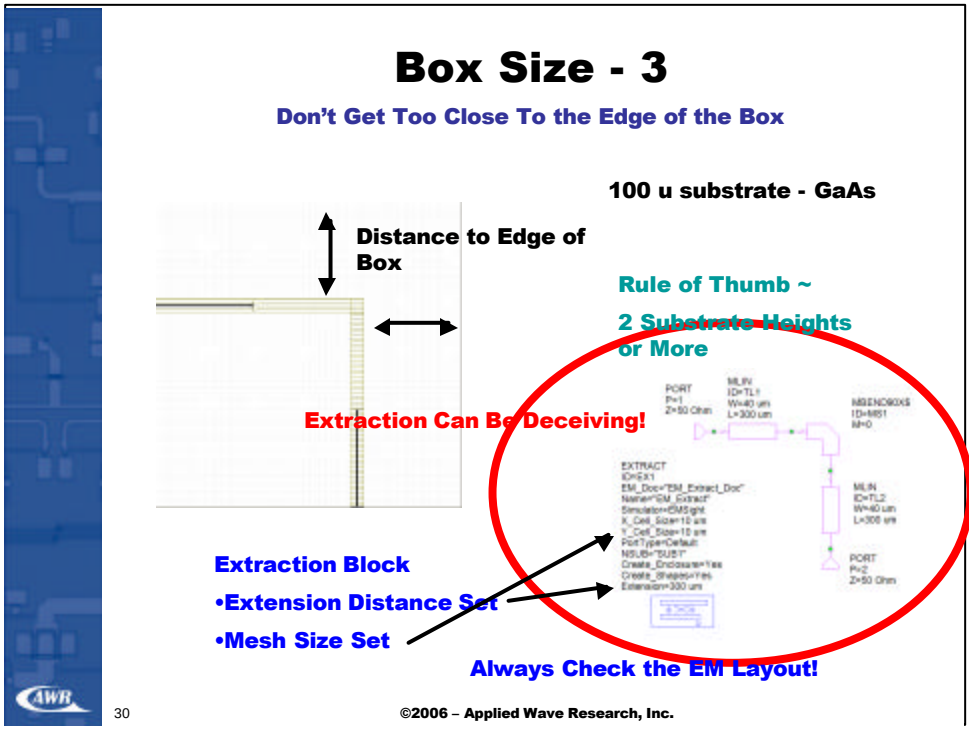
The slide shows the EM layout view, and the 3D EM layout view. These should always be checked to make sure things look reasonable. Many problems occur because the designer thinks that because the layout looks right in the schematic layout view, it will automatically look right in the EM layout.



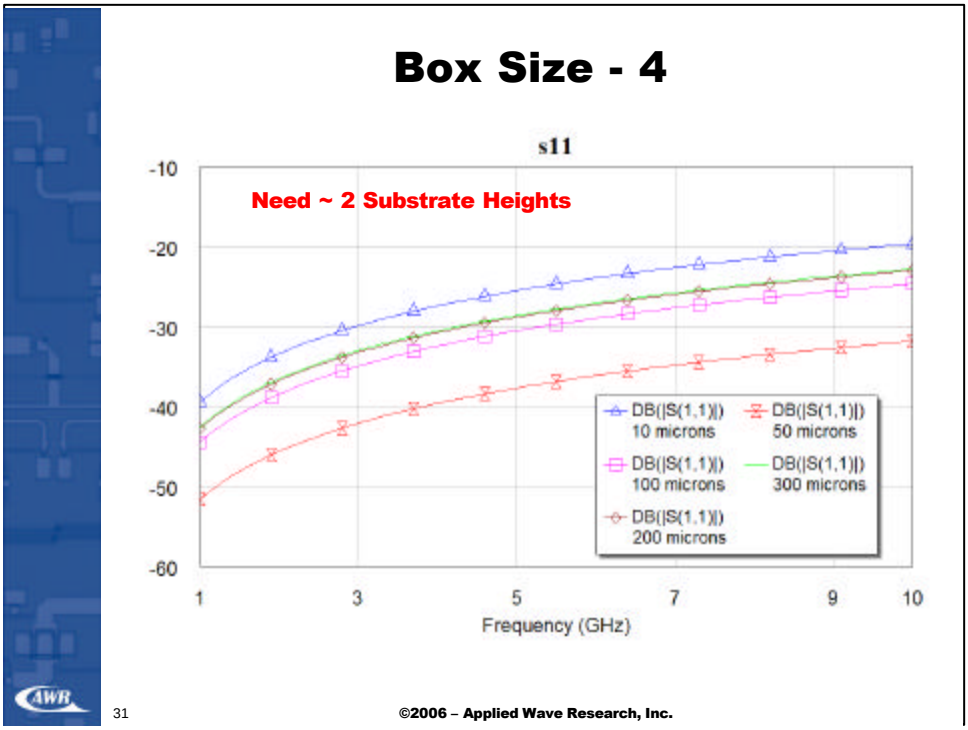
This example illustrates the problem of too small a box. If the box is too small, it will load the circuit and produce erroneous results.



The normal rule of thumb for microstrip circuits is that the box walls should be at least two substrate heights away, or two line widths away – which ever is larger.

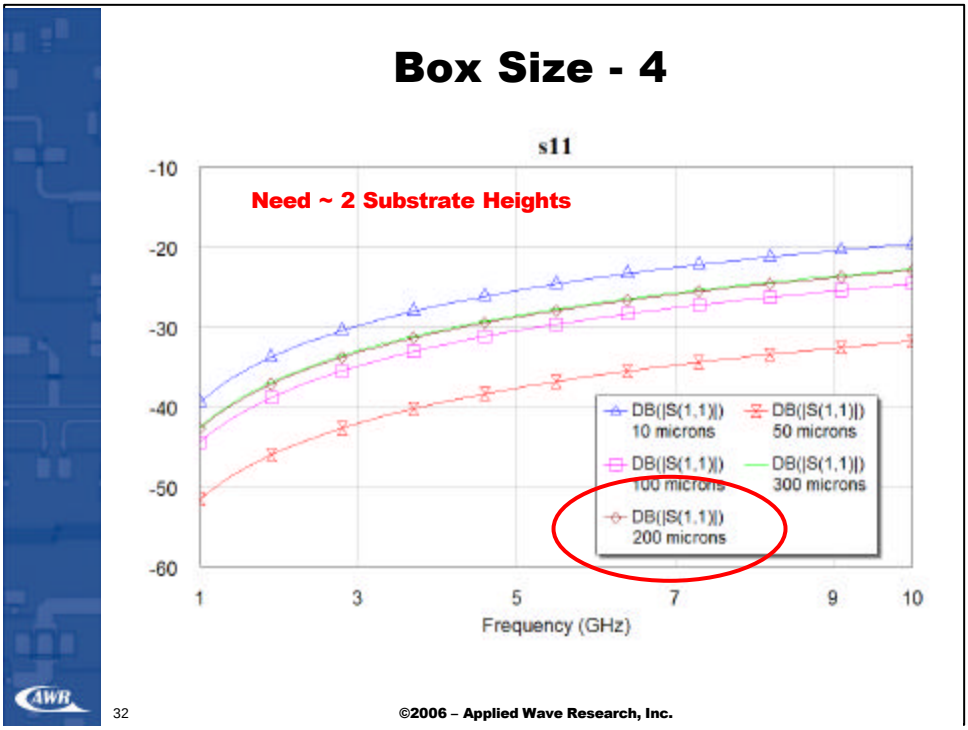


The box size and mesh are controlled from the Extraction block.



This graph show S11 for the bend in the previous slide. The size of the box has been varied. The five curves show the results for 10 microns, 50 microns, 100 microns, 200 microns, and 300 microns.

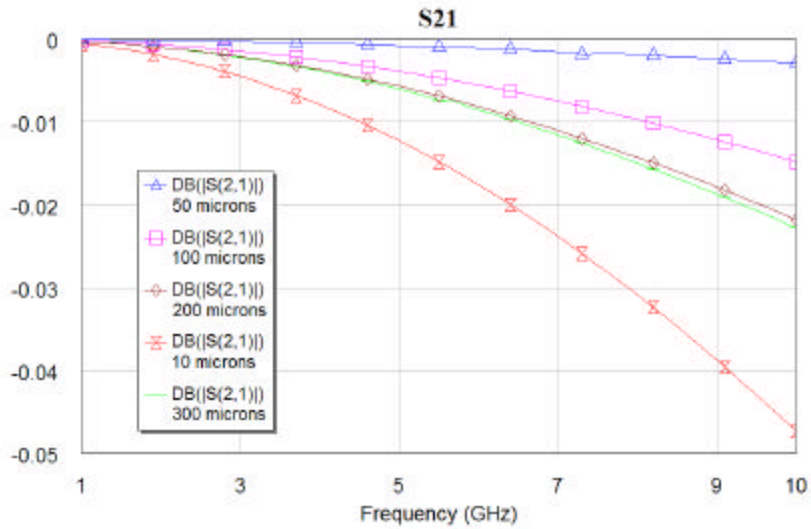
The substrate is 100 micron thick GaAs.



The box should be far enough away that the S parameters are not changing as it's distance is varied. The curves show that there is no change as the box wall is 200 microns from the lines; the 200 and 300 micron curves are on top of one another. The 10, 50, and 100 micron curves differ noticeably from each other, indicating the wall is too close.

Note that the 200 micron number is consistent with the two substrate thickness rule-of-thumb.

Box Size – 5



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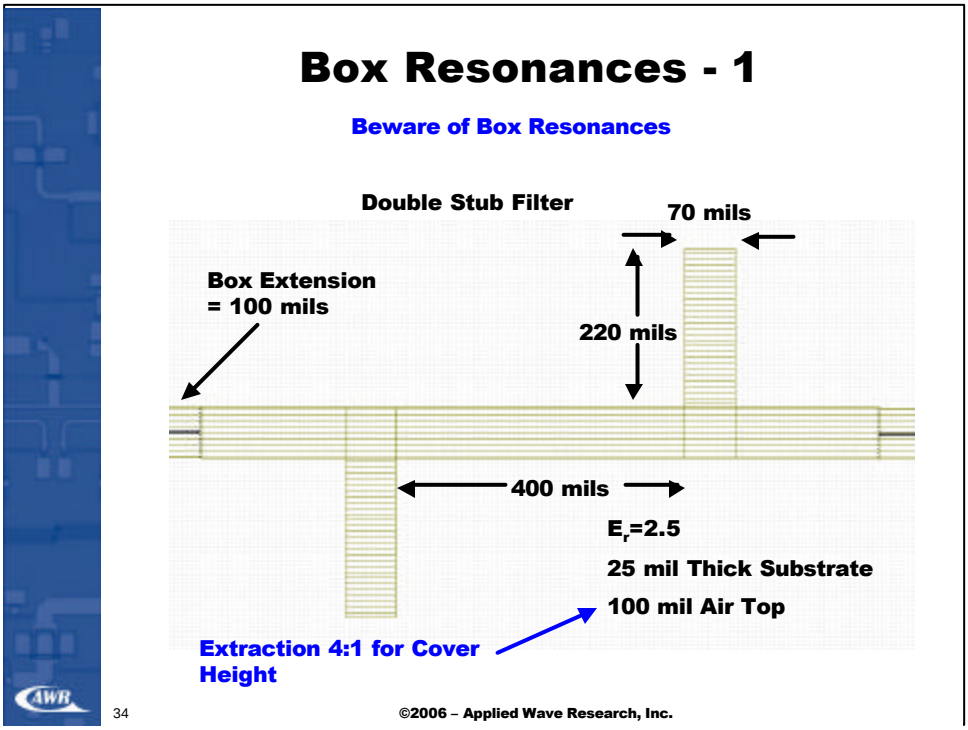
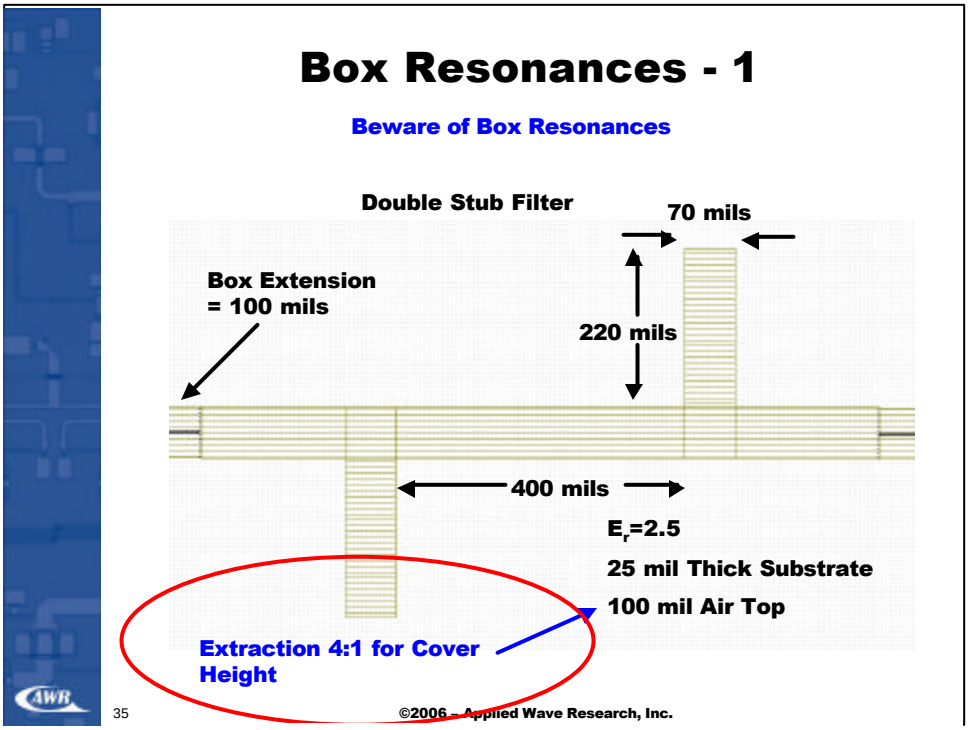
This graph shows S21 for the same problem. The same conclusion is reached – 200 microns is the minimum distance needed for the wall to the circuit.



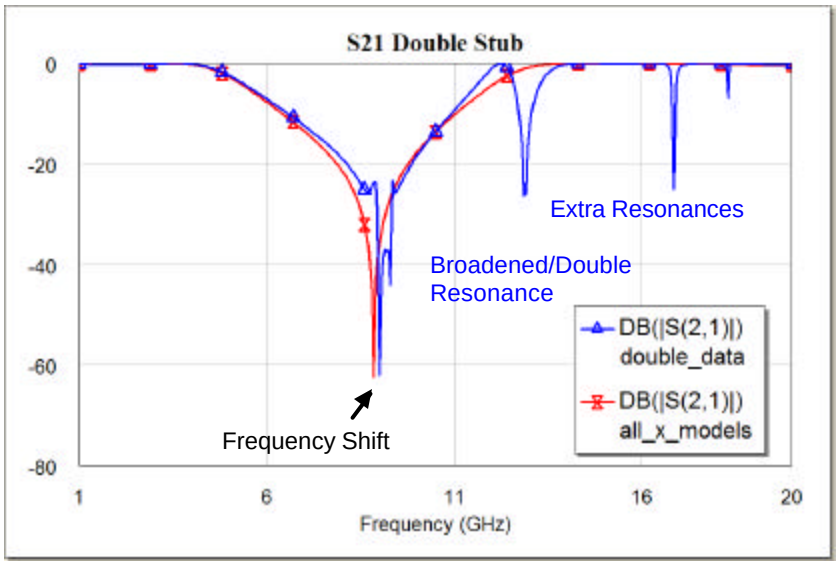
The next common problem we will discuss is box resonances. The example shown is a double stub filter on an organic board. The filter has been extracted, and simulated using EMSight.



The size of the box is set to be 100 mils longer than the nearest conductors.

Note that the Extraction block sets the cover of the box automatically to four times the total substrate thickness. The details of this will change in 7.0.

Box Resonances - 2



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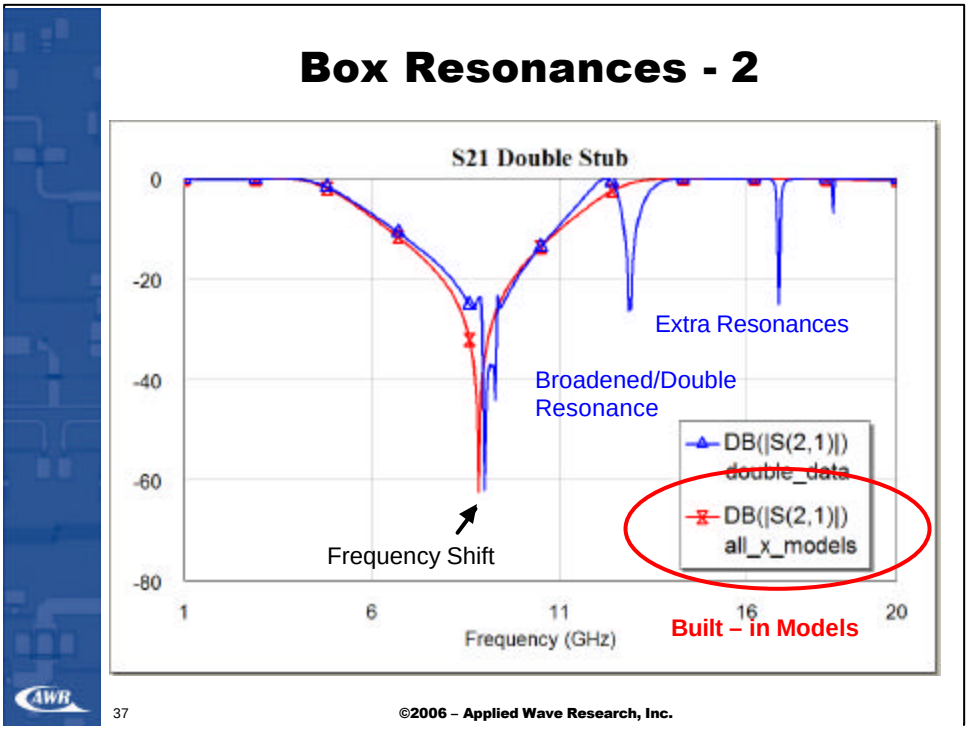
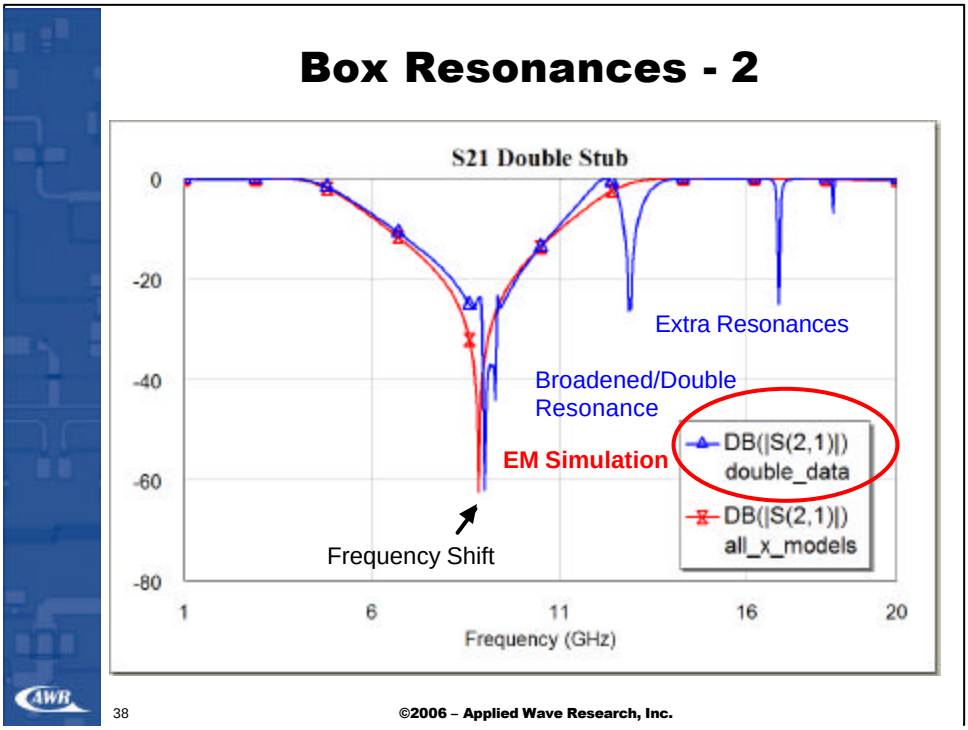
The graph shows S21 in dB for the stub, when simulated from 1 to 20 GHz.



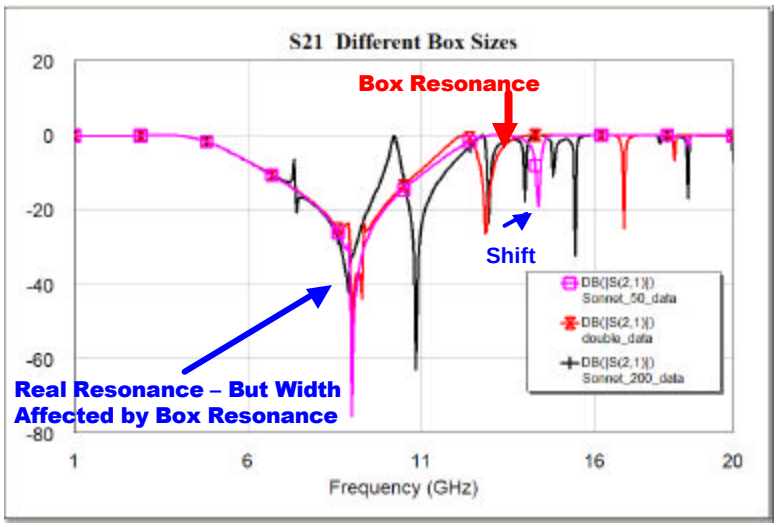
The red curve is the circuit simulation using X models internal to the software. These are the most accurate discontinuity models available in AWR's model libraries.

Please see the Interconnect webinar for more on X models. It is available in the Knowledge Base, Article number 166450.



The blue curve is the EMSight simulation. Some deviations from the predicted, modeled results are observed. First, the resonance has been shifted. It also has been broadened. There also are other resonances at higher frequencies. The designer needs to know if these effects are “real”. They may be produced by the inability of the built-in models to model coupling between different parts of circuit; or, they could be due to the simulation box.

Box Resonances - 3



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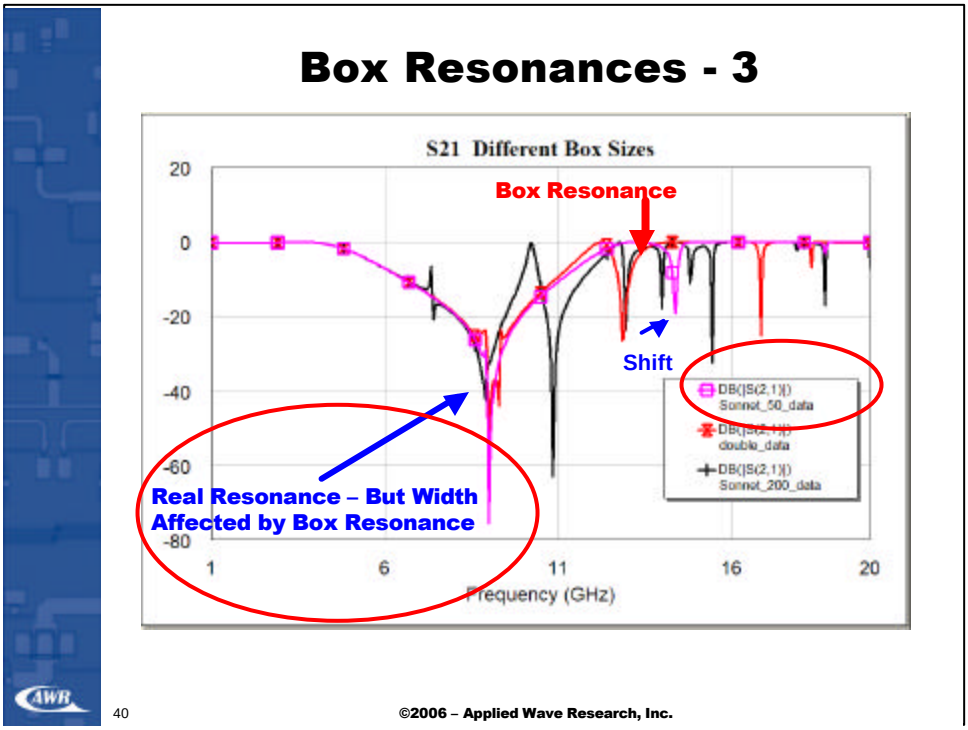
The designer can see if the box is affecting the simulation in one of two ways:

•The box size is changed.

•An “absorbing” boundary condition is put on top of the box.

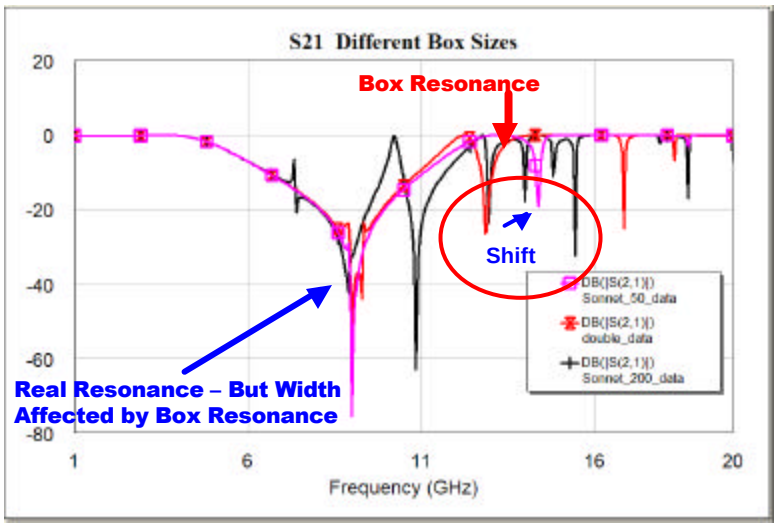


The magenta curve shows the magnitude of S21 when the box is reduced to 50 mil extensions (instead of the 100 mils before).

The main resonance is still there, but has narrowed up again. Clearly the box has some kind of resonance.

Note – These simulations were obtained using Sonnet's simulator. EMSight gave the same answer for the cases that were compared. The Sonnet simulator has a nice feature of giving a warning that the box may have cavity resonances in it (which it did in this case).

Box Resonances - 3



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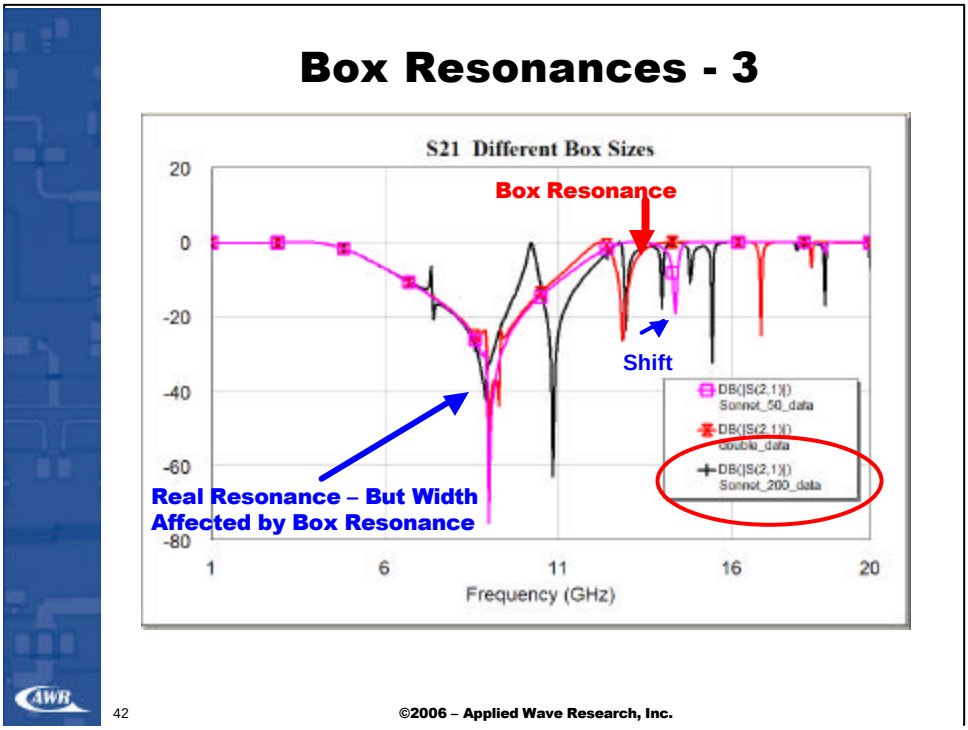
The circle shows the higher resonance shifting up in frequency as the box is made smaller. This indicates this is a box resonance. The smaller the box, the higher the frequency before the resonating dimension is ½ a wavelength.

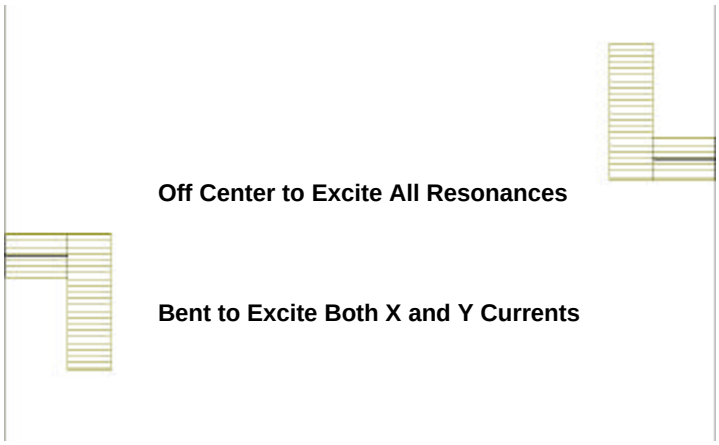


The black curve shows the magnitude of S21 when the extension is 200 mils instead of the original 100 mils. The box has therefore been made larger.

The main resonance is still there, but it's depth is altered. There is also a box resonance starting at a lower frequency, about 7.25 GHz. This resonance was probably the reason for the widening filter response in the main notch. It has been moved down in frequency as the box has been made larger.

Box Resonances - 4

Check With Open Stubs



Off Center to Excite All Resonances

Bent to Excite Both X and Y Currents

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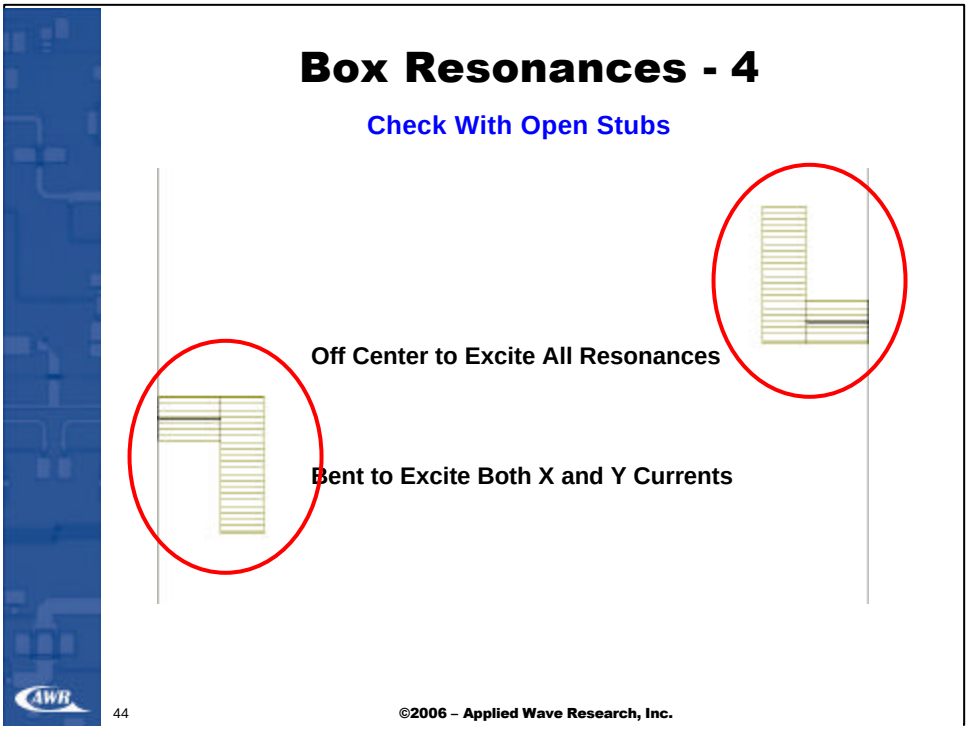
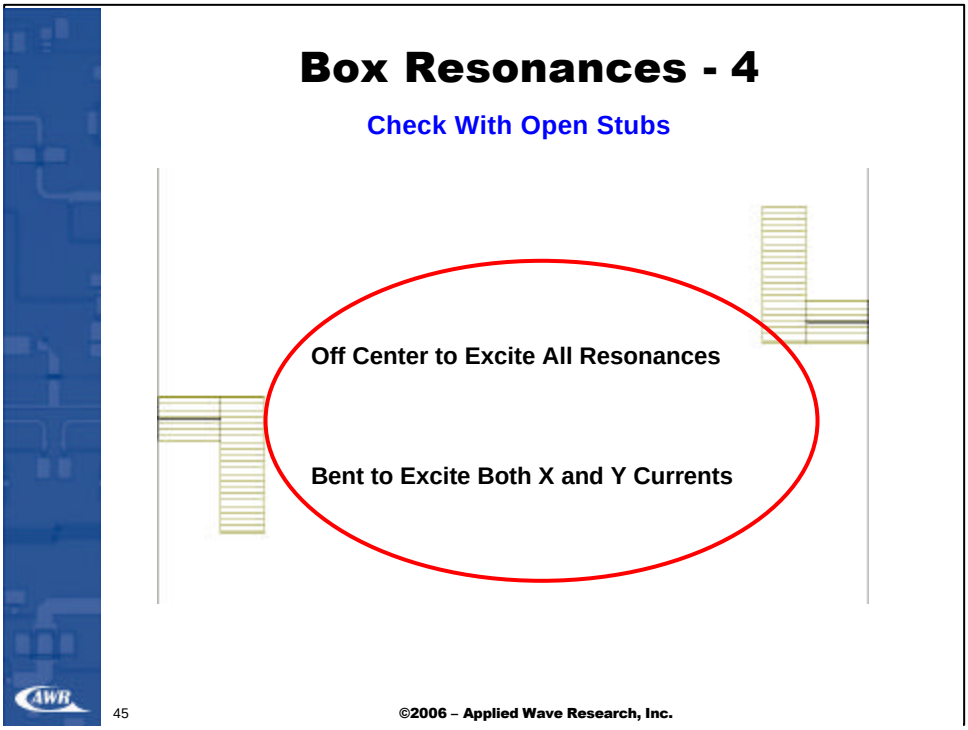
Another way to check for box resonances is to use open stubs.

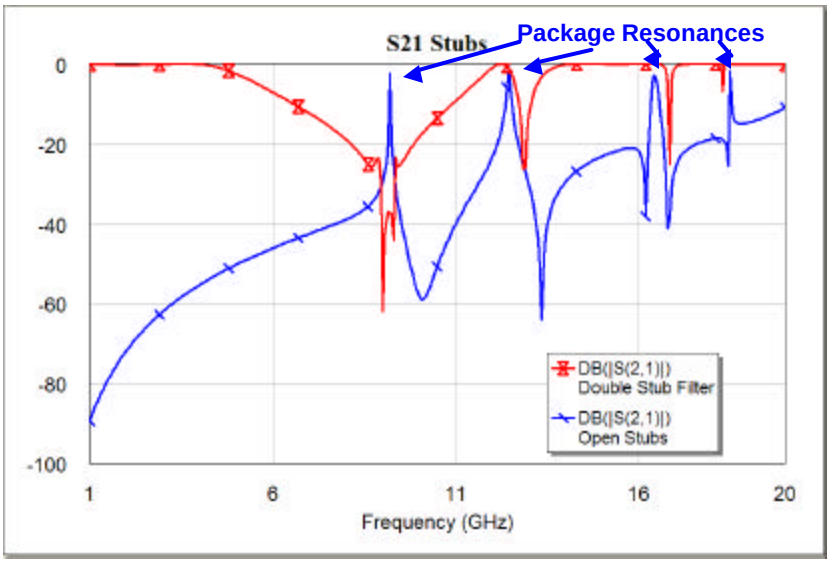


This two port circuit consists of two open stubs. In normal circumstances, the stubs will not interact much, giving a very low S21 value. However, at a box resonance, a large transfer of energy will occur. This can be used to see where the box is resonating.



The stubs are bent into an L shape, to make sure currents in both directions are excited. The bends are also placed off center to break up any symmetry in the geometry. If they were symmetrical along the midline of the box, it's possible that a resonance of another symmetry would not be excited, and therefore go undetected.

Box Resonances - 5



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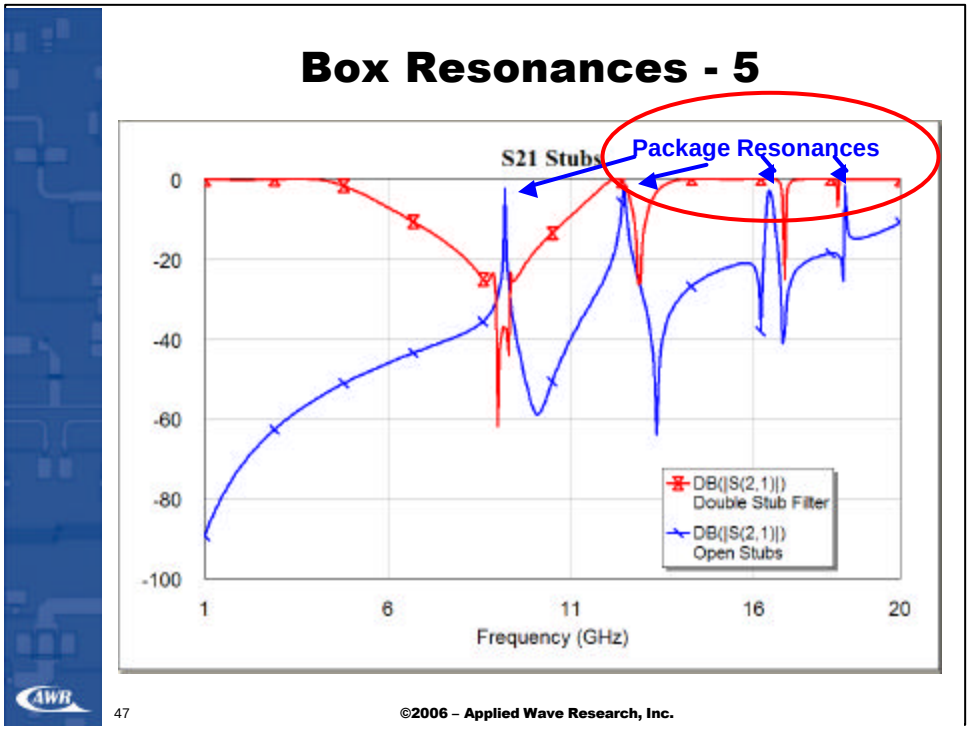
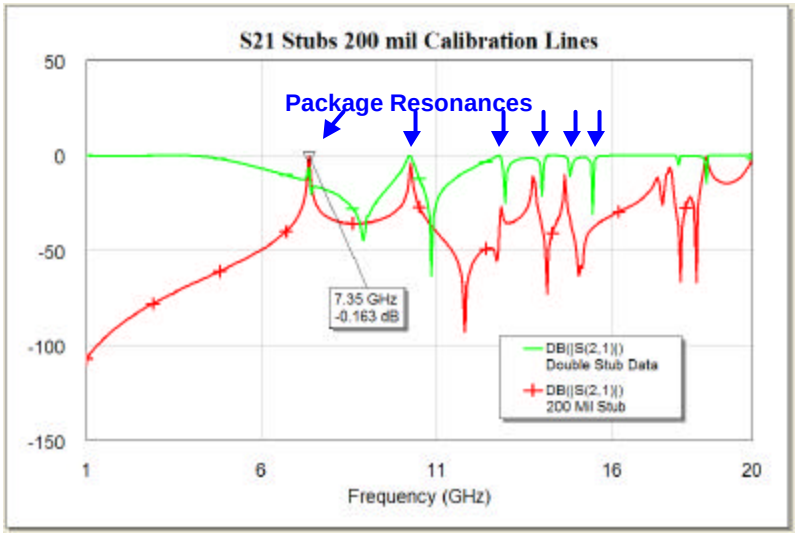
The blue curve shows the magnitude of S21 for the stubs.



Notice there are package resonances. Also notice that the first resonance is on top of the filter resonance. This is what was giving the broadening in the filter response.

Box Resonances - 6



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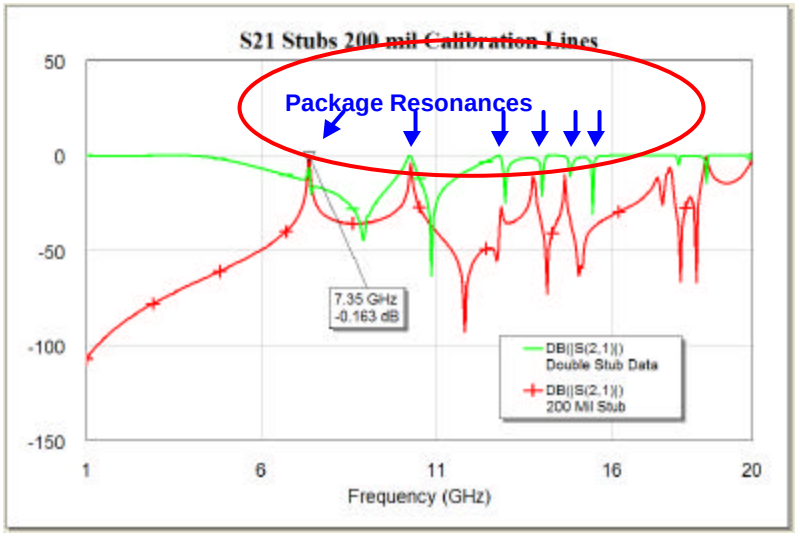
The same technique is applied here with the box the same size as the filter with 200 mil extensions.

Box Resonances - 6



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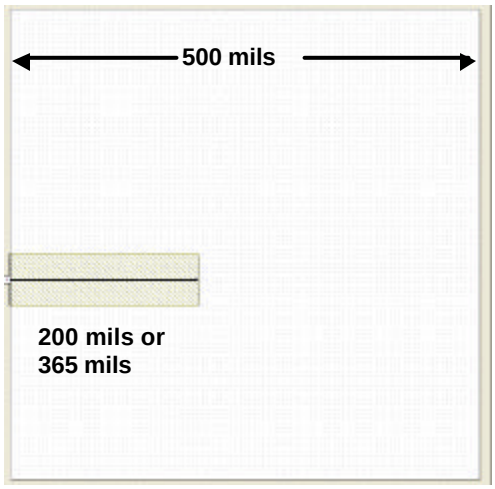
The position of the package resonances is again correctly predicted.

Box Resonances - 6

Trouble – Deembedding Line ½ Wavelength



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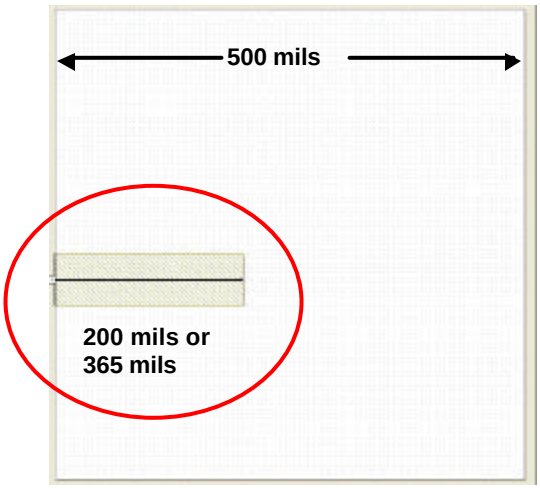
It is possible to get another type of spurious resonance. This occurs when the deembedding line is a multiple of a ¼ wavelength. The details of why this is the case will be given in a future webinar. However, it should be apparent that an open stub ¼ wavelength long will appear as a short at the port. It is necessary to know the current at the port to get the S parameters, and getting currents for a short sounds like an ill posed problem.

Box Resonances - 6

Trouble – Deembedding Line ½ Wavelength



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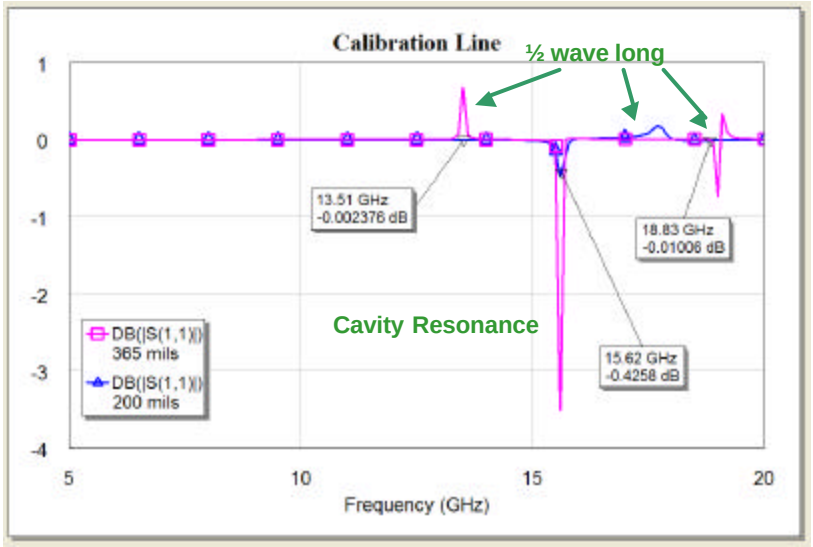
In this example, a stub is deembedded to the end of the line. The box is 500 mils long. The stub can be either 200 mils or 365 mils long.

Box Resonances - 7



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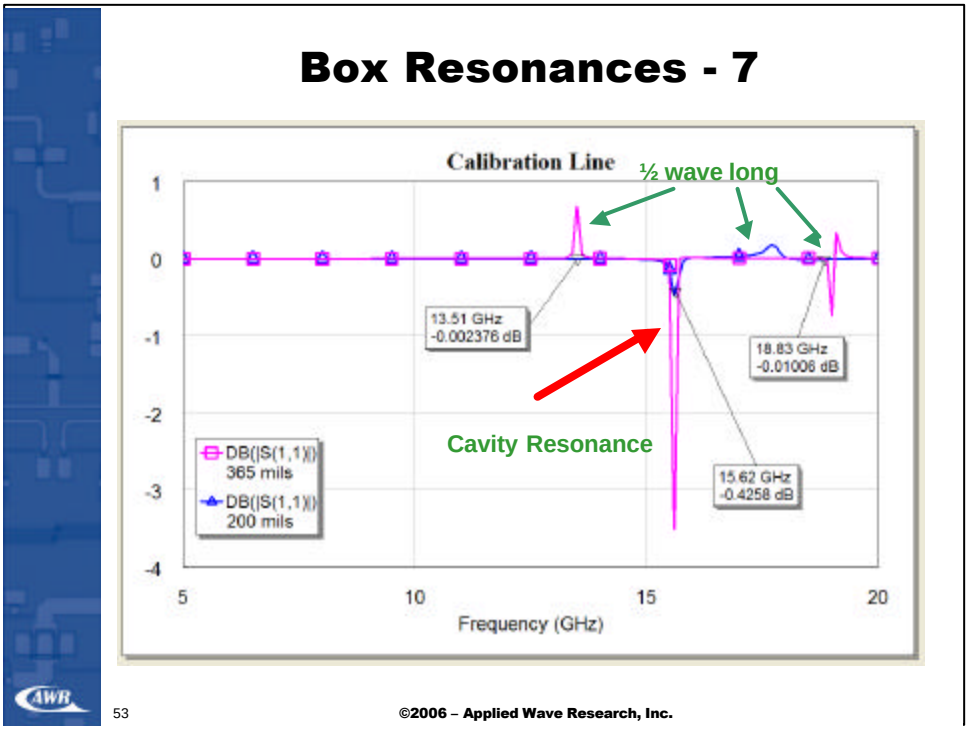
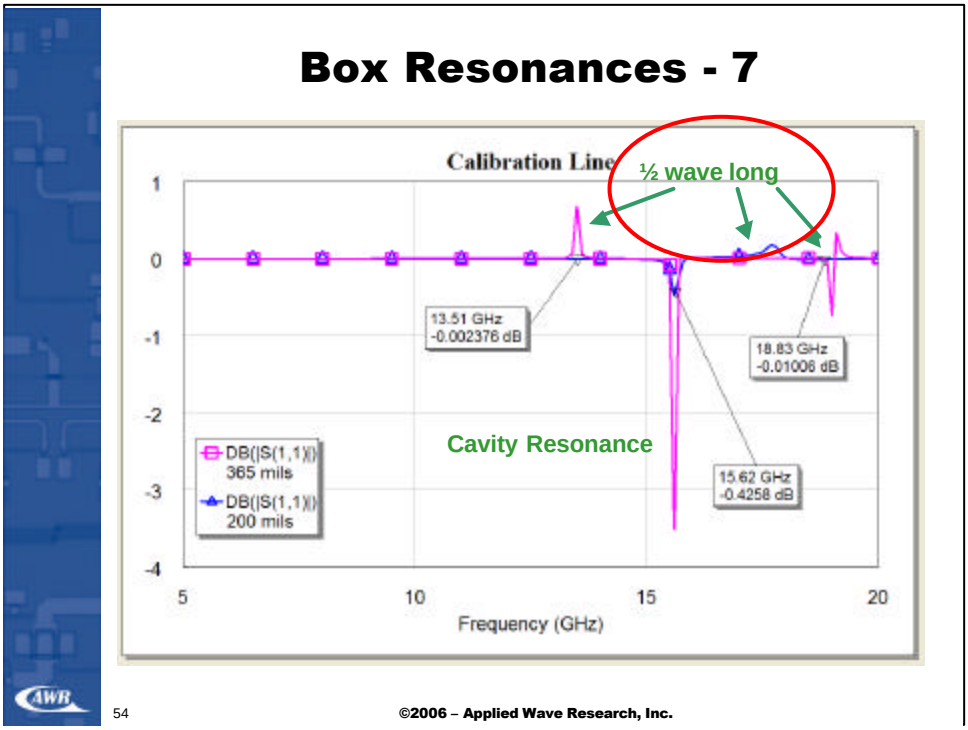
The results for the magnitude of the two simulations for S11 are shown. Notice there is a cavity resonance at 15.62 GHz. The two different line lengths do not change the position of the cavity resonance, as is expected.



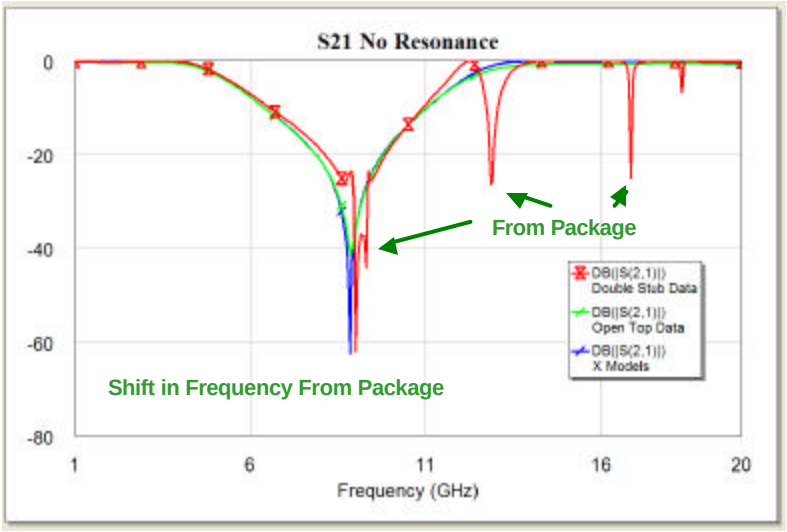
The cavity resonance corresponds to the box being one wavelength long. A quick way to see this is about correct, is to use the TXLINE calculator under Tools. Use 500 mils for a physical length, and 2.5 for the dielectric constant, 25 mils for the substrate thickness, and 55 mils for the width. It gives 345 degrees electrical length for 500 mils. Of course this is approximate, as it really is a cavity resonance, not a microstrip line mode - which is what TXLINE is calculating.



The other resonances are in the deembedding line itself.

The resonance in the magenta 365 mil line, is when the line is ½ a wavelength long (= 2 quarter wavelengths). Notice that the results are non-physical with the magnitude of S11 > 1. This shows the S parameter calculation has failed. Other calibration errors due to resonances in the deembedding lines can be seen at higher frequencies.

Box Resonances - 8



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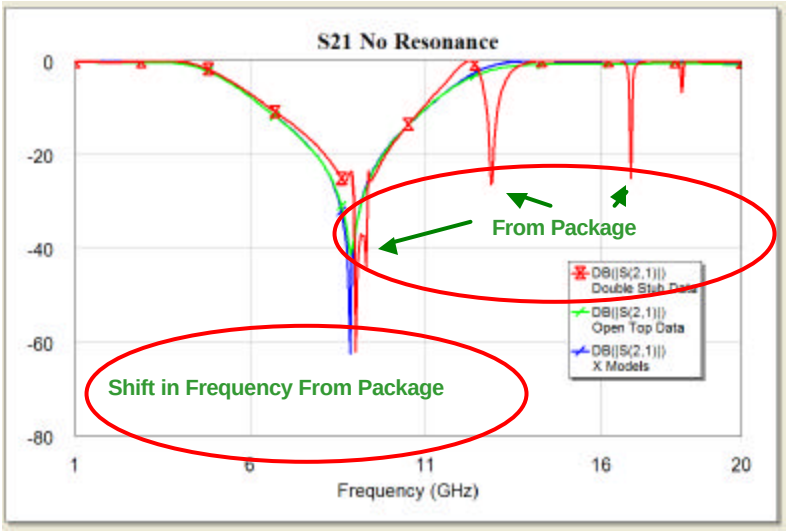
We now can identify with confidence the various causes of resonances in our double stub filter.

Box Resonances - 8



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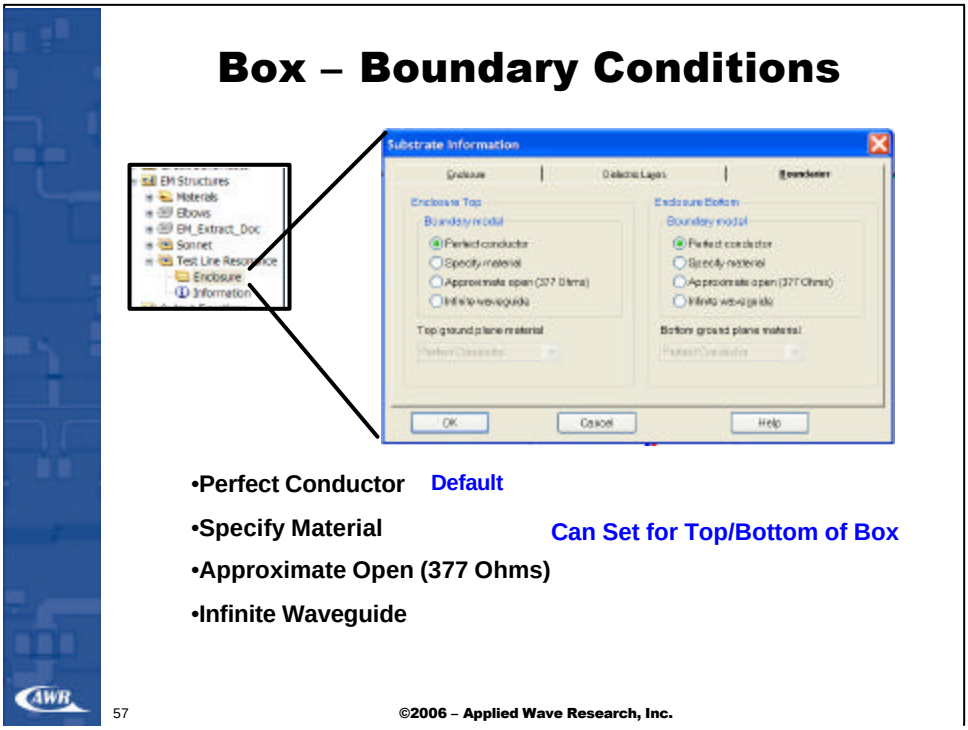
Package resonances are shown. There also is a package resonance close to the original resonance, which is broadening the filter's resonance.



The final topic in today's webinar will be on boundary conditions for EM simulations in EMSight. Note that these same boundary condition concepts are used in many simulators besides EMSight.

The slide shows the EM Document/Enclosures dialog box with the Boundaries tab selected.

The various possibilities are:

•Perfect conductor – which is the default setting.

•Specify Material.

•Approximate Open (377 Ohms).

•Infinite Waveguide.

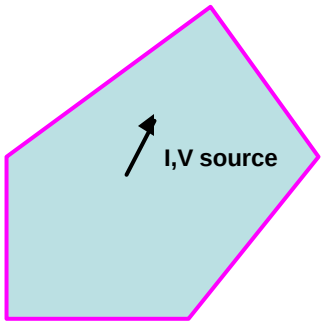
Note that only the top and bottom surfaces of the box can be selected. The side walls are always perfect conductors.

Box – Boundary Conditions -2

Impedance Boundary Conditions

Maxwell's Equations Say -

1. **Given a Closed Region**
2. **Given I, V Sources**
3. **On Boundary: Impedance Boundary Condition**



then...

There is one and only one solution!

$$E_{tan} = Z_s a_n \times H_{tan}$$

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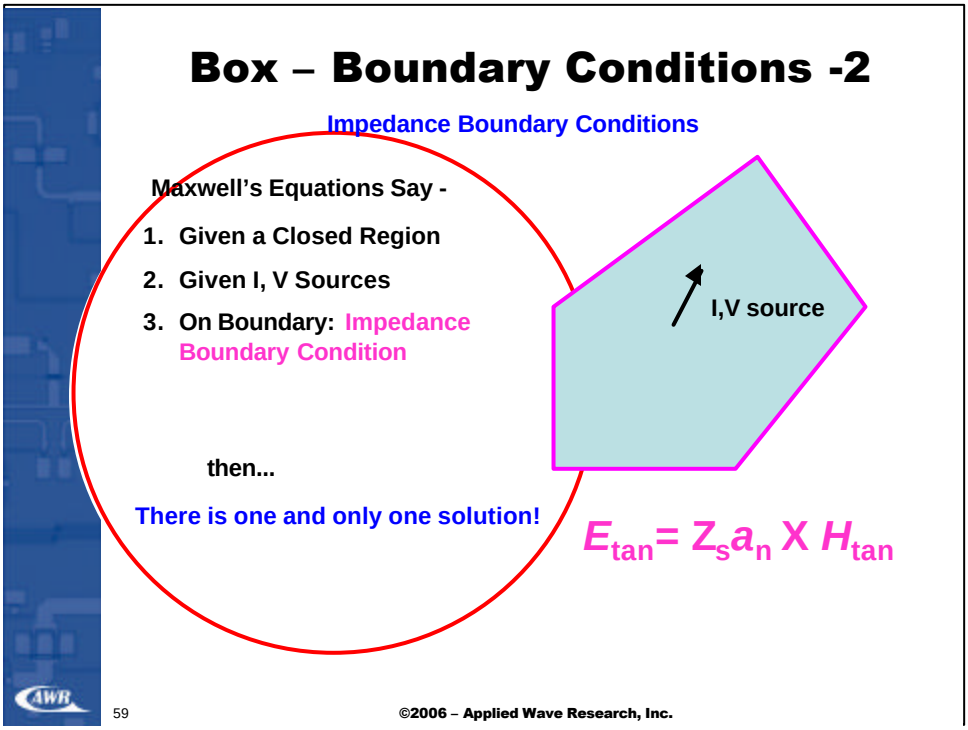
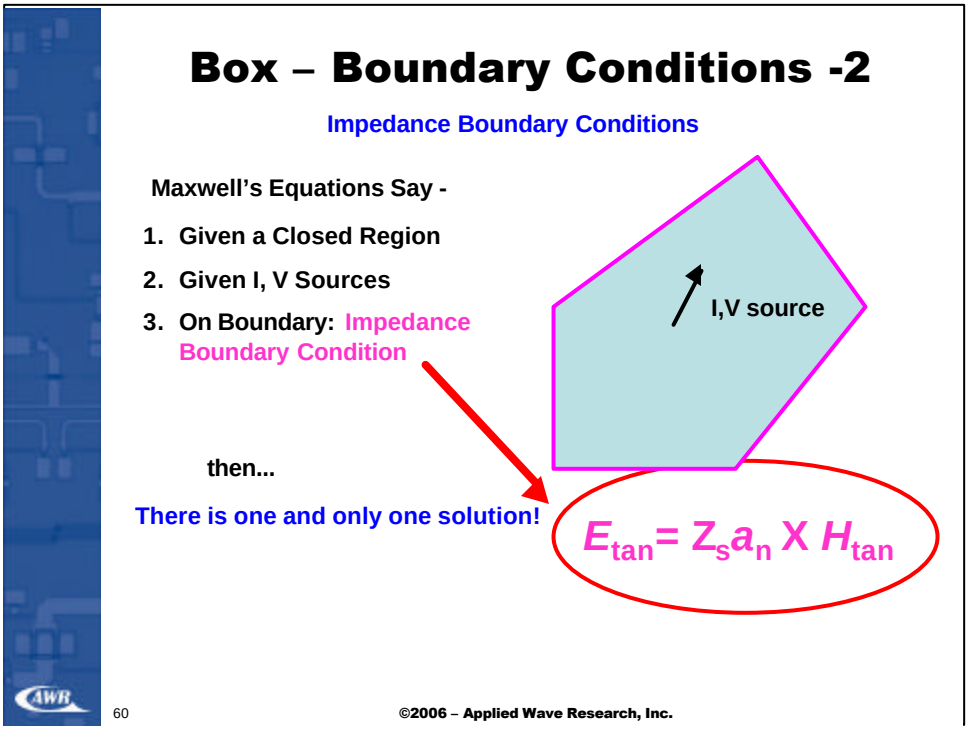
This slide explains why boundary conditions are important.



A fundamental theorem in Maxwell's equations (the equations of EM theory) states that if you have a closed region of space, with given sources in it (for example current and voltage sources), and an impedance boundary condition defined at the boundary – there is one, and only one solution to the problem.

Therefore, for the EM box, if impedance boundary conditions are placed everywhere, the simulator is being given a well posed problem to solve.



An impedance boundary condition is a relationship between the tangential electric and magnetic fields on the surface of the boundary. The equation states that they are related to each other by the surface impedance Z_s.

Box – Boundary Conditions - 3

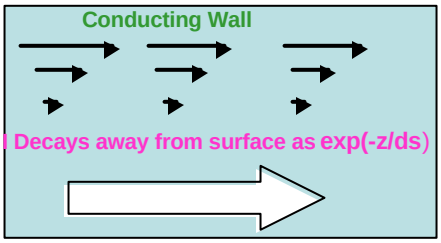
$Z_s = 0$ Perfect Electric Conductor

Z_s ~ 0 "Good" Electric Conductor

Means loss tangent: s/? e >> 1

Skin Depth: d_s = v2/(? µ s)

Interior of Box



Interior of Box

$E_{tan} = Z_s a_n X H_{tan}$

On Boundary, with -

$Z_s = (1+j)/(s\, d_s)$

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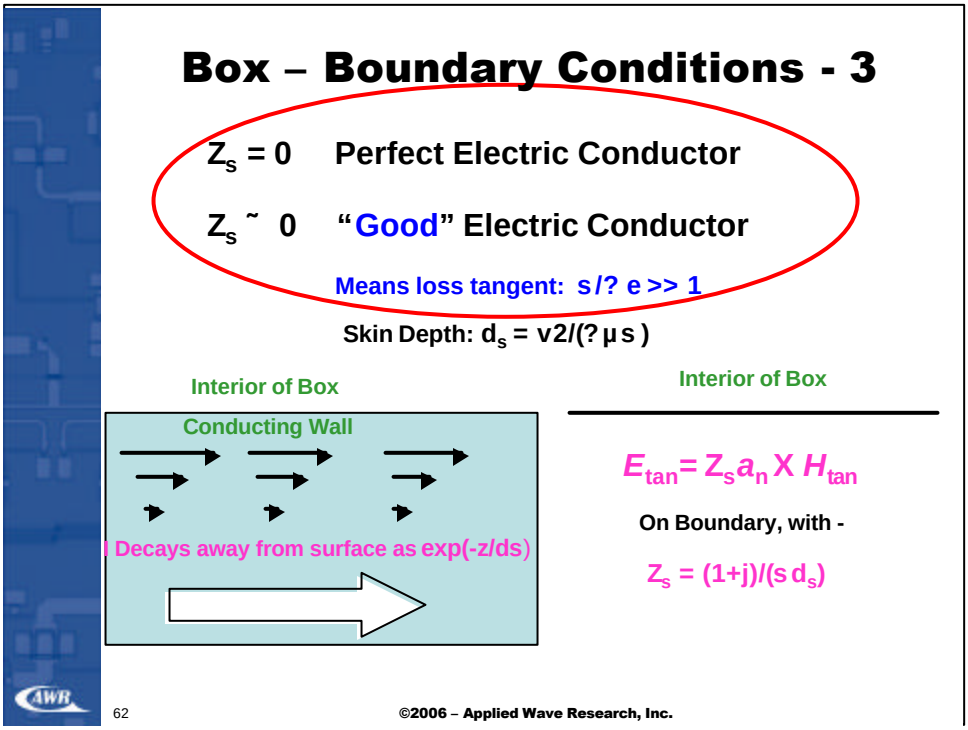
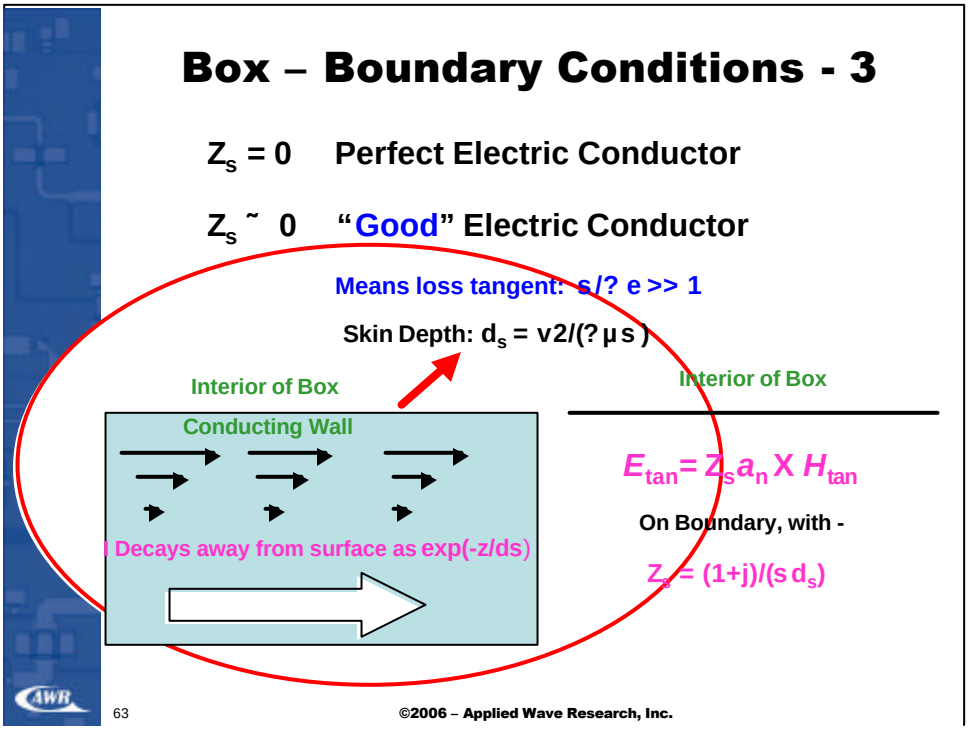
The form of the surface impedance is now examined in more detail.



The default case for Z_s, is that it is 0. This is a perfect, electric conductor, where the tangential, electric field is 0.

If Z_s is almost zero – it is a very "good" conductor, but not perfect. A good conductor means the loss tangent is >> 1. Loss tangent is a dimensionless quantity defined to be: s /? e, and:

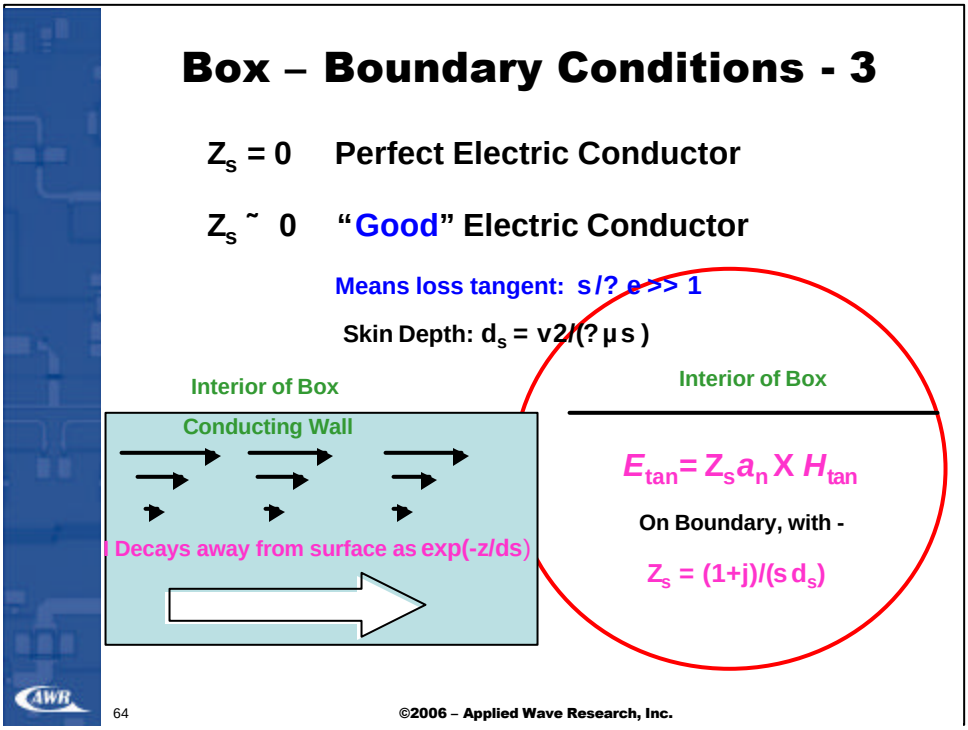
- s – the conductivity of the material in S/m.
- ? – the angular frequency in radians/sec.
- e – the permittivity in F/m.



A good conductor can be defined in terms of skin depth. The current flow in a conductor is strongest at the surface, and decreases exponentially as one goes into the conductor. This is shown in the circled figure. The decay in amplitude is exponential with vertical distance – z. It goes as:

$\exp(-z/d_s)$, where d_s is the skin depth. The skin depth is defined as –

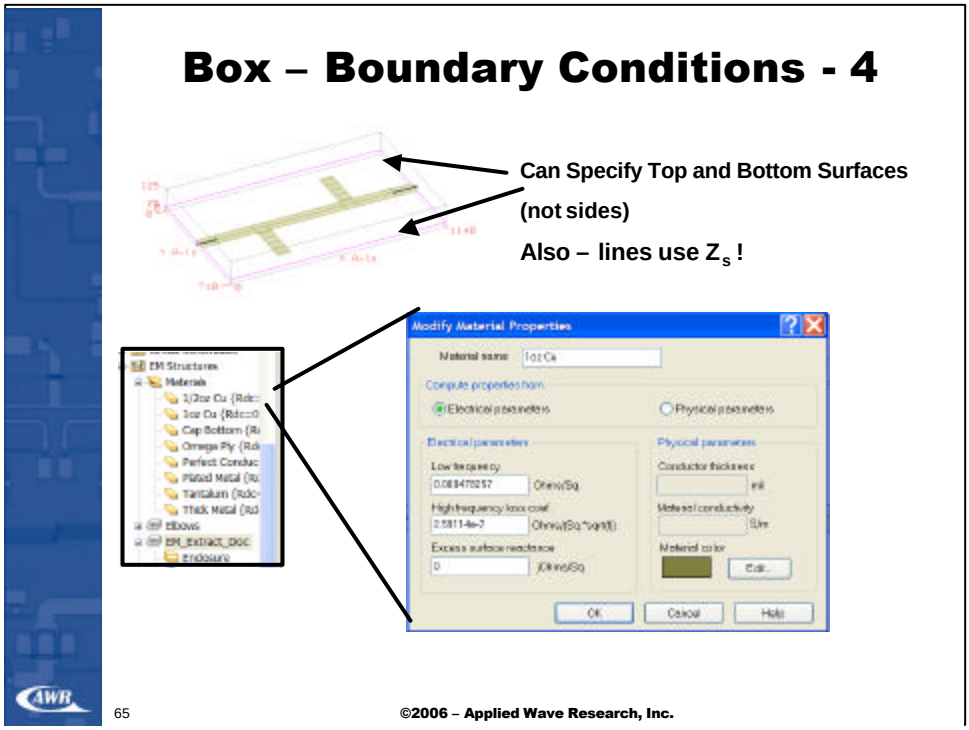
$d_s = v2/(? \mu s)$, where µ is the permeability in H/m. The other parameters are defined in the previous slide.



We are trying to solve the fields in the interior of the box. We can replace the conducting wall by an impedance boundary condition at the edge of the metal. The surface impedance, Z_S, is defined in the slide. So long as the conductor is a "good" conductor, the solution in the interior of the box is almost the same as when we had the non-zero thickness conductor. This is of tremendous computational advantage as we don't have to solve in the conducting region. It has been replaced by a surface.

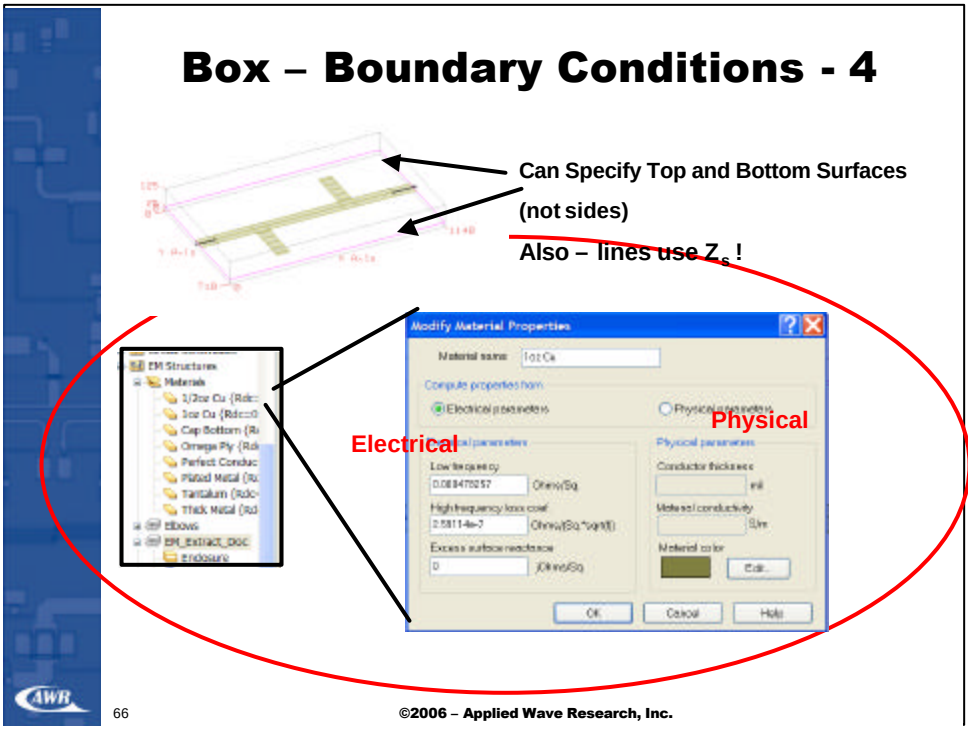
This is how EMSight works with lossy conducting lines. They become infinitely thin, impedance boundary conditions. So long as the skin depth approximation is valid, the solution will be accurate. For example, the skin depth of copper at 10 GHz is 2/3 of a micron. On a board, the line is typically at least 30 microns thick, and the approximation is more than adequate.

This method has difficulty on chips, where lines have large vertical to horizontal aspect ratios. Many lines are thicker than they are wider. Therefore, the zero thickness approximation is doubtful at best.



Materials can be entered into the EM Socket in two different ways – as electrical or physical parameters.

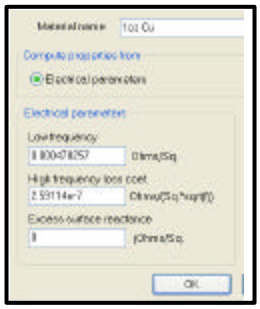
The way this is accomplished will be different in 7.0.



The materials tab in the EM Simulation Browser lists the various materials that may be used in EM simulation. The material may be specified with electrical properties or physical properties.

Box - Boundary Conditions - 5

Electrical Specifications



Low Frequency (O/sq) → R_{DC}

$Z_s = (1+j)R_{DC}$

High Frequency Loss Coeff (O/sq*sqrt(f)) → **hflc**

$Z_s = (1+j)/(s\, d_s) = (1+j)*hflc*\sqrt{f}$

$hflc = \sqrt{(p\, \mu/s)}$

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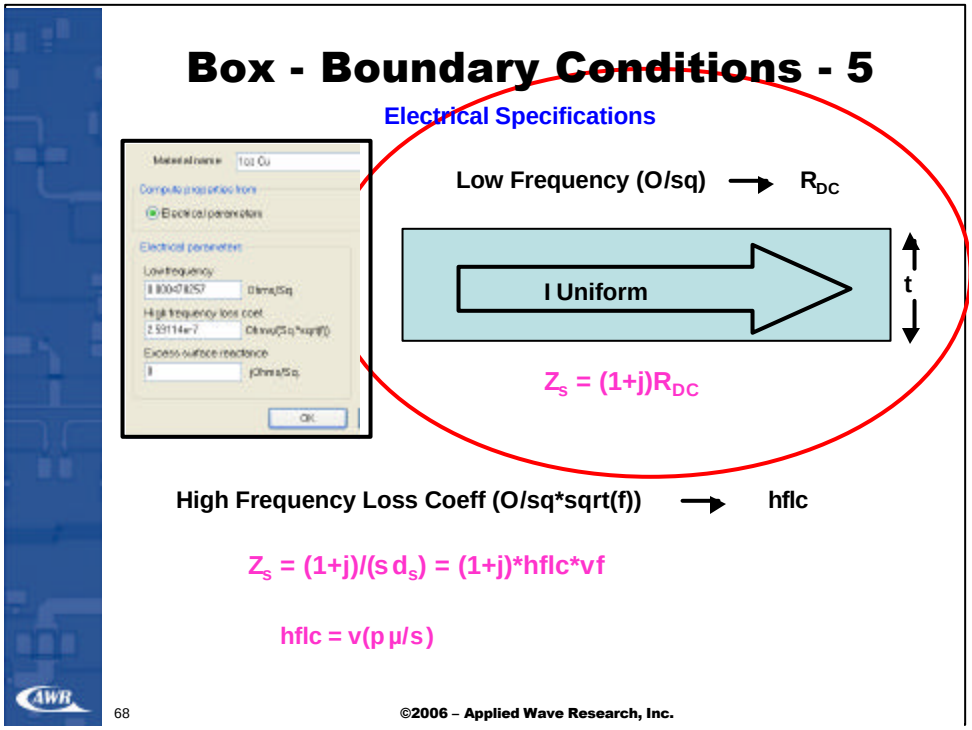
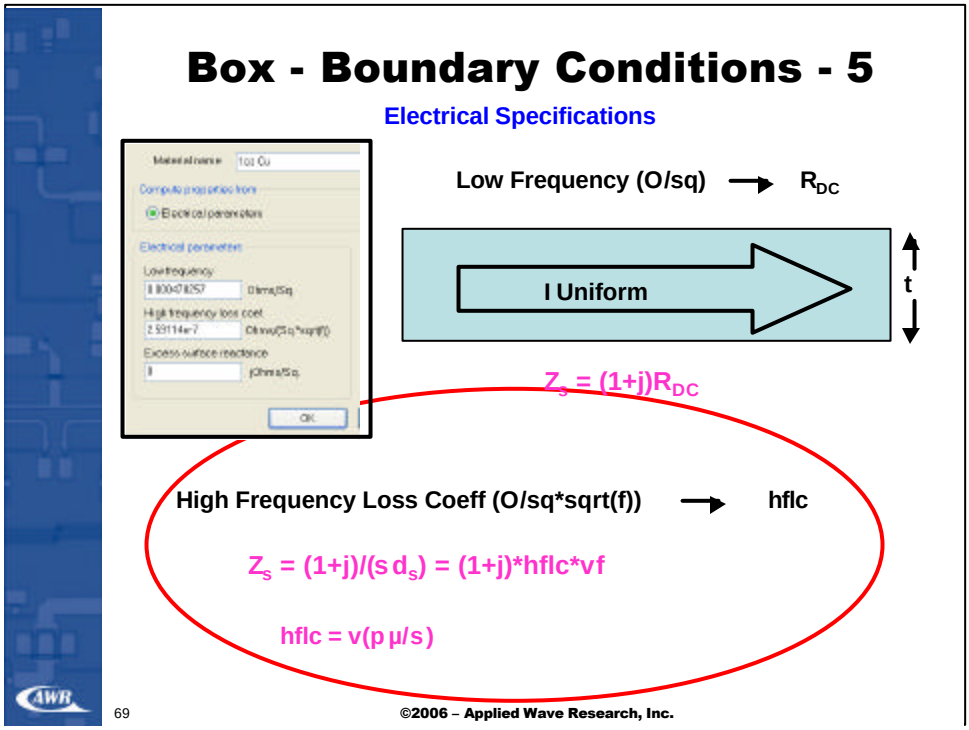
The electrical properties require a Low Frequency surface resistivity in Ohms/sq. This is the standard type of number that designers are used to when thinking of film resistors.



The DC resistivity assumption is very different than what was discussed previously with regard to skin effect and good conductors. Indeed, skin effect does not even exist at DC. Rather the current is uniformly distributed through the conductor. Mathematically, one can show the surface impedance is as shown. The designer just enters the surface resistivity in Ohms/sq which is R_{DC} in the figure.



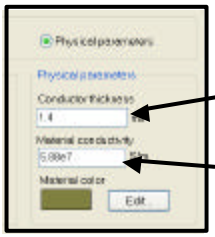
The high frequency loss relates more to what was discussed earlier. The designer enters the high frequency loss coefficient – Ohms/sq*sqrt(f). Notice that the units are not the same as the low frequency loss coefficient.

This value assumes that a well developed skin effect is taking place, and that the resistivity is increasing as the square root of frequency, because the skin depth is getting smaller as the square root of frequency.

The excessive surface reactance tab should always be left at 0. It is useful in superconducting modeling applications.

Box – Boundary Conditions - 6

Physical Specifications



Thickness

Conductivity

Low Frequency (O/sq) → R_{DC}

$R_{DC} = 1/(s*\text{thickness})$

Skin Depth: $d_s = v2/(?\,\mu\, s\,)$

Switch when d_s ~ t

High Frequency

$Z_s = (1+j)/(s\, d_s)$

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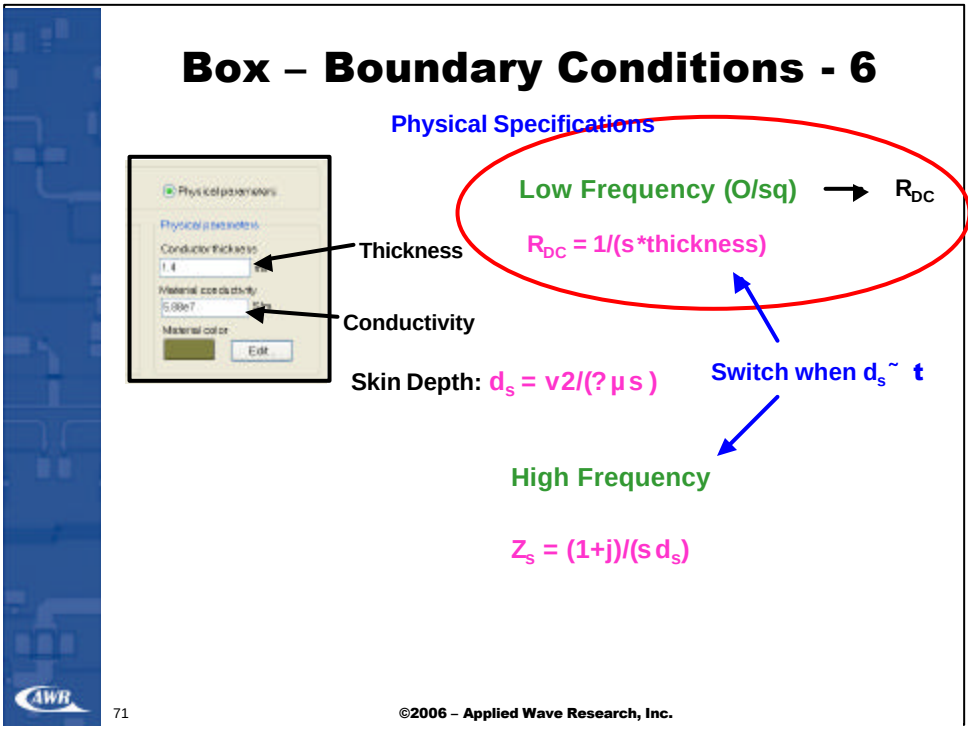
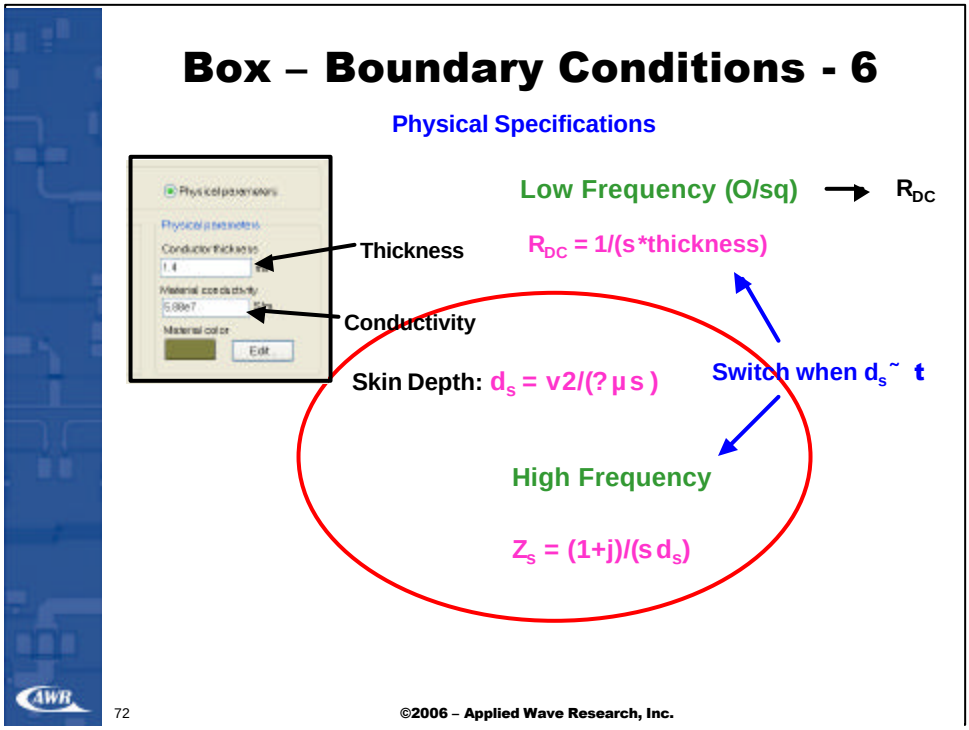
The conductor can be specified in the alternative manner, by using physical specifications. The thickness and conductivity are input.



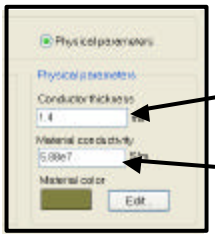
The electrical parameters can now be derived, where the DC resistivity is given by the circled formula.



The high frequency loss coefficient is determined by the following formula.

Box – Boundary Conditions - 6

Physical Specifications



Thickness

Conductivity

Low Frequency (O/sq) → R_{DC}

$R_{DC} = 1/(s*thickness)$

Skin Depth: $d_s = v2/(?\mu s)$

Switch when d_s~ t

High Frequency

$Z_s = (1+j)/(s\, d_s)$

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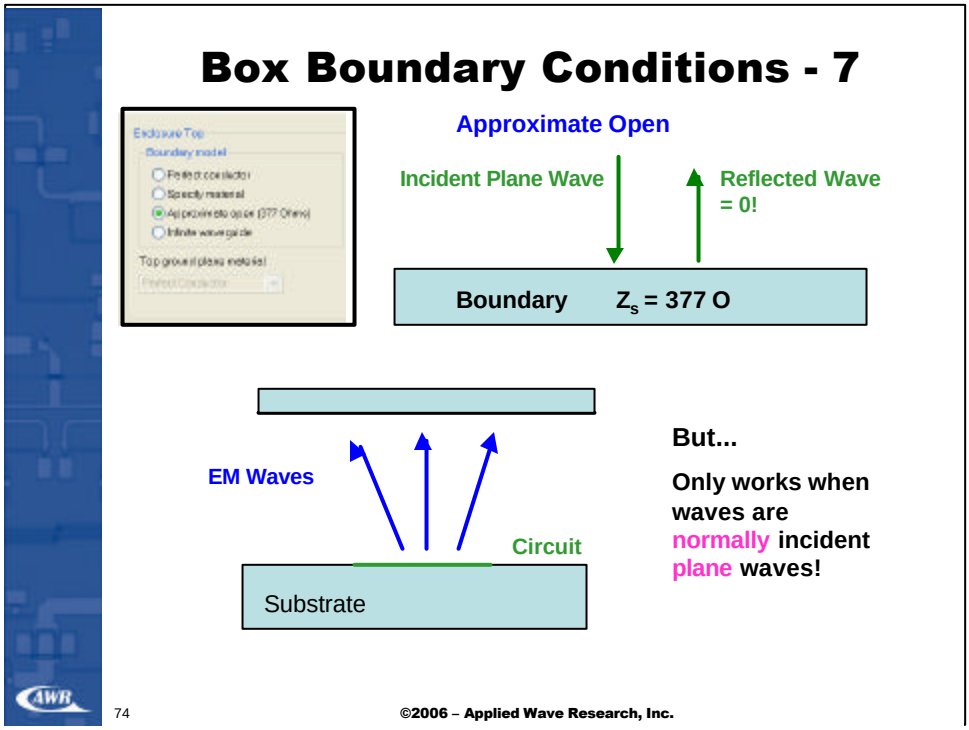
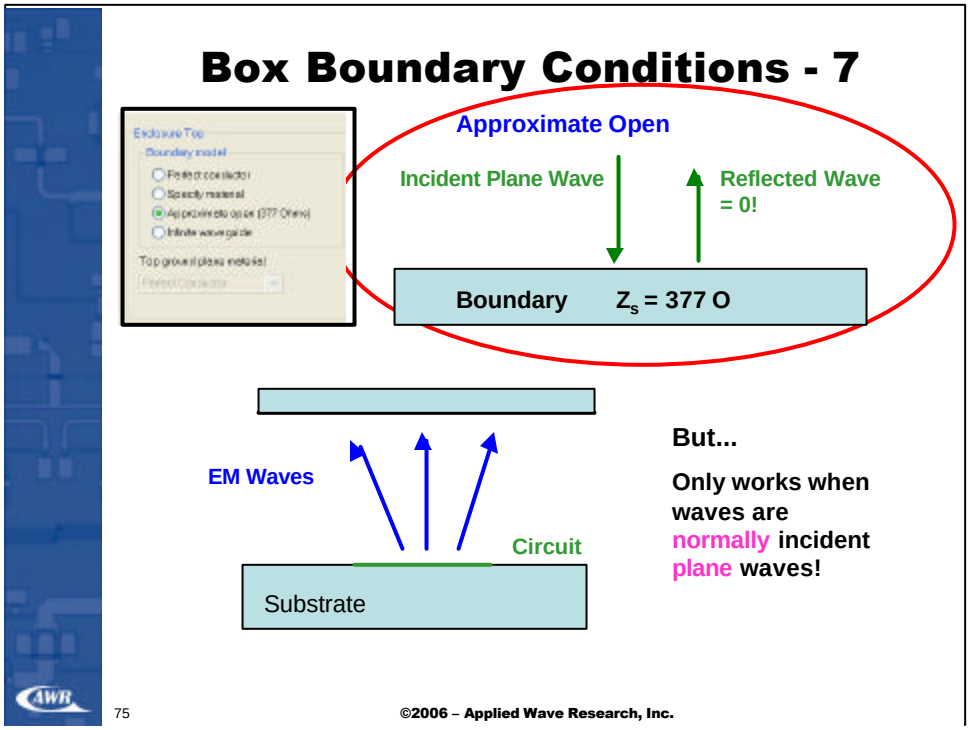
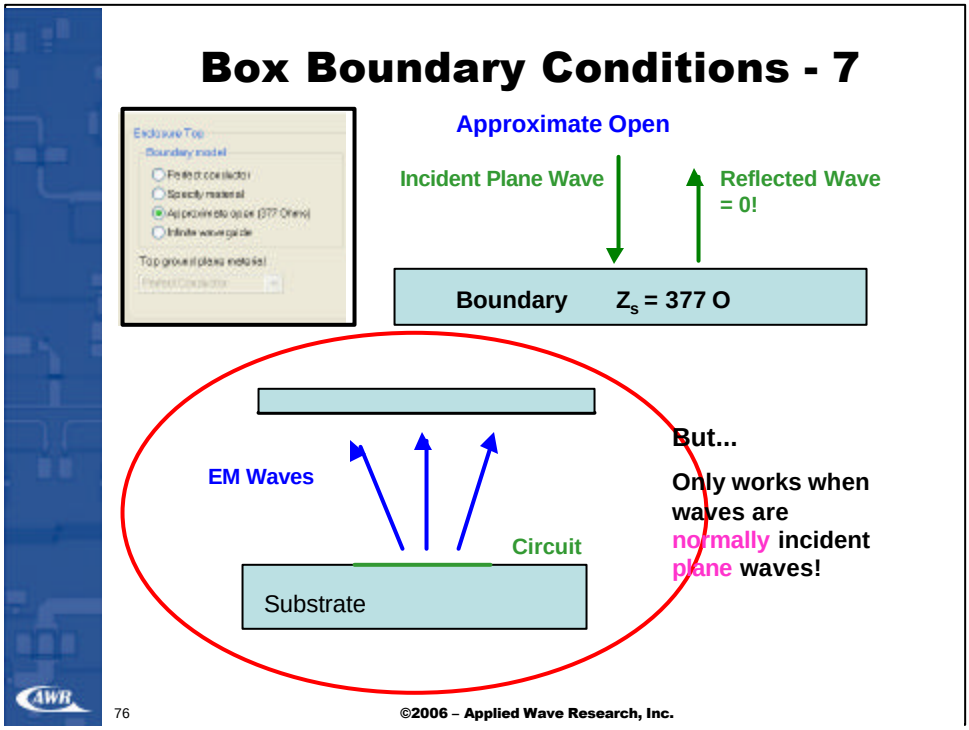
When does the simulator switch from the low frequency to the high frequency value of resistivity. When the skin depth is equal to the thickness of the conductor, the switch is made.



There is one more important category of impedance boundary condition to consider – the approximate open. The physics behind this boundary condition is completely different than the previous use of impedance boundary conditions for good conductors.



The approximation is based on the following observation. If a plane wave in free space (vacuum) is normally incident on a resistive surface with surface impedance of 377 Ohms/sq, there will be no wave reflected. Notice that this has nothing to do with a good conductor – mathematically, it is equivalent to a surface resistor.



Therefore, making the top of the box an approximate open, should make the box look like the top of the box is off – as no waves reflect.

This approximation is typically used in patch antenna problems.

The problem is that the approximation is only exact for normally incident, plane waves. As the box top is moved closer to the antenna, this approximation is more and more suspect. The waves are not normally incident, and they are not planar. Rather you eventually end up in the near field of the antenna.

Despite this difficulty, useful results can be obtained. Another use of the approximation is as a resonance killer. In the previous box resonance example, I killed all the box resonances when I made the top of the box an approximate open. This is the simulation equivalent of adding absorber to the top of a box to kill a resonance.