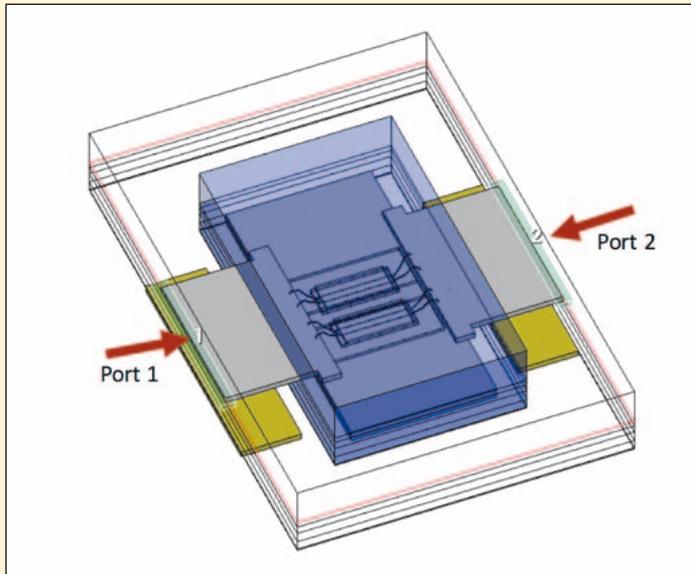
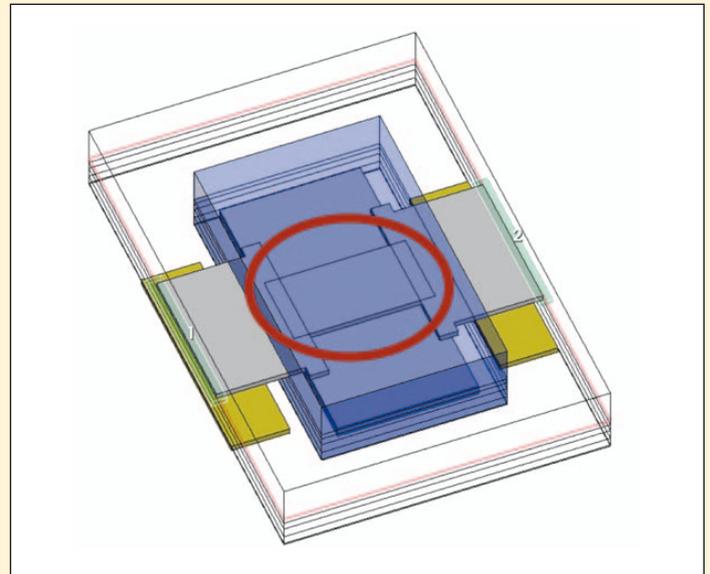


# Five tips for successful 3D electromagnetic simulation



**Figure 1:** The geometry of the problem under study with filter chips placed in a module. The customer needed to characterize the signal path between Ports 1 and 2



**Figure 2:** Simplifying the problem by removing the chip completely and shorting the two signal tabs together by means of a simple conducting plate, circled in the figure

This application example documents the steps taken to help a customer resolve a complex EM Simulation problem in Analyst 3D finite element method simulator within NI AWR Design Environment. The customer was developing a module design for a filter on a chip and needed to understand the RF signal path. The following five tips were developed in order to help this customer and other Analyst users more easily diagnose and successfully overcome EM simulation issues and understand how to analyze a 3D module simulation that is providing confusing results.

**Tip 1:** Simplify the geometry – whenever possible

**Tip 2:** Check that the S-parameters make physical sense – including connectivity, passivity, and energy conservation

**Tip 3:** Check the wave ports and modes - count the transverse EM (TEM) modes in wave ports

**Tip 4:** Trace the return paths – follow the currents when analyzing S-parameters

**Tip 5:** Understand boundaries – what is being used and why

## Tip 1: Simplify the Geometry

### Geometry Under Study

The module contained two filter chips attached to signal tabs by means of bond wires. The customer was interested in characterizing the signal path between Ports 1 and 2, as shown in Figure 1. The signal went onto the module at Port 1, along the connecting tab, down the bond wires, along the microstrip lines on the two chips, and then up the bond wires on the other side of the chips and out of Port 2. In the real structure, the filter was of course more complicated than a simple microstrip line, however, it was simplified for this application example to make sure the issues weren't because of the filter. The simpler the geometry, simulation settings, and other factors can be made while still being able to see the problem, the better the chance will be of actually understanding and solving it. As an example, the

chip was completely taken out of the problem at one point in this study, as shown in Figure 2. Since the result was about the same behavior, it was concluded that the problem was not in the chip filter.

### Conflicting Results

The customer's concern was the unexpected S-parameters produced by Analyst, shown in Figure 3. It would be expected that S21 would look like a through line, as the signal path basically went from one port to the other. The magnitude of S21 in dB is the blue curve. Rather than being about 0 dB over DC to 6 GHz, as expected, it was down at about 6.6 dB at DC, and got worse with increasing frequency. The customer had left a number of series capacitors in the circuit and so had a harder time seeing the issue, as S21 will go to 0 at DC in that case. Once again, when in doubt, simplify. The magnitude of S21 for the simpler structure shown in Figure 2 is also graphed in Figure 3 as the pink trace called Super Simplified. Notice it has

*AWR  
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Dr. John Dunn,  
AWR Group,  
for his contributions  
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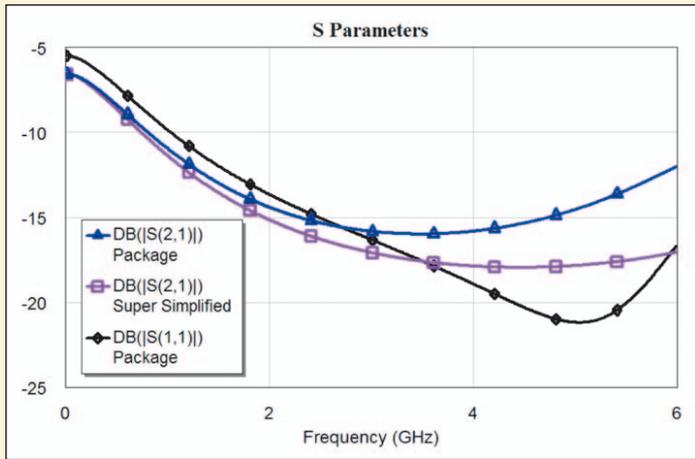


Figure 3: S-parameters for the structure in Figure 1. The S-parameters were not what was expected

about the same behavior as the structure with the chips in it in Figure 1. The chips were not the problem.

**Tip 2: Check That the S-Parameters Make Physical Sense**

First, three preliminary standard tests were run that are done with most Analyst projects: connectivity, passivity, and energy conservation. These tests are easy to carry out and often yield some interesting insights.

**Connectivity**

The connectivity test in Analyst indicates if the structure is connected properly, which can save a significant amount of time. Since this circuit returned simulation results with the return loss (S11) much higher than expected, it was immediately suspected that something was hooked up incorrectly. However, the return loss did not indicate an open circuit (it would be infinite). Still, the test was easy to run and might shed some light on the problem. The simplest way to check DC connectivity is to use the mesh connectivity checker in Analyst. Clicking the connectivity icon in the 3D view of the geometry shows a color coded view of the mesh that touches any metal. The same color indicates the shapes are electrically connected at DC. Figure 4 shows the results. At first glance, all seemed in order. Ports 1 and

2 were connected to the bond wires through the connecting tabs. Nothing was shorting to the copper block, which supports the structure. This figure will be revisited later in this example, when other issues are addressed.

**Passivity**

Next, a passivity check was run on the S-parameter data, as shown in Figure 5. The passivity measurement is located in Analyst under Linear Measurements and can be used on any S-parameter data. It also works on measured data from a network analyzer. The measurement checks to see if the data is passive; for example, to see if it is creating energy. S-parameter data should be passive, unless it is an active structure such as a linear amplifier. A positive number shows that the data is passive; negative numbers indicate non-passivity and potential problems. Figure 5 indicates this data was indeed passive, as would be expected, so there were no problems with the data. If it had been non-passive, it could throw into question the validity of the simulation.

**Energy Conservation**

The final check was to look at the energy balance in the S-parameters. Users should always look at this test after passivity. If the passivity test fails badly, there is no physical significance to the S-parameters and the energy measurement can't be interpreted

in a meaningful way. The energy measurement results are shown in Figure 6. The measurement is called Summation of Power in Network (SUMPWR) and is located under Linear Measurements. SUMPWR adds up the sum of the squares of a row of the S-parameter matrix. For example, if Port 1 is excited, it shows

$$|S_{11}|^2 + |S_{21}|^2$$

Assuming that the S-parameter file is physically meaningful, this indicates how much power is absorbed in the structure. In order to understand how it works, imagine putting 1 W of power into Port 1.

Three results can occur:

- it can reflect back ( $|S_{11}|^2$ )
- it can go through the circuit ( $|S_{21}|^2$ )
- it can be absorbed into the circuit, where the assumption is that no energy is being generated, for example, by an amplifier.

The power absorbed in the circuit is therefore

$$1 - |S_{11}|^2 - |S_{21}|^2$$

How is the power absorbed? It could have conducting loss, resulting in heating, it could have dielectric loss, also resulting in heating, or it could radiate, for example when there is an antenna. It isn't possible to tell

how much of the three ways are responsible for the loss from this one measurement. The measurement SUMPWR, as shown in Figure 6, for excitation of Ports 1 and 2 respectively, therefore shows the amount of power not absorbed, that is, the amount of power reflected and transmitted. If it is 1, no power is absorbed. If it is 0, all power is absorbed. What can be expected for a physically reasonable circuit? The assumption would be that some power is absorbed and the amount of power absorbed goes up with frequency. After all, radiation and losses increase with frequency. In addition, if there was a resonance in the antenna or filter, it would be expected to see a peak in absorption at the resonance frequency. This behavior is what is shown in Figure 6. The curve goes downward with increasing frequency (increased power absorption). Figure 6 shows the results as two curves, because they can be different when different ports are excited. For this simple structure with a great deal of symmetry, about the same answer was obtained for either port excitation.

To summarize, all three standard tests – connectivity, passivity, and energy conservation – looked good and the S-parameters were obeying the laws of physics. The problem must lie elsewhere.

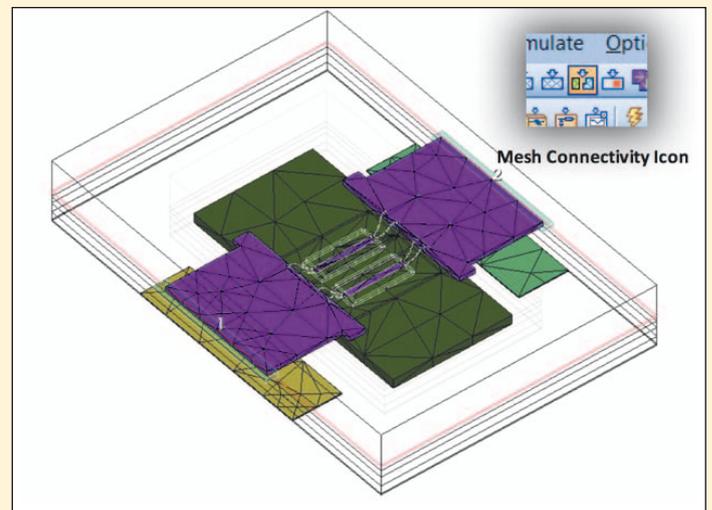
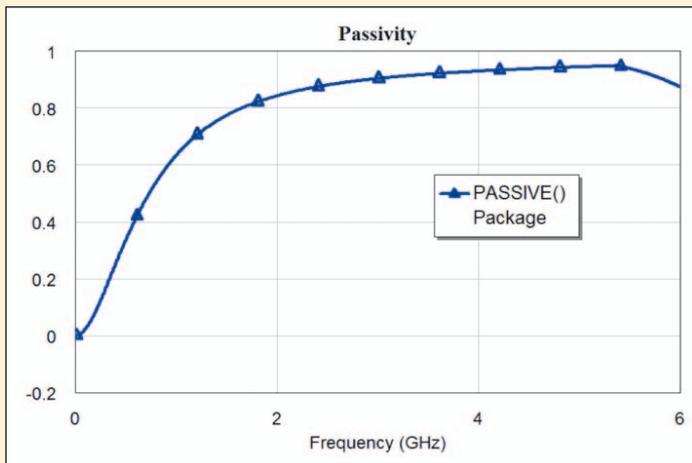


Figure 4: Clicking the mesh connectivity icon shows a color-coded view of the DC connectivity of the layout



**Figure 5:** The S-parameter data is passive according to the passivity measurement. A positive value indicates passivity, in other words, no energy is being produced

### Tip 3: Check the Wave Ports and Modes

Analyst's wave ports can be a common source of error and confusion. The next step was to look at the Analyst wave ports, Ports 1 and 2. Wave ports have a number of subtleties. There are two common issues that should be checked when examining wave ports. First, there can be more than two conductors touching the ports. Second, check the boundary conditions for the problem, especially where they touch the wave ports.

#### Wave Ports

A wave port is a type of port in Analyst in which a conducting line attaches to a simulation boundary and a port is attached. (As a technical note, the user must go in and explicitly change the port type to a wave port; the default type of port is a lumped port). Think of a wave port as the numerical version of a waveguide that is attached to the boundary, with the same cross-sectional geometry as the circuit. For example, looking at Port 1 in Figure 1, imagine the cross-sectional geometry of conductors and dielectrics extending backwards unchanged for a very long distance, which is shown in Figure 7. The port is excited by injecting power into the waveguide mode. Analyst then determines how much is reflected back to the port and

transmitted to other ports, thereby obtaining the S-parameters. The de-embedding arrow coming out of Port 1 in Figure 7 will be explained in a moment.

The trick is to get the waveguide mode, which is an electromagnetic concept in which the wave going down the line has a characteristic cross-sectional field pattern. Different modes have different field distributions, for example, the classic microstrip mode in this example has the fields concentrated between the line and the ground plane beneath it. Analyst solves for this mode by meshing up the boundary with the port on it and then seeing what modes are supported. Mathematically, Analyst solves for the eigenvalues of the matrix, which results from meshing the port. Each eigenvalue represents a mode—Analyst then sorts the eigenvalues. In a real waveguide there are an infinite number of modes; in the numerical solution there are a large but finite number, but in this example only the quasi-TEM set of modes was used.

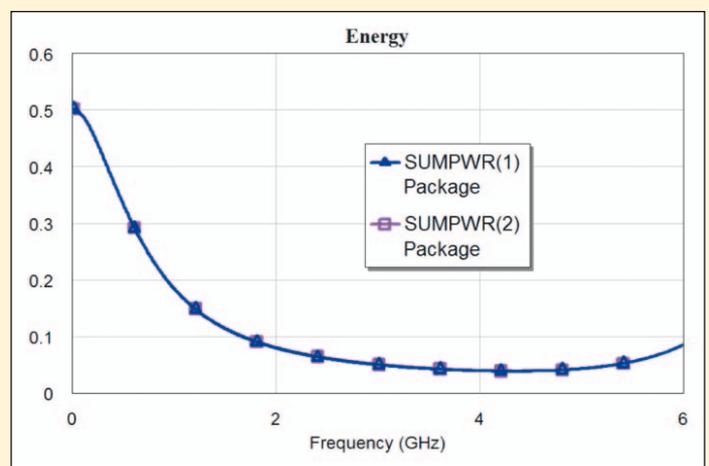
A TEM mode is a very special type of mode, in which the wave going down the guide has only a negligible electric or magnetic field in the direction of propagation. These modes have very nice properties and this example concentrates on two of them. First, the currents going down the signal line are equal and opposite

to the returning currents on the ground conductors. Second, the voltage can be uniquely defined across the waveguide's cross section; in other words, regardless of what path is taken from Point A to Point B along the conductors, the same voltage drop will occur. These two properties are not true in general for modes in a waveguide. For example, in a hollow metal waveguide commonly used in power radar systems, voltage is not uniquely defined and therefore not used very much. These two properties of quasi-TEM modes sound like circuit theory: current in equals current out and voltage can be defined. As a matter of fact, circuit theory comes from these equations. The prefix "quasi" is used with TEM mode in this example to mean close enough to a TEM mode that voltage and circuit can still be used like concepts in describing the mode and will be sufficient for practical engineering work. The quintessential example of a quasi-TEM mode is a microstrip line. The only way to make it a true TEM mode is to have an air substrate, which usually isn't the case.

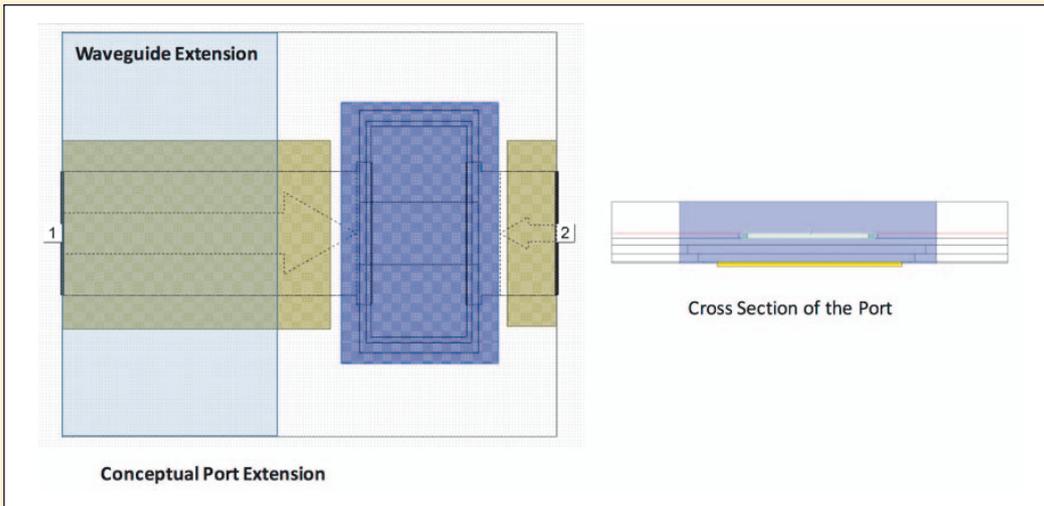
The critical point is that Analyst, when used in NI AWR Design Environment, specifically Microwave Office circuit design software, can only work with quasi-TEM modes. While this may seem like a severe restriction, it must be remembered that this

is the entire basis of any circuit simulator. Without quasi-TEM modes, it isn't possible to talk about current and voltage laws very well. (It should be noted that it is possible to study non-TEM modes in Analyst, but only through the standalone 3D editor. A separate license for Analyst MP is also needed.) How many quasi-TEM modes does Analyst need to calculate? It depends on the port's geometry, in particular the number of conductors. If the number of conductors in the port are taken and one is subtracted, the result is the number of quasi-TEM modes that are supported by the geometry. For the port under discussion, the cross section of Port 1, shown on the right side of Figure 7, has metal conductors at the signal line labelled (1) and the metal plate at the bottom of the dielectric. The boundary conditions around the edge of the port are all approximate open. Consequently, the total number of conductors is two and one quasi-TEM mode is supported. Analyst should have no trouble finding the right mode for this problem.

Sometimes, things are not so straightforward. There can be other pieces of metal that intersect the port. For example, in Figure 8 the geometry has been modified by adding two side grounds to the launch at Port 1. The left side of the figure shows the two pieces of metal, which



**Figure 6:** Checking the energy absorption for the S-parameter file, the expected behavior of more energy being absorbed (curves going downward) with frequency can be seen



**Figure 7: The wave port can be conceptually thought of as a waveguide attached to the boundary and excited in a quasi-TEM mode**

then are attached to the bottom ground tab by two vias. The left picture shows the DC connectivity, and it can be seen they are grounded. The problem is that Analyst does not know that the two side pieces of metal are grounded when it calculates the modes at Port 1. The right side of the figure shows the geometry at the port. Since the two pieces of metal are not attached in the port plane, there are three quasi-TEM modes. This follows from the fact that there are four conductors: the signal line, the two side pieces of metal, and the bottom conducting plate. Analyst will then excite some combination of the three modes when it calculates the S-parameters for Port 1. Often, the final choices are correct, but the possibility of incorrect results is increased. This situation is usually resolved by making sure there are vias right at the port. Analyst will then see the side grounds connected to the bottom conductor and thereby correctly calculate the only quasi-TEM mode.

The most common place where this can occur is a stripline or coplanar line geometry. In V13 of Microwave Office, Analyst now supports the ability to make the port's extent smaller than the entire boundary wall. This feature can be used to ensure the port only includes the conductors needed to obtain the correct mode. It is important to check

the boundary conditions at the port. If they are conductors, they count as metal in the mode calculations. The problem under consideration has all boundaries defined as open boundary conditions; in other words, they are not conductors. Therefore, there is not an issue. But, for example, if the top and bottom boundaries were conducting, as in a stripline situation, it would be necessary to add two conductors when calculating the modes.

**Check the Modes**

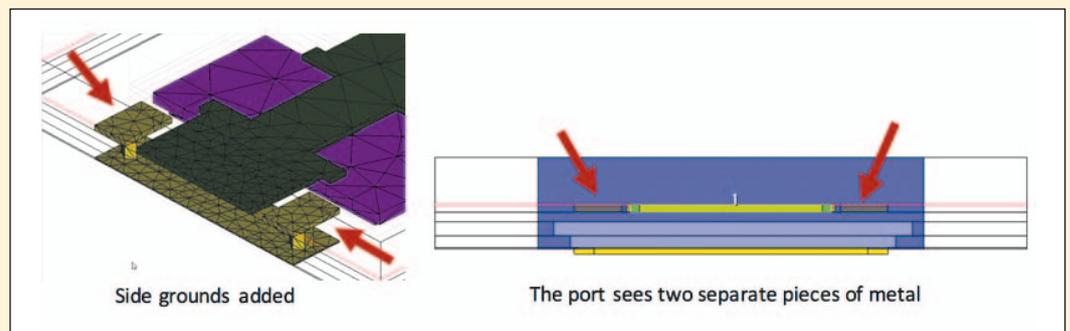
It is a good practice to look at two measurements when trying to decide if a wave port is behaving correctly. First, examine the modal impedance,  $Z_{in}$ , as shown in Figure 9. This measurement resides under the measurement category, Electromagnetic, and is called  $Z_{in}$  Port. It calculates the

impedance of the mode used by the given port. This is not to be confused with the measurement called  $Z_{in}$ , located under the measurement category Linear. That measurement essentially looks at the reflection coefficient and calculates the equivalent load impedance.

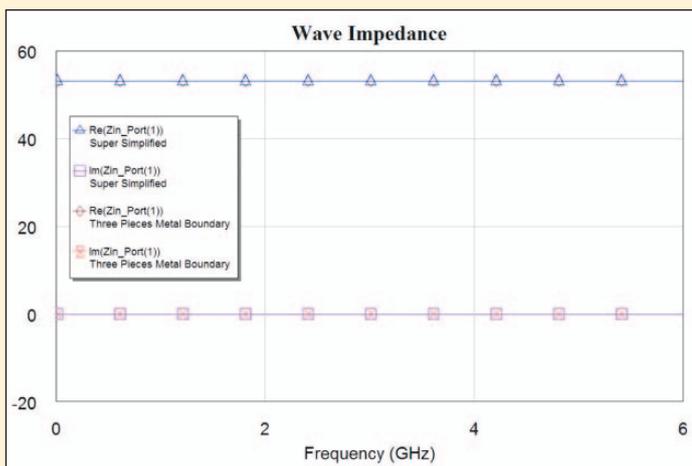
The modal impedance is a complex number, so both the real and imaginary parts have been plotted on a rectangular graph. The graph in Figure 9 shows the modal impedance for Port 1 of the geometry shown in Figure 7. The results shown in Figure 9 are good for two reasons. First, the imaginary part of the modal impedance is zero. For a TEM mode, with no lossy materials or dielectrics, it should be identically zero. For quasi-TEM modes, it should be a small num-

ber. If a significant imaginary part to the modal impedance is seen, it should be suspected that there is a bad mode calculation, unless of course the geometry has a highly lossy metal or dielectric. Second, the real part isn't varying with frequency very much, which is called dispersion. The modal impedance will not be dispersive for a TEM mode with lossless materials. For a quasi-TEM mode, it should be slightly dispersive. Again, if highly dispersive behavior is seen, it is important to know why.

In a highly lossy material, for example, the actual value of the impedance, about 54 ohms, agrees reasonably well with simple approximations, where a microstrip line with ground plane below is assumed. Look to see what the TX-LINE, the transmission line calculator in Microwave Office, gives for an answer. Figure 10 shows that TX-LINE gives an impedance of 54.8 ohms for a microstrip line with an air substrate and a line width of 200 mils. This is in close agreement with the Analyst calculation of about 54 ohms. (Agreement within an ohm of line impedance calculations and approximate formulae is usually considered adequate for normal engineering designs.) In contrast, the geometry in Figure 8 had problems when the modal properties were simulated. The calculation for the model solve should converge quickly, less than a minute. This was the case for the ports in the original structure. For the port in Figure 8, the software took several minutes to



**Figure 8: The left figure shows a modified geometry where the feed for Port 1 has two side grounds attached to the bottom ground plate by vias. The right figure shows the port geometry with the extra side conductors**



**Figure 9:** The modal impedance is the same for the two different geometries shown in Figures 7 and 8. The Super Simplified is for the original structure, shown on the left in Figure 8. The Three Pieces Metal Boundary is the modified project, which is shown in the right picture of Figure 8

get an answer. This is an indication that Analyst is having difficulty deciding on the right TEM mode. Again, the problem is that the port solver does not know that the side metal is grounded. The final answer does have a port impedance that agrees with the simpler one line case, as shown in Figure 9.

Analyst users are sometimes confused by the port impedances of the S-parameters generated. S-parameters created by Analyst are automatically renormalized to 50 ohms. A wave impedance of 54 ohms at Port 1 is shown in Figure 9. But this is not the normalization of the S-parameters that are shown in Figure 3. If the normalization of the S-parameters needs to be changed, place the S-parameter data in a schematic as a sub-circuit, attach ports, and then change their port impedances to the desired values, for example 75 ohms. When the S-parameters are plotted using the schematic as the data source, they will be normalized to the new port impedance values. This is also true of a Smith chart, where the normalization of the chart is the same as the port that is being measured. So, for example, the Smith chart will show  $S_{11}$  normalized to 75 ohms if Port 1 is 75 ohms in the schematic.

Figure 11 shows the other measurement, the propagation constant, which is often used if the user is worried about modes behaving correctly. The propagation constant is found in the measurements under Electromagnetic and is called K\_Port. This measurement shows the real and imaginary parts of the wavenumber. Any wave propagates in the z direction according to:  $\exp(-z)$ . The wavenumber is complex. The measurement refers to the complex number K, which is sometimes used by the physics community. Figure 11 shows both the propagation constant (real part of K) and the attenuation constant (imaginary part of K).

The results are exactly what would be expected. The attenuation is 0, as the mode is propagating, and there are no lossy frequencies in the normal way. The measurement for the three-conductor case is also shown in Figure 8. The two cases give the same answer, indicating that Analyst has converged to the right mode for the more complicated three-conductor case.

#### Tip 4: Trace the Return Paths

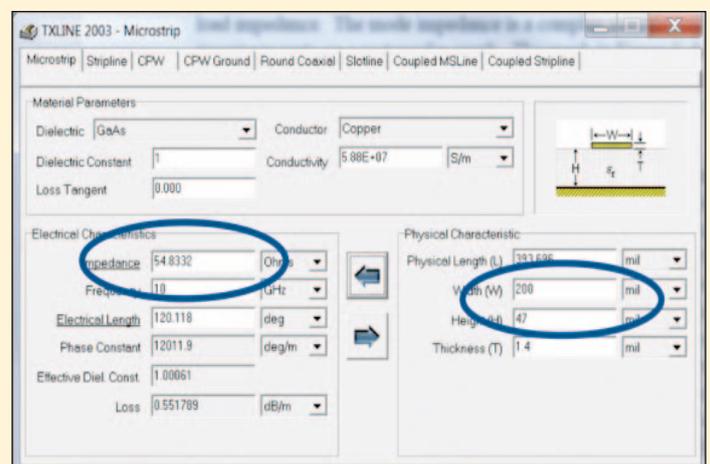
The return loss was perplexing. It would be expected that the signal to go from Port 1 to 2 with almost no reflection, especially

at lower frequencies. Why was this not the case? It was decided to try investigating the return current path for Port 1. As previously discussed, there was a quasi-TEM mode, where circuit theory should locally be valid. For any mode of this type, the current coming out of the port must return on the neighboring conductors. Indeed, this is the way to find the local ground of any port. One of the first things to try when there is a return loss that is not understood is to trace the current through the circuit. It must make a complete circuit. Looking again at Figure 4, the current leaves Port 1 and travels along the metal to Port 2. This is the point of the colors in the annotation. The purple color shows the metal is connected, which is good. Next the return current is traced. The current comes back into the circuit on the teal blue strip at the bottom of Port 2. If there is a concern that Port 2 doesn't have a connection between the top conductor, the dark green one, and the bottom conductor, the teal blue one, remember it is a mode at Port 2. For purposes of this application example, the port can be imagined as a current source connecting the two conductors. This comes out of the physics of the quasi-TEM mode: the current must get back to the green conductor on the bottom of Port 1. Now there is a problem - there is

no conductive path between the two bottom conductors.

#### Tip 5: Understand Boundaries

Why isn't it an open circuit? The logical assumption is that it can't be an open circuit - the magnitude of  $S_{11}$  would be 1. So, how did the current get back to Port 1 if there was no metal connecting the two port grounds? There is only one way it could be occurring: the boundary conditions need to be examined more carefully. In this example all the boundaries of the bounding box were set to approximate open. It is important to understand what that means. Boundary conditions in Analyst set a relation between the electric and magnetic fields on a surface. The relationship between the two is called an impedance boundary condition. Any meshes that touch this boundary are required to satisfy the boundary condition. The simplest example of a boundary condition is for a perfect conductor, where the part of the electric field tangential (parallel) to the surface must be zero. Indeed, this is the electromagnetic definition of a perfect conductor. Equally simple mathematically is a perfect open boundary condition, where the tangential part of the magnetic field to the surface is zero. Physically, this means no current can flow on that surface, as current is proportional to the



**Figure 10:** TXLine calculates the impedance of quasi-TEM modes for common line geometries. The predicted impedance is 54.8 ohms

tangential part of the magnetic field. The two boundary conditions will be used later in the example to illustrate the concept.

What is the approximate open boundary condition? It is an impedance boundary condition that makes the surface look like a  $377 \Omega^2$  resistive surface. Conceptually, it can be thought of like a lossy absorber made of, for example, carbon.  $377 \Omega^2$  is a magic number. If a plane wave in air (or vacuum) is hit a  $377 \Omega^2$  surface, nothing comes back because the wave is completely absorbed. If the bounding box surfaces are made of such a material, the objects inside don't see the walls of the box. It appears as if the box isn't there. In other words, this boundary condition can be used to make it appear the structure is in an infinitely big box, which is good. After all, the bounding box only exists because Analyst can't mesh out to infinity. There are, however, limitations. First, there is no reflection only if the wave has two important properties: it must be a plane wave, and it must be normally incident. Plane waves are not generated in real structures. For example, with a patch antenna, the fields near the antenna are far from a plane wave. It is only when the user gets very far away from the antenna that they look locally like a plane wave, and this would lead to making a very large box.

The user compromises and hopes the walls are far enough away to give a reasonably small reflection. Second, the waves will not be normally incident. Indeed, as the waves deviate more and more from normally incident, the reflection from the surface gets larger and larger. Eventually, at grazing incidence, the waves will completely reflect. Incidentally, because of this limitation, there are much fancier absorbing boundary conditions that can be used. For example, Analyst has a boundary condition option called perfectly matched layer (PML). It works by creating a number of very thin layers on the boundary, like the layers of an onion. It gives much lower reflections for waves that are not plane and not normally incident. But, it adds a lot of meshes to the problem, as Analyst has to mesh up the thin layers. Therefore, it is recommended that PML not be used except for antenna problems, where accurate calculation of the radiated field is critical. Normally, the approximate open boundary condition is good enough if judiciously used.

In this example, the current was returning along the approximate open boundary. The user thought of it as a perfect absorber, but it wasn't. The current will try to get back along the path of least resistance, or more correctly, least impedance. As lossy as it was, the resistive boundary was

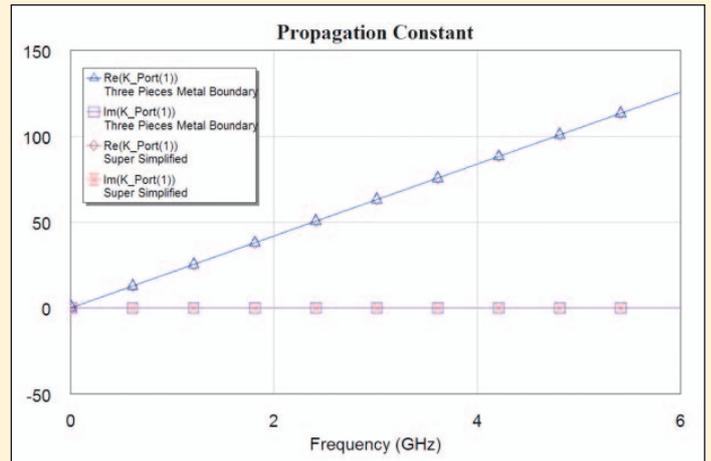


Figure 11: The propagation (real part of K) and attenuation (imaginary part of K) constants for the mode

the only way for the current to return. The boundary looked like a sheet resistance, which increased the equivalent load impedance that Port 1 sees. Thinking back to Figure 3, the return loss was about 6.6 dB at low frequency because the approximate open boundary condition giving a atypical, lossy connection between the two ports. How is the hypothesis checked? First, change the boundary condition on the bottom boundary to a perfect conductor. (If wanted, it could be set to a good conductor, like copper, which will return the same answer.) Figure 12 shows the result. The curve labeled Conducting Bottom Boundary shows the results when the bottom boundary is made a perfect electric conductor. The magnitude of S21 is 1 (0 dB) at DC, as expected. There is now a complete conducting path for the current. Changing the boundaries to perfect opens or perfect magnetic conductors was also tried. As seen in Figure 12, the magnetic conductor boundaries curve shows the S21 is 0 at DC (negative infinity dB). The wave is completely reflected.

**Mystery is Solved**

Now it can be seen that the problem was that there was no ground return. It was difficult to find because of the approximate open boundary condition. The current was forced to return along this boundary condition,

which can be thought of as lossy material. Therefore, a perfect reflection at Port 1 couldn't be seen, which would be the case if the boundary was a perfect open. The lesson learned here is to always think of the current return when analyzing a circuit. It can give unexpected results.

This example finishes with a class of problem that can exhibit this current return on the boundary issue and can be confusing.

**Isolation Studies**

Modern electrical circuitry requires that the various parts of the system be isolated from one another. Signal integrity engineers use electromagnetic simulations to predict the coupling levels between various blocks of the circuitry. Typically, a simplified version of the layout is used, where an open stub is excited at Port 1 in the first block and the received signal is examined at the second block with another open stub attached to a second port. The stub geometries and locations are chosen to model a typical signal path in the two blocks. The coupling between the elements is affected by the surrounding circuitry and the housing the circuit containing the circuits. For example, if the circuits are in a metal package, the coupling between the various parts of the circuit can increase dramatically at package resonances. The point is that the boundary conditions used in the simu-

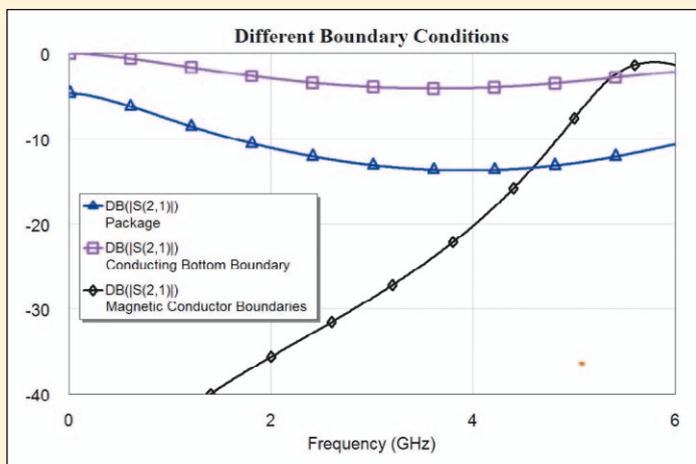
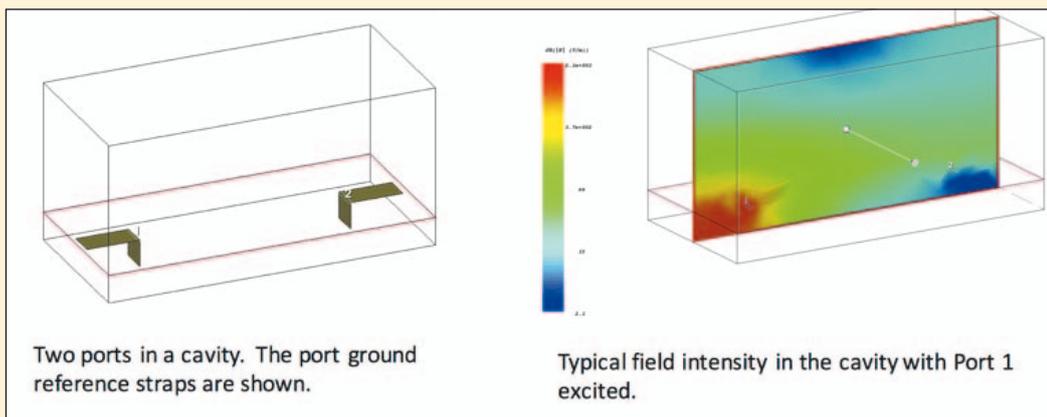
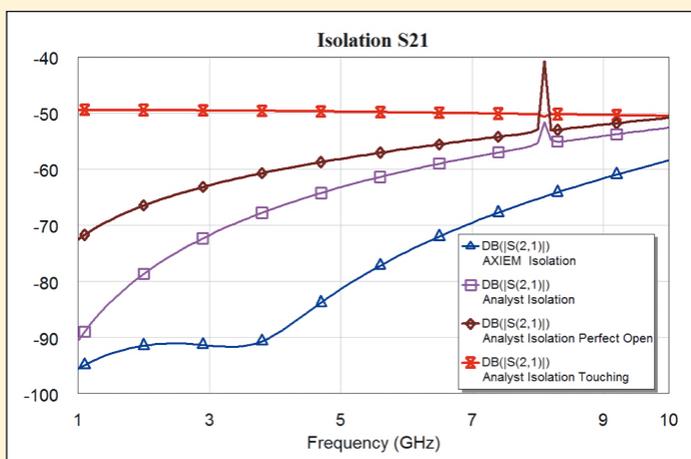


Figure 12: The magnitude of S21 is 1 (0 dB) when a ground plane is included. A perfect magnetic conducting boundary results in S11 = 1 at DC (-150 dB)



**Figure 13:** The left figure shows the two stubs with ports attached in Analyst. The ground reference straps are also shown. The right figure shows the electric field intensity for a typical simulation, where Port 1 is excited. The field is strongest near the first stub as expected



**Figure 14:** Simulation results for the two stubs. The magnitude of S21 shows the relative quality of the isolation between the sections of the circuit

lator can result in unexpected results. The boundary conditions are chosen to be “open” or radiating boundaries. The problem is this type of boundary is only an approximation to a circuit in an open environment. Since the two stubs are not electrically connected, the degree of isolation can be greatly influenced by the boundary condition chosen. These concepts are illustrated with the following simple example.

Figure 13 shows the geometry being studied. Two microstrip stubs are placed on a printed circuit board (PCB) with conducting ground plane. The board was 0.5 mm thick Teflon. The structures are simulated from 1-10 GHz. The stubs have a port on one of their ends and the other

end is left open. The width of the stubs is 0.5 mm, their length is 1.0 mm, and they are separated by 5.9 mm. The magnitude of S21, the insertion loss, is studied. Ideally, if the two stubs are well isolated, S21 should be very low. The right picture in Figure 13 shows a typical electric field strength when the stub on the left is excited. As expected, the field is strongest under the first stub, with some of the energy coupling to the other stub. Figure 14 shows the magnitude of S21 when different boundary conditions are used for Analyst.

The results for AXIEM planar EM simulator have also been included. AXIEM has no simulation boundary, rather, the board extends to infinity, as does the air region above the board. The

AXIEM results (blue curve) show the highest isolation, as might be expected. The next best isolation is the purple curve, which is Analyst using side and top boundaries of approximate open, in other words, the 377 ohm/square boundary condition discussed earlier in this example. The Analyst boundary is a box 6.0 x 2.9 mm and 5.0 mm in height. The left and right edges of the box are 0.1 mm from the ends of the stub, as shown in the left picture of Figure 13. There is a box resonance at about 8.1 GHz. This type of resonance occurs when a simulation box dimension, here the long horizontal direction, is a multiple of half a wavelength. The brown curve is the same geometry, except magnetic walls are used on the sides and top of the box. The isolation is lower and the box resonance is higher. This occurs because the energy cannot escape the box, or more accurately, cannot be absorbed by the impedance boundary. The final red curve is when the stubs touch the ends of the box. The isolation is dramatically reduced; in this case return current is injected into the sides of the box. Remember, the boundary condition is really that of a lossy resistor and it will support current if it has to. Notice the resonance is also suppressed.

The point of this example is that designers must be aware of what type of boundary they are using if they are conducting isolation

studies in systems. Obviously, the conclusion is suspect at resonance frequencies in the simulation bounding box. An absorbing boundary condition can give a value closer to a simulation with no simulation box, but what can throw designers off is that current gets launched onto the boundary. How can this be resolved? Try different boundary conditions and box sizes for isolation studies. Be extra careful to appreciate that the approximate open boundary might actually be giving a sneak path for the return current and giving a spurious isolation value.

## Conclusion

This application example has provided five best practices for diagnosing and resolving an Analyst 3D module simulation that was giving poor results. First, simplify the geometry where possible. In this case, the chip filter was removed. Keep removing parts of the geometry until the problem disappears and there will be a much better understanding of what the issue is. Second, check the S-parameters to make sure they are obeying the laws of physics:

- Connectivity
- passivity, and
- energy conservation.

If they aren't, there might well be simulation problems, for example, non-converged answers or improper grounding definitions at ports. Third, understand how the wave ports work. Users can get unexpected modes, giving strange answers. Fourth, remember the complete circuit has a return path for the current. Understand where it is going – it has just as much influence on the S-parameters as the signal path. Fifth, understand what boundary conditions are being used. They are part of the simulation and can influence the circuit. In this case, the boundary condition gave a sneak return path for the current, thereby throwing off the answers in a non-obvious way. ◀