In this presentation, we will explore the modeling of a cutting-edge plasma field traveling-wave-tube that's currently being researched by Dr. Vishant and his team as the Central Electronics Engineering Research Institute of India and answer the question, “How can I use VSim to design a model complex electron devices that involves unconventional physics, such as the plasma process? And perhaps more importantly, why do I want to choose this over other products?”

My name is Andy I completed my Ph.D. in May of 2021. That's this year, I and joined Tech-X as an applications engineer in June of 2021. My Ph.D. specialization is in vacuum electron device simulation and analysis, specifically cavity magnetrons. I also have formal education in areas listed here.

A couple of notes before we start: The TWT simulation project to be discussed here is part of Dr. Vishant’s research. Dr. Vishant is a Tech-X client, and he has generously granted limited permission for this presentation. Since this simulation is part of ongoing research that has not been published, aspects of the presentation setup and results shown in the following presentation are not optimized. Tech-X respects and protects the confidentiality of their clients and their research.

The primary focus of this presentation is to showcase VSim’s capability rather than discussing the science of the device that has been simulated. In other words, this is more of a VSim presentation rather than a TWT presentation.

The presentation is divided into five parts. First, I will show you how the geometry of the structure can be built natively in the visual composer graphical user interface. Second, I will show you how to do a mode analysis based on a single element or a single pitch of the periodic structure. Third, I will show you how to set up the input signal and the electron beam to get velocity modulation. Then I will show you I will show you how to add a plasma into the simulation and how to setup the plasma process. Finally, I will discuss why VSim is the ideal tool for doing research on a device like this.

Some basic device descriptions: This is a staggered double vein slow wave structure that is designed for the W-band or 75 to 110 gigahertz. This structure doesn't cover the entire W-band but it covers a significant portion of it-so it's a wide band structure. This geometry of this slow wave structure was originally published by Lai and others and the original publication can be found here. This figure on the slide shows a visualization of the geometry with parameters-notice that the figures are actually negatives of the actual devices. This shows a vacuum portion of the structure. So now I will show you how a geometry like this can be quickly built in the VSim composer GUI.

So, in VSim, you look in VSim under geometries, you can go to the CSG tab where will contain all the shape primitives you can use. So in this mode, you can, you can compose shape primitives, and you can do Boolean operations on these shape primitives that include union, intersection, and subtraction.

So, to build a structure like this, to build a structure like this, this structure is basically a collection of boxes that can be unioned or subtracted, and then this shape will be achieved. So to do that, I have already inputted all the parameters to save some time. So what can be done here is you start with a basic box, then you get a little box, that is the part you want to cut out, then you simply do a box one minus box two, then you'll have this shape with a notch in there. Then you'll repeat the same thing and cut out the rest. The third step, you'll have this, then you'll cut out two more sections, you'll have the complete shape. So it's really just as simple as this.

If I fill in all the other elements, you can see, we started with a basic box like this. Now I cut out a section, cut off another section, cut out two more sections, then we have our a single pitch of our periodic structure-easily done. And what if we want to have multiple periods or we want to add more periods or subtract periods? That can be simply done by right clicking on this structure and click “Create Array.” And then all you need to do is to define the spacing between each period-in this case is will be the value of the width of a single period along the axial direction-which I believe is pitch value.

So say we want to make five periods of it, then we'll have a five period structure, and you can add and subtract periods easily this way. So the geometry building is very simple for this type of, for this type of geometry. And I believe we'll have another presentation after this exclusively on geometry manipulation, so I will go as far as this for this presentation.

So now the next thing to do is mode analysis. So mode analysis can be done based on a single element. And the purpose of doing a mode analysis is to get a frequency response of the structure. So there are some very well defined steps to do this in VSim. First, you define a current source that contains multiple frequencies and add it to the simulation to excite a structure. Then a periodic boundary condition can be defined in the axial direction-that is a direction or allows the periodicity of the structure.

After that, you need to give it enough time to allow the simulation to run sufficiently long or until you sort of close for some kind of steady state, which is frequency dependent. In this case, since the frequency is very high, you don't need to rise for as long. Then what you end up with is the electric field profile that contains the mode of the structure, and this mode can be computed by using a VSim analyzer called “extractModesViaOperator”.

So I will show you how it's set up just briefly. Let's go right off of this, since we're doing a single pitch. So, here is the driving signal here which is a which is a very simple function.

So, this is the driving signal that is inserted into the simulation and the way you insert it is in current distribution: you'll define a general distributor current, and this current can be artificially inserted into the center of the, of the structure. Then, if you observe this function, you define a lower bound of the frequencies, and you'll define a higher bond of frequency, and you’ll define the frequency of Delta-that is how big you want each frequency step to be. And this function is pretty well known.

So, afterwards, when you run this simulation. Also periodic boundary conditions are in basic settings. In this case periodic direction is periodic x, which is along the axial direction. And after running the simulation, you can run the analyzer which is here, “extractModesViaOperator.” Here are the complete directions on how you can run this analyzer. And also, the contents of this analyzer is, can be found in a Python file. If you if you can read Python, you can actually go directly into the original Python file and see what's the function is actually doing. Alternatively, you can read this paper, which is published by Tech-X people to talk about how this analyzer extracts modes and why it's reliable.

So after you compute, after you run analyzer, you’ll have output like this. Usually, you’ll have a real frequency, you’ll have imaginary components, that's just a numerical thing. That's all the parameters that satisfies the algorithm. Usually, we want to select frequencies, select frequencies, real components when the imaginary component of the frequency is very small or near zero. So in this case, since we're looking at the W-band, we can clearly see there's a mode at 84 gigahertz, there's a mode around 91, around 95, around 110, around 103. So, these are the modes ,or the frequency response of the periodic structure based on a single element that can be very quickly done.

And the next thing is to show velocity modulation. So, there are several things to be done here. The first thing is we need to have an input signal into the structure and then we need to set up a wave absorber as output. So, this type of simulation whatever goes into it, has to exit it somehow or be absorbed somehow. Then we need to set up the electron beam and then we need to add an external magnetic field. And the last thing is to add some diagnostics of the quantities we want to see.

So I will show you how to do that. I will pause the screen share. So okay, let's start here. So first of all, let's explain, let me explain where we are. So we just built the geometry. In this case, I repeated the periodic structure 30 times. So there are 30 pitches. This is not the original designs, the original design has 80 pitches. But for the sake of demonstration, I'm only doing 30. But also, if you'll notice, this periodic structure is also embedded in a waveguide. So if I get rid of the structure I can see here is a waveguide.

It may be larger. We’ll add in the structure and you'll have basically built the TWT. And the reason why the tail end is much longer is because it's filled, it's going to be filled by the, by a wave absorber to absorb the output. So what do I do now?

So this is basically where there are no other settings. So everything under field dynamics, this is what you are going to have when you are just booting up a brand new VSim simulation. And here I have some history set up already. On this history is what we'll talk about-slightly later. Let's talk about, let's talk about inputs first.

Actually, let's start with the most, let’s start with the easiest thing, the easiest thing is to add the external magnetic field into the simulation. So in this case, the magnetic field direction is obviously x. So to do that, you simply go to Field Dynamics, go to field, right click on fields, add field and say external field. Designers have this default name, we can change that to Applied B.

Then, if we look at what we can put into this we can select what type of field it is. It's can be magnetic, electric, or current. But, note that whatever you put into here is applied to the entire simulation domain. You can, you can make that not the case by having masking functions on the components. But in this case, since we're having a uniform magnetic field in the x direction, all we need to deal with is component zero, and let's give it something like one tesla, and component one and two. By the way, component zero is x, component one is y two is z. And this field is not time dependent. So that's all we need to do to add the magnetic field.

But the next thing is that we need to be able to launch a wave into this input port, which is right here. So the way you do that is also very simple. The nice thing about this model is this input port is right on the lower x boundary, so to do that, and also it's a waveguide port. So to do that you add a boundary condition. Right here: fields boundary conditions, add field boundary condition and there are all of those boundary conditions that are available in this case, if you look at the very last one is a rectangular waveguide.

So let's call that RF input. On the frequency, let’s give it something artificial in the range, let's call it, just give it 100 gigahertz voltage, two volts. Start Time zero starting from the beginning stop time. Let's call it one second, which is eternity for this. On the turn on time, let's give it a half of a nanosecond. It has launched from the lower x and it's polarizing in why we Is this direction here? polarizing in why, and then you'll set up your center coordinates like where your waveguide is center. If your waveguide is off the axes, you will need to do a shift. In this case, I already already have parameters defined very conveniently so in this case is center y, center z. And if we look at what they are

center, why is the center point of this waveguide and center z is the center point in z. So, you need to tell it, what's the what's the width or the height of this opening is, which have also parameters for already but alternatively, there are a list of waveguides that's commonly used that you can choose from but if your waveguide is none of those, you can simply put in your own parameters here, and then you'll have a wave input. Easy enough. So, now let's talk about how do you put in an electron beam. The way to do that is first of all, if you look at this input screen, there is no particles here yet. And to access particle settings, you need to go through basic settings and here you'll have a list of switches. For particles currently set to no particles if we started to include particles, now you'll have this new tab called particle dynamics. In this case, for this step, we will we will add electron beam First we'll take care of the plasma part later so but electrons let's call that lectrons so now the particle is added as there are all those settings on the on particle Wait, there's Yuka you can adjust. But no, we what we want, what we really want is emitter. So electron emitter, in this case, since we're emitting from a boundary, we can do a slab settable flux.

This is a boundary emitter. If you're emitting from some geometry with even inside of the simulation domains that is not on a boundary what you'll do is a shape settable flux in this case if we're looking at what's the difference in shape settable flux your emission surface is defined by an object and in a slot it made her your emotion surface is simply a boundary so that's the difference there. So let's get rid of this. So in this case or electron beam in sintering, from the lower x boundary, which were already as x lower we can work our lives the initial offset as it is the physical offset as this. So there are there are several different measure models you can use in this case, since or so the default particle weight is set as constant weight. A euro you can do variable weight as well as pretty accurate to do variable weight but if you want to learn or something, some stuff more precisely, you can do constant weight. And we'll do variable weights you see a weight Yeah, I guess for, for slough setubal. You're you only have three choices you have emission flux, emission Current emission rate I think you'll have more choice when you're emitting from a shape. sasheer Yep. So if you're doing a shape emitter, you'll have current density flux, child Ling Mayer, which is space charge limited fill or nordheim field emission or you can do Richardson Duchesne thermionic emission, well, that's only if you are emitting from a surface, which in this case, if you want to do any of these emission profiles, you can simply define a geometry object. here as well. Someone mentioned there is a difference between constant and variable weight particle Yes, there there are on your lay, I will I will let other people explain this later. But your lay a variable wage give you give you a bit more freedom on your on your immersion models, if I said this to constant wage, it's willing not lead me to some of those emission profiles. But

correct the comments was constant way particles can now feel image because of the lack of freedom. Right. So if you want to do any of these emission models, you have to use variable weight as well. But in this case, since we're just doing a simple electron beam from a boundary, we can just do a slab flux, we can simply do something like a measuring current density. In this case, the the unit is in amps per meter squared, I believe. Start times zero stop time one, which is from beginning to the end. And current density. You can set let's use something arbitrary say 1000. Which is pretty big. And velocity coordinate system is can be either global or local, or surface. So what is global, you're just using the global coordinate system. If you are using surface zones, a coordinate system is normalized to whatever emission surface and in that case, your your direction zero will be the direction that's perpendicular to the surface. One, two will be the two parallel directions to the surface. So in this case, we'll use something arbitrary say use something like 18 five, it was southerns, which is very fast. This is 1000 optimal. This is not the optimal punching velocity of this tool, but since we're just demonstrating a point here's the velocity we use and then we're emitting from the lower x surface

or using computer which oh crap. Okay, now what we also need in this case is a is a masking function because we don't want to embed from the entire lower boundary. And in this case, let's see mission current density. I'm missing a tub here and sync Samsung this will be turned on to see Ray as the matter oh I see right. There it is. So what happened there is that the course I started with constant ways were first added the matter, it is going with the constant wage setting. So why change this affair change this to verbal wage very as the matter is counting as as a variable wage emitter, and then I will have access to this macro particle rate, which allow me to define my masking function. So, in this case, what I really want is a sheet beam that's basically launching into the gap of the periodic structure. And producers are how to define a masking function. In this case, the masking function is usually defined it defined by heaviside functions. So a sink or have a function already defined as he made her mask. So if we look at what this is, let's look at what is emit her mask is basically a beam profile. So this is telling me I have a beam that is centered as a center of the waveguide with a height of 0.12 millimeter and worse in Z of eight millimeter. So it's a pretty skinny, skinny beam, but it's wide. So that's my emitter setup. But as I mentioned before, whatever goes into the simulation, how to access the simulation as well. So that is true for both the particle and the field. So for the field, we need to add something as the end of the simulation, put down, pause the wave. In this case, what we generally use is a match absorbing layer on ma l as this layer absorbs for absorbs wave of all frequencies, but it's nice to be sufficiently sick. So in this case, I already have a sickness defined which I believe is called LML. School

is a very long list of variables. By remember, it's called l ml. And let's say let's see if this Oh, I see I can just put it in how to find it.

Oh ml right here. And let's see what L and L is. So it's usually defined as a it's your a reference to the longest wavelength you have. And in this case of four times the longest wavelength is used. So it will say is about 12 and 12.6 millimeters which is quite sick. For the spa. If you have an 80 period structure that is a much lesser portion.

damping factor 0.5 and we need to tell it where it is in this case is in the upper surface. So there is or there is or wave damper. And let's call that an L upper. That's your to give a descriptive names. So that his or waves thing now when the particle things. So, all of this the waveguide and the the periodic structure is already defined as PVC, the way you do it is when you do your geometry definition you can tell vism one material is the geometry, in this case it will be this union, which is all PC. But the fact is PC, it doesn't mean it's absorbed, it's automatically absorbs particles until your television to absorb particles there. So, in this case, we will have several will need several particle things. So, the first particle is saying, oh, the way to define it is also electrons, you'll have particle boundary conditions. And here are a lot of different ones. In this case. The tool we will be using is boundary absorb and save. And Casa absorb unsafe boundary absorber safe is simply when you want to sync particle as a simulation boundary. In this case, since or upper x boundary is open, we'll use this condition for the for the upper x particle sync, let's call that precisely that, let's call the upper x sink. And we say is our x, then this upper x simulation boundary will begin to absorb electrons and record the number of electrons that's absorbed. But when we are dealing with shapes such as the waveguide itself, and the periodic structure, the setting to use is your la casa absorbine serif. And this is a similar similar to the matters, this will allow you to to input a geometry or to reference to a geometry that's saying that geometry is a particle thing. So in this case, let's have a wave, guys think. And the shape is a shave. And well how waveguide alter minus wave that in there, which is this. So this is now a particle sync. Now we need another thing for the slow wave structure itself. And if you don't want to do it separately, you can also simply union the waveguides with the with the slow wave structures, and you will only have one geometry to deal with. Or sometimes there are benefits to dealing with them separately. In this case, another one, let's call that slow wave structure sink. This case we put in or slower structure. just for completeness, let's also define a sink as a lower x boundary.

Lower x slop. So no, basically all the simulation boundary possible all the possible places that particles can be exiting the simulation are defined as particle things. So that part is complete. And histories are already set up. In this case, I'm only recording two things that the input voltage into the slow wave structure and this output voltage. But there are a whole array of other things to look at. And we have a pretty complete documentation on what these things are to access those documentations. Simply there's the Help button. Click on those you can pull out or documentation and you can go into the reference manual to see what every single Yes. But anyway, let me show you what the results of the setup We have are struggling with a with a zoom window. So before we run the simulation on the way, visualize that in the face space by plotting the x direction on the x axis and the velocity, the electron velocity x in the y axis, we can see this velocity modulation down the tube. As you can see, the amplitude is pretty small, because in the case, in this case, says my electron beam is very fast, this coupling to a to a minor mode now is the primary mode. And the implication is also small consequentially, but you can see the signal is being amplified, very small, because it's a lesser mode. So anyways, that's all for this section. Let's go back to the main presentation. And the next thing is we need to add a plasma into this slow wave structure. Oh, what's the point of adding this plasma you may ask the goal is to use a plasma to self focus electron beam so that the device can function in the absence of an externally applied magnetic fields. Many things can happen when you add a plasma process into a device like this. But for simplicity, we'll all the only plasma process we will be dealing with here is impact ionization. So in this case, I decided to use argon because it's relatively easy to ionize. And the plasma is introduced as the fluid, if you will. So choice, you can add this plasma in as particles or simulators that way as well. And here is a list of things we will need to do for this step. So let's go through it. Now, let's go with where we end up here. So first of all, we need to define whether to tell the system that you are including a plasma process. So the way you do that is in basic settings. Here is a professional framework, you'll want to change that to reactions. Now under particle dynamics, you'll have this whole new reaction tab with a lot of different process. In this case, we're dealing with a particle flow problem. And the first thing we do is to add the fluid. And the way we do that is simply right click on fluid, add neutral fluid. Now we'll have a neutral flow at zero, you can define its temperature, what type of fluid it has, and its volume

and its density. So, in this case, we are doing argon. So we already have argon in this, let's say something like 2000 Kelvin, a halt plasma volume, you can do a Cartesian 3d slab, in this case, you can alter this parameters to cover the entire simulation region, then you will have a fluid that's that is filling the entire volume zones, the most important thing to set up is that you want to want impact organization. So we go to impact on ASEAN and see what we all have here. So we basically have a formula of A plus B equal to use a positive plus B plus our secondary electron. So we already know we have electron into argon. So we need to actually define the argon as a particle as well. Not the argon itself, because we already defined that but we'll need to add our Got IO into the into the simulation and that is under charged particles you can add it as argon ion we can call this are gone plus you will have argon ion added to the simulation and the if we look at the USD this will also have this ether. So this is secondary electron. So you also need to define that separately as well. So we define another electron term, and we call that secondary. Same setting as before, so, knows that we just added two new particle species into the simulation and also species nice who have their own particles things as well. And I will omit that part since we are low on time. So, now what you can do is you can say electrons, let's call this argon, you can tell this and electrons. So, your background is argon. So your incoming electrons your positive ion is argon plus your outgoing, B is the secondary electrons, and your electrons are just electrons. Okay, you're all going to be his electrons. And you're he is secondary just follows the order we defined it. And then you need to give you the cross sectional a congressional congressional cross section. So you can either to a constant or you can import it as a two column data there are this experimentally determined data sets available on the internet. But you will need to you'll need to cite it if you use it in research. And we want this collisional process to update every time step, we'll leave it as isotropic. So, that is basically all the setup, we will need to do to ask the plasma is actually quite simple. And if I show you the result of it

may pause the results. The result is sasheer. So, this is a simulated result of this process. So, in this case, we have our incoming electron beam in blue and the red particles are gone. positive ions plus one ions and the green particles are secondary electrons due to impact organization. And also this in this simulation, there is no applied magnetic field. So there's no external magnetic field, we can see this plasma process taking place in the structure. And by the end of it, basically pretty much all the all the primary electrons are down, you only have secondary electrons out and you can see it's diverging because there's no magnetic field. So that's how you add in easily adding a plasma and simulate this process. But obviously this still requires a lot of more fine tuning. Let's continue with our main presentation. We did that part. So what we want to do next for this research so the next step is to optimize the technical parameters to get proper velocity modulation and the desired plasma effect. And talk for Sean's expressed that he would also like to simulate the simulation to address this to address a skin depth effect to get a more accurate, realistic simulation, since we're dealing with a very high frequency here. So this is how the analyzer called compute coverage. That is specifically designed to aid solving problems like this and this work is currently ongoing work. So, now, I will try to answer the question why do I want to use this for a research like this. So first of all, for all reason is you vissim uniquely provides a unified simulation platform that enables em electromagnetics particles and plasma process to be model within the same simulation. As this is a unique capability. The vision computer, the vision composer, graphical user interface enables rapid modeling of complex devices, which greatly smoothens the learning curve for using the software and gradually speed up the modeling process. So that if an engineer is using the software, the engineer can speed can spend less time learning about the software and spend more time optimizing their designs. For more demanding power users such as many research scientist, this provides the user with algorithm and data visibility is far beyond both all for competitor product. In this regard, I personally consider vision as radically transparent. In the sense of algorithm and data visibility. Many of our algorithms behind the visions engine and the analyzers can be published, are already published by tech x or open academic journals. Users of vsam have full and obstructed access to low level inputs. and are able to tweak virtually every aspect of the simulation setup, or the analyzers such as extract mode analyzer I showed you, you can, you can pretty simply going into the vision files and see and read the parts of ourselves was the analyzer is doing so there is no, there is no mystery or black boxes anywhere. In short contracts is a standard for all competitors, or commercial competitors to encapsulate their algorithm in black boxes, and users rarely have access to lower level setups that goes beyond the GUI.

In simple words, vism have no problem holding your hands and make your life easier if you're just begin beginning to learn the software, or when you want to do modeling pretty rapidly on some well defined problems. On the other hand, if you are trying to push into new territories of science and scientific computation, VSM will now try to get into a way where you need to go beyond the GUI and work with low level inputs directly, which opens the doors for many possibilities. So I believe that's the end of my presentation. And I will take any questions. We'll have five minutes.

Very nice. Very nice. Andy. Nice.

To have one question. So are the inner world wars of the waveguide coincide with a pure audix structure edges? So that is a good question. That's, that's a that's a pretty specific geometry problem. And I think MinJae MinJae asked a question. I think he asked because he saw the the interview geometry is actually sort of sticking out of the waveguide when you overlap it. And that is a geometry nuance, I didn't personally build our geometry. So I will have to look into it. What is the argon pressure? That is? I'm actually not quite sure. That's a good question, I think is let's look at the argon plasma. So in this case, we do have a direct pressure input or we have temperature and density. And those think pressure can be derived from that I believe.

How much current is transmitted compared to emission. To access that information, you will need to set up a Yours, your house was set up another diagnostic in this case, I only have input voltage versus output voltage. But if you want to access that information, you can define particle histories. And you can look at your emission current as a you can look at your absorb current. And if you define absorbed current both as the upper x, which is your exit, and then your lower x, which is your input port zones a difference in between will give you the ratio between transmitted and, and reflected or if you'll compare the transmitted to emit to emitter, you can see that too, but that diagnostic can be easily added.

I have I had another question that was sent to me. So how long does it take to simulate a structure like this with

with plasma present. So let's see. In this case, we did a similar as a full structure with simulated always 30 period, if we look how long it took me two computers. So my last step is as 955. Let's look at where my first is

nursery five. So this simulation actually only took about 20 minutes to compute. And this is computer with 32 cores. So we have another question are secondary? Are the secondary electrons involved in new acceleration and coalition as primary electrons? Do they have new weight? That's a good question. So secondary electrons secondary electrons are treated as a completely different species than the zanzi primary electrons. And what are their, whether their weight is different or not, depending on what type of setup you're using, if you if you so want the course even even within even within the premier electrons, your weight is variable, your weight is variable. So I think when you set up the secondary electrons, which I didn't include or don't have, in this case, in this case, secondary electrons in this case I have a set up as constant weight, but you can you can you can use variable weight on this or you can make everything constant. So it's depending on the setup, but the principles there is they are treated as completely different species. So what is a grid cells you used of 20 minutes of 32? course and how many micro particles are used? Good question. So in this case, let's look at a greater definition. So in this case, we have cells accessoires, and cells D is are automatically computed. Let's look at what they are. So in z there are 28 in Y is 28 as well. So it's 28 by 28. And allows the lens of the tubes are a force for 21. So it's 28 by 28 by 421. How much does that give you? So, okay, but 28 by 421 that gives you about

about a quarter more than a quarter of a million cells and the market particle that is used. Let's check that out. So in the particle setting, sole particle, fourth cell is 200. And the emission, Mako particle emission rate is also 200. So it's it's pretty it's it's not necessarily what I would call course.

All right, any final questions? Go ahead and ask them now before we let Andy go. I will say that if you have not tried out the latest version of the SIM, the sim 11, which we released in May, you can go to the tech x website at TX Corp comm which is TX Corp COMM And you can go online and request a 30 day evaluation of the software if you are a current license holder, but you would just it's an older version and you want to test it out. Same thing we want you to see what what we have now and some of the new features and really kind of experience all the improvements. We've added. Any final questions? Before we wrap up, our next talk coming up is going to be in 30 minutes it's going to be Dr. Mark Durant or sorry not Dr. Sir, excuse me, it is going to be marked around and he is going to be presenting on manipulating geometries in the sim. So if you want you can take a brief break and come back at 10am Mountain Time and we will have more. Thank you so much, everyone. We'll see you in a bit