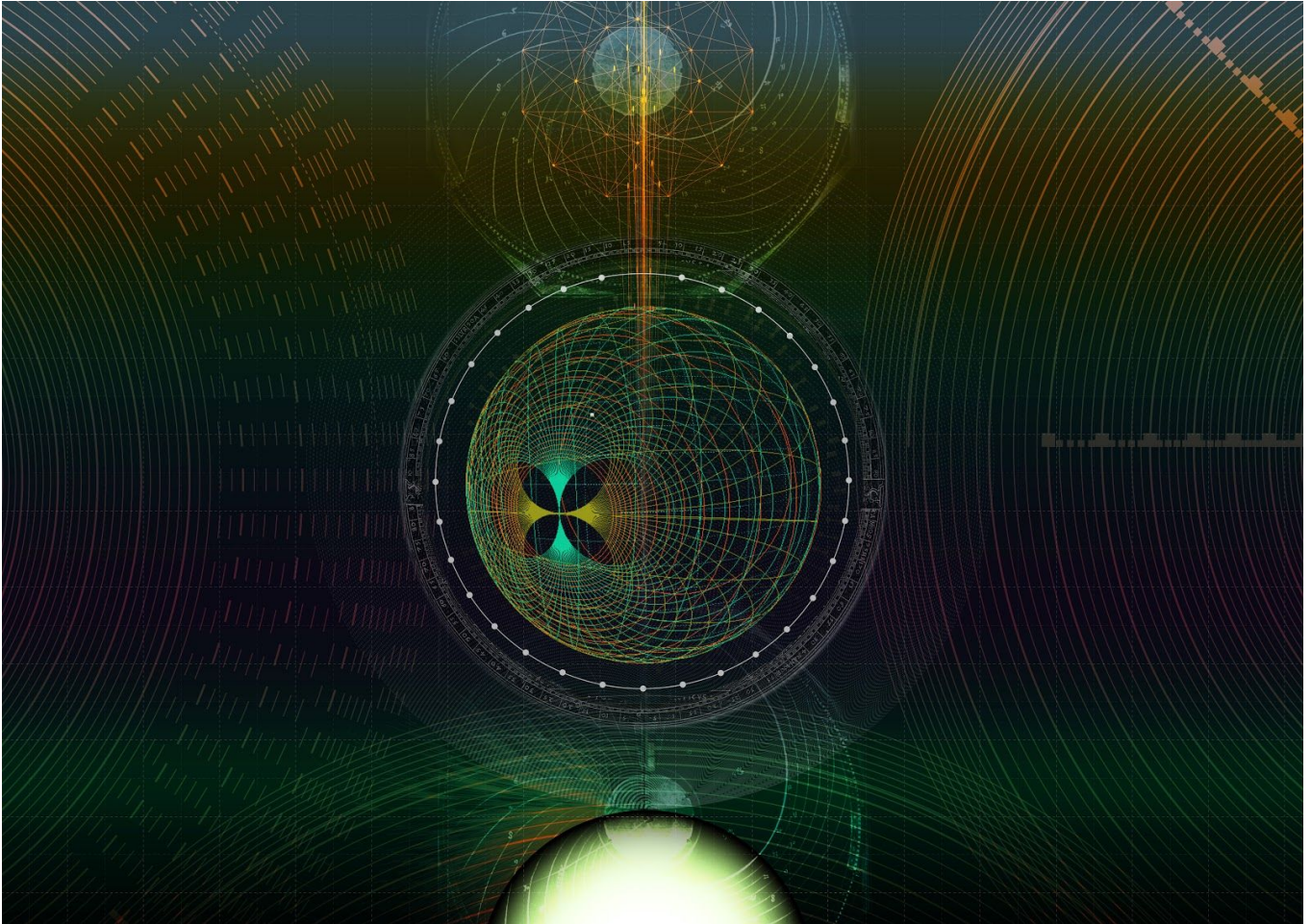


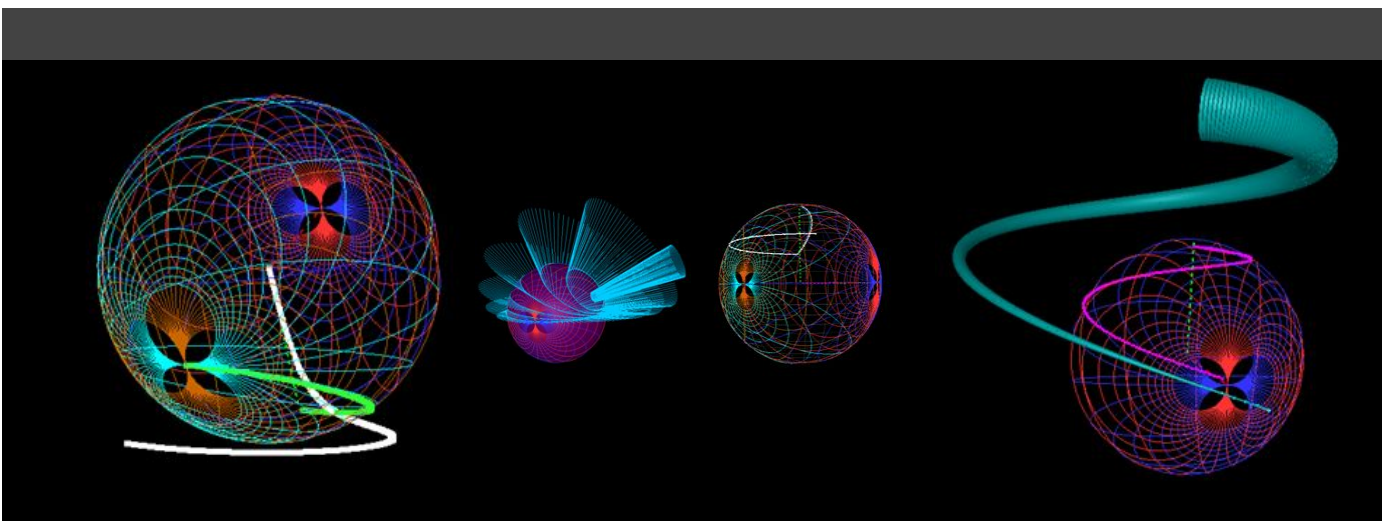
# 3D SMITH CHART 1.0

version 1.0

## USER GUIDE



[www.3dsmithchart.com](http://www.3dsmithchart.com)



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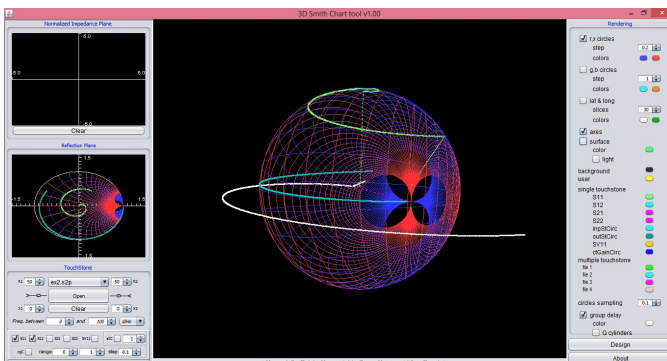


# INTRODUCTION

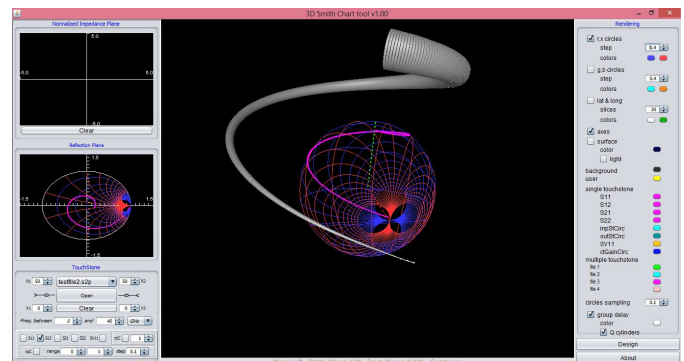
3D Smith Chart is an advanced tool for high frequency 1 & 2 port circuits, supporting learning, analysis and design. Some of its distinctive characteristics are:

- State of the art concepts, backed by recent reputed journal publications written by the producers
- Works for all active & passive microwave circuits, even with negative resistance !
- Displays Amplifier Stability circles
- 3D Unilateral transducer gain & group delays & quality factors
- Educational design mode on 2D & 3D Z-Y Smith charts on constant r,x,g,b circles & more
- S parameters display
- dynamic frequency sweep & complex ports
- Full 3D visualization
- Intuitive user interface
- 1 minute install
- Highly configurable

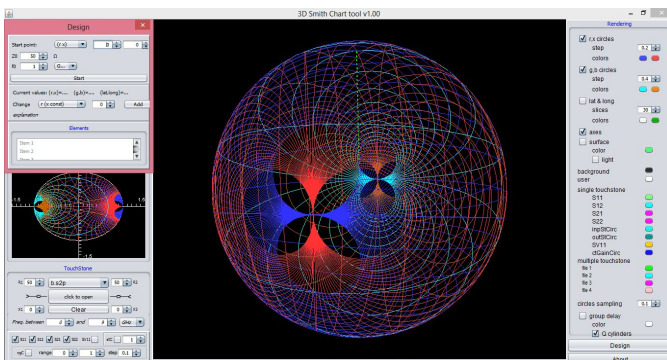
The following figures present the main window of the tool and illustrate some of its capabilities:



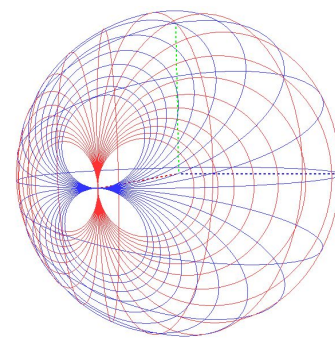
*S parameters and group delays*



*S parameters and quality factors*



*S parameters and group delays on ZY 2D and 3D Smith charts*



*Reconfigurable display*

## OVERVIEW

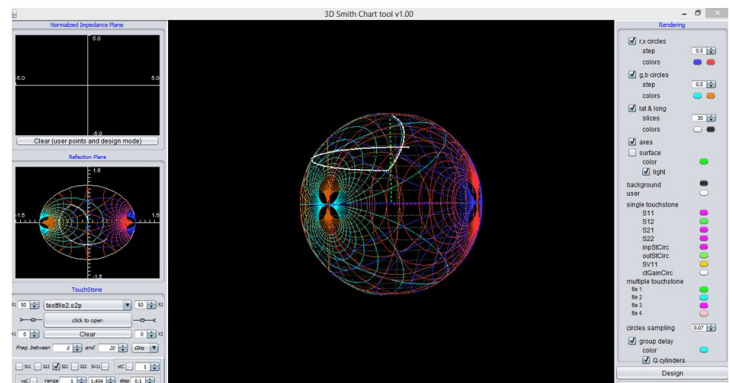
The **advanced analysis mode** for two port microwave circuits is based on proof of the concept articles published in reputed journals, such as IEEE Transactions on Microwave Theory and Techniques (2017), Microwave Journal, IEEE Microwave and Wireless and Wireless Components Letters and Electronics Letters (2011-2016).

This mode shows, both on the innovative 3D Smith chart and the classical (2D) Smith chart:

- **S-parameters**
- **Amplifier stability circles**
- **Unilateral transducer power gain circles**
- **group delays**
- **Q factors** (from user uploaded touchstone files)

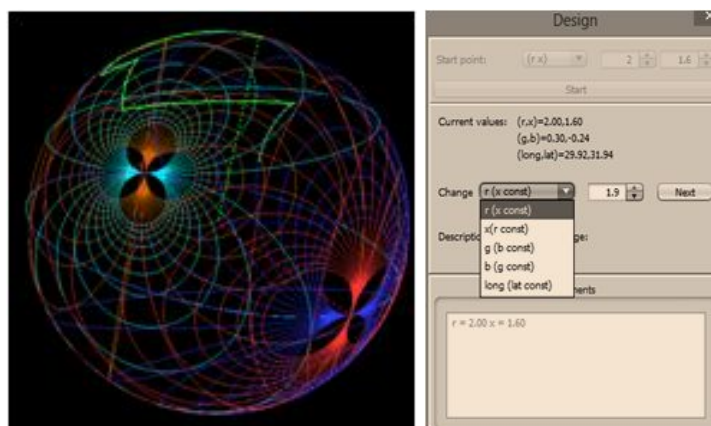


*A view of the tool*



*Matching on the 2D&3D Smith charts*

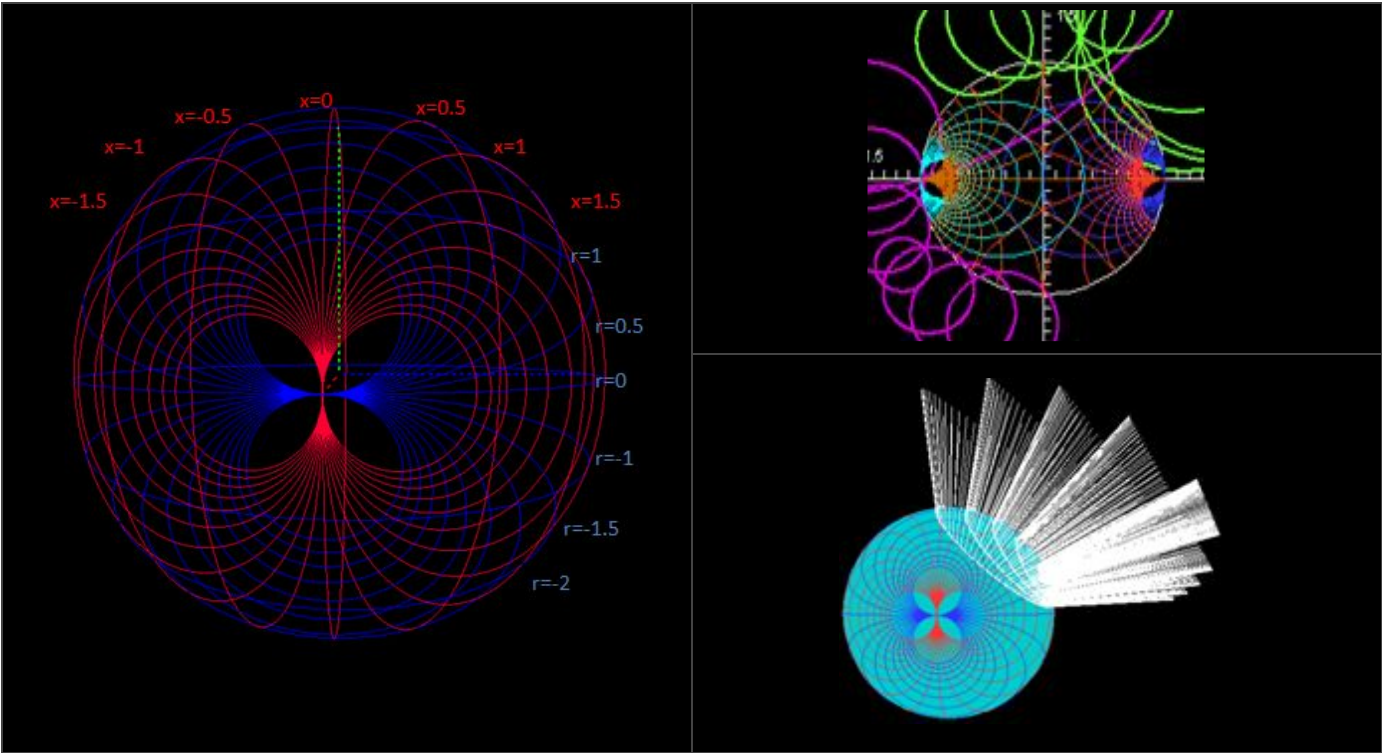
A new Z-Y **educational design mode** allowing the user to visually match circuits by adding components along constant reactance, resistance, susceptance, conductance paths and constant reflection coefficient magnitude circles in order to visually match the circuit. The design is permanently visualized on both the innovative 3D Smith Chart and the classical Smith Chart.



*Educational mode matching*

# PRINCIPLES

Dictionary	Smith chart	3D Smith Chart
Positive resistance	Interior of unity circle	North hemisphere
Perfect match	origin	North pole
Inductive	Above x axes	East
Capacitive	Below x axes	West
Purely resistive	Ox axes	Greenwich meridian
Reflection coefficient ==1	Unit circle	Equator
Reflection coefficient ==infinity	NO	South pole
Negative Resistance ( Reflection coefficient >1)	NO (towards infinity)	South hemisphere
r,x,g,b constant	Circles, circle arcs, 1 line	Circles
Power levels/group delays	NO	3D space (Exterior >0, Interior <0)



# USE MODES

## ANALYSIS

- [Import touchstone files \( s1p and s2p\).](#)
- Represent the S parameters on 2D Smith chart
- Interactive dynamic tuned frequency sweep representation of the S-parameters
- Compute ( and plot) stability circles and unilateral transducer power levels
- Interactive unique sweeping-tuning mode of the characteristic impedance ( real and imaginary parts) , use of a unique frequency sweeping mode in a game-like aiming interface and dynamic S-parameters representation during the sweeping.
- Represent the S-parameters on 3D Smith chart imported from s2p and s1p touchstone files on a highly reconfigurable Z-Y 2D/ 3D Smith chart.
- Display group delays on the 3D Smith chart/ over the S21 (s2p files) and over S11 in the case of s1p files
- Display quality factors over the S21 parameter

## EDUCATIONAL DESIGN

- The user can type from the keyboard the desired normalized impedance parameters ( the program automatically displays their S-parameters) and then choose a matching route ( through unlimited points- which are recorded) by **choosing a path** on the constant **resistance-conductance** , **reactance-susceptance** or **constant reflection coefficient circles in any direction**.
- **By checking the recorded route** to the desired matching point ( **r,x g,b parameters at each point**) and looking only to the **clockwise/ anticlockwise movement** which one has chosen ( see table 1), **the user can directly compute** the values of the corresponding R, L, C, transmission lines, short circuit and open stubs used at each step.
- The program automatically tells the user what kind of circuit one has added- depending on the choice made ( path chosen/ orientation)
- The track is recorded and displayed in both Smith chart ( ZY configuration), 3D Smith chart (ZY) configuration



# INSTALLATION

On Windows machines run the provided installation kit. The process is very straight forward.

## MINIMAL SYSTEM REQUIREMENTS

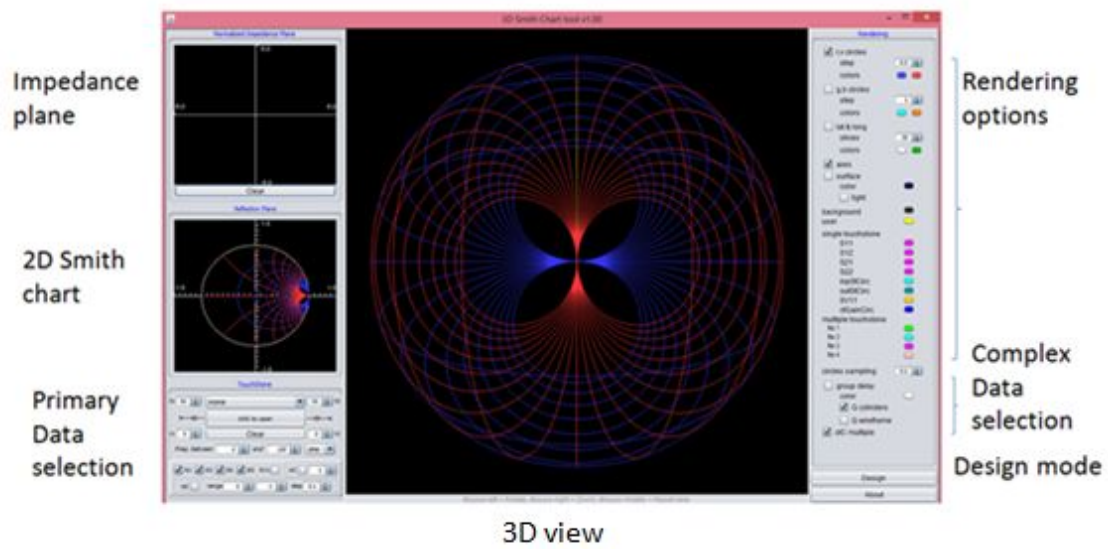
1. Operating system: Windows
2. CPU: Intel Core 2 Duo or faster processor
3. GPU: OpenGL 2.0 or later compatible card
4. RAM: 4Gb
5. Display: 1024x768
6. HDD space: 250MB
7. Internet connection for download and activation

## LAUNCHING AND ACTIVATING THE PRODUCT

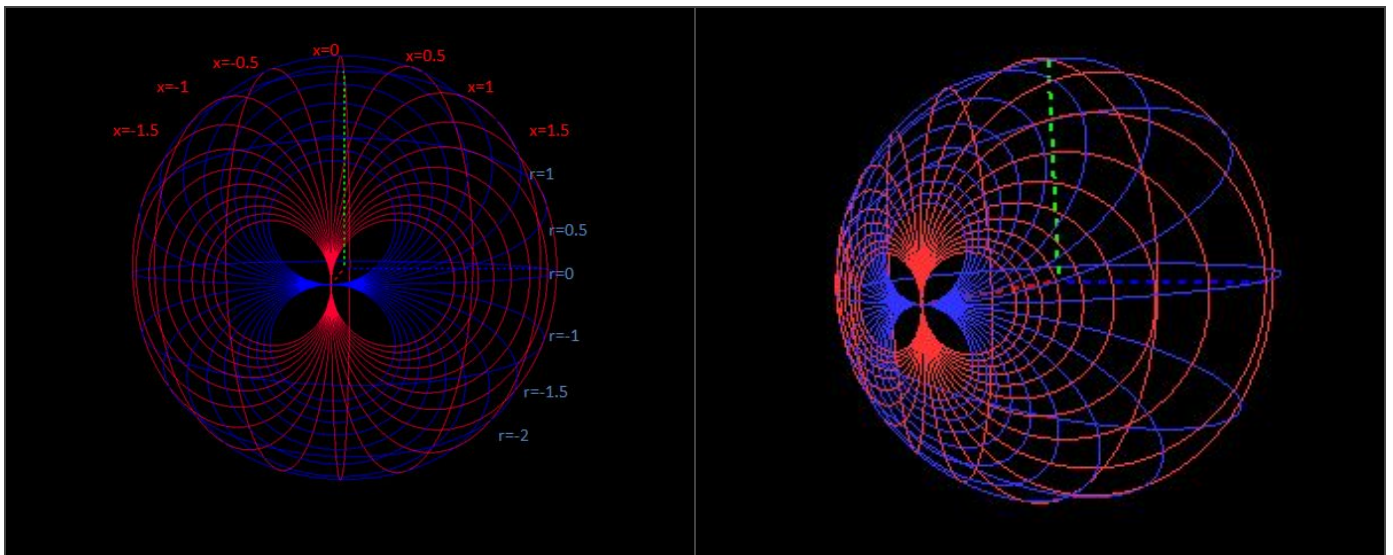
### Windows

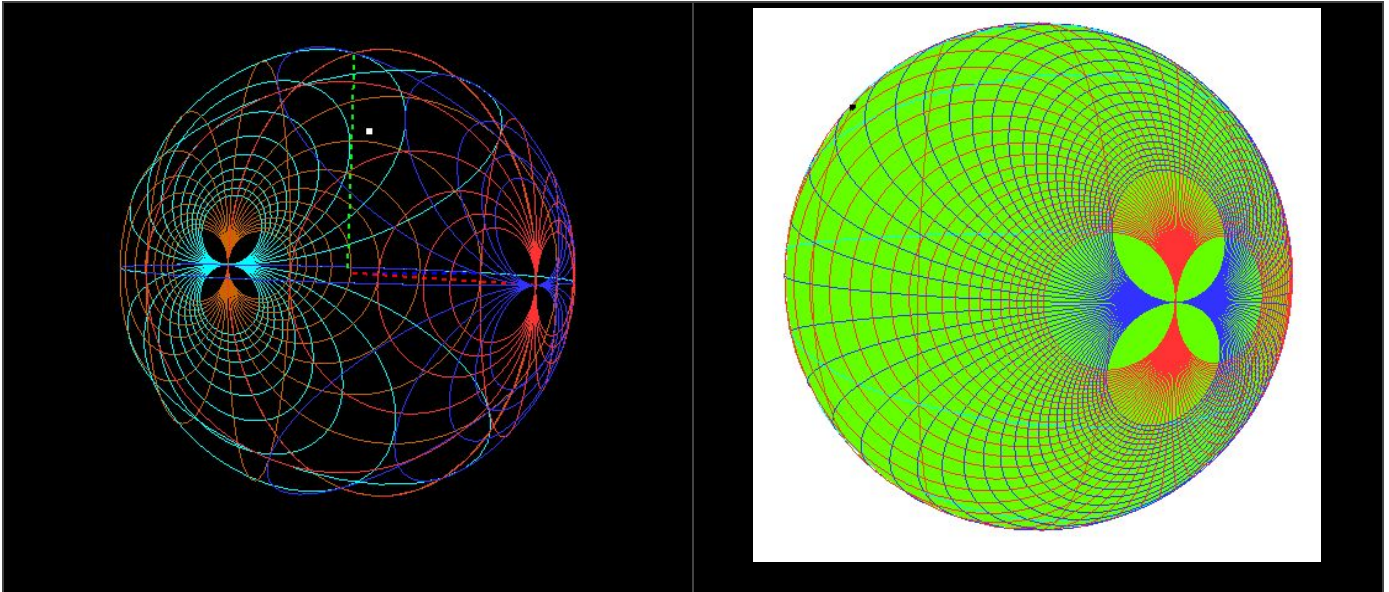
- Simply launch the application shortcut named '3D Smith Chart Tool' generated by the Installer.
- On first startup you will be prompted to enter your license key.
- After doing so click the 'Activate' button to activate your license
- After successfully validating and activating the application will start

# PROGRAM INTERFACE



## 3D VIEW





3D reconfigured views

$x$ =Normalized reactance;  $r$ =Normalized resistance ;  $g$ =Normalized conductance;  $b$ =Normalized susceptance

On the 3D Smith chart the default settings are set on a 0.5 step between the  $r,x$  circles.

The user can change the colors and the step between the circles keeping in mind that the equatorial latitude circle is the  $r=0$  and that the Greenwich longitude circle is the  $x=0$ . Furthermore,  $r>0$  North hemisphere,  $r<0$  South hemisphere,  $x>0$  East,  $x<0$  West.

## CUSTOMIZATION

The user can change the display of the 3D Smith chart 3D view window by checking/ unchecking several boxes on the [rendering options](#)

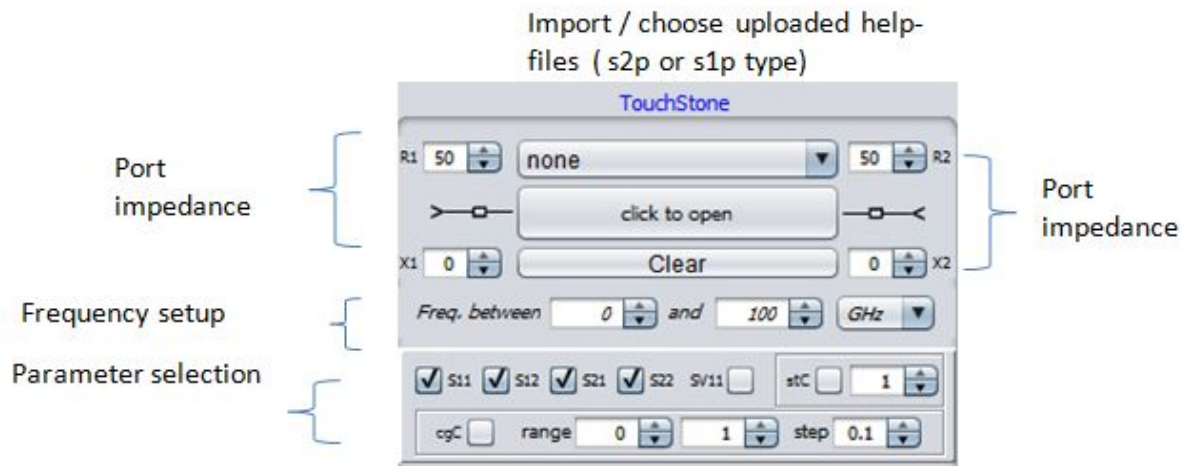
<input checked="" type="checkbox"/> $r,x$ circles	
step	<input type="text" value="0.2"/>
colors	<span style="color: blue;">■</span> <span style="color: red;">■</span>
<input checked="" type="checkbox"/> $g,b$ circles	
step	<input type="text" value="0.3"/>
colors	<span style="color: cyan;">■</span> <span style="color: orange;">■</span>
<input type="checkbox"/> lat & long	
slices	<input type="text" value="30"/>
colors	<span style="color: white;">■</span> <span style="color: green;">■</span>
<input checked="" type="checkbox"/> axes	
<input checked="" type="checkbox"/> surface	
color	<span style="color: green;">■</span>
<input type="checkbox"/> light	
background	<input type="text" value=""/>

## ZOOMING AND ROTATING

Zoom: press the right mouse button and hold it while moving the mouse.

Rotate: press and hold the left mouse button and move it.

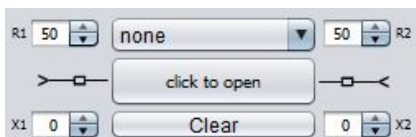
# PRIMARY DATA SELECTION



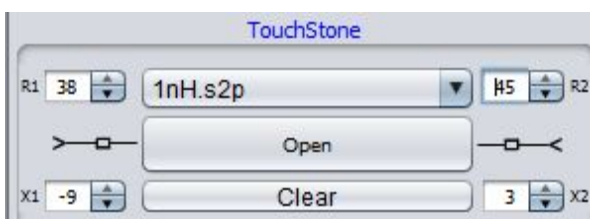
- The user can upload any desired s2p or s1p touchstone file
- The user has to choose the analysis frequency interval, can change it whenever and see “live” how the parameters change

## DATA SELECTION

### Import touchstone files



Each touchstone file has to be imported through this block.



The block is mainly designed for s2p touchstone files

It can deal also with s1p files, if the user selects such a type of file the second port vanishes automatically, however in this case the user cannot modify the port impedance.

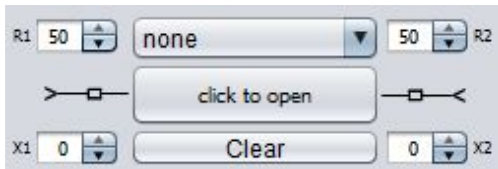
The group delay option if selected will be displayed over the s11 parameter





The data selection block

## Port impedances

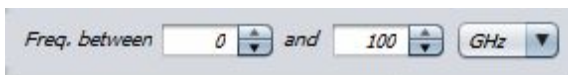


$Z_{01} = R1 + jX1$  = input port impedance

$Z_{02} = R2 + jX2$  = output port impedance

The user can then choose the characteristic impedances of the two ports introducing the real parts ( R1, R2) and the imaginary parts ( X1, X2).- The option is implemented for plotting all the S-parameters and power wave reflection coefficients ( the later one for the input port). Please check [Reactance&Resistance&Ports&theory](#)

## Frequency selection



Select the range/ units and play in real time with the display ( tune)

## S parameter selection

The parameters will be displayed only if the boxes are checked

Please change their colors in order to distinguish them

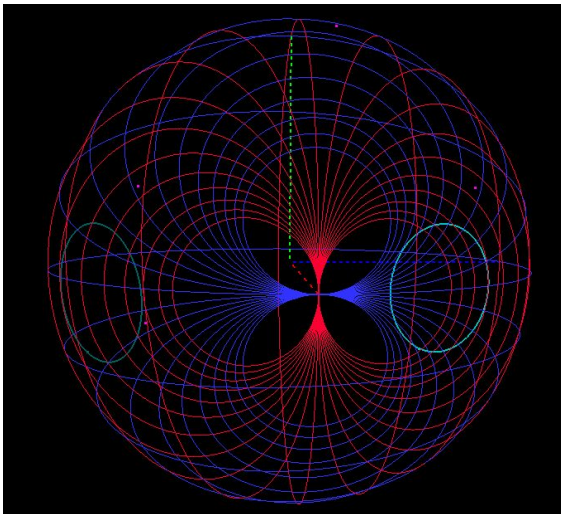


Choose the color of them from the [Rendering tab](#)



The SV11 [8] - represents the voltage reflection coefficient when using complex port impedances ( please see the [ex1](#) -voltage reflection coefficient). If using complex port impedances, S11 represents the power wave reflection coefficient [8] ( please see [ex1](#) ).

## Stability circles



Stability circles- ( South= out of the Smith chart)

Check the stability circles box



You can choose the color of them from the [Rendering tab](#) for the input and output circles as you desire ( input and output)



You can the sampling ( visual option) from the [Rendering tab](#) too :

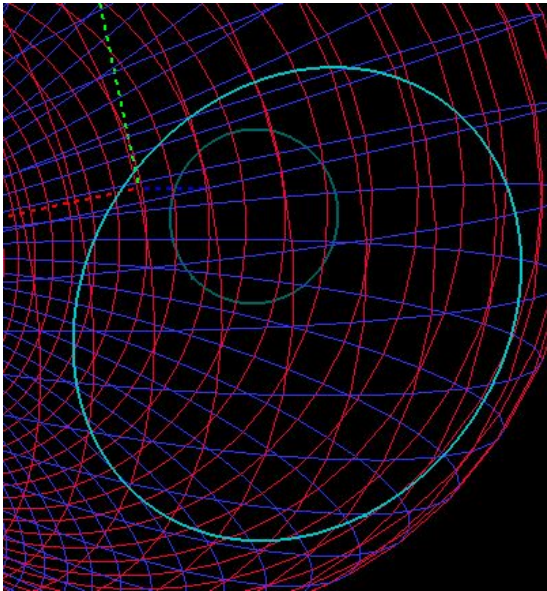
circles sampling 0.01

Please be aware that the stability circles will be plotted for the first frequency line of the touchstone file

If you wish to plot stability circles from several frequency points please select the option :

☒ stC multiple

( on the rendering options)

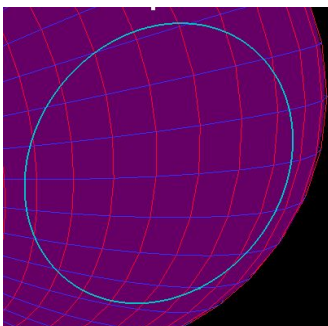


*Zooming on the stability circles - to see  $r,x$  values*

If you wish to read off the values corresponding to a specific stability circles:

Place the mouse over the points of interest and read off in the impedance plane the  $r,x,g,b$  corresponding values.

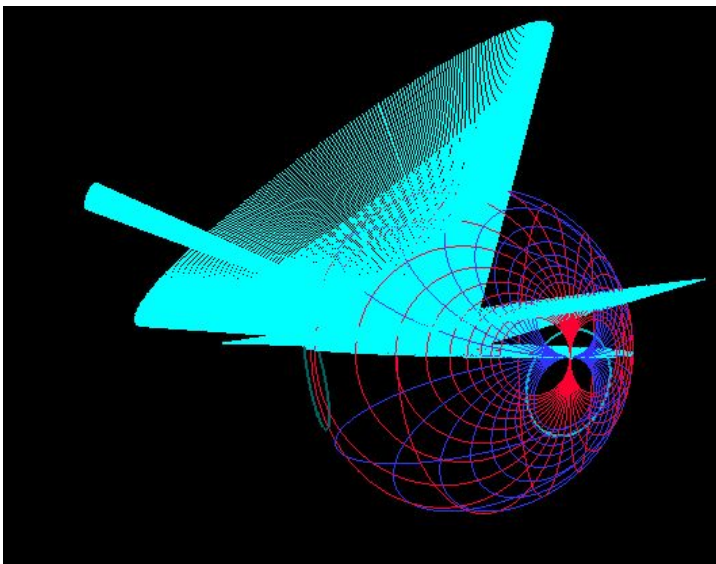
Reading off the values of interest may be easier if the surface box from the [Rendering tab](#) is checked, and then again by placing the mouse over the points of the stability circle of interest the user can read off in the impedance plane the values of interest [Ex 4](#).



*Zooming on the stability circles - to see  $r,x$  values-turning on the surface*

## Unilateral constant constant gain circles:

The unilateral input constant gain circles can be plotted for any touchstone file by clicking in the box: The user selects the range and step. The values correspond to the square root of the magnitude. ( i.e if one is interested in a specific value in dB one has to convert it in its magnitude and then take the square root. Please see [Ex 5](#) for a detailed example and [Ex 5b](#) for how one can use them in the practical design.

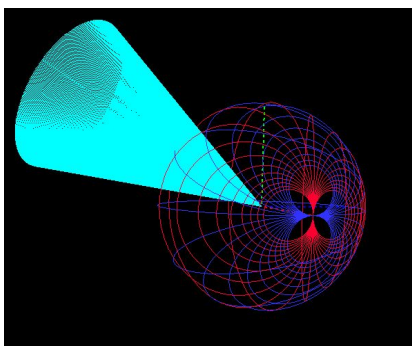


cgC ☒ range 0 1.6 step 0.46

*4 constant power level circles over 4 power gain circles*

Please change the range properly to focus on a single constant gain circle of interest :

cgC ☒ range 1.25 1.25 step 0.01



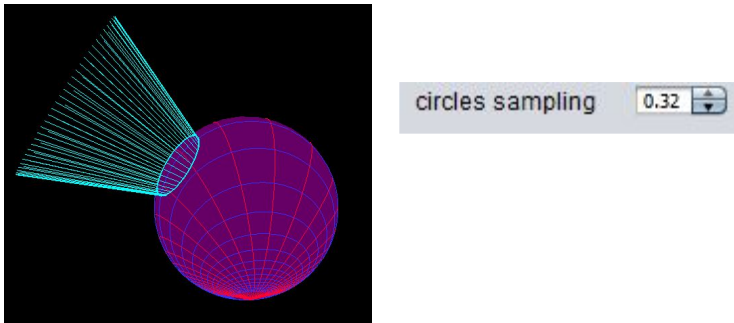
The circle sampling is important to be reduced when analyzing a specific gain circle in the [rendering tab](#)

circles sampling 0.01

*A constant power level over a power gain circle*

The important thing in gain analysis and gain design is to identify the circuit needed to [get the desired gain](#)



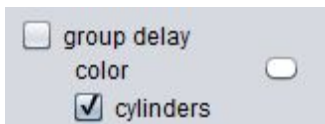


*A constant power level over a power gain circle with the sampling/ surface color changed to read off the  $r, x$  values*

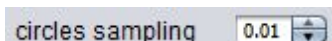
## COMPLEX DATA SELECTION

### *Group delay and quality factors*

The group delay and quality factors are only for the transmission parameters (S21) and can be plotted by checking the box from the rendering tab: [Rendering tab](#)



Choose the sampling ( visual option) from the [Rendering tab](#) too :



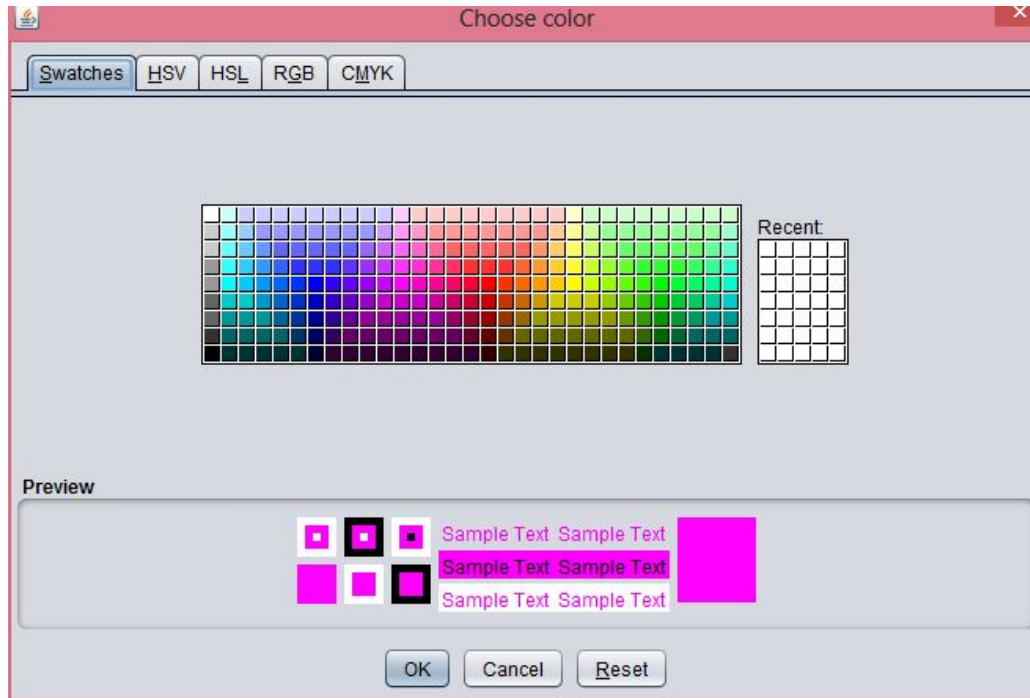
## RENDERING OPTIONS

The Rendering tab includes a unique visualizing option for any desired parameter presented before.



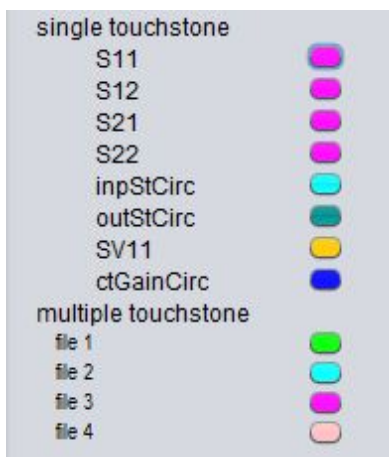
### *Rendering*

The user can change the colors of the selected parameters and their steps ( rx,g,b,lat/long) by clicking on them



Color palette

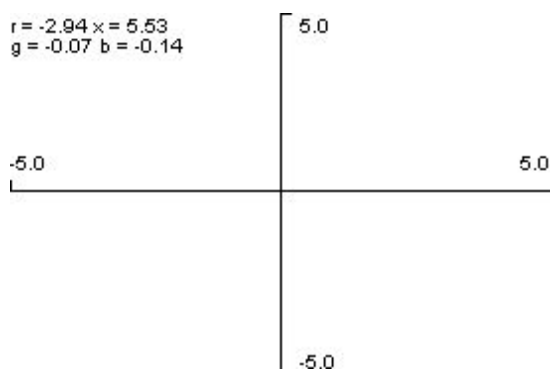
inpStCirc and outStCirc stand for input and output stability circles while ctGainCirc- for constant gain circles  
If the user chooses to display more touchstone files simultaneously the colors change to the ones selected  
( for each touchstone file)



Rendering window part

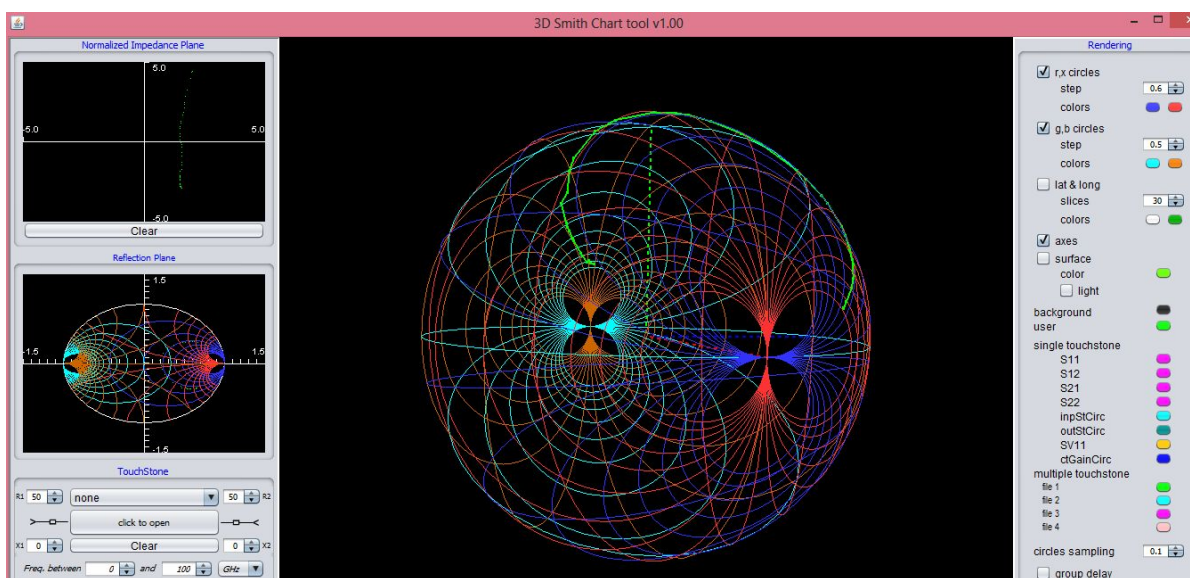
## NORMALIZED IMPEDANCE WINDOW

- The user can read on the normalized impedance window the values of  $r, x, g, b$  for any point while placing the mouse over it on the 3D main window



*The  $r, x, g, b$  values in the normalized impedance window*

- The user can draw in the normalized impedance plane and see the reflection coefficient of the drawn normalized impedance on the 3D Smith chart main window and on the 2D Smith chart



*A drawing in the impedance plane can be seen on the Smith chart/3D Smith chart*

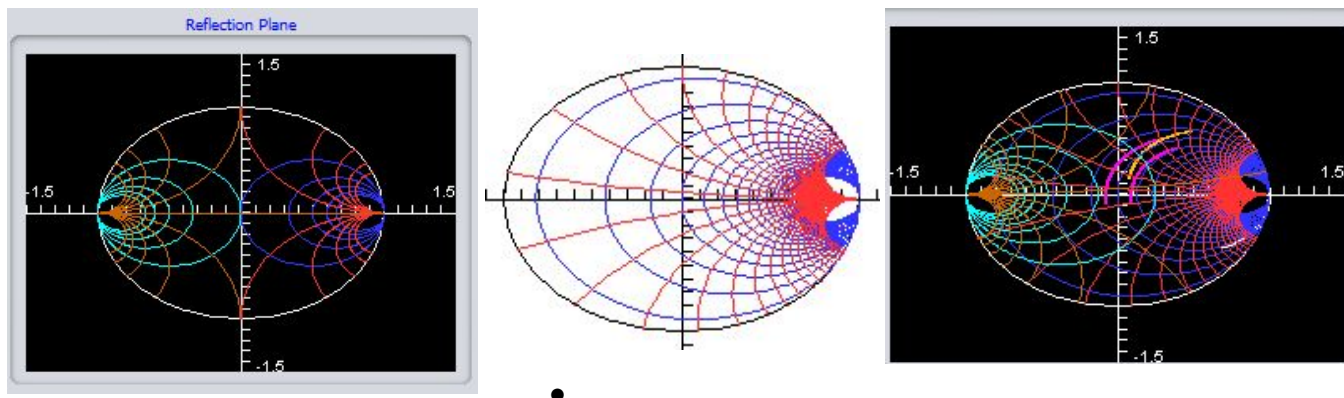
The user can change the color of the drawing from the rendering options by clicking on user



## 2D SMITH CHART

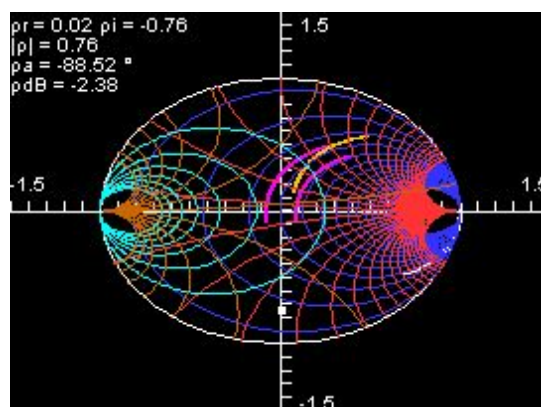
Please note that the Smith chart will be rendered with r,x,g,b circles if selected from the rendering tab.

You can choose from the rendering tab the background on the rendering options



*2D Smith chart reconfigured views*

- Any S parameter selected will be displayed here too
- Anything done in the design mode will be displayed here too
- The user can read off any value of interest for the reflection coefficient ( when placing the mouse over the desired point/ S parameter of interest at any desired frequency on the 3D main window. The displayed values are: real part, imaginary part, magnitude; angle ( =longitude on the 3D Smith chart too); magnitude(dB)



*2D Smith chart reconfigured views (r,x,g,b circles and S parameters)*

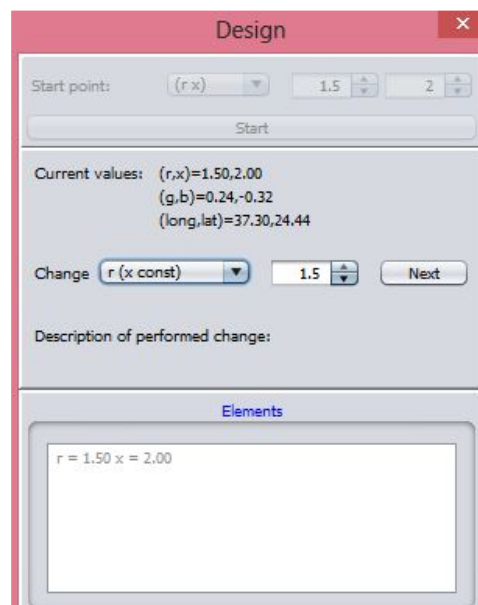
## DESIGN MODE

By pressing the design button the following window will appear:



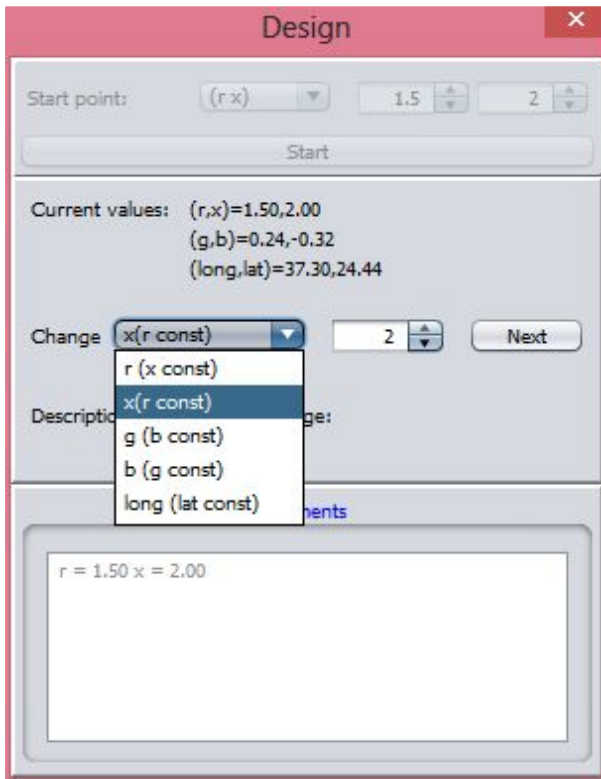
*Main window of the design mode*

The user has to select a starting point ( type r,x) or (g,b):



*Main window of the design mode displays the current values in three formats and the list of the elements added ( once next is selected)*

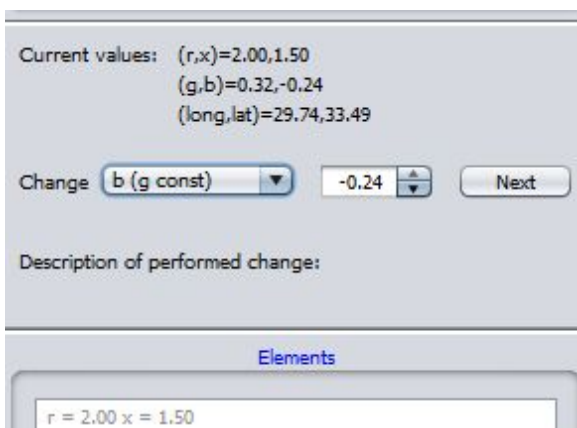
Then the user can choose one of five possible paths:



$r, x, g, b$  and constant latitude circles ( magnitude of the reflection coefficient= constant)

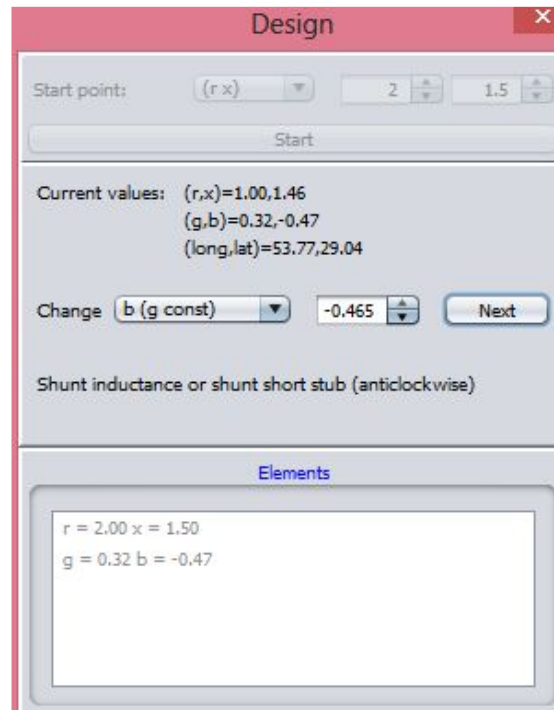
- The user has to select on which constant circle one likes to move and then to choose a direction (increasing values-clockwise); decreasing values- anticlockwise ( for the  $r, x, g, b$  circles ). The difference between final and initial values give the user the element's value. Please see the examples
- For the constant latitude circles( reflection coefficient's magnitude= constant) the user can add segments of maximum 10 degrees at each step ( clockwise). The longitude difference between the endpoint and starting point tells the user the length of the transmission line Please se the examples

Let us assume the user changes  $b$  (  $g$ = constant)- this means that the user will move on the  $g$  circle which passes through the chosen point ( in our case  $g=0.32$  circle)

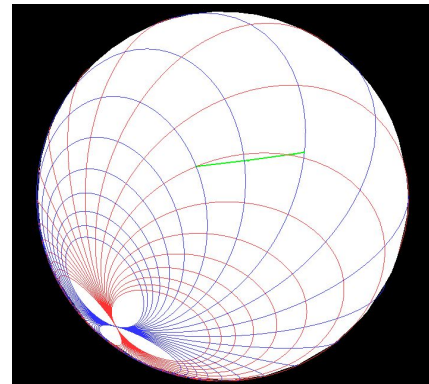
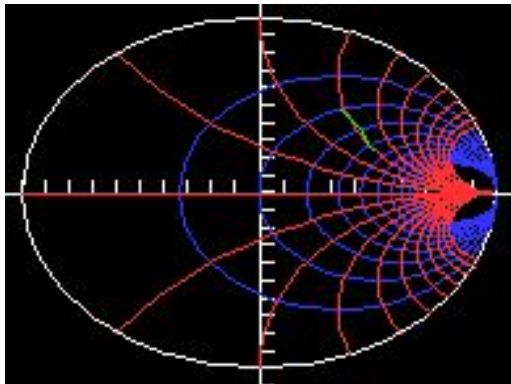


*Main window of the design mode*

Then the user has to choose the next point ( next  $b$  ) . Let us choose  $b=-0.465$



*Design mode main window*

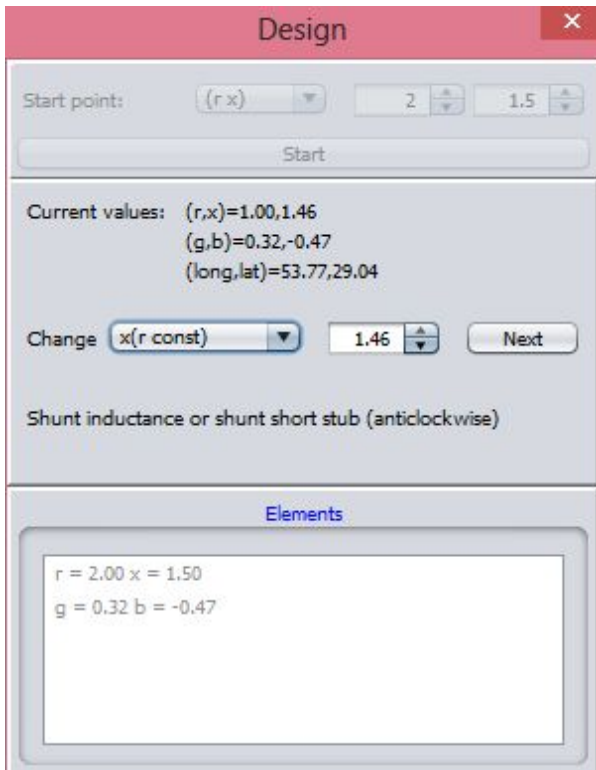


*Effect of adding elements in the design mode*

If the user wishes to see the movement on the  $g=0.32$  circle, the user has to check the  $g,b$  box in the rendering options.

The user has reached the  $r=1$  circle- the user can see live the consequences of the choices made. Please note that the user can see this visually on the 3D main window and on the Smith chart or else read directly in the design window the current position which states:  $(r,x)=(1,1.46)$  thus  $r=1$ .

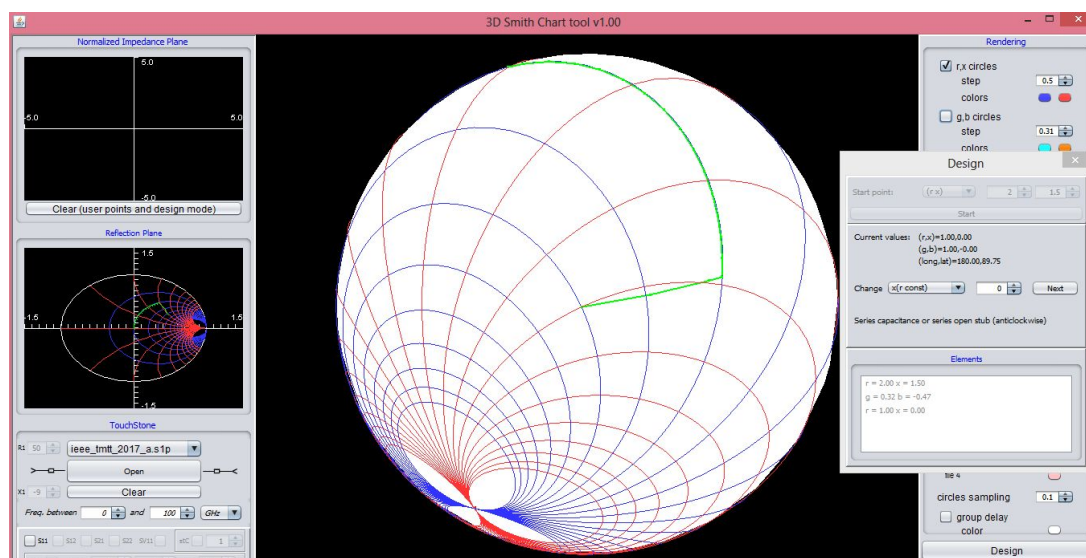
Now let us assume we would like to match the circuit: we have to bring it into the origin- thus we have to choose the path  $r=\text{constant}=1$



*Design mode main window*

As one can see the program displays the  $r=1$  and  $x=1.46$  at the point reached; to get the match we have to decrease  $x$  to 0. When the user presses next the result of the action will be displayed on the Design window, 2D Smith chart and 3D main window. Unless you press Next the program displays the result of the previous choice.

Let us press  $x=0$ . The user reached the North pole/ center of the Smith chart



*Design mode - adding elements on  $r,x,g,b$  circles*

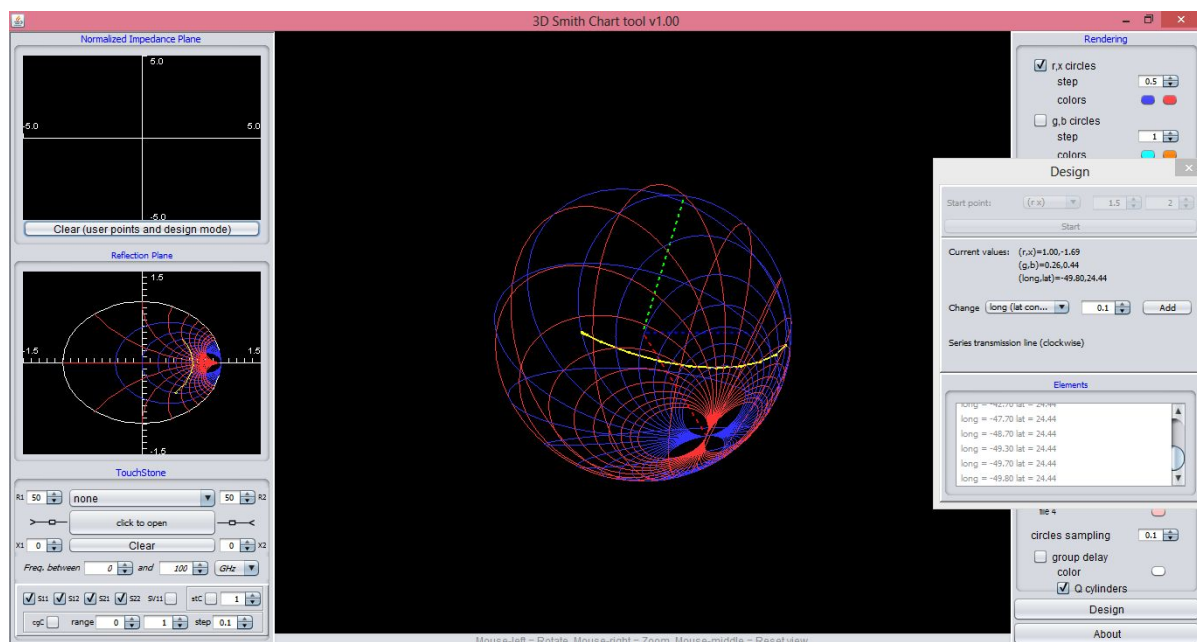


Please note that in order to get visually to the desired matching point it is advisable to choose :

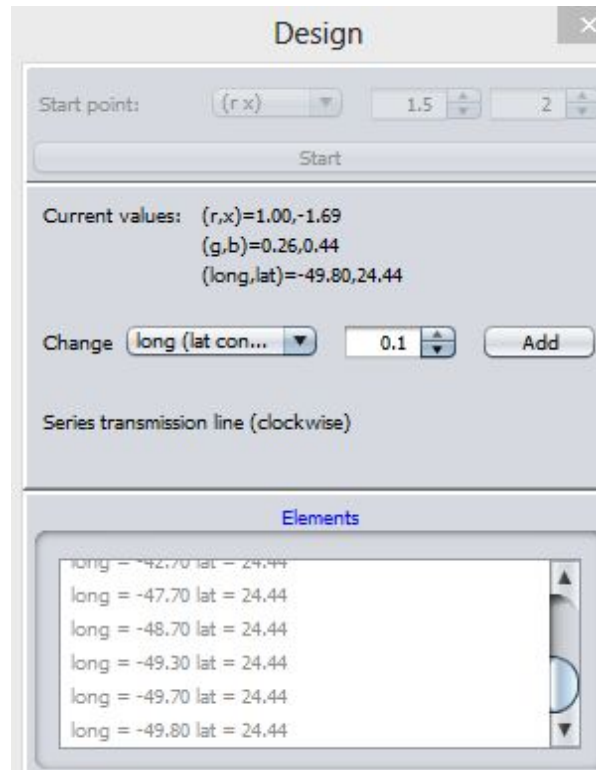


In order to see the  $r=1$  and  $g=1$  circles. If the user does choose a different rendering these circles may or may not be displayed- depending on the steps!

Let us consider that we would like to reach the  $r=1$  circle on a lossless transmission line:



*Adding lossless transmission lines ( constant latitude circle)- adding small lengths step by step towards the  $r=1$  circle ( longitude changes)*

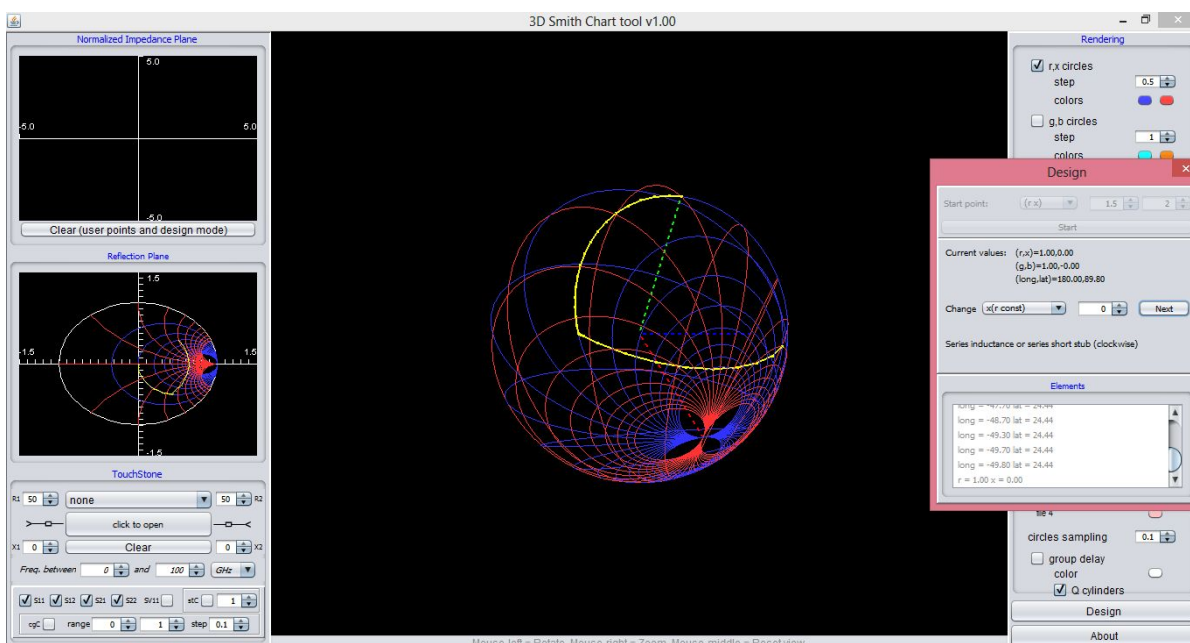


*Adding lossless transmission lines ( constant latitude circle)- adding small lengths step by step towards the  $r=1$  circle ( longitude changes)-circle reached when  $x=-1.69$*

Please note that we have reached the longitude -49.8 ( West) and we started from 37.3 ( East) thus we have made a movement of 87.1 degrees corresponding to an electrical length of 43.65 degrees.

Again to reach the North pole we have to move on  $r=1$  circle now.

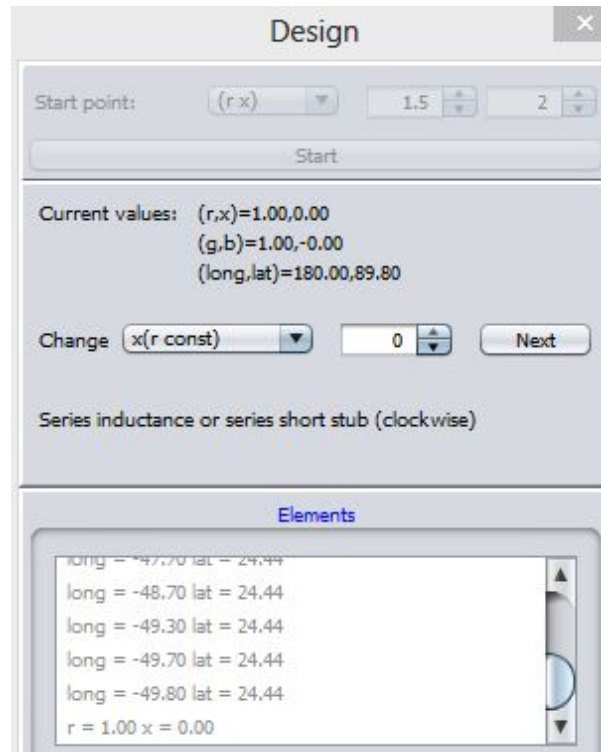
Choose  $x$  (  $r$  const) and press next 0 ( to increase the  $x$  from -1.69 to 0):



*Adding the proper stub from  $(r,x)=(1,-1.69)$  to  $(r,x)=(1,0)$*

The program tells you what kind of an element you have added.

To compute its value please see the example files



*North pole or center of the Smith chart is reached Current value  $(r,x)=(1,0)$*

## DESIGN MODE IMPORTANT FEATURE

From each point you enter, you can reach any other point on the corresponding circle you have chosen: if you add L,C elements however you will see that you may not be able to perform a complete rotation once you have chosen a direction of movement.

- Please type:  $g=1$   $b=-1.47$

Design

Start point: (g b) 1 -1.47

Start

Current values: (r,x)=0.32,0.47  
(g,b)=1.00,-1.47  
(long,lat)=126.32,28.73

Change g (b const) 1 Next

Description of performed change:

Elements

g = 1.00 b = -1.47

*g=1 b=-1.47 is displayed*

Let us now try to get to (g,b)=(1,0). Option 1: let us increase b from -1.47 to 0 ( clockwise)

Type b=0 and next

Design

Start point: (g b) 1 -1.47

Start

Current values: (r,x)=1.00,-0.00  
(g,b)=1.00,0.00  
(long,lat)=180.00,90.00

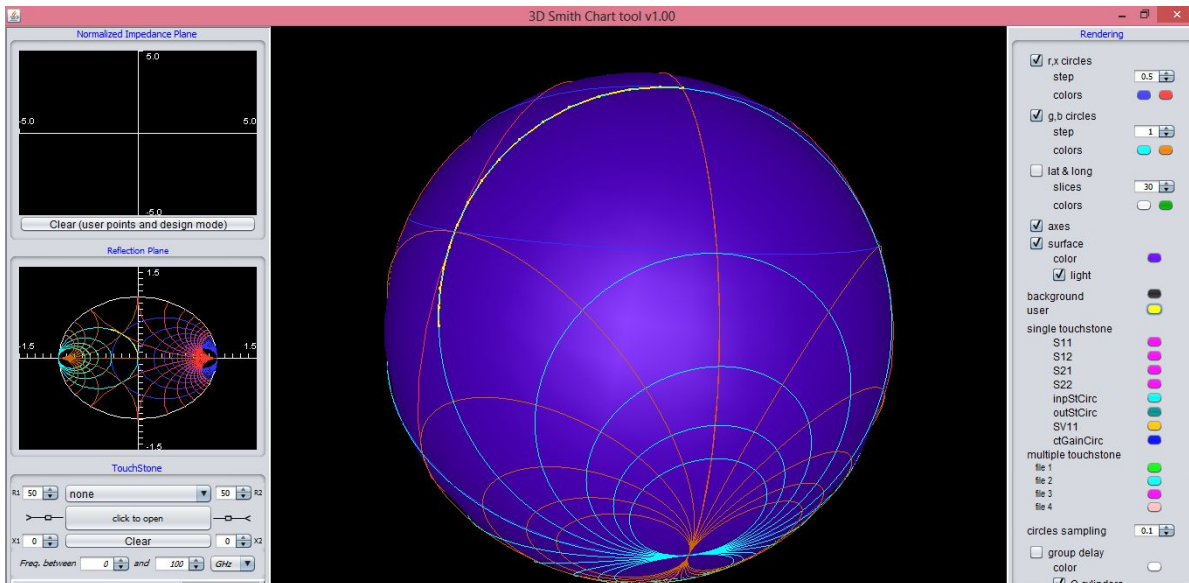
Change b (g const) 0 Next

Shunt capacitance or shunt open stub (clockwise)

Elements

g = 1.00 b = -1.47  
g = 1.00 b = 0.00

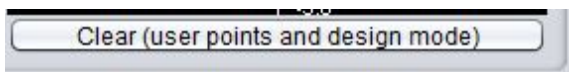
*g=1 b=-1.47 is displayed together with the next point (1,0)*



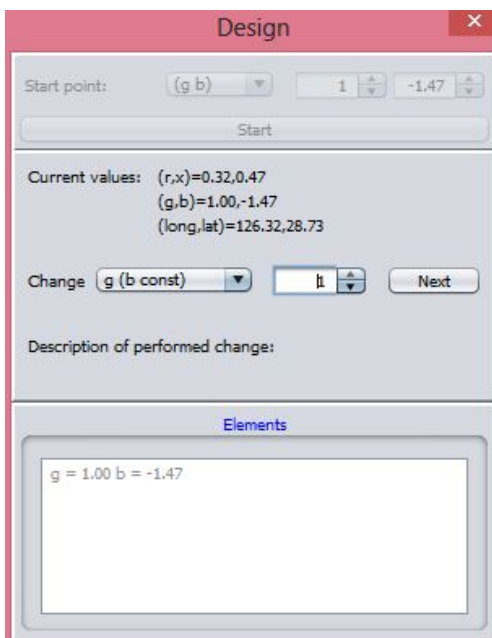
*Clockwise movement ( matching - shunt open stub)*

Let us assume now that we wish to reach the North pole anticlockwise:

Clear the operations:



- Please type:  $g=1$   $b=-1.47$



*$g=1$   $b=-1.47$  is displayed*



- Please try to decrease  $b$  ( decrease=anticlockwise) dramatically and type -30

Design

Start point: (g b) 1 -1.47

Start

Current values: (r,x)=0.00,0.03  
(g,b)=1.00,-30.00  
(long,lat)=176.19,0.13

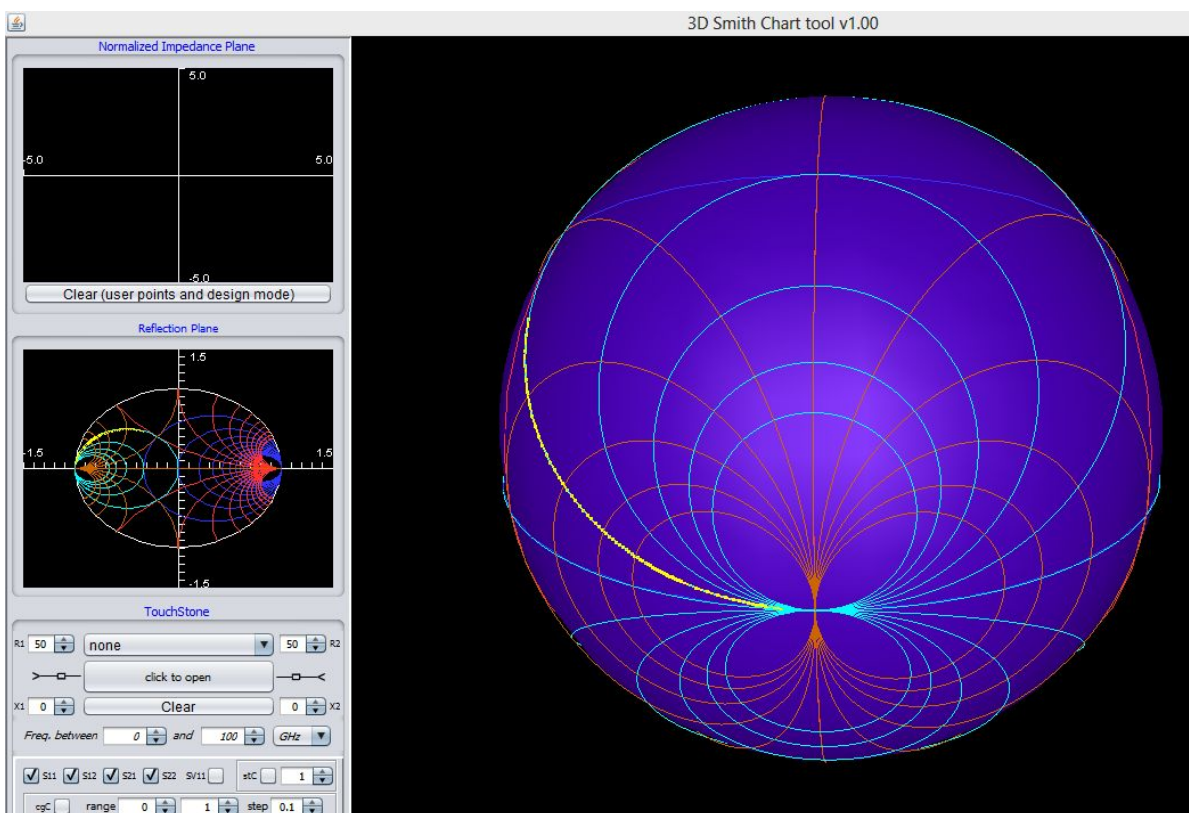
Change b (g const) -30 Next

Shunt inductance or shunt short stub (anticlockwise)

Elements

g = 1.00 b = -1.47  
g = 1.00 b = -30.00

*We have added a short stub but cannot exceed  $b < -128$*



*Shunt short stub added*

- Please try to decrease  $b$  dramatically and type -128

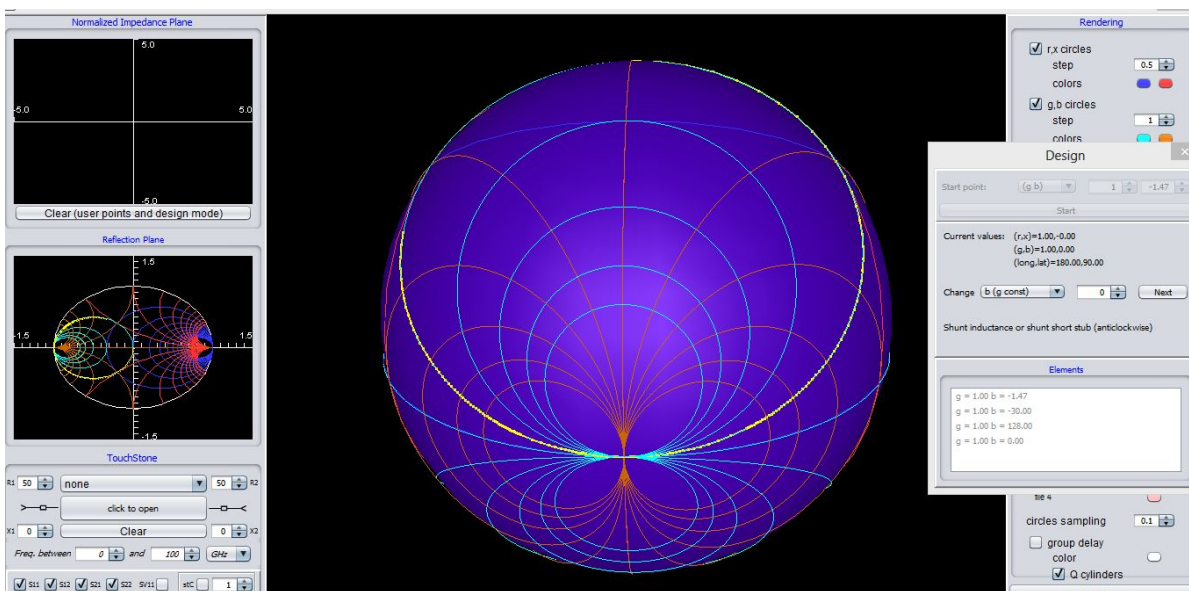
At this stage the program swaps to +128 and you can switch on the other part of the circle, and continue decreasing until you get 0. Please note that no lumped element can perform this sign change thus you have used a stub .



*Automatic detection of a passing through infinity- the program switches to +128 and you can continue decreasing and add a longer short stub until you reach the north pole/ center*

Please try to decrease b dramatically and type **-128**

- Please press now 0 to decrease ( anticlockwise) to (g,b)=(1,0)
- The way in which you can compute the final elements values is explained in the Examples ( simply look on the initial values and final values)



*Shunt short stub added - of the proper length needed to reach the North pole*

When you have to pass through the open circuit or short circuit the magnitude of x and b increase to infinity. No lumped element can switch signs but stubs can do. When you are limited on your path clockwise or anticlockwise simply type +128 or -128 and the program will automatically pass through infinity keeping your direction ( and thus allowing you to use a stub to perform the match)

# EXAMPLES

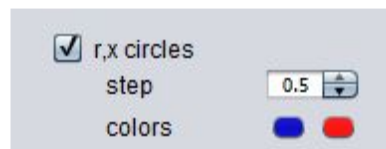
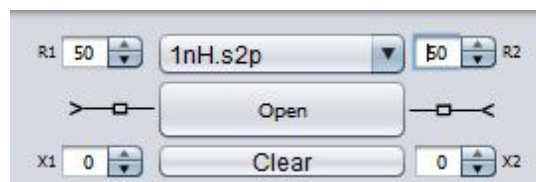
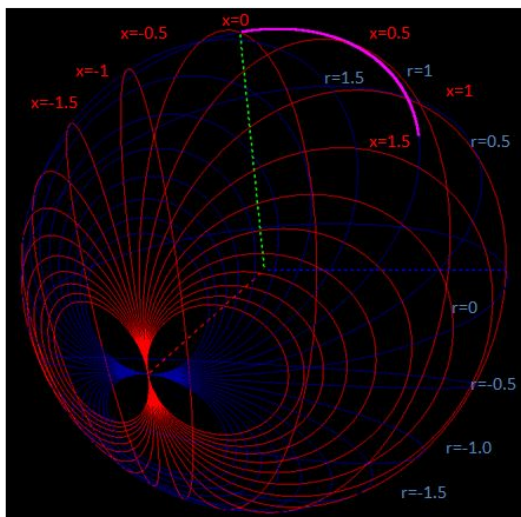
## ANALYSIS MODE-PASSIVE CIRCUITS

### A SERIES INDUCTOR OF 1nH.

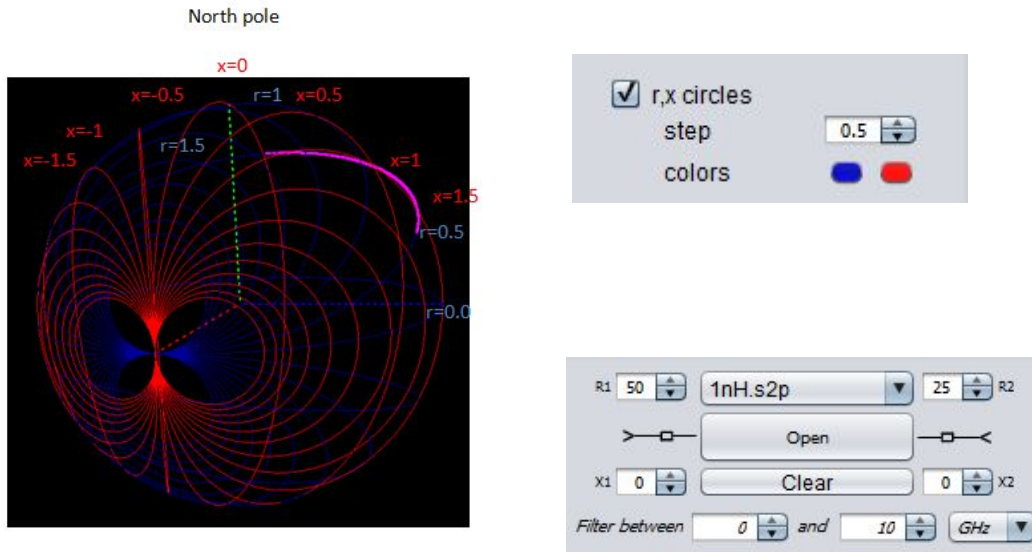
#### SIMPLIFIED VISUAL EXPLANATION

What happens as we analyze the reflection coefficient of series inductor of  $L=1$  nH loaded with a 50 Ohm impedance at a generator with a given real impedance is:

- The reflection coefficient will move on a path of  $r=\text{constant}$  ( clockwise); if the load and the source impedances are equal , on the  $r=1$  circle while  $x$  - its normalized reactance- will become more and more bigger thus we will move on the  $r=1$  circle towards higher values of  $x$ .
- If we wish to use different load impedances, for example considering the source impedance of  $Z_s=50$  Ohms and the load impedance of  $Z_l=25$  Ohms, then as the frequency increases we will move always on the  $r=0.5$  circle, if the load impedance is 75 Ohms, we will move on the  $r=1.5$  circle.



*Getting familiar with different customizations of the main window*



## REACTANCE&RESISTANCE&PORTS&THEORY

$R$ =Resistance while  $X$ = Reactance;

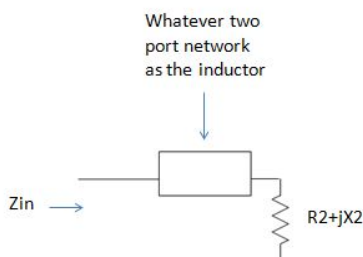
$Z = R + jX$ = Impedance

$Z/Z_0$ =normalized impedance input impedance= $z = r + jx$

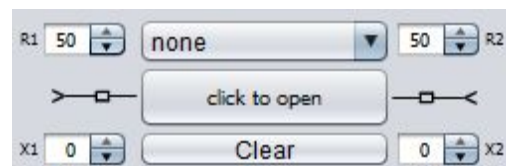
Let us consider a 1nH inductor from the help files and let us first consider  $Z_0 = R_1 = 50$  Ohms and  $Z_0 = R_2 = 50$  Ohms

$Z_{\text{inductor}} = R + jX = 0 + jX$ ;  $Z_{\text{in}} = Z_{\text{inductor}} + Z_{\text{load}}$

$Z_{\text{in}} = jX + R_2 + jX_2 = jX + 50$  and  $z_{\text{in}} = Z_{\text{in}}/Z_0 = r + jx$



Port 1 with  
 $Z_0 = R_1 + jX_1$



Port 2 with  $Z_0 = R_2 + jX_2$

The reactance of the a  $L=1\text{nH}$  inductor will be:  $X=wL=2\pi f_{\text{GHz}} \cdot 10^{-9}=6.283 \cdot f_{\text{GHz}}$

$R_L=\text{load impedance}=R_2=50\text{ Ohms}$

$Z_{\text{in}}=jX+R_2=jX+50$

$z_{\text{in}}=Z_{\text{in}}/Z_0=Z_{\text{in}}/(R_1+jX_1)=Z_{\text{in}}/50=r+jx$

$r=R_2/R_1=50/50=1$

The normalized reactance is:  $x=X/50=6.283 \cdot f_{\text{GHz}}/50=0.1257 f_{\text{GHz}}$

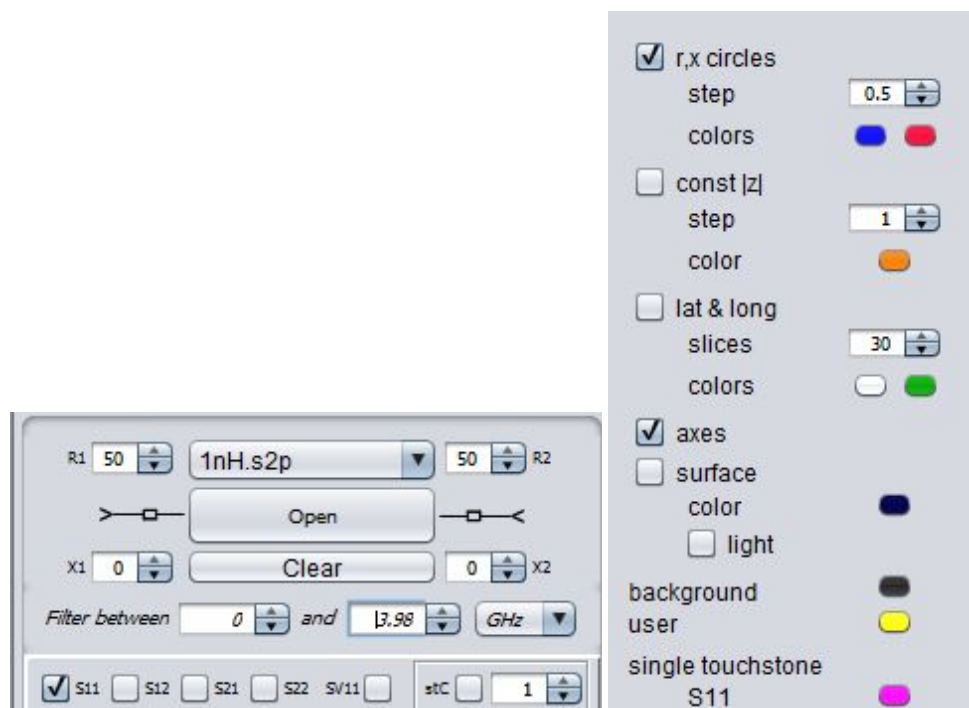
$z_{\text{in}}=r+jx=1+j0.1257 f_{\text{GHz}}$  the normalized resistance is always 1; the only variable is the x

$L=1\text{nH}$	3.98GHz	7.96GHz	9.55GHz
$x=0.1257 f_{\text{GHz}}$	0.5	1	1.2

Thus the constant normalized reactance is moving on a line in the normalized impedance plane with  $r=1$  and  $jx$  variable as x changes with frequency

## REACTANCE&RESISTANCE CIRCLES

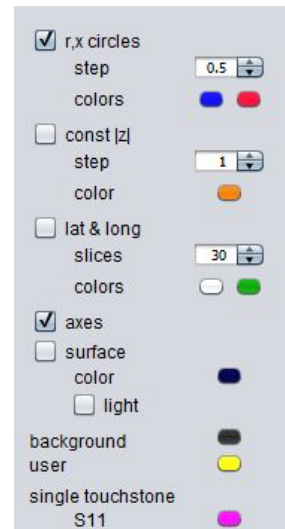
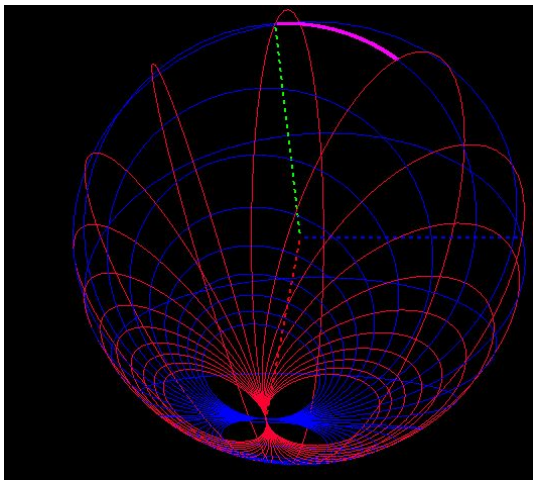
Let us analyze the the inductor in the frequency interval between 0 GHz- 3.98 GHz.





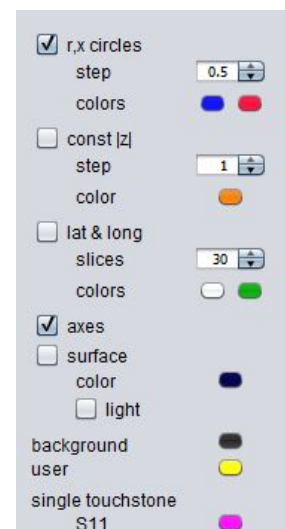
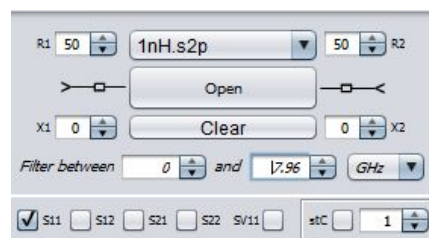
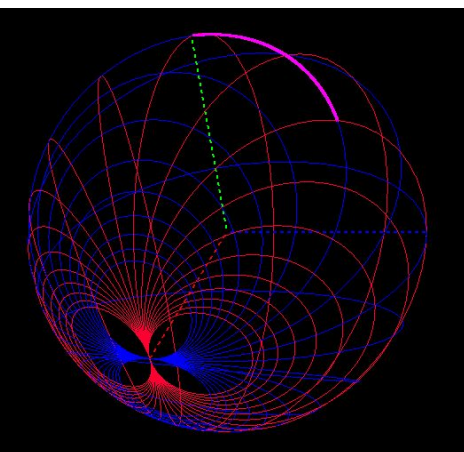
What happens is the following:

We move on the  $r=1$  circle until we get to the  $x=0.5$  circle. It is easy to check what circle of constant resistance or reactance we are on by setting the step of the  $r,x$  circles (step=0.5- second circle east is the 0.5 reactance circle). The same by setting the mouse on the 3D Smith chart one can read the corresponding  $r$  and  $x$  circle values on the impedance plane left side corner.



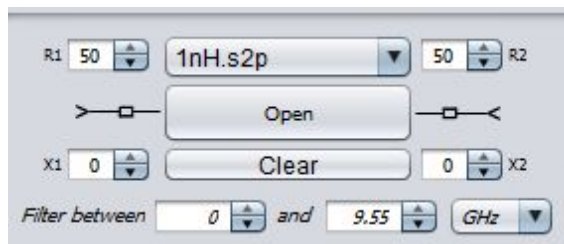
*Analyze performed on a limited frequency range*

Let us analyze the the inductor in the interval 0 GHz- 7.96GHz, again keeping the same step we can see that now we reached the second circle of constant  $x$  East of Greenwich thus of  $x=1$ .

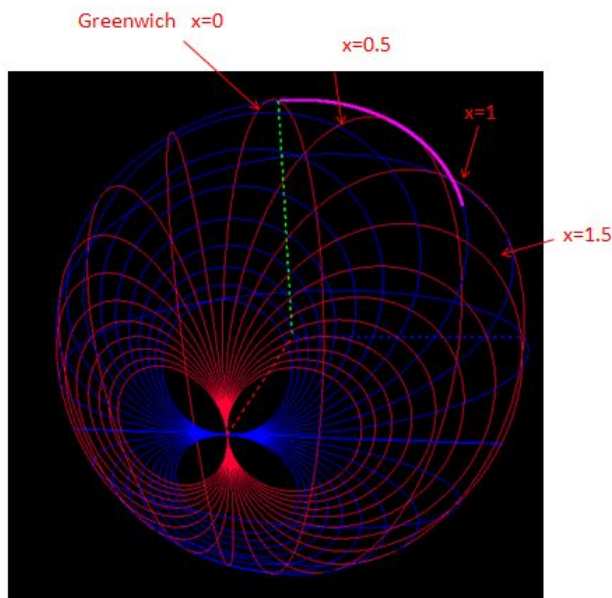


*Getting familiar with different customizations of the 3D view*

Looking with a step of 0.5 between the constant  $x$  circles we cannot see the value of  $x$  reached at 9.55 GHz on the 3D Smith chart ( we could only by going with the mouse on the point - read it in the impedance plane).



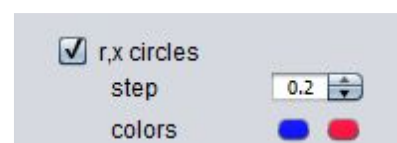
*Change of the frequencies*

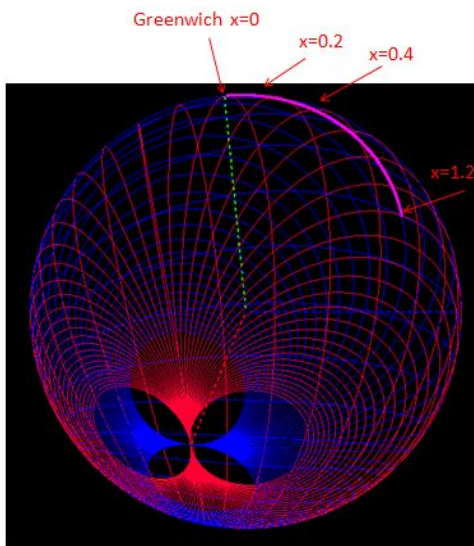


*Getting familiar with different customizations of the 3D view*

*0.5 step of  $r, x$  circles*

However by changing the step we can choose  $r, x$  step=0.2 and then we can get the image below and get the value from the table

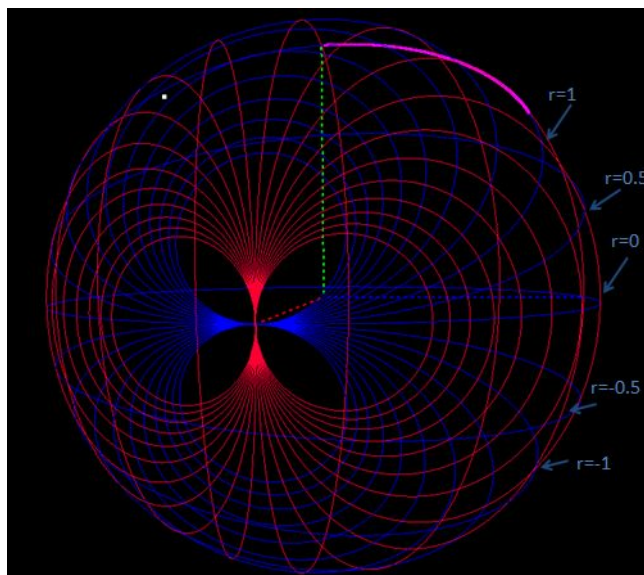




*Getting familiar with different customizations of the 3D view*

*0.2 step of  $r, x$  circles*

Counting on the red ( $x$ ) circles we are on the sixth circle with a step of 0.2; thus on the 1.2 constant  $x$  circle; counting from the  $x=0$ =Greenwich circle.

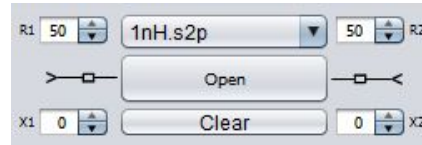


*Getting familiar with different customizations of the 3D view*

*0.5 step of  $r, x$  circles*

It is worth mentioning that by changing the frequency we change the reactance of the circuit but we do not change the resistance which stays constant  $r=50/50=1$  thus we will always move on the  $r=1$  circle.

## REFLECTION COEFFICIENT (LATITUDE LONGITUDE)



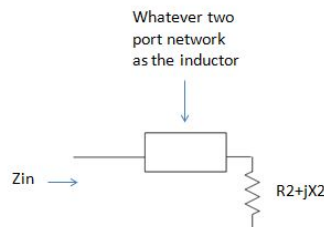
AND

$$Z_{in} = j\omega L + R_2 + jX_2 = j\omega L + R_2 + 0 = j\omega L + 50$$

$$Z_{01} = 50$$

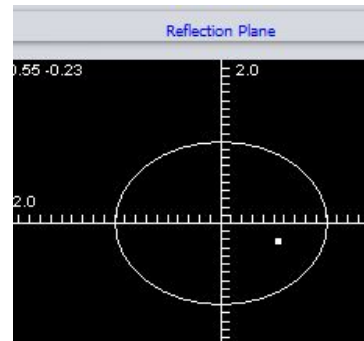
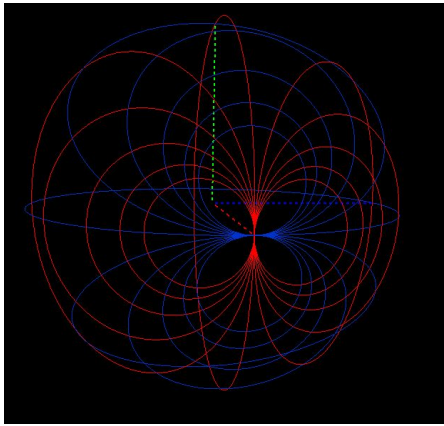
$$S_{11} = \frac{Z_{in} - Z_{01}}{Z_{in} + Z_{01}} = \frac{\frac{Z_{in}}{Z_{01}} - 1}{\frac{Z_{in}}{Z_{01}} + 1} = \frac{z_{in} - 1}{z_{in} + 1} = \frac{r + jx - 1}{r + jx + 1}$$

$$S_{11} = \frac{Z_{in} - Z_{01}}{Z_{in} + Z_{01}} = \frac{j\omega L + 50 - 50}{j\omega L + 50 + 50} = \frac{\frac{j\omega L}{50} + 1 - 1}{\frac{j\omega L}{50} + 1 + 1} = \frac{0.1257fLj}{0.1257fLj + 2} = \frac{xj}{xj + 2}$$



The  $S_{11}$  parameter is of form  $(ag(f)+b)/(cg(f)+d)$  since  $x$  depends on  $f$ . All transformations of this type map lines into circles. In our case  $g(f)=jx=j0.1257*f$  is a line in the impedance plane.

( thus it is straightforward that  $S_{11}$  will be moving a circle)



### *Some theory*

To read the value please put the mouse over the frequency point of interest in the 3D main window and read on the 2d reflection coefficient the value

Latitude and longitude:

The longitude gives the angle of the reflection coefficient ( on a constant longitude circle the angle is the same) ( East inductive + sign convention) , West- negative sign convention. Looking on the longitude one may check the angle

L=1nH	3.98GHz	9.55GHz
$x=0.1257f_{\text{GHz}}$	0.5	1.2
Angle (S11)=Longitude	75	59

The user can check these values by putting the mouse over the frequency point of interest and read them in the impedance plane (r,x) or checking and checking the longitudes on the 3D Smith chart window.

Latitude:

On a latitude circle the reflection coefficient's magnitude is constant



The latitude is connected with the reflection with:

Abs(S11)=

$$\left( \frac{1 - \sin\left[\frac{\text{lat}\pi}{180}\right]}{1 + \sin\left[\frac{\text{lat}\pi}{180}\right]} \right)^{0.5}$$

lat	0	15	30	45	60	75	90	-15	-30	-45	-60	-75	-90
Abs (s)	1	.77	.57	.41	.27	.13	0	1.3	1.7	2.4	3.7	7.6	inf

Equator

N pole

Southp.

You can check all values by placing the mouse over the frequency point of interest on the 3D main tool and then look as suggested below

Getting familiar with different customizations of the 3D view

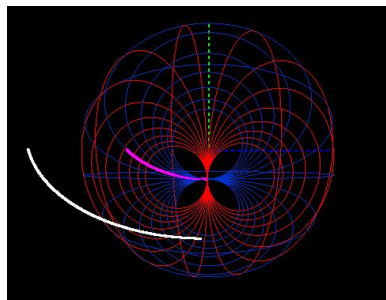
L=1nH	Read in the tool	3.98GHz	9.55GHz
x=0.1257f <sub>GHz</sub>	-3d main window - impedance plane	0.5	1.2
S11=(xj)/(xj+2)	-reflection coefficient plane -	0.058+j235	0.26+0.44
Angle (S11)=Longitude	Reflection coefficient plane	75	59
Abs(S11)	-Reflection coefficient plane - or read latitude	0.24  lat=63	0.51  lat=35

## GROUP DELAY 3D (ADVANCED OPTION)

The group delay is normalized to its maximum value over the frequency range of analysis and can be displayed as below:

$$\tau(\omega) = -\frac{d\angle S_{ij}(\omega)}{d\omega}$$

$$\tau_N(\omega) = \frac{\tau(\omega)}{|\tau(\omega)|_{MAX}}$$



3D group delay ( white over the S21 parameter)

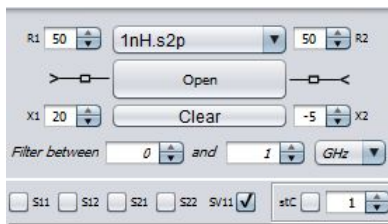
☒ group delay  
color ☐

For an academical explanation of the concept the user may check also reference [1]

# VOLTAGE REFLECTION COEFFICIENT- COMPLEX IMPEDANCES (ADVANCED OPTION)

Let us now consider that we work with complex impedances, for example:

$$Z01=(50+j20) \text{ ohms, while } Z02= (50-j5) \text{ ohms}$$



*SV11- box for voltage reflection coefficient- use it when you have complex parts of the ports-input port*

Please check the SV11 box in order to see the voltage reflection coefficient if complex port impedances occur.

$$Z_{in}=Z02+Z_{inductor}= Z02+ jX= 50-j5+j\omega L=50-j5+j6.283 \cdot f_{GHz}$$

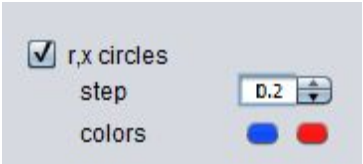
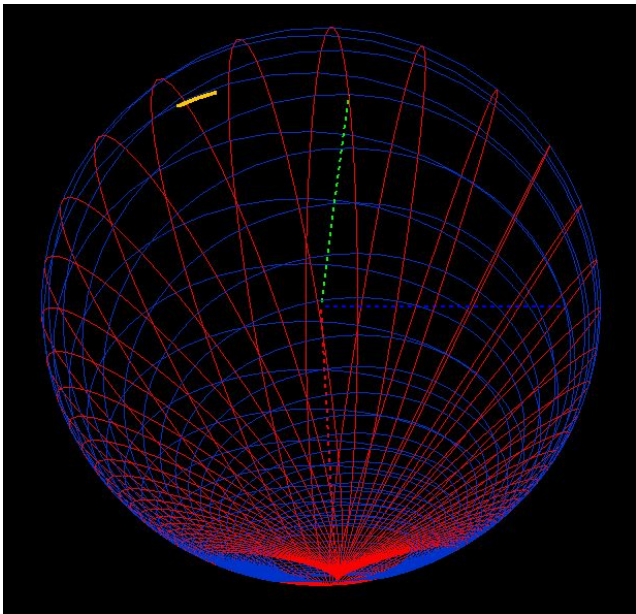
$$z_{in}=Z_{in}/Z01= (50-j5+j6.283 \cdot f_{GHz})/(50+j20)=0.827+0.0433f_{GHz}+j(-0.431+0.108f_{GHz})$$

$$r=0.828+0.043f_{GHz}$$

$$x=-0.43+0.108f_{GHz}$$

L=1nH	0GHz	1GHz	10GHz
x	-0.43	-0.32	0.65

r	0.828	0.87	1.26
---	-------	------	------



Getting familiar with different customizations of the 3D view  
0.2 step of r,x circles

Again if the user is interested in the value of the voltage reflection coefficient in this case, one should put the mouse over the frequency point of interest and read in the reflection coefficients plane the value.

$$S_{11} = \frac{Z_{in} - Z_{01}}{Z_{in} + Z_{01}} = \frac{\frac{Z_{in}}{Z_{01}} - 1}{\frac{Z_{in}}{Z_{01}} + 1} = \frac{z_{in} - 1}{z_{in} + 1} = \frac{r + jx - 1}{r + jx + 1}$$

r=0.828+0.043f<sub>GHz</sub>

x=-0.43+0.108f<sub>GHz</sub>

L=1nH	Read in the tool	1 GHz	10GHz
SV11	Put the mouse of the point of interest and read the value in the reflection plane	-0.04-0.18j	0.18+j0.24

--	--	--	--

## Ex 2: SERIES INDUCTOR AND LOSSLESS TRANSMISSION LINE

### SIMPLIFIED VISUAL EXPLANATION

3D:

Let us now imagine that we add to our circuit a [transmission line](#) which has the same characteristic impedance as the source impedance and it is lossless. What happens with the reflection coefficient? Depending on the length of the transmission line, its reflection coefficient will move on a constant latitude clockwise from the given position ( longitude) ( if we move towards the generator).

### THEORY

Let us now consider that we add a transmission line of angle  $A=90$  deg at 5 GHz connected to the inductor of  $L=1$  nH.

The voltage reflection coefficients magnitude will stay unchanged  $|S_{11}| = |S_{11}|$  but its phase changes: it will rotate with the angle  $2 \times 90 = 180$  degrees towards the generator-clockwise (

$$Z_{in} = Z_0 * \frac{Z_L + jZ_0 * \tan(\beta l)}{Z_0 + jZ_L * \tan(\beta l)}$$

$$S_{11i} = S_{11l} * e^{-2j\beta l}$$

This happens with the reflection coefficient if and only if  $Z_0=Z_{01}$  which happens in most of the cases.

The voltage reflection coefficient of the inductor loaded with the 50 Ohms second port impedance was already computed as:

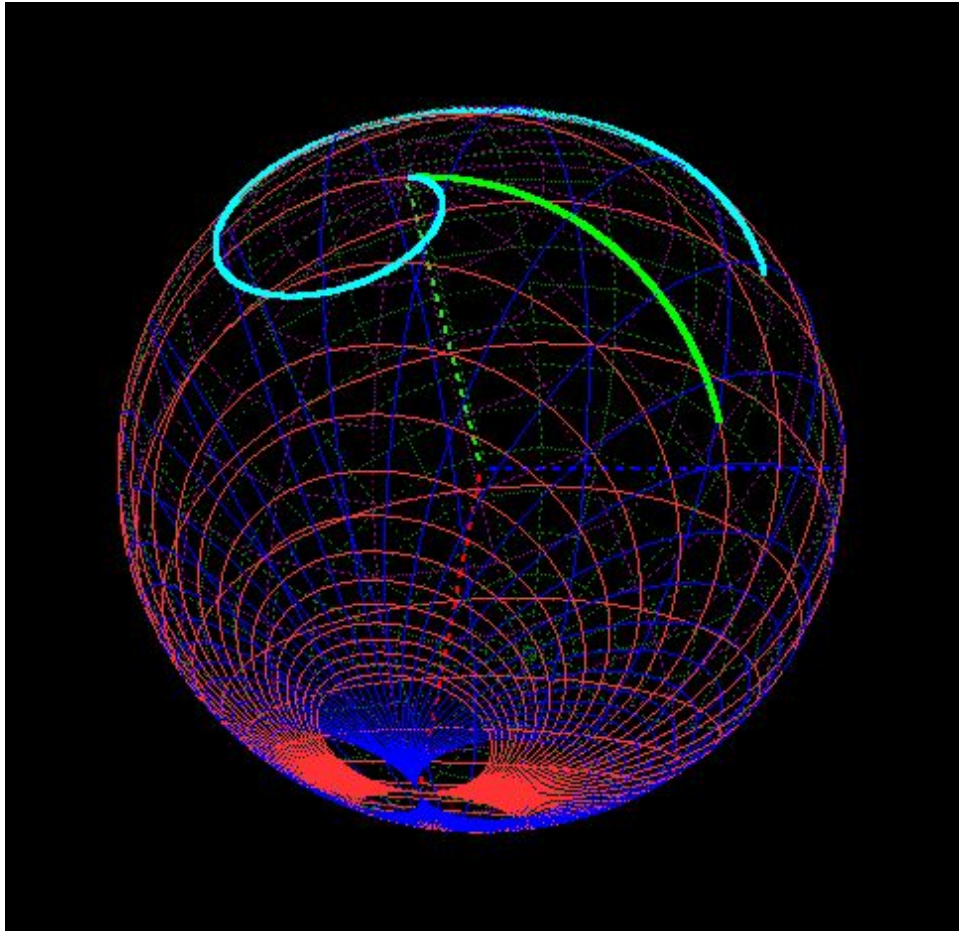
$$S_{11} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = \frac{j\omega L + 50 - 50}{j\omega L + 50 + 50} = \frac{\frac{j\omega L}{50} + 1 - 1}{\frac{j\omega L}{50} + 1 + 1} = \frac{0.1257fLj}{0.1257fLj + 2} = \frac{xj}{xj + 2}$$

$$x = 0.1257f_{\text{GHz}}$$



$L=1nH$	Read in the tool placing the cursor over the frequency point of interest.	5GHz
$x=0.1257f_{GHz}$  $r=R2/R1=1$	-3d main window or - impedance plane	$x=0.5$  $r=1$
$S_{11}=(xj)/(xj+2)$	-reflection coefficient plane	$0.09+j0.29$
S11 angle= longitude	Read on the 3D main window or in the reflection coefficients plane/ reflection coefficient's plane	73 East
S11 latitude	Read on the 3D main window or Read magnitude directly in the reflection coefficient ( converted from latitude)	57 North

At 5 GHz what happens then is that we move 180 degrees on the 57 North latitude from 73 East, thus the new S11 will have the same magnitude but the angle with 180 degree difference so that it will be on 57 N and 107 West and will have the value  $=-S_{11}=-0.09-0.29j$ .

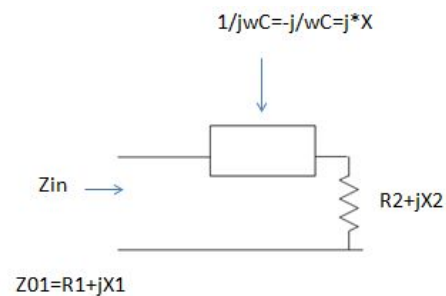
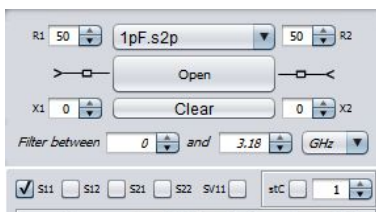


*Getting familiar with the 3D view/ transmission lines*

## Ex 3: A SERIES CAPACITANCE OF $C=1$ pF:

Consider  $Z_0=50$  Ohms for example ; then:

The reactance of the will  $X=-1/2 \pi /f_{\text{Hz}}/10^{-12}=-159/f_{\text{GHz}}$

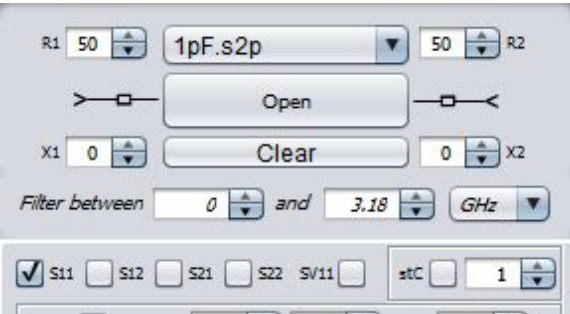


$R_L$  =load impedance= $R_2=50$  Ohms

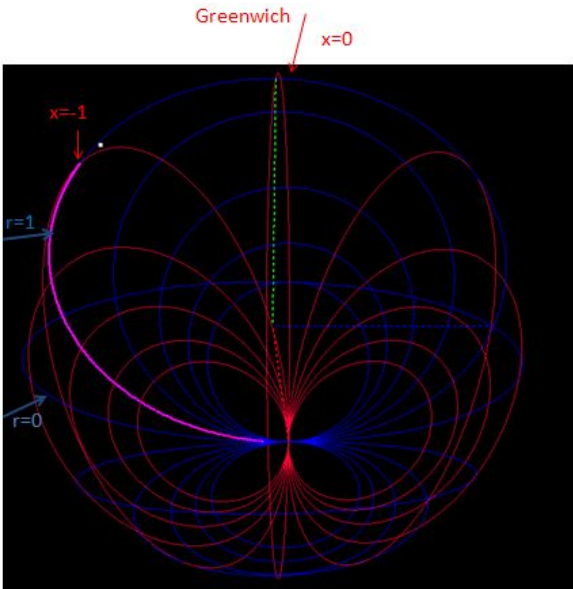
$r=R2/R1=50/50=1$   
 $z_{in}=r+jx=1+jx$  the normalized resistance is always 1; the only variable is the x  
 $x=X/Z01=Z/R1$

$x=X/50=-159/f_{GHz}/50=-3.183/f_{GHz}$

C=1pF	3.18GHz	6.37GHz	7.96GHz
x	-1	-0.5	-0.4
r	1	1	1



Displaying S11 over a limited frequency



Getting familiar with the 3D view/ rendering



Analyzing the capacitor between 0 and 3.18 GHz we can see that again the S11 parameter moves on the  $r=1$  constant normalized resistance circle and by properly choosing the step we can indeed see that at 3.18GHz the normalized reactance will be -1.

Again one could easily go with the mouse over the point of interest on the 3D Smith chart and read in the impedance plane the values of the corresponding resistance and reactance.

Again to read off on the 3D Smith chart the  $x=0.4$  value.

## Analysis mode-active circuits

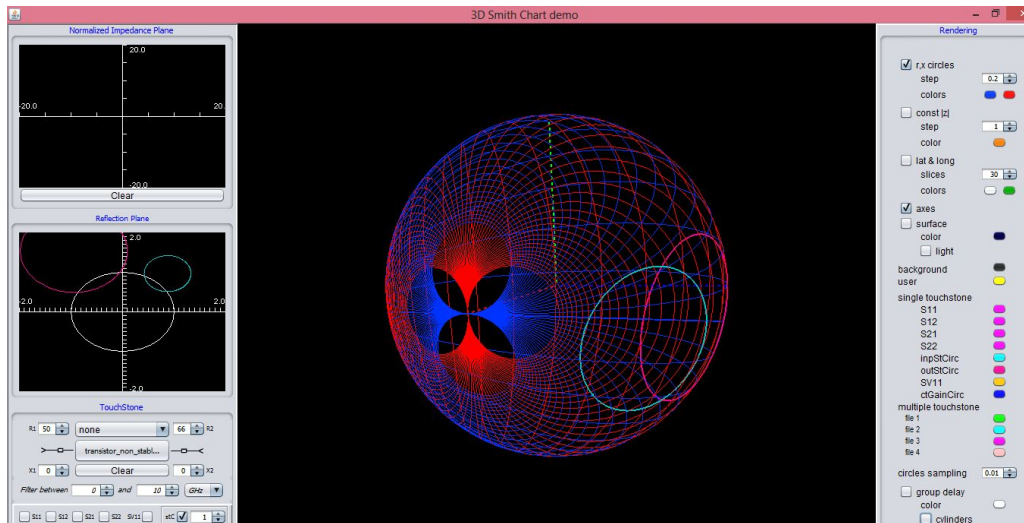
### Ex 4: AMPLIFIER STABILITY CIRCLES-TRANSISTOR EXAMPLE

The stability circles can be completely shown on the 3D Smith chart tool by activating their box and choosing the desired frequency range of analysis.



Let us consider the transistor with the following S parameters at 0.8 GHz

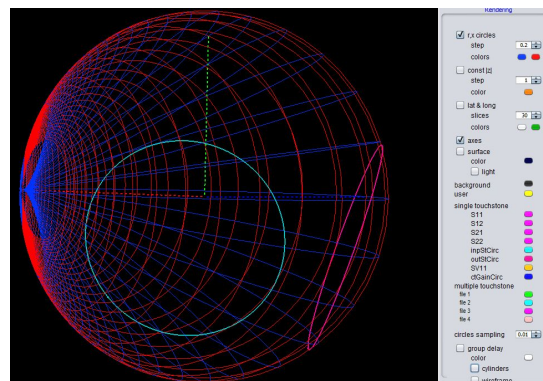
F- GHz	S11 mag	S11 angle	S12 mag	S12 angle	S21 mag	S21 angle	S22 mag	S22 angle
0.8	0.65	-95	5	115	0.035	40	0.8	-35



### Getting familiar with the 3D view- two stability circles

Let us zoom in into the input stability circle with an  $r, x$  circle step of 0.2. In the rendering window

If we examine the circle we may notice that its



### Getting familiar with the 3D view- two stability circles: zooming in/ easier to read in the impedance plane the $r, x$ values corresponding to them

The most northern point lies below the  $r=0.2$  circle.

To see exactly its most northern point please go with the mouse over it and read off in the impedance plane the values of  $r, x$

Since the circle does not include the north pole in its interior it means that the region of instability lies inside of it.

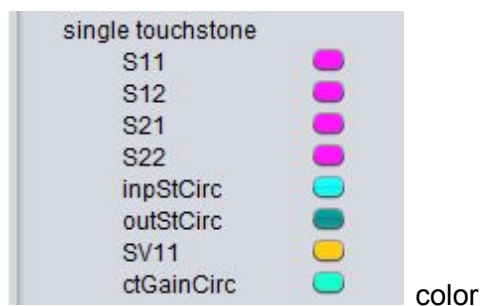


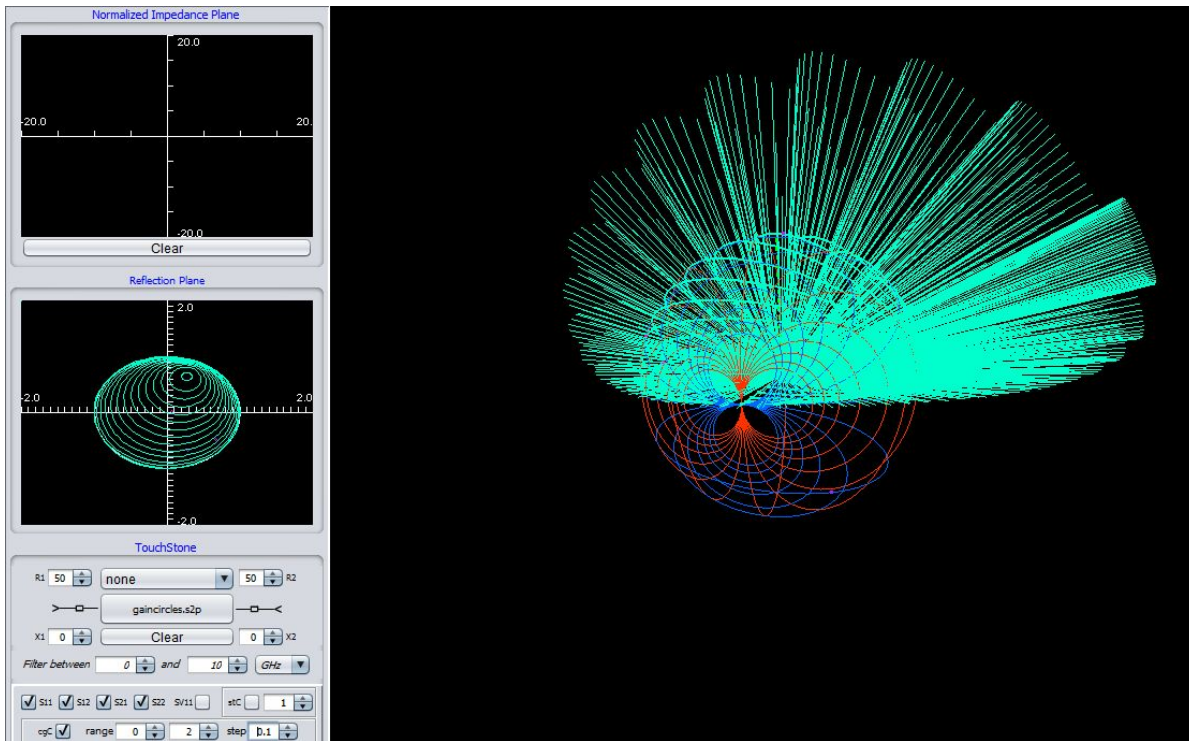
## Ex 5: (INPUT) UNILATERAL CONSTANT GAIN CIRCLES-

Consider the transistor with the following parameters: ( gaincircles.s2p file)

F- GHz	S11 mag	S11 angle	S12 mag	S12 angle	S21 mag	S21 angle	S22 mag	S22 angle
0.8	0.707	-67	5.45	119	0.058	40	0.84	-32

To plot the stability circles we can select their range (in abs value) and their step:





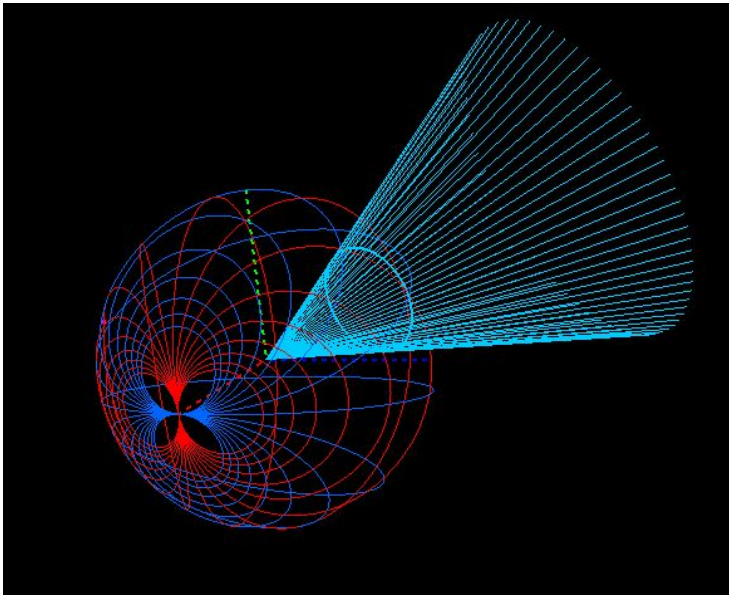
*Transducer power gain circles*

The gain of this transistor is  $10 \log(\text{mag}(s_{21})^2) = 14.7 \text{ dB}$

Let us find the source which allows one to increase its gain to 2.3 dB.

This means:

- Find the gain circle who has the value of  $10 \cdot \log(10, x^2) = 2.3 \text{ dB}$  ; please see the [unilateral constant gain design rules](#) for a more detailed explanation
- $x = 1.31$ , simply plot the desired circle.



Please change their sampling in order to see them as you desire

## Design mode- Lumped circuits (L,C)

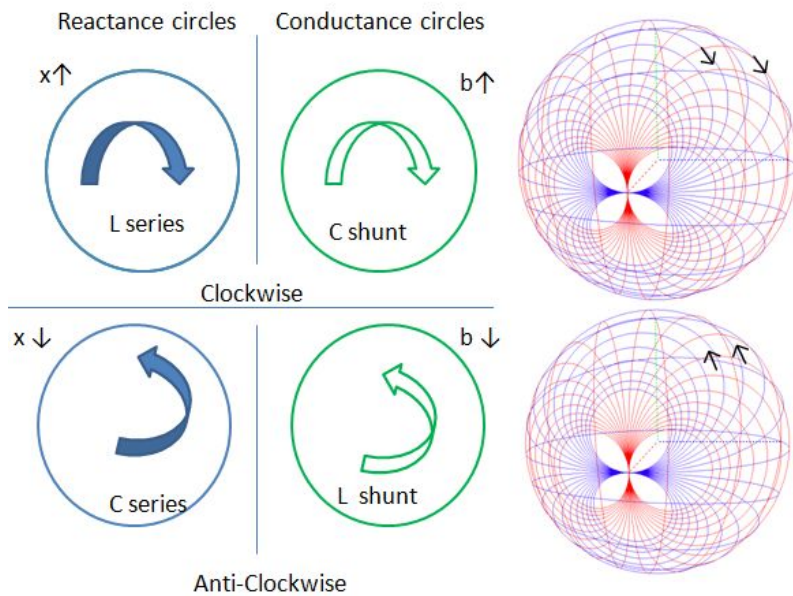
The design mode allows the user to draw on the 3D Smith chart the matching circuits on the [constant resistance circles  \$r\$](#) , [constant normalized reactance circles  \$x\$](#) , [constant normalized conductance circles  \$g\$](#) , [constant normalized susceptance circles  \$b\$](#)  and [constant magnitude of reflection coefficient circles \(latitude\)](#)

Regardless of the surface one may assign to any simple closed curve on it ( as the circle is too) an orientation which can be clockwise or anti clockwise.

**Rules:  $r$  circles: moving clockwise on them=adding series inductors; anticlockwise capacitors.**

**Rules:  $g$  circles: moving clockwise on them=adding shunt capacitors; anticlockwise shunt inductors.**

## LC DESIGN GUIDELINES



The design mode is a visual feature which helps the user to match its circuit at the desired frequency starting from one point:

- Introduce from the keyboard the point of interest in the impedance plane.
- The aim is to get to the North pole in order to get the matching moving only on constant  $r, x, g, b$  and latitude circles:
- The path one follows gives one matching network.

## LC -COMPUTATION

Action	Z	Y	3D tool/2D	Hint
Type $r_1 ; x_1$ i.e $R_1/Z_0; X_1/Z_0$	$P_1 r_1 + jx_1$	$g_1 + jb_1$	Look on main window/ reflection plane	
<b>case1:</b> Move <b>clockwise</b> on <b>r1</b> circle and click on a point	$P_2 r_1 + jx_2$	$g_2 + jb_2$	Look on all windows and read $Z_2, Y_2$ in the impedance plane	$x \uparrow$ thus $x_2 > x_1$ ; $(x_2 - x_1) = wL/Z_0$ i.e $L = Z_0(x_2 - x_1)/w$
<b>case2:</b> Move <b>anti clockwise</b> on <b>r1</b> circle and click on a point	$P_3 r_1 + jx_3$	$g_3 + jb_3$	Look on all windows and read $Z_3, Y_3$ in the impedance plane	$x \downarrow$ $x_3 < x_2$ ; $(x_2 - x_3)Z_0 = 1/wC$ ; $C = 1/(x_2 - x_3)/w/Z_0$
<b>case3:</b> Move <b>clockwise</b> on <b>g3</b> circle and click on a point	$P_4 r_4 + jx_4$	$g_3 + jb_4$	Look on all windows and read $Z_4, Y_4$ in the impedance plane	$b \uparrow$ $b_4 > b_3$ ; $(b_4 - b_3)Y_0 = wC$ ; $C = (b_4 - b_3)/Z_0/w$
<b>case4:</b> Move <b>anti clockwise</b> on <b>g3</b> circle and click on a point	$P_5 r_5 + jx_5$	$g_3 + jb_5$	Look on all windows and read $Z_5, Y_5$ in the impedance plane	$b \downarrow$ $b_5 < b_4$ ; $(b_4 - b_5)Y_0 = 1/w/L$ $L = Z_0/w/(b_4 - b_5)$



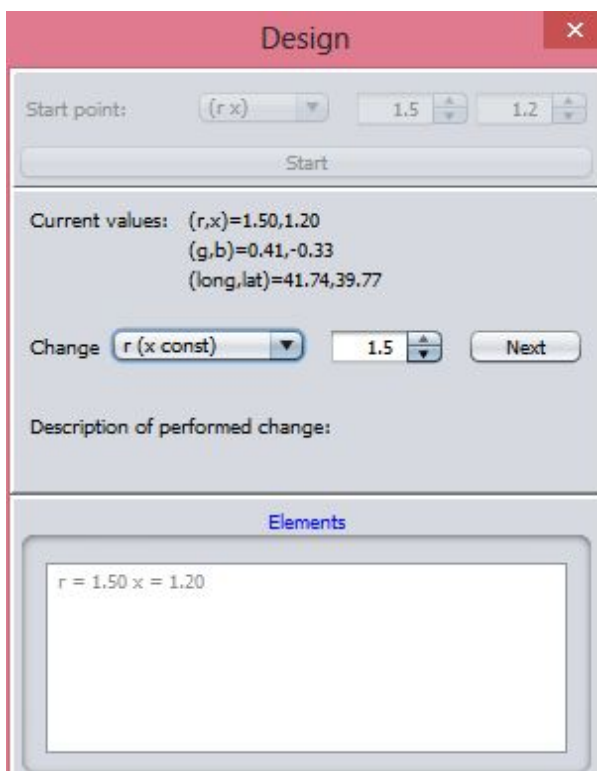
## EXAMPLE 1B

Let us consider the  $Z_{load} = 25 + j60$  and that we wish to match it to a 50 Ohm impedance, for example at 1 GHz. using L, C elements we get:

$r = 75/50 = 1.5$ ;  $x = 60/50 = 1.2$ ; we type in the impedance plane

1. **Type P1**  $z_1 = 1.5 + j1.2$ ; you get too  $y_1 = 0.41 - j0.33$ ;

The point is drawn on the 3D Smith chart / 2D Smith chart



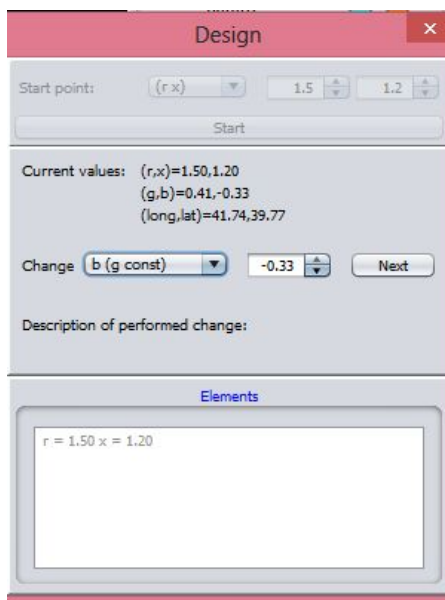
*The starting point current values are displayed in three formats*

- Start drawing on any of the 5 possible directions( constant x, constant r, constant g, constant b circles) a path **in order to meet the  $g=1$  circle or  $r=1$  circle** which go **through the north pole** and drop the cursor once meeting it, this will be **P2** and **you can read it's value in the impedance plane** (z and y values)
- Since our aim is to add L,C elements we can just move on constant r or g circles ( since we will change only the reactance or susceptance)

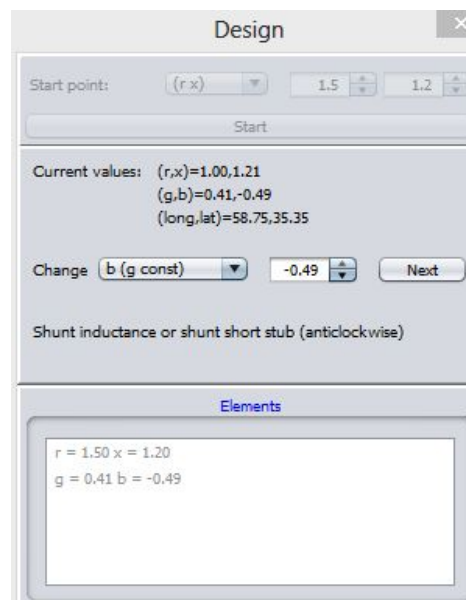
## SOLUTION 1:

.Move on the  $g=0.41$  circle which passed through P1 on the 3D Smith chart ([anticlockwise-case 4](#)) until you meet the  $r=1$  circle

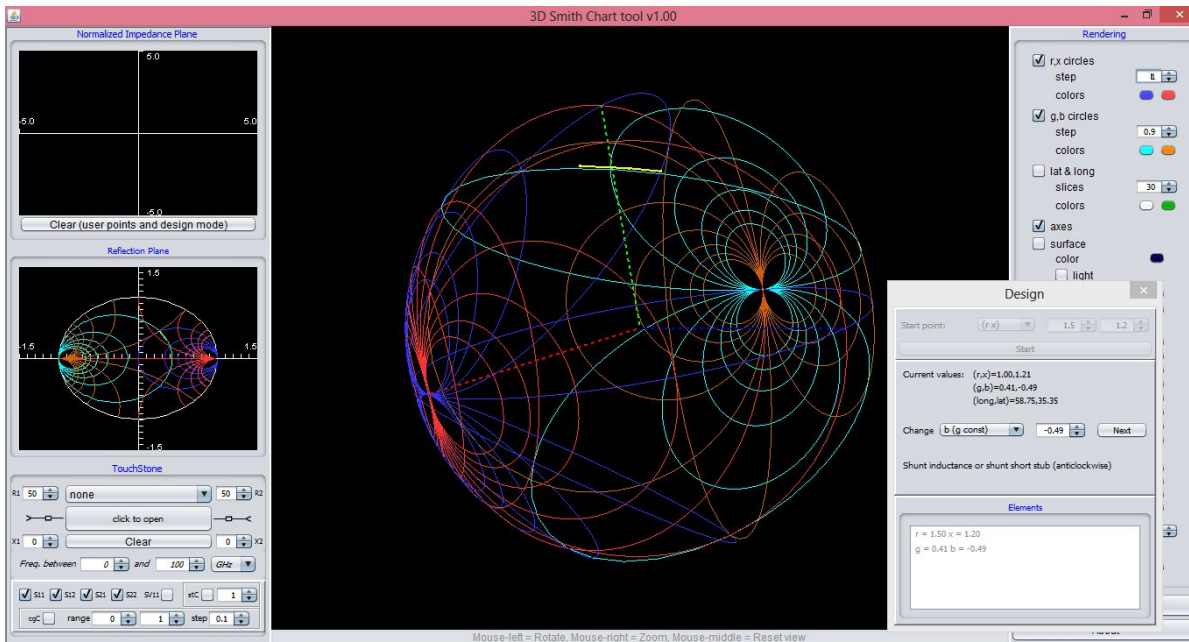
1. Choose change b and type -0.49 and then next: the program displays the type of element you added



*Initial value  $(r,x)$ ,  $(g,b)$ ,  $(\text{lat}, \text{long})$*



*We change b keeping g to its initial value, the operation is displayed*



*We change b keeping g to its initial value- move on a constant g circle- 2D and 3D (yellow)*

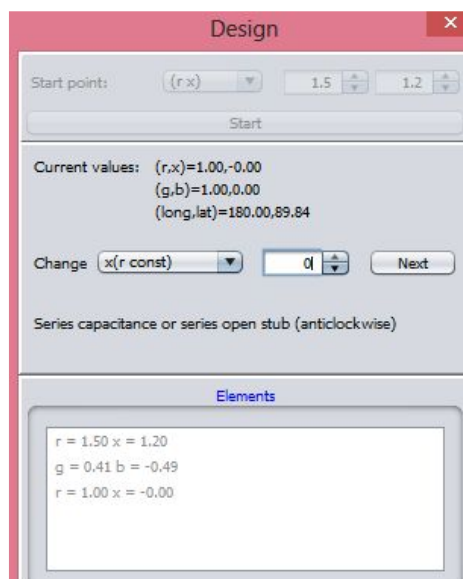
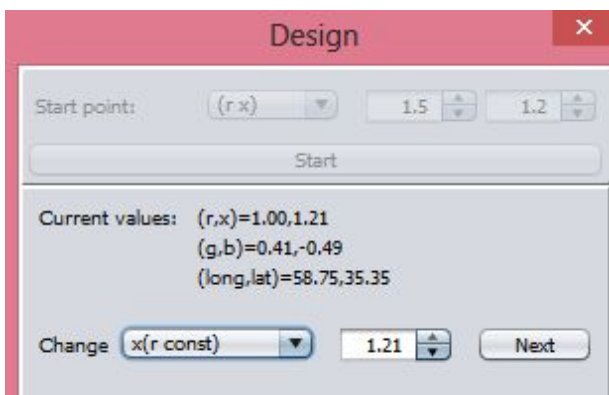
Please note that you may not know that at  $b=-0.49$  you would meet the  $g=1$  circle; for this it is advisable to use little values when pressing next to see live how the current position changes ( both visually and in the design window)

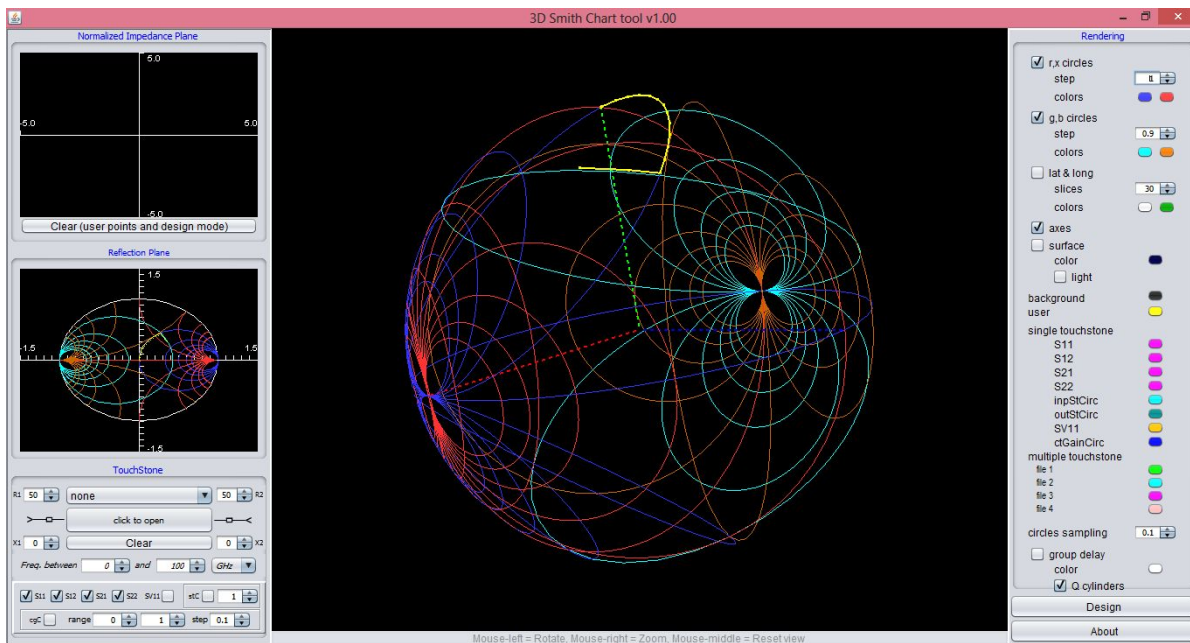
$y_1 - y_2 = b_2 - b_1 = 0.16$  ( $0.49 - 0.33$ ), we have added the shunt inductor with  $b=0.16$

Now: Move ([anticlockwise-case2](#)) on the  $r=1$  circles until you reach the north pole

**2 Choose change x ( r const)** and change x in the negative direction ( anticlockwise) ( from 1.21 down to 0) thus press 0 and next

The program displays the type of element you added





Complete path towards the North pole/ center of the 3D smith chart ( yellow)

You have added a series capacitor with  $x=x_2-x_3=1.21$

For getting the real circuit values simply use the table corresponding to the points on the path:

[anticlockwise-case 4](#) to get  $L=50/2/\pi/10^9/0.166=47.95\text{nH}$

and [anticlockwise-case2](#)

$C=1/(1.207)/2/\pi/10^9/50=2.64\text{pF}$

## SOLUTION 2:

$z_1=1.5+j1.2$ ;  $y_1=0.41-j0.33$ ; shown in the impedance plane

- Move on the  $g=0.41$  circle [clockwise-case 3](#) which passed through P1 on the 3D Smith chart (clockwise) until you meet the  $r=1$  circle
- Choose change  $b$  in the positive direction ( clockwise) to 0.49

$$z_2 = 1 - j1.20 ; y_2 = 0.41 + j0.49$$

Design

Start point: (r x) 1.5 1.2

Start

Current values: (r,x)=1.50,1.20  
(g,b)=0.41,-0.33  
(long,lat)=41.74,39.77

Change b (g const) -0.33 Next

Description of performed change:

Elements

r = 1.50 x = 1.20

Design

Start point: (r x) 1.5 1.2

Start

Current values: (r,x)=1.00,-1.21  
(g,b)=0.41,0.49  
(long,lat)=-58.75,35.35

Change b (g const) 0.49 Next

Shunt capacitance or shunt open stub (clockwise)

Description of performed change:

Elements

r = 1.50 x = 1.20  
g = 0.41 b = 0.49

*Current point and following point ( b is changed on the constant  $g=0.41$  circle ( where the initial point was)*

$y_2 - y_1 = 0.49 + 0.33 = 0.82$ , we have added a shunt capacitor with  $b=0.82$ ;

1. Move [clockwise-case 1](#) on the  $r=1$  circle until you reach north pole, and **press the mouse, you will get:  $z_3=1+j0$ ;  $y_3=1+j0$**
2. You have added a series inductor with  $x_3 - x_2 = 1.20$

To get the real circuit values simply check column 3 in the [LC design table](#)

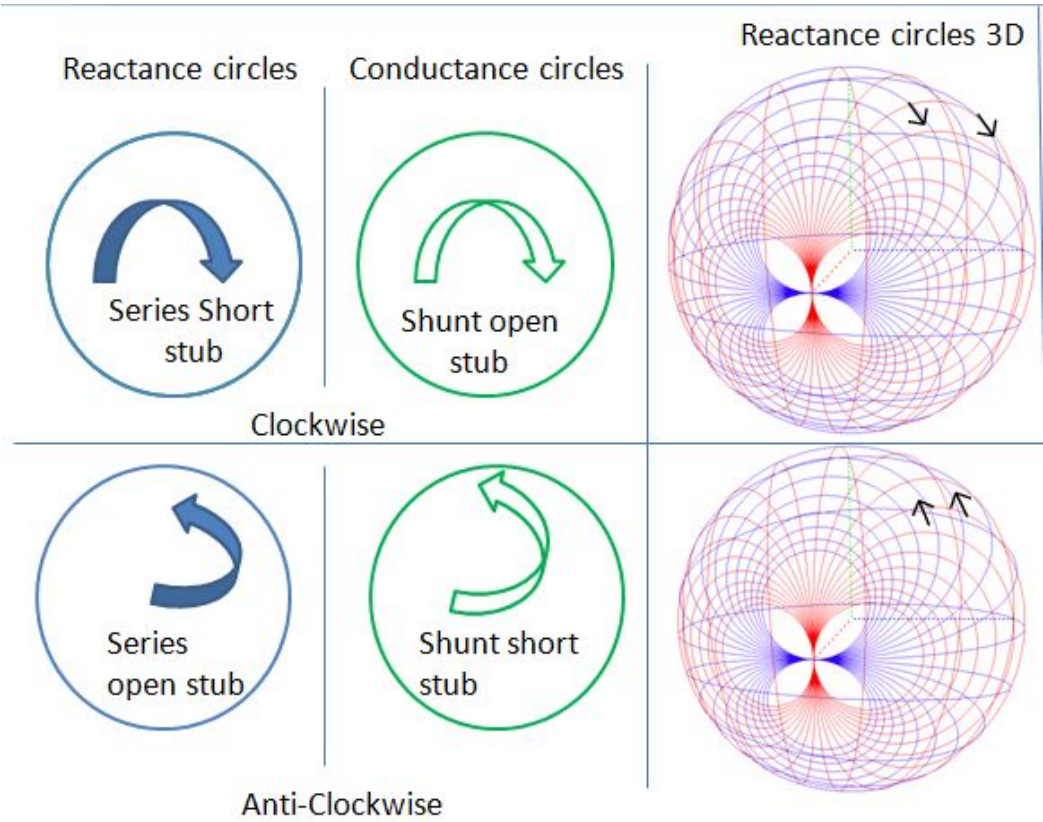
[clockwise-case 3](#)  $C = 0.82 / 50 / 2\pi / 10^9 = 2.57 \text{ pF}$

and [clockwise-case 1](#)  $L = 50 * 1.20 / 2\pi / 10^9 = 9.6 \text{ nH}$



Design mode :stubs (shunt, series)

# STUB (SERIES, SHUNT, SHORT, OPEN) DESIGN GUIDELINES

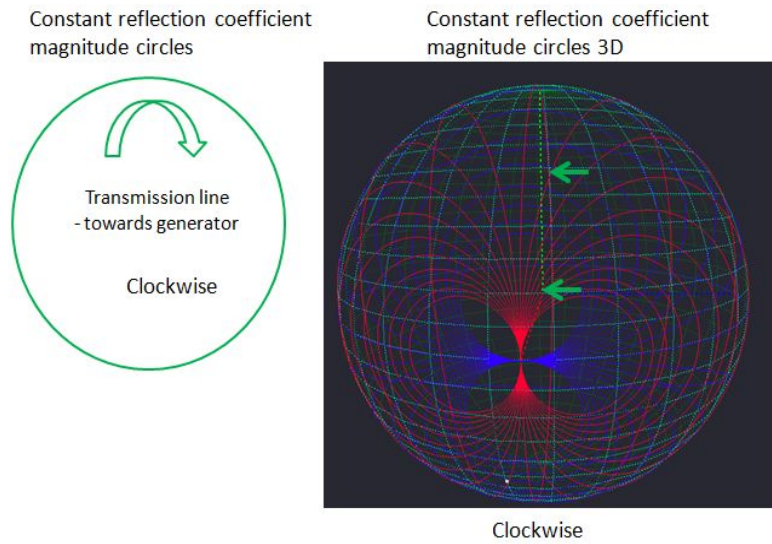


## STUB COMPUTATIONS

Action	Z	Y	3D tool/2D	What's the buzz
--------	---	---	------------	-----------------

Type $r_1 + jx_1$ i.e $R_1/Z_0; X_1/Z_0$	P1 $r_1 + jx_1$	$g_1 + jb_1$	Look on main window/ reflection plane	
<b>Case 1:</b> Move <b>clockwise</b> on $r_1$ circle and click on a point	P2 $r_1 + jx_2$	$g_2 + jb_2$	Look on all windows and read $Z_2, Y_2$ in the impedance plane	<b>Series short stub</b> $\text{deg} = \text{Arctan}(b_2 - b_1)$ ; if negative add 180 degrees
<b>Case 2:</b> Move <b>anti clockwise</b> on $r_1$ circle and click on a point	P3 $r_1 + jx_3$	$g_3 + jb_3$	Look on all windows and read $Z_3, Y_3$ in the impedance plane	<b>Series open stub</b> $\text{deg} = \text{ArcCot}(b_2 - b_3)$ If negative add 180 degrees
<b>Case 3:</b> Move <b>clockwise</b> on $g_3$ circle and click on a point	P4 $r_4 + jx_4$	$g_3 + jb_4$		<b>Shunt open</b> $\text{deg} = \text{Arctan}(b_4 - b_3)$ If negative add 180 degrees
<b>Case 4:</b> Move <b>anti clockwise</b> on $g_3$ circle and click on a point	P5 $r_5 + jx_5$	$g_3 + jb_5$	Look on all windows and read $Z_5, Y_5$ in the impedance plane	<b>Shunt short</b> $\text{deg} = \text{ArcCot}(b_4 - b_5)$ If negative add 180 degrees

# LOSSLESS TRANSMISSION LINES



## TRANSMISSION LINES COMPUTATIONS

Movement/latitude circle (clockwise)	Line length degrees	Length (lambda)
degrees= Longitude (2)-Longitude(1) measured clockwise	deg=degrees/2	$l = \lambda * \text{deg} / 360$

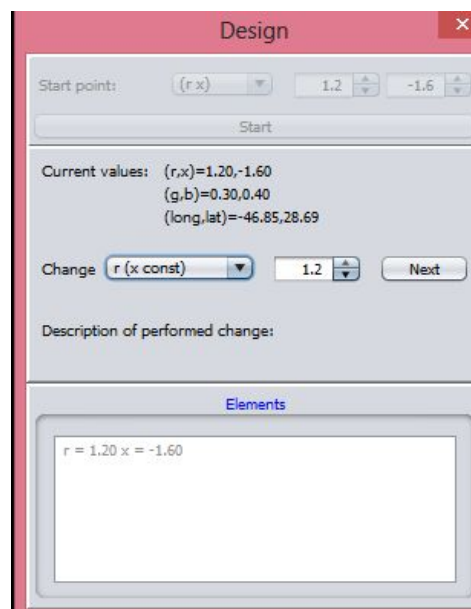
**EXAMPLE 2B ( SHUNT SHORT STUB-TRANSMISSION LINE)**

Match a  $Z_L = (60 - j 80)$  Ohm load to a 50 ohm impedance at 2 GHz using a series transmission line and a [short shunt stub](#).

## SOLUTION 1:

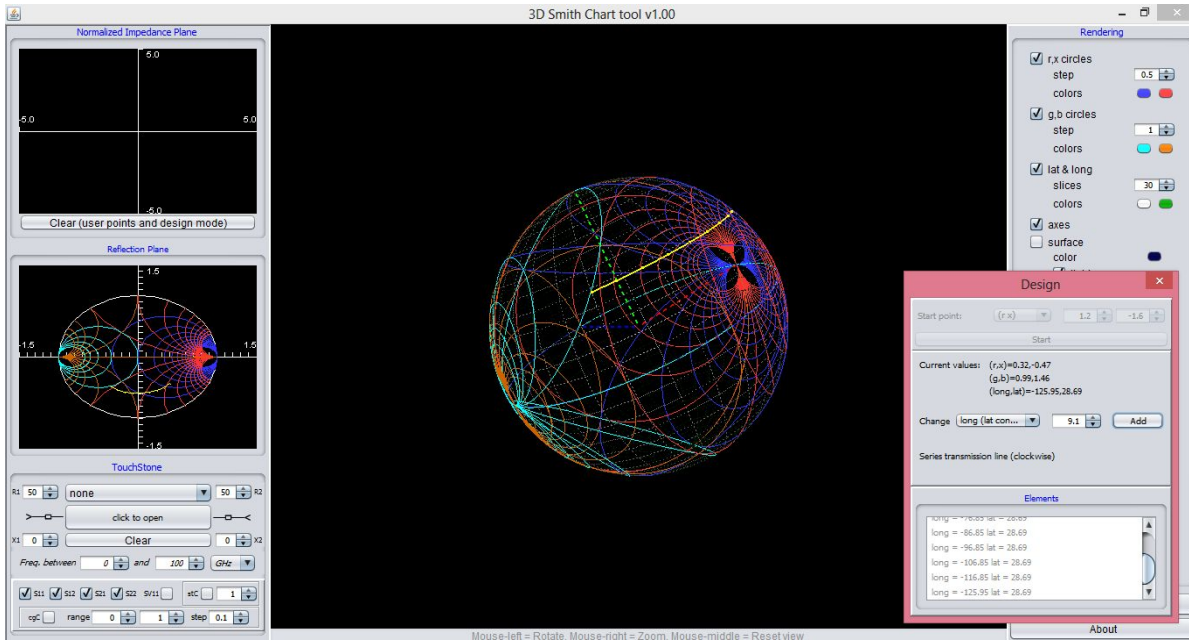
Normalizing to 50 Ohms we get:  $Z_1 = 1.2 - j1.6$  which we enter in the impedance plane

We have to move on the [transmission line clockwise](#) on the latitude circle until we meet the  $g=1$  circle and then [anticlockwise](#) towards Northpole



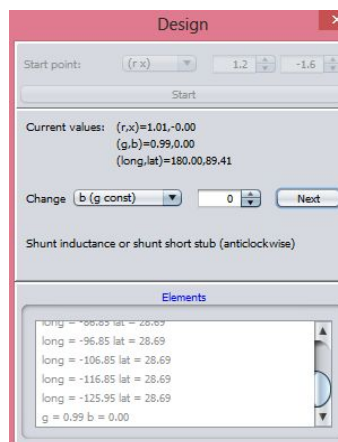
*Position of the initial point ( r,x) (g,b) (lat long) - three systems of coordinates ( Z,Y, earth like)*

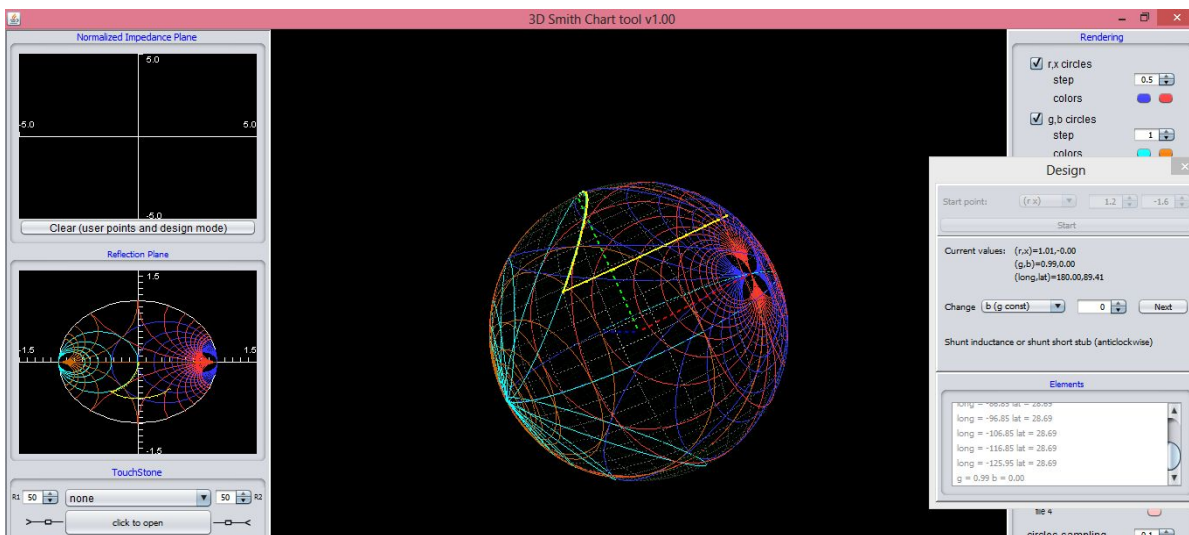
1. **The point is at longitude -46.**until we meet the  $g=1$  circle. Please select long and add ( move on the 28.69) latitude circle in steps of 10 or smaller until you reach your destination ( meet  $g=1$  circle) - the program tells us that we are at around -126 longitude when we meet it



*Adding small parts of a transmission line until we reach the  $g=1$  circle ( yellow path 2D& 3D). Please look at the longitude at the initial point and at the longitude at the point where we meet the  $g=1$  circle ( or in the design window or in the Reflection plane ( by placing the mouse over the 3D view in the two distinct points)*

- We have moved 80 degrees, thus using the [transmission line table](#) to a 40 degrees electrical length=0.11 lambda. The point has  $Z_2=0.32-j0.47$  and  $Y_2=1+j1.46$
- Now we move from  $Z_2$  to the North pole on the  $g=1$  circle [anticlockwise](#) to get to the North pole. For this simply press  $b=0$  and then Next ( don't forget that the North pole has  $x=0$  and  $b=0$ ) - thus if you have any doubts which direction to choose simply type 0 and then the program will bring you directly to the target.





Getting to the perfect match on a constant latitude circle and on a constant  $g$  circle : yellow path 2D&3D, please check the elements added or else place the mouse over the starting and ending point of the route to see the initial/intermediate and final points

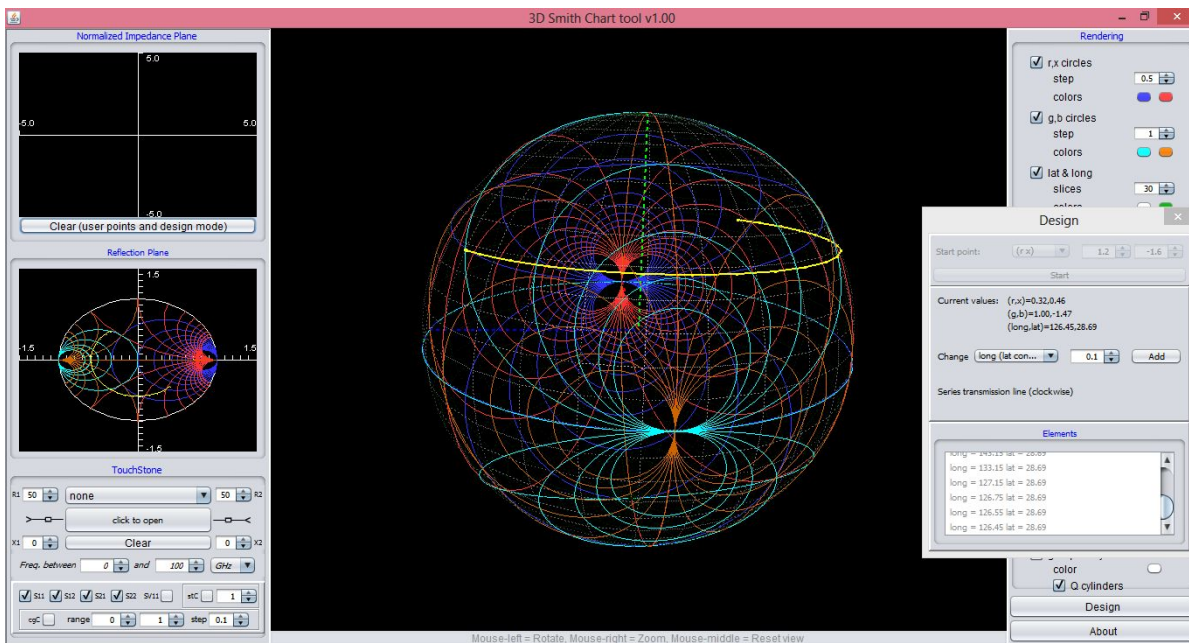
- As depicted on the [Stub design rules on the 2D and 3D Smith chart explanation](#) -case 4 we have  $\text{angle} = \text{ArcCot}[b_2 - b_3] = \text{ArcCot}[1.46 - 0]$  thus 34 degrees, thus using the [transmission line table](#) column 3:0.094 lambda

## SOLUTION 2:

The point is at longitude -46 (West).

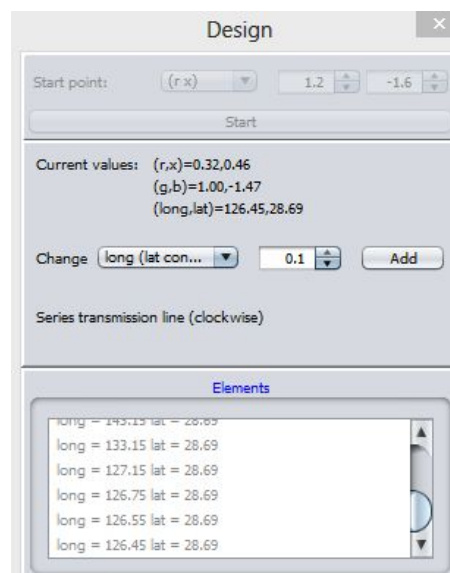
- We move on the [transmission line clockwise](#) on the latitude circle **until longitude we meet the  $g=1$  circle in the second point**





*A movement on a lossless transmission line: Please read the initial point longitude in the elements window/ final one' or else place the mouse over them and read it in the reflection coefficient plane- their difference gives/2 the electrical length of the line*

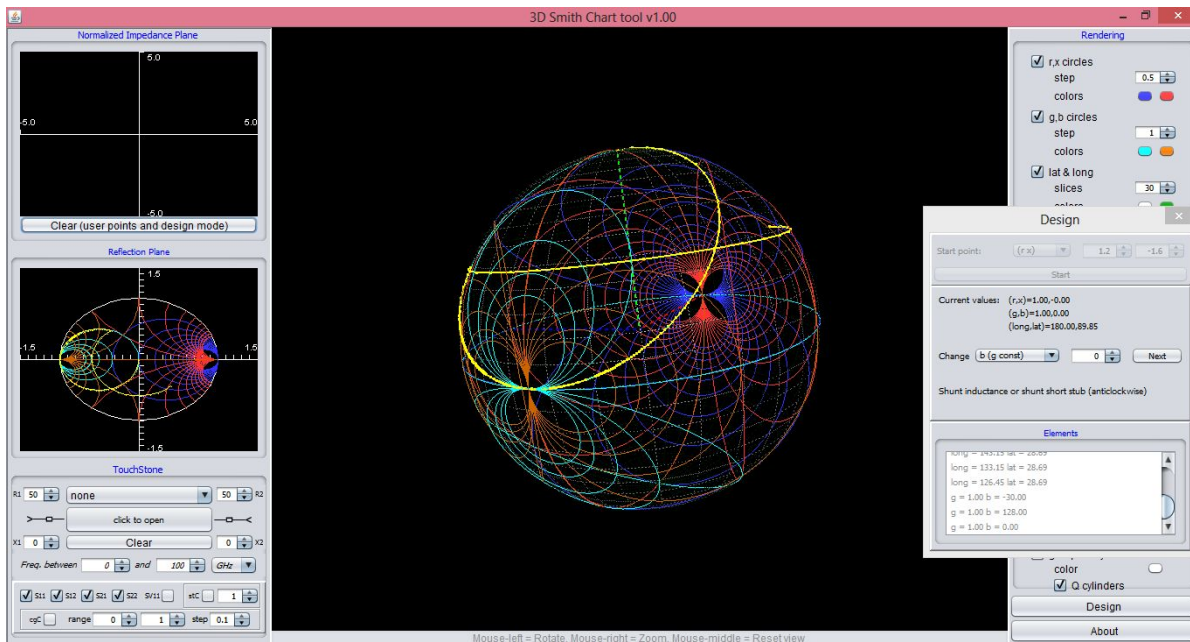
Adding carefully small steps we finally see that we meet the circle ( visually)- and also in the current values: we can see  $g=1.00$ :



We have moved from -47 West to 126 East thus a movement of  $180-47 +180-126=187$

- 187 degrees, thus the electrical length of the transmission line=using the [transmission line table](#)  $197/2 =97$  which corresponds to a line length of (using the [transmission line table](#)/ column 3,  $l=\lambda \cdot 0.97/360$ )

3. Now let us force us to add a short shunt stub ( to go anticlockwise) and try to reach like this the north pole:



*A movement on a lossless transmission line followed by an anticlockwise movement on a short shunt stub towards the perfect matching*

For this we have decreased the value of  $b < -128$ ; and then we can see how  $b$  switched to  $+128$ ; from here we simply type  $b=0$  and we decrease to  $0$  ( thus we made an anticlockwise rotation to the North pole

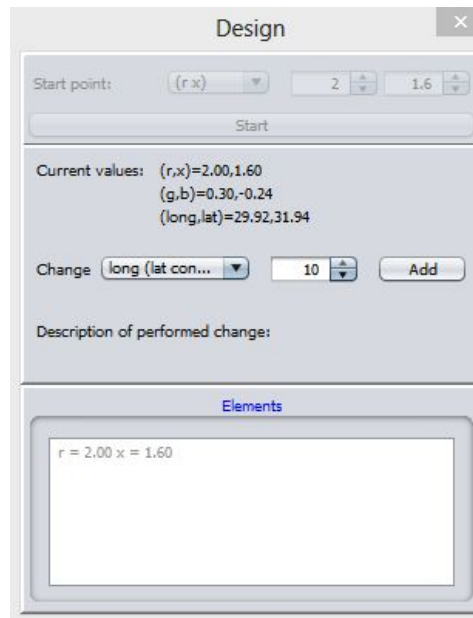
( anticlockwise- please take care on this [stub design rules table](#) case 4 )

Checking the [Stub design rules on the 2D and 3D Smith chart explanation](#)-case 4:  $\text{Arcot}(-1.46) = -33$  (negative value -thus we add 180 degrees) i.e have moved  $180-33=147$  degrees thus checking the [transmission line table](#)  $147/360=0.4\lambda$ .

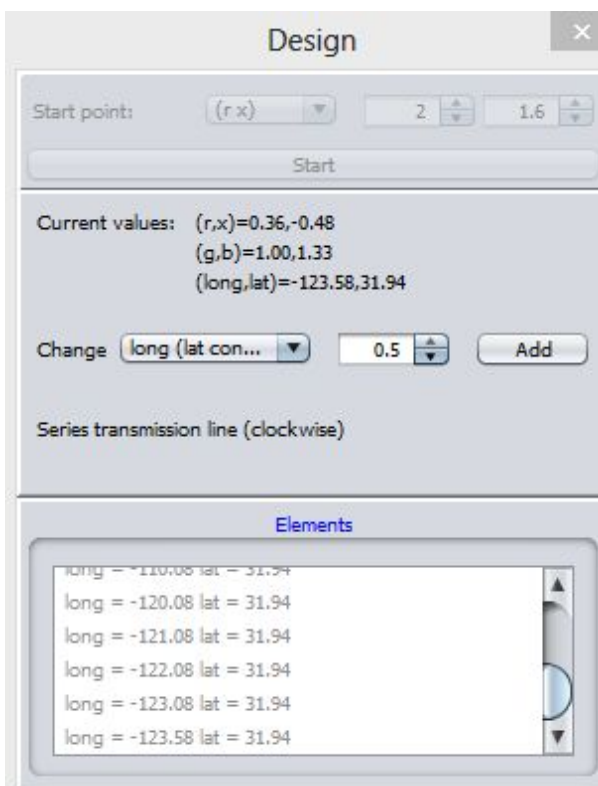
## EXAMPLE 3B ( LINE/SHUNT OPEN STUB)

Matching of a load impedance of  $100 + j 80$  to  $50 \text{ Ohm}$  line at  $2\text{GHz}$  with a series transmission line and [open shunt stub](#).

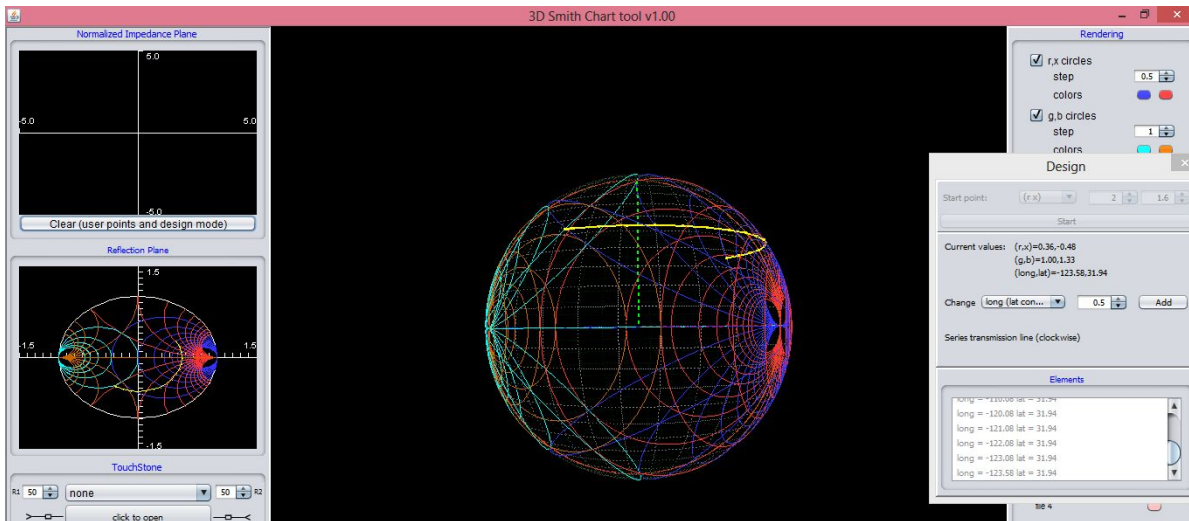
1. We type  $Z_1 = (100/50 + j80/50) = 2 + j1.6$  in the design mode :



2. We move on the [transmission line clockwise](#) on the latitude circle **on the 3D Smith chart on the [latitude](#) circle of  $Z_1$  until we meet the  $g=1$  circle**



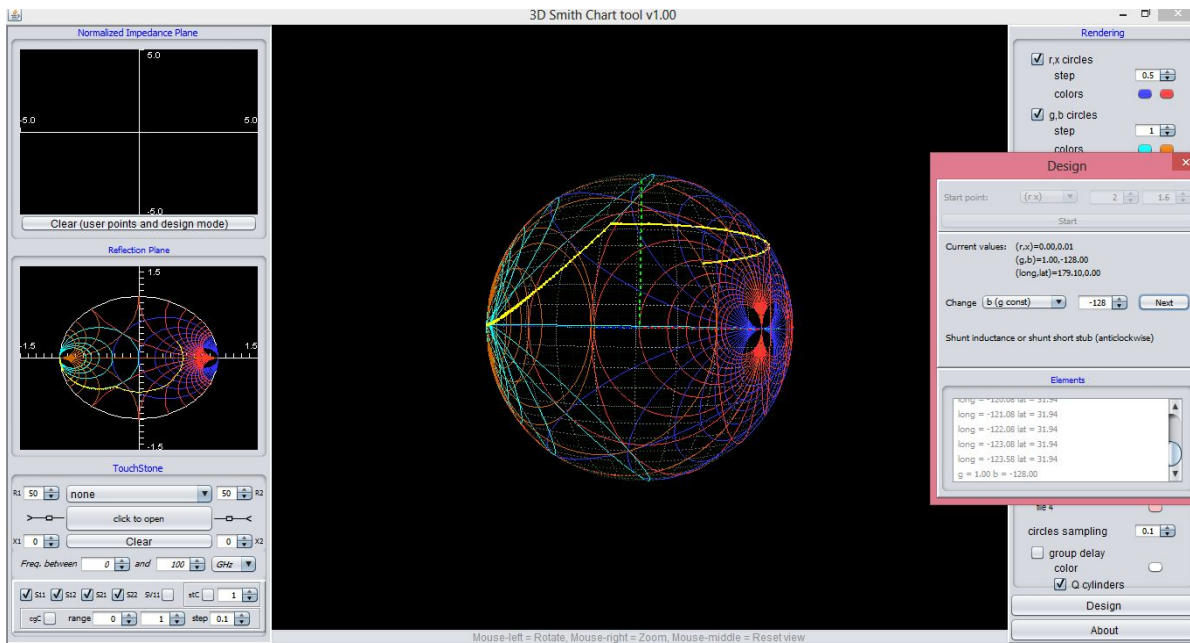
You can either check visually on the 3D main window and on the Smith chart or you can see “live” on the Design mode window how  $g$  changes whenever you are moving on the latitude circle.



*A movement on a lossless transmission line: Please read the initial point longitude in the elements window/ final one' or else place the mouse over them and read it in the reflection coefficient plane- their difference gives/2 the electrical length of the line*

3. We move on the  $g=1$  circle clockwise ( [Stub design rules on the 2D and 3D Smith chart explanation](#)-case 3) until the north pole

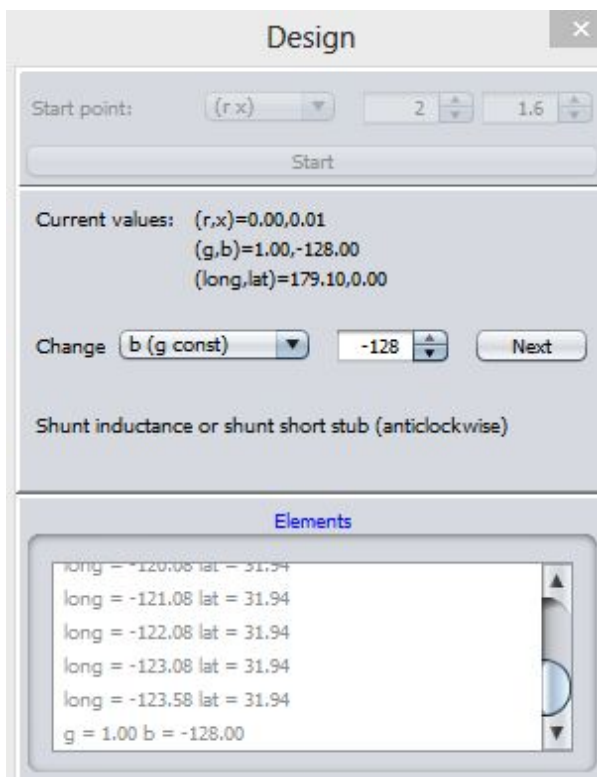
For this move clockwise on the  $g$  constant circle thus type a positive please type 128 - you will get:



*A movement on a lossless transmission line followed by a move on a shunt open stub part*

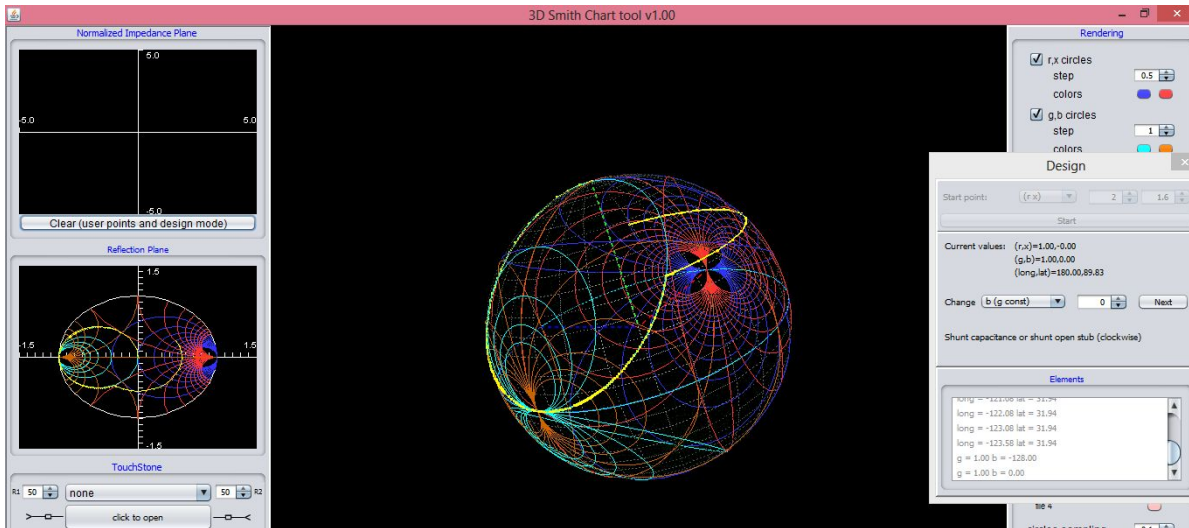
If you increase further on you can't advance because you pass through an accumulation point.

However the program detects this and restart on the other site at -128



Now simply increase to 0 ( you always walk clockwise):

You will get:



*A movement on a lossless transmission line followed by a move on a shunt open stub until we reach the matching point ( again please read the initial and final values or in the elements window or in the reflection /impedance plane) by placing the mouse over the points*

Using your initial point coordinates:  $\text{ArcTan}(-1.33) = -52$  deg; thus we moved  $180 - 52 = 127$  deg thus using the [transmission line table](#) 127/360 thus 0.36 lambda

## EXAMPLE 4B (LINE- SERIES OPEN STUB)

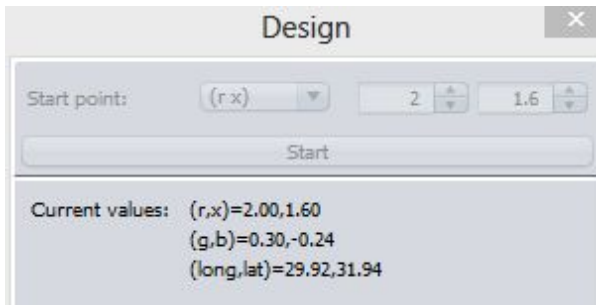
Match a load impedance of  $100 + j80$  to 50 Ohm line at 2GHz with a series transmission line and series open stub.

Looking in [Lossless Transmission lines table](#) and [Stub design rules on the 2D and 3D Smith chart explanation](#) we know that we have to move on a series transmission line (clockwise) until we meet the  $r=1$  circle and then move on it anticlockwise to the north pole (case 2)

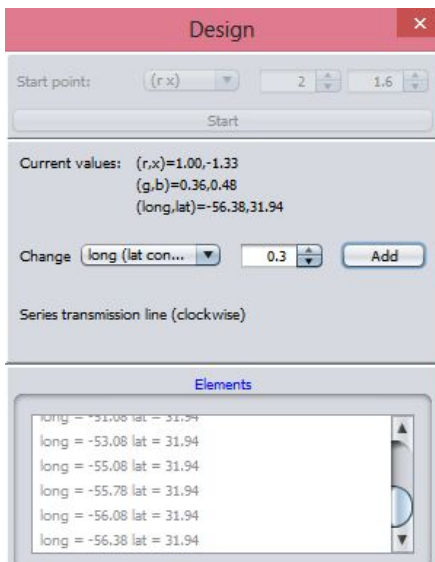


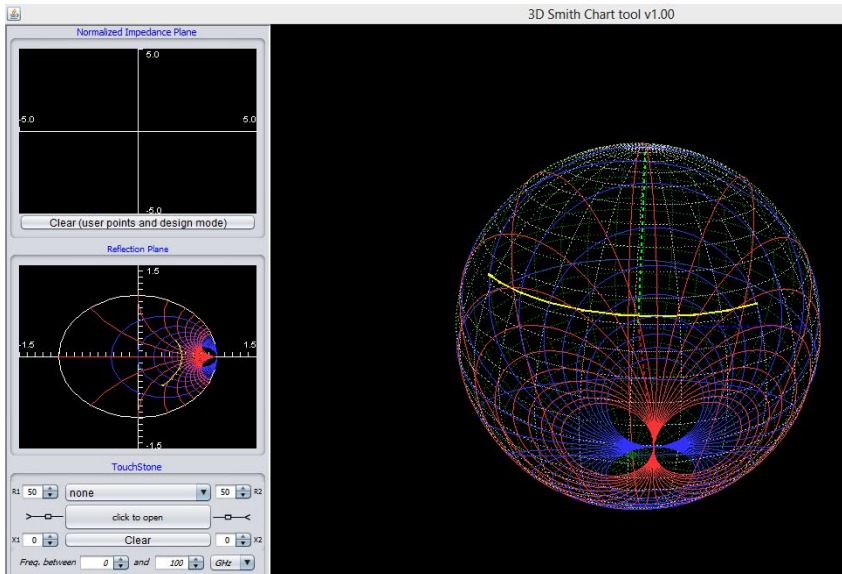
# SOLUTION 1

Type  $z_1=2+j1.6$



Move on the latitude circle until you meet the  $r=1$  circle ( change the longitude until  $r=1$  in the design window or look on the main windows):

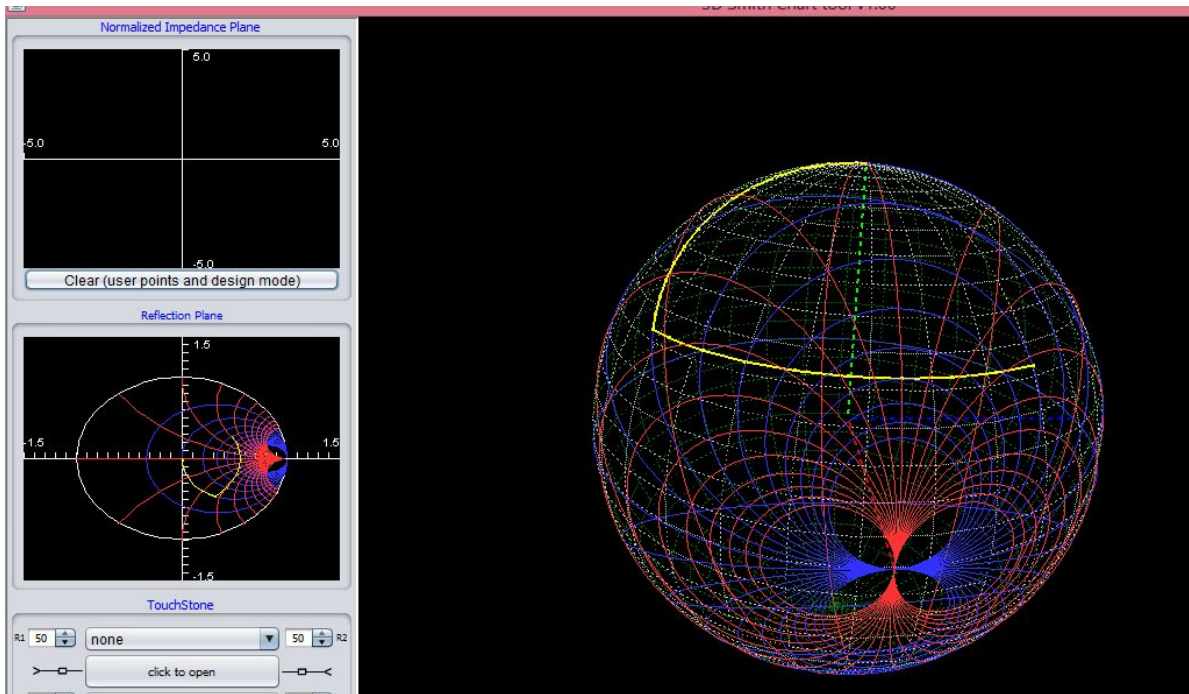




You have moved from 29.92 E to -56.38 W thus 86.3 degrees=[Lossless Transmission lines table](#) an electrical angle of 43.15 deg thus 0.12 lambda

Move anticlockwise to the north pole on the  $r=1$  circle:

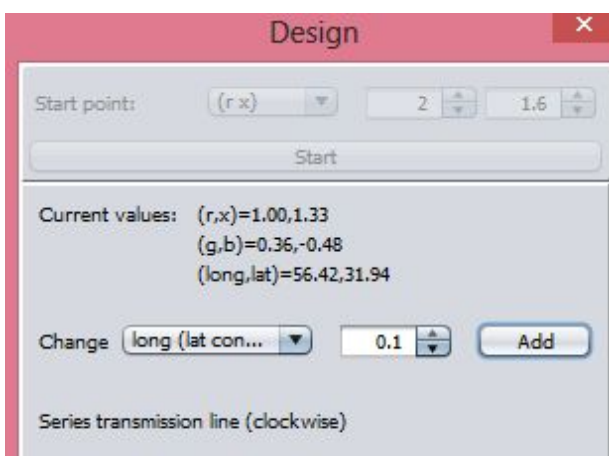
- Choose change x and type 0 ( to change it from -1.33 to 0)



Checking [Stub design rules on the 2D and 3D Smith chart explanation](#) case 2 we have added a short stub:  
 $\text{arcCot}(-1.33) = -37^\circ$  thus ( we add  $180^\circ$  deg) and get the length of  $180 - 37 = 143$  thus  $143/360 \cdot \lambda = 0.4 \lambda$

## SOLUTION 2

1. Type  $z_1 = 2 + j1.6$
2. Move on the latitude circle until you meet the  $r=1$  circle in the second point .





4. Now move anticlockwise on the  $r=1$  until the north pole: type  $x=0$  ( reduce it from 1.33)

Design

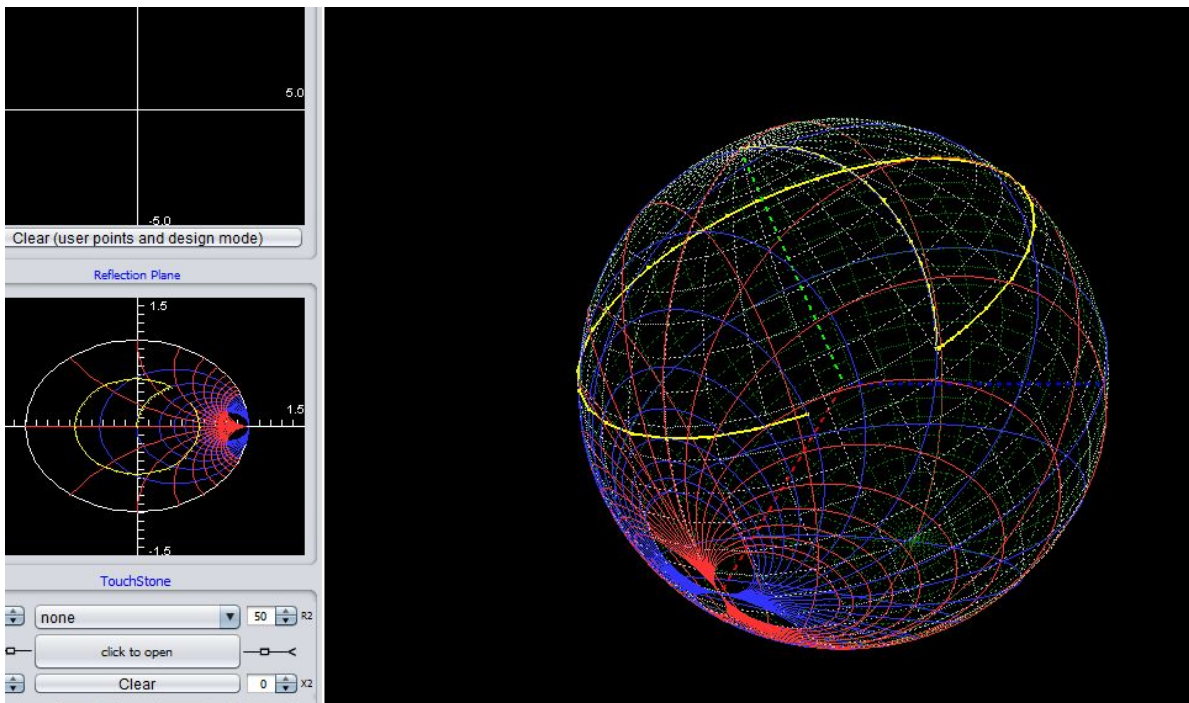
Start point: (r, x) 2 1.6

Start

Current values: (r,x)=1.00,0.00  
(g,b)=1.00,-0.00  
(long,lat)=180.00,89.83

Change x(r const) 0 Next

Series capacitance or series open stub (anticlockwise)



5. [Stub design rules on the 2D and 3D Smith chart explanation](#) case 2-on the  $r=1$  circle until the North pole. You moved  $\text{ArcCot}(1.33)=37^\circ = 37/360 \cdot \lambda = 0.1\lambda$

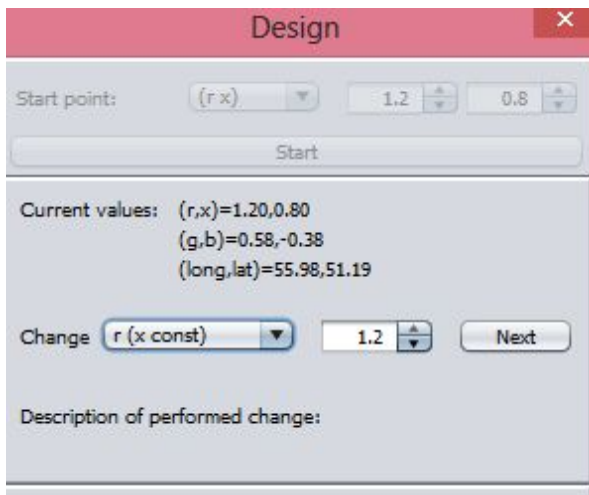
## EXAMPLE 4B (LINE- SERIES SHORT STUB)

Match the normalized impedance  $Z_L=1.2+j 0.8$  to 1 using a series transmission line and a series short stub.

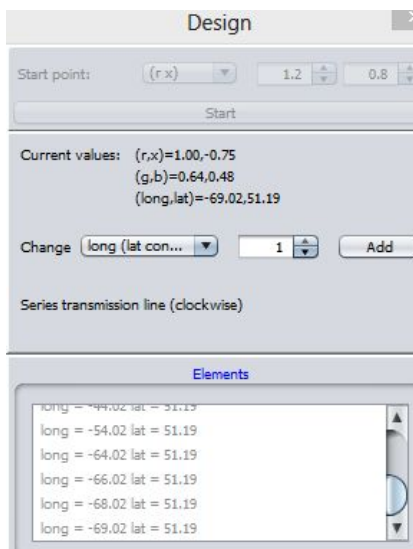


# SOLUTION 1

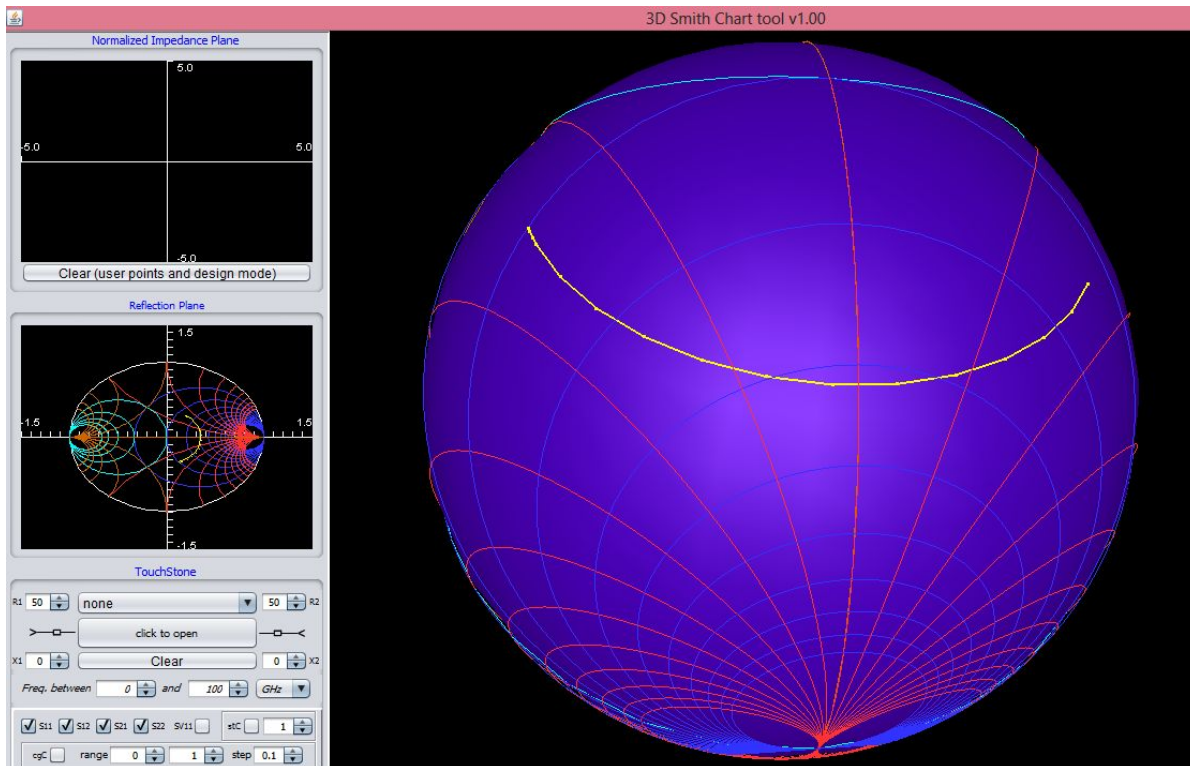
1. Type  $z_1 = 1.2 + j0.8$



2. Move, following the on the constant latitude circle until you meet the  $r=1$  circle and you get  $z_2 = 1 - j0.75$  ( look when you meet the  $r=1$  circle or simply by adding small steps look when  $r=1$  in the design window.

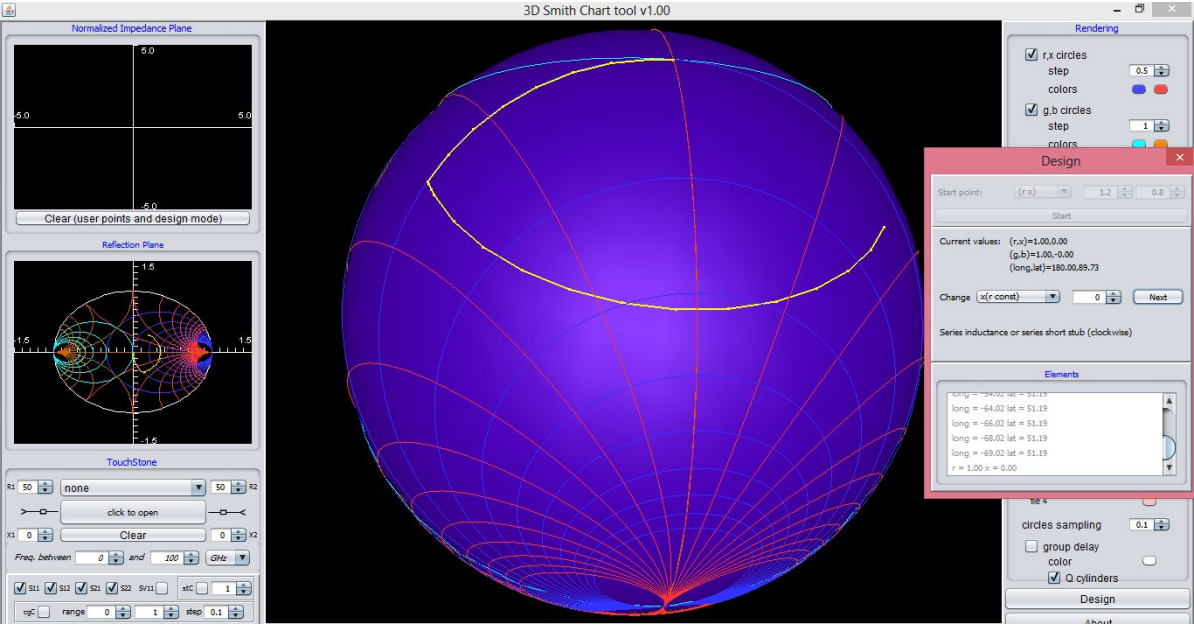






You have moved from longitude 56 E to -69 W clockwise thus 125 degrees which corresponds to an angle of 125 degrees which corresponds to an deg [Lossless Transmission lines table](#) of  $125/2=62.5$  thus  $62.5/360 \cdot \lambda = 0.173 \lambda$

- Get clockwise to the North pole ( positive change)

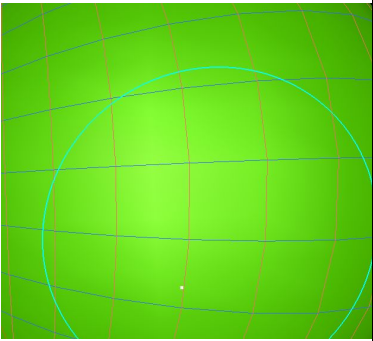
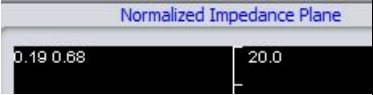
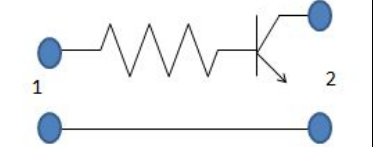


3. Then [Stub design rules on the 2D and 3D Smith chart explanation](#) -case 1 we move clockwise on the  $r=1$  circle to the north pole. You moved  $\text{Arctan}(0.75) = 37^\circ$  deg thus  $0.1 \lambda$

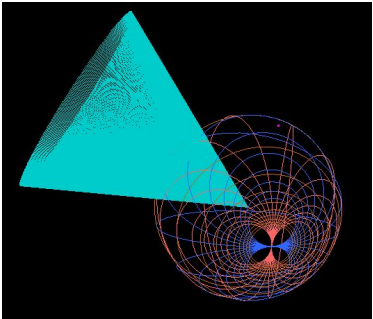
Advanced design mode

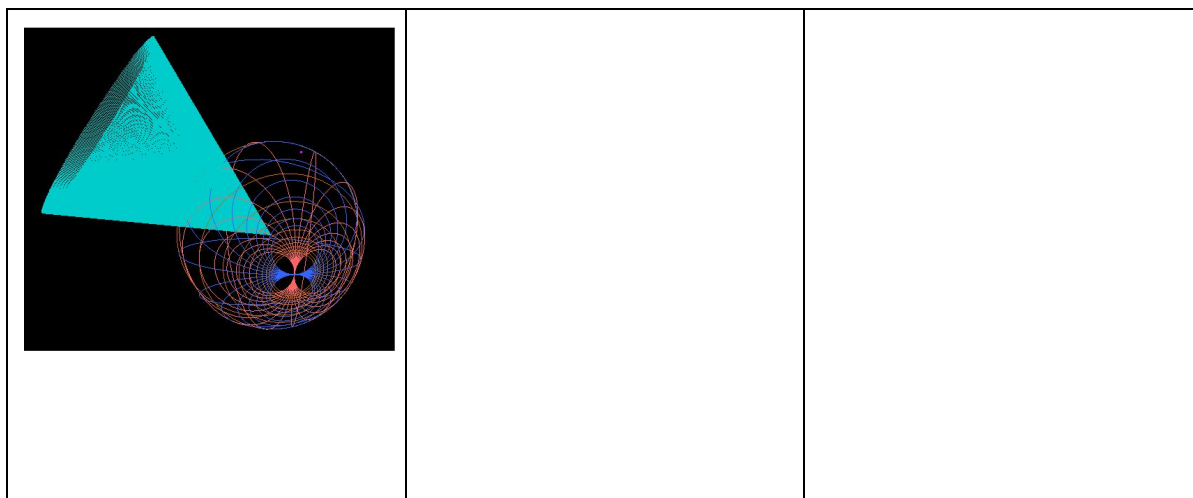
STABILITY CIRCLES- STABILIZING CIRCUIT DESIGN

Series circuit	Action
	<div><input checked="" type="checkbox"/> r.x circles step 0.1 colors blue red</div> <div>stC <input checked="" type="checkbox"/></div>

	<p>Zoom further in, check the surface box too for a better visualization</p> <div><input checked="" type="checkbox"/> surface color <span style="background-color: #00FF00; border: 1px solid black; display: inline-block; width: 15px; height: 10px;"></span> <input checked="" type="checkbox"/> light</div>
	<p>Put the mouse over the point of the circle with highest r and read off the value in the impedance plane</p>
	<p>Put the mouse over the point of the circle with highest r and read off the value in the impedance plane</p>
	<p>Add the resistance <math>r \cdot \text{port impedance}</math> to your circuit</p>

UNILATERAL CONSTANT GAIN CIRCLES- STABILIZING CIRCUIT DESIGN

<p>Increase the gain with p (dB)</p>	<p>Identify the maximum gain of the source</p>	<p>Identify loads which Allow a desired gain</p>
<p>Solve <math>10\text{Lg}(x^2)=p</math>; <math>x=(10^{(p(\text{dB})/10)})^{.5}</math></p>	<p>Decrease the step to the minimum possible and play with the range to see when no circles are displayed anymore. Use the minimum step to identify the value of x for which no increase can be more achieved</p> <div><input checked="" type="checkbox"/> cgC range 1.8 <input type="button" value="↑"/> <input type="button" value="↓"/> <input type="button" value="P"/> <input type="button" value="←"/> <input type="button" value="→"/> step 0.01</div>	<p>We plot the desired gain first as done before:</p> 
<div><input checked="" type="checkbox"/> cgC range 1.2 <input type="button" value="↑"/> <input type="button" value="↓"/> <input type="button" value="P"/> <input type="button" value="←"/> <input type="button" value="→"/></div> <div>ctGainCirc <input checked="" type="checkbox"/></div>		



## Ex 5B STABILIZING THE AMPLIFIER-SERIES (INPUT)

Stabilize the amplifier from [EX 4](#) with the minimum series resistance possible

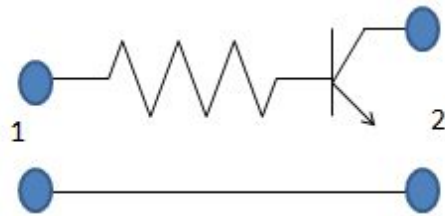
F (GHz)	S11 mag	S11 angle	S12 mag	S12 angle	S21 mag	S21 angle	S22 mag	S22 angle
0.8	0.65	-95	5	115	0.035	40	0.8	-35

Becomes ( ex5b.s2p)

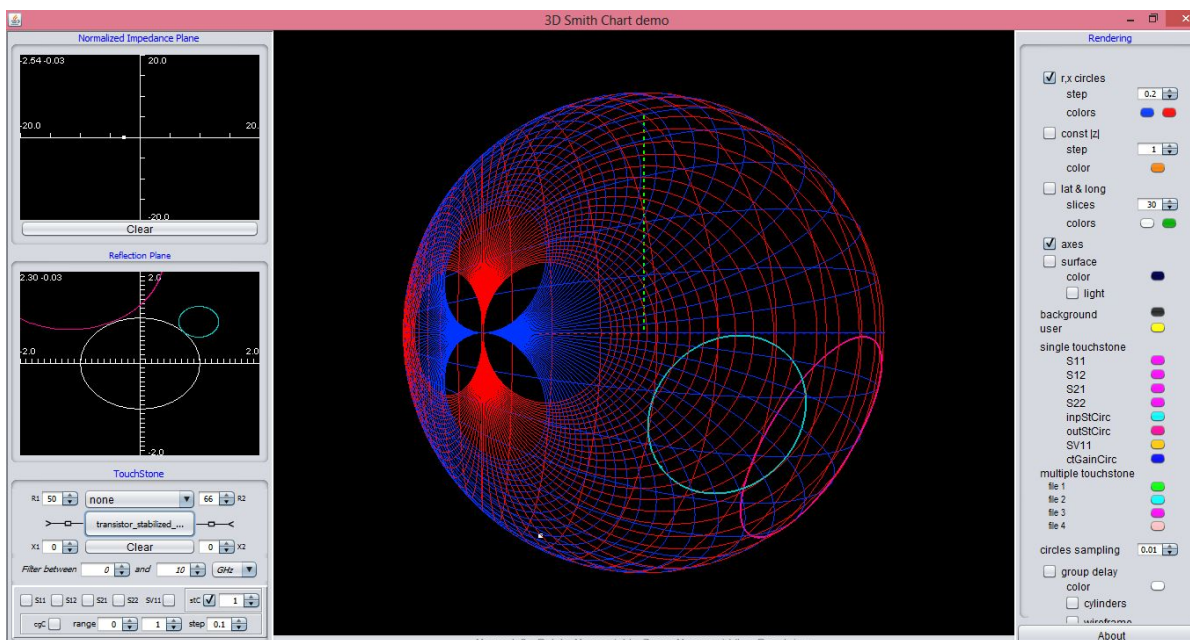
F (GHz)	S11 mag	S11 angle	S12 mag	S12 angle	S21 mag	S21 angle	S22 mag	S22 angle
0.8	0.528	-88.5	4.5	111	0.03	36	0.78	-35.1

By adding a series resistor at the input of the amplifier whose resistance equals the minimum value of the resistance circle intersecting it- we can thus stabilize it with its minimum cost.

By simple checkin in the tool ( following [Stability circles- stabilizing circuit design](#) )we can see that  $r=0.2$  is a correct solution ( since it is a bit above the circle) thus we add a series resistance of  $r=0.2$  i.e  $R=r*50=10$  Ohm at the input of the circuit



Please load the file transistor\_stabilized\_series- one can see now how both circles went south thus unconditional stability was achieved.

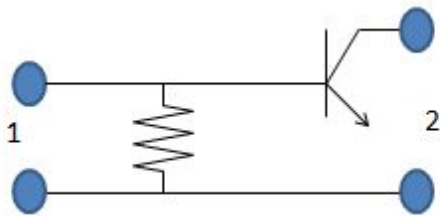
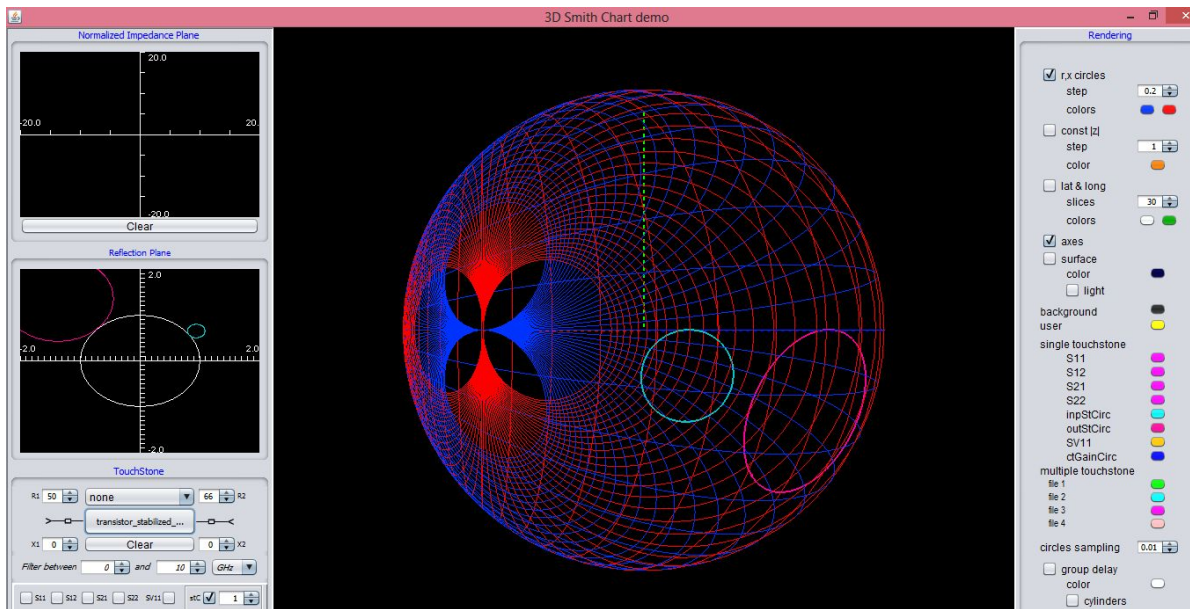


( you can load it together with the transistor\_non\_stable) and you get:( the input stability circles have all the same color), while the output stability circles have all the same color too.



# STABILIZING THE AMPLIFIER-SHUNT (INPUT)

By checking the value of  $g$  on the most northic point of the circle we get: the value of the shunt resistance around 70 Ohms and we get ( please load the ex5b\_shunt\_transistor\_stabilized\_shunt):

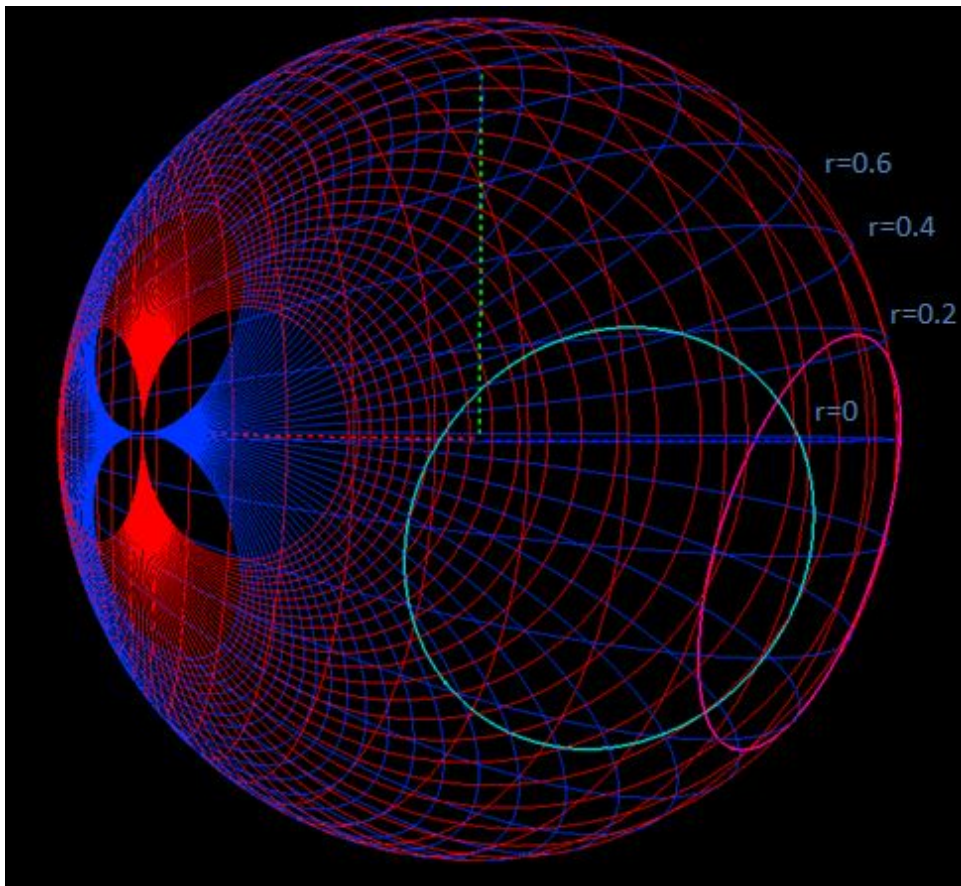
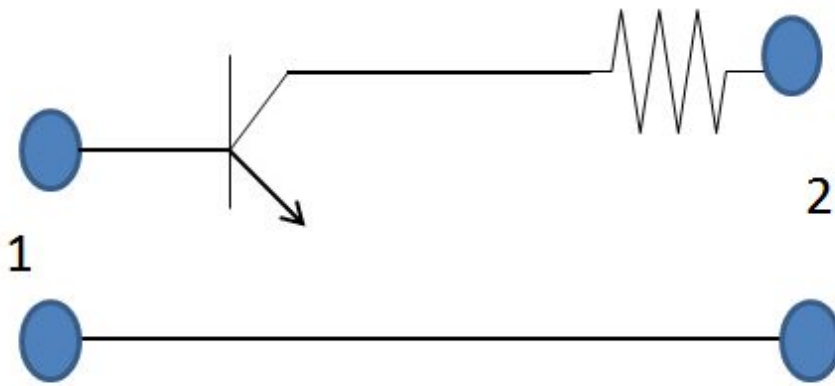


One can see how by adding this shunt resistor the transistor gets unconditionally stable ( circles are south)

# STABILIZING THE AMPLIFIER-SERIES(OUTPUT)

Again by visual inspection we can see the value of the minimum series resistor which connected at the output can assure unconditionally stability. ( please zoom in )- we see that the circle of  $r=0.6$  lies above the most northern point of the circle thus choosing an output resistance of this value we are sure of unconditionally stability. To see the exact minimum value one has to move the mouse above the circle and read off the value of  $r$  in the normalized impedance plane and see 0.58 as the min value. Thus by choosing  $0.58 \times 50 = 29$  one stabilizes the amplifier





## EXAMPLE 6B ( UNILATERAL CONSTANT GAIN )

Consider the BJT transistor parameters at 1GHz the following [11] :

F- GHz	S11 mag	S11 angle	S12 mag	S12 angle	S21 mag	S21 angle	S22 mag	S22 angle

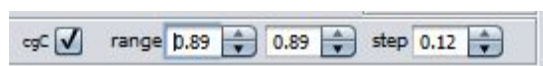
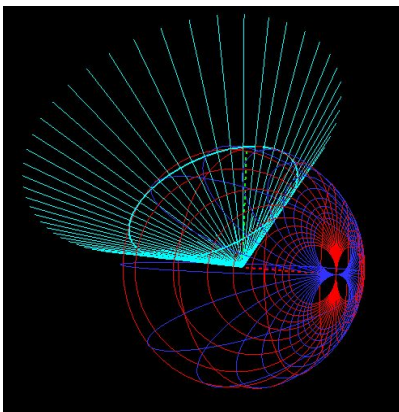
1	0.73	175	0	0	4.45	65	0.21	-80
---	------	-----	---	---	------	----	------	-----

- a) Plot the unilateral constant gain circles corresponding to some constant unilateral power gain circles of the source and determine its maximum possible gain

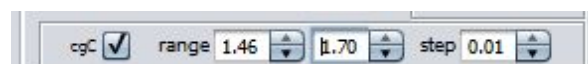
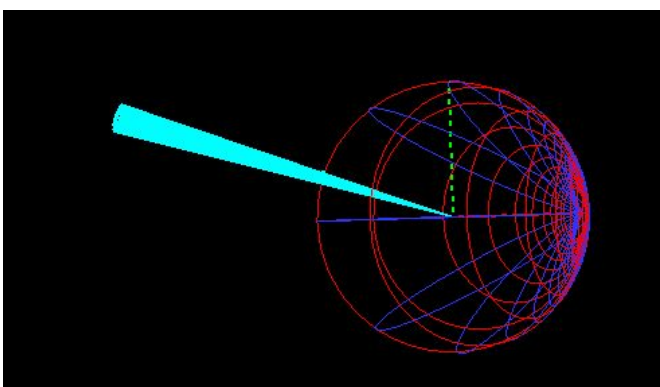
Solution : considering some values as in [11] the user can simply write the x values and get the circles:  
 $x = (10^{(p(\text{dB})/10)})^{.5}$  ( see please the [design rules](#)).

p(dB)	-1	0	1	3.31
x	0.89	1	1.12	1.463

The 1dB unilateral power gain circle can be simply displayed by choosing the corresponding x (0.89) and choosing the range from 0.89 to 0.89 ( so that no other circle should occur).



The -1 dB unilateral constant gain circle.



- b) Use the program to identify the maximum unilateral power gain (input)

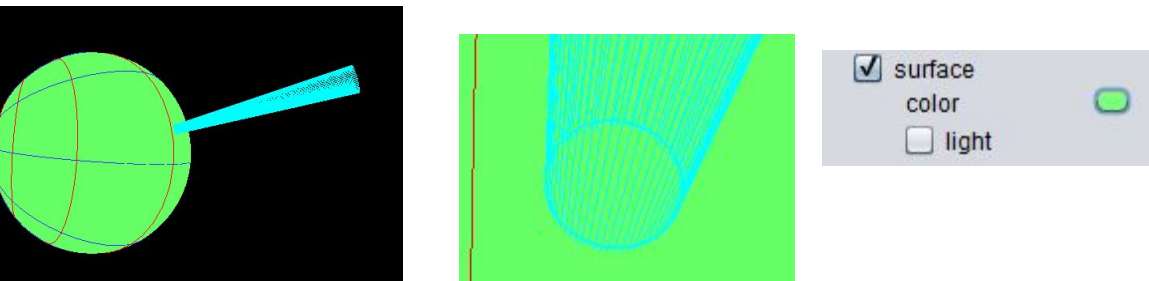
The 3.31 dB circle ( $x=1.46$ ) represents the maximum unilateral constant gain circle of the source ( no matter how much we still increase the maximum range ) no other circle will appear anymore.  $p=10*Lg(x^2)$

The user can try to increase the the range and see that no other circle will appear. Using the theory the user could alternatively check  $10*Lg(1/(1-Abs(s_{11})^2))$

cb) Calculate the the optimum source load :

The optimum source load is given where the maximum unilateral constant gain circle appears. Put the mouse over this circle point ( by zooming in ) and read off the corresponding  $r$ , and  $x$ .

If needed check the surface option too to get a solid color for the surface of the sphere:

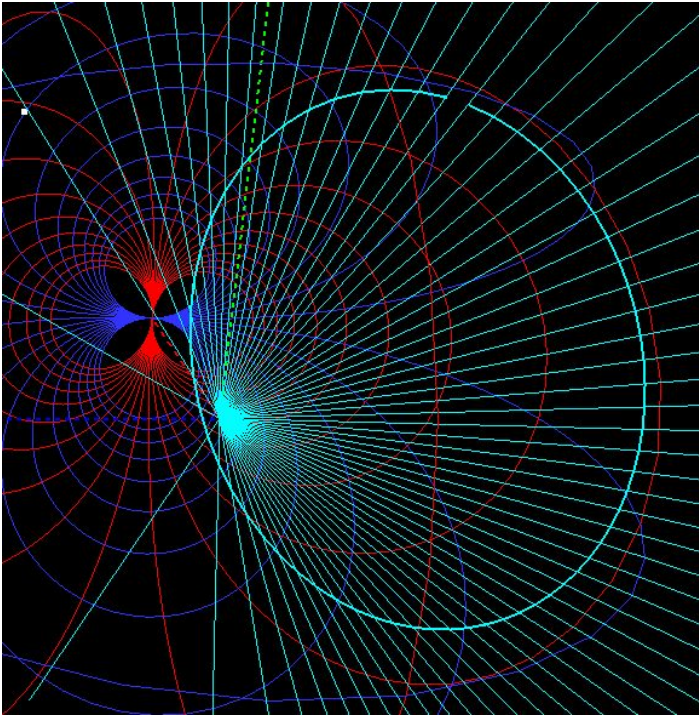


Read the  $r$  and  $x$  in the impedance plane. Multiply with 50 to get the non-normalized value

d) Design a network which increases the gain with 2dB:

$x=(10^{(2/10)})^{.5} = 1.259$ . Put the mouse over a random point on the circle ( for example one can choose as in [11]  $0.42 +j2$

Move from the north pole to the chosen point



EXAMPLE 7B ( UNILATERAL CONSTANT GAIN UNSTABLE)

F- GHz	S11 mag	S11 angle	S12 mag	S12 angle	S21 mag	S21 angle	S22 mag	S22 angle
1	2.27	-120	0	0	4	50	0.6	-80

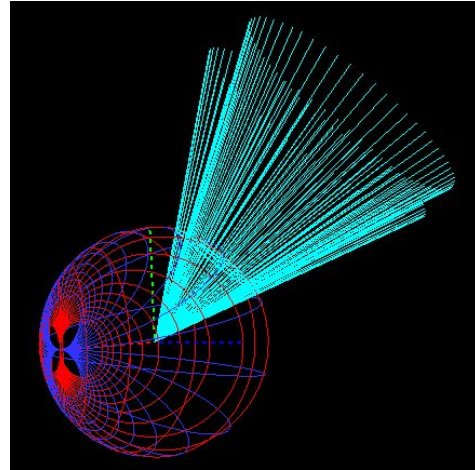
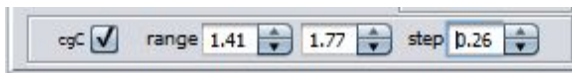


a) Plot the source constant gain circles for 3dB and 5dB

We use again the [formula](#):

p(dB)	3	5
x	1.41	1.778

$$x=(10^{(p/10)})^{.5}$$



b) Determine the stability region:

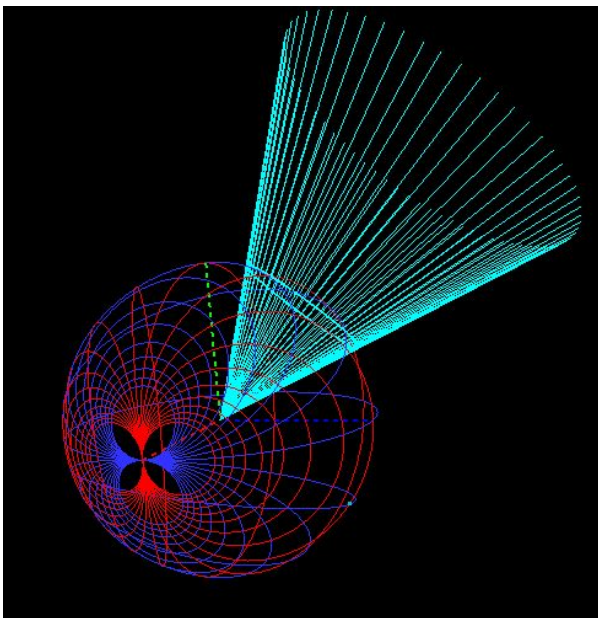
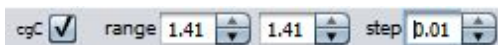
Please consider that the absolute value of S11 exceeds unity thus we are in a special case[11]

Type from the keyboard the point to 1/ Conjugate (S11) in the impedance plane, for this you have to solve  $(z-1)/(z+1)=1/\text{Conjugate}(S_{11})$  and you get :  $r=-0.493$  and  $x=-0.46$

Choose the region with  $r_i < \text{abs}(r)$  thus the region

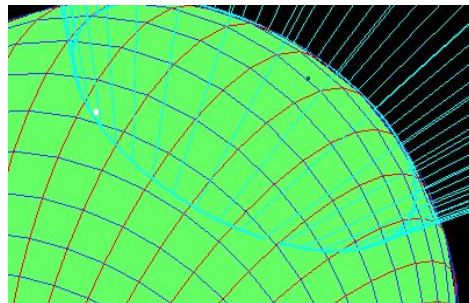
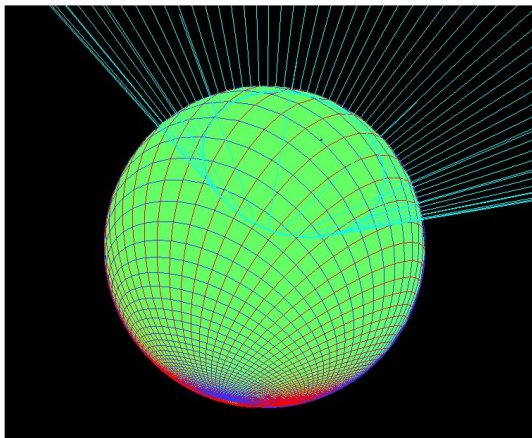
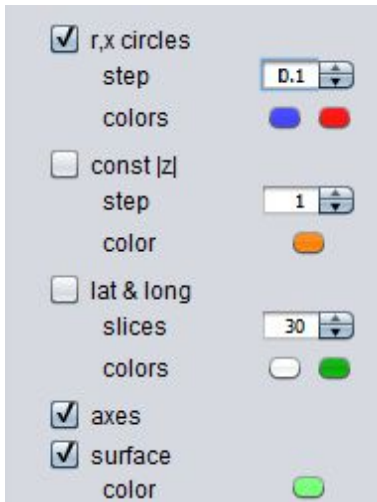
c) Design the input matching network for 3dB with the highest degree of stability:

For this : plot first the 3dB stability circle





Now identify on it the point with the highest value of  $r$ : For this check the surface box and change the  $r, x$  circle frequency to a finer one and then put the mouse over the points of the circle with higher  $r$ :



Zooming in we may see that the points with highest value of  $r$  lie between 0.9 and 1, by placing finally the mouse over the point closest to 1 which belongs to the circle we may read in the impedance plane the value of  $r=0.97$ - read off this value and the  $x$  corresponding to it:  $x=0.5$ .

Now type in the impedance plane : the point  $r=0.97$  and  $x=0.5$



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- [2] A.A.Muller, E.Sanabria Codesal, A. Moldoveanu, V. Asavei, D. Dascalu “ A survey of infinite regions of recent generalized Smith charts, extensions and applications” **Romanian Journal of Information Science and Technology** (ROMJIST) 2016 in press, Sept. 2016
- [3]. A.A. Muller, E. Sanabria “ A hyperbolic compact generalized Smith chart”, **Microwave Journal**, pp. 90-94, August 2016.
- [4]. A A. Muller, S. Lucyszyn, 'Properties of purely reactive Foster and non-Foster passive networks" **IET Electronics Letters** , vol 51, no. 23 , pp 1882-1884, Nov. 2015.
- [5]. A.A. Muller, E.Codesal-Sanabria , A.Moldoveanu, V. Asavei, P. Soto, V.E. Boria, S. Lucyszyn, “Apollonius Unilateral Transducer Power Gain Circles on 3D Smith charts,” **IET Electronics Letters**, vol. 50 no. 21, pp. 1531-1533, Oct. 2014
- [6] A.A. Muller, P. Soto, D. Dascalu, and V.E. Boria, “The Practical Applications of the 3D Smith chart”, **Microwave Journal**, vol. 55, no. 7, pp. 64-72, July 2012
- [7]. A.A. Muller, P. Soto, D. Dascalu, D. Neculoiu and V.E. Boria, “A 3D Smith Chart based on the Riemann Sphere for Active and Passive Microwave Circuits,” **IEEE Microwave and Wireless Components Letters**, vol. 21, no. 6, pp. 286-288, June 2011
- [8]. A.A. Muller, P.Soto, A. Moldoveanu, V. Asavei, V.E Boria, “A Visual Comparison between the Voltage and Power Wave Reflection Coefficient of Microwave Circuits” **IEEE Asia Pacific Microwave Conference**, pp. 1259-1262, December 2012, Kaohsiung, **Taiwan**

## PRODUCERS

Andrei A. Muller

Alin Moldoveanu

Victor Asavei

User/Web interconnectivity

Cristi Fleischer

Advisers

Pat Hindle

## NON-AUTHORED REFERENCES

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[N2]. L. Besser, R. Gilmore, “ Practical RF circuit design for Modern Wireles Systems”, Artech House, 2003.

[N3].G. Gonzalo “ Microwave transistor amplifier analysis and design” Prentice Hall, N.J., 1984.

[http://cc.ee.ntu.edu.tw/~thc/course\\_mckt/note/note4.pdf](http://cc.ee.ntu.edu.tw/~thc/course_mckt/note/note4.pdf)

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