3D Smith charts

A.A Müller[1], P.Soto[1], A. Moldoveanu[2], V. Asavei[2], E.Sanabria-Codesal[3], V.E.Boria[1]

[1] Grupo de Aplicaciones de las Microondas (GAM), iTEAM, Universitat Politècnica de València, Spain, [2]Faculty of Automatics and Computer Science, Politehnica University Bucharest, Romania, [3] Etsit- Universitat Politècnica de València

andrei@iteam.upv.es

Abstract- The paper presents the applications of the recently proposed 3D Smith chart by means of a completely updated 3D Smith chart tool issued in September 2013. It is capable to deal with both active and passive microwave circuit parameters simultaneously. The 3D Smith chart key maps all the active and passive loads on the surface of the unit ball (inverted Riemann sphere), so that circuits with negative resistance are now assembled in the South hemisphere, circuits with positive resistance (classical 2D Smith chart) are mapped into the north hemisphere, whereas inductive and capacitive circuits are placed at the East and West of Greenwich meridian, respectively. The 3D Smith chart updated tool can plot simultaneously and in an unique manner scattering parameters, power wave reflection coefficients, voltage reflection coefficients, input and output stability circles, and deal with real and also complex characteristic impedance ports.

Introduction

The Smith chart [1] was proposed in 1939 and has become through the years an icon of microwave engineering, being even used in the design of logos. Although originally intended to be a graphical aid for eliminating the drudgery of computation with complex numbers, the Smith chart still remains a highly useful tool for representation and comprehension of microwave data [2], becoming an universal aid to the design of matching circuits and the display of measurements. Although the Smith chart was developed more than seven decades ago, it is still widely used by the microwave community. To have a finite and practical size, the classical 2D Smith Chart is constrained to the unit circle. Hence, loads with reflection coefficient magnitude greater than 1 cannot be plotted. These loads often appear in active circuits and in lossy transmission lines with complex characteristic impedances. The reason for seeking an expansion was determined by the desire to have a unique chart suitable for “including also the negative impedances” without sacrificing the usual benefits the Smith chart usually offers. Recent attempts to overcome this limitation failed to provide a simple unitary model for it, with neat solutions being based on empirical intuition [3] or with solutions based on difficult arithmetical manipulations which also lose many of the planar Smith Chart properties [4,5].

The authors aimed to overcome the limitations of the 3D models recently proposed [3-5] as well as to avoid the usage of the additional negative Smith chart [6]. As a result, they proposed a novel and simple 3D Smith Chart providing an unitary model for visualizing circuits with both negative and positive resistances [7-9].

Actually, the authors proposed in [7] a compact solution where the infinite regions of the reflection coefficient plane become finite points. This is done using the mathematical concept of the Riemann sphere. It is totally difficult to visualize the infinity far apart (as it may occur in active devices) on the planar 2D Smith chart. An outer edge of the complex plane is a vague definition for that. Fortunately, Riemann interpreted the numbers in the extended complex plane as points on a sphere after applying a stereographic projection which performs a one-to-one correspondence between the extended complex plane and the unity radius sphere (i.e., the unit sphere). Using Riemann's theory and Bocher's geometrical insight of infinity with respect to inversive transformations (in fact, the classical 2D Smith chart is also based on an inversive transformation) the novel 3D Smith chart proposed in [7] successfully unifies the active and passive circuits visualization while keeping the circle shape of arcs unaltered (Figure 1).

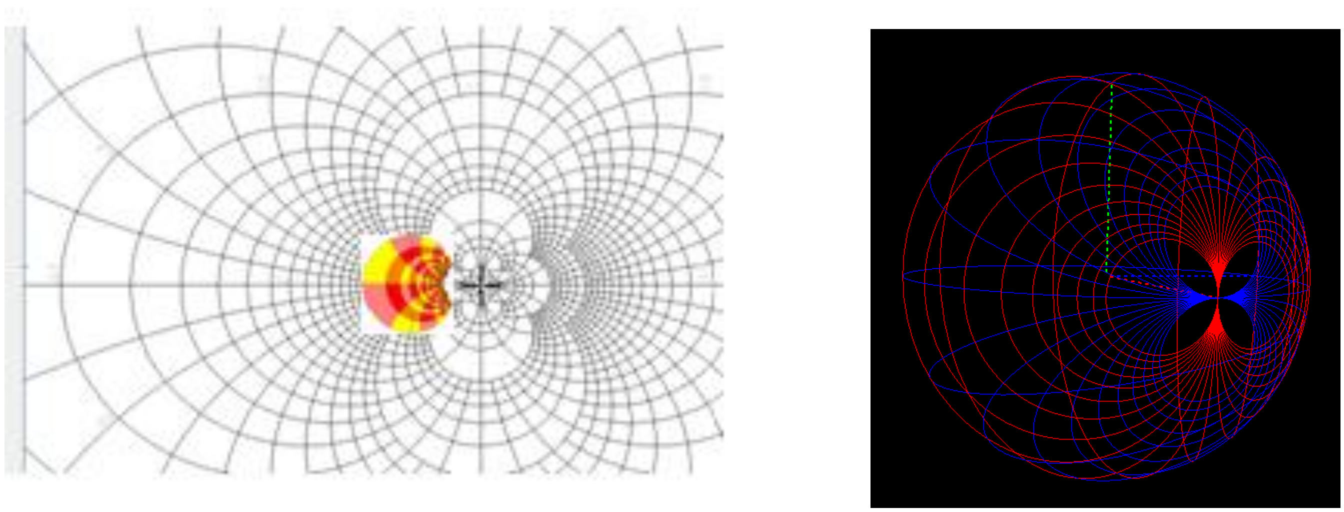

Figure 1: a) Extended 2D Smith chart: circuits with negative resistance are mapped far away from the classical Smith chart (colored), b) 3D Smith chart: North hemisphere: passive circuits, South hemisphere: circuits with negative resistance, East: inductive, West: capacitive.

In the following parts of the paper, and using the new visualization capabilities of the completely updated Smith chart tool (issued in September 2013), some benefits of the 3D Smith chart proposed in [7] will be presented.

Amplifier stability input and output stability circles

A two port circuit is unconditionally stable if the input and output stability circles are mapped outside of the unit disk. In a wide frequency range, this problem generates visualization problems in 2D, due to the scaling required to be able to plot the entire stability circles, identify the problematic regions and look for a possible solution. Moreover, and due to properties of the stereographic projection, the stability circles in the planar Smith chart also transform into circles on the Riemann sphere [8].

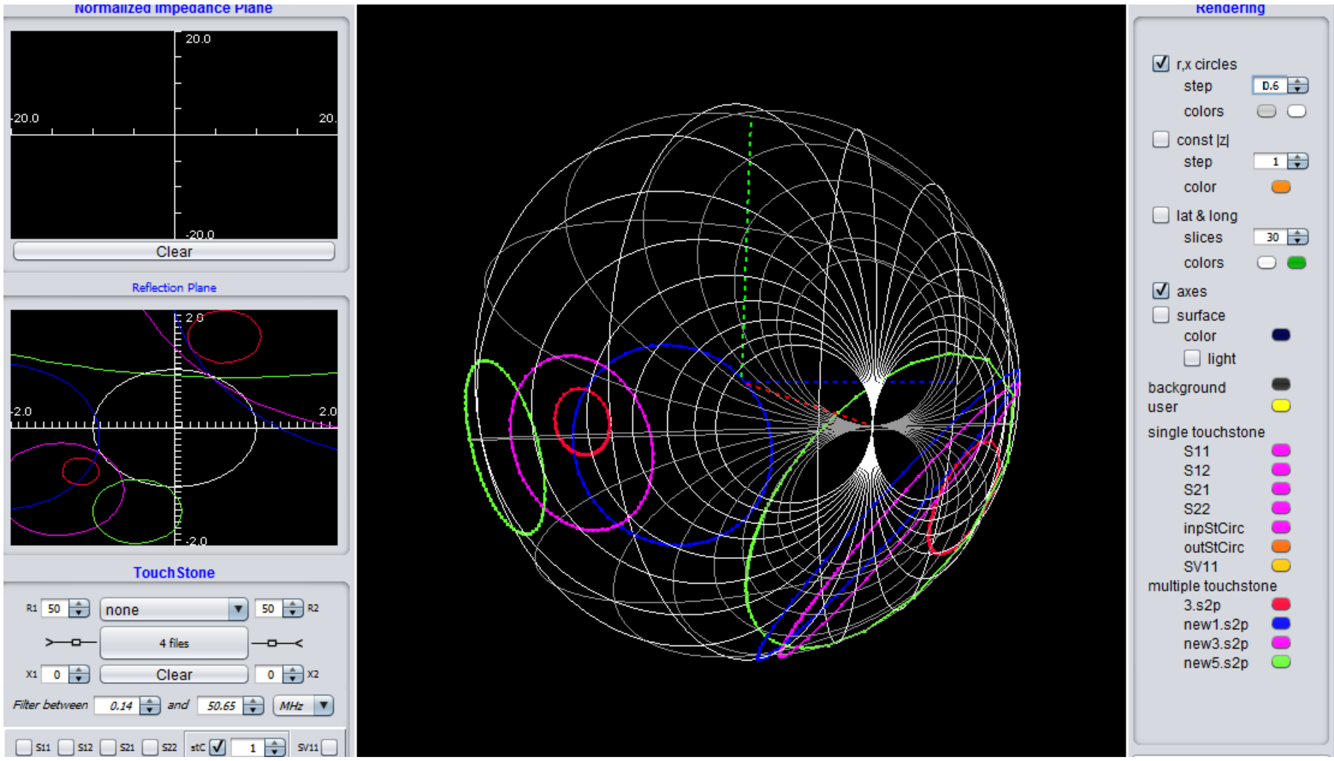

Figure 2: Input and output stability circles at different frequencies for different transistors (green, blue, pink and red), using a different color for each frequency or transistor type.

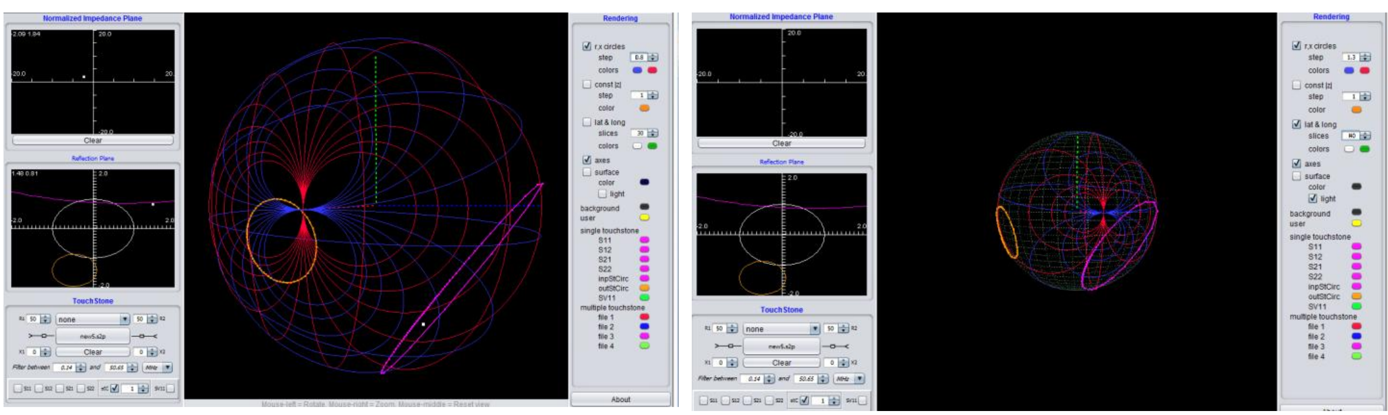
Figure 3: Input and output stability circles for the transistor (named new5.s2p) (see Figure 2 green circles). If the user of the 3d Smith chart tool is only interested in the stability circles for this specific frequency (circuit), one can change the colors, zoom and reconfigure the visualization setup.

The 3D Smith chart tool exploits the aforementioned visualization advantages of the 3D Smith chart, being its present version able to plot different input and output stability circles concurrently. In Figure 2 input and output stability circles of a randomly chosen transistor are plotted. On the left part of Figure 2 one can see the limitations of the 2D representation; the reflection plane must be scaled in the 2D representation. This scaling reduces the 2D Smith chart, thus making more difficult to get a visual insight of the problem even for a single frequency. Based on the information visible on the 3D Smith chart representation, the tool user only has to add to the transistor specific elements in order to map the circles into the South hemisphere.

The 3D Smith chart tool offers the user the possibility to analyze more in detail each single frequency case for a desired circuit. The input and output stability circles of the new5.s2p transistor are shown in Figure 3 (plotted in green colors in Figure 2). These circles are represented in Figure 3 with pink and orange in order to differentiate them, thus allowing the user a handier way to start its design process.

Voltage and power wave reflection coefficients

In [9] it had been geometrically proven that the magnitude of the power wave reflection coefficient of microwave networks with complex port impedances can never exceed unity, while the magnitude of the voltage reflection coefficient can be greater than 1 in the same circumstances.

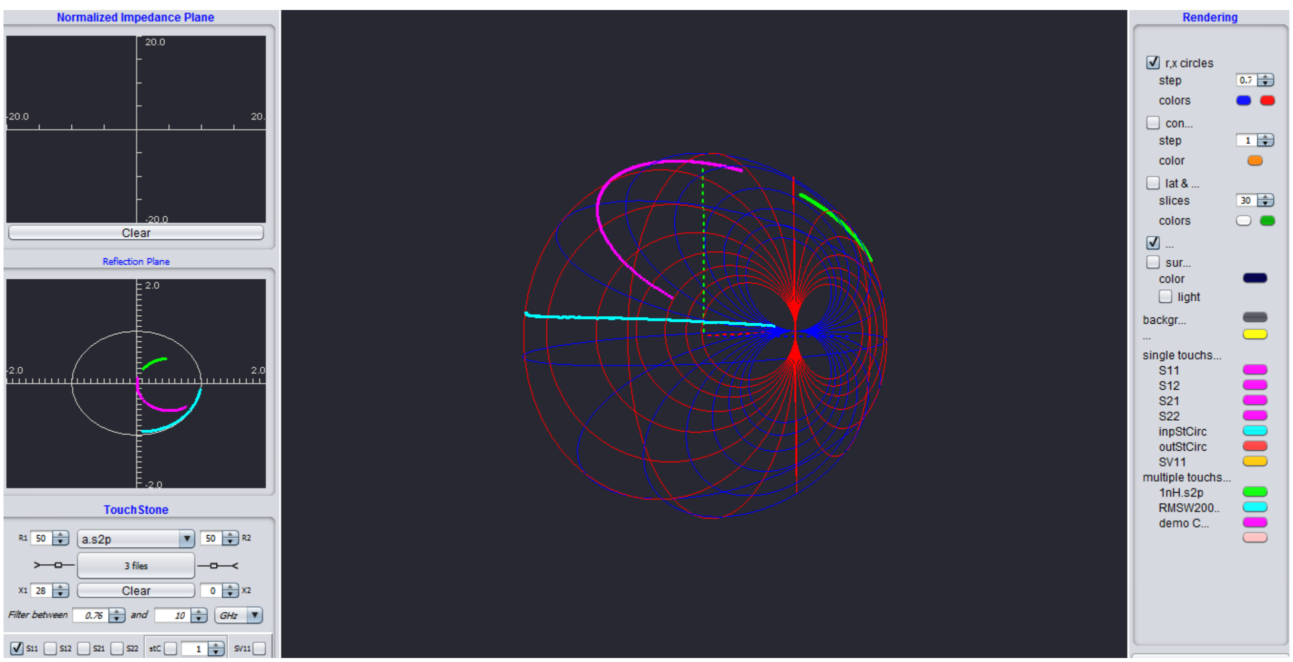

Figure 4: Power wave reflection coefficient (S11) of 3 networks: a 1nH inductor (green), a Radant MEMS switch (light blue) and a simple R,L,C series circuit (pink) seen from a port with impedance of 50 + j26Ω while matched at a second port on with a 50Ω impedance (simulations between 0.76 and 10 GHz).

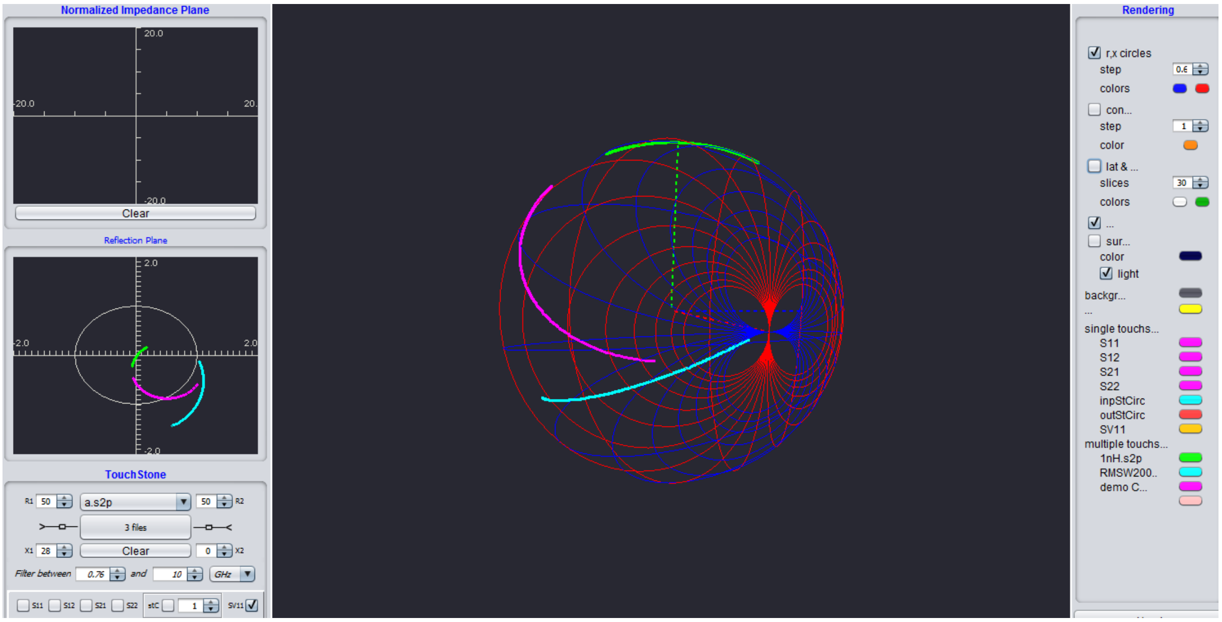

Figure 5: Voltage reflection reflection coefficient (SV11) of 3 networks a 1nH inductor (green), a Radant MEMS switch (light blue) and a simple R, L, C series circuit (pink) seen from a port with impedance of 50 Ω + j26Ω and matched at a second port on a 50Ω impedance (simulations between 0.76 GHz and 10 GHz). In this case the voltage reflection coefficient can exceed unity thus it is mapped in the south hemisphere

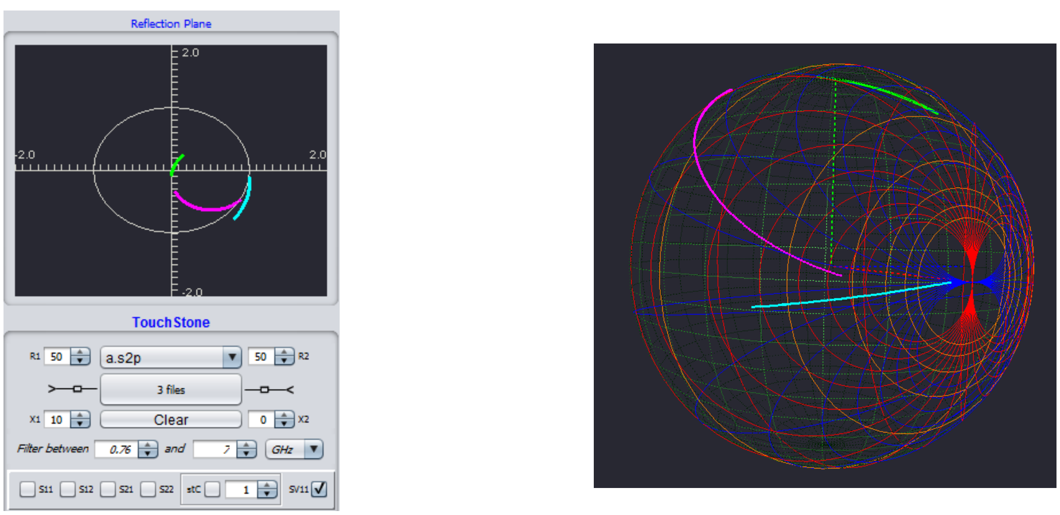

Figure 6: Voltage reflection reflection coefficient (SV11) of 3 networks: a 1nH inductor (green), a Radant MEMS switch (light blue) and a simple R, L, C series circuit (pink) seen from a port with impedance of 50 Ω + j10Ω and matched at a second port on a 50Ω impedance (simulations between 0.76 GHz and 7GHz) . The user can change the port impedance and the frequency range thus analyzing in real time the phenomenon.

Using the updated 3D Smith chart capabilities various power wave reflection coefficients (Figure 4) and voltage reflection coefficients (Figure 5) are plotted simultaneously. It can be seen that the magnitude of the voltage reflection coefficient of both the RLC series and Radant MEMS RSMW 200 switch exceed unity and are thus mapped into the South hemisphere. This occurs for an input port with impedance of 50 + j26Ω while matched at a second port on a 50 Ω impedance. In Fig 6 one may see some possible advantages of the 3D Smith chart tool interface capabilities: the user can tune the input and output ports real (R1, R2) or (X1, X2) imaginary parts or change the frequency range smoothly. Changing the input port impedance to 50 + j10Ω while decreasing the simulation maximum frequency to 7 GHz: the voltage reflection coefficient (SV11) of both the 1nH inductor (green) and RLC circuit switch (light blue) will not exceed in absolute value the unity anymore (both are settled in the north hemisphere in Figure 6).

Conclusions and future developments

The 3D Smith chart has the potential to deal with active and passive microwave circuits simultaneously: it can be used in stability circles visualization, complex matching, oscillator design and many other applications involving positive and negative resistances. The 3D Smith chart Java tool interface allows the user to deal with different kinds of s2p touchstone files at the same time, being able to plot input and output stability circles, power wave and voltage reflection coefficients, reflection parameters while dealing with complex port impedances that can be tuned in a smooth manner by the user. In the future it is desired to increase the interface compatibility with other microwave programs while considering to add to the 3D Smith chart tool a new dimension (one is using now only the surface of the unit ball) via a kind of (gnomic or stereographical) projection [11] or by defining some vector fields, in order to plot other potential quantities of interest (power levels, etc).

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