## RF and Microwave Design with JavaScript

## *The Book I wish I had when Learning RF*

## Jerry Wiltz

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## For Marian

## Introduction

Welcome to RF and Microwave design. When you hear wireless, you are hearing RF and  Microwave. This is a book about RF design and analysis using JavaScript. It is a book about turning RF components such as transmission lines, inductors, and amplifiers into their n-port representation and hooking them up together to create an overall circuit and finally compute  the electrical performance. It is also a book about a JavaScript library that is easy for anyone to use with on any computer or smartphone with an Internet Browser. Another goal of this book is making RF theory accessible to more designers and technicians. While formulas and math are a big part of  this, we can start simple. I will assume all readers will know basic arithmetic but may not know more complicated things like imaginary numbers or matrix operations, but I will introduce them in an easy way.

I have been working in RF and Microwave for over 30 year you can see me at [LinkedIn](https://www.linkedin.com/in/jerry-wiltz-aa548320) and  [GitHub](https://github.com/JerryWiltz). It was very thrilling for me to see the hardware, such as a bandpass filter, come to life and perform as expected. Seeing the filter frequency response in the lab match the electrical modeling was very gratifying for me. Back in the day, you could tell if someone was really an RF designer if they had heard of either “Matthaei, Young, and Jones”, (Microwave Filters, Impedance-Matching Networks, and Coupling Structures), or the “Red Russian” (Handbook of Filter Synthesis, by Anatol I. Zverev), or “The Blue Bible” (Reference Data for Radio Engineers, by ITT). So I would go to these books, get the equations, and write some software to automate them, and produce working designs from them that performed as expected. As good as these books were, they did really cover s-parameters and n-ports in any real way. The books that addressed s-parameters for me in the 1980’s were, “Computer Aided Design of Microwave Circuits” by Gupta, Garg, and Chadha; “Microwave Circuit Design Using Programmable Calculators” by Allen and Medley; and “Design of Amplifiers and Oscillators” by Vendelin.

There are all kinds of powerful commercial software available, such as Microwave Office and ADS by Keysight among many others. Not only are they used by professionals for design, they are available for students to learn about RF theory and techniques as well. I wanted to get back to the basics and I wanted to learn and write and application in JavaScript. Atwood’s Law states that, “Any application that can be written in JavaScript, will eventually be written in JavaScript.” I wanted to write simple and robust software in JavaScript that runs in the browser of computers and smartphones could perform basic design very quickly and be a learning tool too. So the basis of this book is the joining of RF techniques using s-parameters in n-ports and using the power and ubiquitousness of JavaScript to do the heavy lifting.

## Overview of the Book

I have wanted to introduce RF design in a very simple way - to get some of the “black magic” out of it and make it more accessible for more people. We will see how well this goes and if I have succeeded in any way. In chapter 1, we will start off with DC and resistors because the math is easier and once we can do things first at DC, moving over to AC will be a lot easier to understand. Speaking of math, we have made that easier too - with a JavaScript library called nPort. Once a concept is understood with a hand calculation, then with that understanding, we remove the tedium with software. We will utilize the software as we need it. After considering simple resistor circuits, we will continue on with voltage dividers and then discuss maximum power transfer. Once these basics are understood, we introduce the decibel and analyse (at DC) the standard resistor 3dB attenuator. We will do this by hand calculation by calculating voltage drops and then by application of Kirchoff’s voltage laws by using nPort to solve a very simple matrix. Lastly in this chapter, we will introduce 2-ports and s-parameters and calculate by hand the s-parameters (at DC) for a 75 Ohm resistor 2-port connected in series and a 75 Ohm resistor 2-port connected in parallel.

Chapter 2 starts with representing AC voltages with their Root Mean Square (rms) equivalent and applying this new concept to the 3dB attenuator in chapter one. Everything is the same, but now we will use nPort to compute and plot the frequency response of the 3dB attenuator from 500 MHz  to 1500 MHz as an example. The next topic is complex numbers. We need them in order to compute the reactance of inductors and capacitors. Now with a very simple circuit, we introduce the condition for maximum power transfer in AC: that the load is the complex conjugate of the source. Easy peasy. The next section of the chapter takes on the determination of individual s-parameters of a wide variety of passive 2-ports, and multiports, R, L, C, Ideal Transformers, Open, Short, Load, and “dummy” interconnects. In order to evaluate the performance of a circuit using multiple n-ports that are connected to each, we need tools to turn them into a single n-port. nPort has methods that handles all of these things easily. We conclude chapter 2 with lumped element low pass filters and synthesizing them with nPort.

Next, chapter 3 introduces ideal transmission lines along with their s-parameters. So now we can look at power dividers, rat race dividers, branchline couplers, and edge coupled filters. We can also “dirty them up” by introducing parasitic (unwanted) inductors and capacitors and seeing how the frequency response degrades from the ideal due to the undesired presence of parasitic elements. Indeed, unawareness or neglect of parasitics contributes to the “black magic” of RF and Microwave. Of course another reason it is called black magic is that parasitic effects, once understood, can be exploited to become part of the circuit. Real black magic. nPort is used to perform all of these analyses. After this, microstrip and stripline transmission line components such as lines, coupled lines, tees, crosses, steps in width, opens, shorts, vias, and lange couplers are introduced bringing us more to the real world of RF and Microwave engineering.

Chapter 4 starts at the very beginning at DC with dependent voltage and current sources. Dependent sources are key to specifying active devices such as transistors and field effect transistors. So we will construct models of active devices using Having s-parameters of 2-port and 3-port active device models, we can add all the passive components introduced in chapters 2 and 3 and perform circuit analysis of RF and Microwave assemblies on circuit card assemblies, on microstrip integrated circuits (MIC), and on microstrip monolithic integrated circuits (MMIC).

# 1 DC and Resistors

This chapter begins with a review of DC theory and resistors. It reviews determining the total resistance of resistors in series : R = R1 + R2 + R3 + …, it reviews determining the total resistance of resistors in parallel 1/Rt = 1/R1 + 1/R2 + 1/R3 + ... , and it reviews circuit analysis using voltage dividers. At this point, the arithmetic is straightforward. We will use all this review material to determine the resistance of a more complicated resistor network. So far, we are building on top what of the review material. Along the way, we review maximum power transfer, which is really the point of the whole thing.

All through this chapter, we will repeated analyze the same 3-resistor 3db attenuator performance by different ways - all using DC theory. We are doing this to gain insight into network theory that will be transferable to AC analysis. We will see we can introduce the s-parameters at DC with resistors where the mathematics is much simpler and will set the stage to understand the s-parameters at AC with resistors, inductors, and capacitors covered in chapter 2.

We will analyze the 3-resistor 3dB attenuator using voltage dividers, using Kirchhoff’s Voltage Law, using Matrices, and finally using **nPort** all the while getting the same result. We perform hand calculations first to understand the theory better. After that, we see how simple it is to use **nPort** to accomplish the same thing. So we analyze by hand for learning and getting insight into circuit performance in order to use software, like nPort,knowing what to expect in advance.

DC Review

We start off with a basic circuit. This is the simplest circuit I can think of. It is shown in figure 1-1. It has a 1 volt DC source and a 1 Ohm resistor load. Note the current convention, current flows out of positive terminals of the source and moves in a clockwise direction.

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