Experiments in Optimization Applied to Antenna Impedance Matching

William Brooks, WB6YVK

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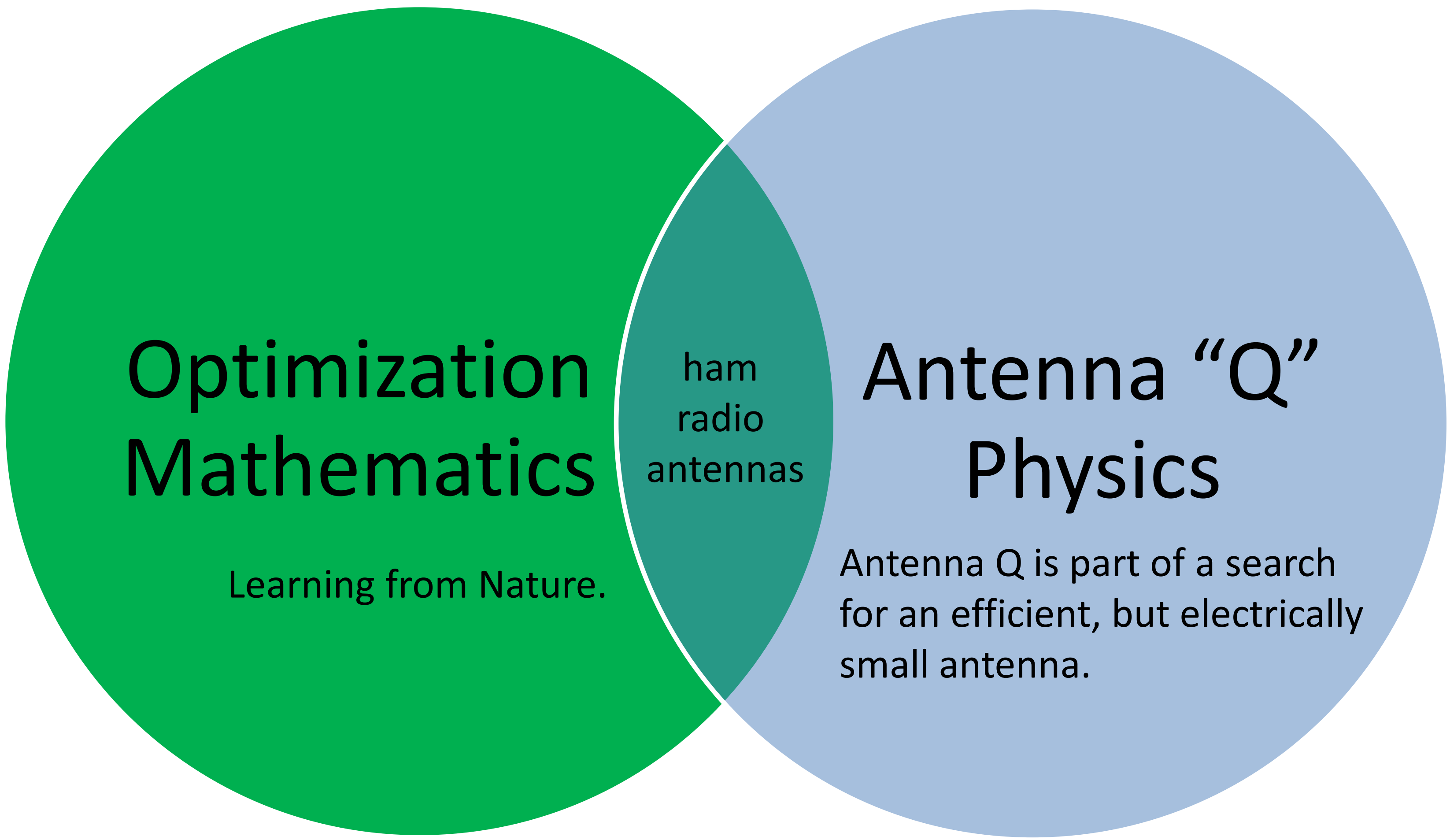
The Intersection of Two Evolving Disciplines



Presentation Outline

- Introductions
- The basic L, T , and Pi circuits
- What governs antenna impedance bandwidth
- Brief overview of well-known impedance matching techniques
- Simple impedance matching circuit topologies
- Introduction to Nature-Inspired Optimization Algorithms
- Introduction of ZNET Optimization Algorithm
  - Examples results using monopole, dipole, delta loop, and Yagi antennas;
    - Resonant and non-resonant antennas, multi-band equalizers, circuit topology “pruning” algorithm.
    - Lumped LC equalizer circuits, and distributed element (transmission line) equalizer circuits.
- Lessons Learned (so far), and future developments.

Scope and Objective

This is a work in progress.....

The scope of this presentation is intended for amateur radio enthusiasts.

- Rigorous antenna Q, Maxwell, Kuroda, Chu, Fano, Gewertz, Hurwitz, Brune, Youla, Gauss, Newton, Powell, Hessian, Jacobian, et al equations will be avoided.....
  - But, the above are helpful to understand the problem.

The objective of these experiments is;

- Learn something new about mathematical optimization techniques.

Preliminaries, Definitions, and Clarifications

Single Match vs. Double Match

- All examples shown here are Single Match; the source is 50+j0 Ohms.

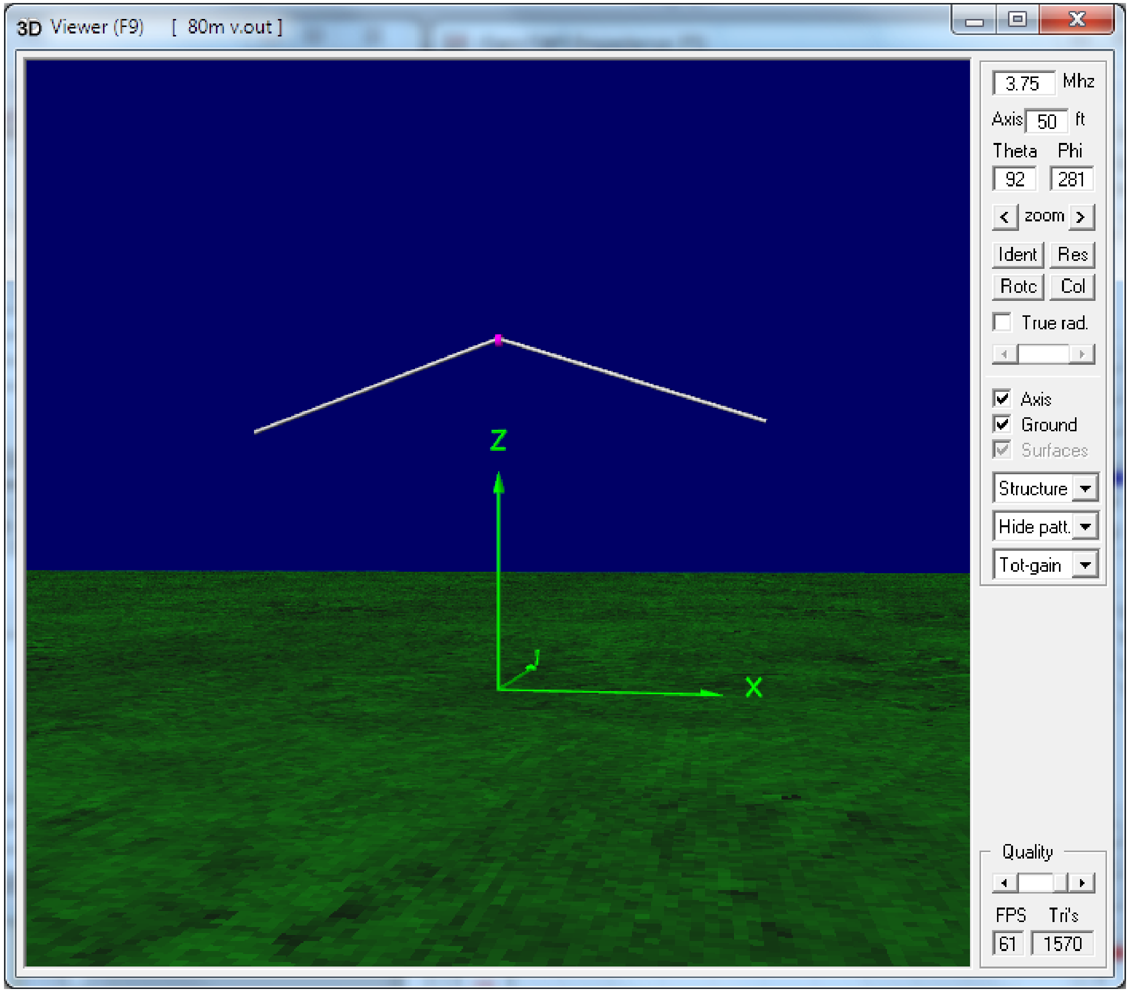
Singly-Terminated Networks vs. Doubly Terminated Networks

- All examples shown here are Doubly-Terminated Networks

Circuit diagrams direction;

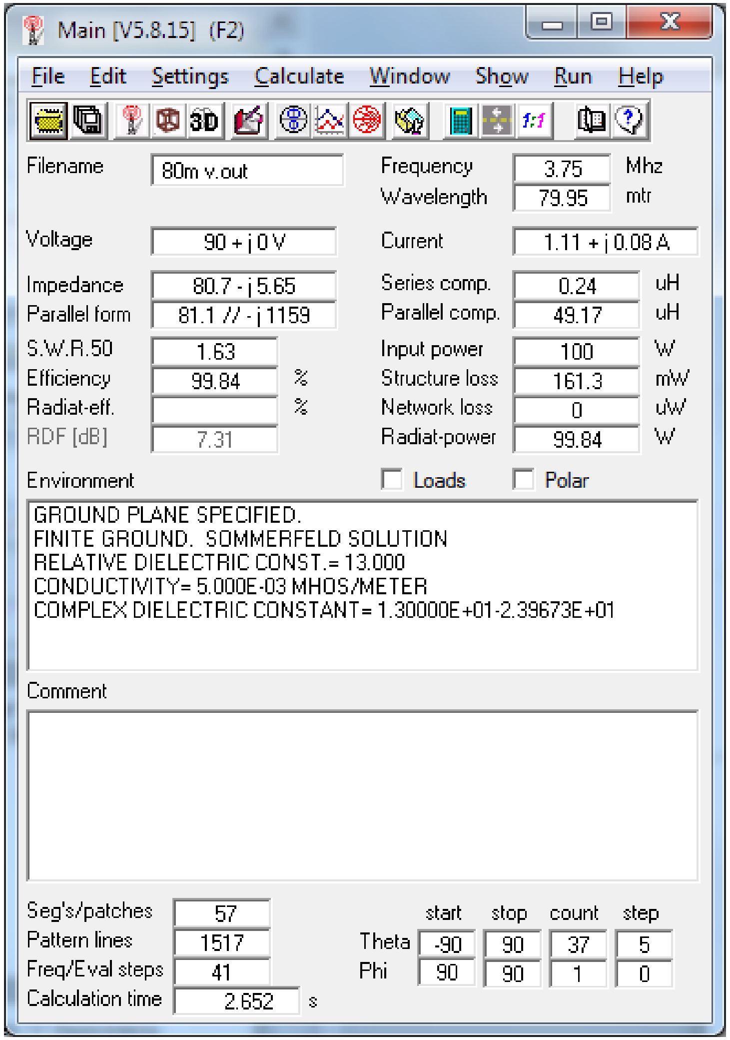
- Many RF circuit design textbooks draw circuits from source left to load right, but
- Many Smith Chart tools (e.g. SimSmith) draw circuits from load left to source right.
- Both will be shown here.

An 80 meter ½ λ Inverted V Wire Antenna

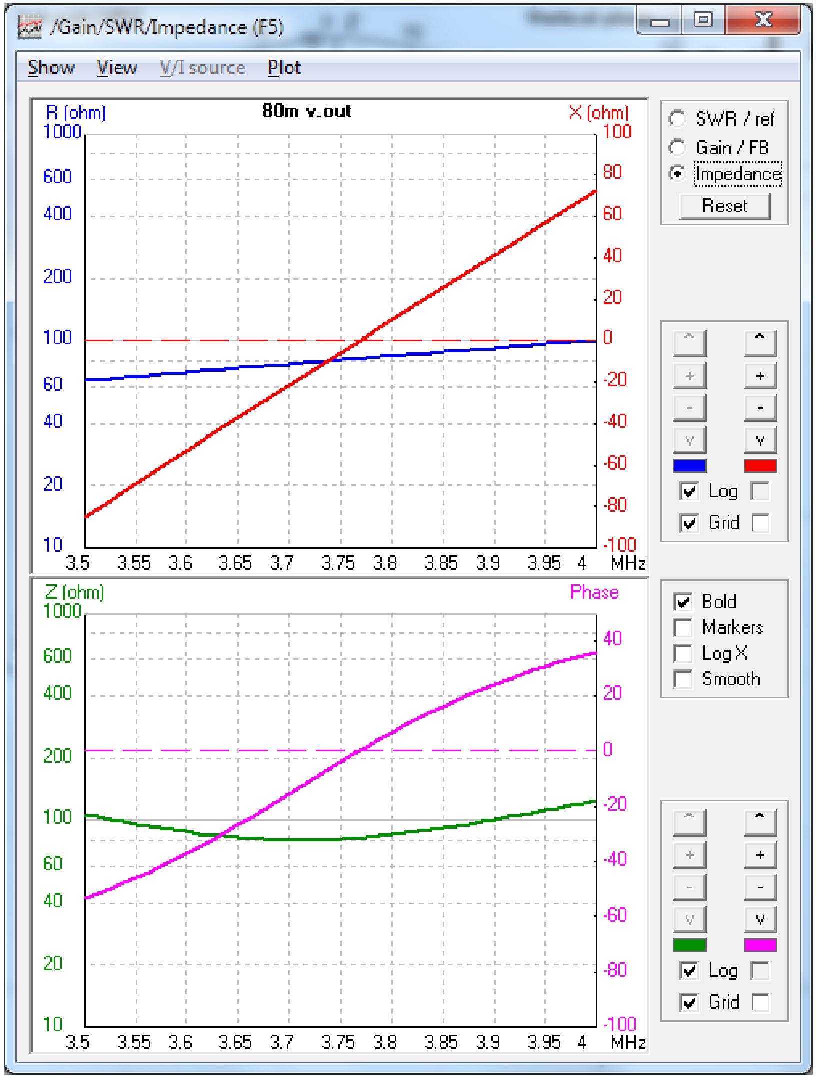


Computer Model of Antenna Physical Geometry

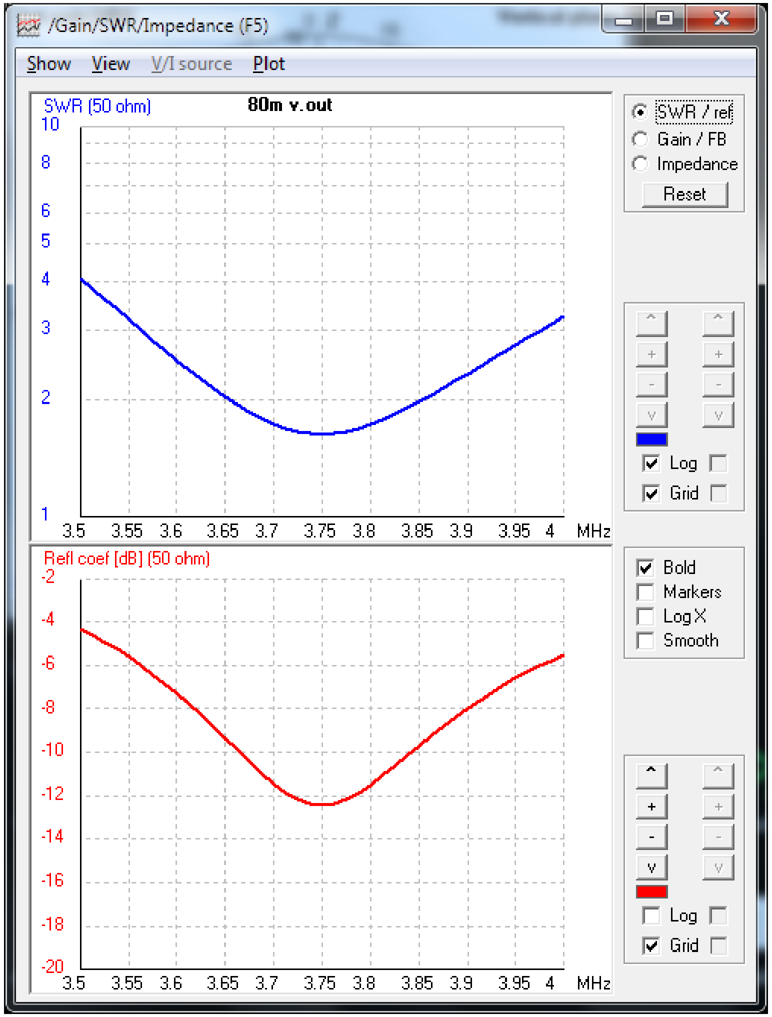
4NEC2 Computation Results using NEC 4.1 Engine



Unmatched ½ λ Inverted "V" Wire Dipole Frequency Sweep of R,X, Z, and Phase

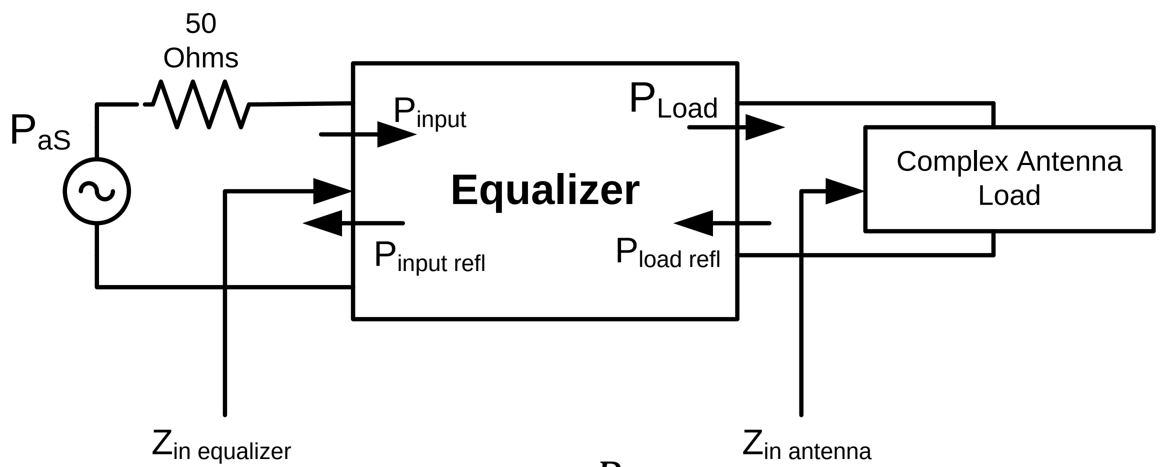


½ λ Inverted "V" Wire Dipole Frequency Sweep of Antenna VSWR and Reflection Coefficient



Computed using NEC4.1 from Lawrence Livermore National Laboratory.

Equalizer Block Diagram



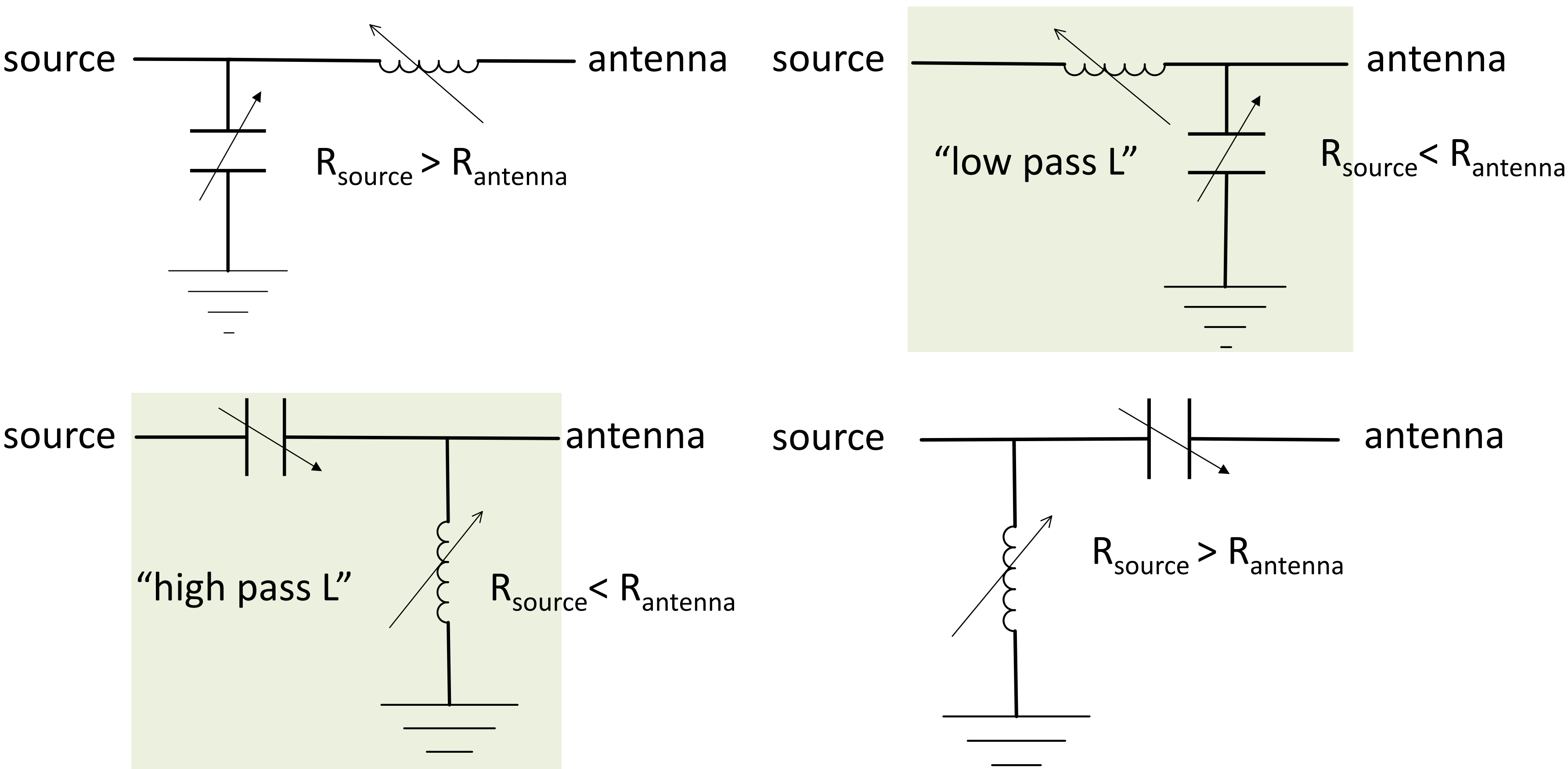
TPG = Transducer Power Gain $TPG = \frac{P_{Load}}{P_{aS}}$

An ideal, “lossless” equalizer $P_{Load} = P_{aS}$

Thomas R. Cuthbert, Jr., PhD, Broadband Direct-Coupled and Matching RF Networks, TRCPEP Publications, Greenwood, AK, (1999), pp.2-4.

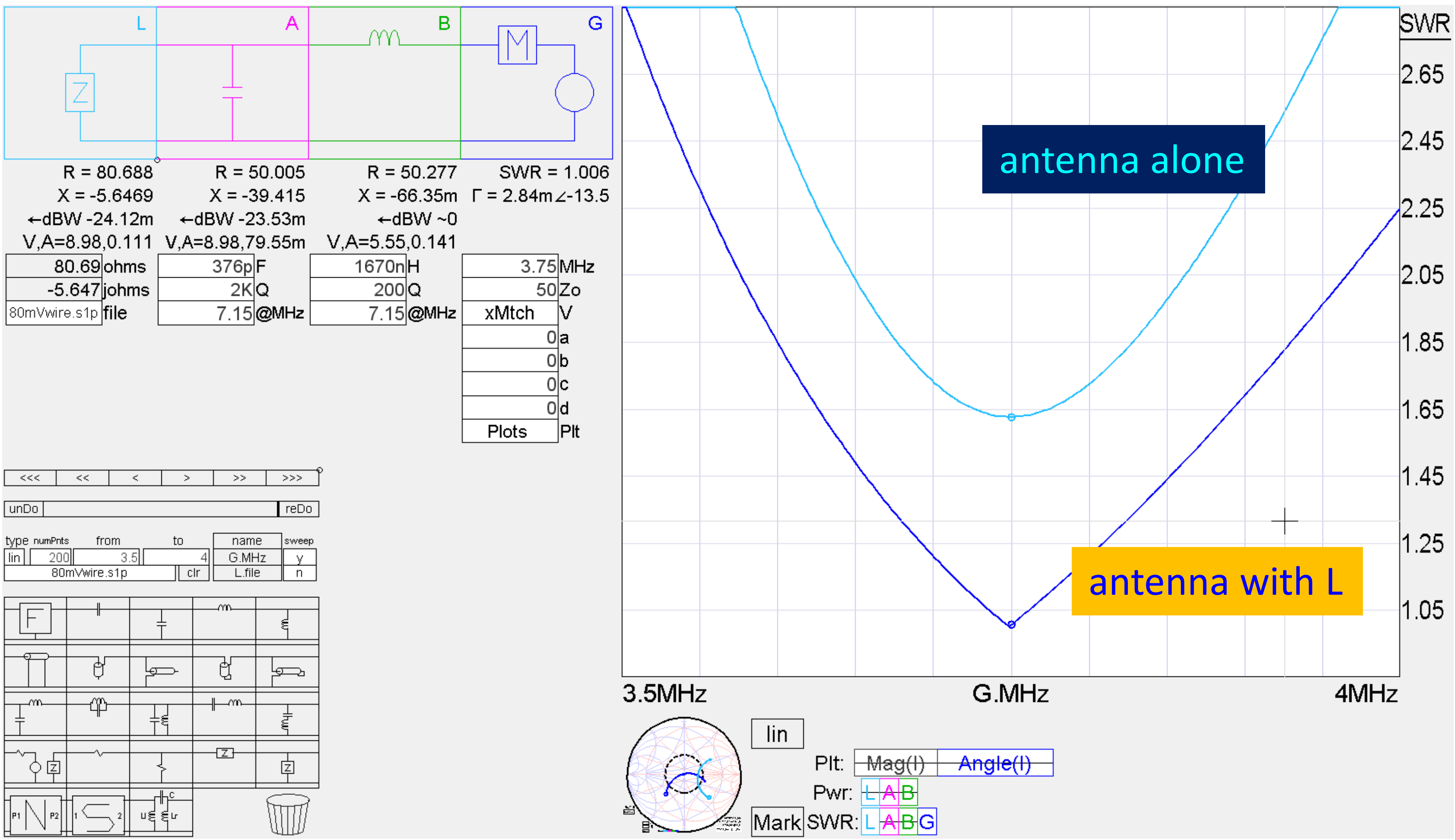
An excellent description and comparison of “power gain”, “transducer gain”, and “available gain” terms is available Power, Transducer, Available, and Insertion Gains Defined from Maury Microwave, http://www.maurymw.com.

Enter the "L" Tuning Equalizer

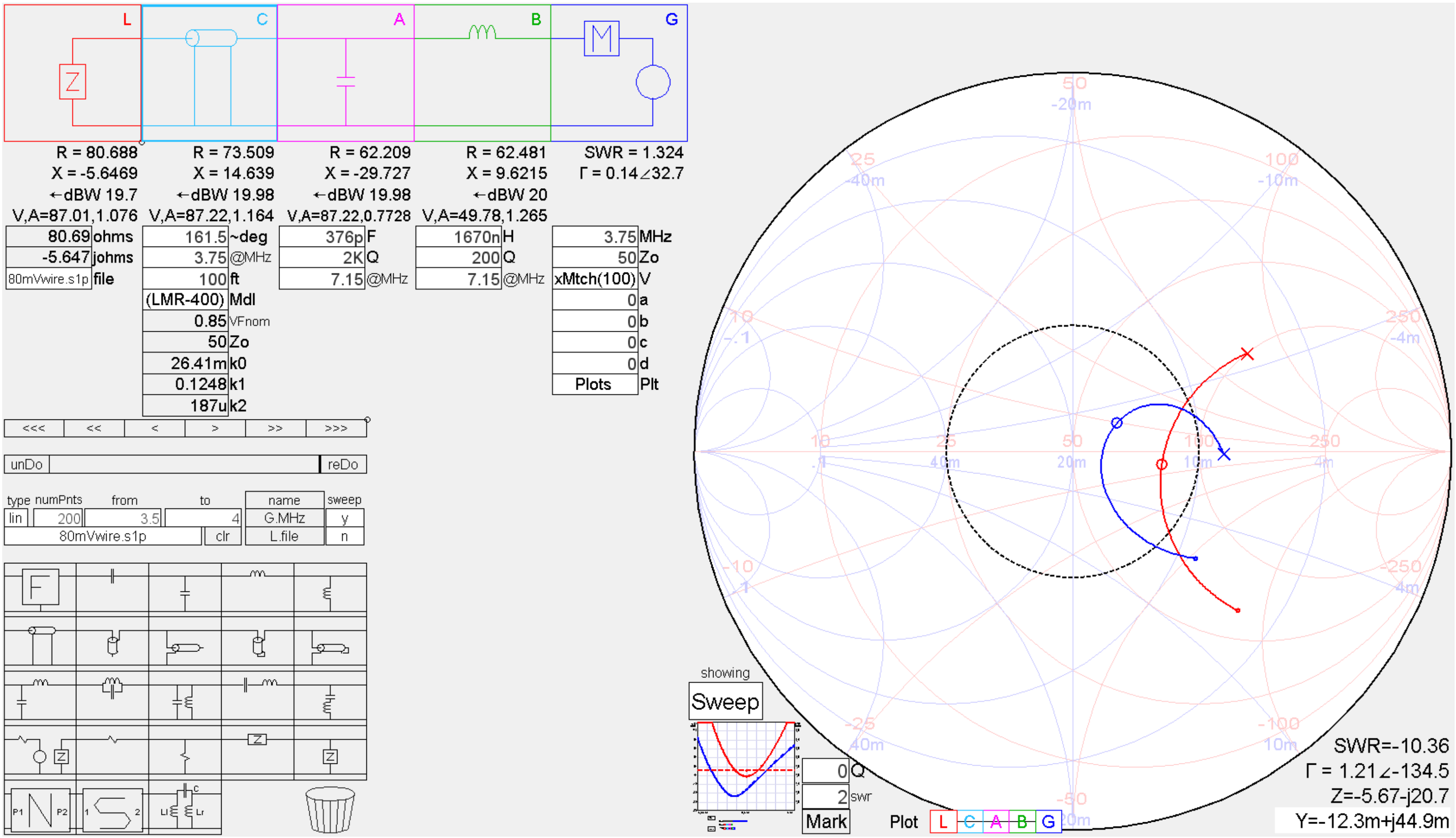


The "L" can also be two inductors, or two capacitors.
Selection of L circuit topology governed by impedance values (location on Smith Chart), VA3IUL offers a graphic summation of "L" circuits and applicable Smith Chart zones at www.qsl.net/va3iul/.

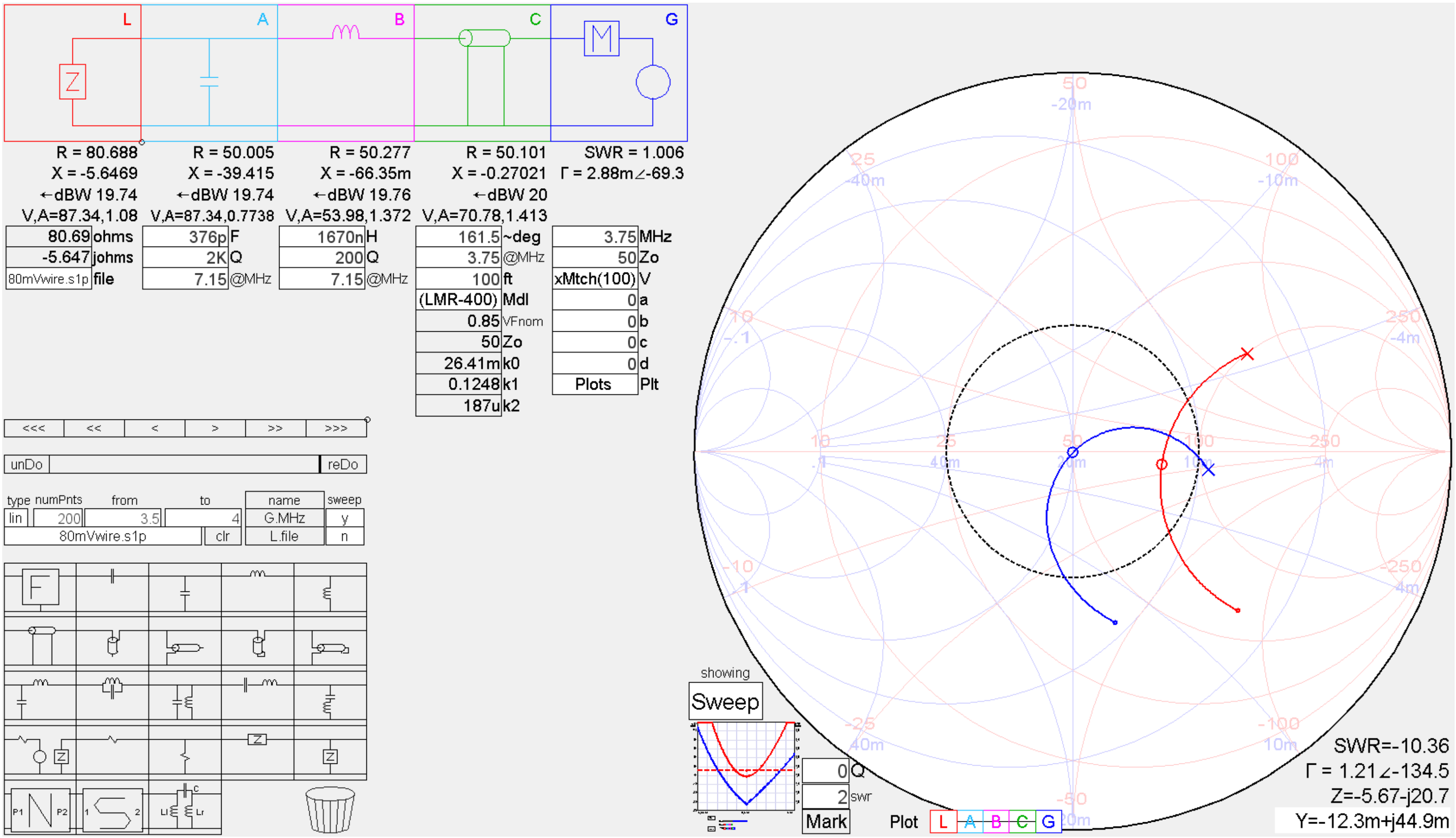
L Equalizer Added to 80 meter ½ λ Inverted V Wire Dipole Antenna



Smith Chart of L Equalizer Added to 80 meter ½ λ Inverted V Wire Dipole Antenna (L equalizer at radio, then 100 feet LMR400 coax to antenna)

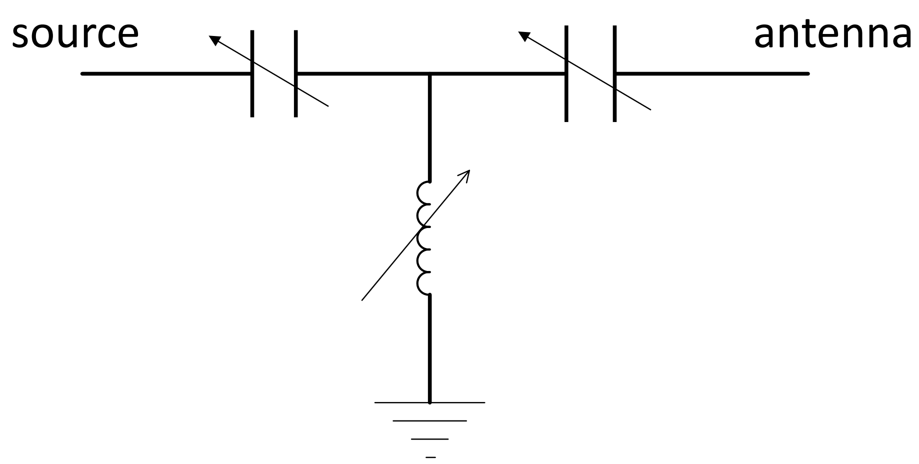


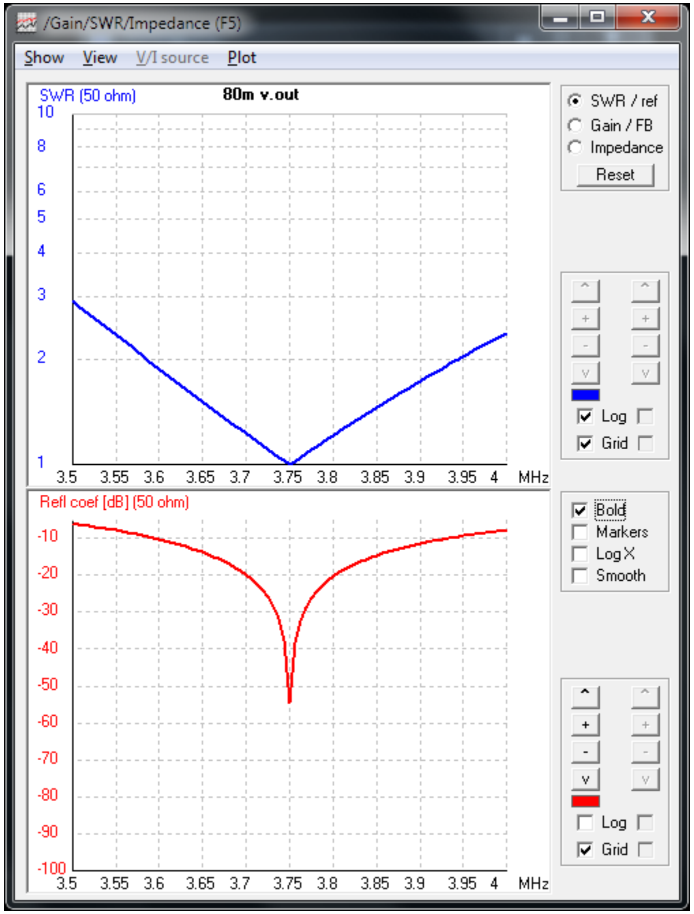
Smith Chart of L Equalizer Added to 80 meter ½ λ Inverted V Wire Dipole Antenna (100 feet LMR400 coax from radio, L equalizer at antenna)



Common Amateur Radio Antenna Equalizers

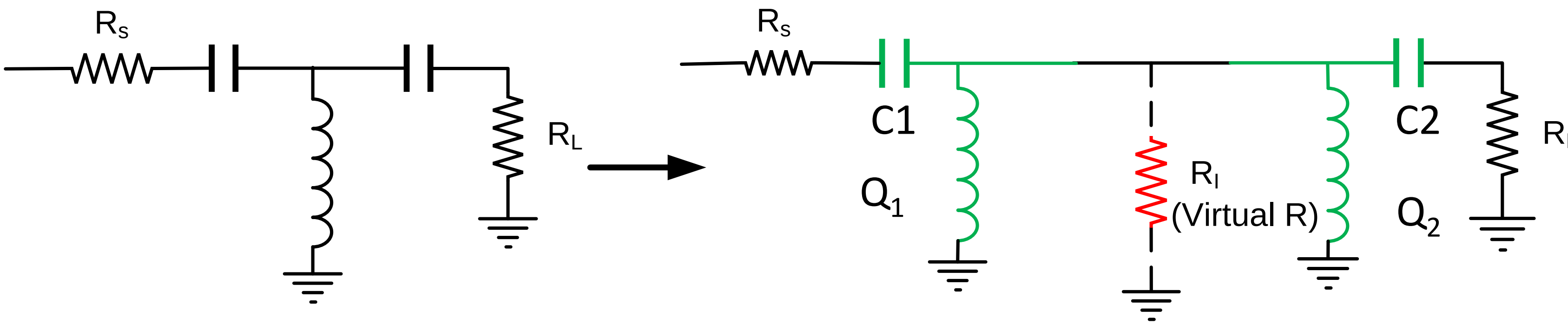
3 element, High-Pass “T” circuit





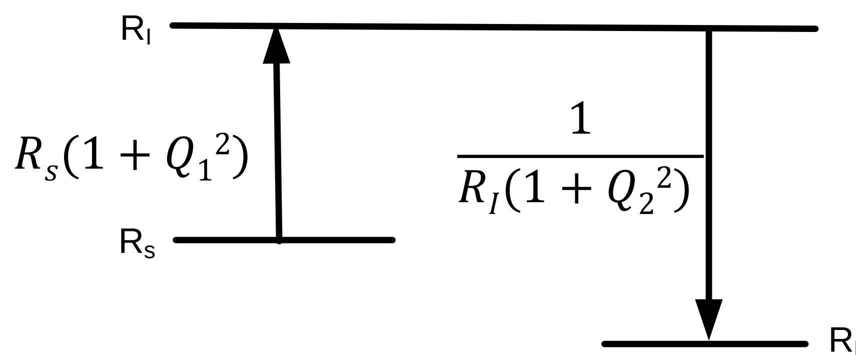
VSWR < 2 achieved over a narrow span of the RF spectrum; adjustable tuning required.

A “T” is Two “L”’s



$$Q_1 = \sqrt{\frac{R_I}{R_S} - 1}$$

$$Q_2 = \sqrt{\frac{R_I}{R_L} - 1}$$



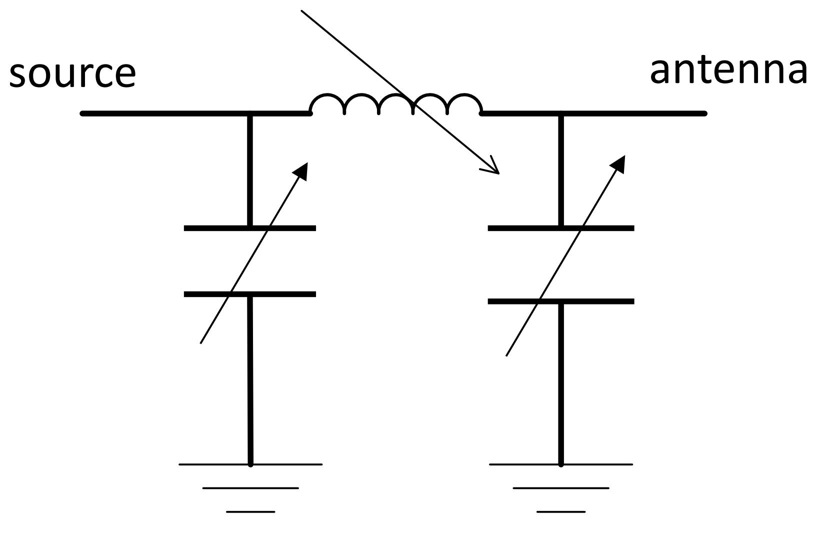
$$Q_0 = \frac{Q_1 + Q_2}{2} > \frac{1}{2}\sqrt{\frac{R_L}{R_S} - 1} \quad \text{If } R_L > R_S$$

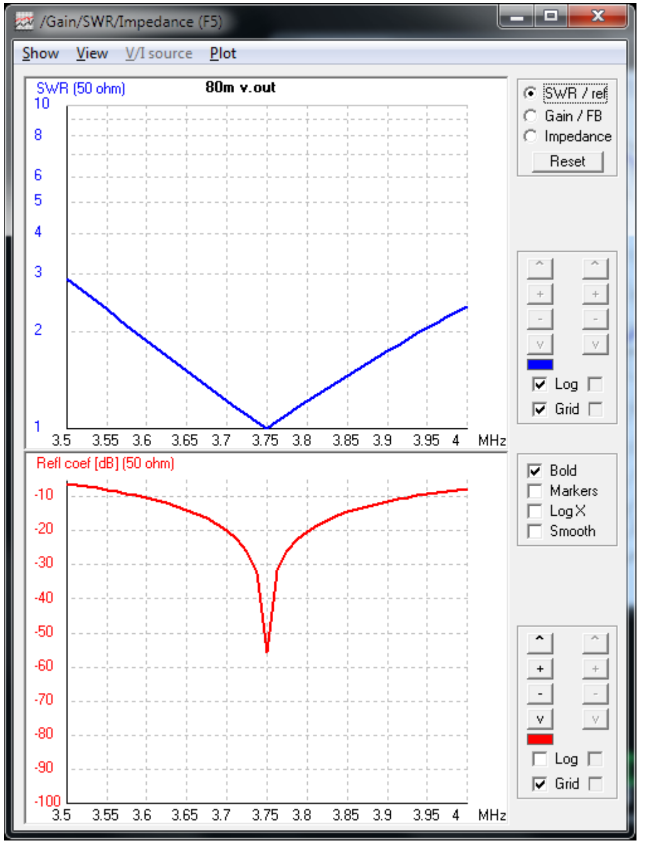
The impedance of the “virtual R” is greater than the impedance at either end, i.e. “step up”, then “step down”.

B.K. Chung, “Q-based design method for T network impedance matching”, *Microelectronics Journal* 37 (2006) 1007–1011.

Common Amateur Radio Antenna Equalizers

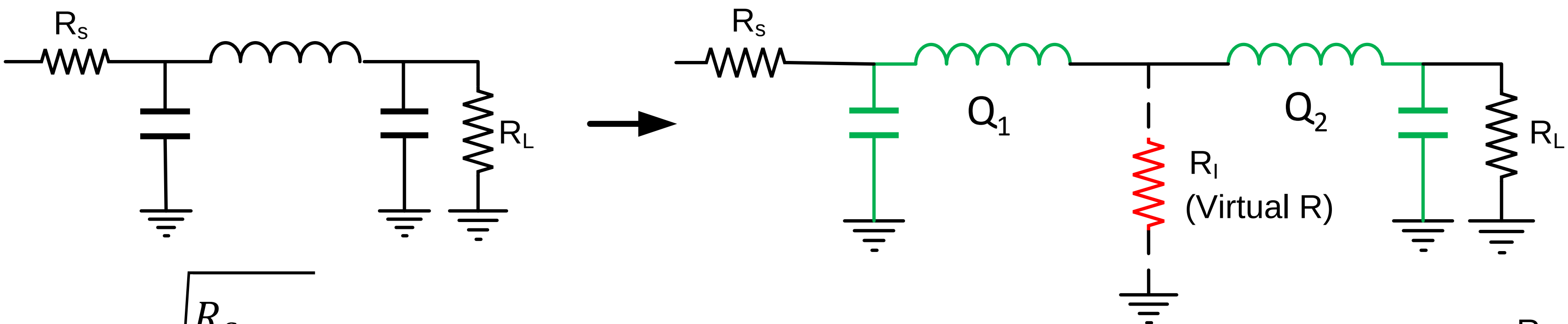
3 element, Low-Pass "Pi" Tuner circuit





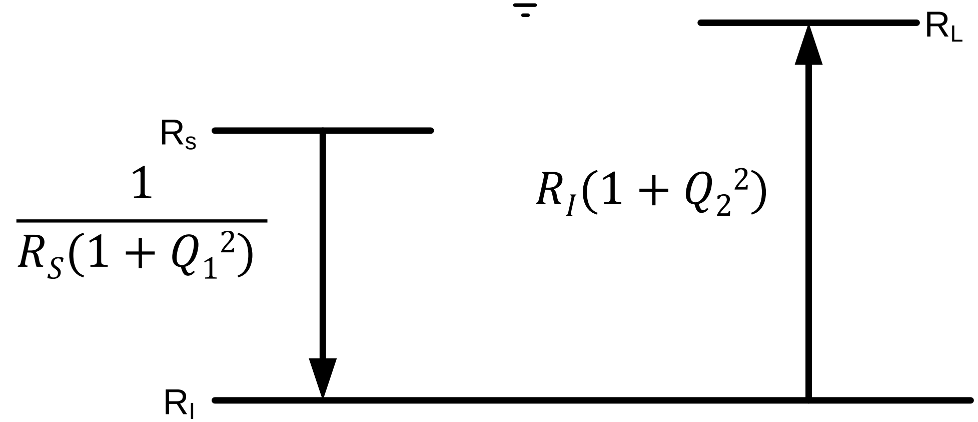
VSWR < 2 achieved over a narrow span of the RF spectrum; adjustable tuning required.

A “Pi” is Two “L”s



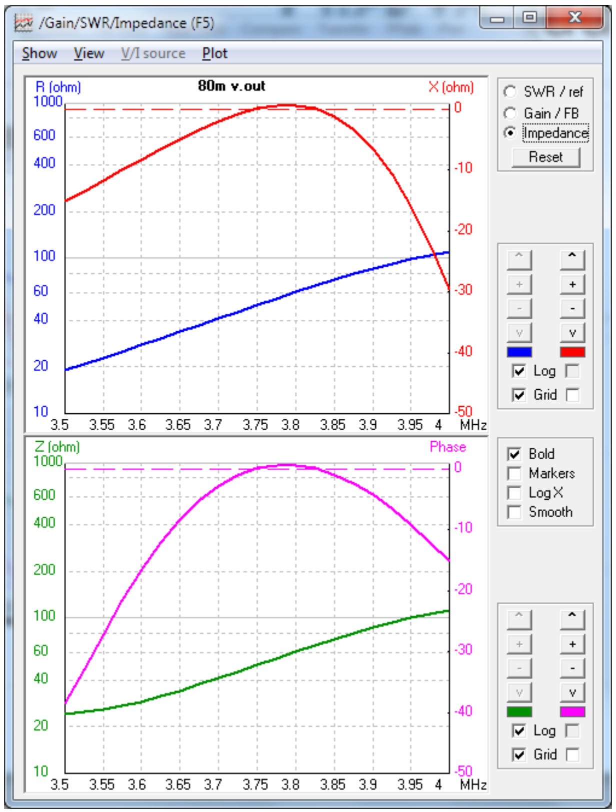
$$Q_1 = \sqrt{\frac{R_S}{R_I} - 1}$$

$$Q_2 = \sqrt{\frac{R_L}{R_I} - 1}$$

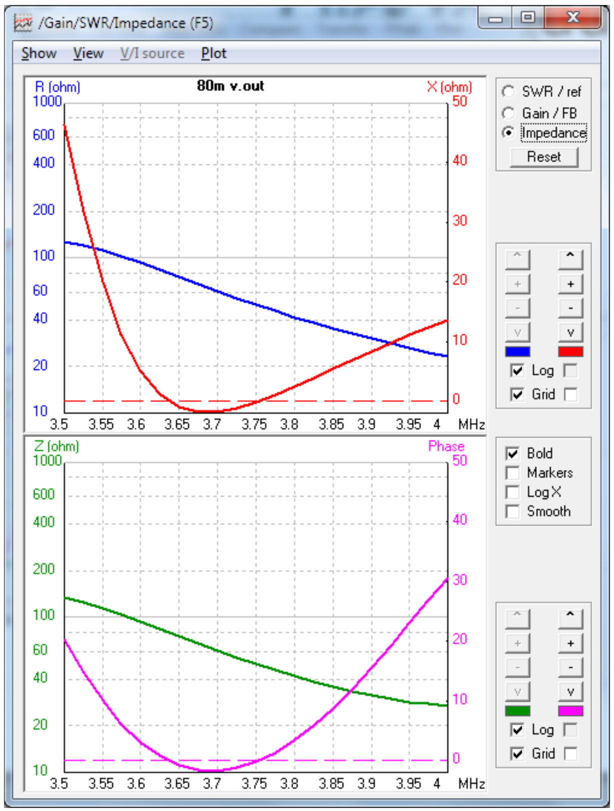


The impedance of the “virtual R” is **<u>less</u>** than the impedance at either end, i.e. “step down”, then “step up”.

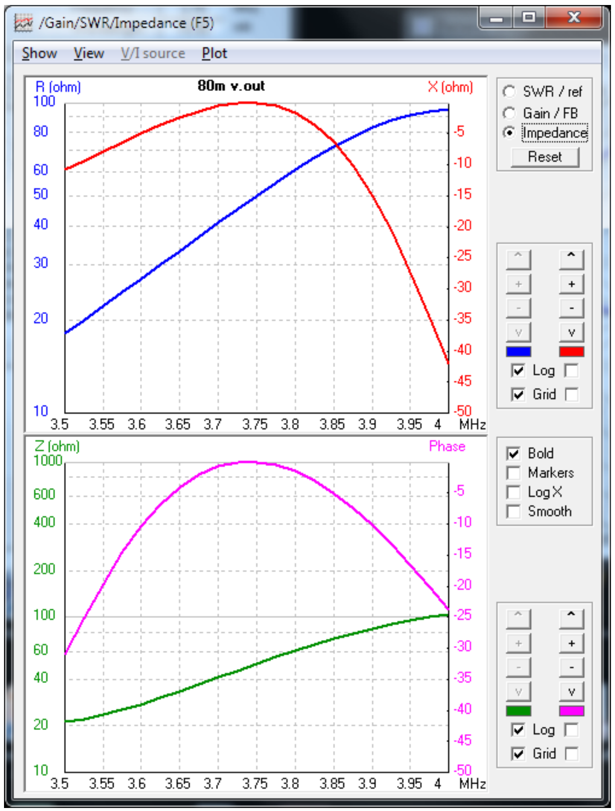
R, X, Z, and Phase of 80 meter ½ λ Inverted V Wire Dipole Antenna Plus Equalizer Networks



Low pass L



High pass T



Low pass Pi

Initial Questions

What governs the impedance match bandwidth of an antenna across a whole frequency band?

How to design such an antenna impedance equalizer?

What Governs the Impedance Match?

The Many Types of Q;

- Antenna Q, "Q_{ant}",
- Match Bandwidth, "Q_{BW}",
- L & C component Q_u,
- Number of equalizer circuit elements.

Randy Rhea created a CD "Q from A to Z" available from http://www.scitechpub.com.

Antenna Q and Impedance (active subjects in recent literature)

240 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 63, NO. 1, JANUARY 2015

Antenna Q and Stored Energy Expressed in the Fields, Currents, and Input Impedance

Mats Gustafsson, *Member, IEEE*, and B. L. G. Jonsson

***Abstract*—Although the stored energy of an antenna is instrumental in the evaluation of antenna Q and the associated physical bounds, it is difficult to strictly define stored energy. Classically, the stored energy is either determined from the input impedance of the antenna or the electromagnetic fields around the antenna. The new energy expressions proposed by Vandenbosch express the stored energy in the current densities in the antenna structure. These expressions are equal to the stored energy defined from the difference between the energy density and the far field energy for many but not all cases. Here, the different approaches to determine the stored energy are compared for dipole, loop, inverted L-antennas, and bow-tie antennas. We use Brune synthesized circuit models to determine the stored energy from the input impedance. We also compare the results with differentiation of the input impedance and the obtained bandwidth. The results indicate that the stored energy in the fields, currents, and circuit models agree well for small antennas. For higher frequencies, the stored energy expressed in the currents agrees with the stored energy determined from Brune synthesized circuit models whereas the stored energy approximated by differentiation of input impedance gives a lower value for some cases. The corresponding results for the bandwidth suggest that the inverse proportionality between the fractional bandwidth and Q-factor depends on the threshold level of the reflection coefficient.**

new expressions by Vandenbosch [7] are useful as they express the stored energy in the current density on the antenna structure. This has been shown to be instrumental in the analysis of small antennas [8]–[11] and also for antenna optimization [11]–[13]. The expressions have been verified for wire antennas in [14] and applied to characteristic modes in [10]. One minor problem with the proposed expressions is that they can produce negative values of stored energy for electrically large structures [9]. Alternative definitions and derivations of the stored energy are presented in [10], [15]–[20].

In this paper, we investigate the stored electric and magnetic energy expressions recently proposed by Vandenbosch [7]. We compare these expressions with the stored energy defined from subtraction of the energy density by the energy density in the far-field term [16]. The results provide a new interpretation of Vandenbosch's expressions [7] and explain the observed cases with negative stored energy [9]. We use Brune synthesis [21] to construct equivalent lumped circuit models from the input impedance, over a wide frequency band to accurately account

Some Representative Impedance Matching Design Approaches

Smith Chart Graphical Approach

Fano “Classical method”

Simplified Real Frequency Technique (SRFT)

- H.J. Carlin, B.S. Yarman, W.K. Chen, P.L.D. Abrie;
  - Curve fitting for Hilbert Transform, Gewertz polynomial manipulations, Brune circuit synthesis.

Direct Search Minimax Optimization Algorithms

- Local vs. global search of solution space,
- Constrained vs. unconstrained variables,
- Deterministic vs. stochastic algorithms.

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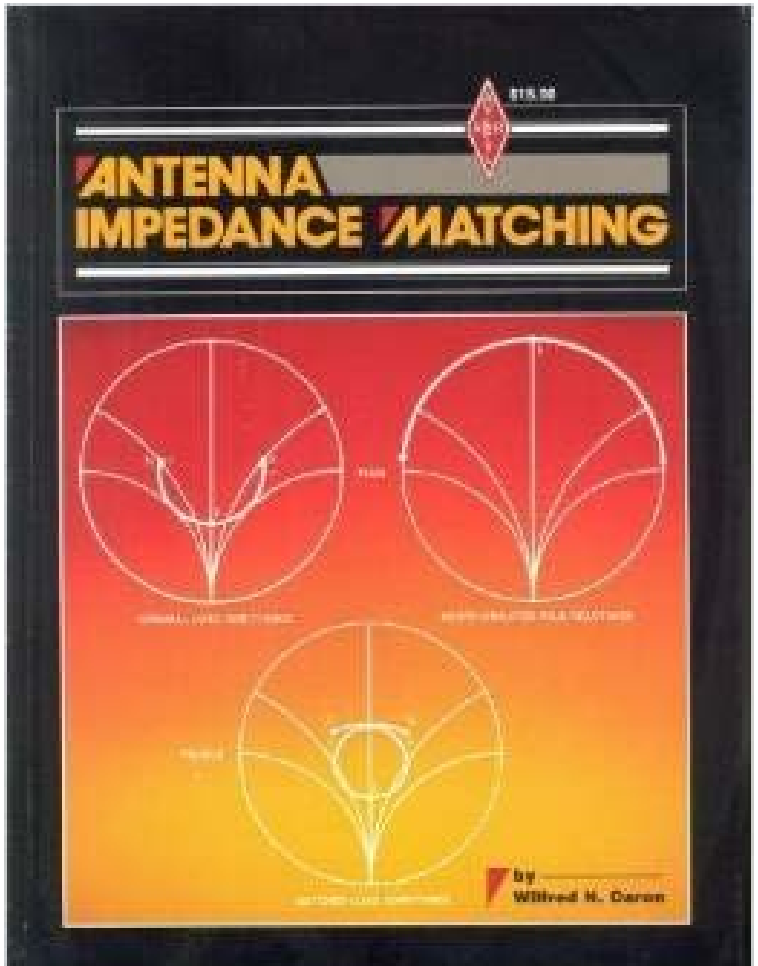
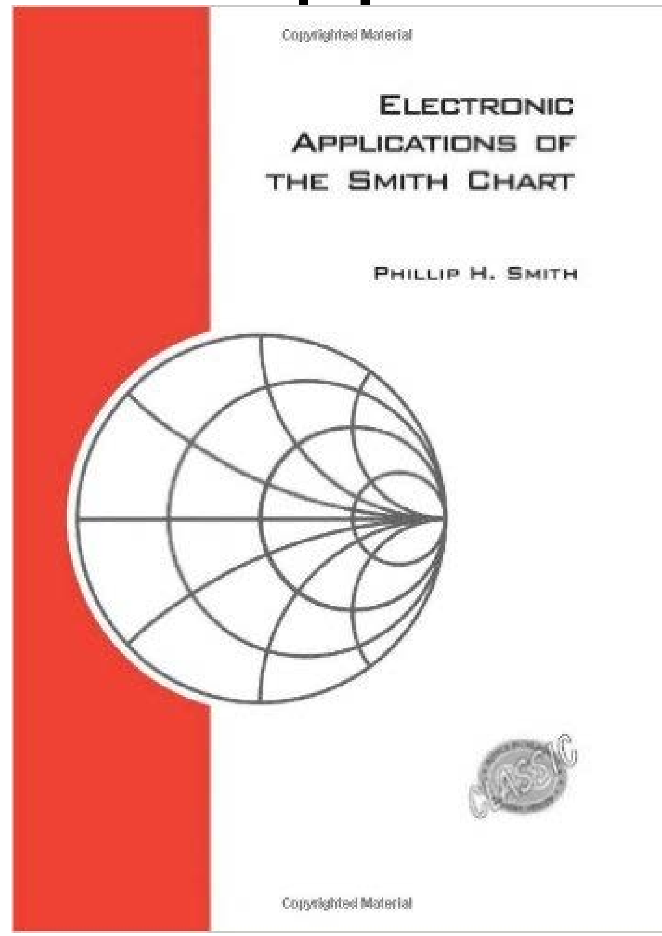


Wilfred N. Caron, 1989



Philip H. Smith, 1995

Anthony A. R. Townsend, The Smith Chart and its Applications, is available online at no cost from http://www.ie.itcr.ac.cr/acotoc/Ingenieria/TEM%20II/Material%20Vario/Smith_Chart_Book_Complete.pdf.

Simple L for Single Frequency Match

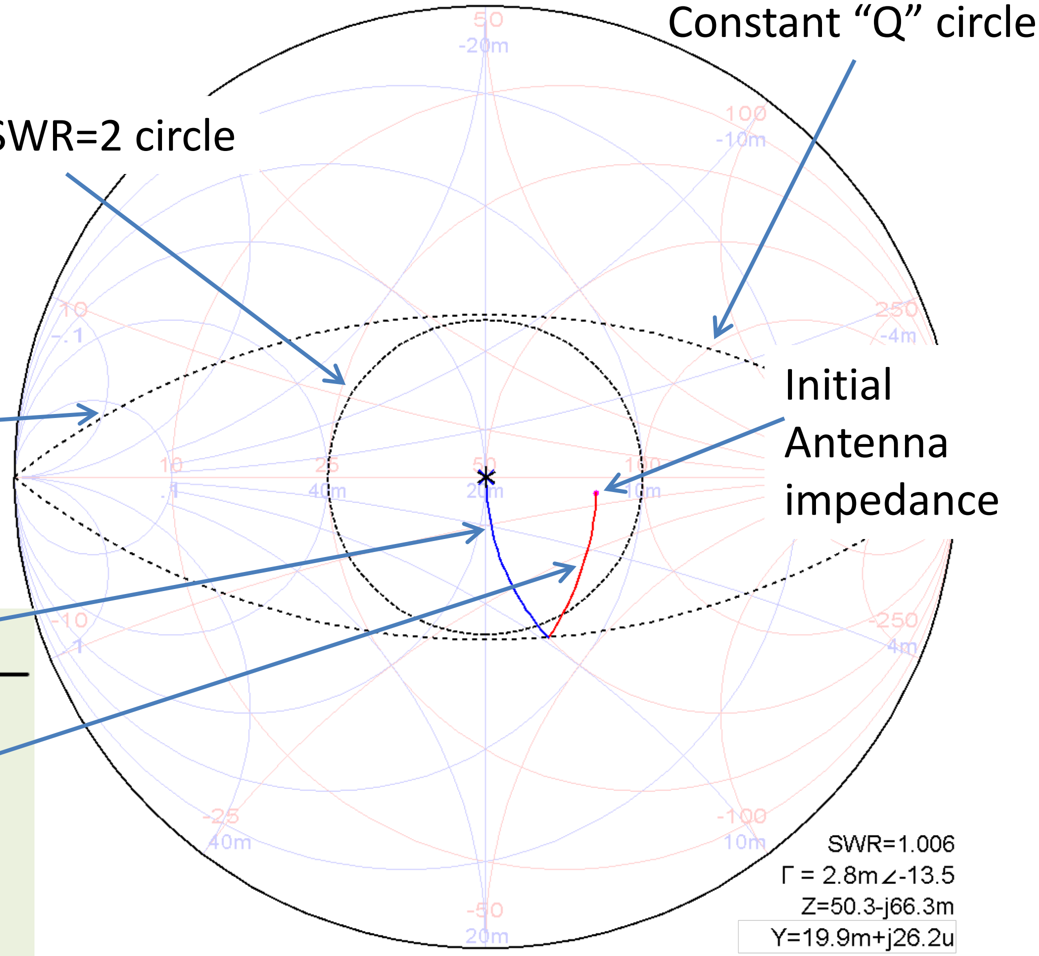
$$Q = \sqrt{\frac{R_{antenna}}{R_{Source}} - 1}$$

$$\mathrm{Q} = \sqrt{\frac{80.688}{50} - 1}$$

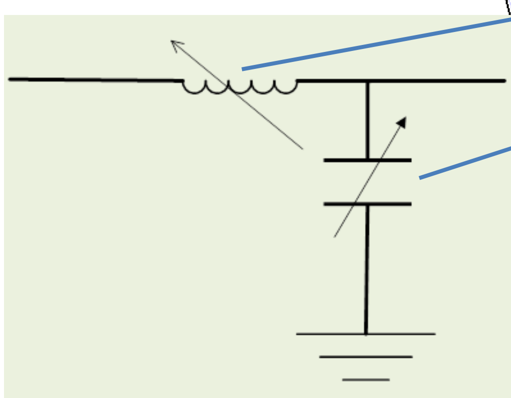
Q= 0.783

VSWR=2 circle

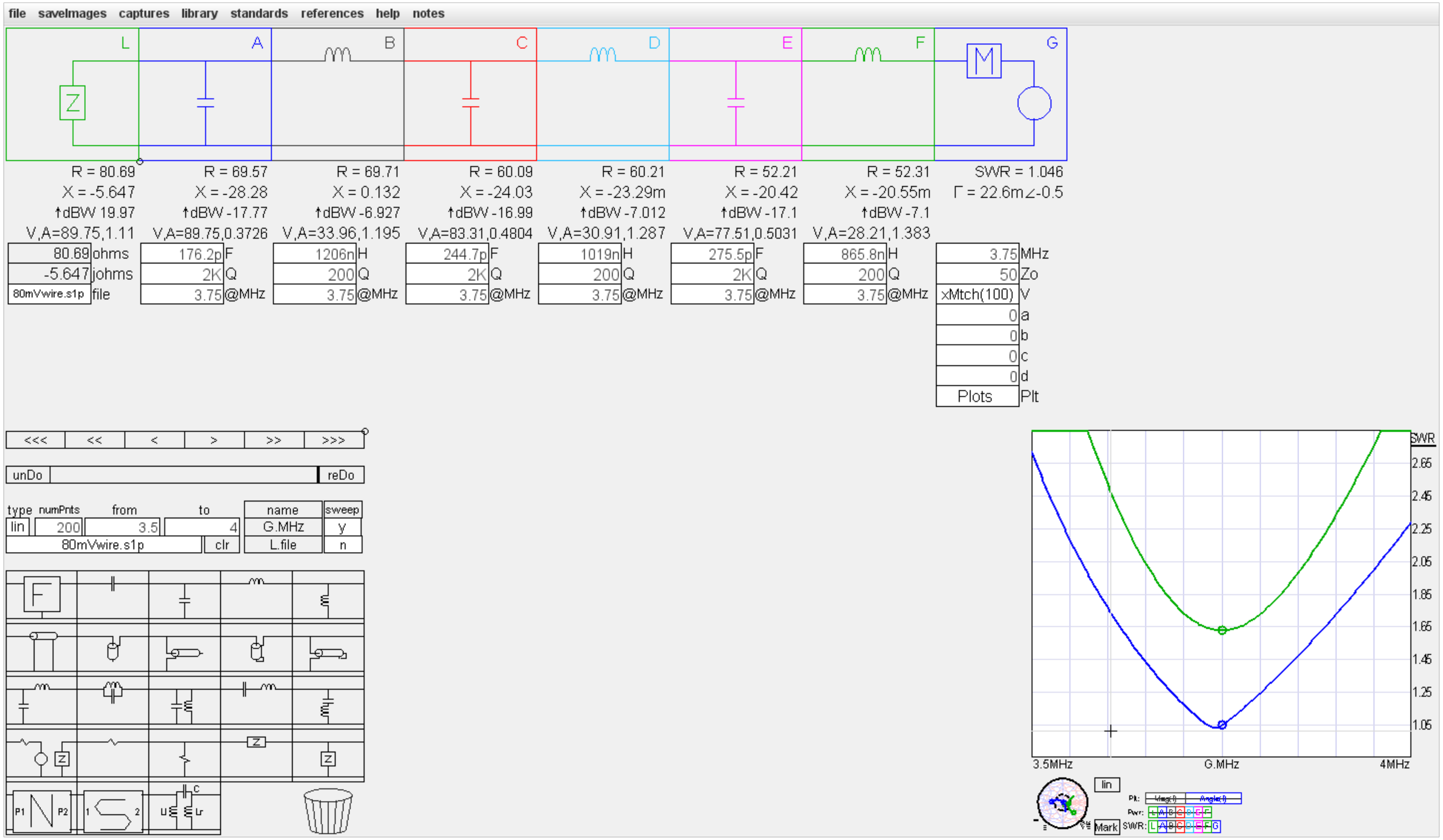
Constant “Q” circle



Initial Antenna impedance



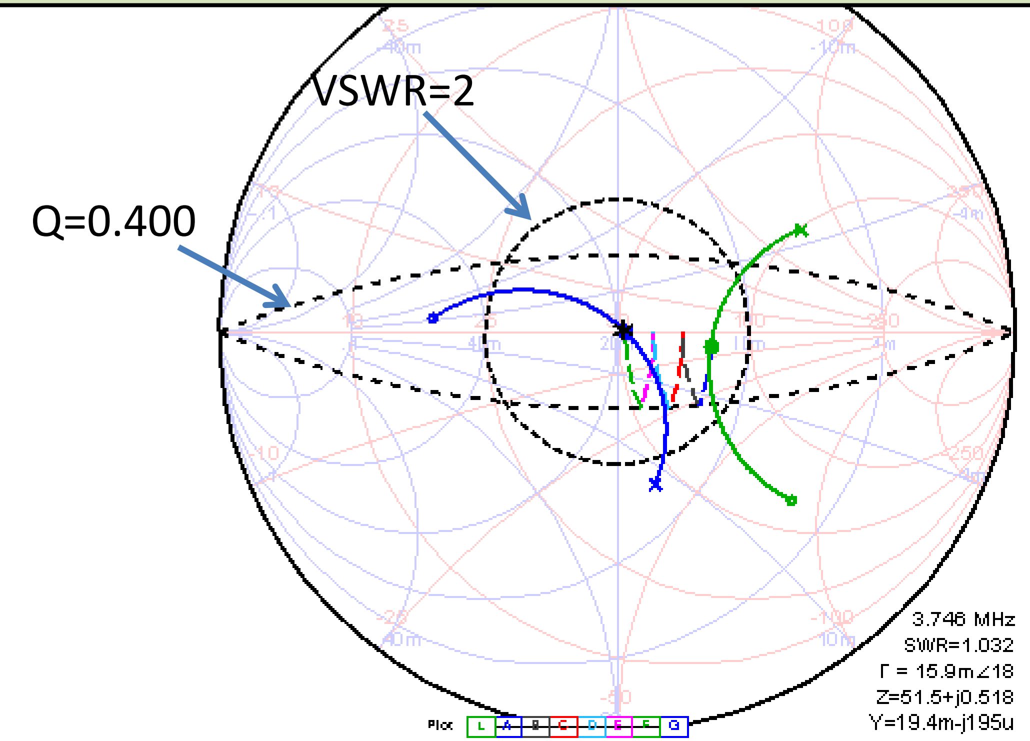
Increasing the Number of Circuit Elements



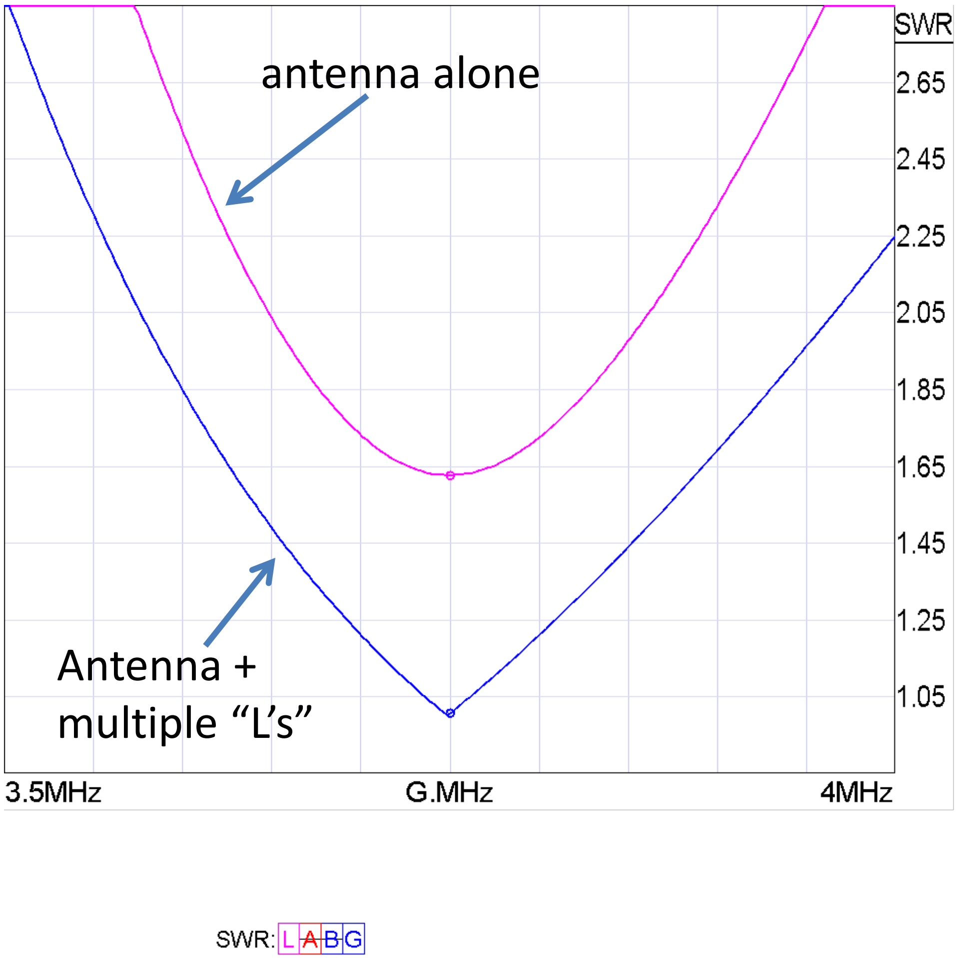
R.W.P. King, <u>Transmission Line Theory</u>, McGraw-Hill, NY (1955) provides details of impedance matching using the Smith Chart.

Multi-L Tuning

Can get more of the antenna inside the VSWR=2 boundary circle.



Frequency Sweep of Multi-L Tuning



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Famous Papers by R. Fano (1948) and H. Wheeler (1950)

Theoretical Limitations on the Broadband Matching of Arbitrary Impedances

R. M. FANO

TECHNICAL REPORT NO. 41

January 2, 1948

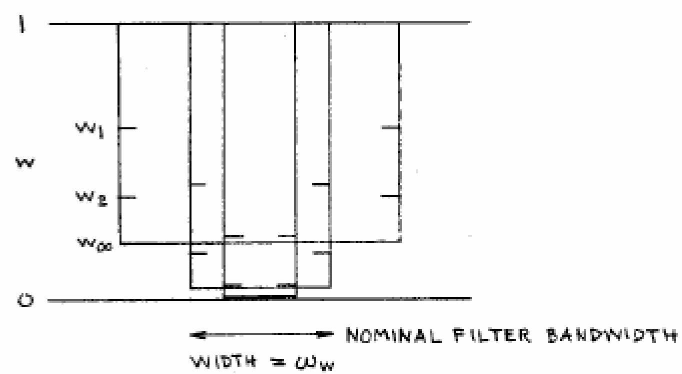
RESEARCH LABORATORY OF ELECTRONICS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Wheeler Laboratories, Inc. Page 12. Report 418
Great Neck, N. Y. 500515

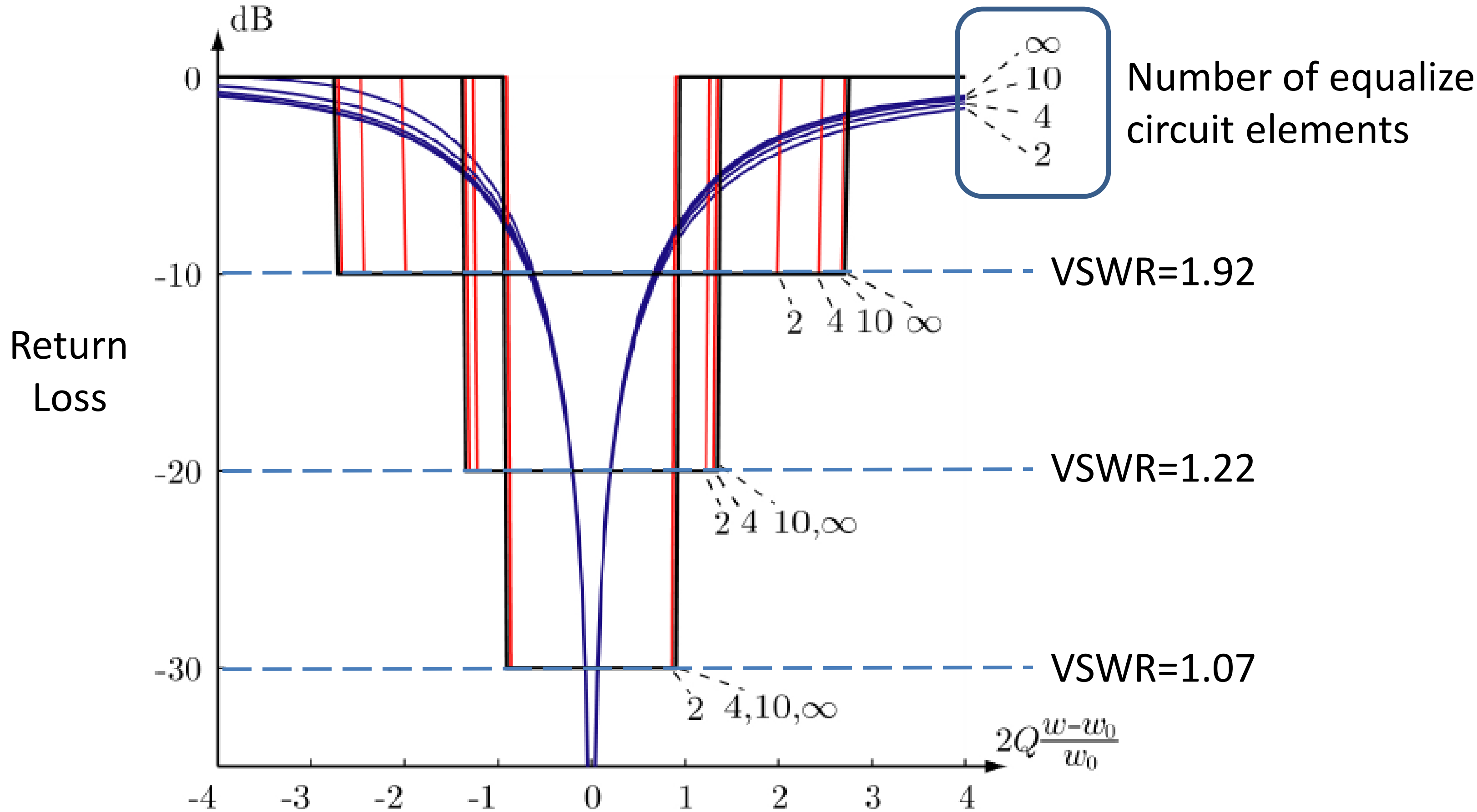
With practical tolerances on the added reactance arms, there is an optimum number of added tunings, such that a greater number would increase the reflection ratio by their tolerances more than they would decrease it by the theory.

Fig. 11 - The variation of reflection ratio with bandwidth.



“Wideband Impedance Matching”, 1950

Return Loss and Q factors with Number of Circuit Elements



M. Gustafsson, "Bandwidth, Q Factor, and Resonance Models of Antennas", *Progress In Electromagnetics Research*, PIER 62, 1–20, 2006.

Fano Limits on Matching Bandwidth

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Keywords: Impedance matching; Q factor; tuning; multifrequency antennas

Lopez [1, 2] has examined the fundamental limits on matching, derived more than 50 years ago by R. M. Fano, and has provided a simple formula. However, Matthaei, Young, and Jones [3], in their 1964 treatise, gave solutions to the simultaneous equations developed by Fano [4-6]:

$$\frac{\tanh na}{\cosh a} = \frac{\tanh nb}{\cosh b}, \tag{13}$$

$$\cosh nb = \Gamma \cosh na, \tag{14}$$

$$\sinh b = \sinh a - 2\delta \sin \frac{\pi}{2n}. \tag{15}$$

Here, there are n matching sections (including the antenna as one), δ is decrement (δ is $1/Q$ of the load at band edges), and a and b are parameters to be determined. Γ is the reflection coefficient. These simultaneous equations were solved by Matthaei et al., with results presented in graphical form. Subsequently, I used Newton-Raphson [7] to obtain precise values of a and b for both equal-ripple VSWR _ 2, and VSWR _ 5.828 (half-power) cases. For VSWR _ 2, Table 1 gives values of a, b, and δ. Note that $n = 1$ is for the antenna alone. Corresponding values for half-power (VSWR _ 5.828) are given in Table 2. The bandwidth improvement factor is just δ for $n = 1$ divided by δ for $n > 1$. Table 3, from Hansen [8], gives these bandwidth-improvement factors.

Coefficients a and b, multiplied by n, are given by Lopez [1] in Table 2. These do not match the exact values of my Table 1 or Table 2; Lopez does not state what value of VSWR his coefficients are for.

Typically, an electrically small antenna represents one resonant circuit; an additional matching circuit doubles the half-power bandwidth, or increases the VSWR = 2 bandwidth by 2.31. A second matching circuit makes a significant improvement for all VSWR; however, more circuits offer diminishing returns. The limit, using many matching circuits, is only a factor of 3.2 for half-power, or 3.8 for VSWR = 2. These results are all for lossless matching circuits; lossy circuits will, of course, increase the bandwidth and decrease the efficiency.

Table 1. Values of a, b, and δ for VSWR ≤ 2.

n	a	b	δ
1	1.81845	.32745	1.33333
2	1.03172	.39768	.57735
3	.76474	.36693	.46627
4	.62112	.33112	.42416
5	.52868	.30027	.40264
∞	0	0	.34970

Table 2. Values of a, b, and δ for VSWR ≤ 5.828.

n	a	b	δ
1	1.14622	.65848	.35355
2	.76429	.56419	.17416
3	.59082	.47449	.14394
4	.50164	.41026	.13207
5	.43483	.36284	.12589
∞	0	0	.11032

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SRFT Beginnings

Herbert J. Carlin, Cornell University

170 IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS, VOL. CAS-24, NO. 4, APRIL 1977

A New Approach to Gain-Bandwidth Problems

HERBERT J. CARLIN, FELLOW, IEEE

Abstract—A new idea for treating the broad-band matching of an arbitrary load to a resistive generator leads to a simple technique for the design of a lossless 2-port equalizer. The method is a numerical one, and only utilizes real frequency (e.g., experimental) load impedance data. No model or analytic impedance function for the load is necessary. Nor is the equalizer topology or analytic form of the system transfer function assumed. The arithmetic is well conditioned and the intricacies of gain-bandwidth theory are bypassed. An example comparing the method with analytic gain-bandwidth theory is given. Two examples proceeding directly from experimental data are presented. One is the broad banding of a microwave avalanche diode reflection amplifier. The other is the gain-bandwidth equalization of a microwave FET amplifier for gain taper and impedance mismatch.

ear combinations. Furthermore, such direct optimization requires a specific assumption of equalizer topology.

Technique for Broad-Band Matching Using Real Frequency Load Data

The technique proposed here is a numerical method which utilizes the real frequency load data $Z_l(j\omega)=R_l(\omega)+jX_l(\omega)$ (or, equivalently, $Z_l^{-1}(j\omega)=Y_l(j\omega)=G_l(\omega)+jB_l(\omega)$) over the band of interest. No model is assumed

BROADBAND MATCHING A COMPLEX GENERATOR

TO A COMPLEX LOAD

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment for the Degree of

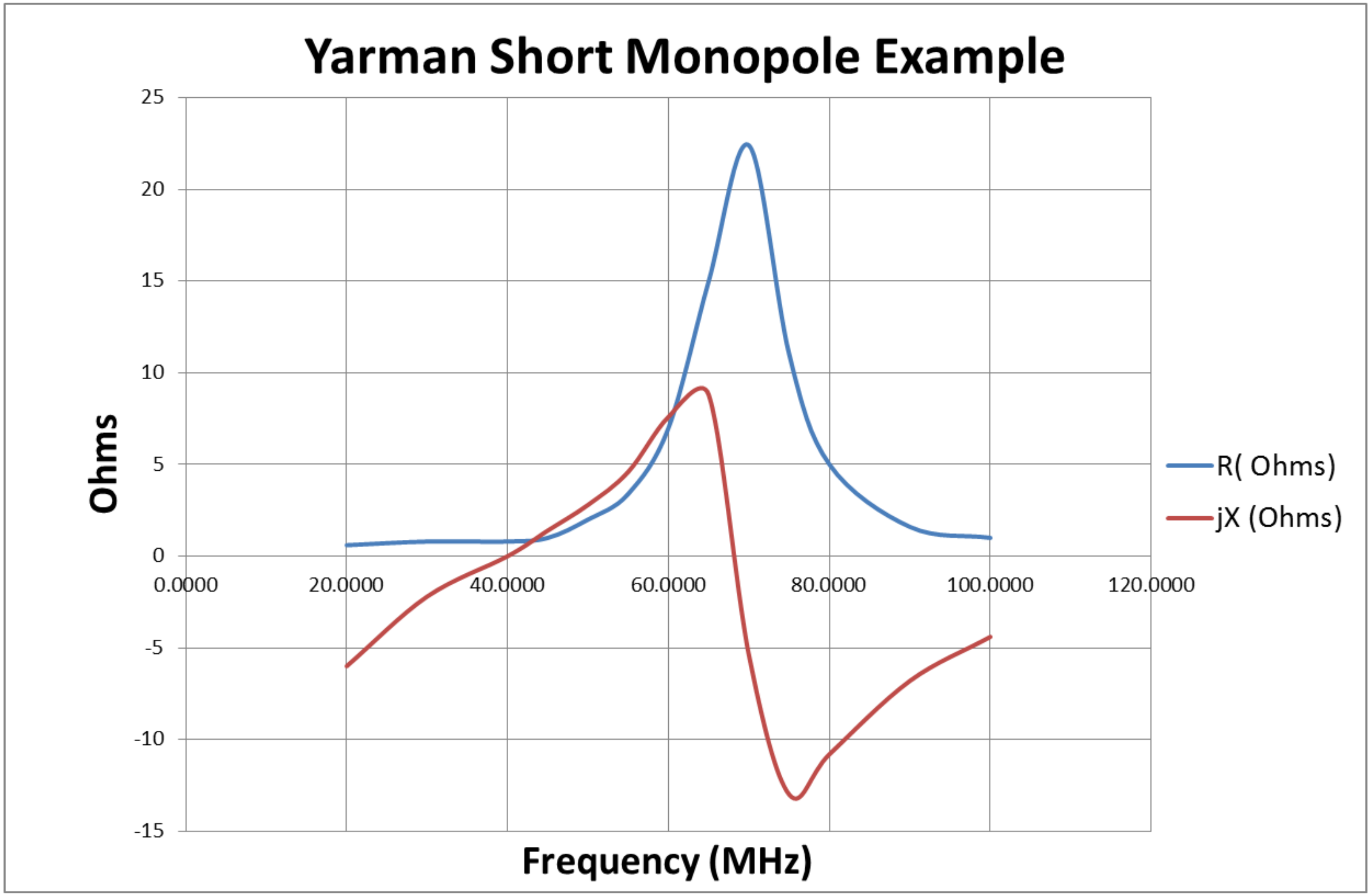
Doctor of Philosophy

by

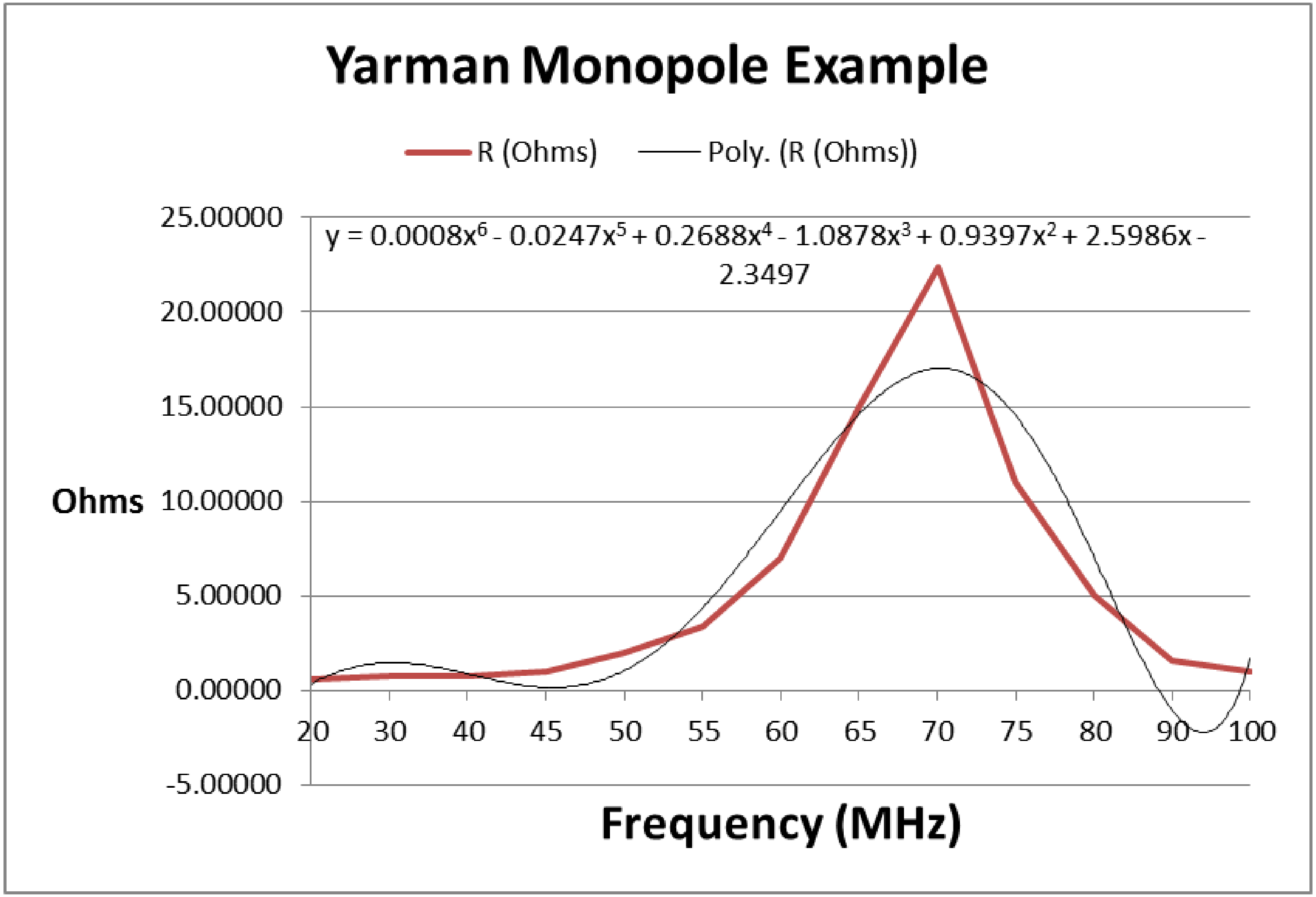
Binboğa Sıddık Yarman

January 1982

SRFT First Steps



Curve Fitting the R values



SRFT Circuit Design

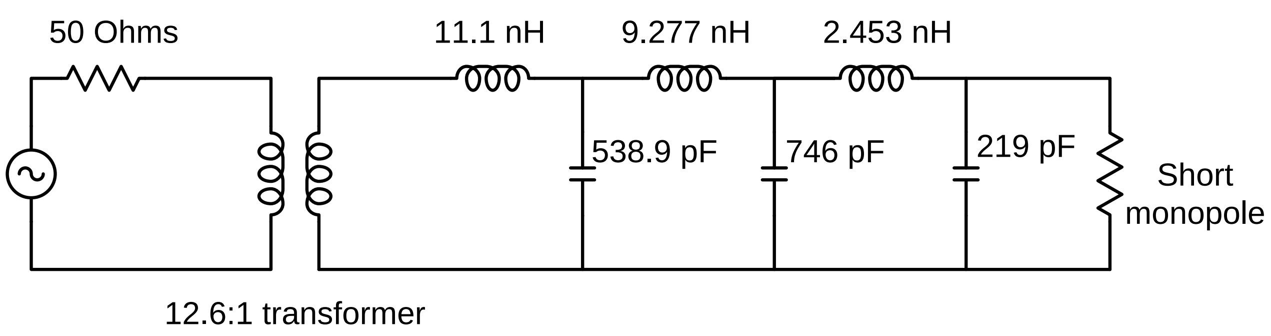
Hilbert Transform of resistance curve fit yields reactance function.

Then, some polynomial manipulation yields Impedance function.

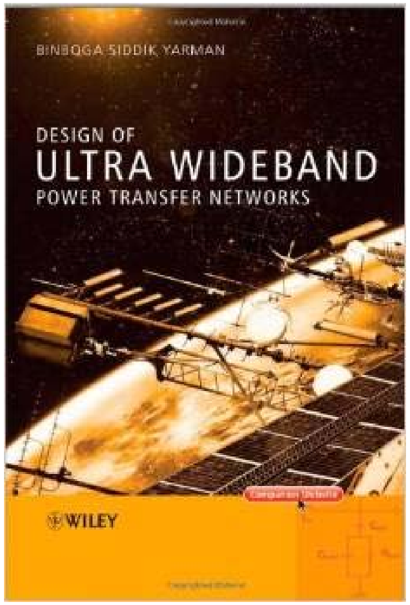
After some more polynomial manipulation, impedance function becomes;

$$Z(p) = \frac{0.144p^5 + 0.35p^4 + 0.42p^3 + 0.404p^2 + 0.19p^1 + 0.517}{p^6 + 2.47p^5 + 3.98p^4 + 5.73p^3 + 4.06p^2 + 2.5p + 0.655}$$

After some long division and Brune circuit synthesis becomes;

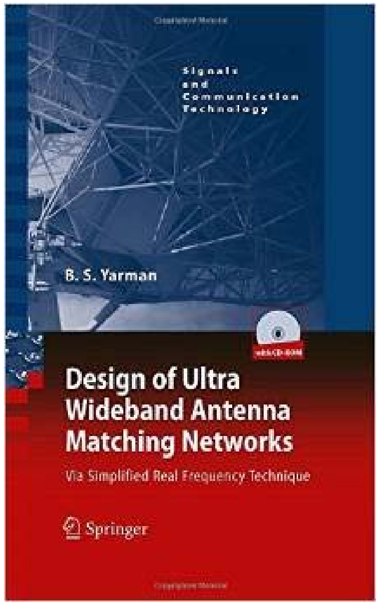


SRFT Techniques Textbooks



B.S. Yarman, 2010

(MATLAB)

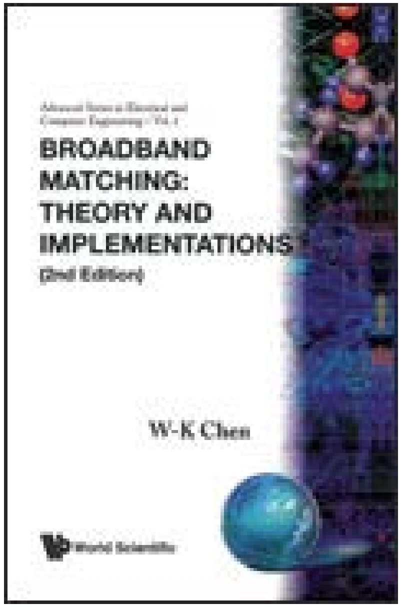


B.S. Yarman, 2008

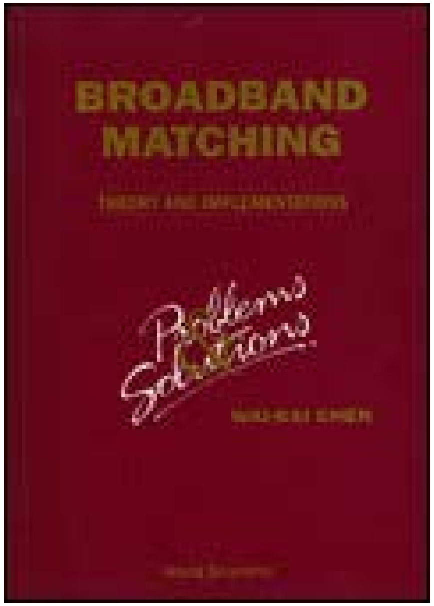
(MATLAB)

Complete updated MATLAB source code for Real Frequency Technique can be downloaded from http://www.siddikyarman.com/?author=1

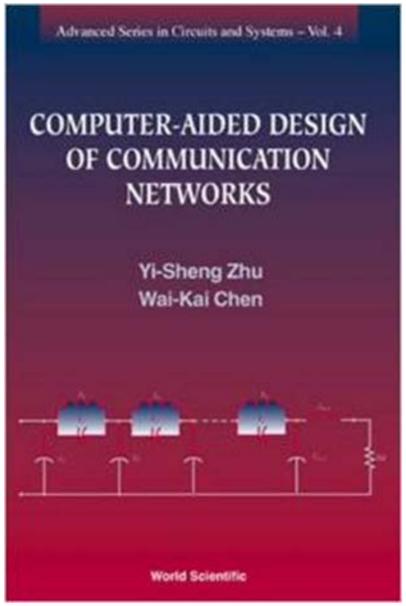
SRFT Techniques Textbooks



1988



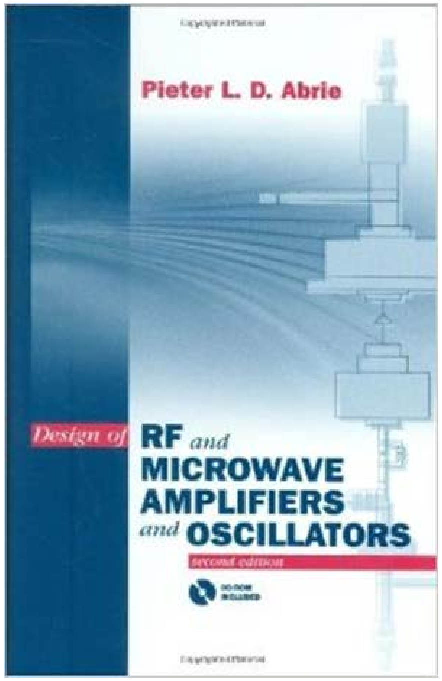
1993



2000
(FORTRAN)

W.K. Chen
University of Illinois at Chicago

SRFT Techniques and Other Textbooks



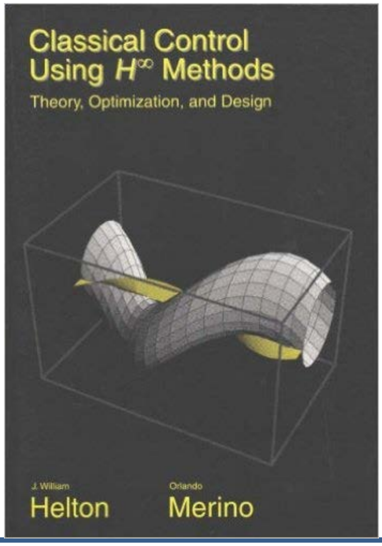
P.L.D. Abrie, 2009

(.exe)

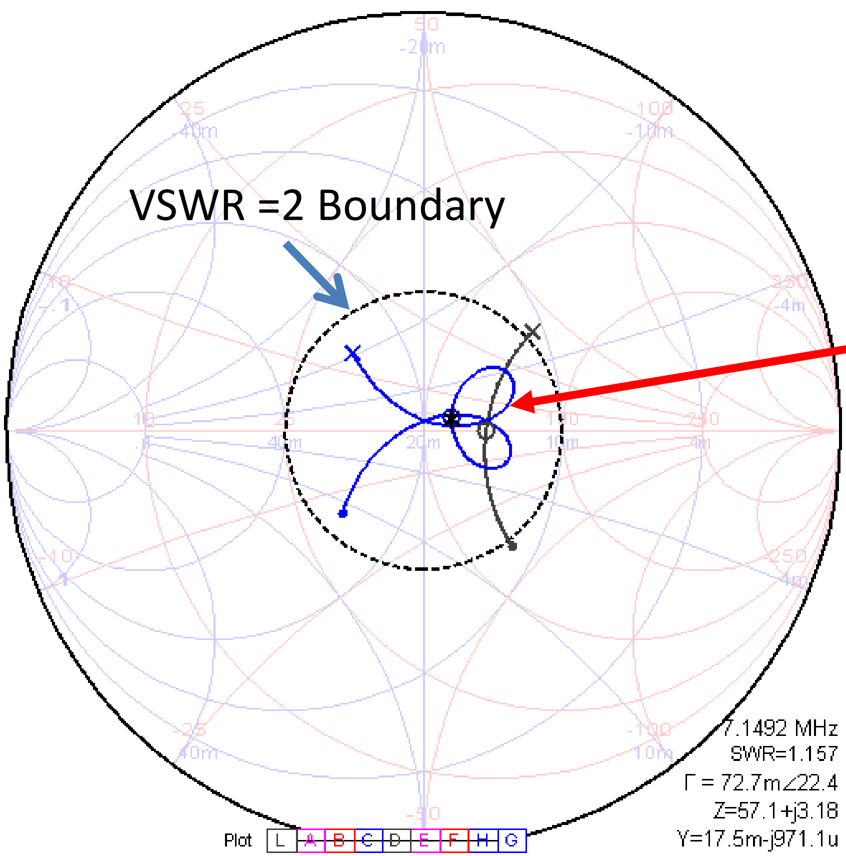
A history of impedance matching techniques by Thomas R. Cuthbert is available online at no cost at;

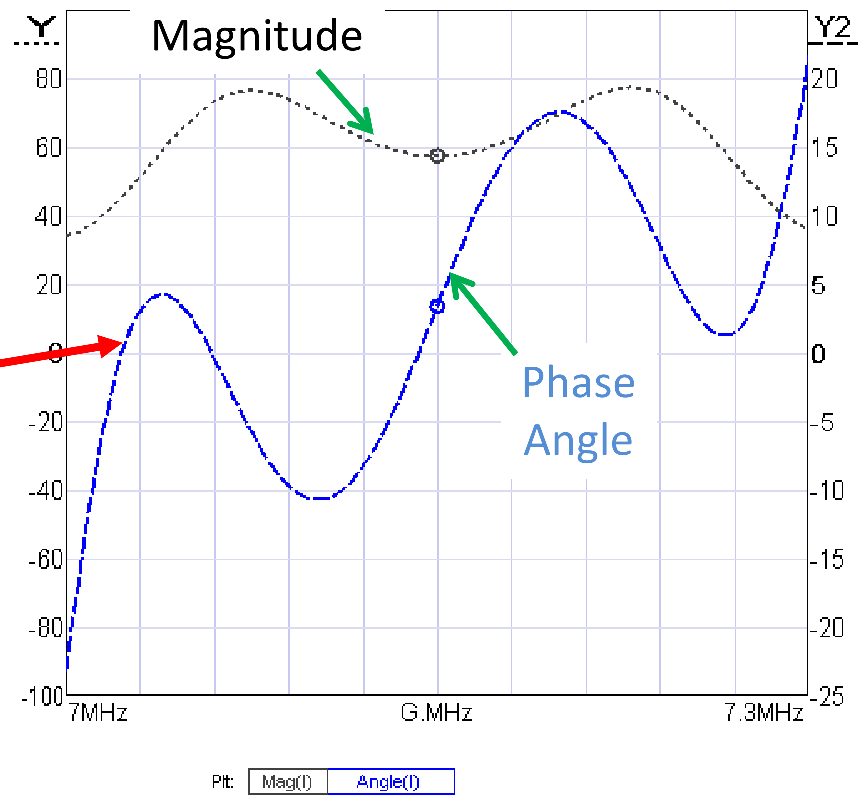
http://ethw.org/History_of_Broadband_Impedance_Matching

In addition, there are other analytical techniques, e.g. "H-Infinity"
by W. Helton @ UC San Diego.



Results Using SRFT





MATLAB RF Toolbox
SRFT Optimization Results

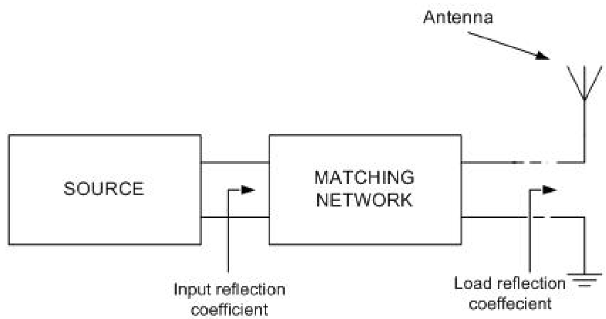
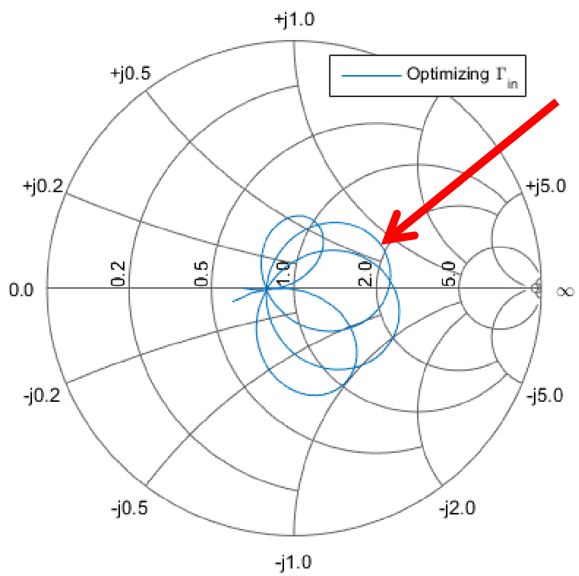
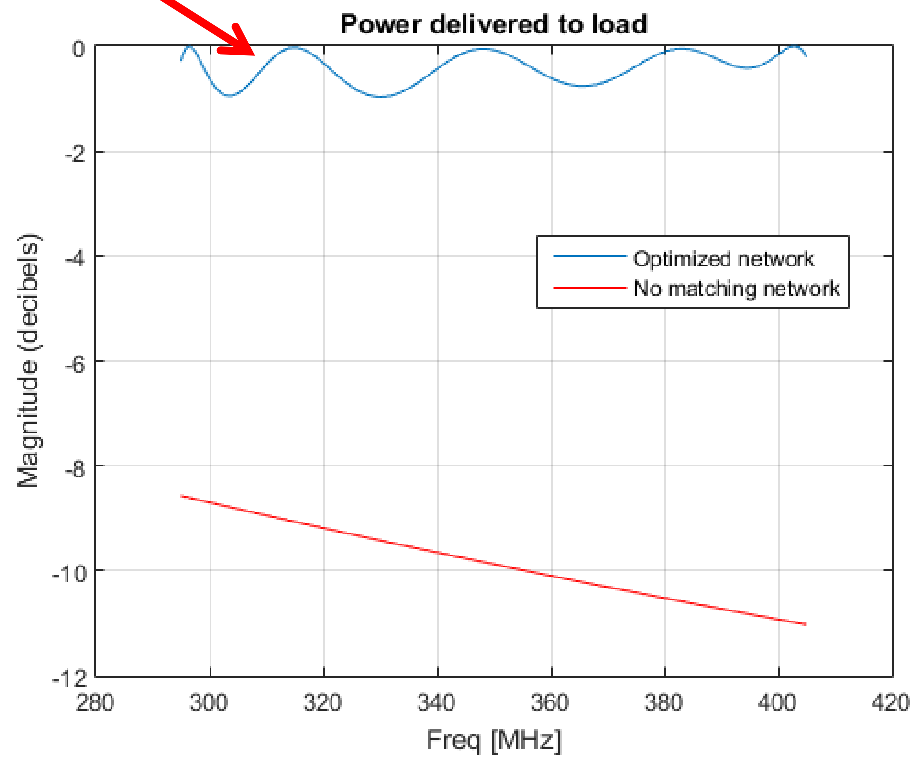


Figure 1: Impedance matching of an antenna to a source

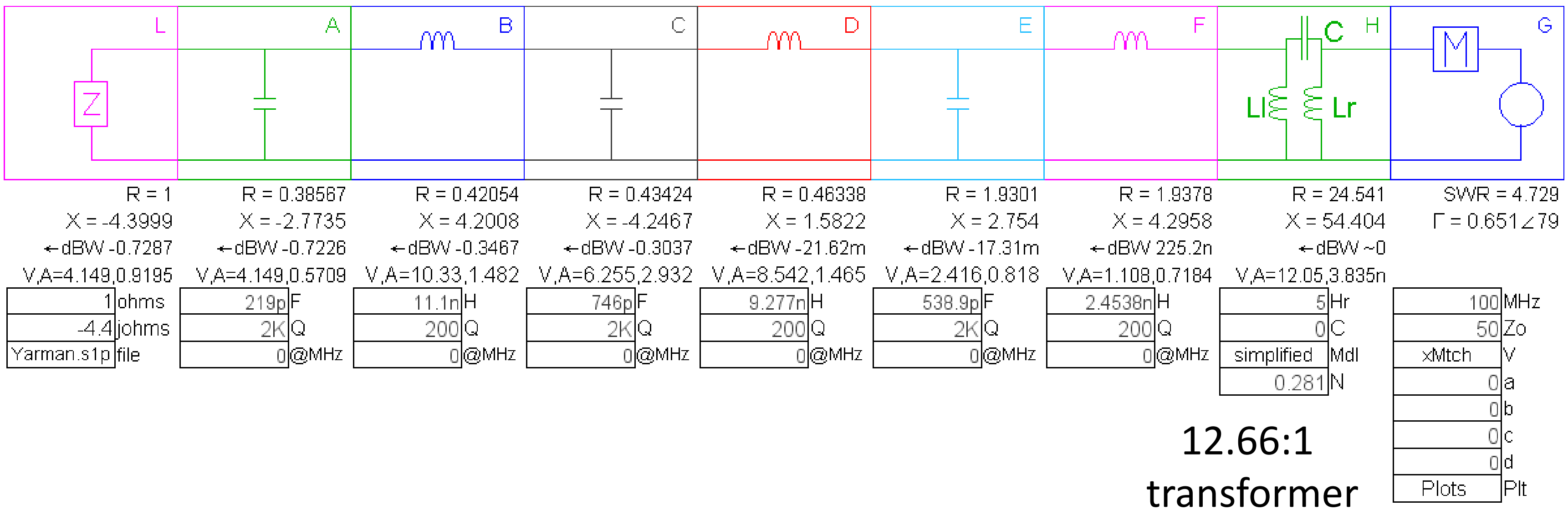


TPG Results Using MATLAB Toolbox



Retrieved from "Designing Broadband Matching Networks (Part 1: Antenna)", http://www.mathworks.com/help/rf/examples/designing-broadband-matching-networks-part-1-antenna.html

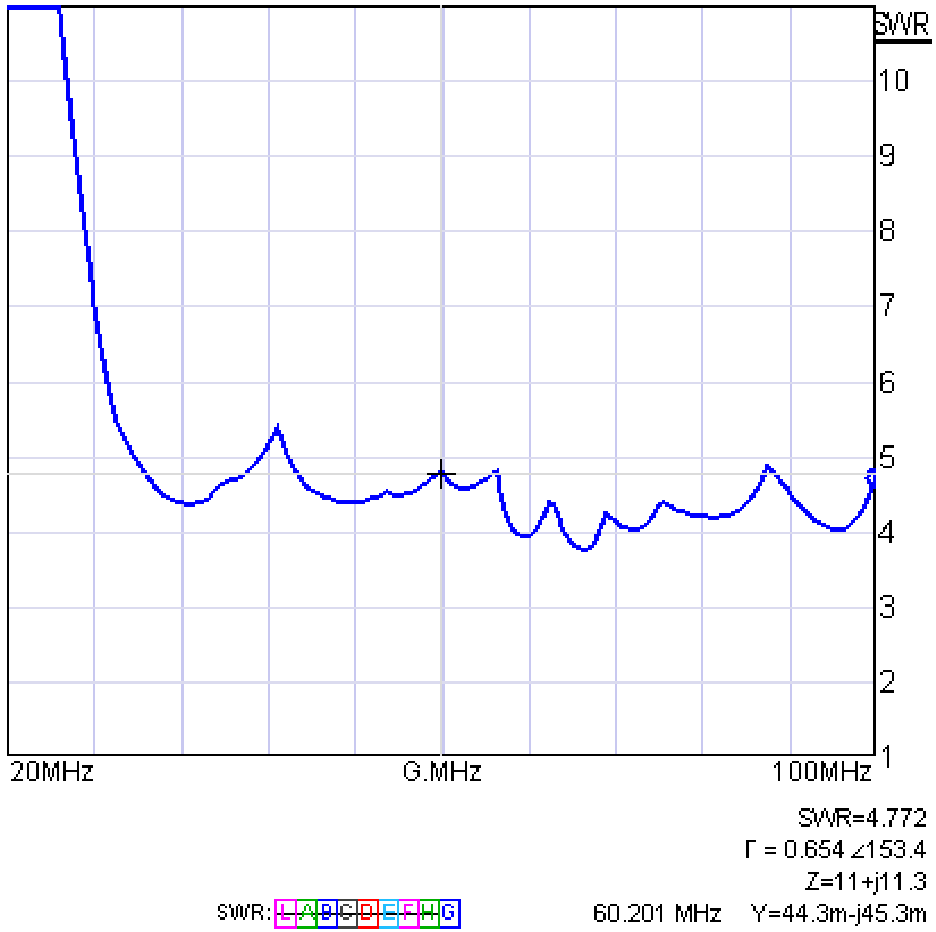
Yarman's SRFT Circuit Solution for the Short Monopole



12.66:1 transformer

"LPP6 circuit topology"

Yarman's SRFT Short Monopole Solution VSWR 20 MHz to 100 MHz



Communications

Design of a Matching Network for an HF Antenna Using the Real Frequency Method

OMAR M. RAMAHI, MEMBER, IEEE, AND RAJ MITTRA, FELLOW, IEEE

Abstract—**The real frequency method (RFM) is used to design a matching network for an electrically short loaded dipole. The RFM is demonstrated to be superior than other analytical and numerical techniques in the sense that it yields the maximum flat transducer power gain possible, and that is does not require any analytical modeling of the load impedance to be matched. For this reason, the RFM is found to be well suited for matching distributed systems such as antennas.**

I. Introduction

Altshuler [1] showed that the dipole antenna can be considered as an open-ended transmission line, and, thus, one could excite a traveling wave along the antenna by placing a resistance equal to the "characteristic resistance" of the antenna at a suitable location along the antenna. Based on these findings, Halpern and Mittra [2] employed the Numerical Electromagnetic Code (NEC) to obtain significant improvement in the matching bandwidth of a dipole antenna; however, they found that the lumped loading approach enables one to improve the bandwidth over only a portion of the HF band. Wheeler [3] and Chu [4] have shown that the matching bandwidth of small antennas is subject to fundamental limitations that are related to the effective volume of the antenna. Consequently, for

loaded dipole antenna. The RFM is numerical, and its most important feature is its capability to work with either experimental or numerically simulated impedance data, and it does not call for any analytical description of the impedance function that is being matched. In the next section we present a summary of the RFM theoretical formulation.

II. Real Frequency Method

The broad-band matching problem considered in this study is the design of a lossless two-port network that couples a load to a resistive generator, as shown in Fig. 1, such that the power delivered to the load is maximized over the frequency band of interest. The problem is readily formulated by dealing with the transducer power gain (TPG), which is defined as the ratio of the power delivered to the load to the power available at the generator. The TPG is expressed as follows:

$$\mathrm{TPG} = T(\omega) = \frac{P_{\mathrm{in}}}{P_{\mathrm{av}}} = \frac{4R_q R_1}{|Z_q + Z_1|^2}. \tag{1}$$

For an ideal match, the error function $|1 - \mathrm{TPG}|$ is minimized over the frequency band of interest. It is important to emphasize that the resulting design will be optimum in the sense that the transfer function of the matching network approximates the maximum flat transducer power gain possible for the prescribed bandwidth and the prescribed load.

For complete realizability of the equalizer, both the resistance

SRFT Limitations (2012)

High Precision LC Ladder Synthesis Part II: Immittance Synthesis With Transmission Zeros at DC and Infinity

Binboga Siddik Yarman, *Fellow, IEEE*, and Ali Kilinc

***Abstract*—In this paper, a novel, high precision bandpass LC ladder synthesis algorithm is presented. The new algorithm directly works on the rational form of a positive real driving point input immittance $F(p) = a(p)/b(p)$ which describes a bandpass LC ladder network in resistive termination. In the new method, firstly, poles at $p = 0$ are removed from $F(p)$, then remaining poles at infinity are extracted. After each pole extraction, coefficients of the polynomial $a(p)$ and $b(p)$ are refined employing the parametric approach to yield an exact bandpass LC ladder which in turn prevents the accumulation of the numerical errors in the course of synthesis. Thus, at the end of synthesis process, a bandpass LC ladder is obtained with high numerical precision.**

***Index Terms*—Darlington's driving point immittance synthesis, lowpass LC ladders, matching network synthesis, network synthesis, real frequency techniques.**

In principle, an LC ladder synthesis is achieved by means of a straight forward long division process of an immittance function. At each step, a pole at DC or infinity is removed. After each step, degree of remaining function is reduced. This process continues until we end up with a constant term. Extracted poles are called the zeros of transmissions. Due to severe accumulated numerical errors, after a few steps, such as 5 or 6, pole extraction process with degree reduction may fail because of divisions by zero (or under flows). At this point, we have no longer LC ladder form. Therefore, we need a reliable and numerically robust algorithm to synthesize immittance functions. Unfortunately, over the years, we have suffered due to the lack of such trustable synthesis algorithm. Recently, we have come up with the idea of correcting immittance functions to warrant ladder

Also see Accuracy and Stability of Numerical Algorithms by Nicholas J. Higham, Published by SIAM (Society for Industrial and Applied Mathematics), Philadelphia (1996).

FILTER LOAD EFFECTS, ABSORPTION,

AND LOADED-Q DESIGN

A Dissertation Presented to the Graduate Faculty of

the School of Engineering & Applied Science

of

Southern Methodist University

in

Partial Fulfillment of the Requirements

for the degree of

Doctor of Philosophy

with a

Major in Electrical Engineering

by

Thomas Remy Cuthbert, Jr.
(B.S.E.E., Georgia Institute of Technology, Atlanta, 1959)
(M.S.E.E., Southern Methodist University, Dallas, 1966)

July 20, 1980

Some Representative Impedance Matching Design Approaches

Smith Chart Graphical Approach

Fano "Classical method"

Simplified Real Frequency Technique (SRFT)

- H.J. Carlin, B.S. Yarman, W.K. Chen, P.L.D. Abrie;
  - Curve fitting for Hilbert Transform, Gewertz polynomial manipulations, Brune circuit synthesis.

Direct Search Optimization Algorithms

- Local vs. global search of solution space,
- Constrained vs. unconstrained variables,
- Deterministic vs. stochastic algorithms.

Some Representative Optimization Algorithms

Classical

- Nelder-Mead
- Hooke-Jeeves
- Powell
- Fletcher
- Fletcher-Reeves
- Newton-Raphson
- Levenberg-Marquardt
- Multi-Directional Search
- **Implicit Filtering ***
- Quasi-Newton
- Gauss-Newton
- Dividing Rectangles (DIRECT)
- Generalized Reduced Gradient (GRG2)

❖ Source code available from http://www4.ncsu.edu/~ctk/iffco.html

Nature-Inspired

- Ant Colony
- Artificial Bee Colony
- Bat Algorithm
- Cuckoo Search
- Differential Evolution
- Firefly
- Wolf Search
- Central Force Optimization
- Gravitational Search
- Particle Swarm
- Simulated Annealing
- Wind Driven
- Shuffled Complex Evolution
- Swarm-Firefly
- DEPSO
- Invasive Weed

Direct Search Optimization Algorithms

SIAM REVIEW
Vol. 45, No. 3, pp. 385–482

Optimization by Direct Search: New Perspectives on Some Classical and Modern Methods*

Tamara G. Kolda†
Robert Michael Lewis‡
Virginia Torczon§

Abstract. Direct search methods are best known as unconstrained optimization techniques that do not explicitly use derivatives. Direct search methods were formally proposed and widely applied in the 1960s but fell out of favor with the mathematical optimization community by the early 1970s because they lacked coherent mathematical analysis. Nonetheless, users remained loyal to these methods, most of which were easy to program, some of which were reliable. In the past fifteen years, these methods have seen a revival due, in part, to the appearance of mathematical analysis, as well as to interest in parallel and distributed computing.

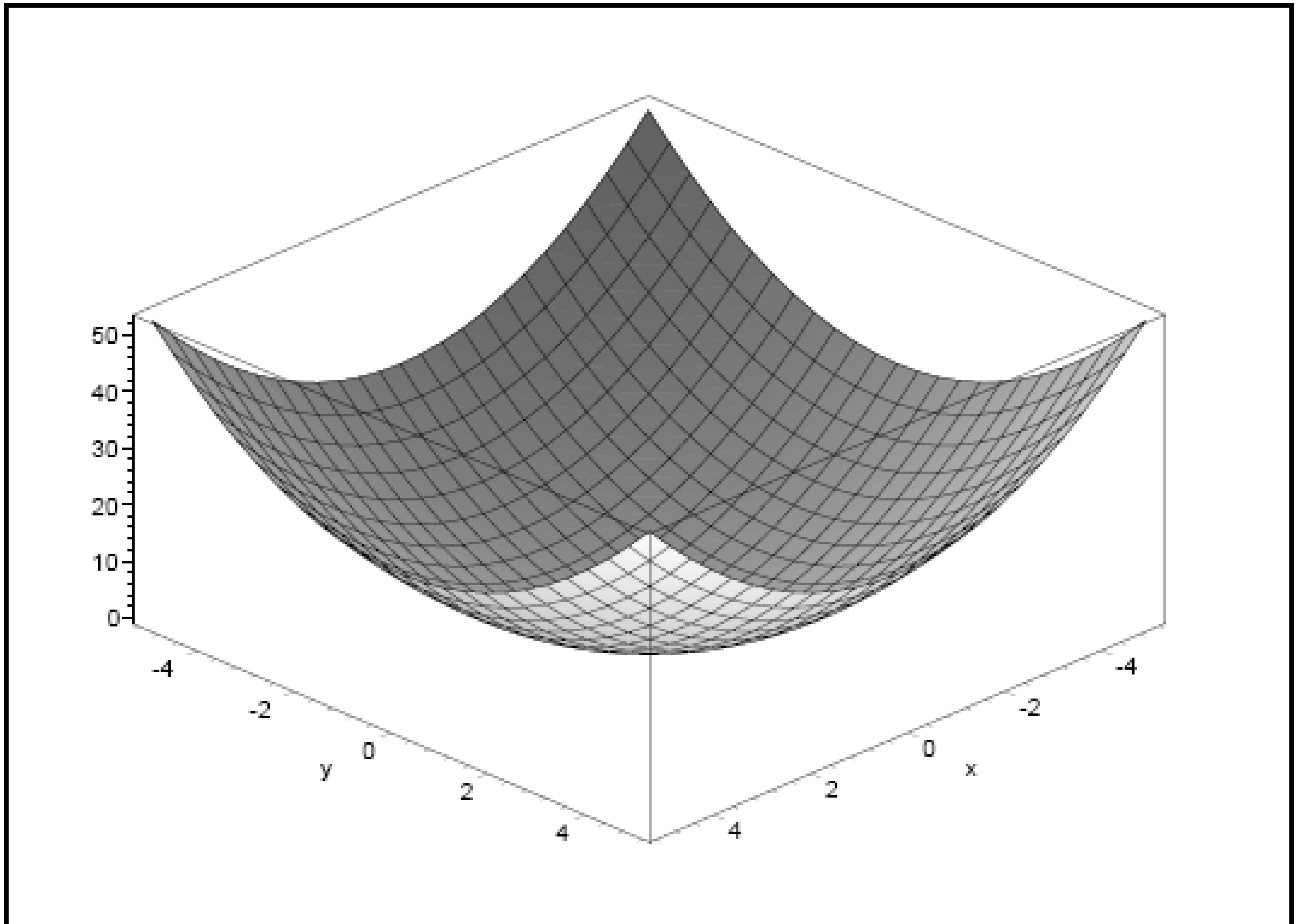
This review begins by briefly summarizing the history of direct search methods and considering the special properties of problems for which they are well suited. Our focus then turns to a broad class of methods for which we provide a unifying framework that lends itself to a variety of convergence results. The underlying principles allow generalization to handle bound constraints and linear constraints. We also discuss extensions to problems with nonlinear constraints.

Key words. nonlinear programming, nonlinear optimization, direct search, pattern search, simplex search, positive bases, global convergence analysis, local convergence analysis, generating set search

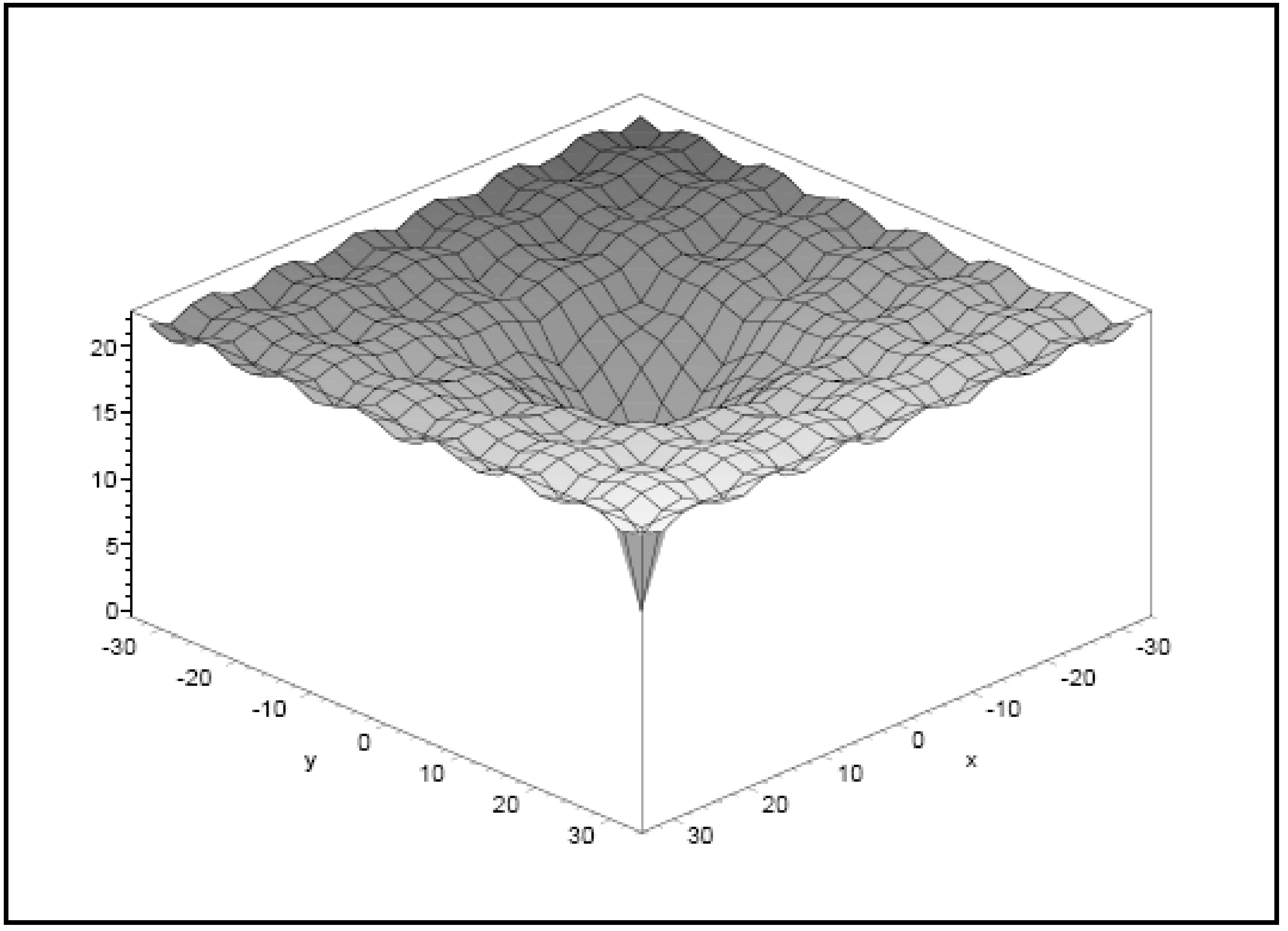
AMS subject classifications. 90C56, 90C30, 65K05

DOI. 10.1137/S0036144502428893

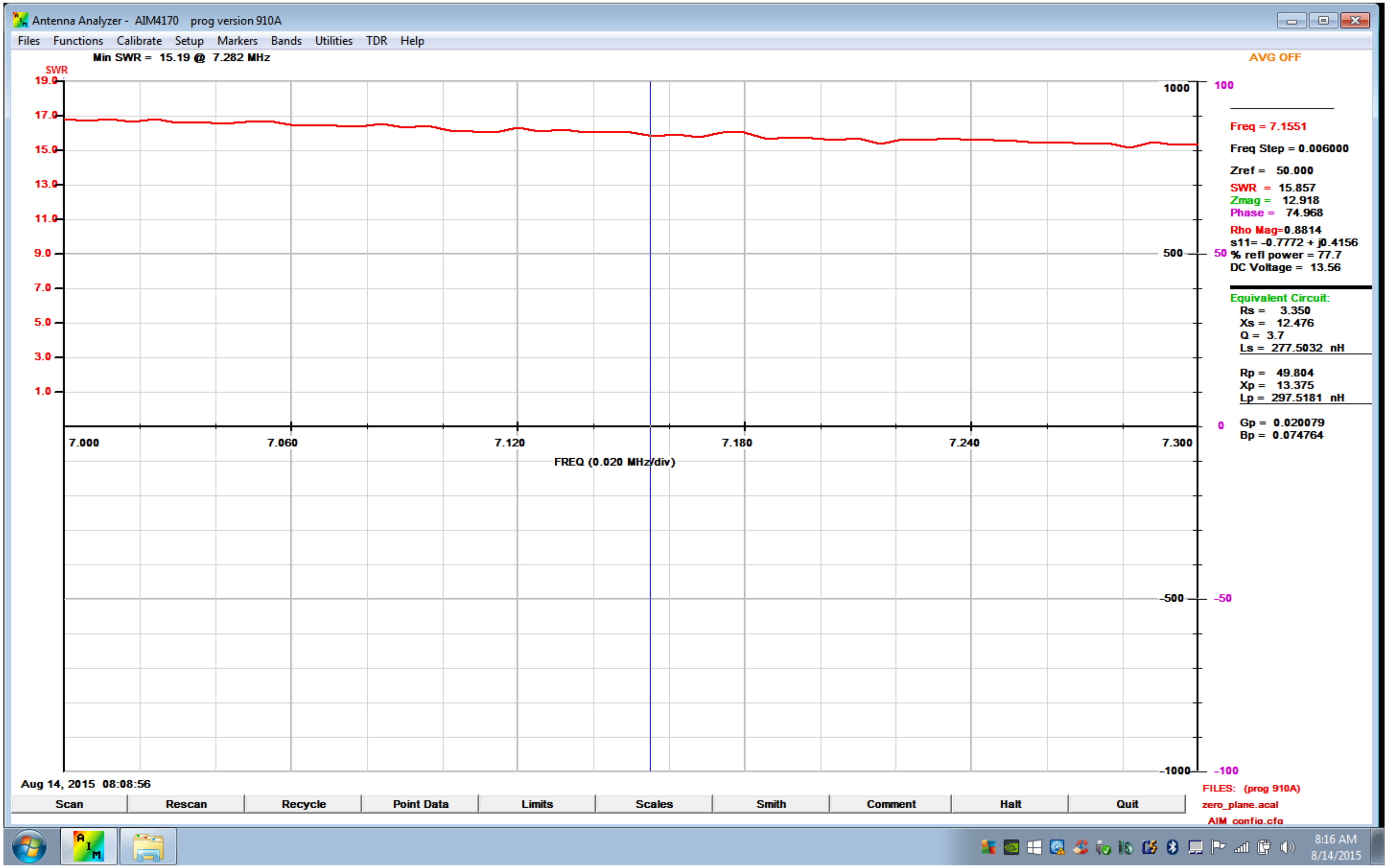
Finding the Global Minimum Easy in a Smooth Convex Landscape



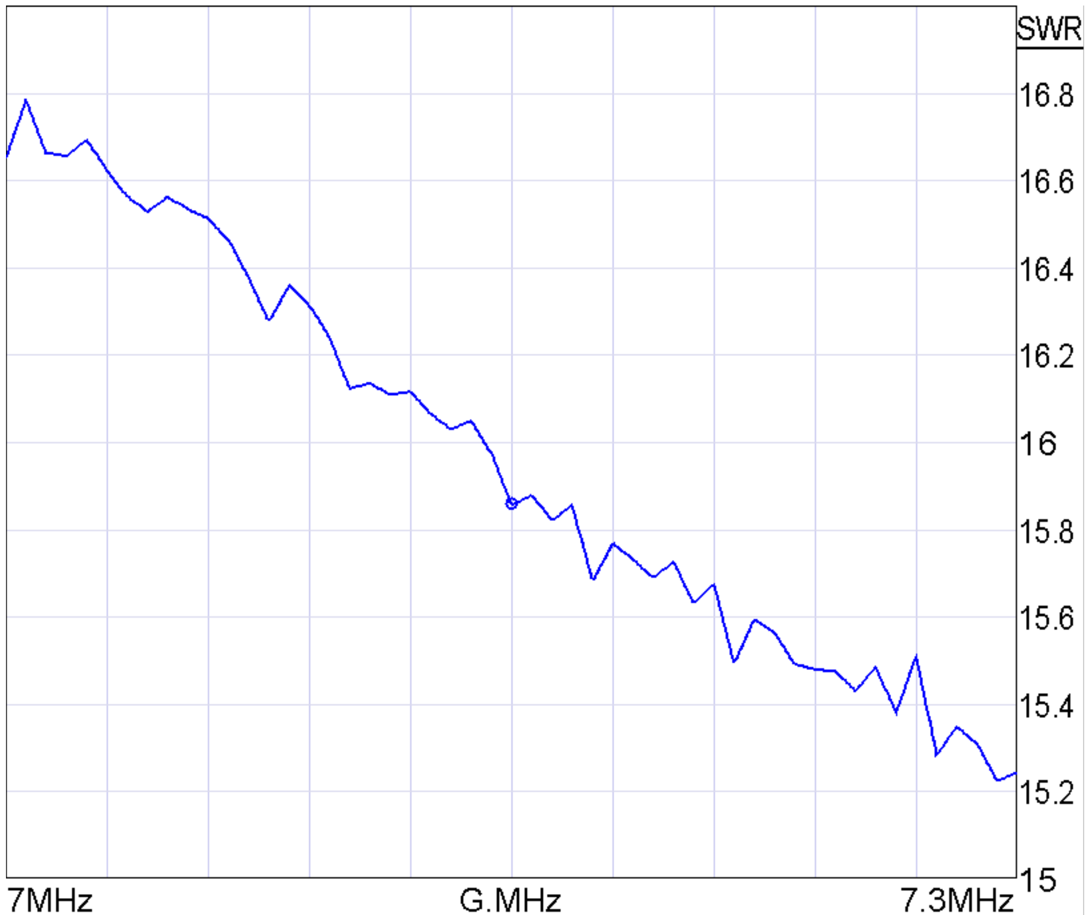
Finding the Global Minimum
Not So Easy in a Not So Smooth Landscape



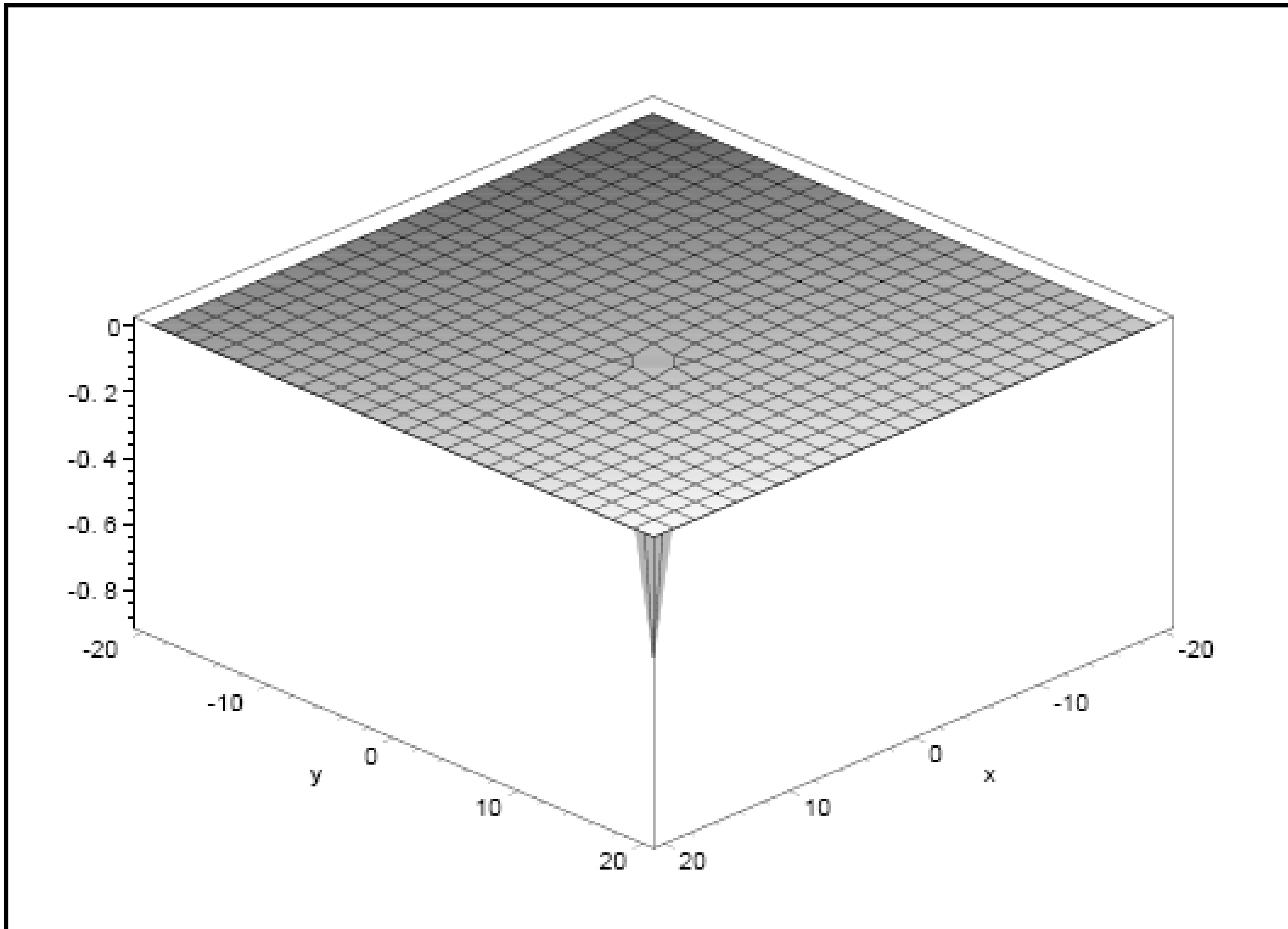
VSWR Measurement Data from AIM 4170



Measurement “Noise” in Measured VSWR



Finding the Global Minimum
Easy to Miss the Minimum



But…….which algorithm?

IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION, VOL. 1, NO. 1, APRIL 1997 67

No Free Lunch Theorems for Optimization

David H. Wolpert and William G. Macready

Abstract—**A framework is developed to explore the connection between effective optimization algorithms and the problems they are solving. A number of "no free lunch" (NFL) theorems are presented which establish that for any algorithm, any elevated performance over one class of problems is offset by performance over another class. These theorems result in a geometric interpretation of what it means for an algorithm to be well suited to an optimization problem. Applications of the NFL theorems to information-theoretic aspects of optimization and benchmark measures of performance are also presented. Other issues addressed include time-varying optimization problems and** *a priori* **"head-to-head" minimax distinctions between optimization algorithms, distinctions that result despite the NFL theorems' enforcing of a type of uniformity over all algorithms.**

Index Terms— **Evolutionary algorithms, information theory, optimization.**

information theory and Bayesian analysis contribute to an understanding of these issues? How *a priori* generalizable are the performance results of a certain algorithm on a certain class of problems to its performance on other classes of problems? How should we even measure such generalization? How should we assess the performance of algorithms on problems so that we may programmatically compare those algorithms?

Broadly speaking, we take two approaches to these questions. First, we investigate what *a priori* restrictions there are on the performance of one or more algorithms as one runs over the set of all optimization problems. Our second approach is to instead focus on a particular problem and consider the effects of running over all algorithms. In the current paper

80 meter wire ½ λ Inverted V Matching

The Pennsylvania State University

The Graduate School

Department of Electrical Engineering

IMPEDANCE MATCHING OPTIMIZATION BASED ON MATLAB

A Thesis in

Electrical Engineering

by

Kaiming Li

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2013

Li used a genetic algorithm, reported 6 hours of computation time to complete an optimization run for a 3 element "Pi" equalizer circuit.

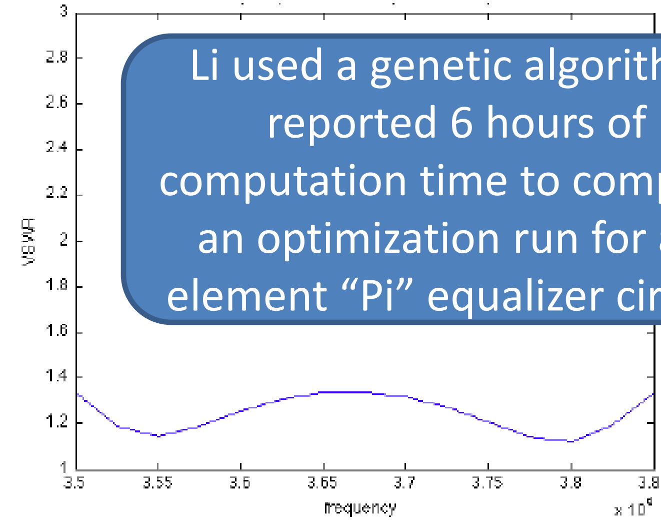


Figure 5-21: VSWR over 3.5-3.85 MHz using Direct Search

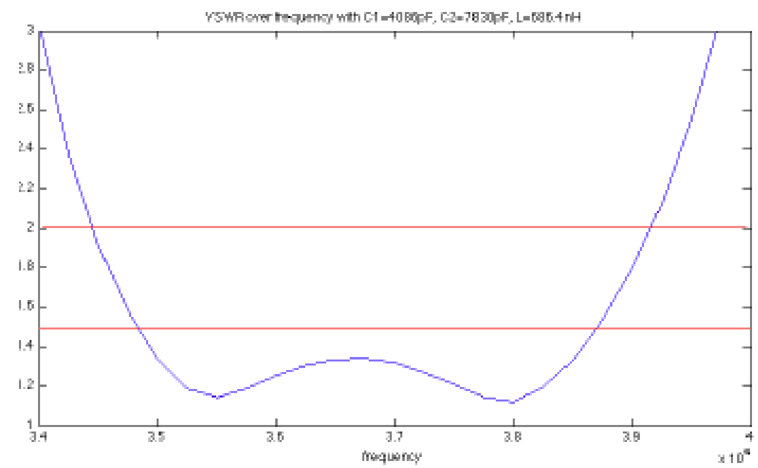


Figure 5-22: VSWR over 3.4-4 MHz using Direct Search

A Minimum in a L Network Landscape Minimum

BROADBAND IMPEDANCE MATCHING OF ANTENNA RADIATORS

by

Vishwanath Iyer

A Dissertation

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

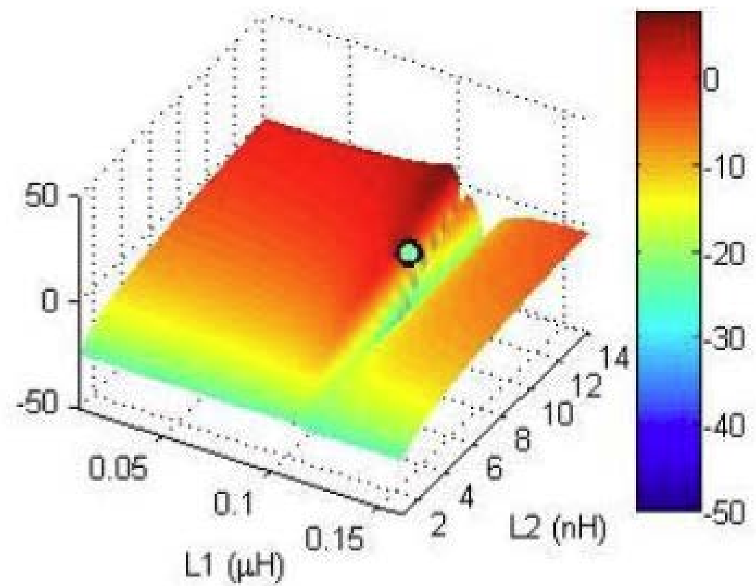
in partial fulfillment of the requirements for the

Degree of Doctor of Philosophy

in

Electrical and Computer Engineering

August 2010



Iyer also used a genetic algorithm, reported 4 hours of computation time was required to complete an optimization run for a “L-T”, 5 element equalizer circuit.

Introduce “ZNET” Design Tool

Accepts industry standard Touchstone file format “.s1p” files that represent load (antenna) electrical impedance data; frequency, resistance, and reactance.

- File data from any of;
  - EM or circuit simulation design tools (e.g. NEC, SPICE, FDTD, etc.), or
  - SWR meter or VNA measurements (e.g. AIM 4170), or
  - TDR measurements with RLGC parameter extraction software.

User selects canonical circuit topology

- e.g. “low-pass”, “band-pass”, “high-pass”, “PiLPiC” etc.,
- ZNET uses “real-life” components with User-supplied unloaded component “Q_u” data.
- All components are fixed values, i.e. no variable components to “tune”.

ZNET performs circuit optimization,

- modifies circuit topology if needed, i.e. includes a “circuit pruning” algorithm,
- provides simulated results with component values, performance metrics, and graphs.

ZNET Design Approach

Modular Software

- Common front end;
  - User Interface,
  - Antenna data file input,
  - Circuit characteristics inputs from User (e.g. circuit topology, constraints, component unloaded Q values, RF power, etc.),
  - Solution report outputs to User (component values, circuit, graphs, comparative results metrics),
- Optimization back-end that “plugs in”;
  - Plug in any optimization algorithm.

Ability to use existing optimization codes when available

- MATLAB, Python, C/C++, FORTRAN.

ZNET Software Overview

Exploits computations performed in linear algebra vector-matrix form.

Uses Nature-Inspired Direct Search;

- Nonlinear minimax optimization of multiple variables,
- “derivative-free”,
- Direct Search
  - Global search by extending to unconstrained optimization.

A.R. Conn, K. Scheinberg, L.N. Vicente, Introduction to Derivative-Free Optimization, Society for Industrial and Applied Mathematics [SIAM], (2009).

ZNET Testing and Verification

or, How Will I Know This is a Good Solution?

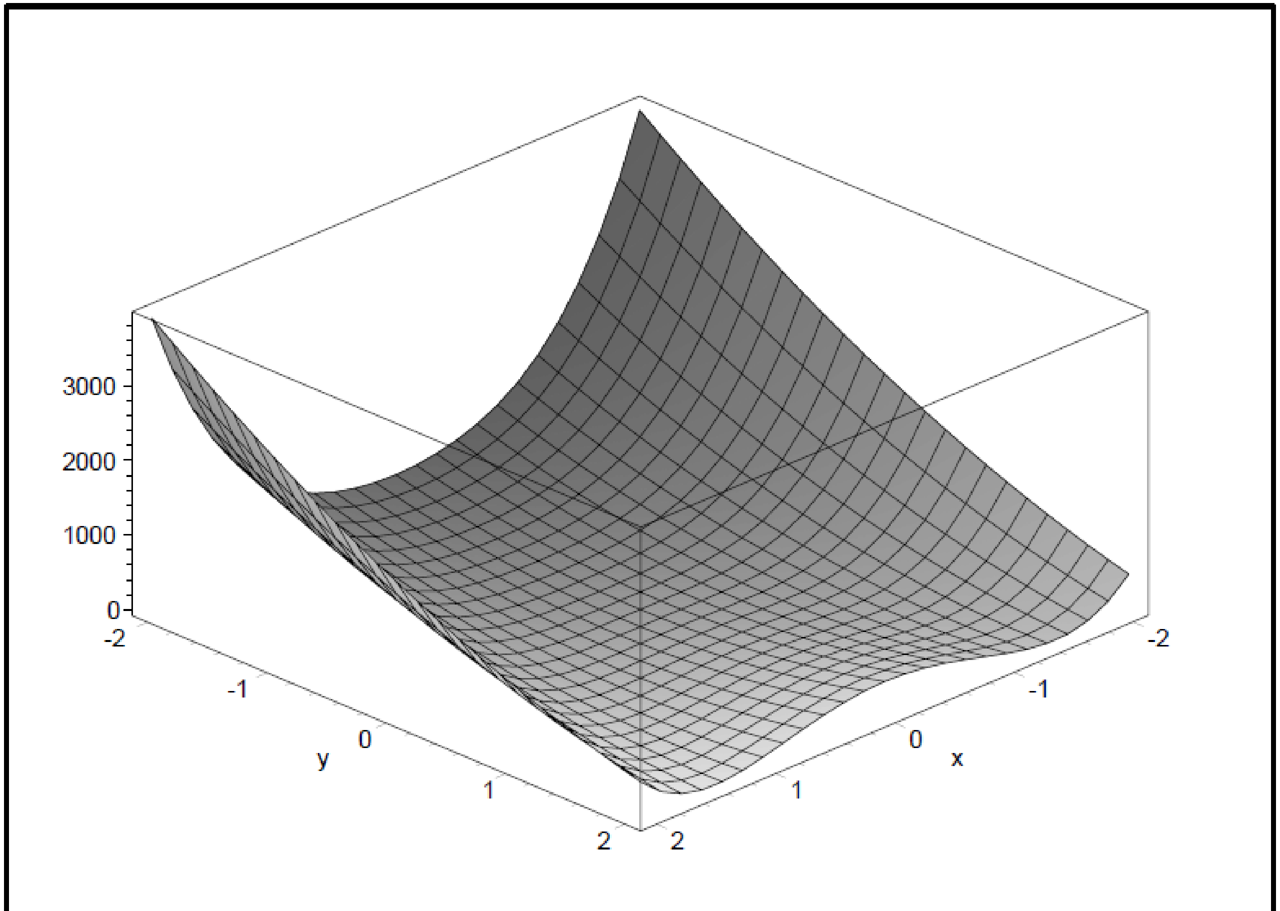
Testing Unconstrained Optimization Software

JORGE J. MORÉ, BURTON S. GARBOW, and KENNETH E. HILLSTROM
Argonne National Laboratory

Much of the testing of optimization software is inadequate because the number of test functions is small or the starting points are close to the solution. In addition, there has been too much emphasis on measuring the efficiency of the software and not enough on testing reliability and robustness. To address this need, we have produced a relatively large but easy-to-use collection of test functions and designed guidelines for testing the reliability and robustness of unconstrained optimization software.

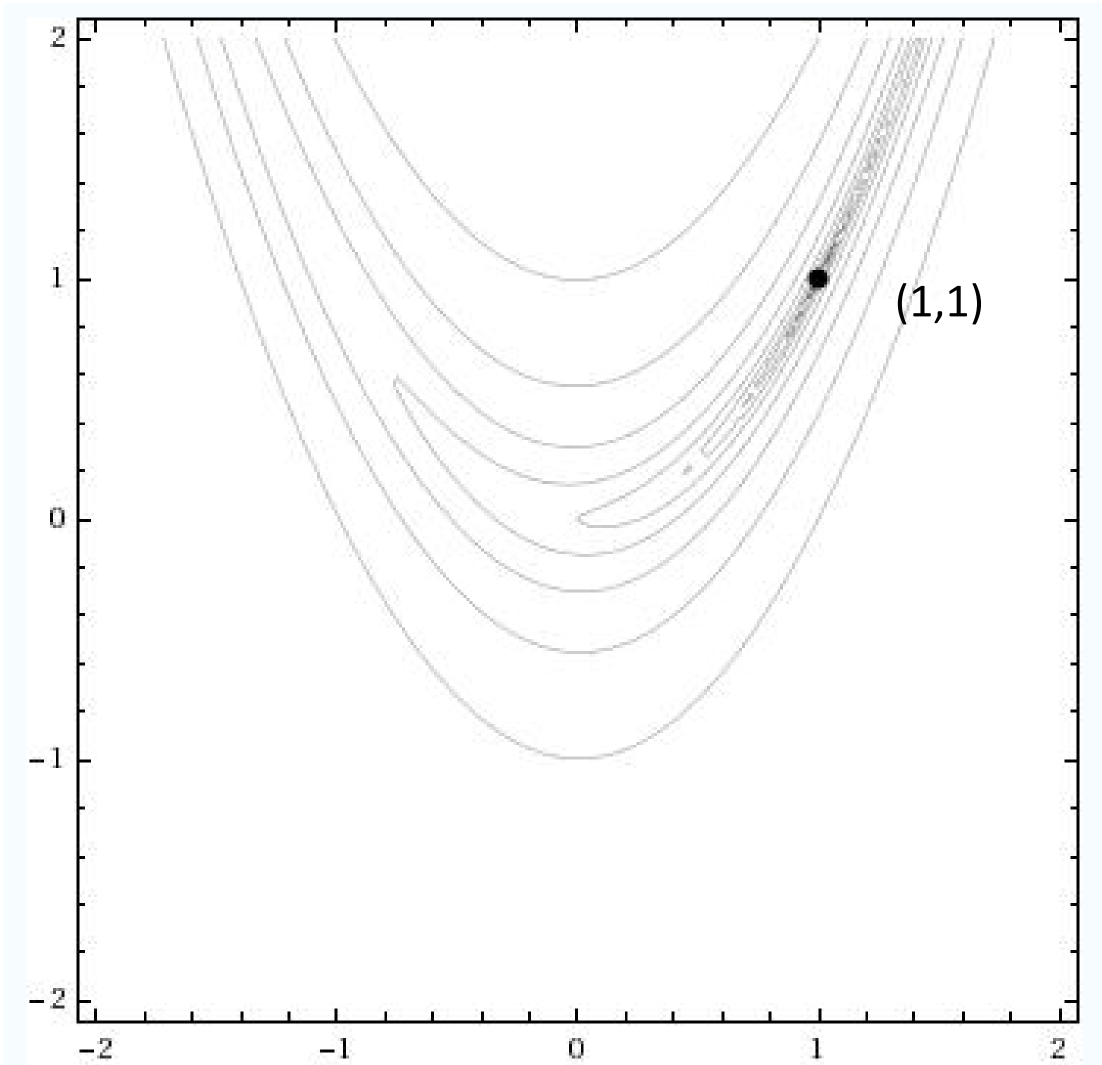
Also see X.-S. Yang, Test problems in optimization, in: Engineering Optimization: An Introduction with Metaheuristic Applications (Eds Xin-She Yang), John Wiley & Sons, (2010).

Verification of Optimization Algorithm Performance Using Known "Benchmark" Problems and Known Solutions

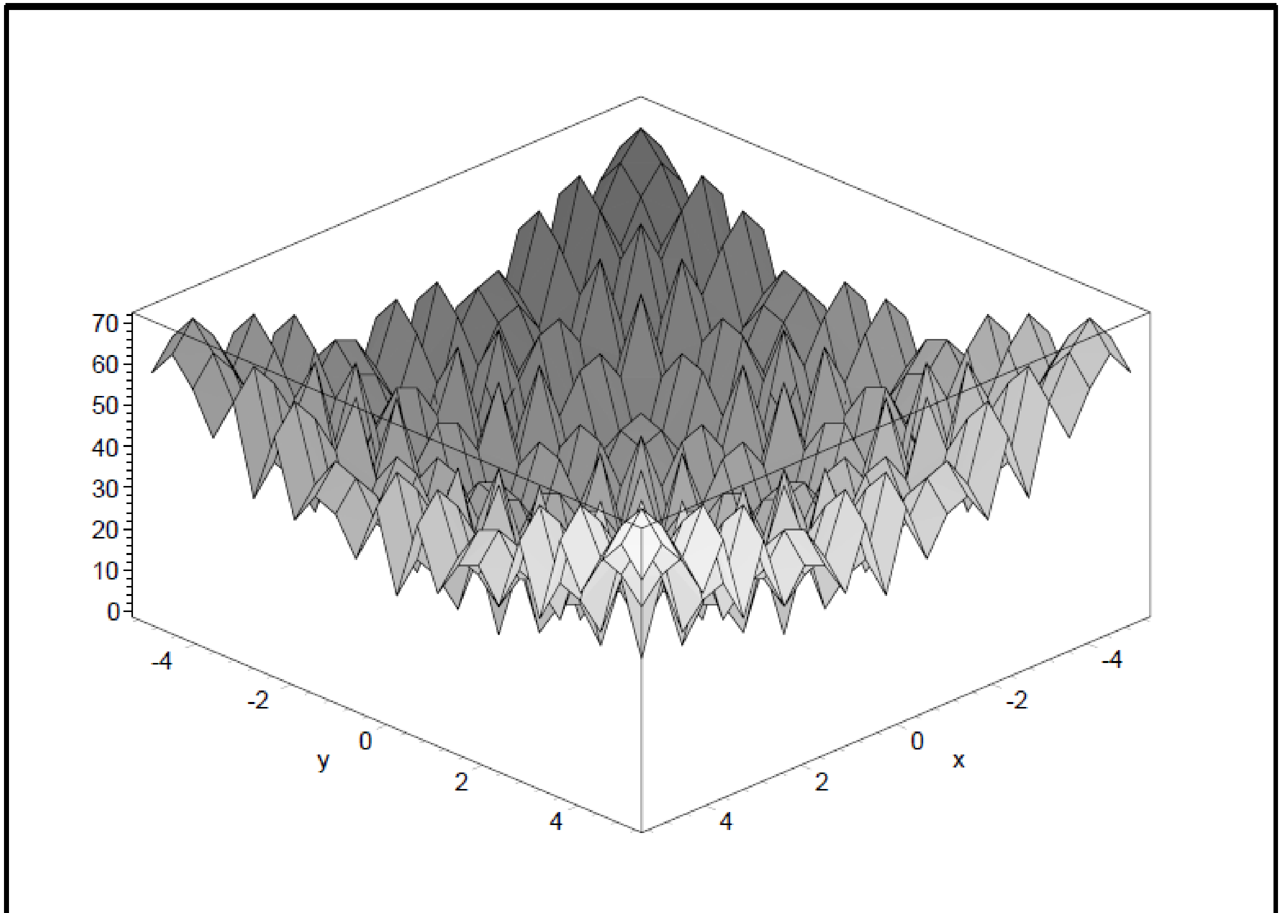


Rosenbrock's Valley, a.k.a. "banana function"

Rosenbrock Optimization Minimum

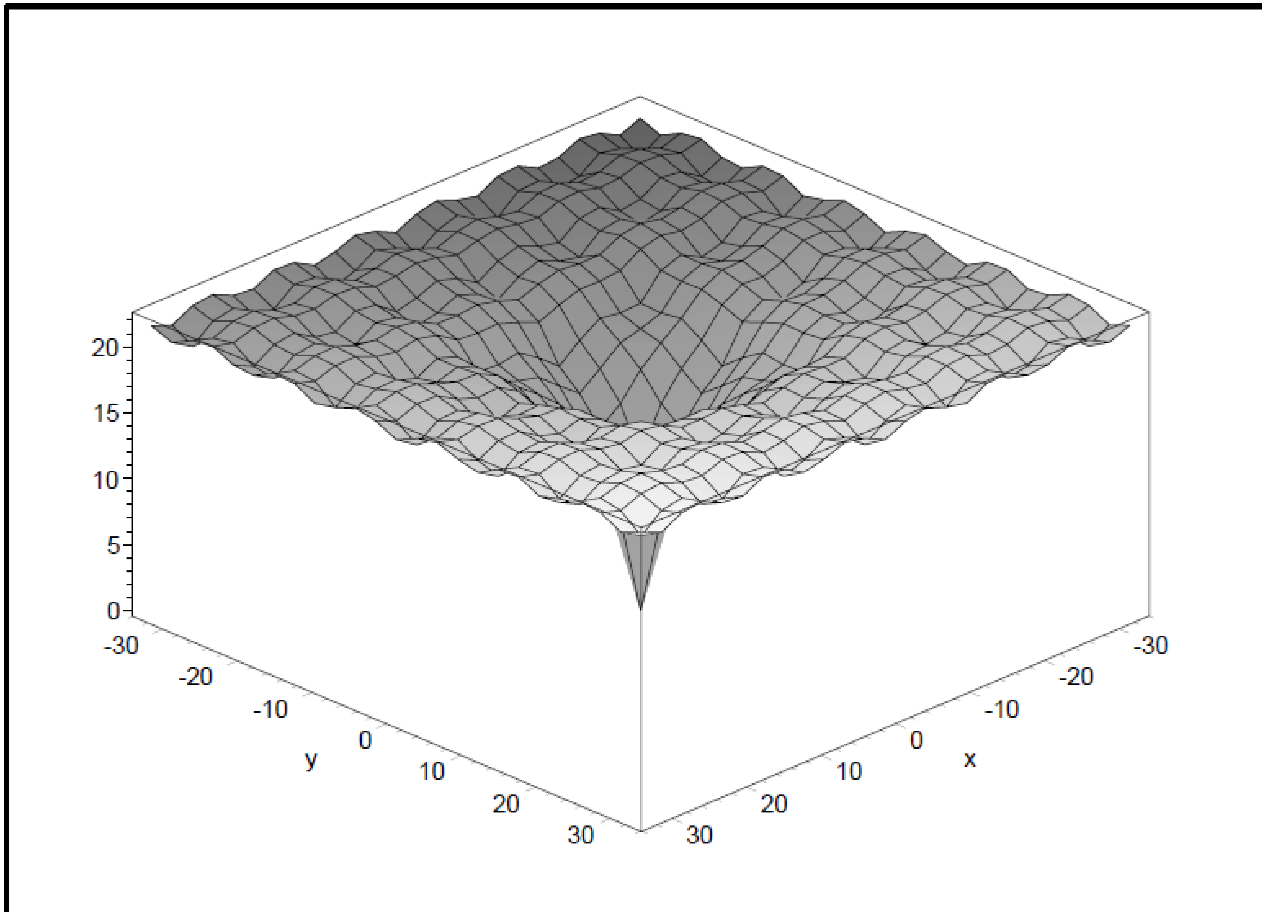


Verification of Optimization Algorithm Performance Using Known “Benchmark” Problems



Rastrigin’s function

Verification of Optimization Algorithm Performance Using Known "Benchmark" Problems



Ackley's function

Why Grid or Random Initial Search is Problematic

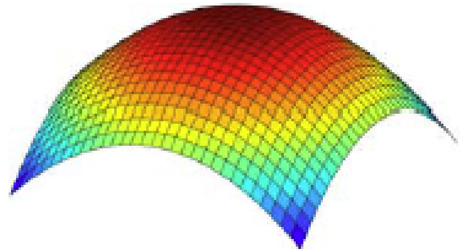


Fig. 1. Unimodal function.

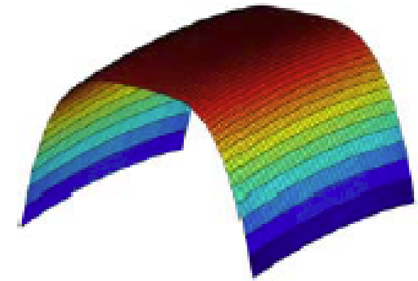


Fig. 2. Functions with significant null-space effects.

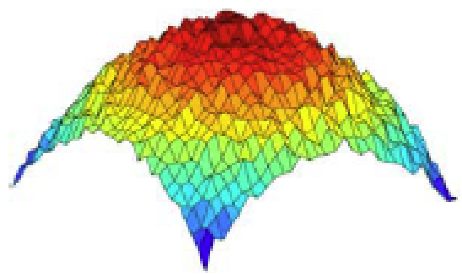


Fig. 3. Essentially unimodal functions.

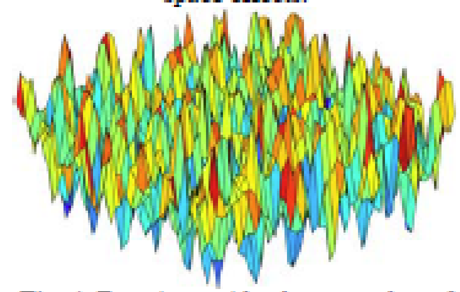


Fig. 4. Functions with a huge number of significant local optima.

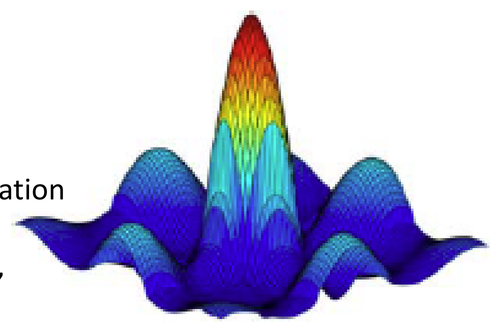


Fig. 5. Functions with a small number of significant local optima.

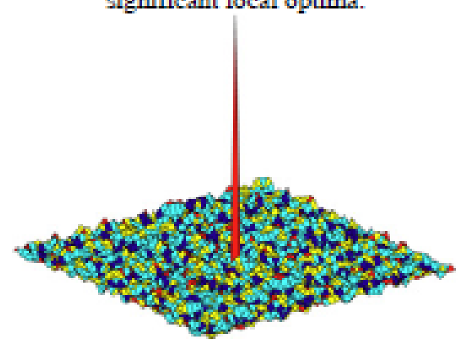
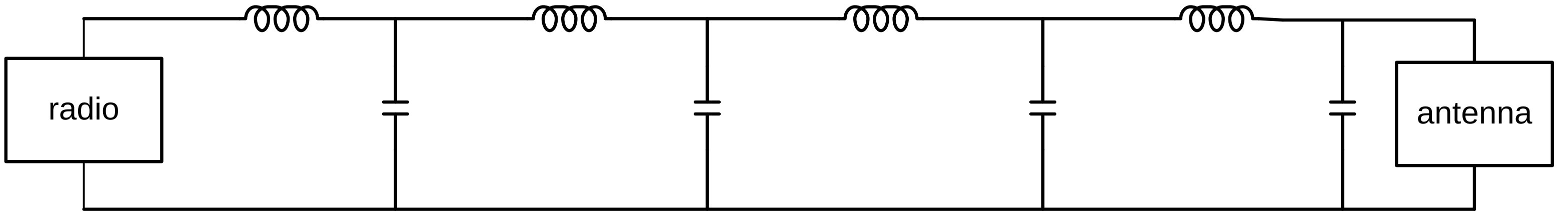


Fig. 6. Functions whose global structure provides no useful information about its optima.

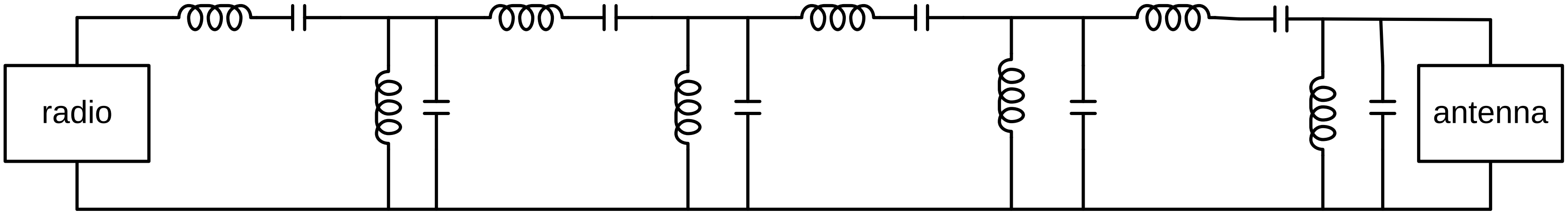
N. Andrei, "An Unconstrained Optimization Test Functions Collection" *Advanced Modeling and Optimization*, Volume 10, Number 1, 2008.

Example Equalizer Circuit Topologies and Nomenclature

Low Pass Equalizer Circuit Topology.
Low Pass Parallel to Load 8 elements…."LPP8".



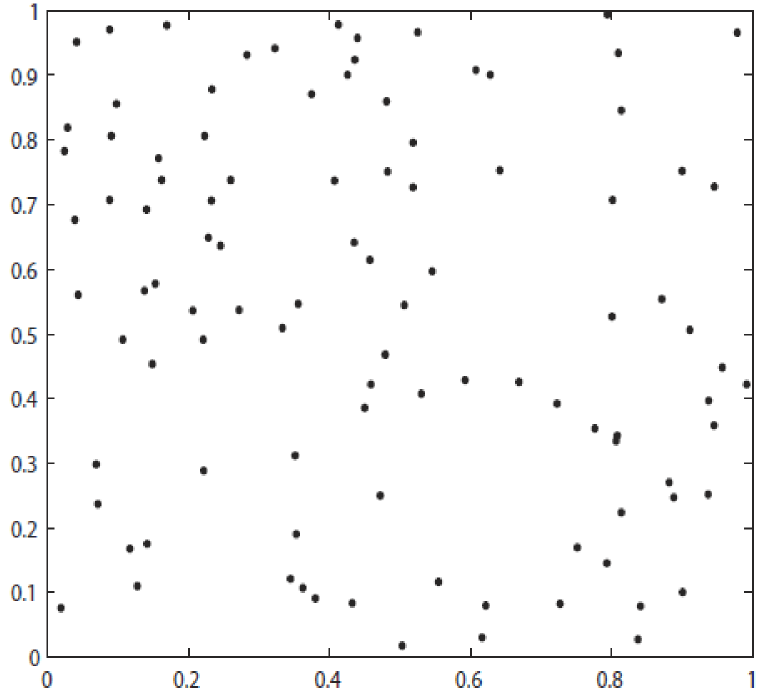
Band Pass Equalizer Circuit Topology.
Band Pass Parallel to Load 8 resonators…."BPP8".



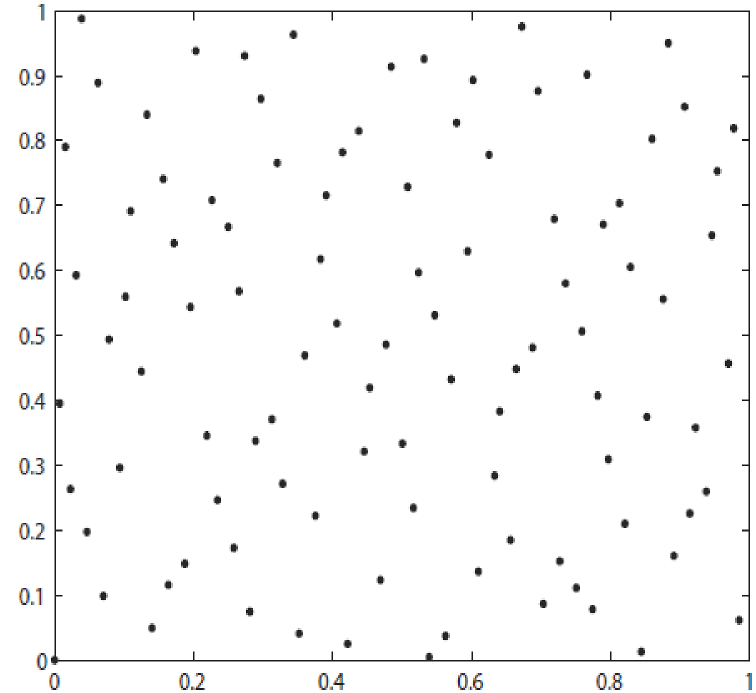
`

Not Grid or Random Initial Values

100 points



Random Distribution



Halton Sequence

B.L. Robertson, Direct Search Methods for Nonsmooth Problems Using Global Optimization Techniques, Ph.D. dissertation, University of Canterbury, Christchurch, New Zealand, 2010.

ZNET Accepts FRX & Touchstone .s1p Formats

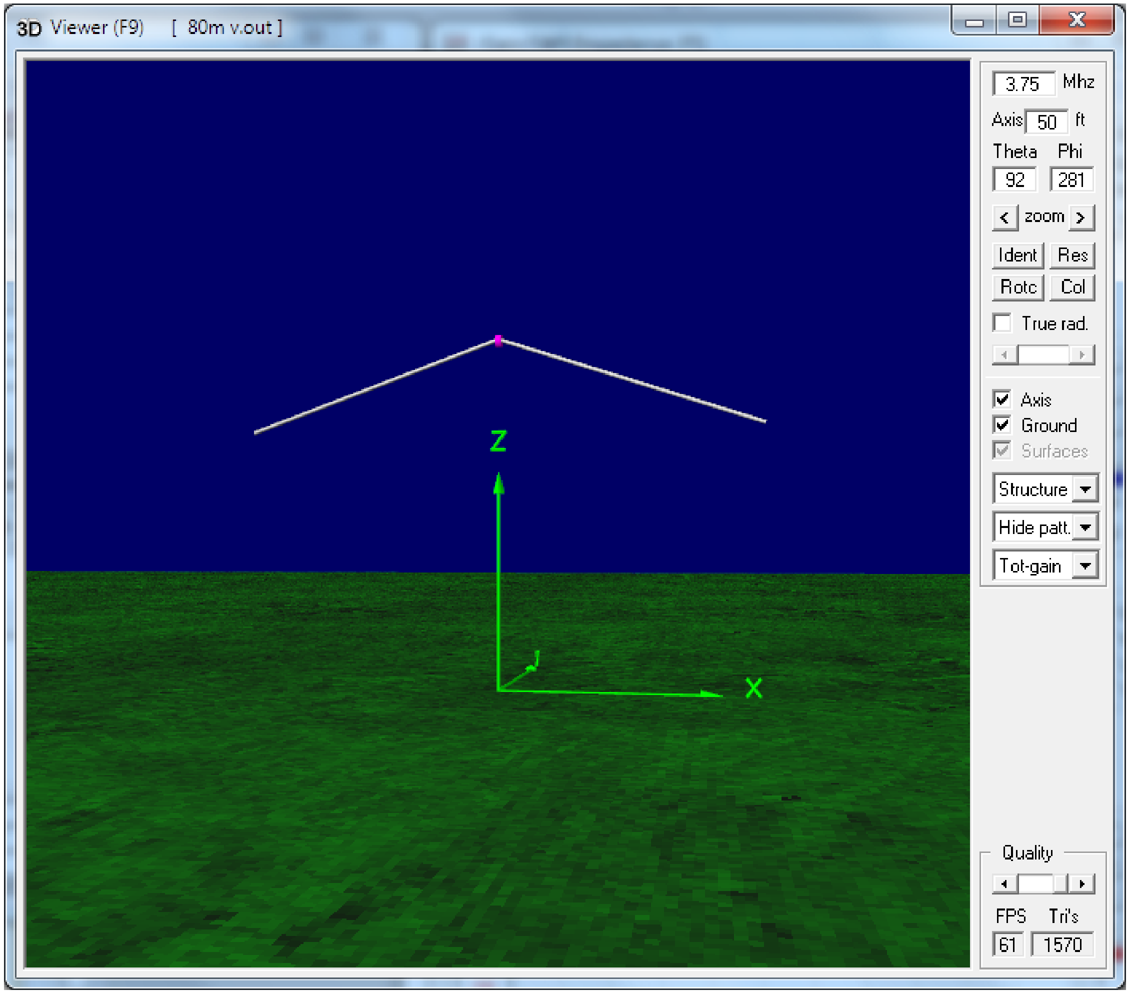
Freq	R	X
3.5000	63.9374	-85.0664
3.5125	64.7067	-81.0424
3.5250	65.4829	-77.0252
3.5375	66.2661	-73.0144
3.5500	67.0562	-69.01
3.5625	67.8533	-65.0117
3.5750	68.6575	-61.0194
3.5875	69.4689	-57.0327
3.6000	70.2874	-53.0517
******	*******	*******
3.9250	94.2681	49.0936
3.9375	95.302	52.9923
3.9500	96.3448	56.8904
3.9625	97.3965	60.7882
3.9750	98.4573	64.6857
3.9875	99.5273	68.5832
4.0000	100.606	72.4809

Data represents antenna impedance as a function of frequency.

Data can be acquired from VNA or SWR meter, or be calculated using antenna simulation software.

Spreadsheet can be used to convert data files types, and to compute initial performance metrics.

An 80 meter ½ λ Inverted V Wire Antenna



Computer Model of Antenna Physical Geometry

ZNET High-Pass "T" and 80 meter Inverted V Wire Dipole Input Screen

octave-3.6.4

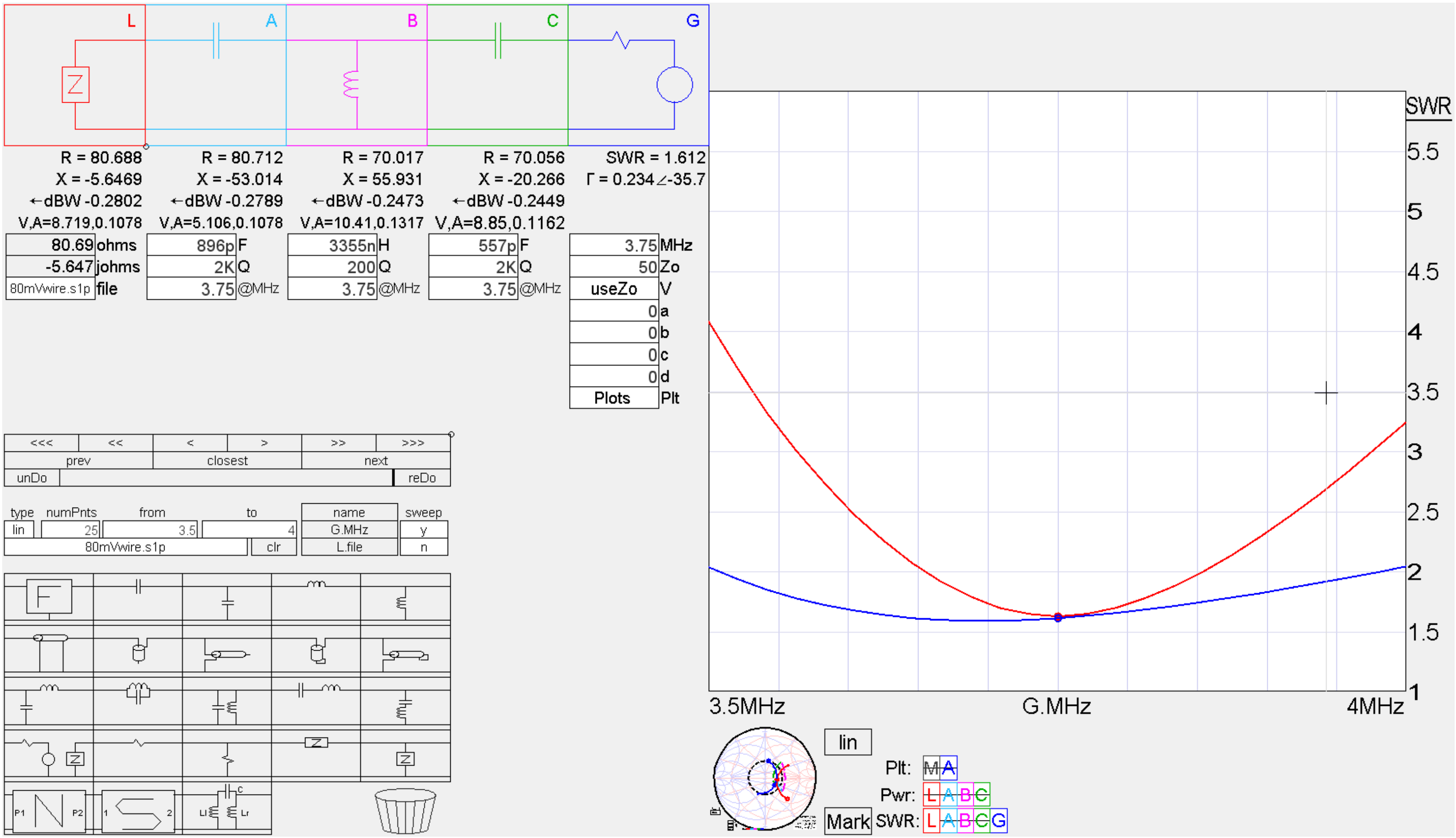
```
                 Broadband Impedance Matching Direct Search Optimizer
                                William M. Brooks

                               Hi-Pass T Algorithm


       --------C3-------------C1---------
       |               |                 |
      Zsrc             L2              Zload
       |               |                 |
       -----------------------------------

 Enter the antenna Touchstone s1p file name (.s1p) : 80mVwire.s1p

 Number of antenna frequency-impedance samples from data file = 501 samples


 Enter the RF power in the load (default = 100 Watts) :
 Enter the capacitor unloaded Q (default = 2000) :
 Enter the inductor unloaded Q (default = 200)   :
 Enter the source impedance (default = 50 Ohms)  :
 Enter the optimization stopping tolerance (default = 1E-5) :


 Optimization in progress.....
```

ZNET High-Pass "T" and 80 meter Inverted V Wire Dipole Output Screen

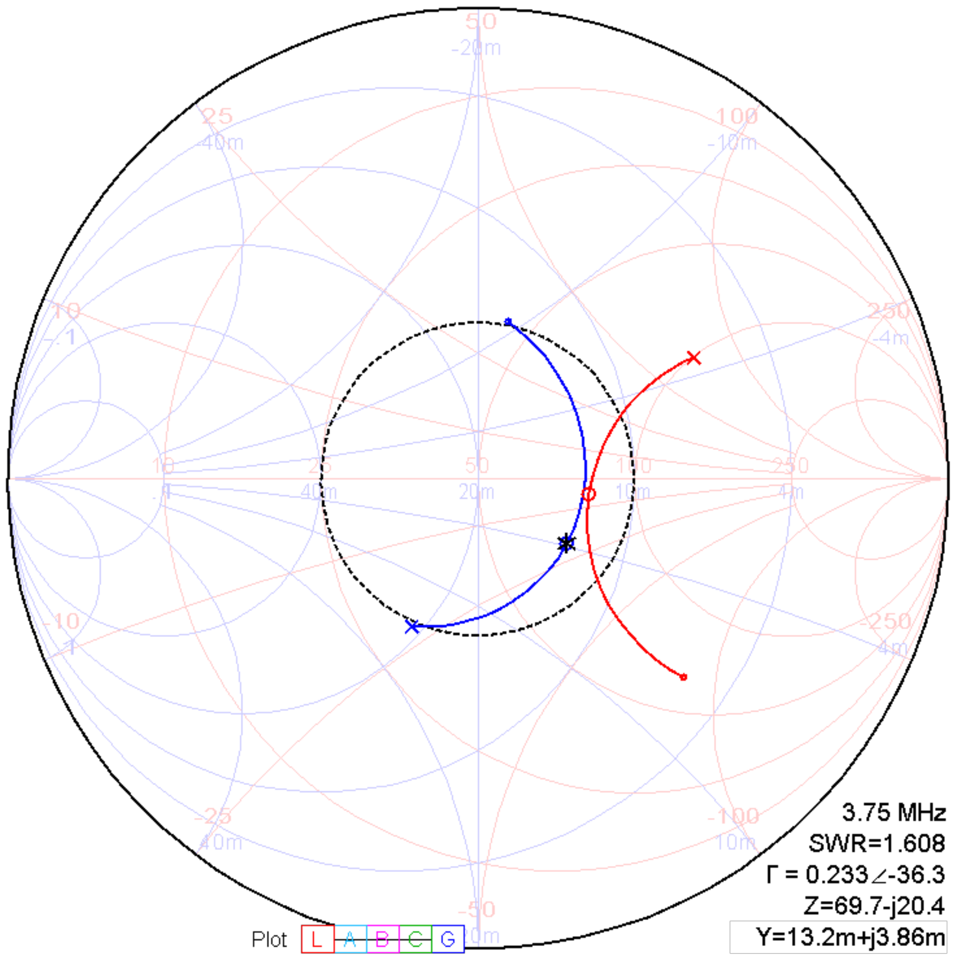
octave-3.6.4

```
Optimization completed!

Number of function evaluations = 3060

Number of objective iterations = 102

Optimization computation time =   4.38 seconds

Convergence = 0
The optimizer converged to the tolerance limit!

TPG Objective Score= 0.714079


    --------C3--------------C1---------
    |               |                 |
    |               |                 |
  Zsrc             L2               Zload
    |               |                 |
    |               |                 |
    -----------------------------------


RF Load Power = 100.00 Watts


C1 = 895.58 pF
L2 = 3354.10 nH
C3 = 557.59 pF


Antenna Q = 7.40

Qbw = 7.48

Fano decrement = 1.01

Estimated Fano bandwidth = 1.447 MHz

Fano VSWR minimum = 1.09

minimum matched VSWR = 1.59

maximum matched VSWR = 2.04

maximum Equalizer Match Loss = 0.27 dB

Capacitor ratio = 1.61

Inductor ratio  = 1.00
```

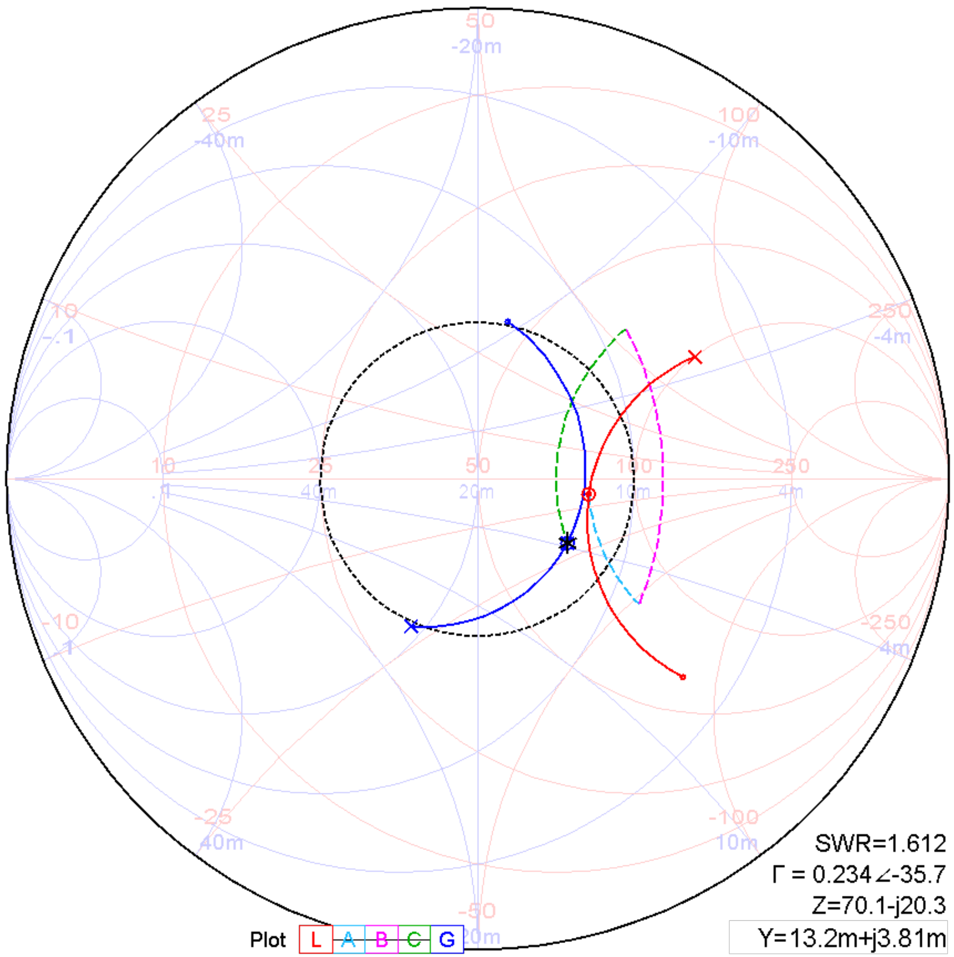
An 80 meter ½ λ Inverted V Wire Antenna with High Pass "T" Equalizer Circuit Topology



An 80 meter ½ λ Inverted V Wire Antenna with High Pass "T" Equalizer Circuit Topology

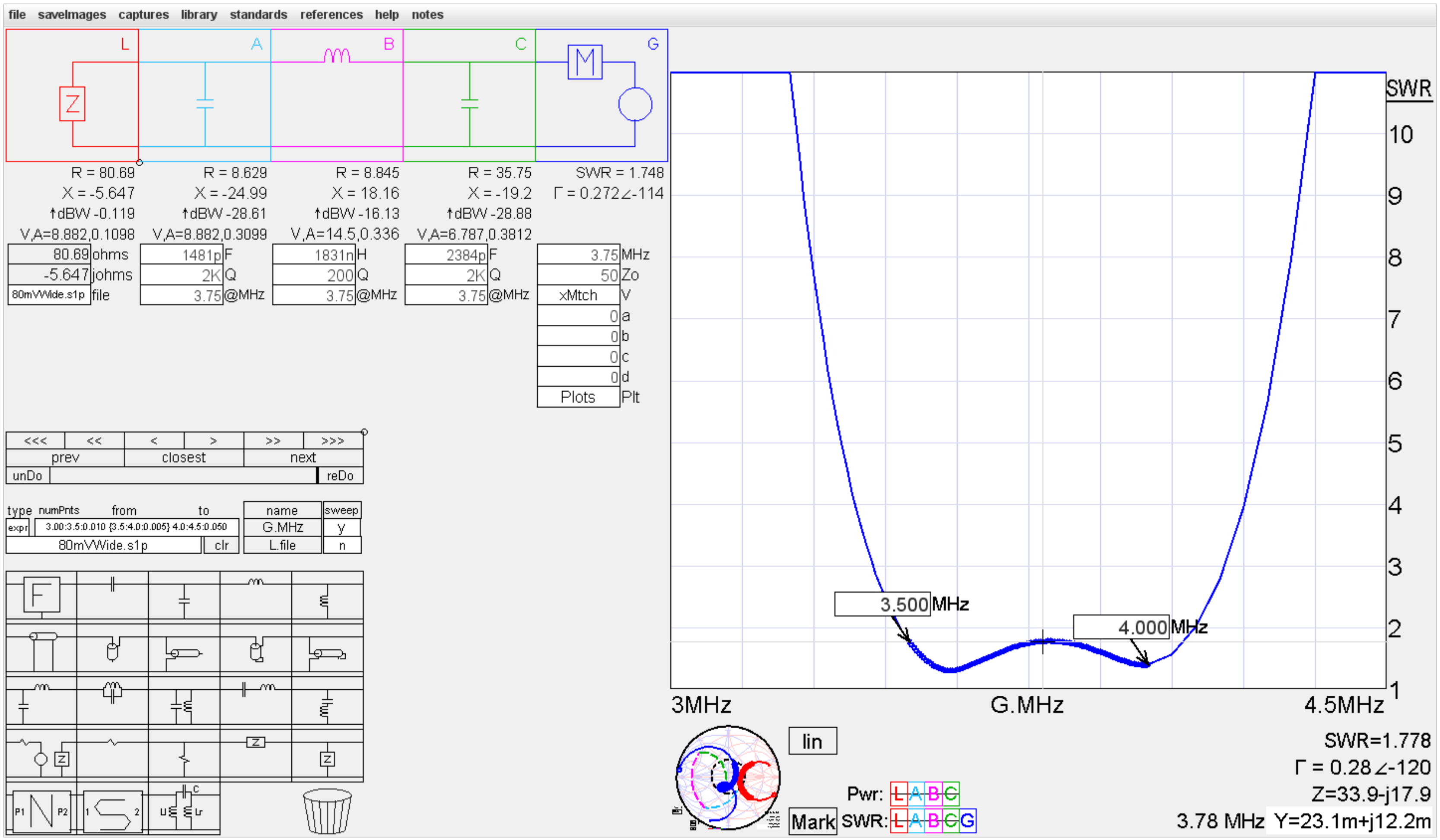


An 80 meter ½ λ Inverted V Wire Antenna with High Pass "T" Equalizer Circuit Topology and Path

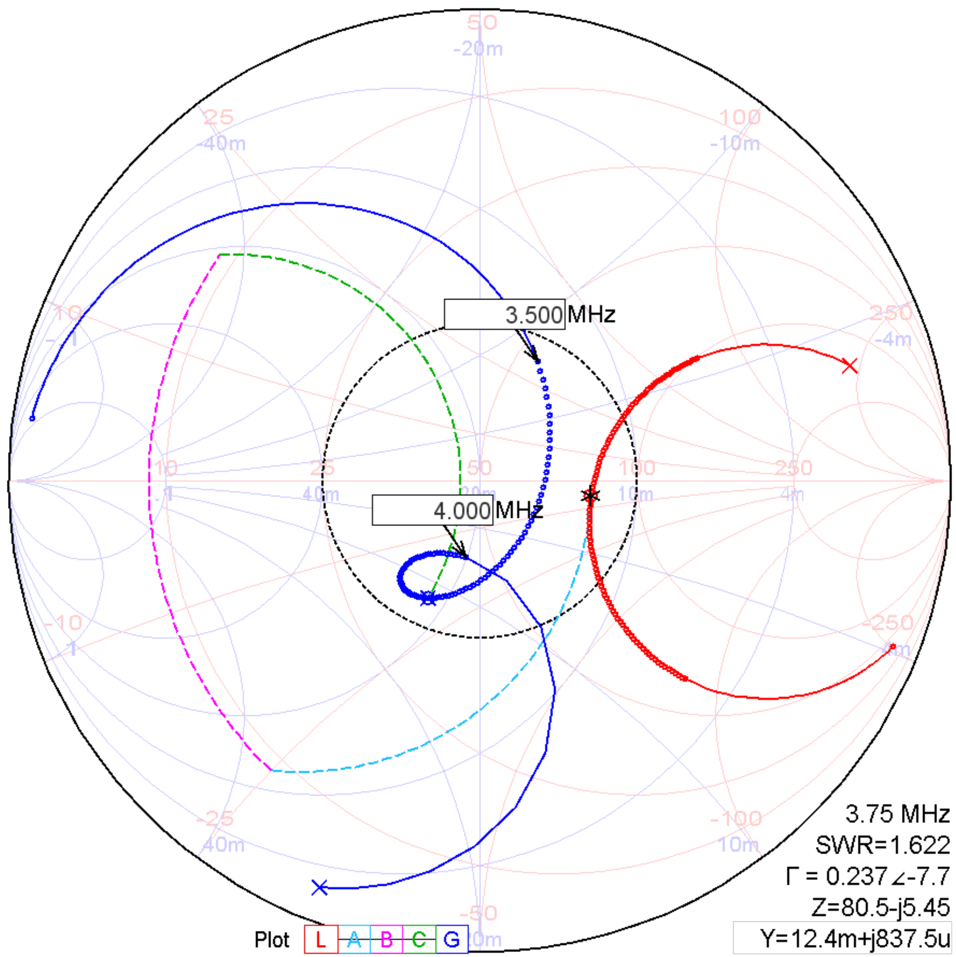


Note the path taken

An 80 meter ½ λ Inverted V Wire Antenna with Low Pass "Pi" Equalizer Circuit Topology

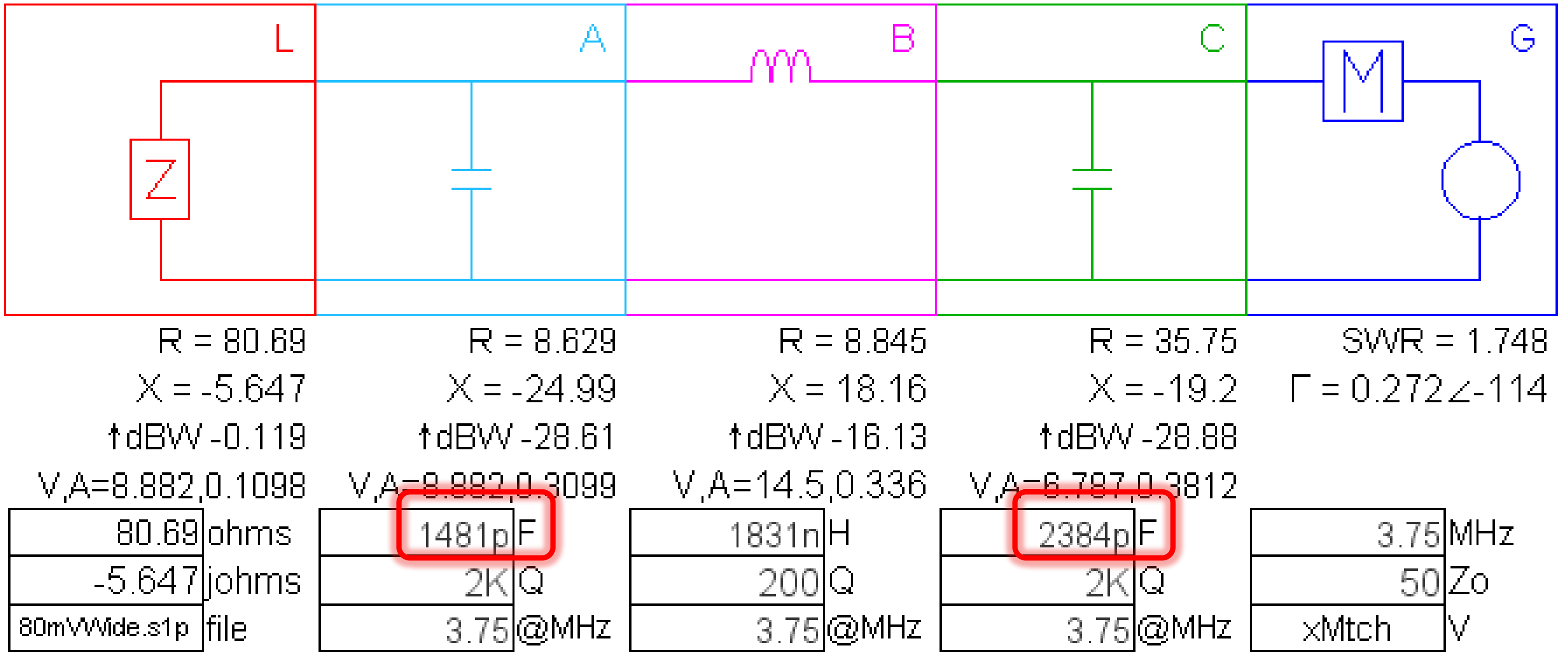


An 80 meter ½ λ Inverted V Wire Antenna with Low Pass “Pi” Smith Chart



Note the path taken.

Using Standard Value Capacitors



Stripline Capacitor

Excel Solver Selects Capacitor Combination

Standard Capacitor Combination Optimizer, WB6YVK

Standard Cap value (pF)	Capacitor Count	Use Excel Solver or OpenSolver in "Data" tab		
3	0	Target Capacitance (pF) =	2384	pF
4	0			
5	0			
7	0	Computed Capacitance (pF) =	2384	pF
10	0			
12	0			
15	0	Quantity of Capacitors Required =	3	
18	0			
22	0			
20	0			
24	1			
27	0			
30	0			
33	0			
39	0			
43	0			
47	0			
50	0			
51	0			
56	0			
62	0			
68	0			
70	0			
75	0			
82	0			
91	0			
100	0			

Use Solver to select minimum number of standard value capacitors to achieve desired capacitance.

Solver is bundled with Microsoft Excel.

LibreOffice Calc has a similar Solver, also includes a solver “DEPSO”.

A *faster* solver “OpenSolver” is available at no cost from http://opensolver.org/

DEPSO Optimizer

IEEE International Conference on Systems, Man & Cybernetics (SMCC), Washington D C, USA, 2003: 3816-3821

Source code: http://www.adaptivebox.net/research/fields/algorithm/pso/index.html

DEPSO: Hybrid Particle Swarm with Differential Evolution Operator

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Institute of Microelectronics,
Tsinghua University,
Beijing 100084, P. R. China
*Email: xiexiaofeng@tsinghua.org.cn

Abstract - *A hybrid particle swarm with differential evolution operator, termed DEPSO, which provide the bell-shaped mutations with consensus on the population diversity along with the evolution, while keeps the self-organized particle swarm dynamics, is proposed. Then it is applied to a set of benchmark functions, and the experimental results illustrate its efficiency.*

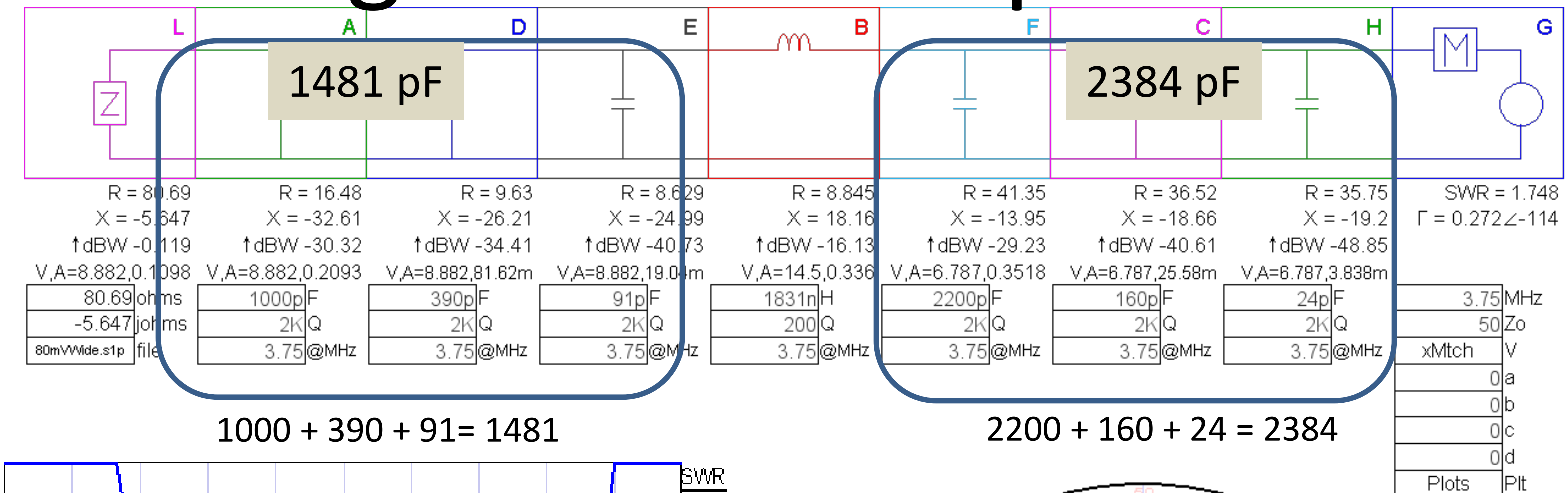
Keywords: Particle swarm optimization, differential evolution, numerical optimization.

the particles oscillate in different sinusoidal waves and converging quickly, sometimes prematurely, especially for PSO with small w[20] or constriction coefficient[3].

The concept of a more-or-less permanent social topology is fundamental to PSO [10, 12], which means the *pbest* and *gbest* should not be too closed to make some particles *inactively* [8, 19, 20] in certain stage of evolution. The analysis can be restricted to a single dimension without loss of generality. From equations (1), v_{id} can become small value, but if the $|p_{id}-x_{id}|$ and $|p_{gd}-x_{id}|$ are both small, it cannot back to large value and

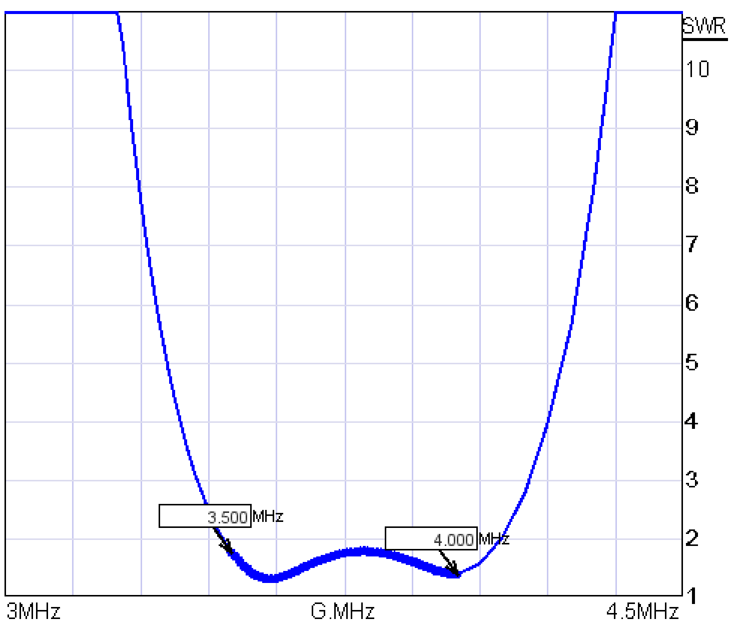
DEPSO is bundled with the "Calc" application in LibreOffice www.libreoffice.org

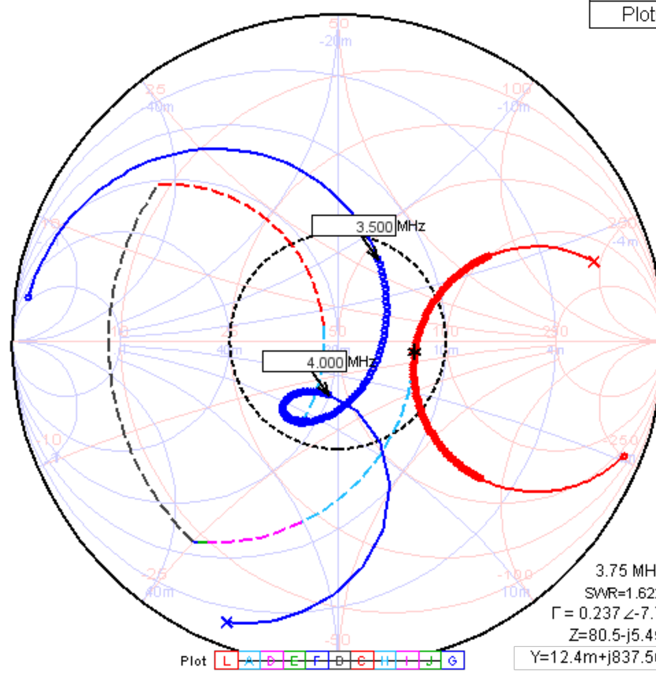
Using Standard Capacitors



1000 + 390 + 91= 1481

2200 + 160 + 24 = 2384





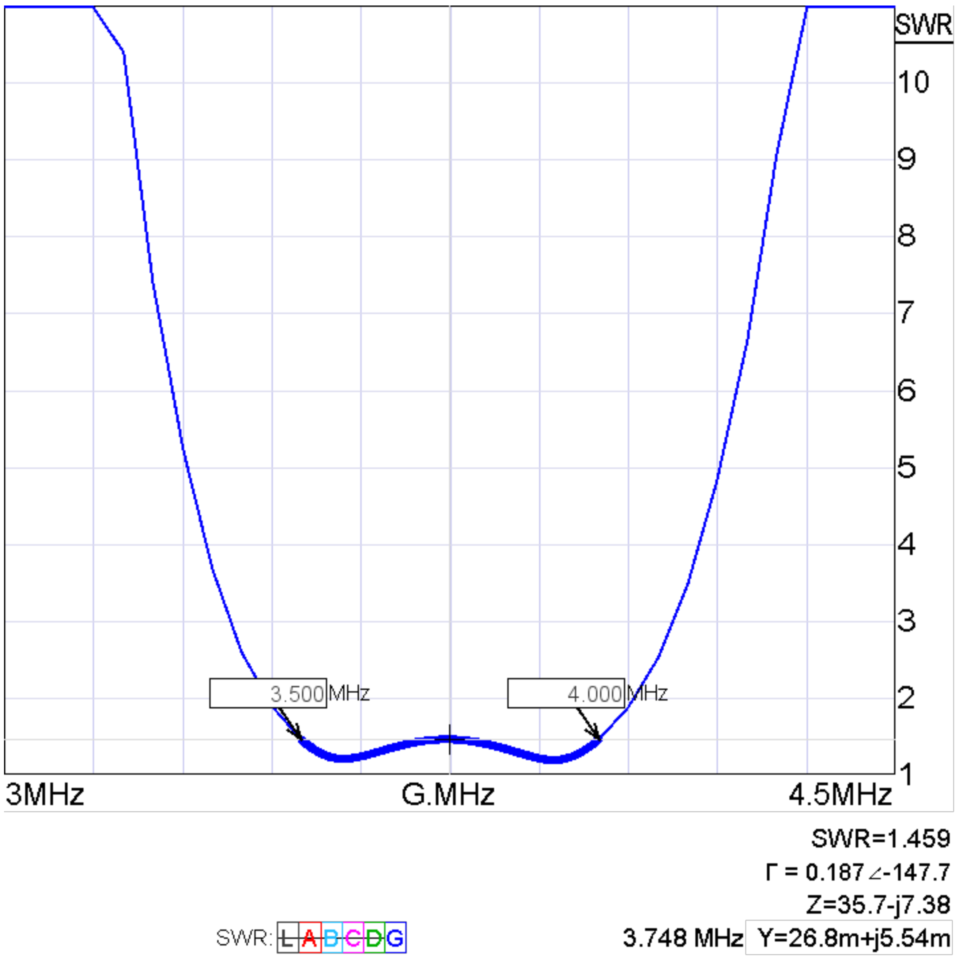
80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology ZNET Solution

octave-3.6.4

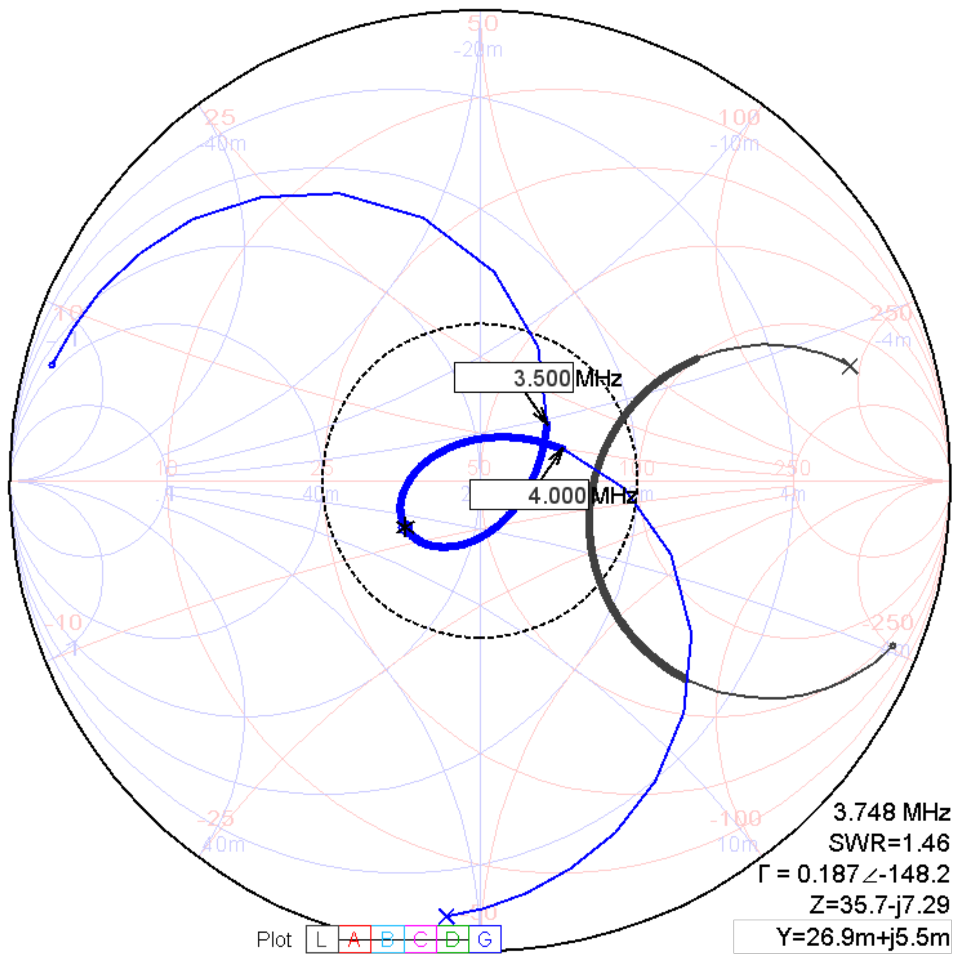
```
Number of function evaluations = 3960

Number of objective iterations = 99

Optimization computation time =   2.87 seconds

Convergence = 0
The optimizer converged to the tolerance limit!

TPG Objective Score= 0.377565


     ------------------L3-----------L1---------
     |            |            |            |
   Zsrc          C4           C2          Zload
     |            |            |            |
     -------------------------------------------



RF Load Power = 100.00 Watts

L1 =  1497.50 nH        1.12 Amps       39.31 Volts

C2 =  1415.60 pF        3.26 Amps       97.98 Volts

L3 =  1996.78 nH        2.99 Amps      140.53 Volts

C4 =  1952.04 pF        2.72 Amps       59.34 Volts


Antenna Q = 7.39

Qbw = 7.48

Fano decrement = 1.01

Estimated Fano bandwidth = 1.448 MHz

Fano VSWR minimum = 1.09

minimum matched VSWR = 1.19

maximum matched VSWR = 1.46

maximum Equalizer Match Loss = 0.08 dB

Capacitor ratio = 1.38

Inductor ratio  = 1.33
```

80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology ZNET Solution

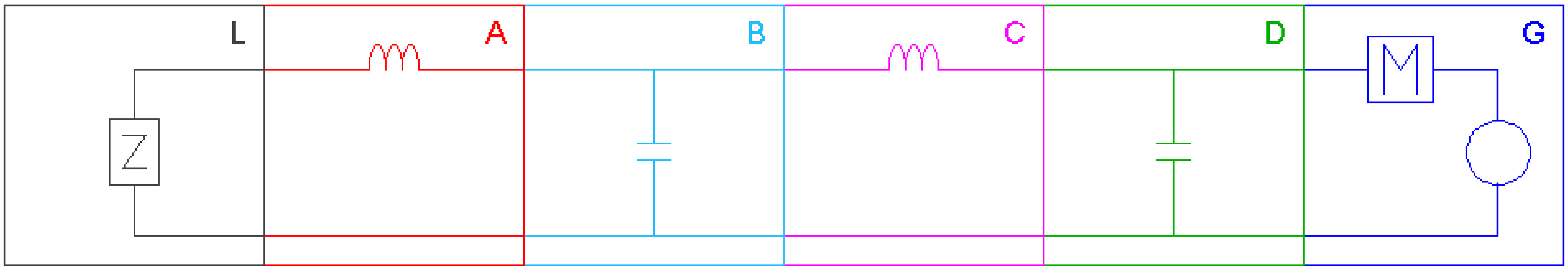
ΔP_{load} = 0.145 dB



80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology Smith Chart

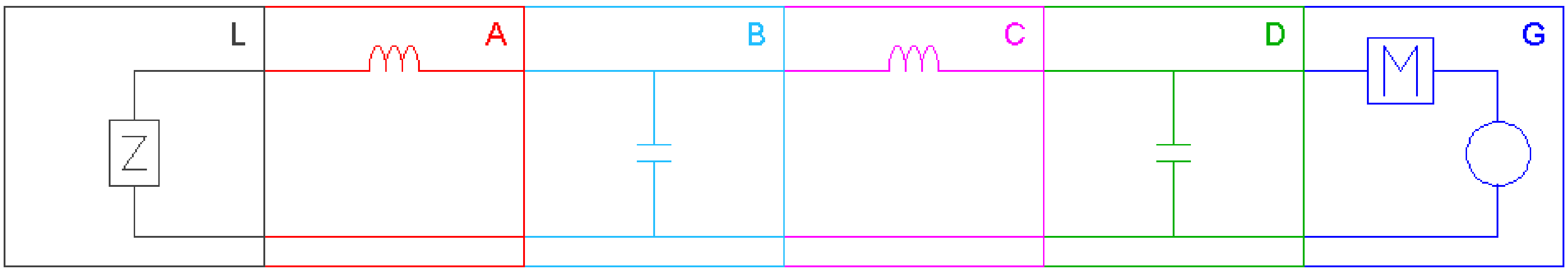


80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology



R = 80.688	R = 80.865	R = 11.128	R = 11.364	R = 35.677	SWR = 1.459
X = -5.6469	X = 29.637	X = -29.923	X = 17.125	X = -7.2239	Γ = 0.187∠-148.4
←dBW -0.1107	←dBW -0.1012	←dBW -94.56m	←dBW -3.711m	←dBW ~0	
V,A=8.891,0.1099	V,A=3.878,0.1099	V,A=9.466,0.3157	V,A=13.95,0.2965	V,A=6.094,0.2803	
80.69 ohms	1497.5n H	1415.6p F	1996.78n H	1952.04p F	3.75 MHz
-5.647 johms	200 Q	2K Q	200 Q	2K Q	50 Zo
80mVWide.s1p file	3.75 @MHz	3.75 @MHz	3.75 @MHz	3.75 @MHz	xMtch V
					0 a
					0 b
					0 c
					0 d
					Plots Plt

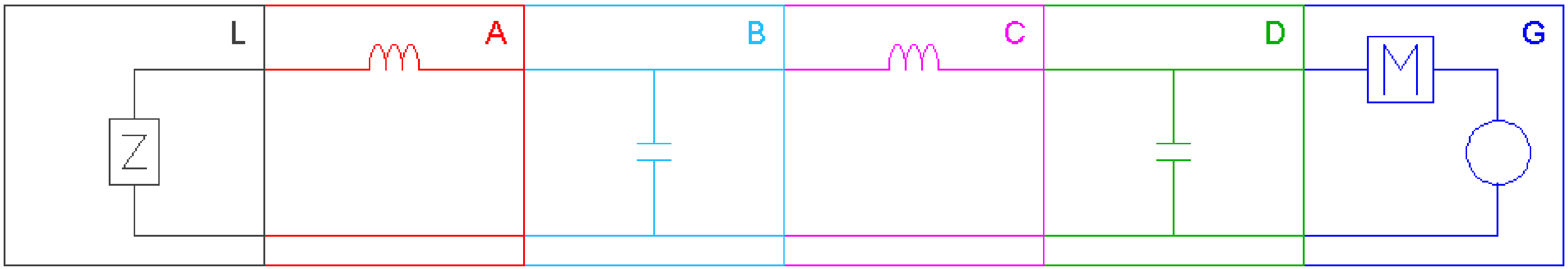
80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology 1000 Watt Power Handling



L	A	B	C	D	G
R = 80.688	R = 80.865	R = 11.128	R = 11.364	R = 35.677	SWR = 1.459
X = -5.6469	X = 29.637	X = -29.923	X = 17.125	X = -7.2239	Γ = 0.187∠-148.4
←dBW 29.89	←dBW 29.9	←dBW 29.91	←dBW 30	←dBW 30	
V,A=281.1,3.476	V,A=122.6,3.476	V,A=299.4,9.985	V,A=441.2,9.377	V,A=192.7,8.864	
80.69 ohms	1497.5n H	1415.6p F	1996.78n H	1952.04p F	3.75 MHz
-5.647 johms	200 Q	2K Q	200 Q	2K Q	50 Zo
80mVWide.s1p file	3.75 @MHz	3.75 @MHz	3.75 @MHz	3.75 @MHz	xMtch(1000) V
					0 a
					0 b
					0 c
					0 d
					Plots Plt

Note the RF voltages and currents in each component.

80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology 1000 Watt Power Handling

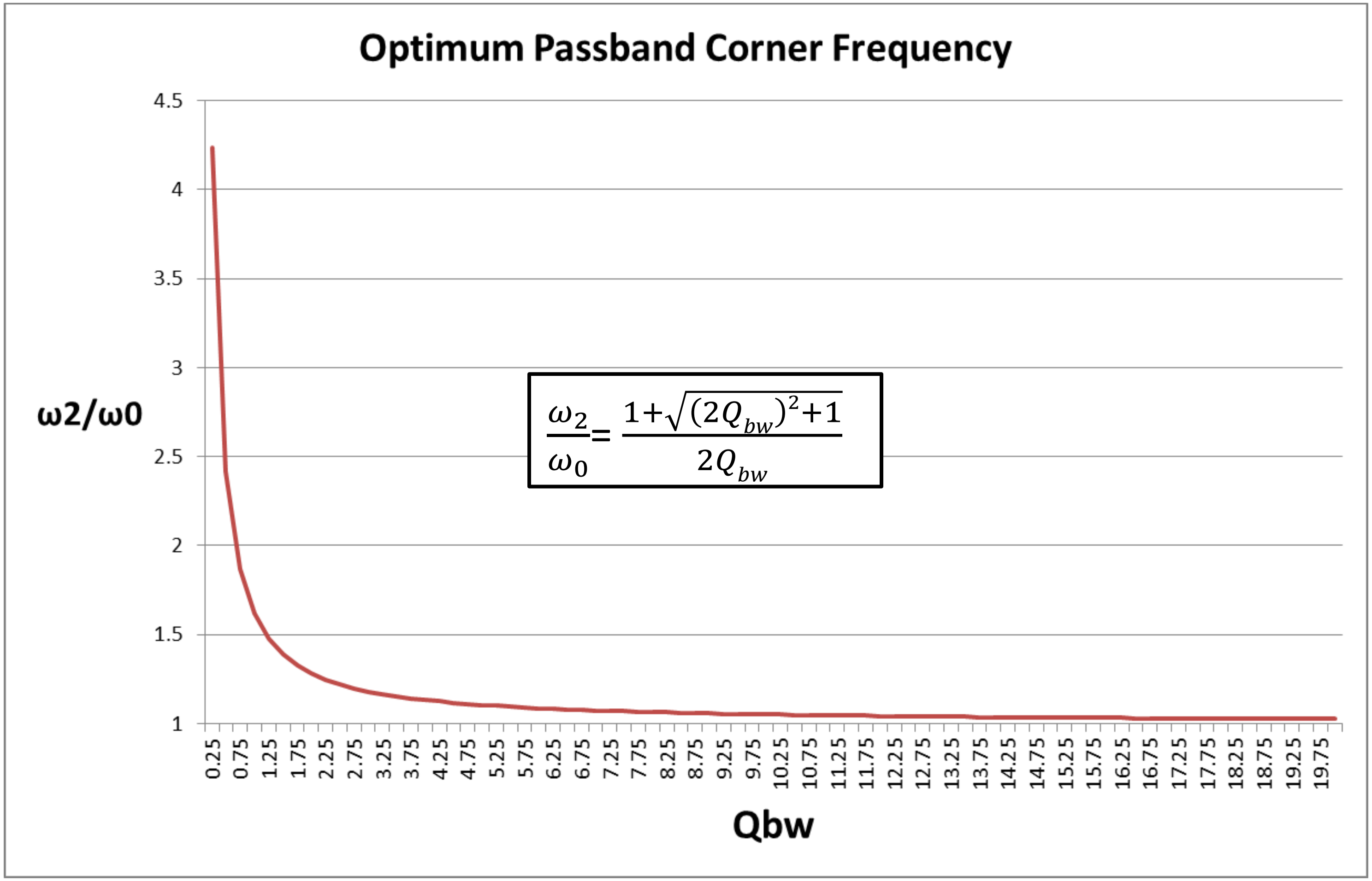


R = 80.688	R = 80.865	R = 11.128	R = 11.364	R = 35.677	SWR = 1.459
X = -5.6469	X = 29.637	X = -29.923	X = 17.125	X = -7.2239	Γ = 0.187 ∠-148.4
↑W 974.8	↑W 2.131	↑W 1.495	↑W 20.68	↑W 0.8541	
V,A=281.1,3.476	V,A=122.6,3.476	V,A=299.4,9.985	V,A=441.2,9.377	V,A=192.7,8.864	

80.69	ohms	1497.5n	H	1415.6p	F	1996.78n	H	1952.04p	F	3.75	MHz
-5.647	johms	200	Q	2K	Q	200	Q	2K	Q	50	Zo
80mVWide.s1p	file	3.75	@MHz	3.75	@MHz	3.75	@MHz	3.75	@MHz	xMtch(1000)	V
										0	a
										0	b
										0	c
										0	d
										Plots	Plt

Note the RF power dissipated by each component.

Optimum Corner Frequency for Passband



T.R. Cuthbert, Broadband Direct-Coupled and Matching RF Networks, TRCPEP, (1999), pg19.

80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology Increased to Optimum Passband

Example: 80 meter band; 3.5 – 4.0 MHz

$\omega_0 = \sqrt{\omega_1 \times \omega_2}$ = $\sqrt{3.5MHz \times 4.0MHz}$
= 3.741 MHz (geometric centric frequency)

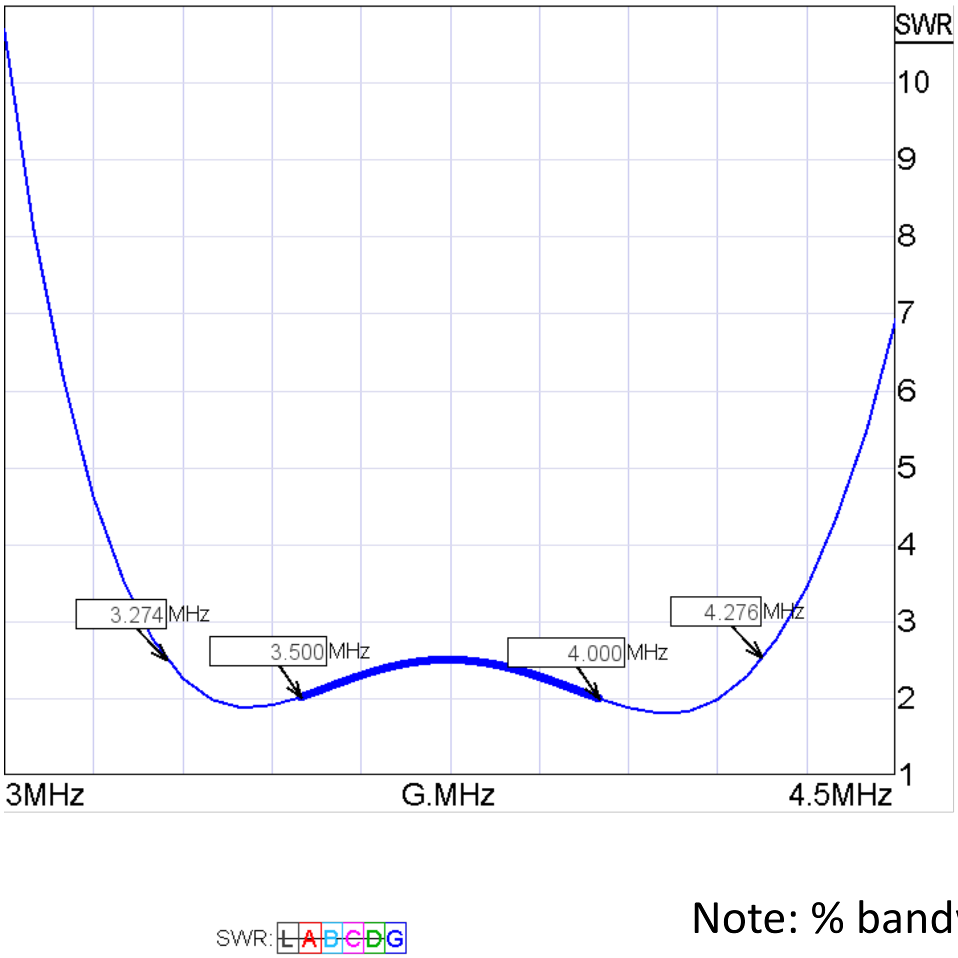
$$Q_{bw} = \frac{3.741}{4.000 - 3.500} = 7.482$$

$$\frac{\omega_2}{\omega_0} = \frac{1+\sqrt{(2\times 7.482)^2+1}}{2\times 7.482} = 1.069$$

new passband $\omega_1 = 3.500/1.069 = 3.274\ MHz$
$\omega_2 = 4.00 \times 1.069 = 4.276\ MHz$

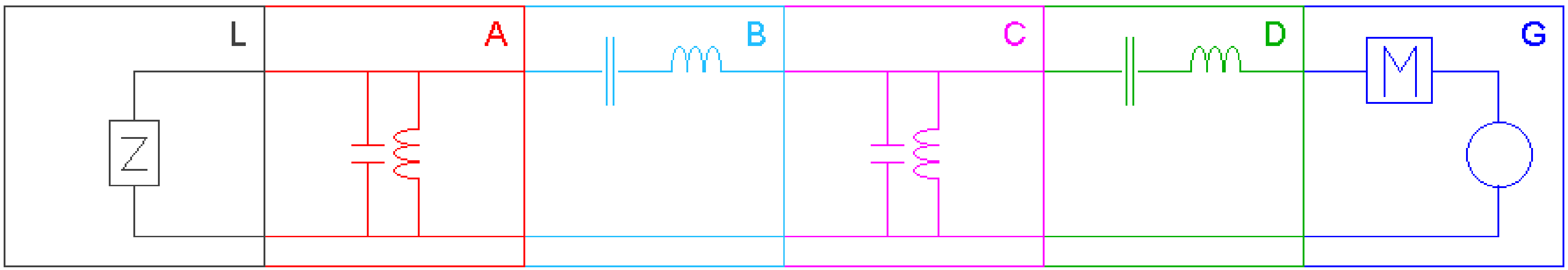
80 meter ½ λ Inverted V Wire on 80 meters using LPS4 Circuit Topology Increased to Optimum Flat Passband

ΔP_{load} = 0.082 dB



Note: % bandwidth increased
From 13.4% to 26.8%, i.e. (x2)

80 meter ½ λ Inverted V Wire on 80 meters using BPP4 Circuit Topology

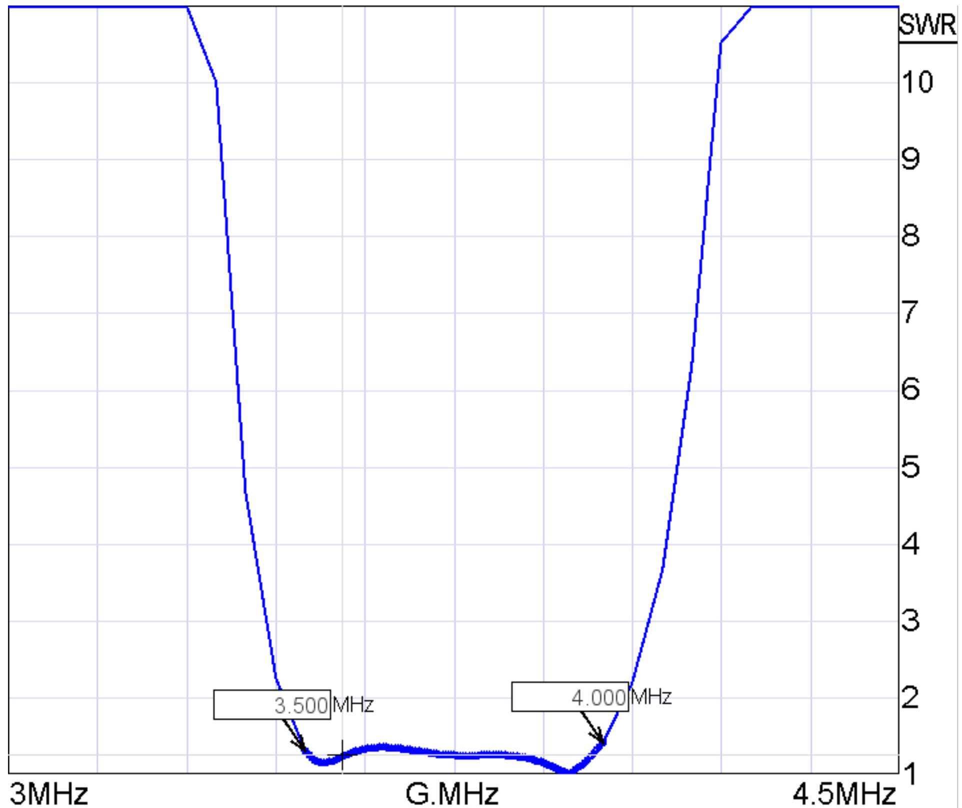


L	A	B	C	D	G
R = 80.688	R = 4.8457	R = 4.934	R = 38.71	R = 40.27	SWR = 1.25
X = -5.6469	**X = 18.988**	**X = 13.056**	**X = -4.9624**	**X = 2.4139**	**Γ = 0.111∠164.5**
←dBW -0.3645	**←dBW -0.265**	**←dBW -0.1866**	**←dBW -0.1715**	**←dBW ~0**	
V,A=8.635,0.1068	V,A=8.635,0.4344	V,A=2.614,0.4406	**V,A=6.15,0.4322**	V,A=1.188,0.1576	

L		A		B		C		D		G	
80.69	ohms	263.3p	F	1979.5p	F	3391.47p	F	153.3p	F	3.75	MHz
-5.647	johms	**750.99n**	**H**	**658.22n**	**H**	**4.40674u**	**H**	**12.063u**	**H**	**50**	**Zo**
80mVWide.s1p	**file**	**11.318**	**MHz**	**4.4092**	**MHz**	**1.3019**	**MHz**	**3.701**	**MHz**	**xMtch**	**V**
		200	**Ql**	**200**	**Ql**	**200**	**Ql**	**200**	**Ql**	**0**	**a**
		2K	**Qc**	**2K**	**Qc**	**2K**	**Qc**	**2K**	**Qc**	**0**	**b**
		3.75	@MHz	**3.75**	@MHz	**3.75**	@MHz	**3.75**	@MHz	**0**	**c**
										0	**d**
										Plots	**Plt**

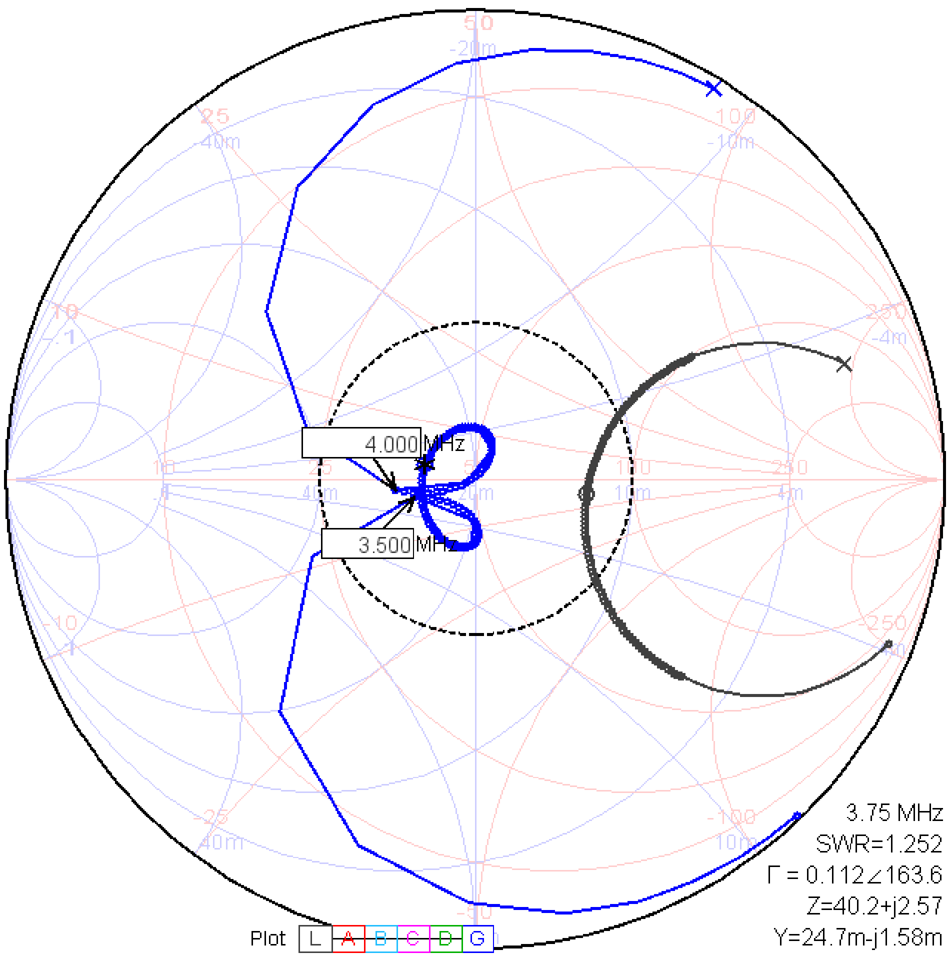
80 meter ½ λ Inverted V Wire on 80 meters using BPP4 Circuit Topology VSWR

ΔP_{load} = 0.207 dB

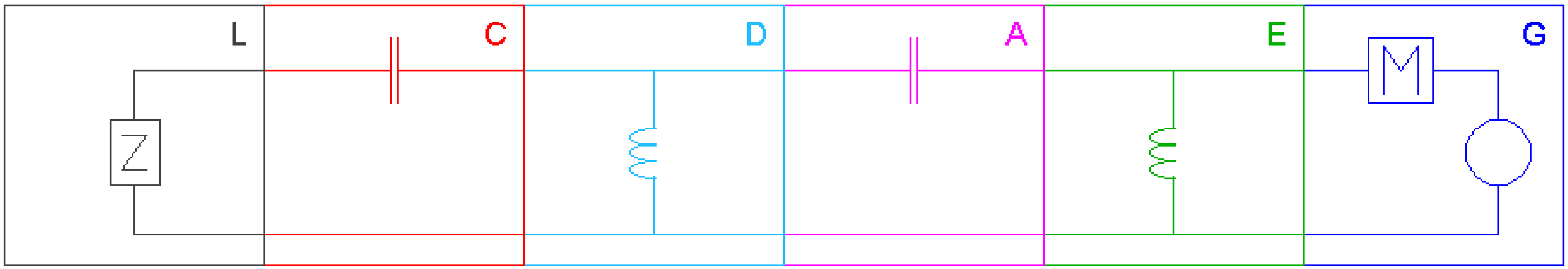


SWR: L A B C D G

80 meter ½ λ Inverted V Wire on 80 meters using BPP4 Circuit Topology Smith Chart

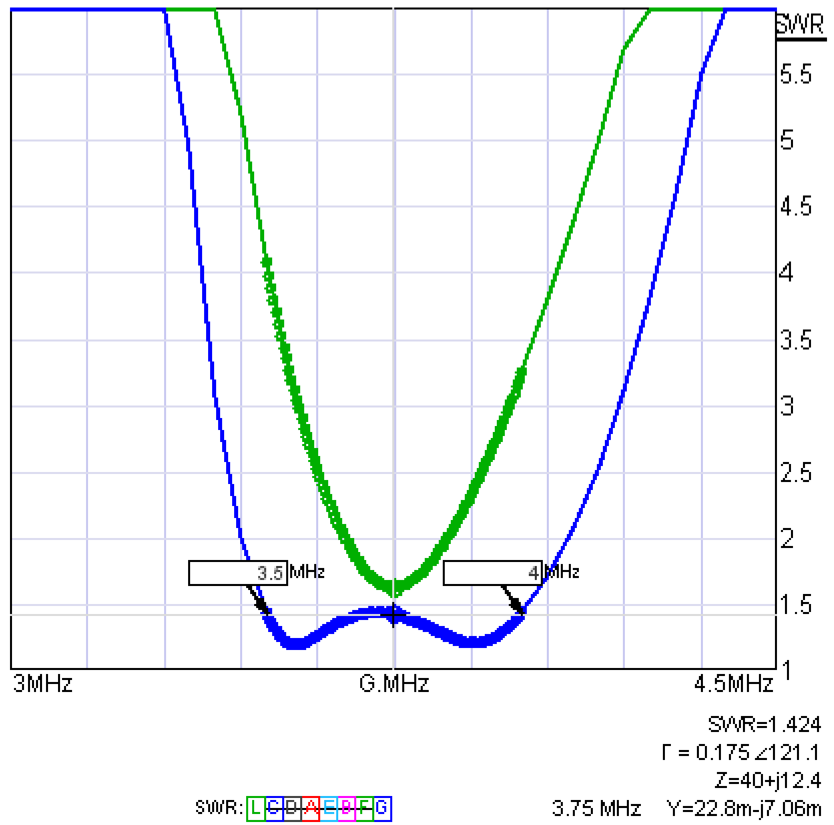


80 meter ½ λ Inverted V Wire on 80 meters using HPS4 Circuit Topology

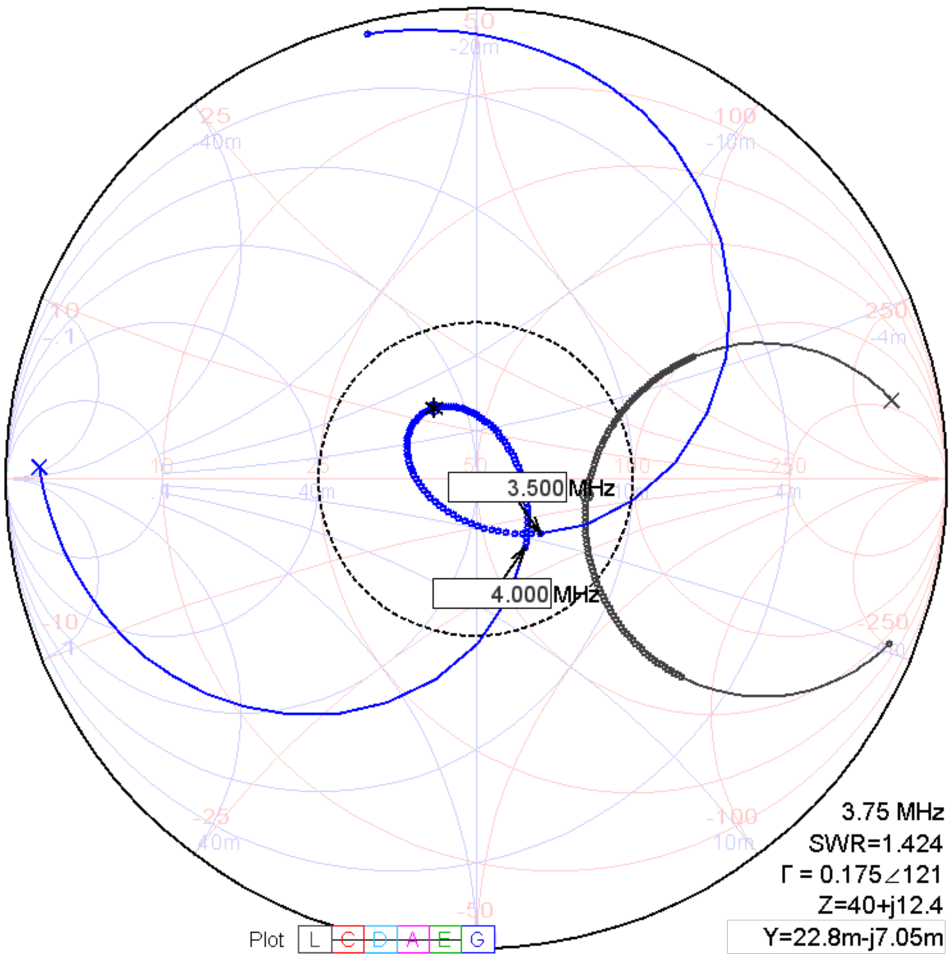


R = 80.688	R = 80.7	R = 12.91	R = 12.936	R = 40.193	SWR = 1.424
X = -5.6469	X = -29.955	X = 31.655	X = -20.217	X = 12.56	Γ = 0.175∠120.1
←dBW -0.1116	←dBW -0.1109	←dBW -49.31m	←dBW -40.6m	←dBW ~0	
V,A=8.89,0.1099	V,A=2.672,0.1099	V,A=9.461,0.2945	V,A=14.35,0.2767	V,A=6.642,0.2802	
80.69 ohms	1746p F	1363.4n H	818.2p F	1006.22n H	3.75 MHz
-5.647 johms	2K Q	200 Q	2K Q	200 Q	50 Zo
80mVWide.s1p file	3.75 @MHz	3.75 @MHz	3.75 @MHz	3.75 @MHz	xMtch V
					0 a
					0 b
					0 c
					0 d
					Plots Plt

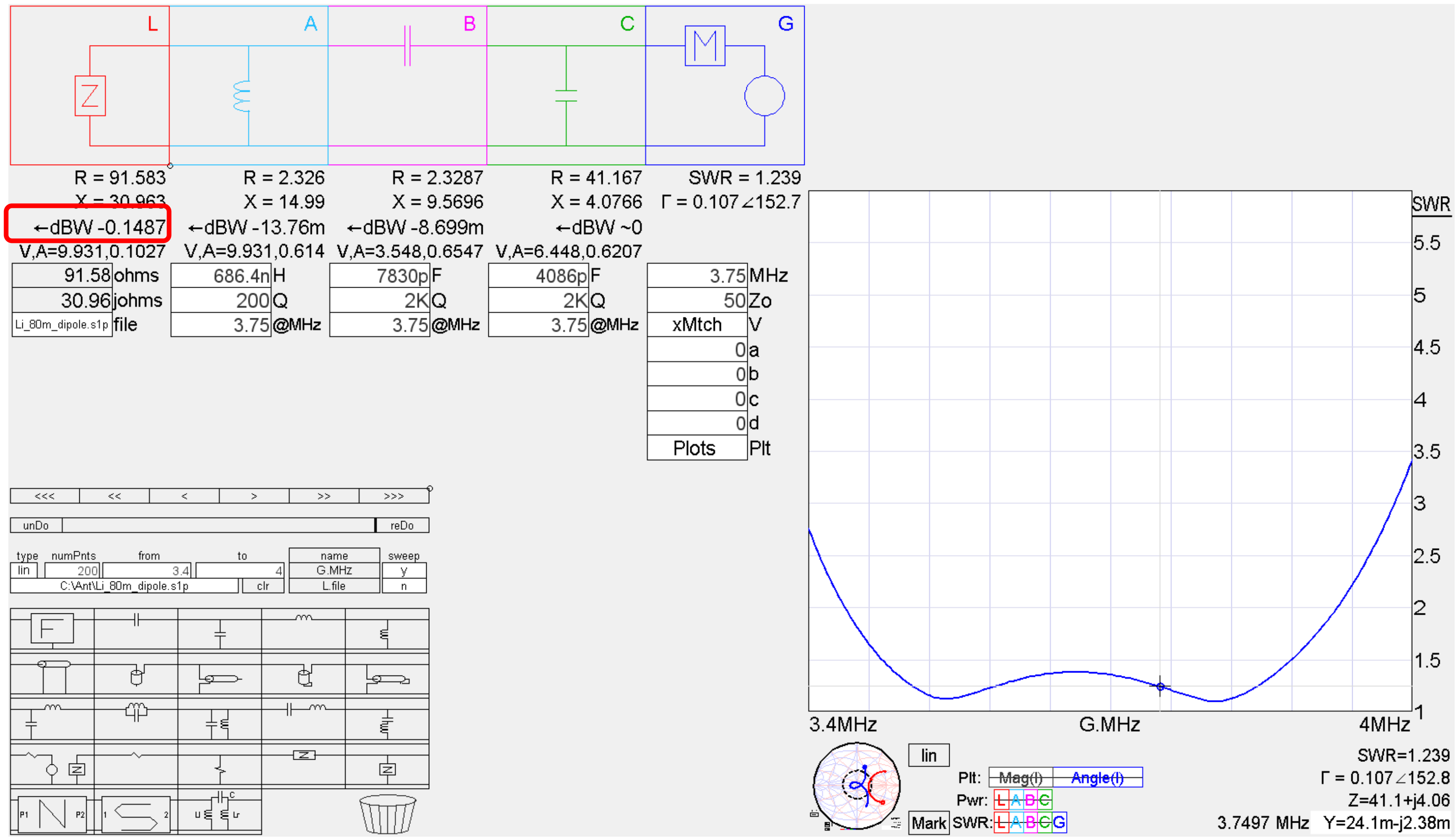
80 meter ½ λ Inverted V Wire on 80 meters using HPS4 Circuit Topology Antenna VSWR Before and After Equalizer VSWR



80 meter ½ λ Inverted V Wire on 80 meters using HPS4 Circuit Topology Smith Chart

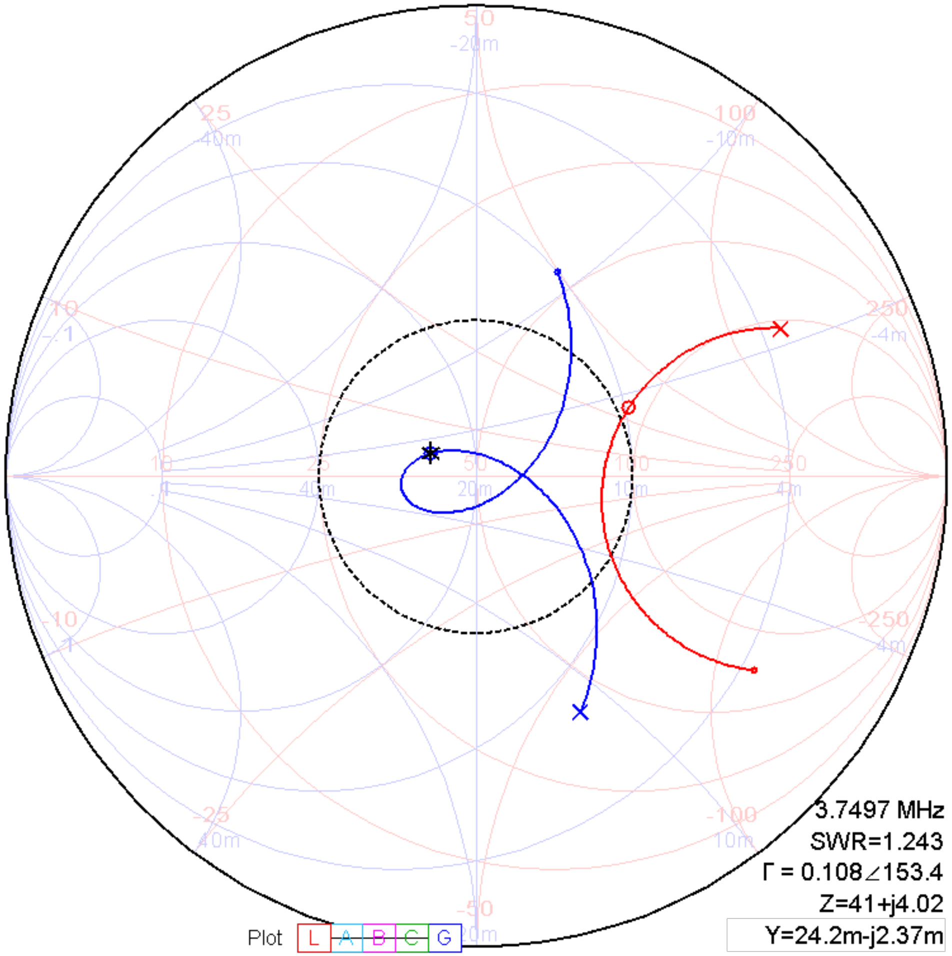


Li's Genetic Algorithm Solution (required 6 hours computer time)



Li's Genetic Algorithm Solution

Smith Chart

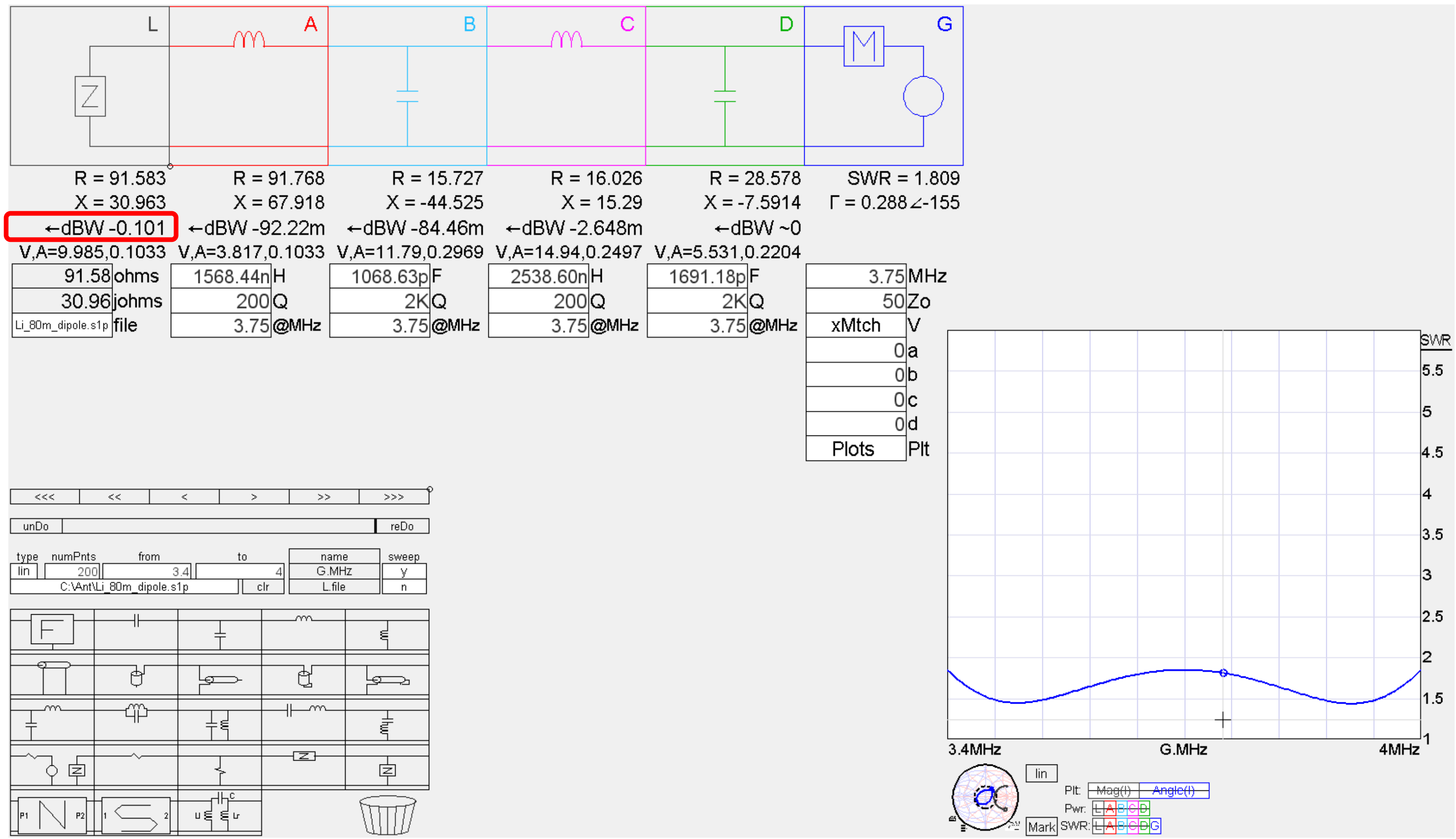


ZNET Solution for Li’s Dipole

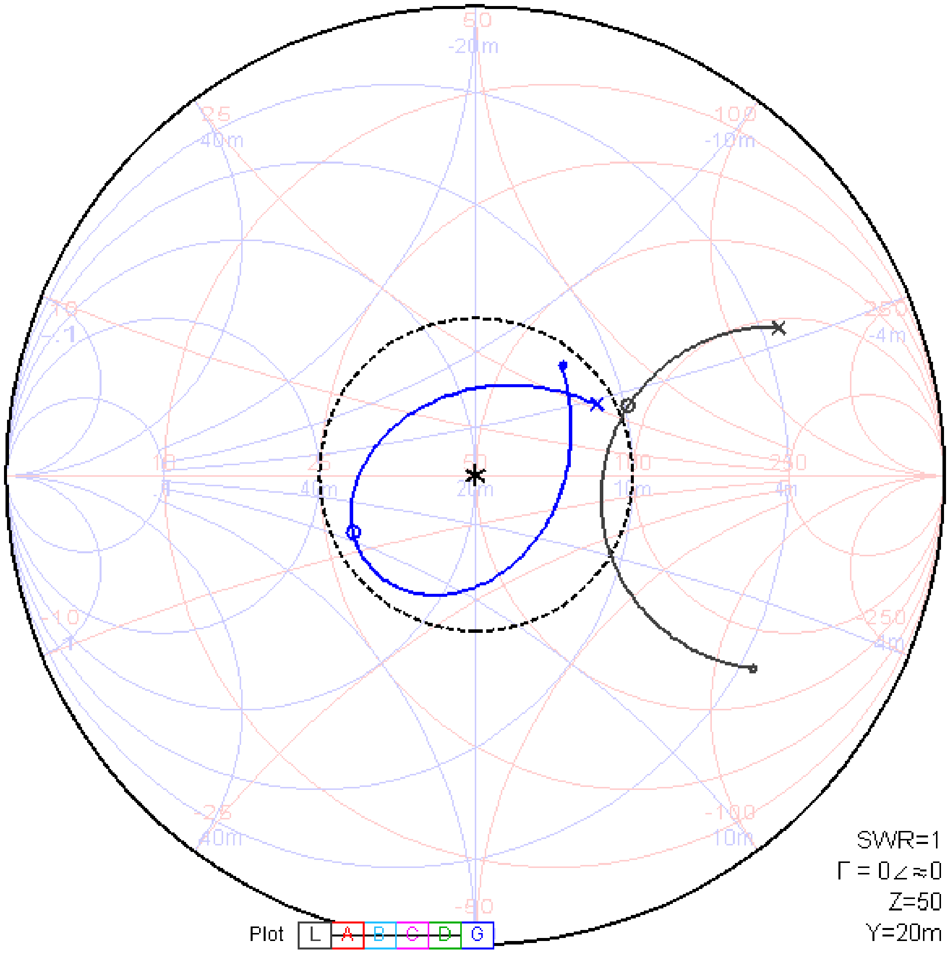
octave-3.6.4

```
Optimization in progress.....


 Optimization completed!

 Number of function evaluations = 3800

 Number of objective iterations = 95

 Optimization computation time =   2.65 seconds

 Convergence = 0
 The optimizer converged to the tolerance limit!

 TPG Objective Score= 0.614577


      -----------------L3-----------L1---------
       |           |           |             |
       |           |           |             |
     Zsrc         C4          C2           Zload
       |           |           |             |
       |           |           |             |
      -----------------------------------------



 RF Load Power = 100.00 Watts

 L1  =  1568.44 nH        1.07 Amps       38.81 Volts

 C2  =  1068.63 pF        2.51 Amps      101.56 Volts

 L3  =  2538.60 nH        2.33 Amps      136.87 Volts

 C4  =  1691.18 pF        2.46 Amps       62.75 Volts


Antenna Q = 9.33

Qbw = 6.15

Fano decrement = 0.66

Estimated Fano bandwidth = 1.131 MHz

Fano VSWR minimum = 1.29

minimum matched VSWR = 1.45

maximum matched VSWR = 1.85
```

ZNET Solution for Li's Dipole using LPS4 Circuit Topology



ZNET Solution for Li's Dipole Using LPS4 Circuit Topology Smith Chart

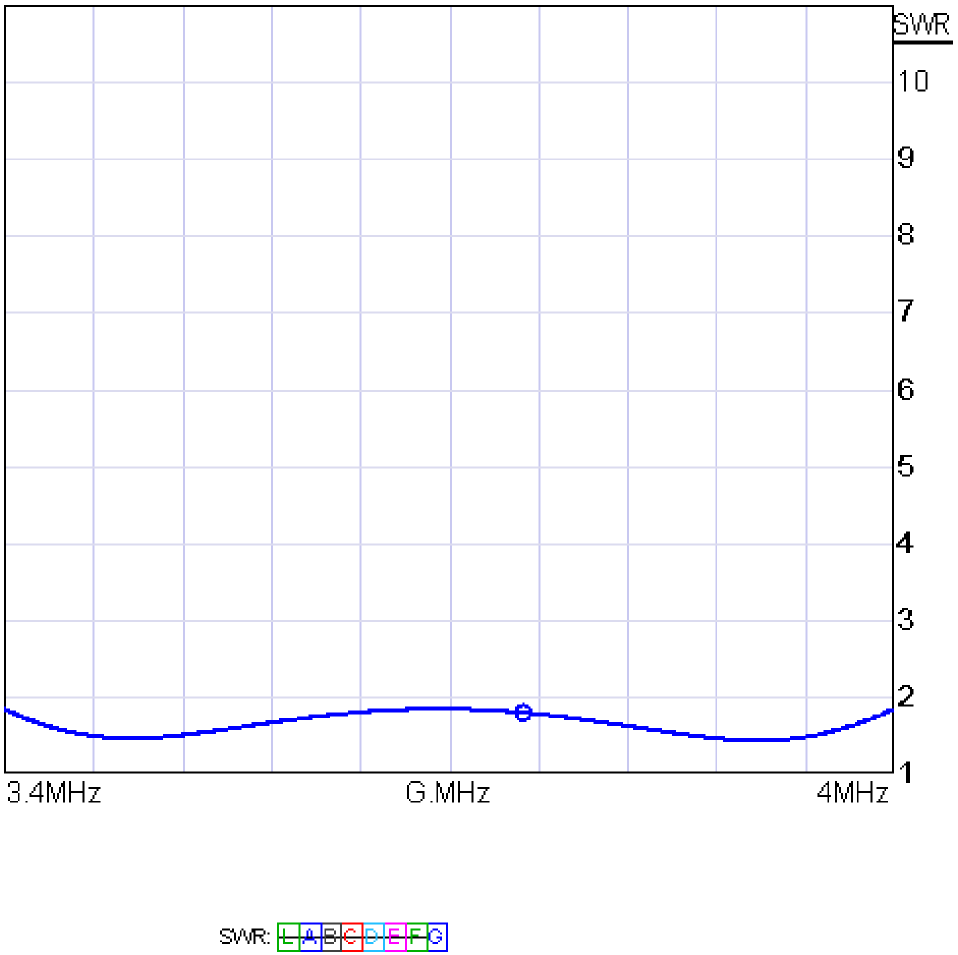


ZNET Solution to Li's Dipole using LPS6 Circuit Topology

octave-3.6.4

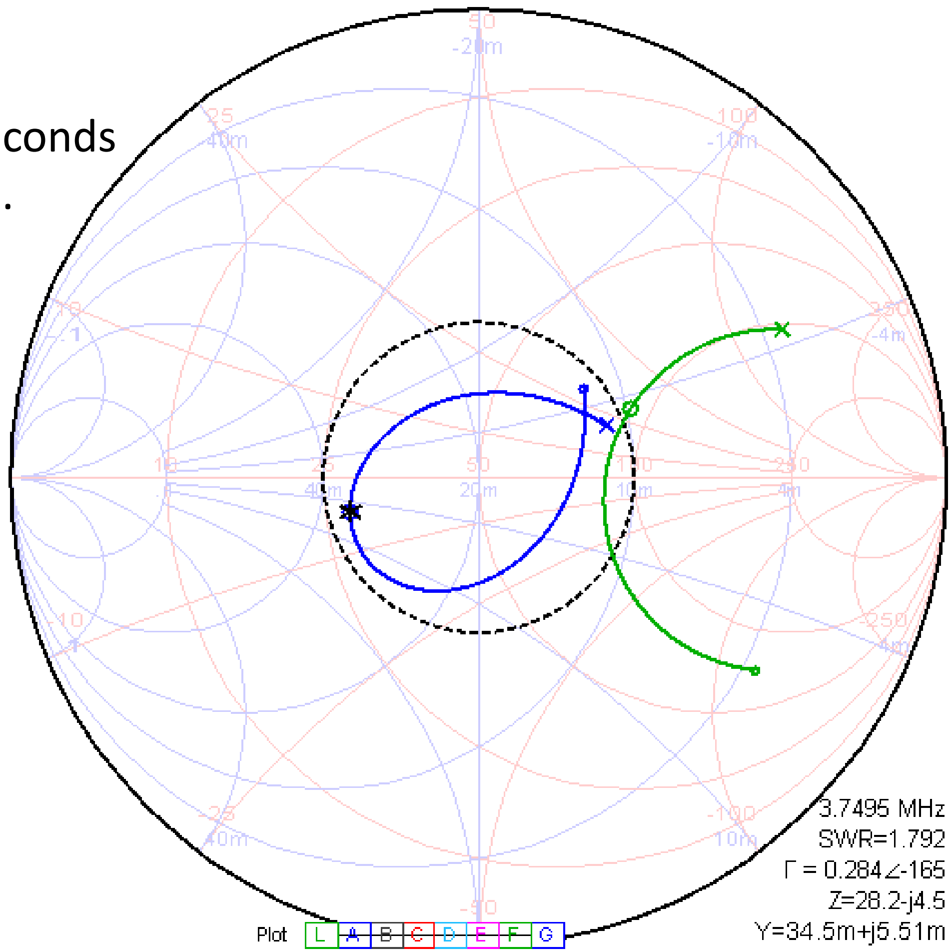
```
Optimization completed!

Number of function evaluations = 16440
Number of objective iterations = 274
Optimization computation time =  11.95 seconds
Convergence = 0
The optimizer converged to the tolerance limit!

TPG Objective Score= 0.608493


  ------------------L5-------------L3-------------L1-----
  |           |             |              |            |
Zsrc         C6            C4             C2          Zload
  |           |             |              |            |
  -------------------------------------------------------


RF Load Power = 100.00 Watts

L1 =  1247.40 nH        1.07 Amps       30.86 Volts
C2 =   986.81 pF        2.26 Amps       98.76 Volts
L3 =  1556.41 nH        2.18 Amps       78.47 Volts
C4 =   617.53 pF        0.68 Amps       47.32 Volts
L5 =  1135.62 nH        2.40 Amps       63.08 Volts
C6 =  1721.23 pF        2.37 Amps       59.52 Volts

Antenna Q = 9.33
Qbw = 6.15
Fano decrement = 0.66
Estimated Fano bandwidth = 1.131 MHz
Fano VSWR minimum = 1.29
minimum matched VSWR = 1.43
maximum matched VSWR = 1.84
```

ZNET Solution to Li's Dipole using LPS6 Circuit Topology

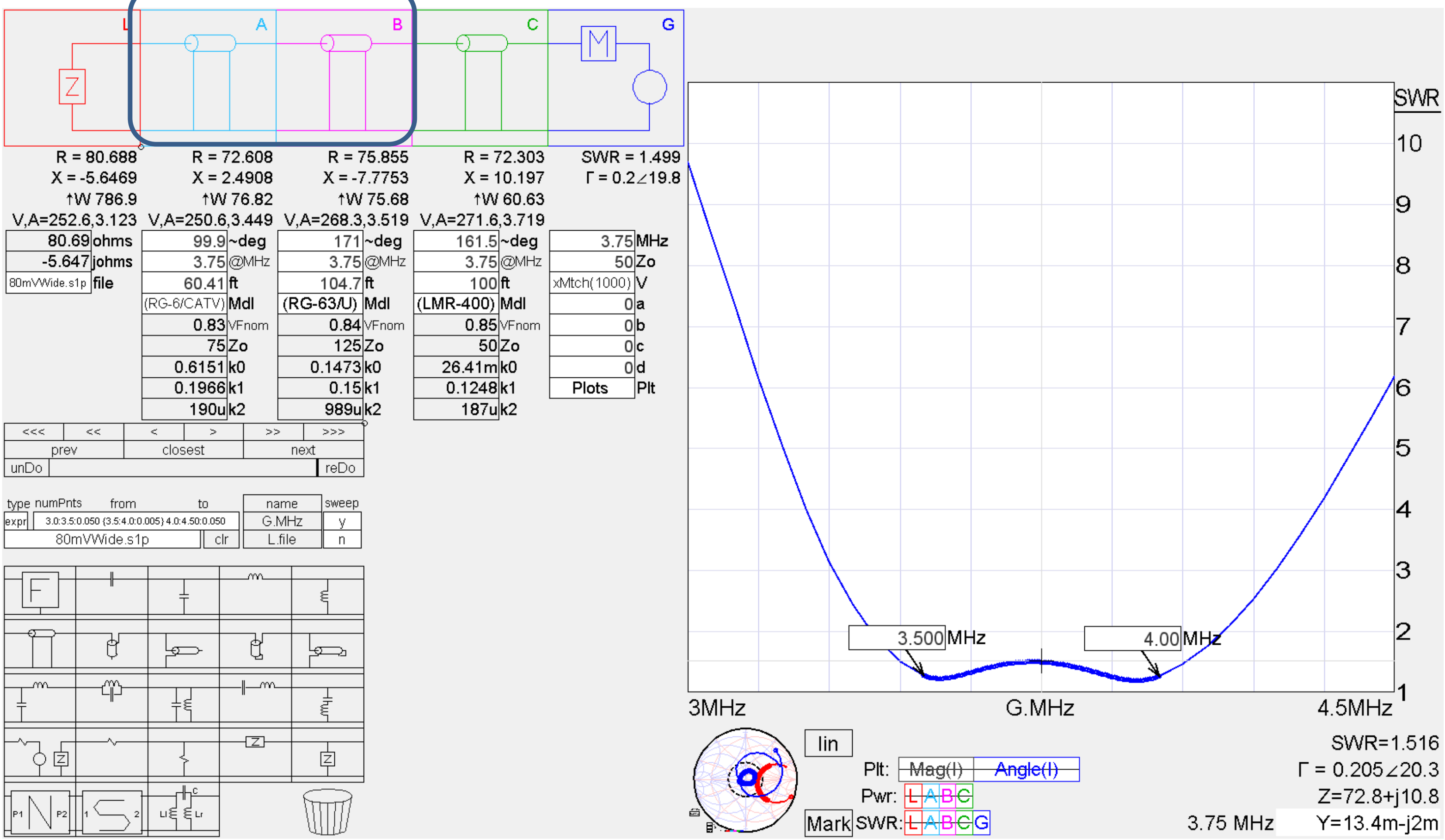


ZNET Solution to Li's Dipole using LPS6 Circuit Topology Smith Chart

Required 11.95 seconds computation time.

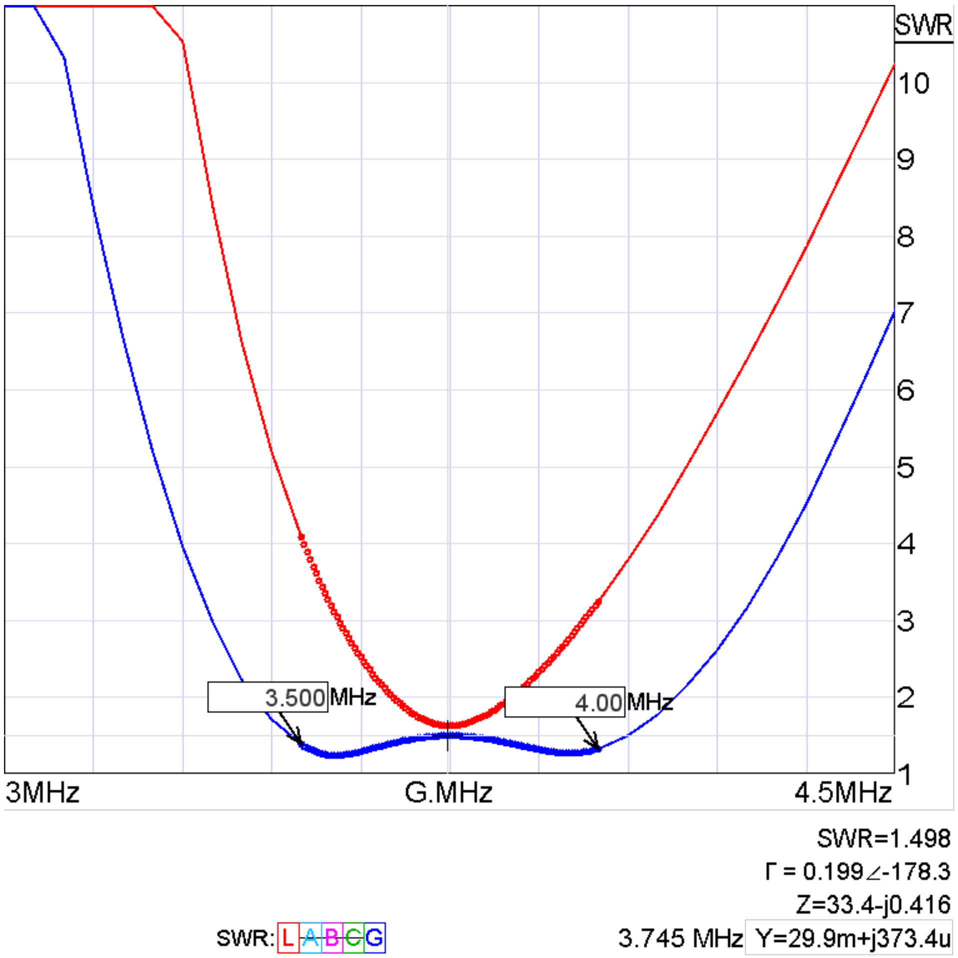


Cascade Serial Transmission Line (CASTL) Impedance Match



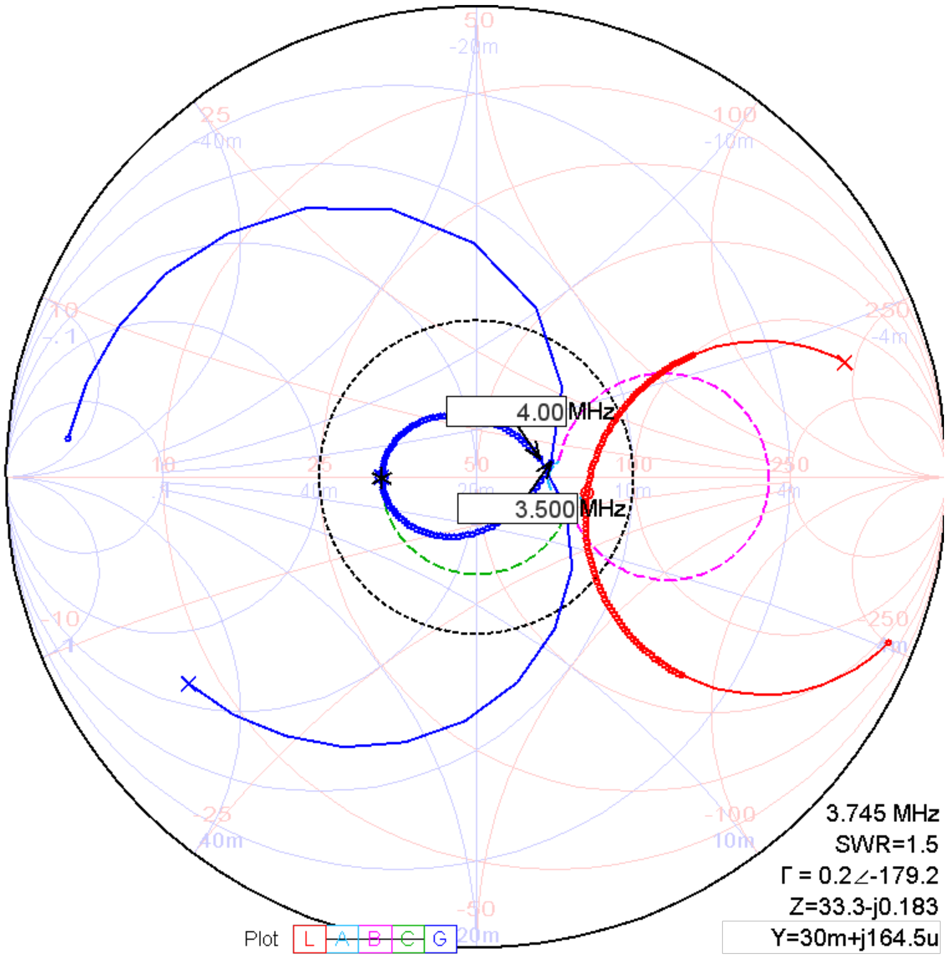
See L.N. Dworsky, Modern Transmission Line Theory and Applications, Wiley, NY (1979).

80 meter ½ λ Inverted V Wire on 80 meters using CASTL Circuit Topology VSWR



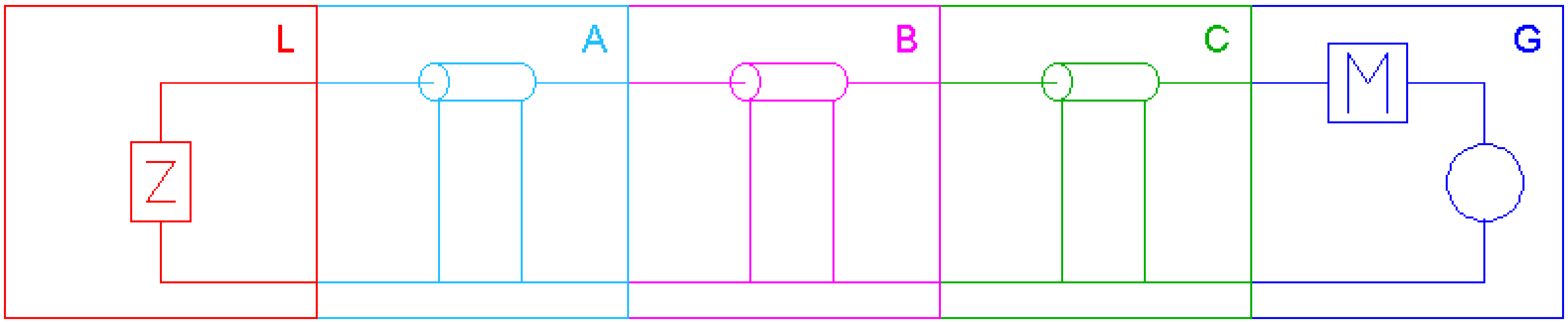
CASTL circuit

80 meter ½ λ Inverted V Wire on 80 meters using CASTL Circuit Topology Smith Chart



Note the path.

80 meter ½ λ Inverted V Wire on 80 meters using CASTL Circuit Topology 1000 Watt Power Handling

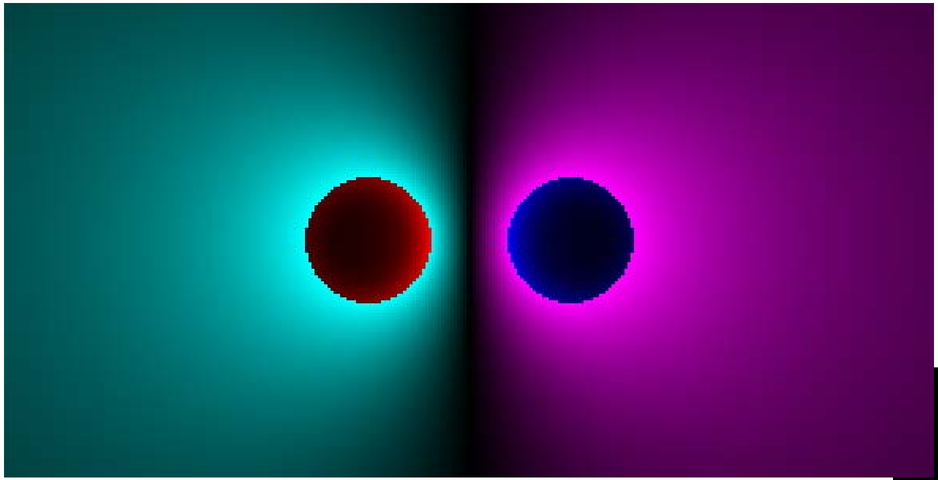


L	A	B	C	G
R = 80.688	R = 72.608	R = 75.855	R = 72.303	SWR = 1.499
X = -5.6469	X = 2.4908	X = -7.7753	X = 10.197	Γ = 0.2∠19.8
↑W 786.9	↑W 76.82	↑W 75.68	↑W 60.63	
V,A=252.6,3.123	V,A=250.6,3.449	V,A=268.3,3.519	V,A=271.6,3.719	

80.69	ohms	99.9	~deg	171	~deg	161.5	~deg	3.75	MHz
-5.647	johms	3.75	@MHz	3.75	@MHz	3.75	@MHz	50	Zo
80mVWide.s1p	file	60.41	ft	104.7	ft	100	ft	xMtch(1000)	V
		(RG-6/CATV)	Mdl	(RG-63/U)	Mdl	(LMR-400)	Mdl	0	a
		0.83	VFnom	0.84	VFnom	0.85	VFnom	0	b
		75	Zo	125	Zo	50	Zo	0	c
		0.6151	k0	0.1473	k0	26.41m	k0	0	d
		0.1966	k1	0.15	k1	0.1248	k1	Plots	Plt
		190u	k2	989u	k2	187u	k2		

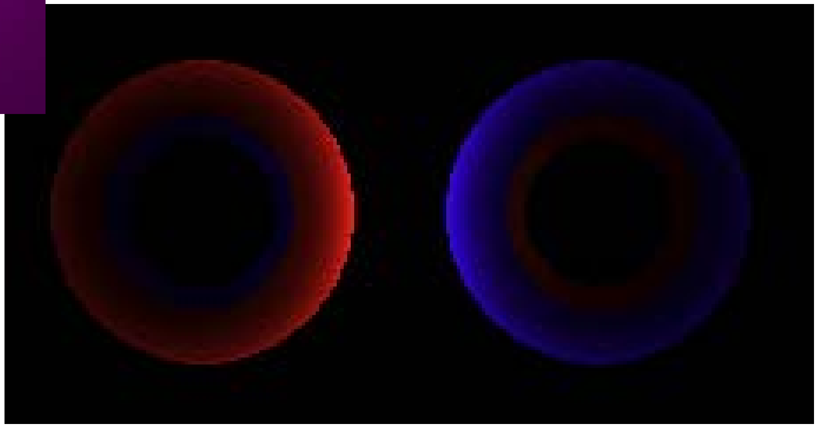
Homebrew Parallel Wire Transmission Lines

Parallel Wire Transmission Line



ATLC2 computed these images. ATLC2 was developed by KQ6QV.
(see URL below.)

Current distribution for closely spaced two conductor transmission lines.



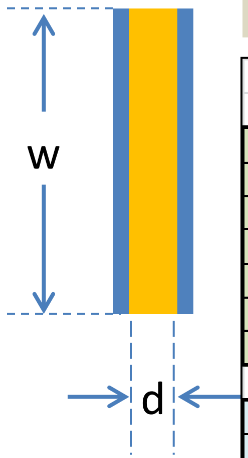
E Field from two-wire transmission line cross-section.

Spreadsheet computes spacing “d” for a required impedance for a given width “wire diameter” and spacing dielectric (e.g. air for lowest loss).

See http://www.hdtvprimer.com/KQ6QV/HomePage.html

Homebrew Parallel Plate Transmission Lines and Stubs

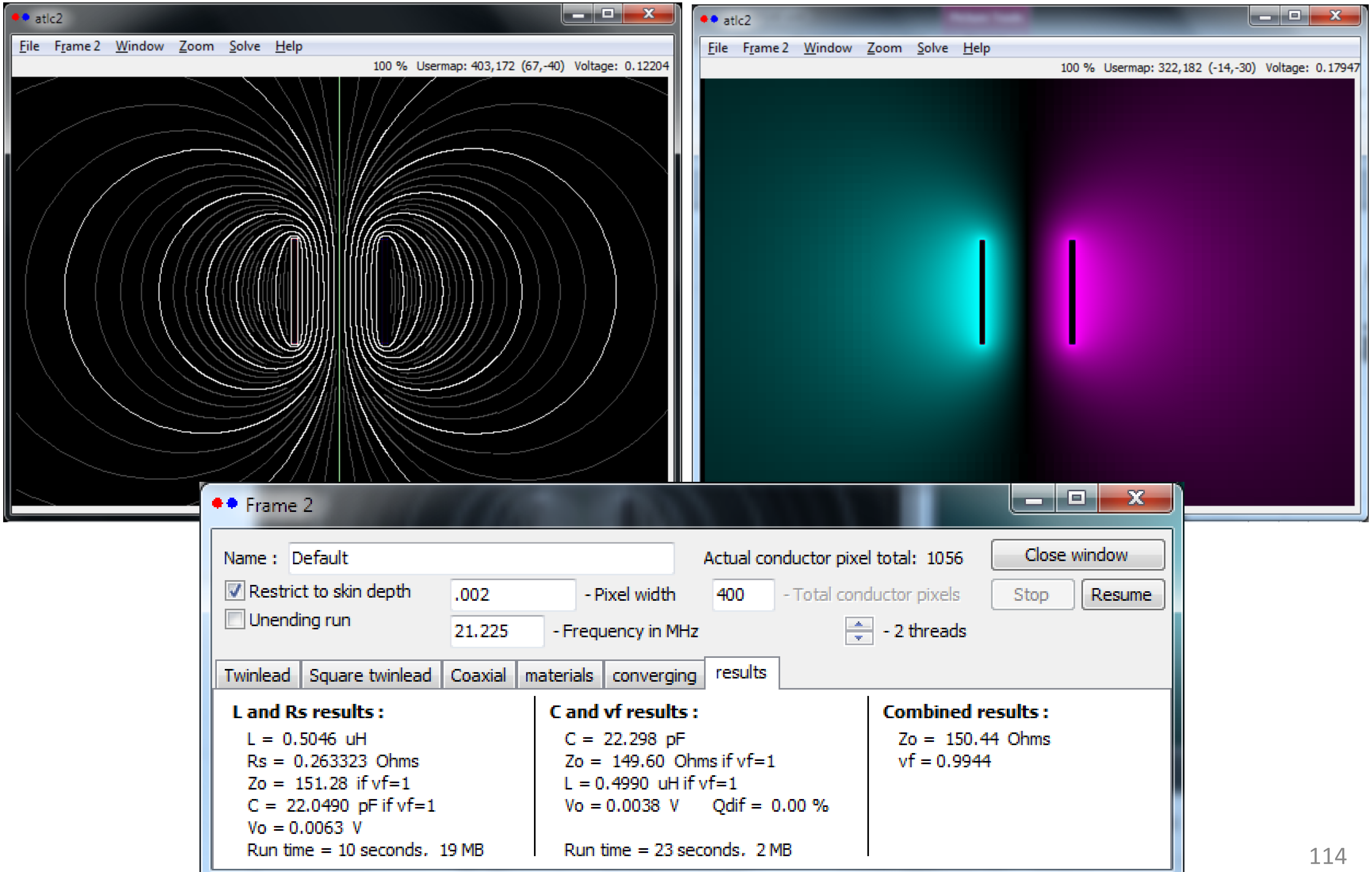
Parallel Plate Transmission Lines and Stubs



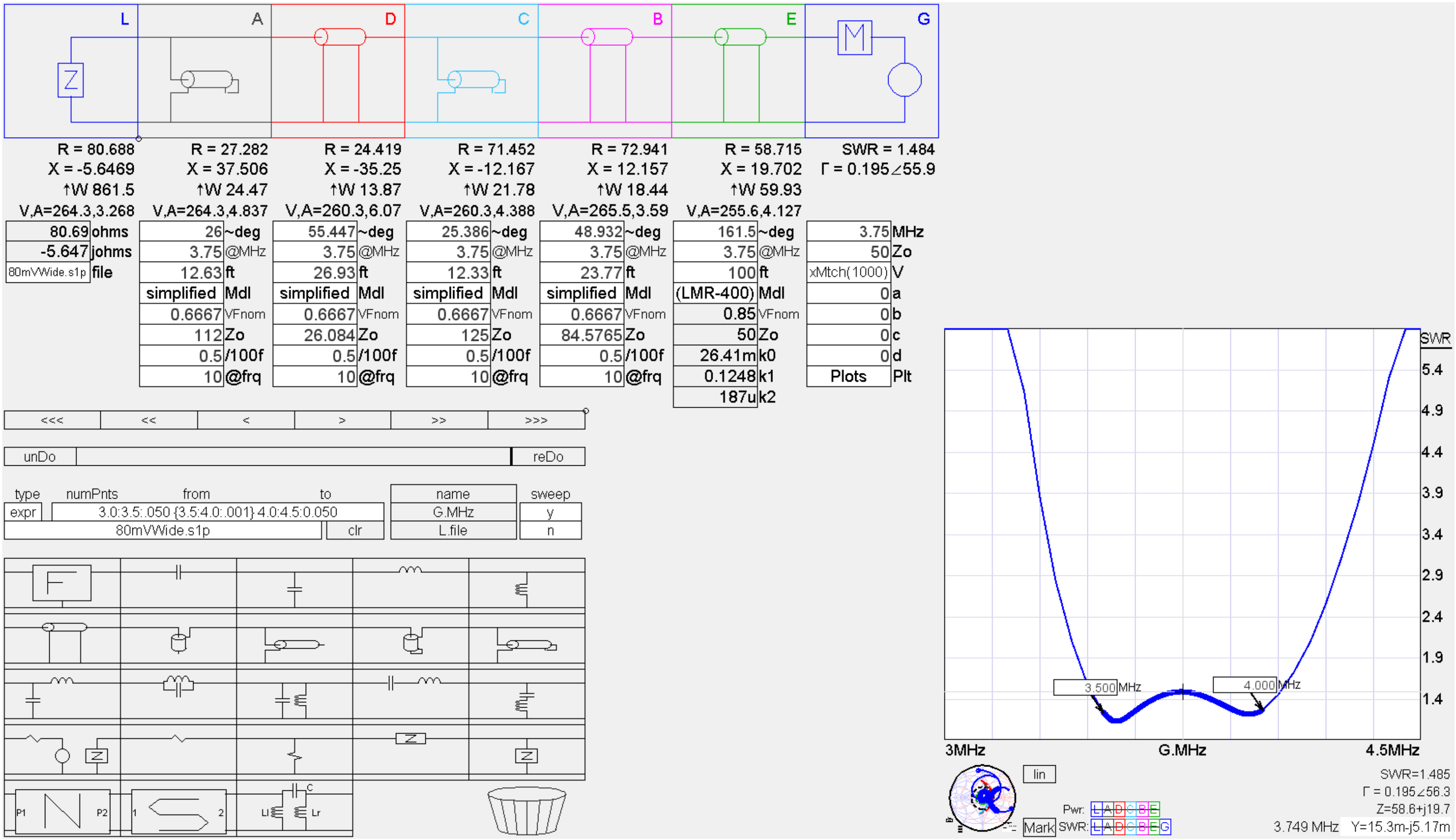
Spreadsheet computes spacing "d" for a required impedance for a given width "w" and spacing dielectric (e.g. air for lowest loss).

Parallel Plate Transmission Line (TEM mode) Optimizer					**WB6YVK**		
			MKS Units	inches			
center frequency =	21.225	MHz	2.12E+07		**Line Impedance**		
Plate Width =	12.7	mm	0.0127	0.500	Zo =	124.999929334706-0.179690404275512i	Ohms
Plate Conductivity =	35400000	S/m	aluminum		Ro =	125.00	Ohms
Spacing =	6.386248872	mm	0.006386249	0.251	Xo =	-0.18	Ohms
Dielectric constant of spacer =	2.3		PTFE				
magnetic constant (u) =	1.25664E-06	H/m					
electric constant (e) =	8.84194E-12	F/m			velocity =	1.9781E+08	m/sec
					vel factor =	0.659	
RLGC Results						Shorted stub as an inductor	
R' =	2.42E-01	Ohms/m			Q stub =	458.7	
L' =	6.31905E-07	H/m					
G' =	1.00E-10	mhos/m					
C' =	4.04E-11	F/m					
Ro =	124.9999293	Ohms					
Xo =	-0.1796904	Ohms					
Zo magnitude =	125.0000585	Ohms					
alpha' =	9.69E-04						

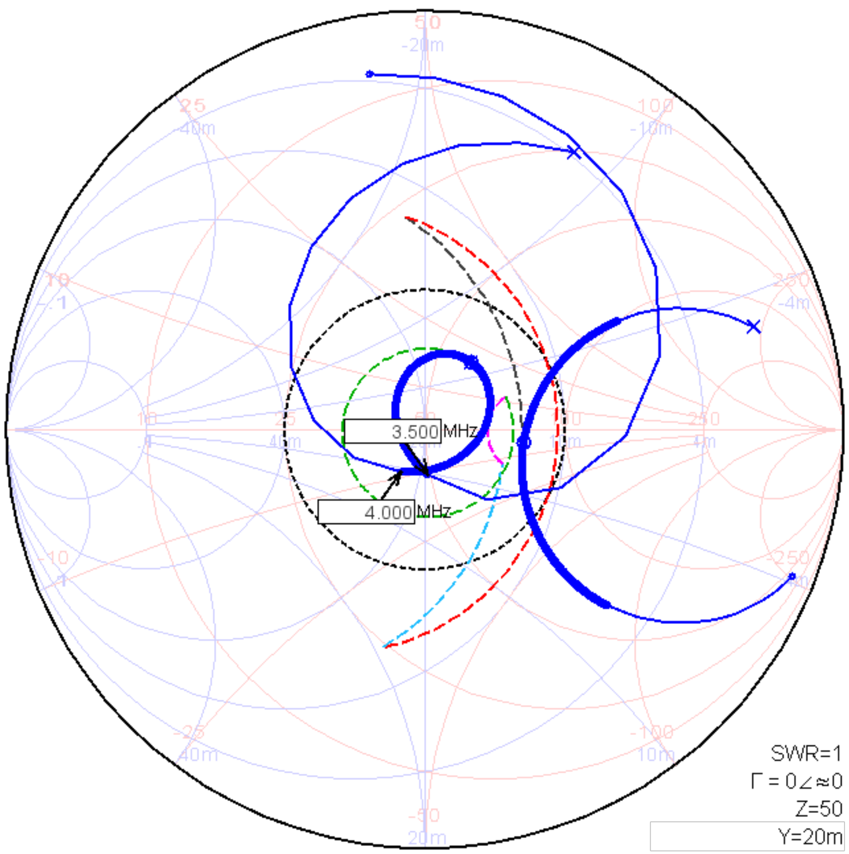
ATLC2 Example: 150 Ohm Parallel Plate Transmission Line

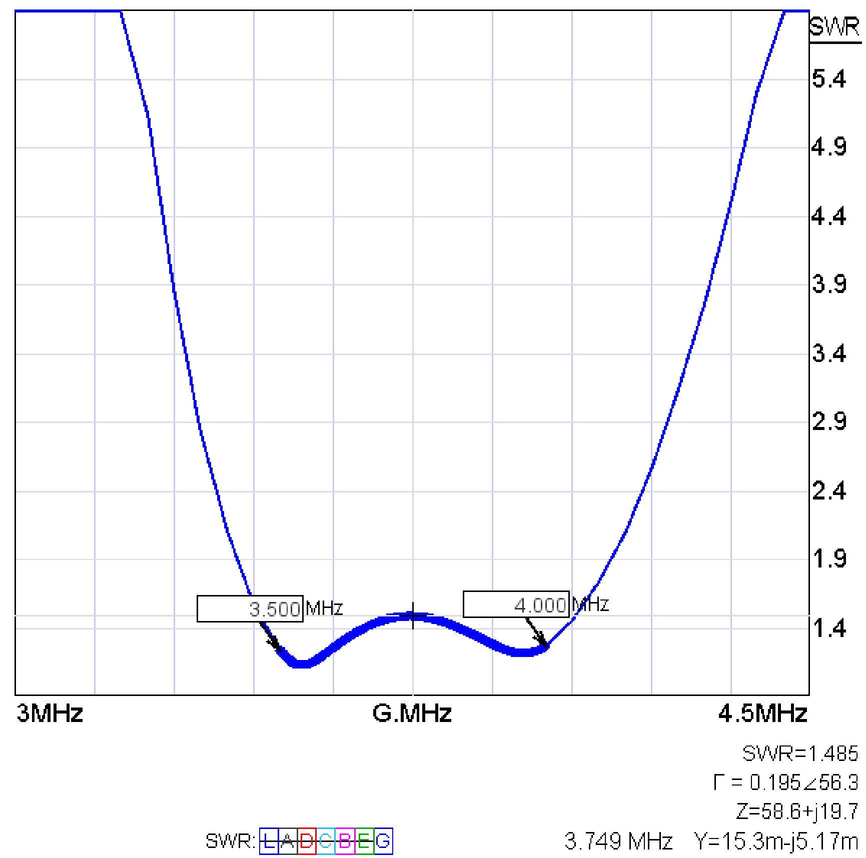


80 meter ½ λ Inverted V Wire on 80 meters shorter CASTL Circuit Topology #4 using non-standard transmission lines and stubs

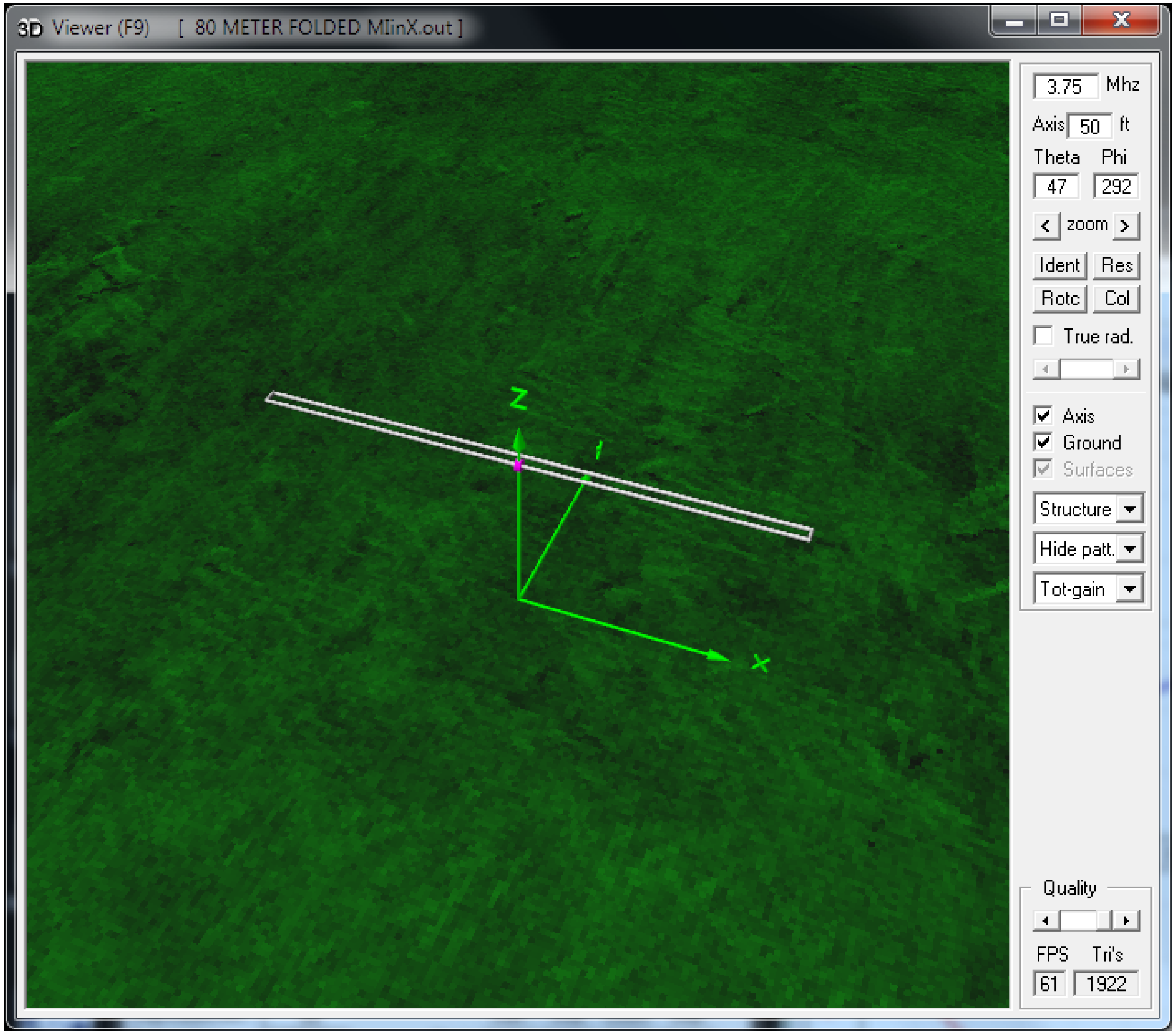


80 meter ½ λ Inverted V Wire on 80 meters shorter CASTL Circuit Topology #4 using non-standard transmission lines and stubs

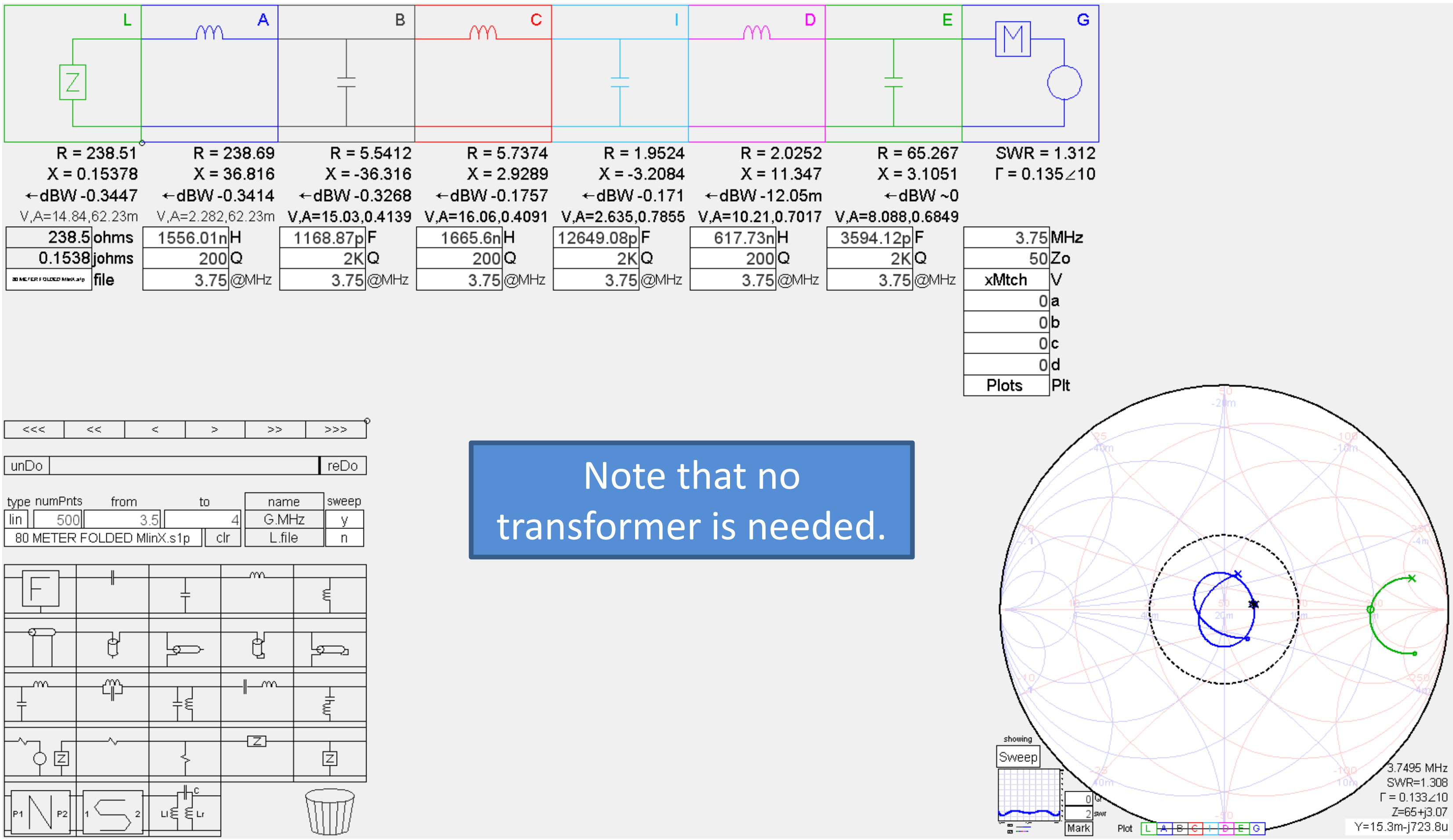




80 meter ½ λ Wire Folded Dipole

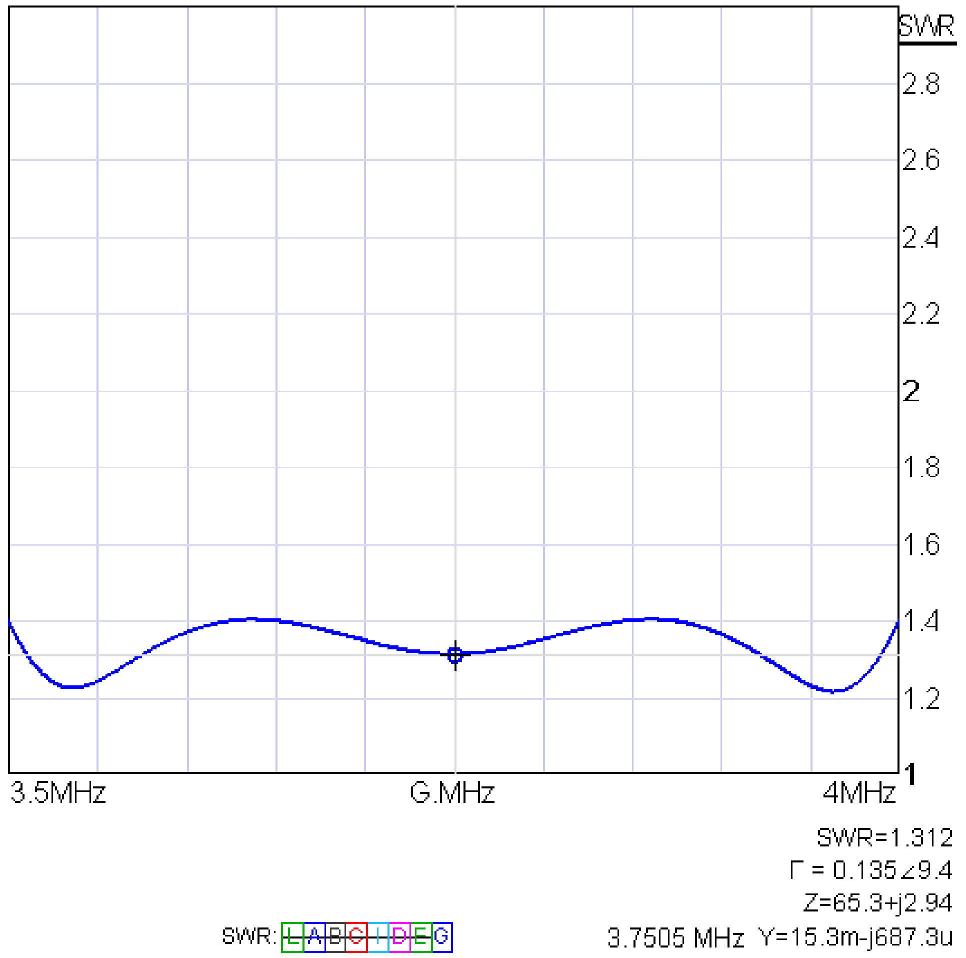


80 meter ½ λ Wire Folded Dipole using LPS6 Circuit Topology

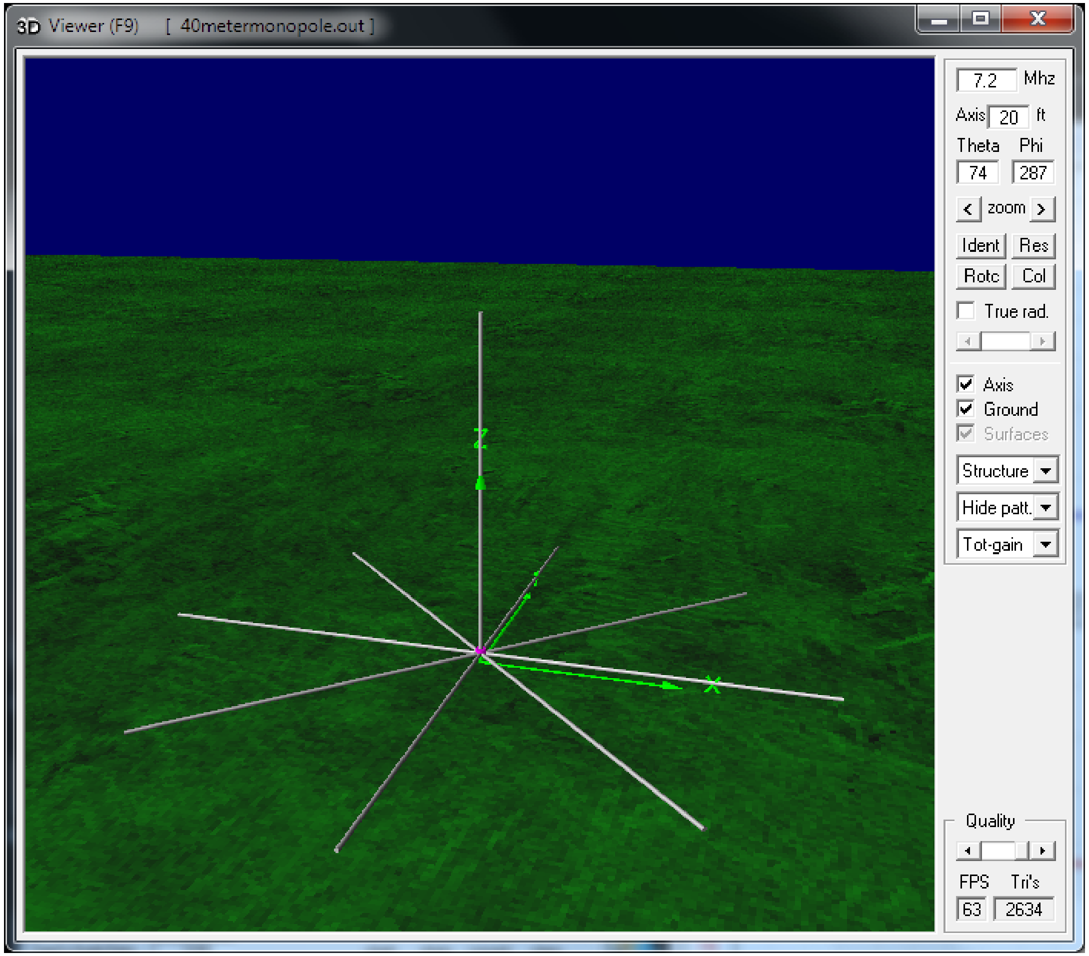


Note that no transformer is needed.

80 meter ½ λ Wire Folded Dipole using LPS6 Circuit Topology



40 meter ¼ λ Monopole

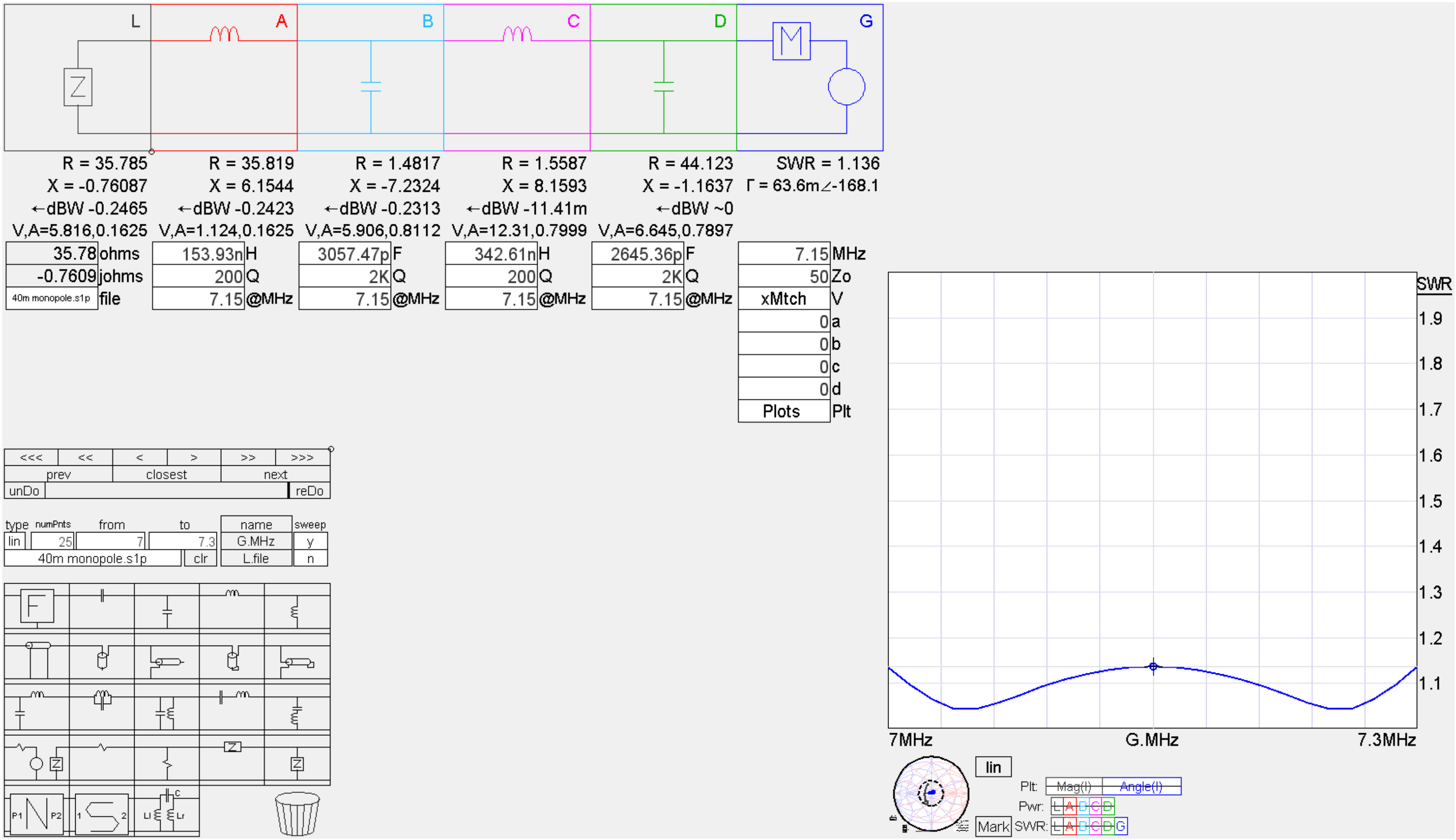


40 meter ¼ λ Monopole using ZNET Solution LPS4 Circuit Topology

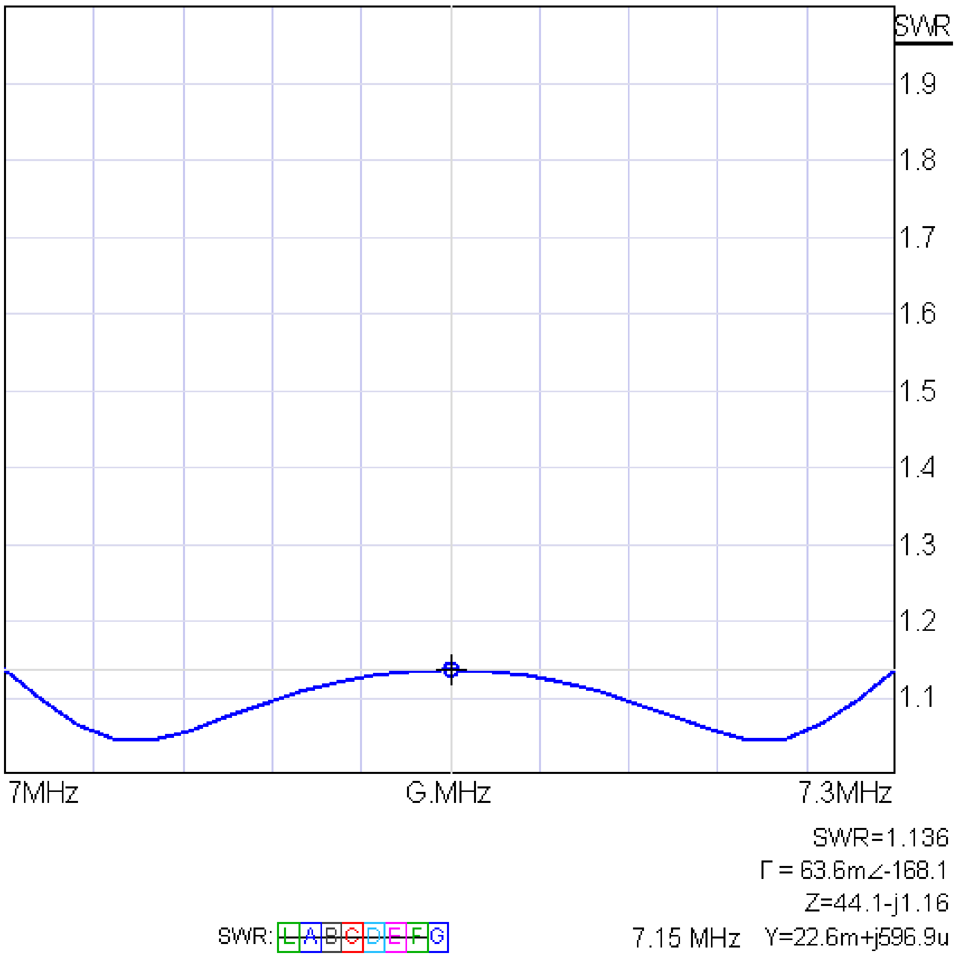
octave-3.6.4

```
 Optimization computation time =   7.32 seconds

 Convergence = 0
 The optimizer converged to the tolerance limit!

 TPG Objective Score= 0.127441


      ------------------L3-----------L1---------
       |             |             |              |
    Zsrc            C4            C2             Zload
       |             |             |              |
      ------------------------------------------


 RF Load Power = 100.00 Watts

 L1 =   153.93 nH        1.67 Amps       11.56 Volts
 C2 =  3057.47 pF        8.38 Amps       60.99 Volts
 L3 =   342.61 nH        8.23 Amps      126.58 Volts
 C4 =  2645.36 pF        8.08 Amps       68.04 Volts


Antenna Q = 13.00
Qbw = 23.83
Fano decrement = 1.83
Estimated Fano bandwidth = 1.573 MHz
Fano VSWR minimum = 1.01
minimum matched VSWR = 1.04
maximum matched VSWR = 1.14

maximum Equalizer Match Loss = 0.01 dB

Capacitor ratio = 1.16
Inductor ratio  = 2.23

center frequency = 7.148 MHz
```

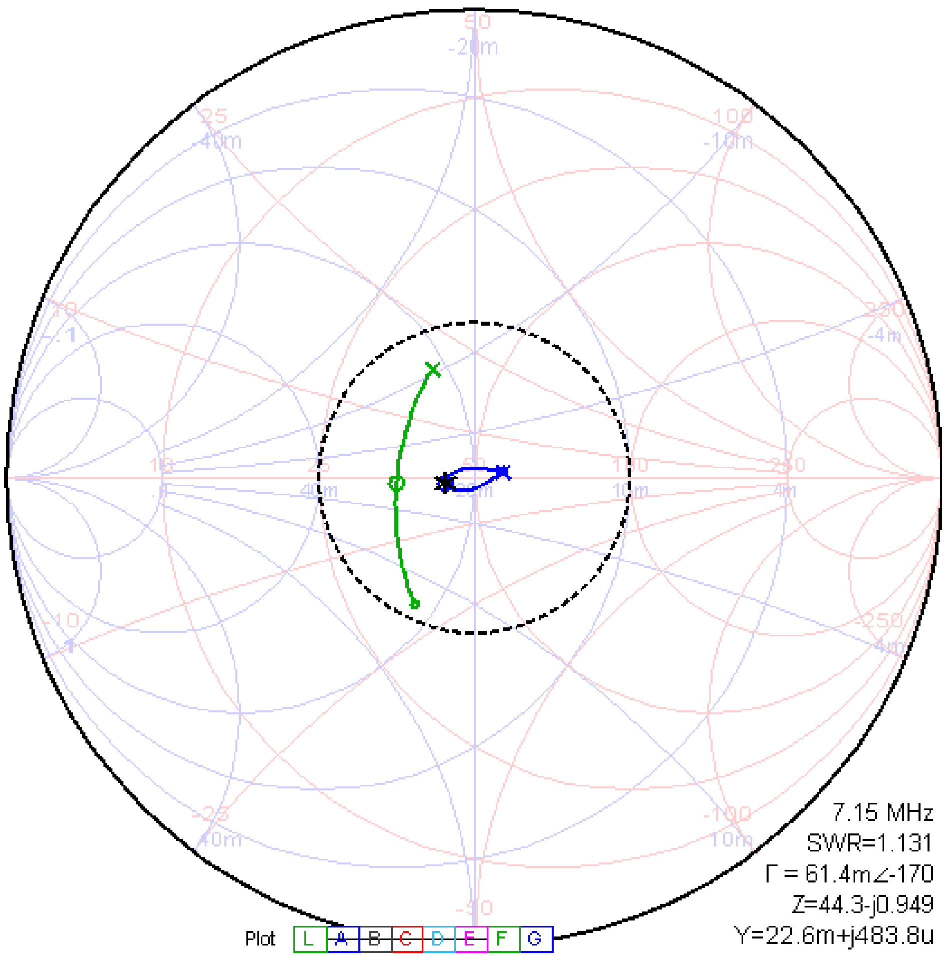
40 meter ¼ λ Monopole using LPS4 Circuit Topology



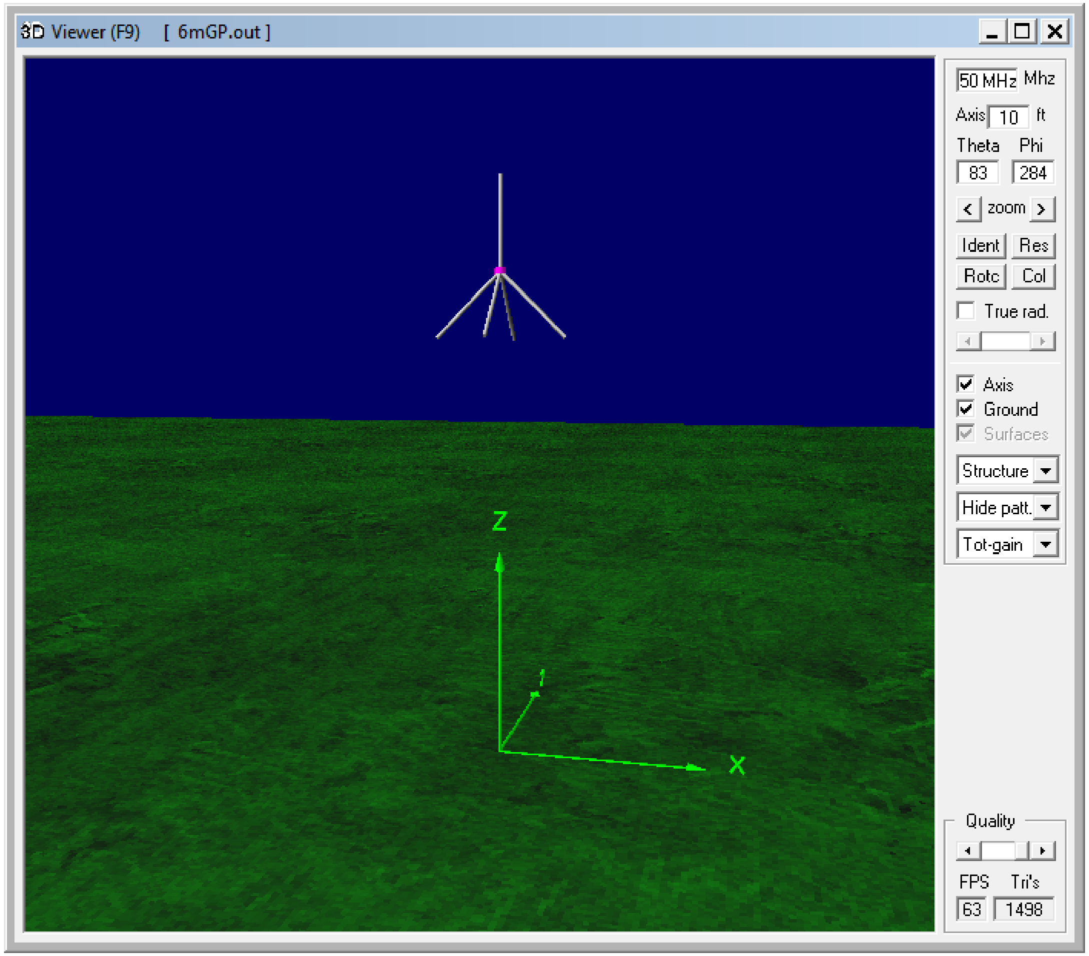
40 meter ¼ λ Monopole using LPS6 Circuit Topology VSWR



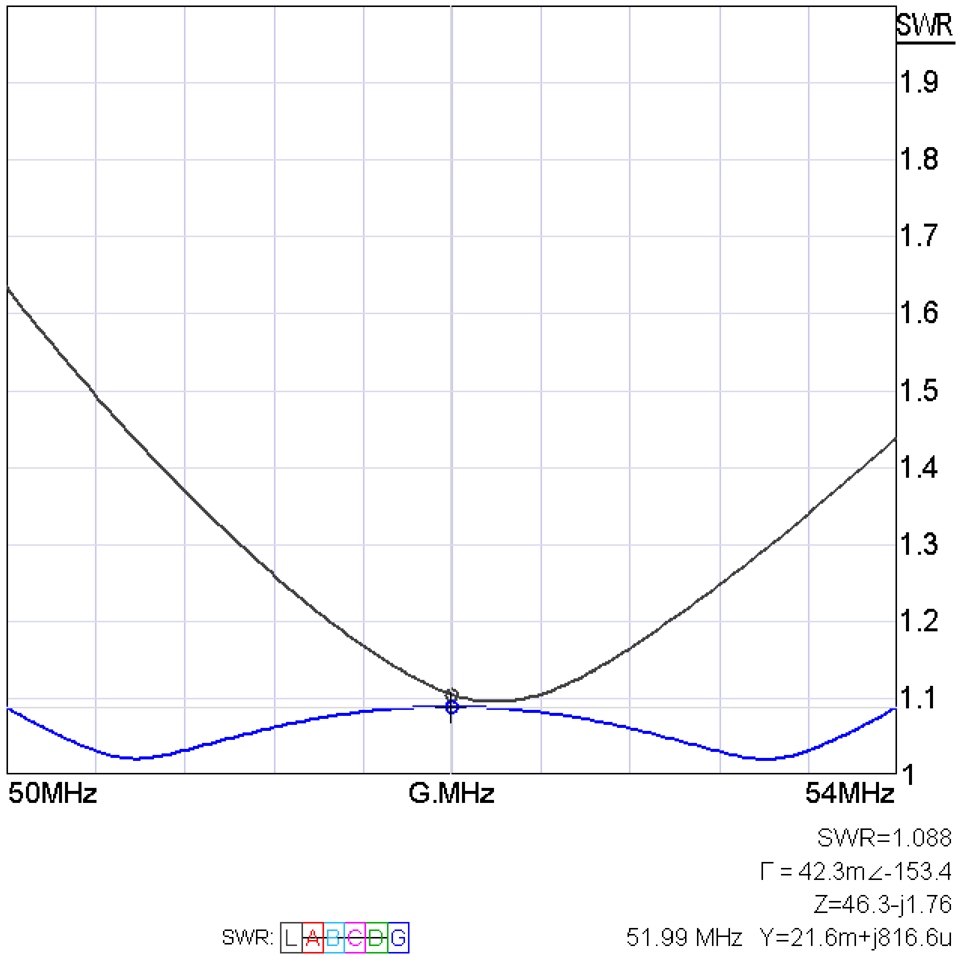
40 meter ¼ λ Monopole using LPS6 Circuit Topology Smith Chart



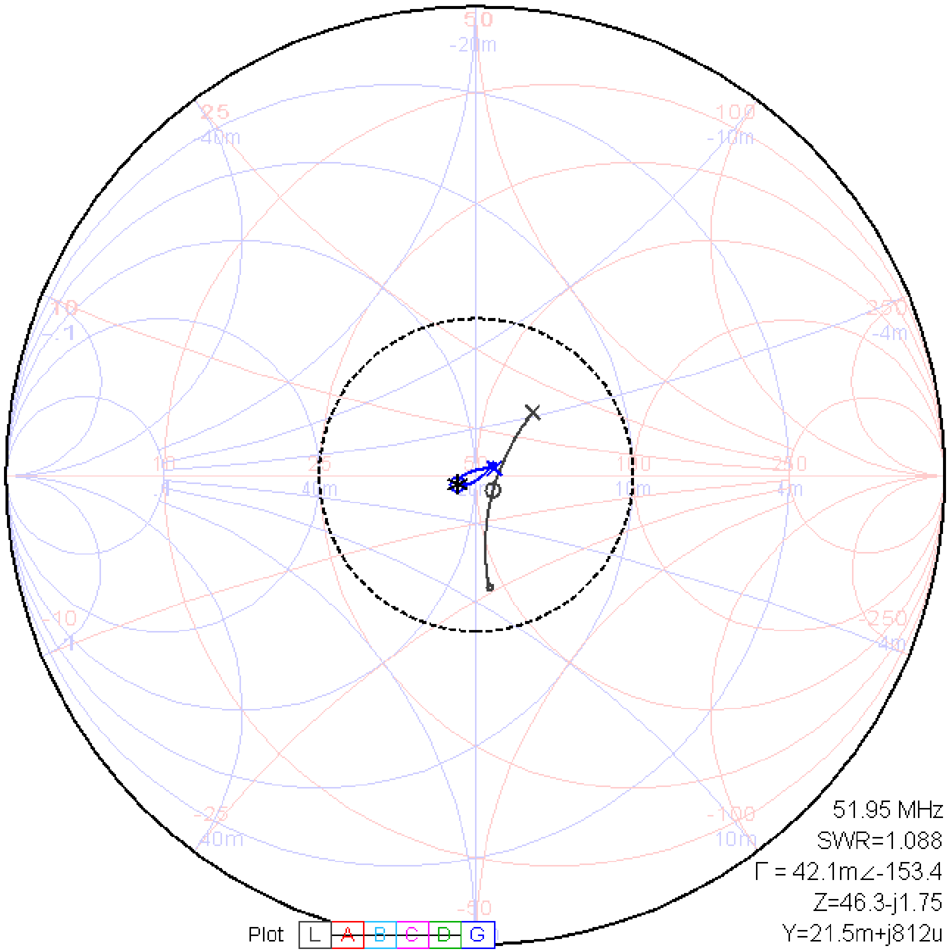
6 meter ¼ λ Ground Plane (Arrow GP52)



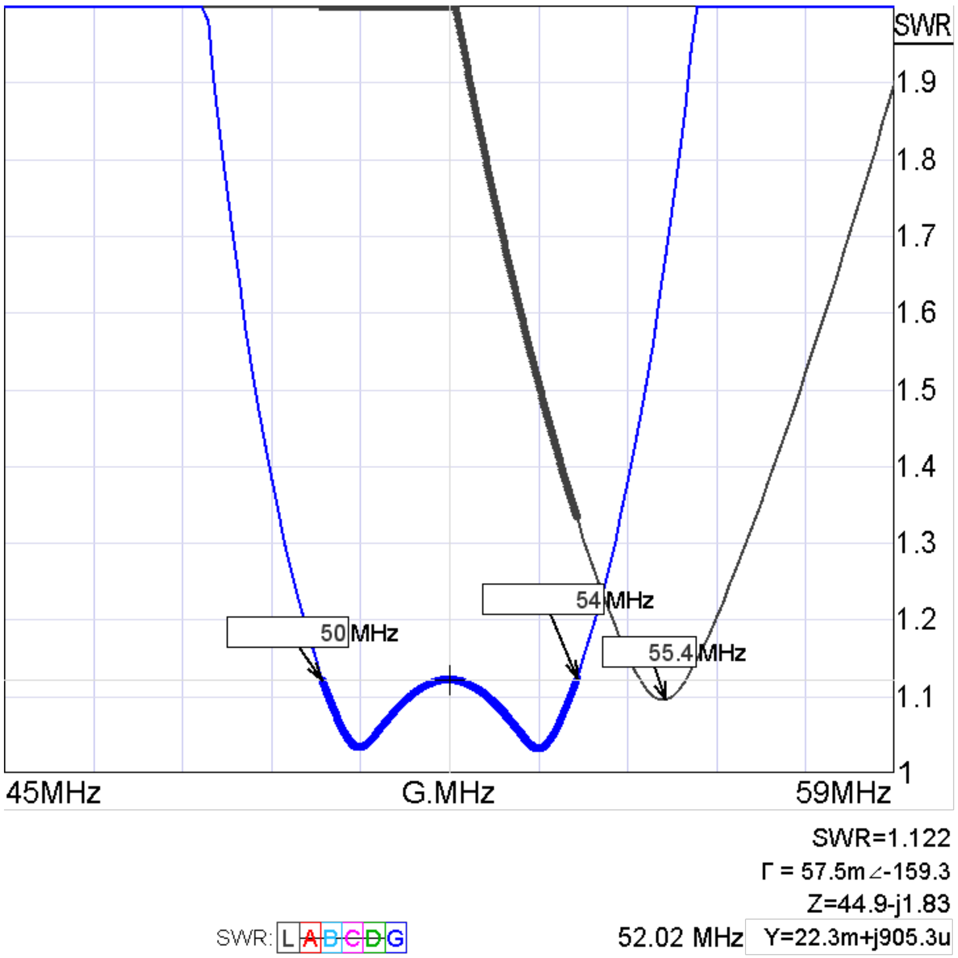
6 meter ¼ λ Ground Plane (Arrow GP52) using LPS4 Circuit Topology VSWR



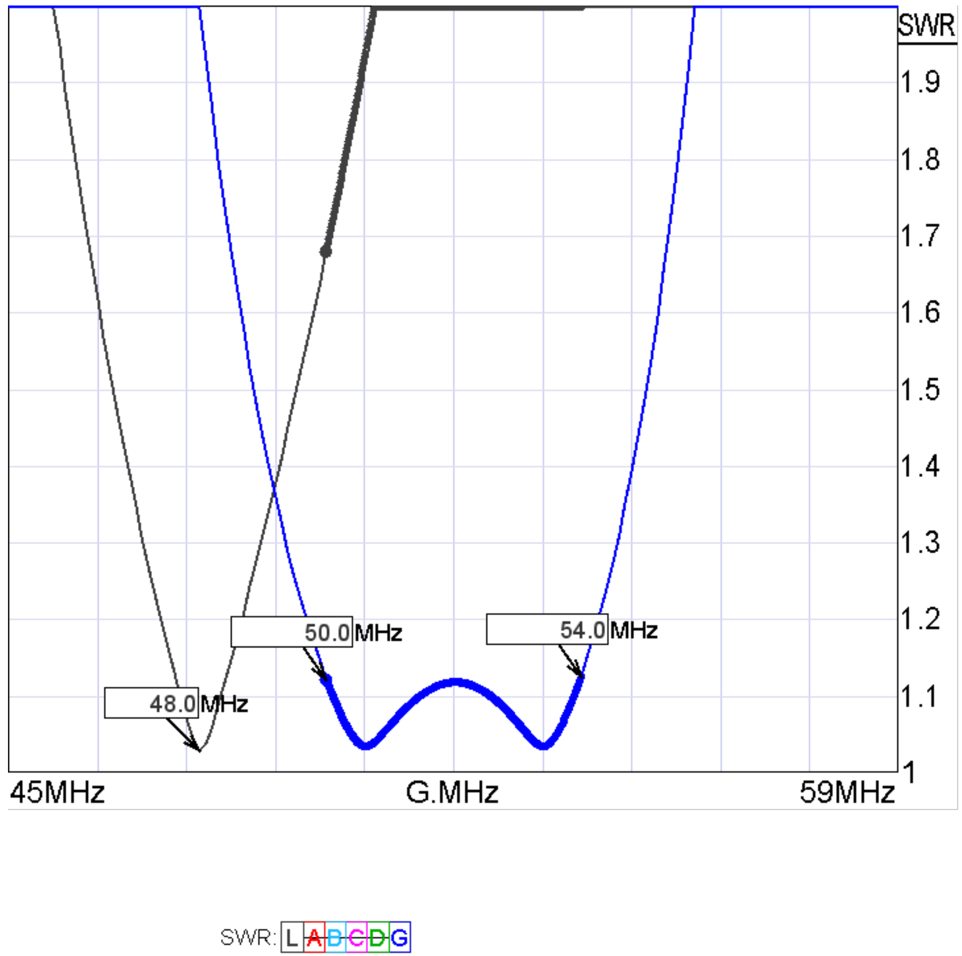
6 meter ¼ λ Ground Plane (Arrow GP52) using LPS4 Circuit Topology Smith Chart



Shortened ¼ λ 6 meter Ground Plane (Arrow GP52) using LPS4 Circuit Topology VSWR

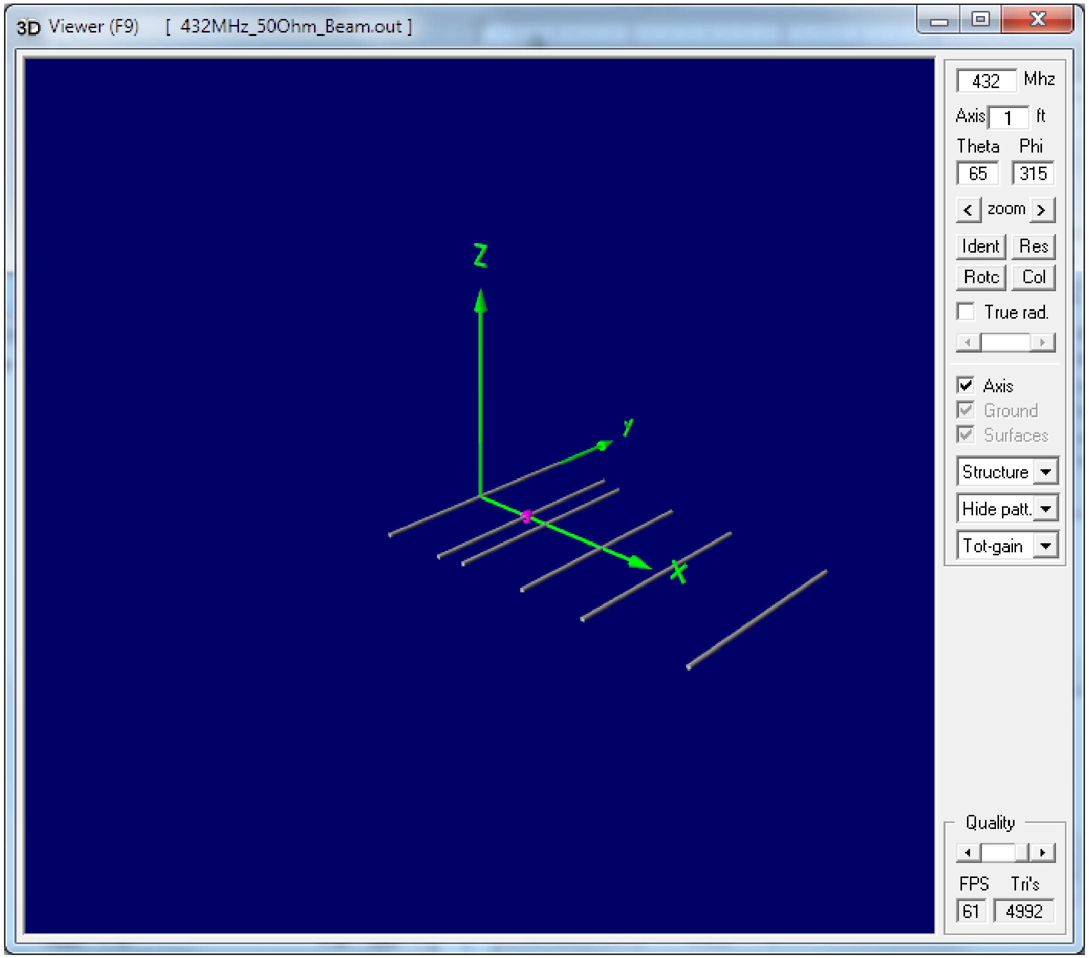


10 foot Ground Plane on 6 meters using LPP4 Circuit Topology VSWR

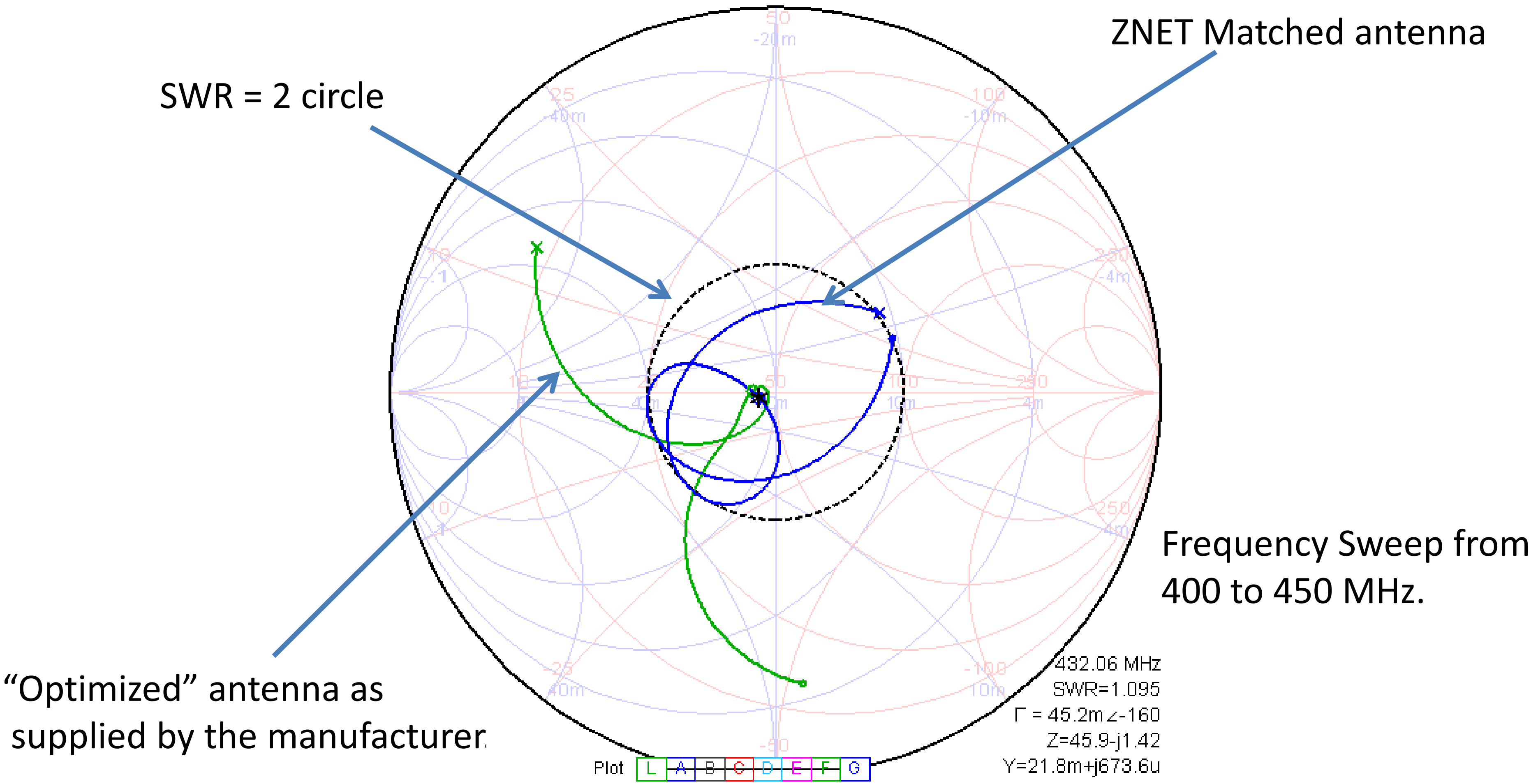


432 MHz Yagi Antenna

Antenna design was “computer optimized” for
420-450 MHz by the commercial manufacturer.



432 MHz Yagi Antenna using LPS6 Circuit Topology Smith Chart



Equal Response vs. 50 Ohms

Achieving an equal response (flat across frequency band) and meeting 50 Ohms are two different goals.

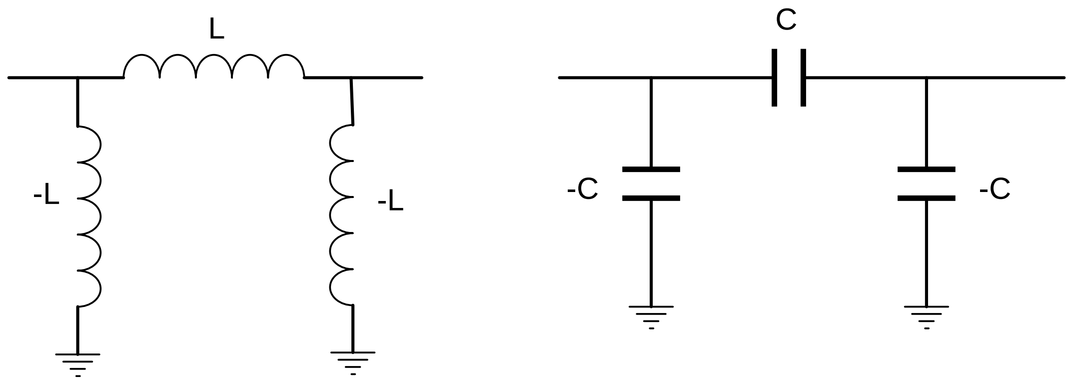
Often, a transformer would be useful to shift the equalized impedance to 50 Ohms…..but often requires an inconvenient transformer ratio.

Enter the Norton transform….

Enter Impedance and Admittance Inverters

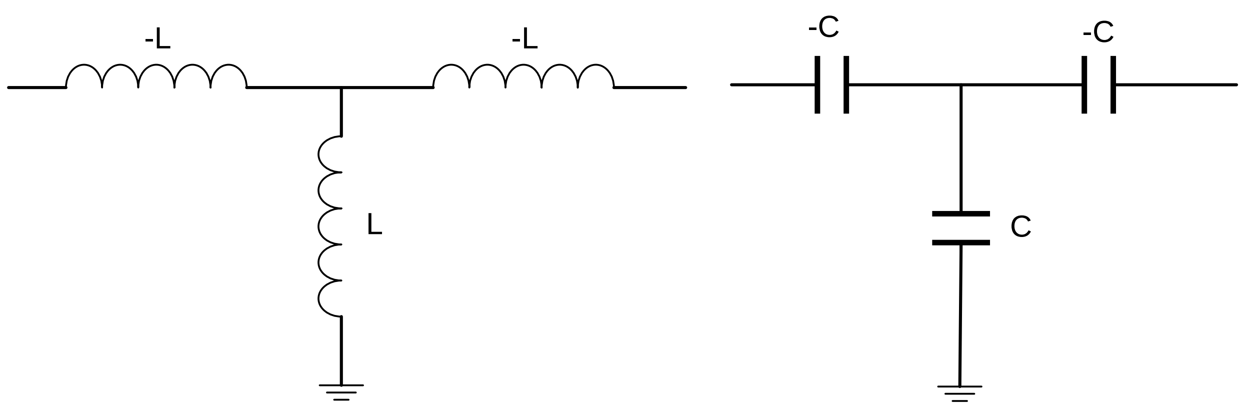
$R_L > R_S$

J-Inverters

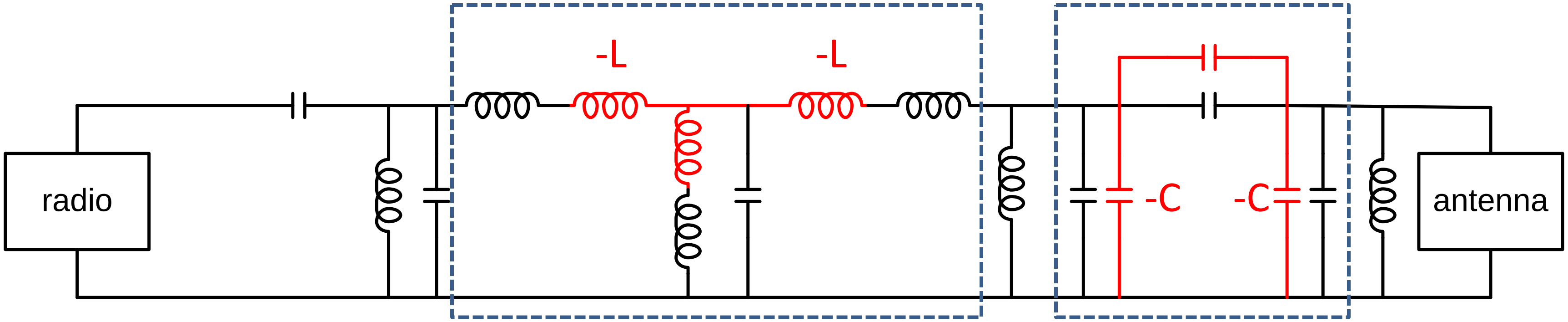


$R_S > R_L$

K-Inverters



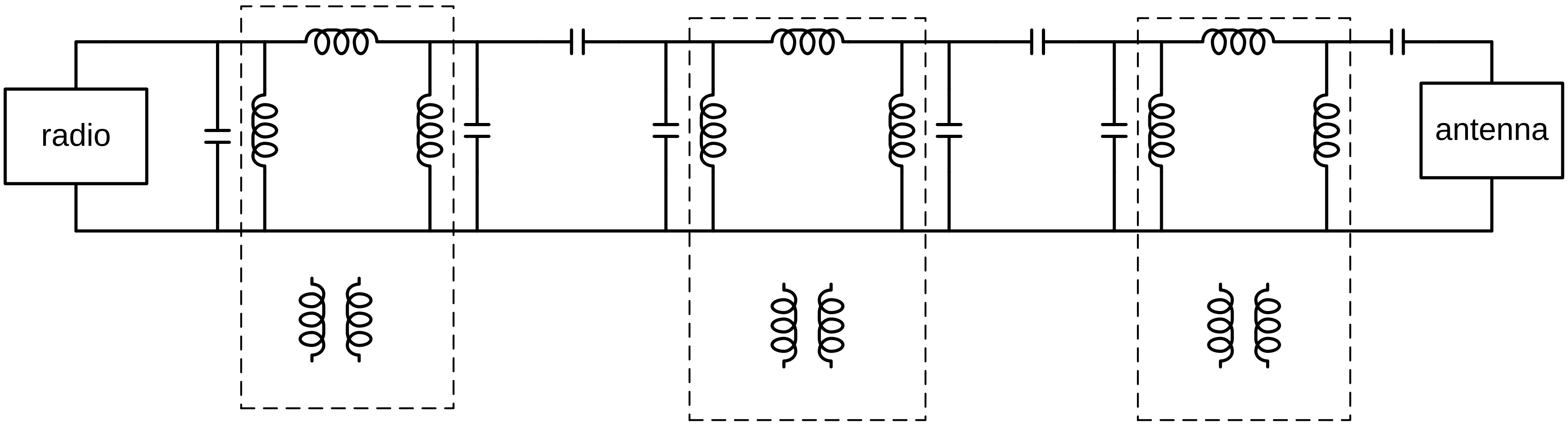
Implementing Norton Transforms



The negative valued components are “absorbed” by the BP resonators.

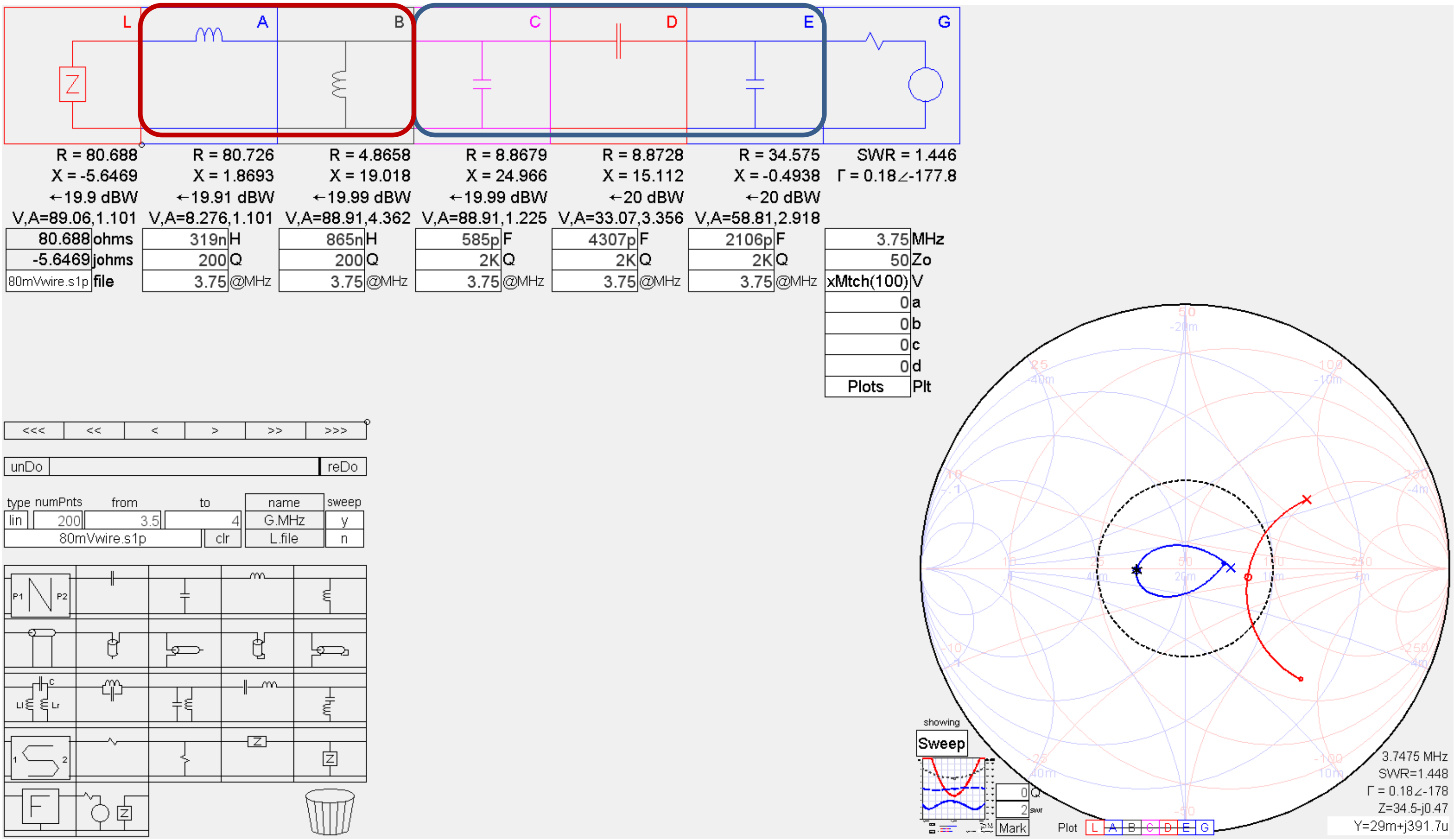
`

Norton Transforms As Transformers

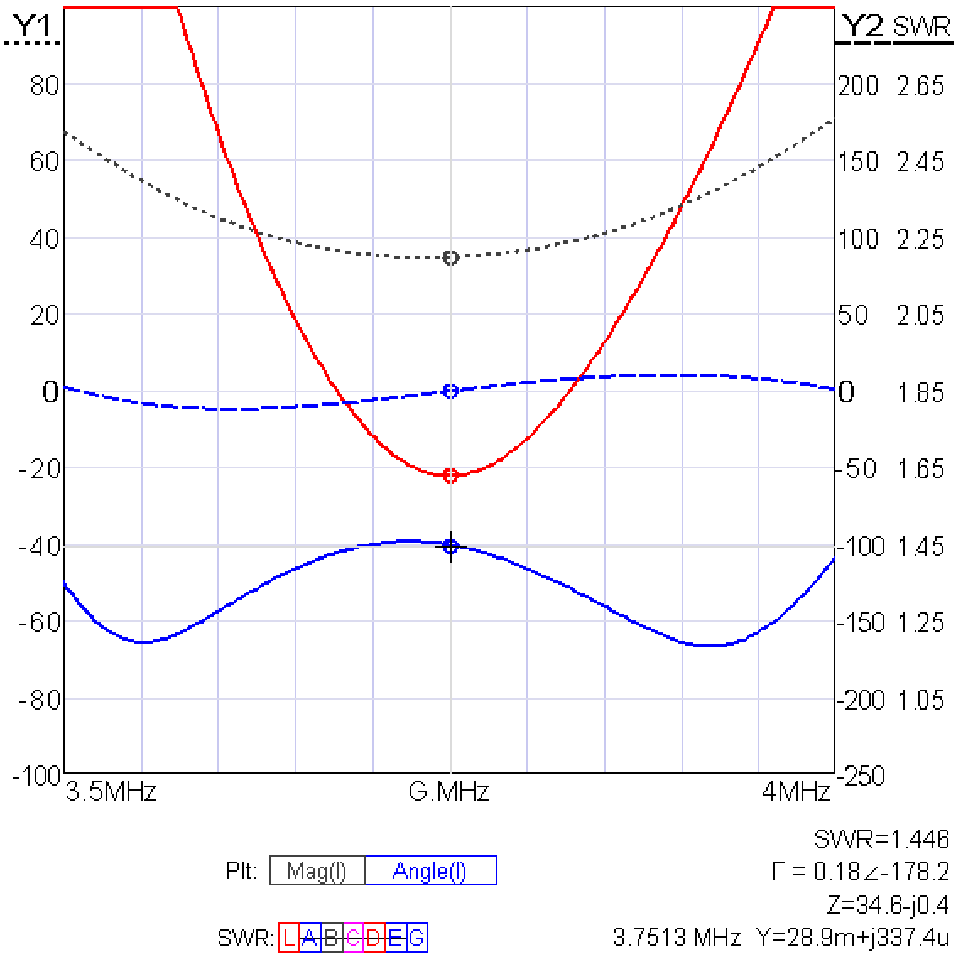


There is a limitation on the achievable transformation ratio, n^2, see Abrie's textbook for details.

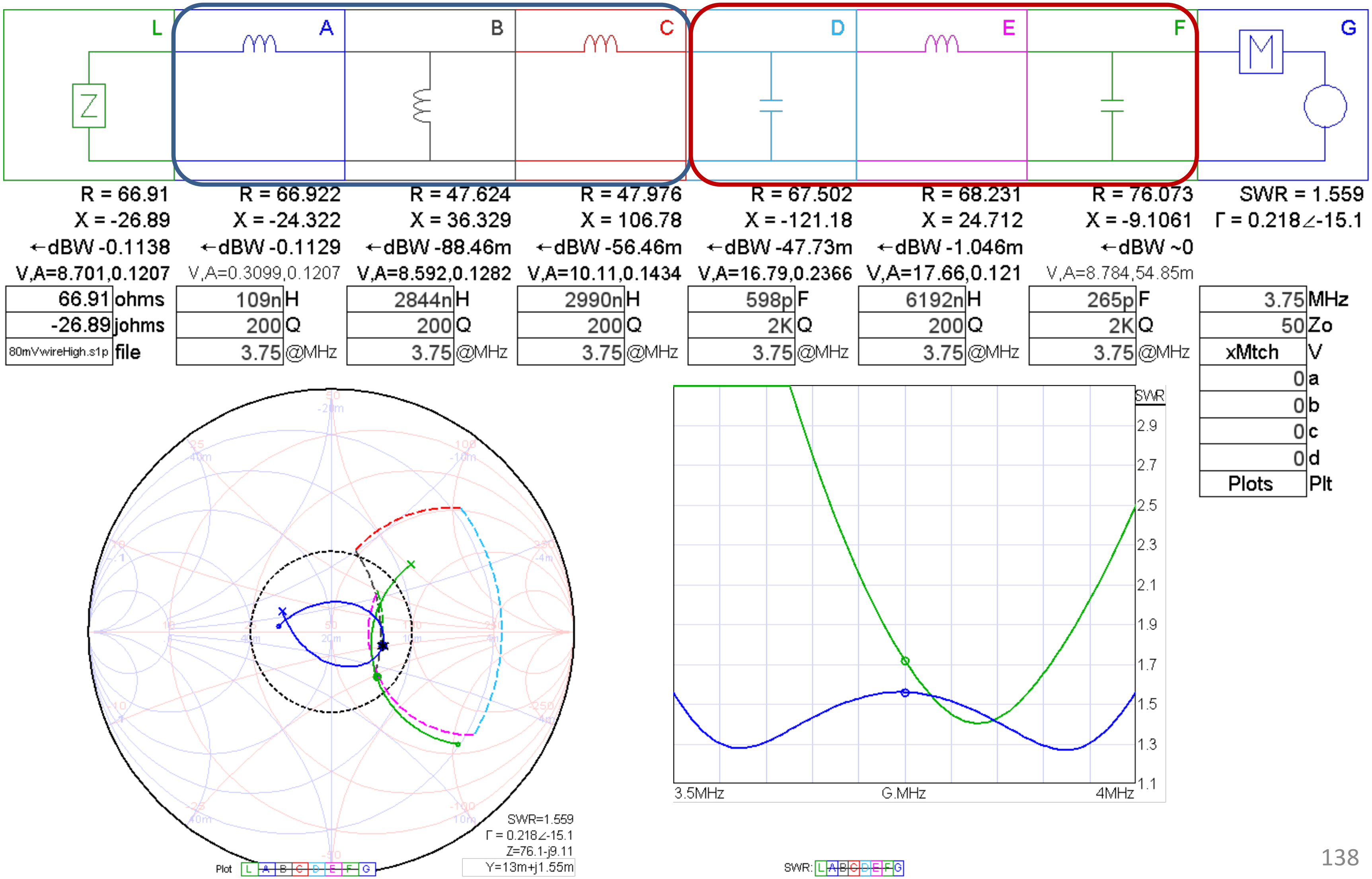
80 meter ½ λ Inverted V Wire using Capacitor "Pi" and Inductor "L"



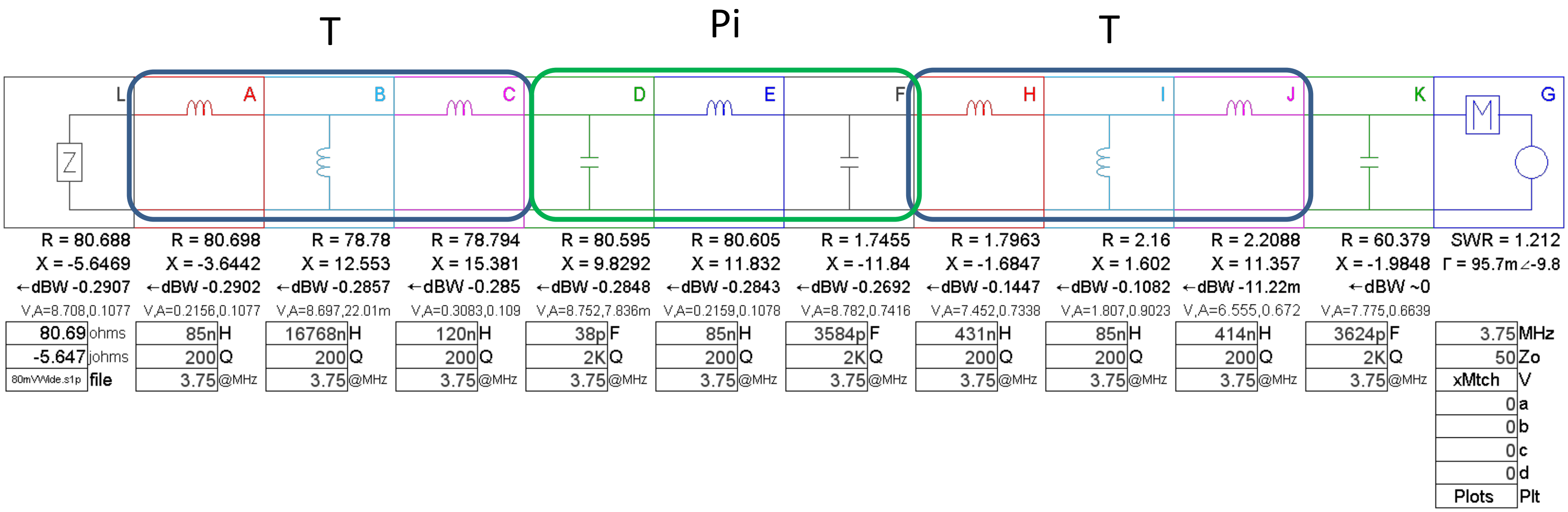
80 meter ½ λ Inverted V Wire using Capacitor "Pi" and Inductor "L"



Using L “T” & Low Pass Pi Transformers “XFMRPI” Circuit Topology

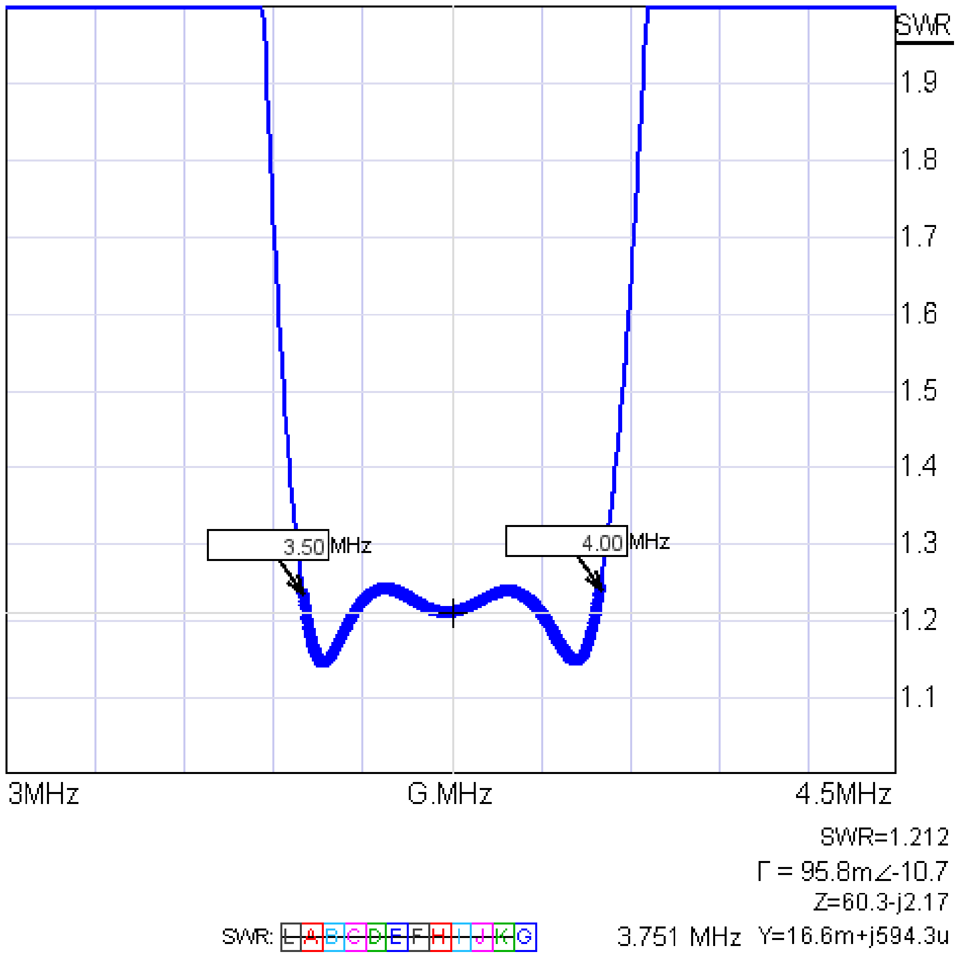


80 meter ½ λ Inverted V Wire using WMB3 Circuit Topology

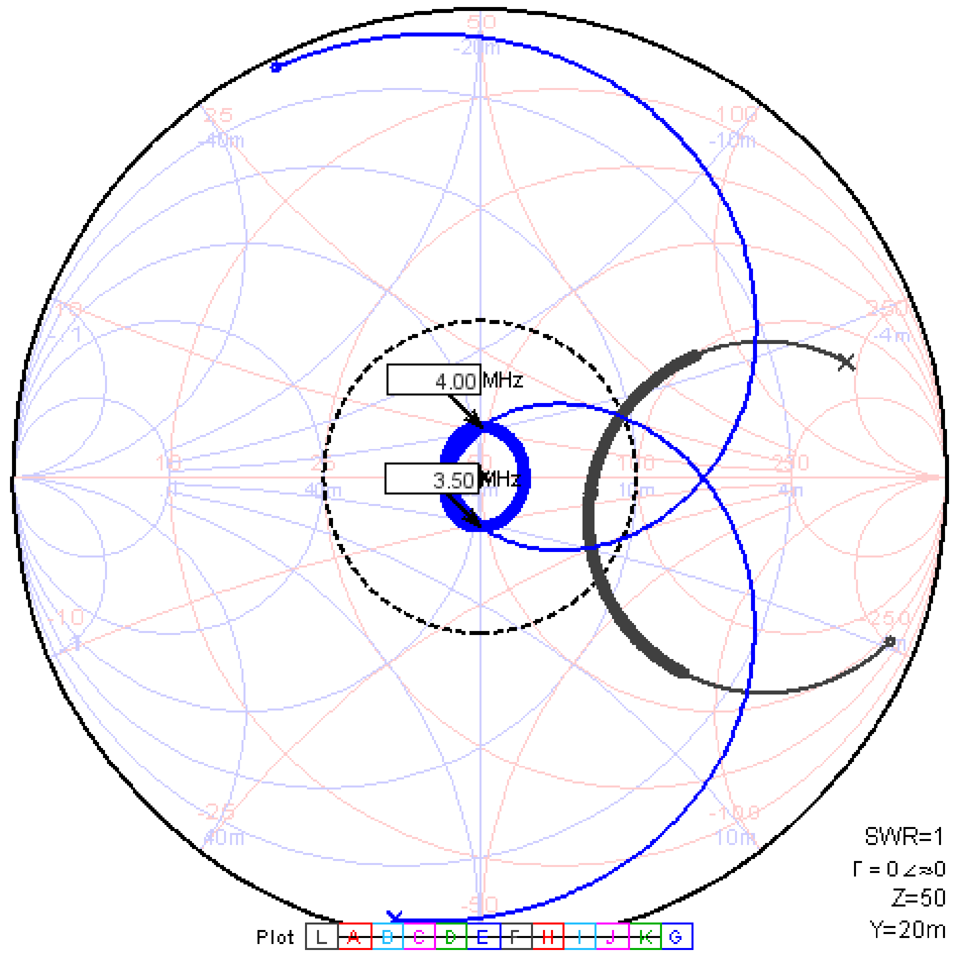


80 meter ½ λ Inverted V Wire using WMB3 Circuit Topology VSWR

ΔP_{load} = 0.154 dB



80 meter ½ λ Inverted V Wire using WMB3 Circuit Topology Smith Chart



Non-resonant Antennas

Monopole antennas,

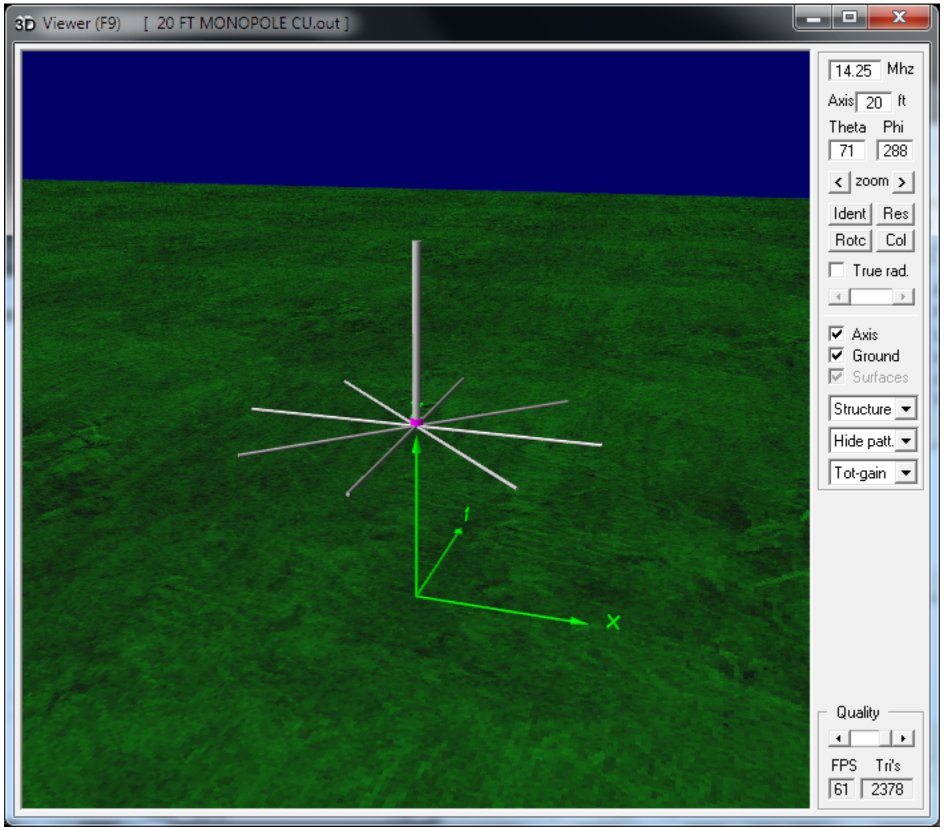
- 20 feet tall monopole,
- 10 feet tall monopole,

Flat top dipole antennas,

- 100ft wide (short) 80 meter wire V dipole,
- 20 feet width dipole,
- 10 feet width dipole.

Multi-band equalizers using single equalizer circuit on a non-resonant antenna.

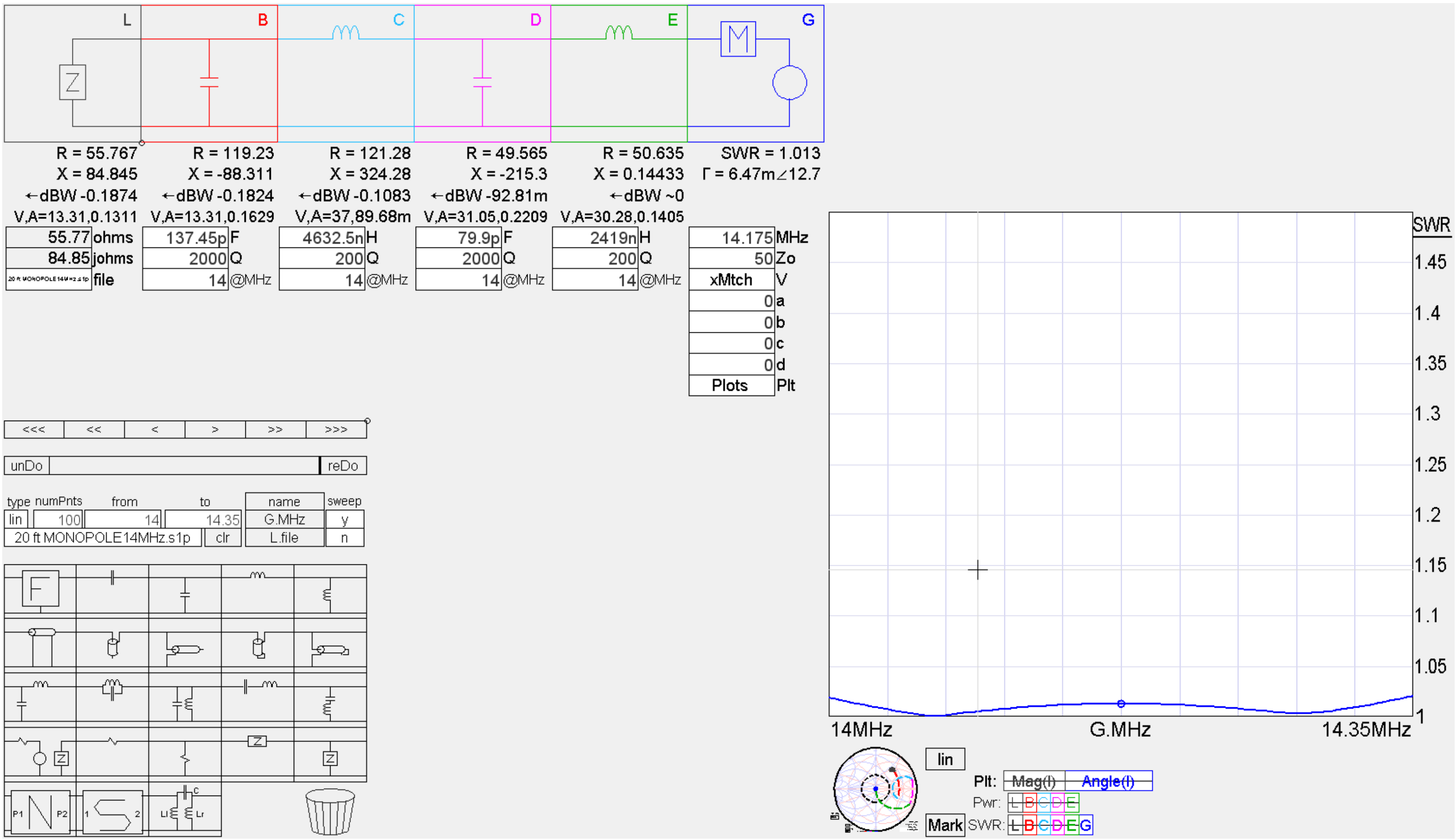
20 Foot Tall Monopole HF Antenna



Computer model image.

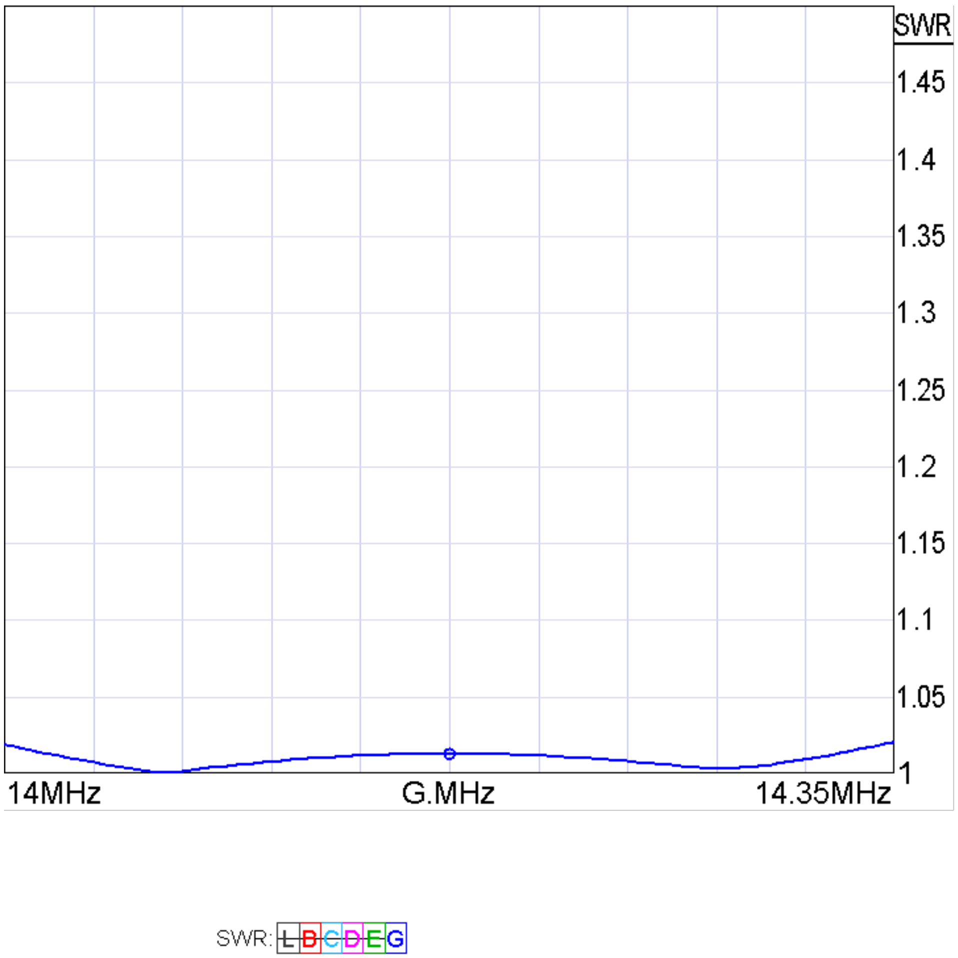
Commercial HF antenna.

20 foot Monopole on 20 meters using LPP4 Circuit Topology

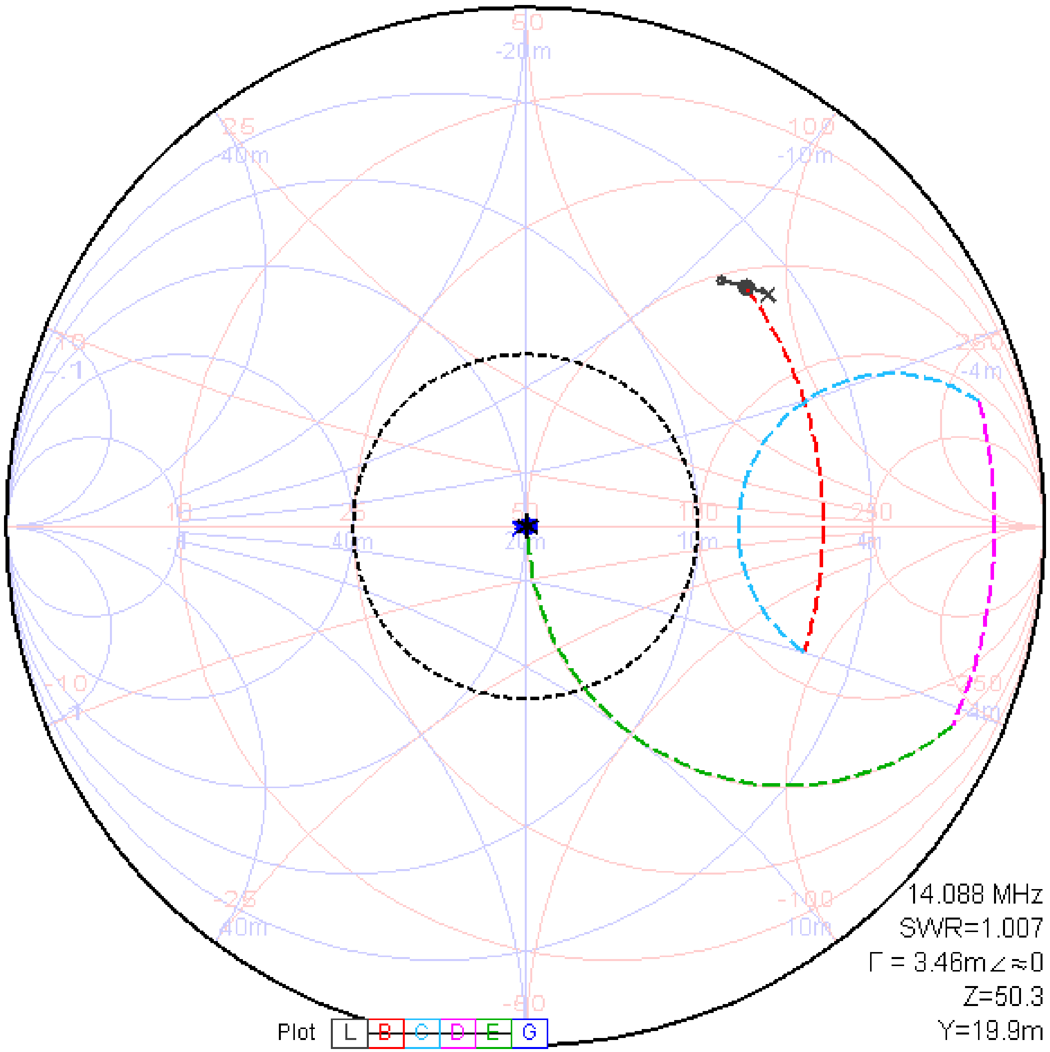


20 foot Monopole on 20 meters using LPP4 Circuit Topology VSWR

ΔP_{load} = 0.012 dB



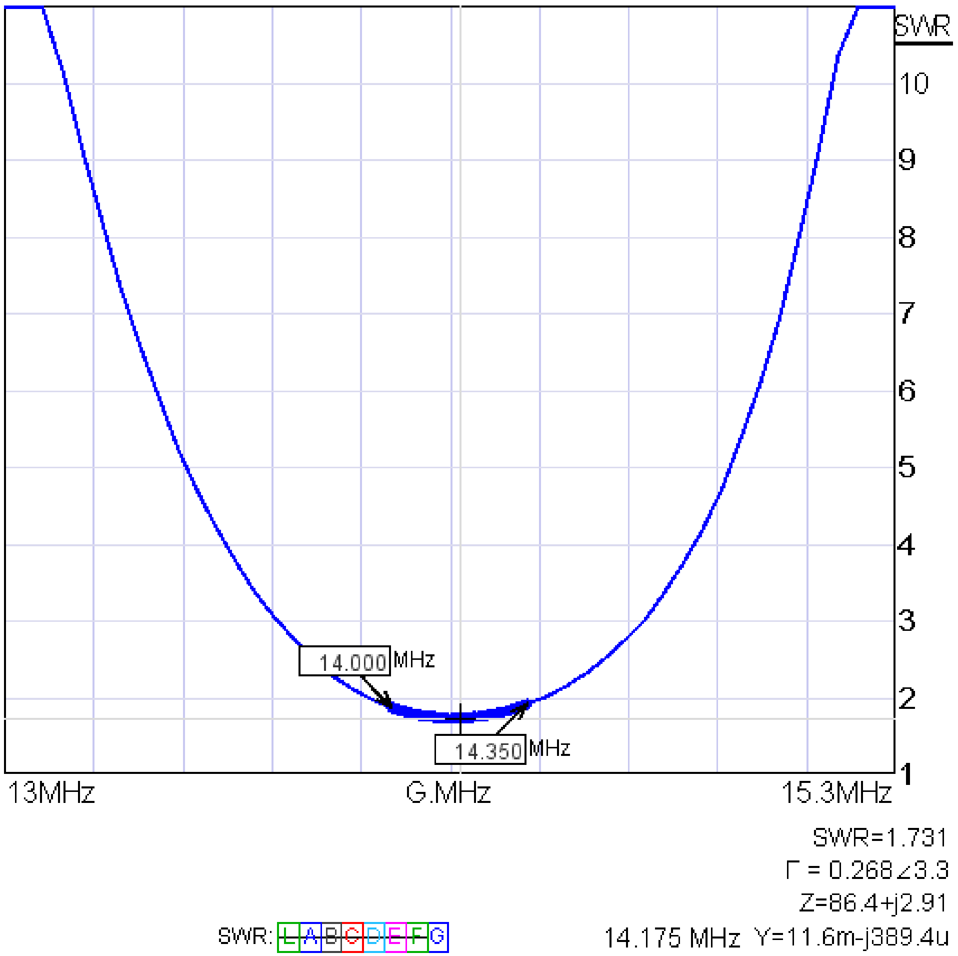
20 foot Monopole on 20 meters using LPP4 Circuit Topology Smith Chart



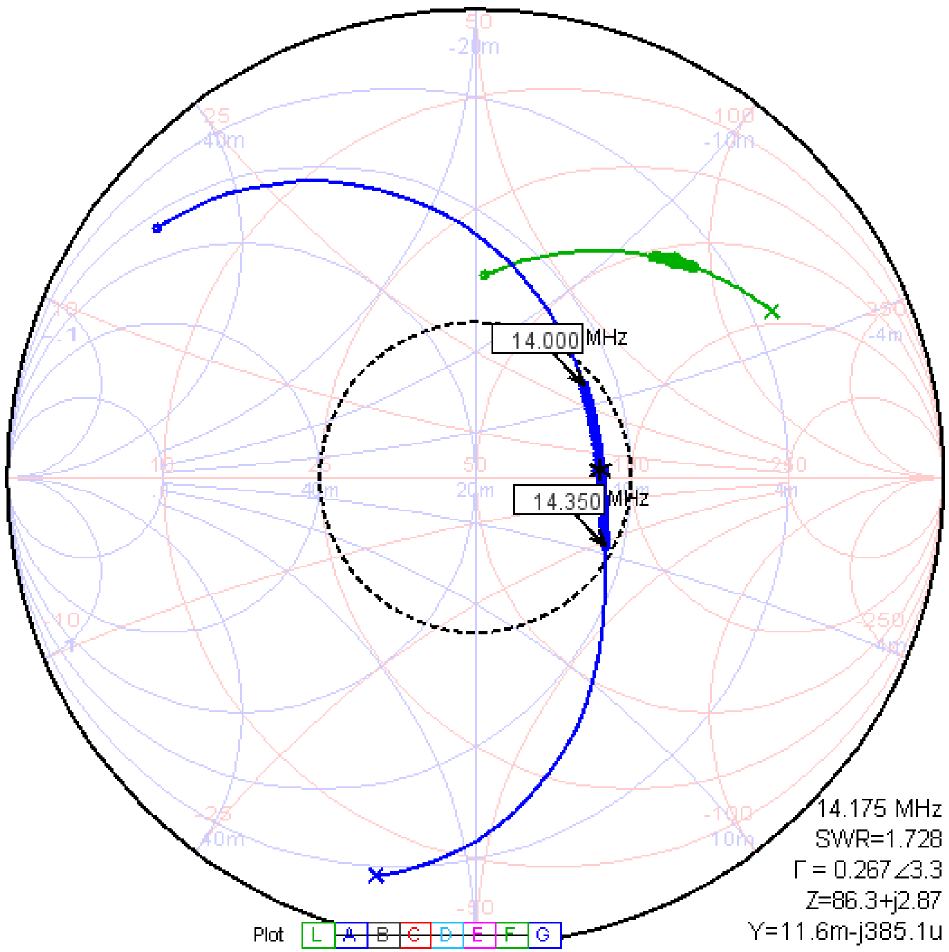
Note the path taken

20 foot Monopole on 20 meters using LPS6 Circuit Topology VSWR

ΔP_{load} = 0.020 dB

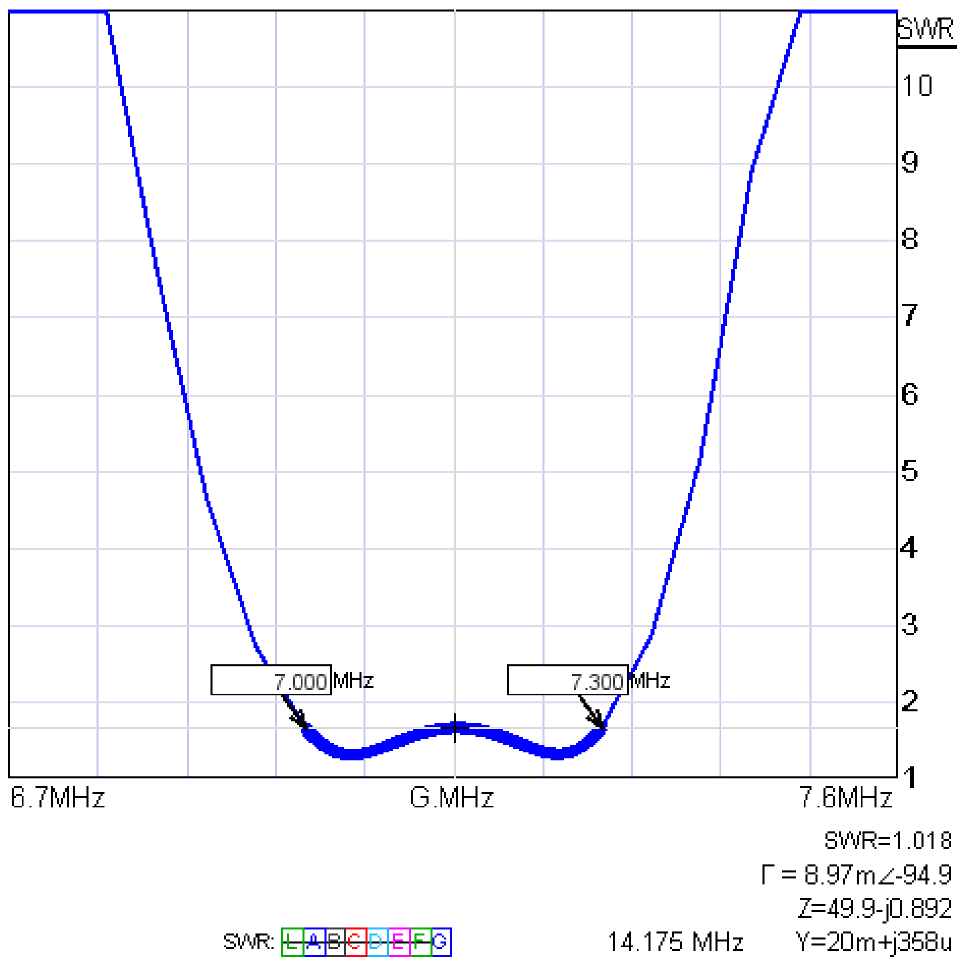


20 foot Monopole on 20 meters using LPS6 Circuit Topology Smith Chart

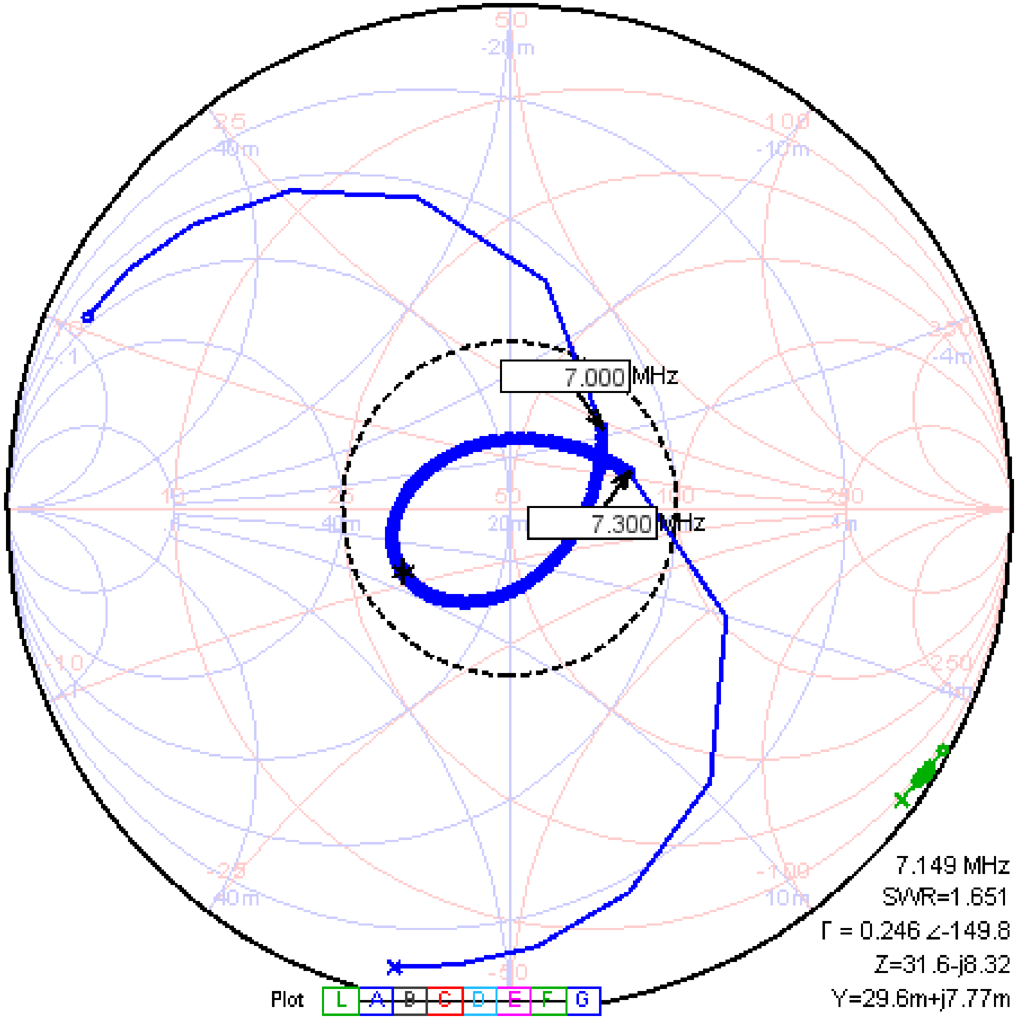


20 foot Monopole on 40 meters using LPS6 Circuit Topology VSWR

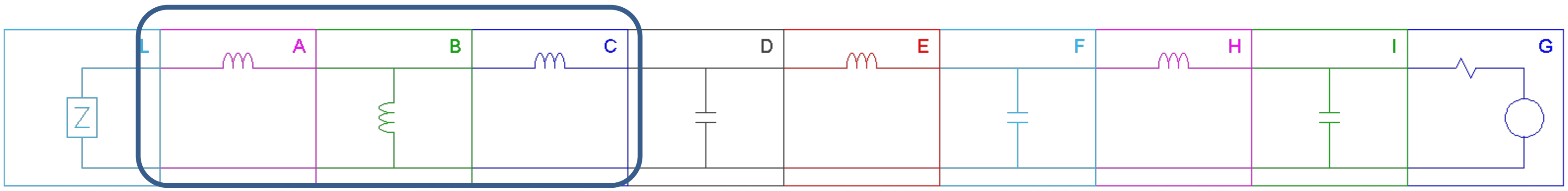
ΔP_{load} = 0.663 dB



20 foot Monopole on 40 meters using LPS6 Circuit Topology Smith Chart



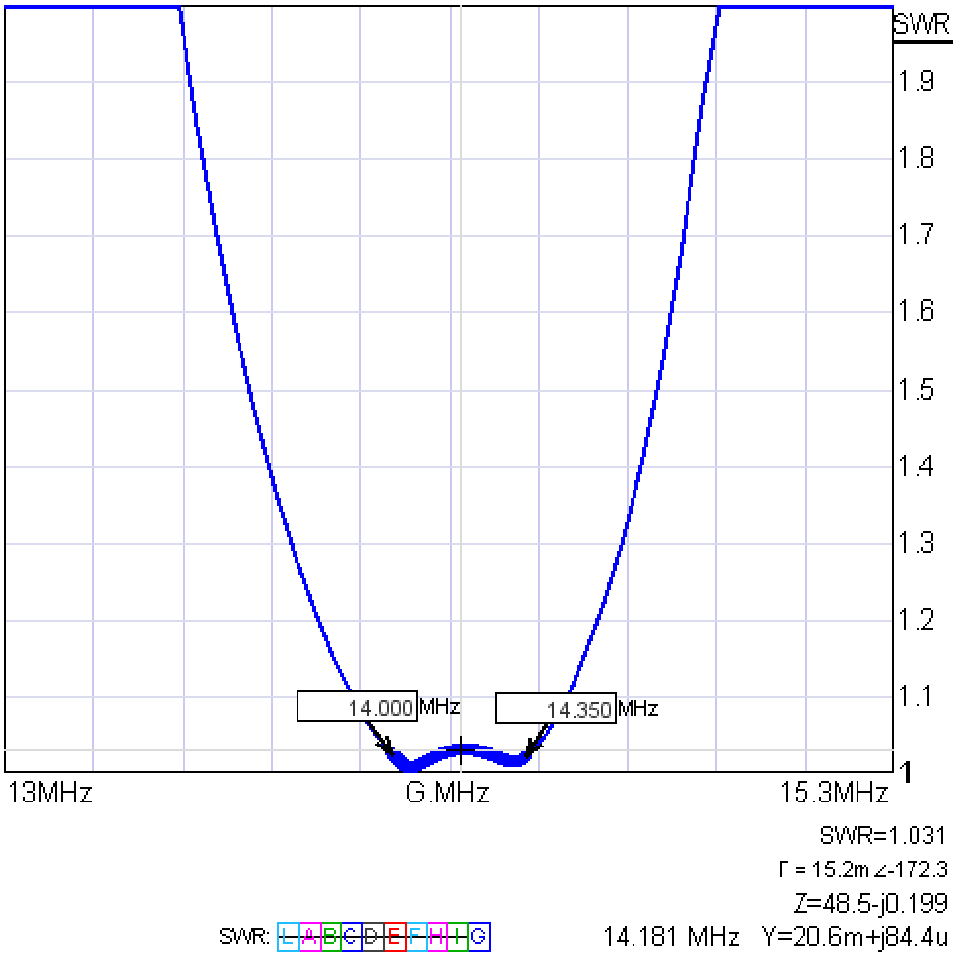
20 foot Monopole on 20 meters using WMB2 Circuit Topology



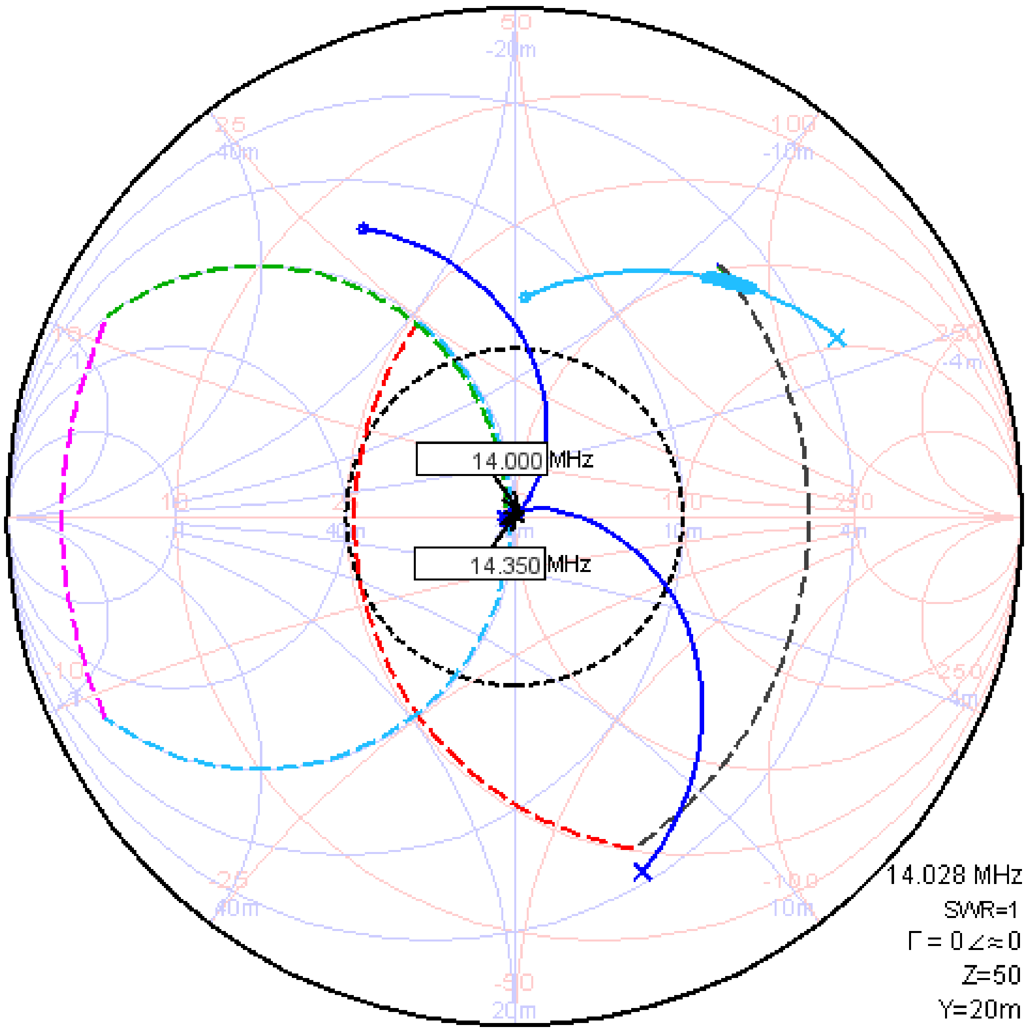
L	A	B	C	D	E	F	H	I	G
R = 55.767	R = 55.77	R = 48.797	R = 48.799	R = 25.739	R = 26.185	R = 2.8566	R = 2.9724	R = 48.524	SWR = 1.031
X = 84.845	X = 85.344	X = 81.893	X = 82.392	X = -64.528	X = 24.625	X = -11.508	X = 11.648	X = -0.21446	Γ = 15.1m∠-171.6
←dBW -0.2802	←dBW -0.28	←dBW -0.2768	←dBW -0.2765	←dBW -0.2674	←dBW -0.1929	←dBW -0.1821	←dBW -9.506m	←dBW -994.7u	
V,A=13.16,0.1297	V,A=64.67m,0.1297	V,A=13.22,10.58m	V,A=69.16m,0.1387	V,A=13.28,0.2968	V,A=17.04,0.1911	V,A=6.87,0.6933	V,A=13.42,0.5794	V,A=6.965,0.562	
55.77 ohms	5.6n H	14025n H	5.6n H	251p F	1001n H	1133p F	260n H	906p F	14.175 MHz
84.85 johms	200 Q	200 Q	200 Q	2K Q	200 Q	2K Q	200 Q	2K Q	50 Zo
[illegible] file	14.175 @MHz	14.175 @MHz	14.175 @MHz	14.175 @MHz	14.175 @MHz	14.175 @MHz	14.175 @MHz	14.175 @MHz	useZo V
									0 a
									0 b
									0 c
									0 d
									Plots Plt

20 foot Monopole on 20 meters using WMB2 Circuit Topology VSWR

ΔP_{load} = 0.044 dB



20 foot Monopole on 20 meters using WMB2 Circuit Topology Smith Chart

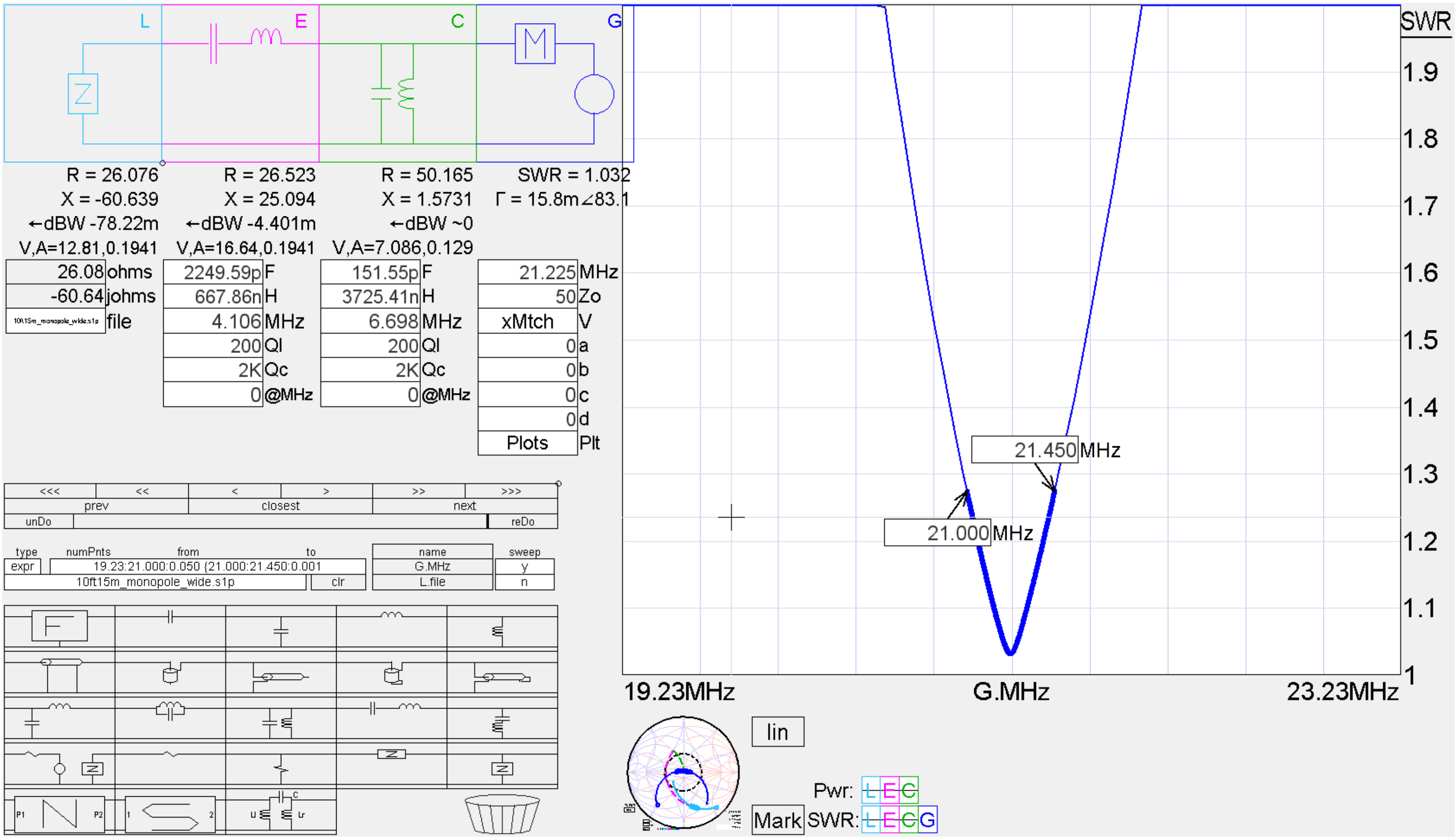


Example ZNET Solution
10 foot Monopole using 15m BPS2 Circuit

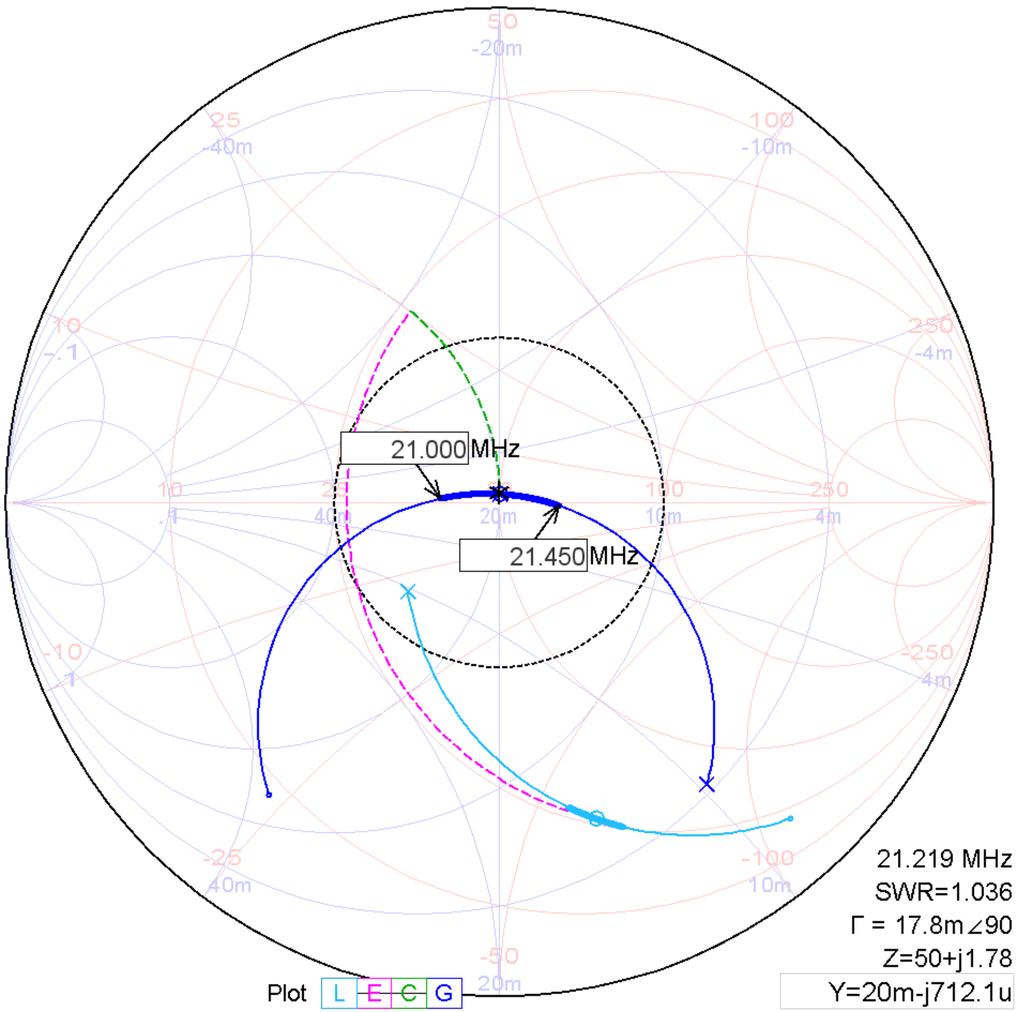
Octave-3.6.4

```
Optimization completed!

Number of function evaluations = 8680

Number of objective iterations = 217

Optimization computation time =   7.10 seconds

Convergence = 0
The optimizer converged to the tolerance limit!

TPG Objective Score= 0.242232


    ---------------------L1---C1----
     |       |    |               |
     |       |    |               |
   Zsrc     L2   C2             Zant
     |       |    |               |
     |       |    |               |
    --------------------------------



C1 = 2249.59 pF
L1 = 667.86 nH
C2 = 151.55 pF
L2 = 3725.41 nH


Antenna Q = 9.91

Qbw = 47.16

Fano decrement = 4.76

Estimated Fano bandwidth = 6.126 MHz

Fano VSWR minimum = 1.00

minimum matched VSWR = 1.03

maximum matched VSWR = 1.27
```

10 foot Monopole on 15 meters using BPS2 Circuit Topology VSWR

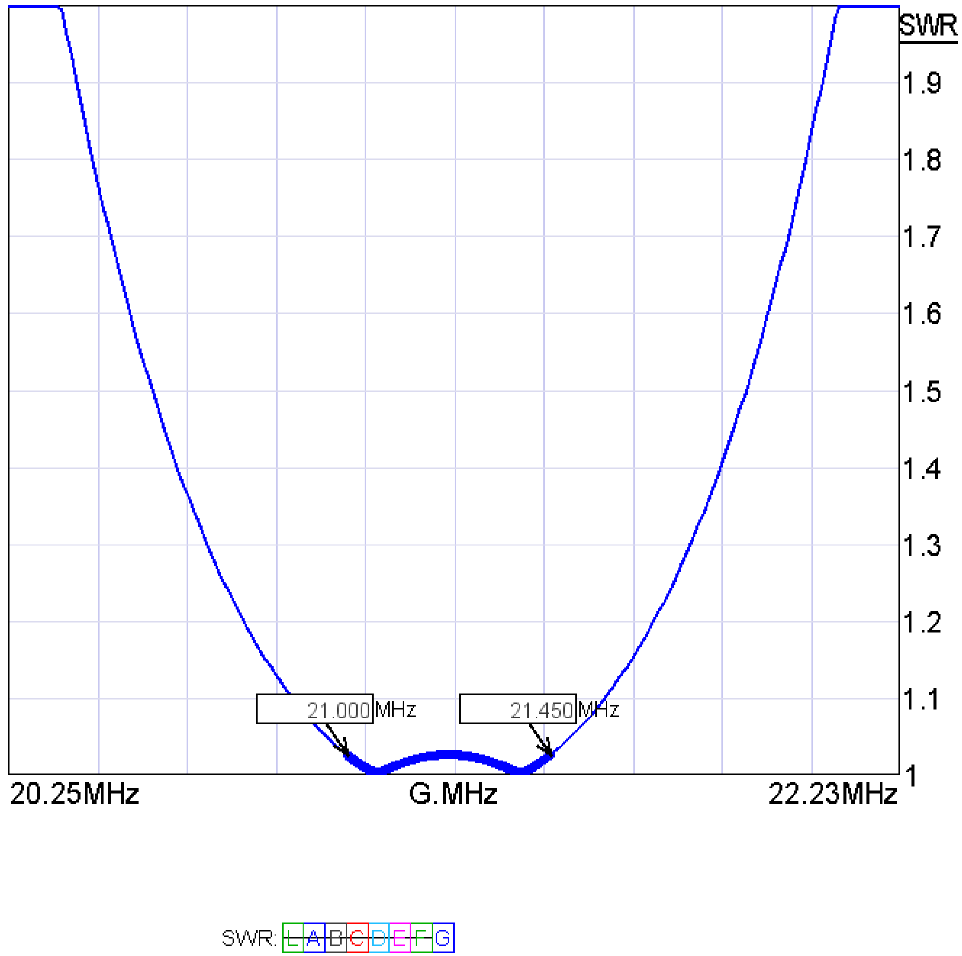


10 foot Monopole on 15 meters using BPS2 Circuit Topology Smith Chart

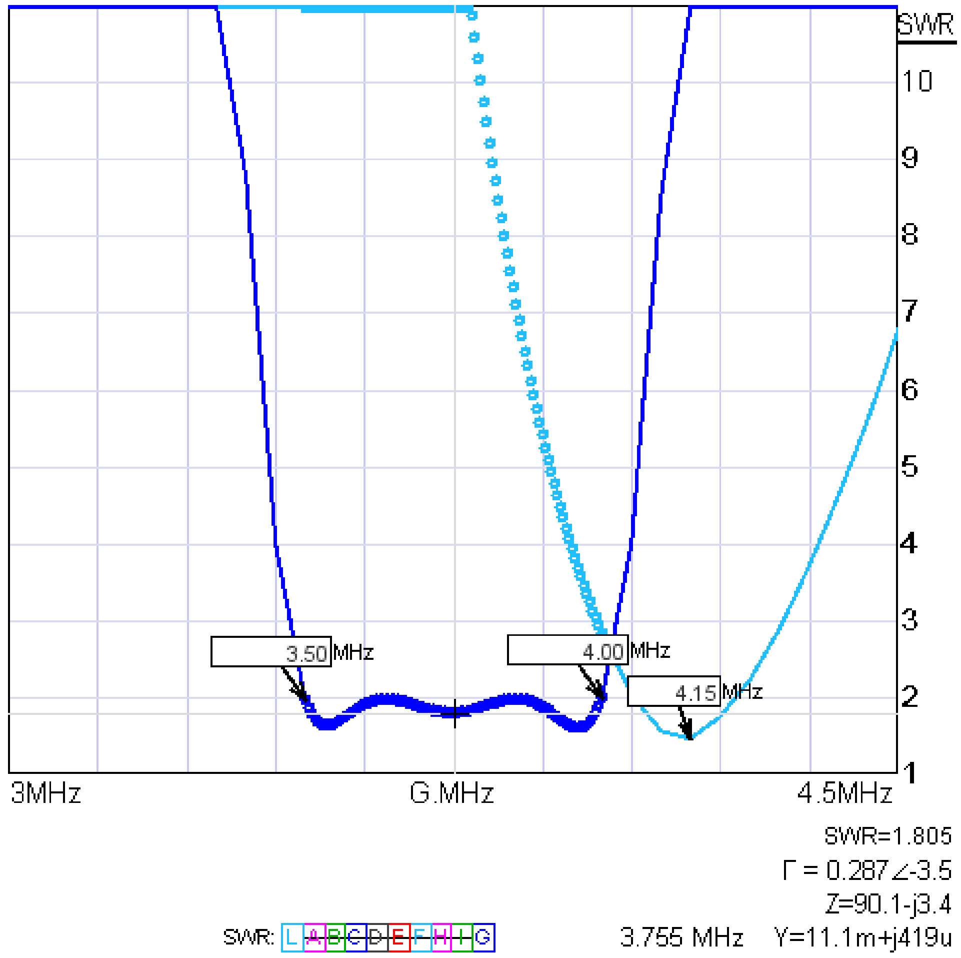


10 foot Monopole on 15 meters using LPS6 Circuit Topology VSWR

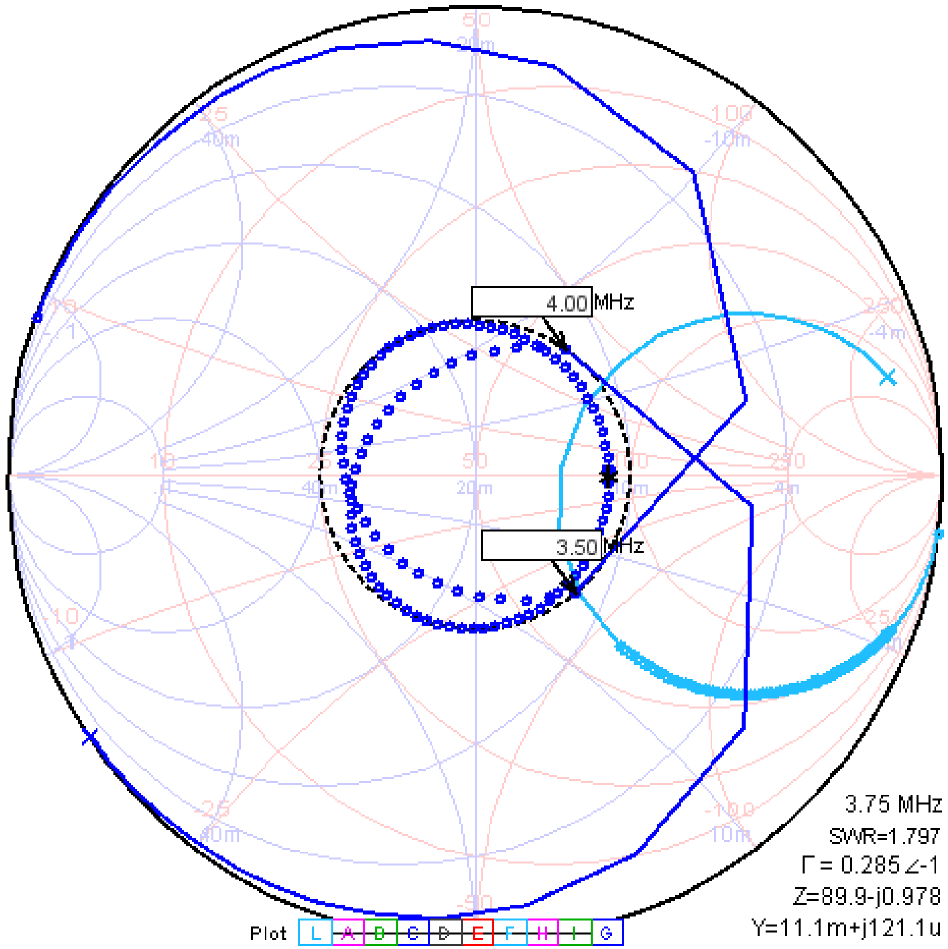
ΔP_{load} = 0.014 dB



80m Inverted V Wire Dipole 100 foot (short) using LPS8 Circuit Topology VSWR

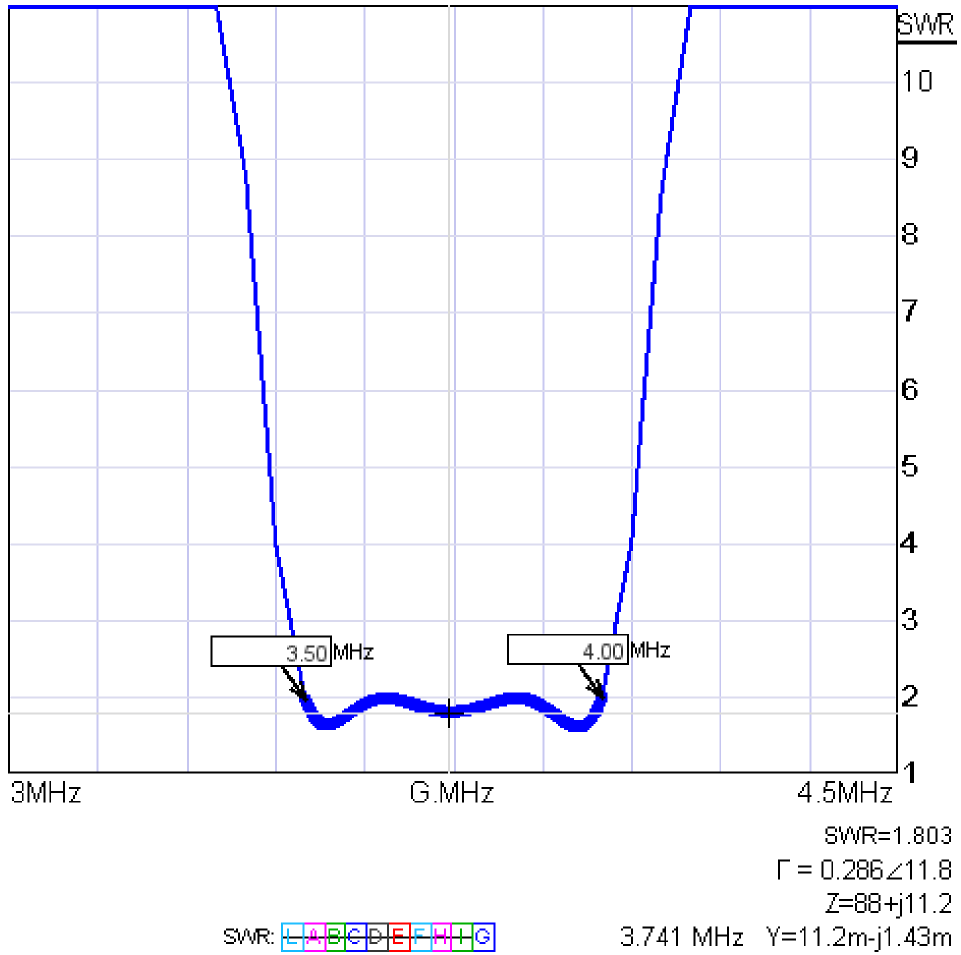


80m Inverted V Wire Dipole 100 foot (short) using LPS8 Circuit Topology Smith Chart

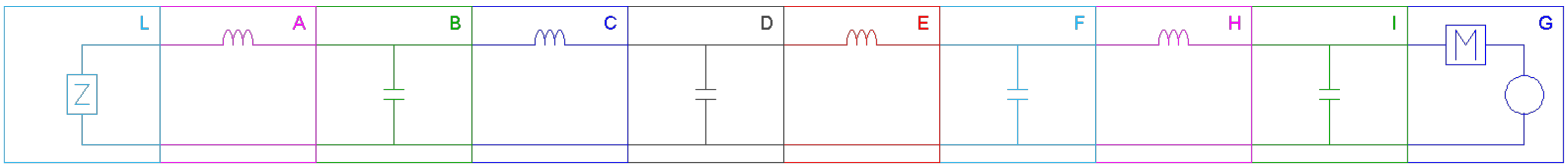


80m Inverted V Wire Dipole 100 foot (short) using LPS8 Circuit Topology VSWR

ΔP_{load} = 0.782 dB

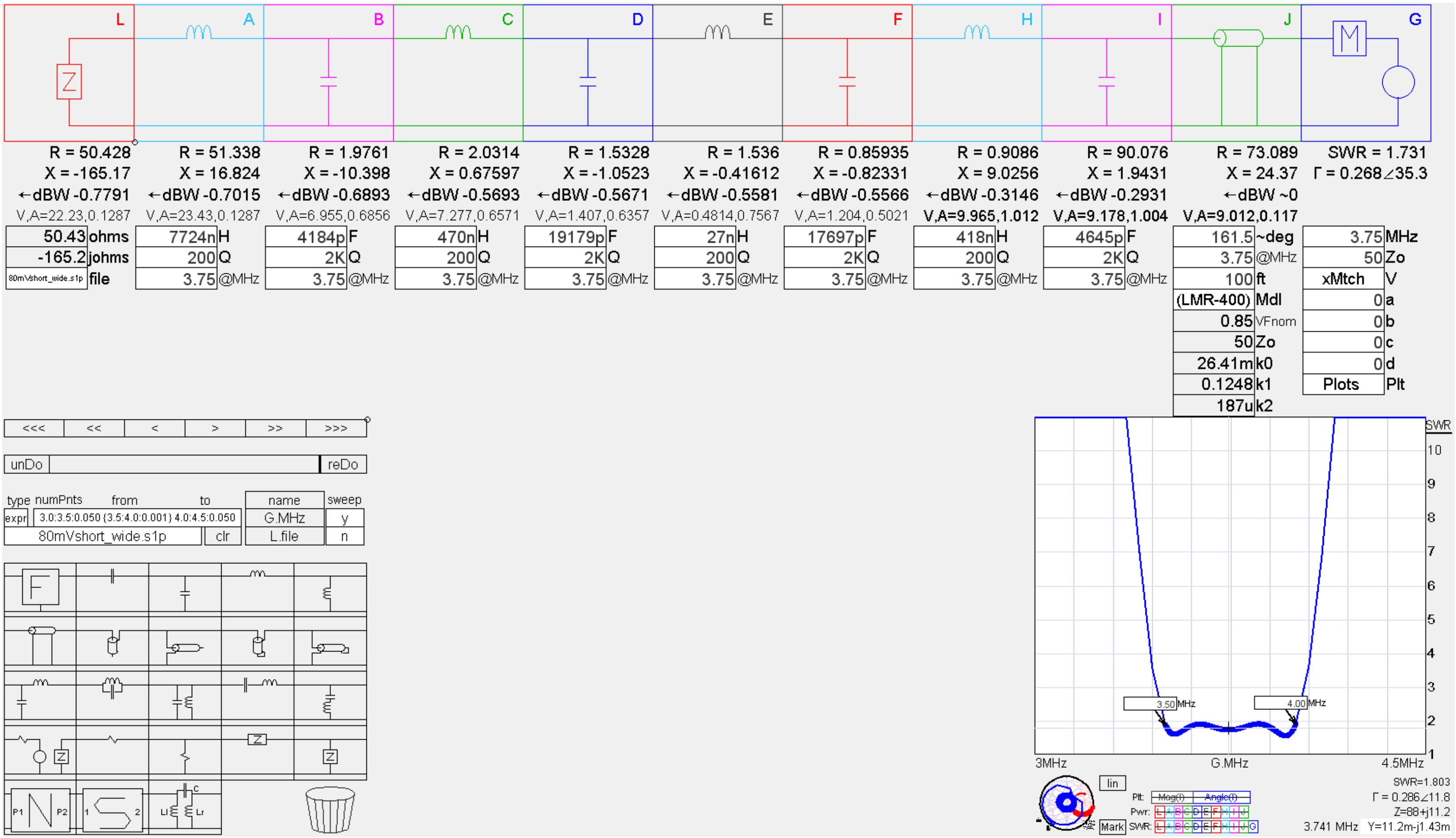


80m Inverted V Wire Dipole 100 foot (short) using LPS8 Circuit Topology (no transmission line from radio)

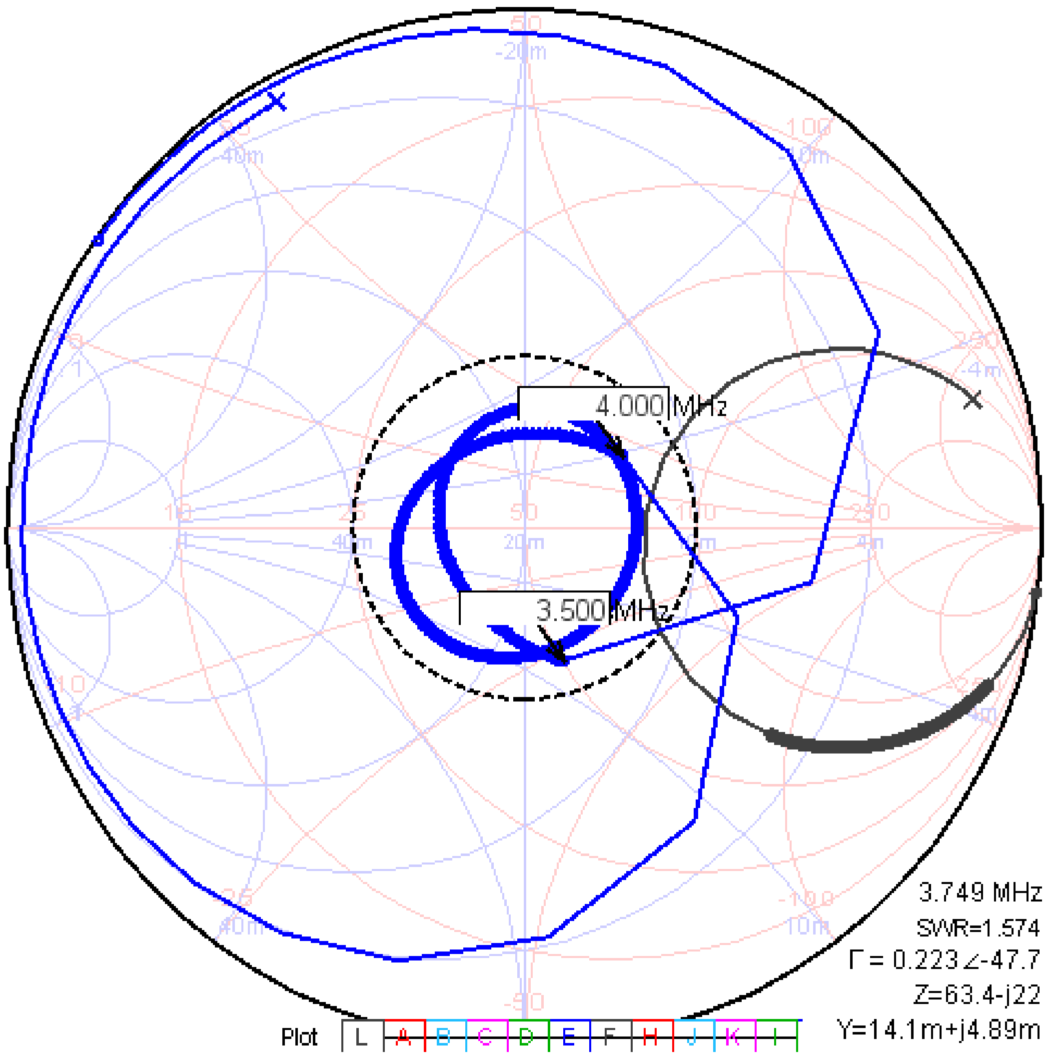


R = 50.428	R = 51.338	R = 1.9761	R = 2.0314	R = 1.5328	R = 1.536	R = 0.85935	R = 0.9086	R = 90.076	SWR = 1.803
X = -165.17	X = 16.824	X = -10.398	X = 0.67597	X = -1.0523	X = -0.41612	X = -0.82331	X = 9.0256	X = 1.9431	Γ = 0.286∠2
←dBW -0.486	←dBW -0.4084	←dBW -0.3962	←dBW -0.2762	←dBW -0.274	←dBW -0.265	←dBW -0.2635	←dBW -21.47m	←dBW ~0	
V,A=23,0.1332	V,A=24.23,0.1332	V,A=7.194,0.7092	V,A=7.527,0.6797	V,A=1.455,0.6576	V,A=0.4979,0.7826	V,A=1.245,0.5193	V,A=10.31,1.047	V,A=9.493,1.039	
50.43 ohms	7724n H	4184p F	470n H	19179p F	27n H	17697p F	418n H	4645p F	3.75 MHz
-165.2 johms	200 Q	2K Q	200 Q	2K Q	200 Q	2K Q	200 Q	2K Q	50 Zo
80m\short_wide.s1p file	0 @MHz	0 @MHz	0 @MHz	0 @MHz	0 @MHz	0 @MHz	0 @MHz	0 @MHz	xMtch V
									0 a
									0 b
									0 c
									0 d
									Plots Plt

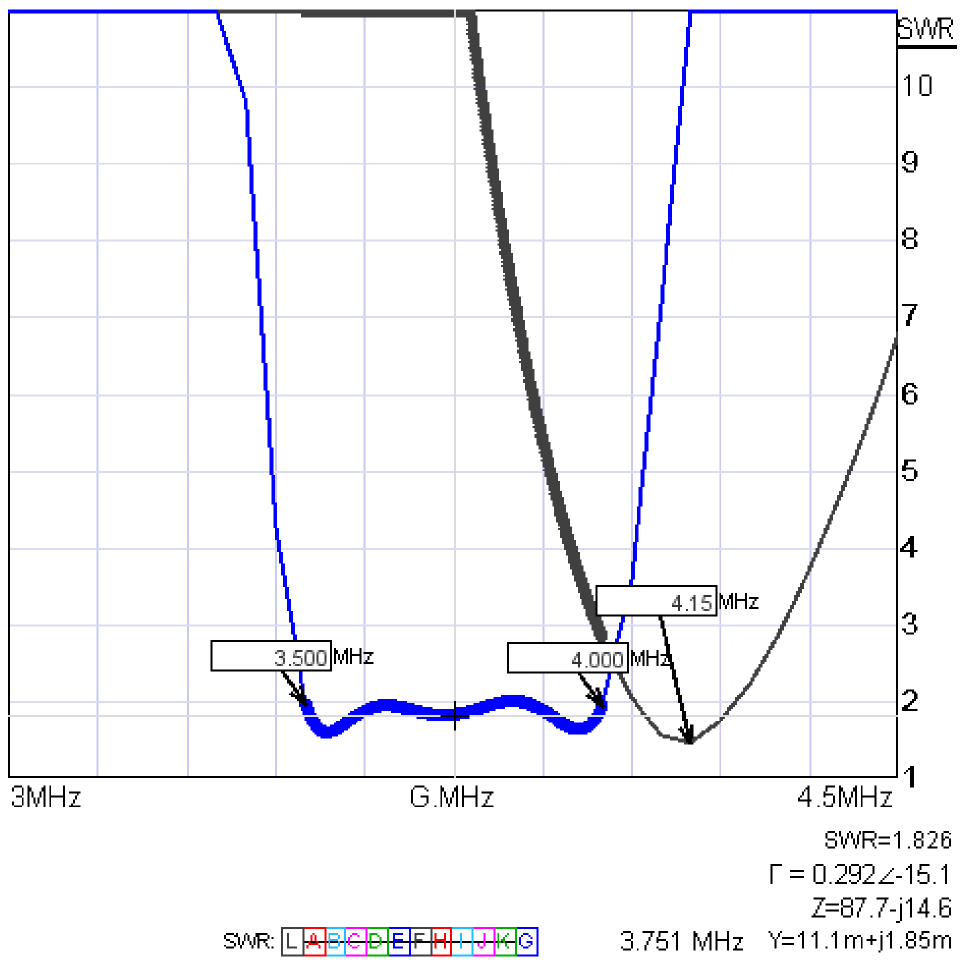
80m Inverted V Wire Dipole 100 foot (short) using LPS8 Circuit Topology (including 100 feet LMR400 from radio)



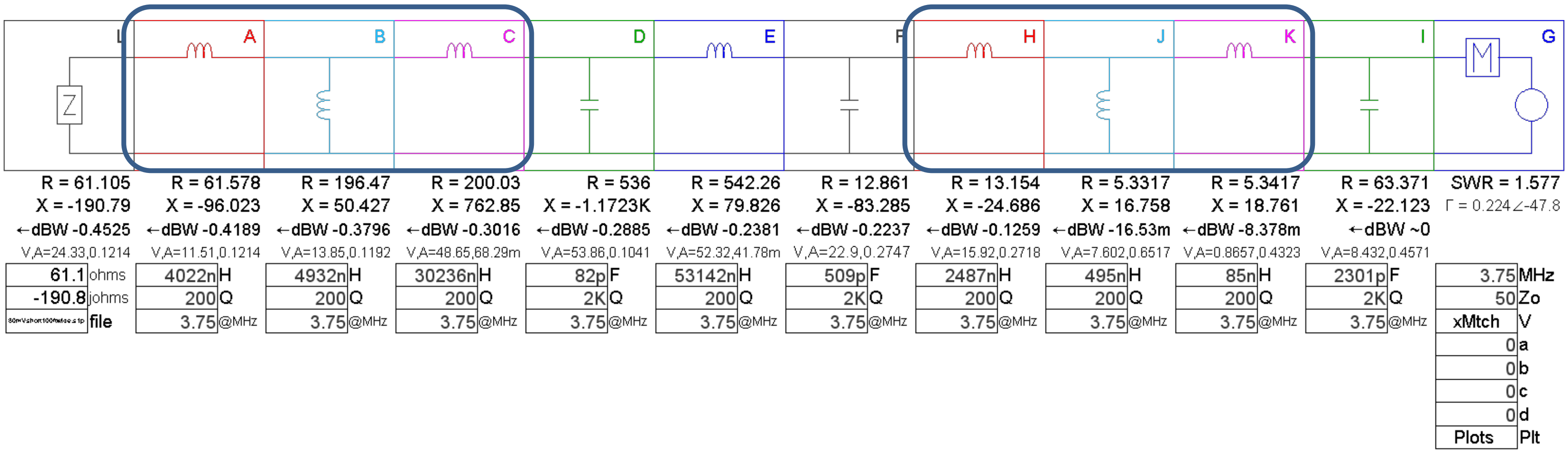
80m Inverted V Wire Dipole 100 foot (short) using WMB3 Circuit Topology Smith Chart



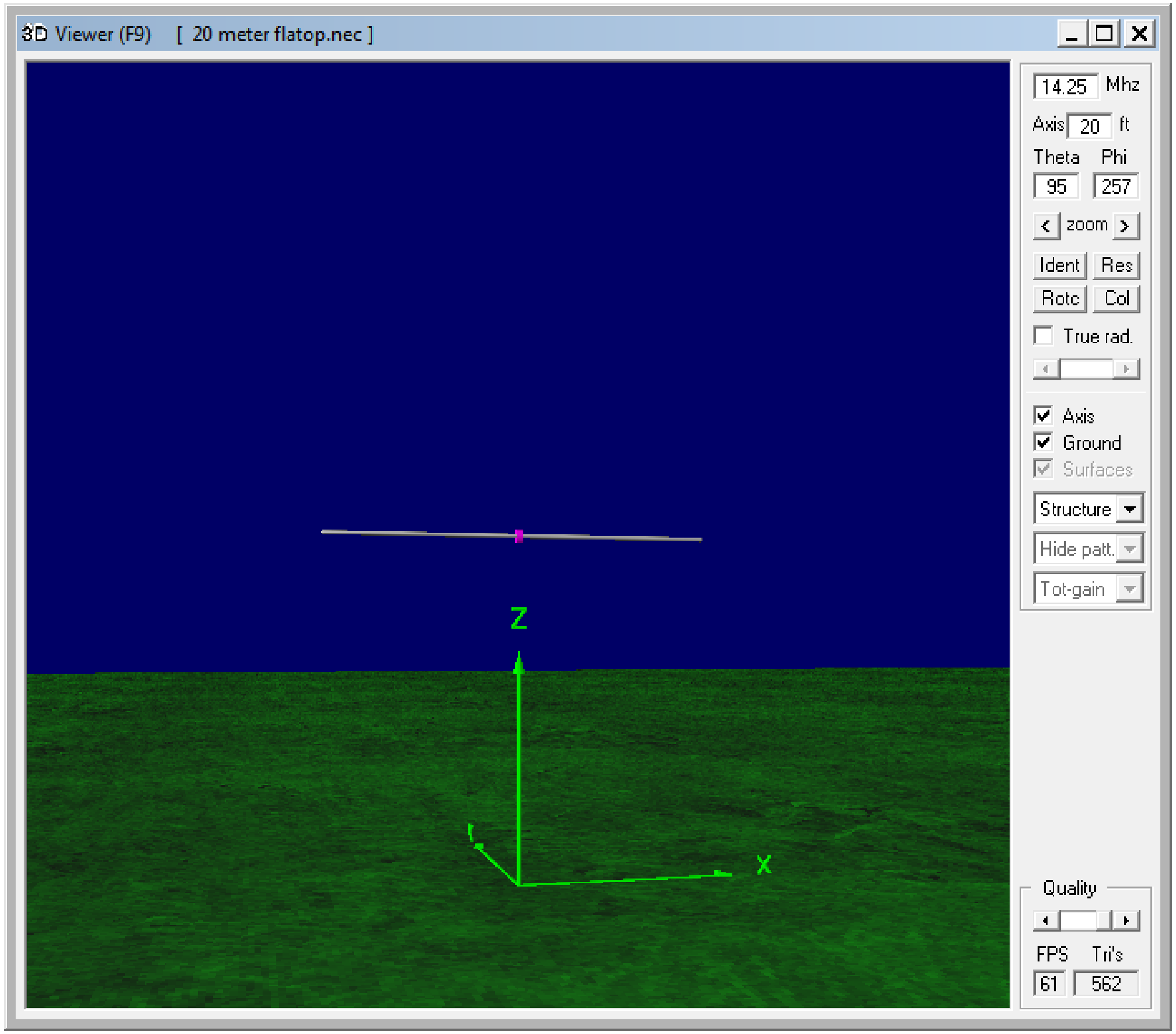
80m Inverted V Wire Dipole 100 foot (short) VSWR using WMB3 Circuit Topology



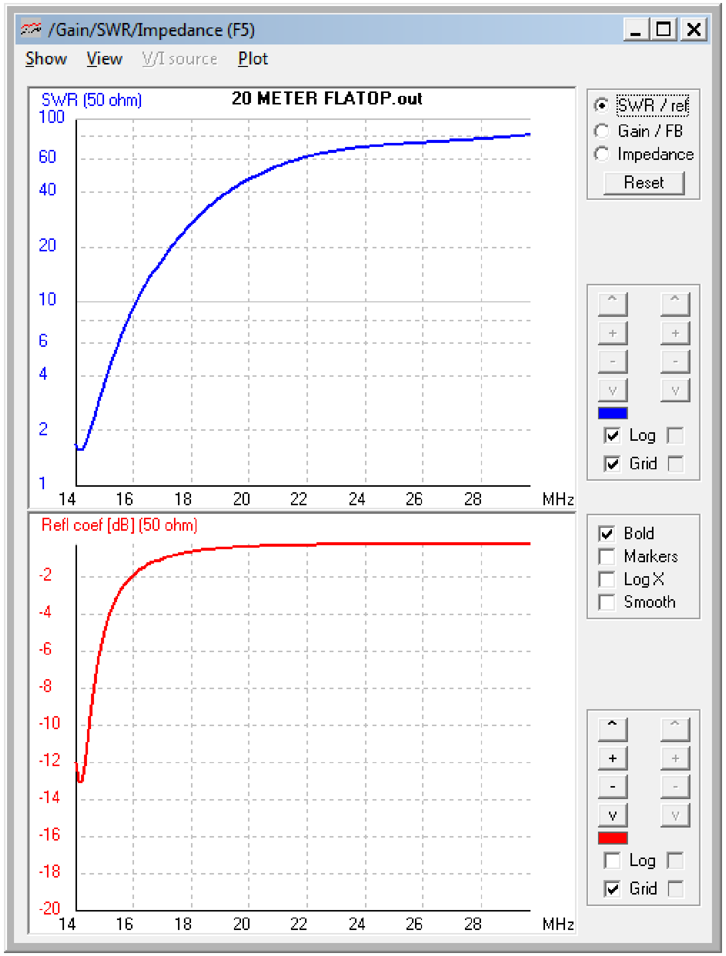
80m Inverted V Wire Dipole 100 foot (short) using WMB3 Circuit Topology

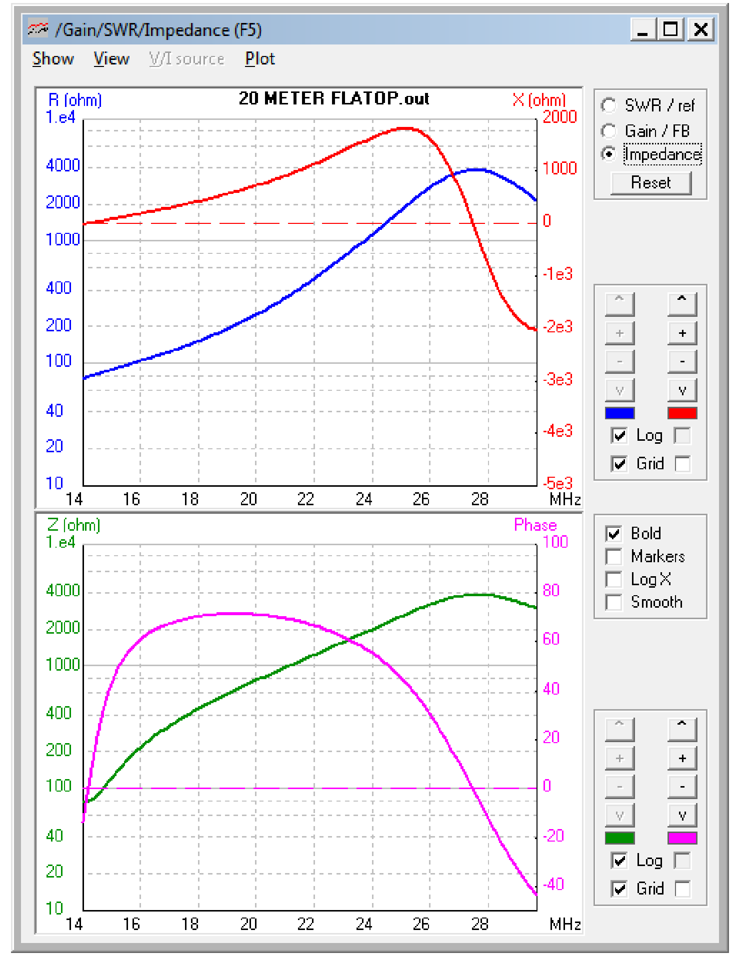


20 foot Flat Top Dipole

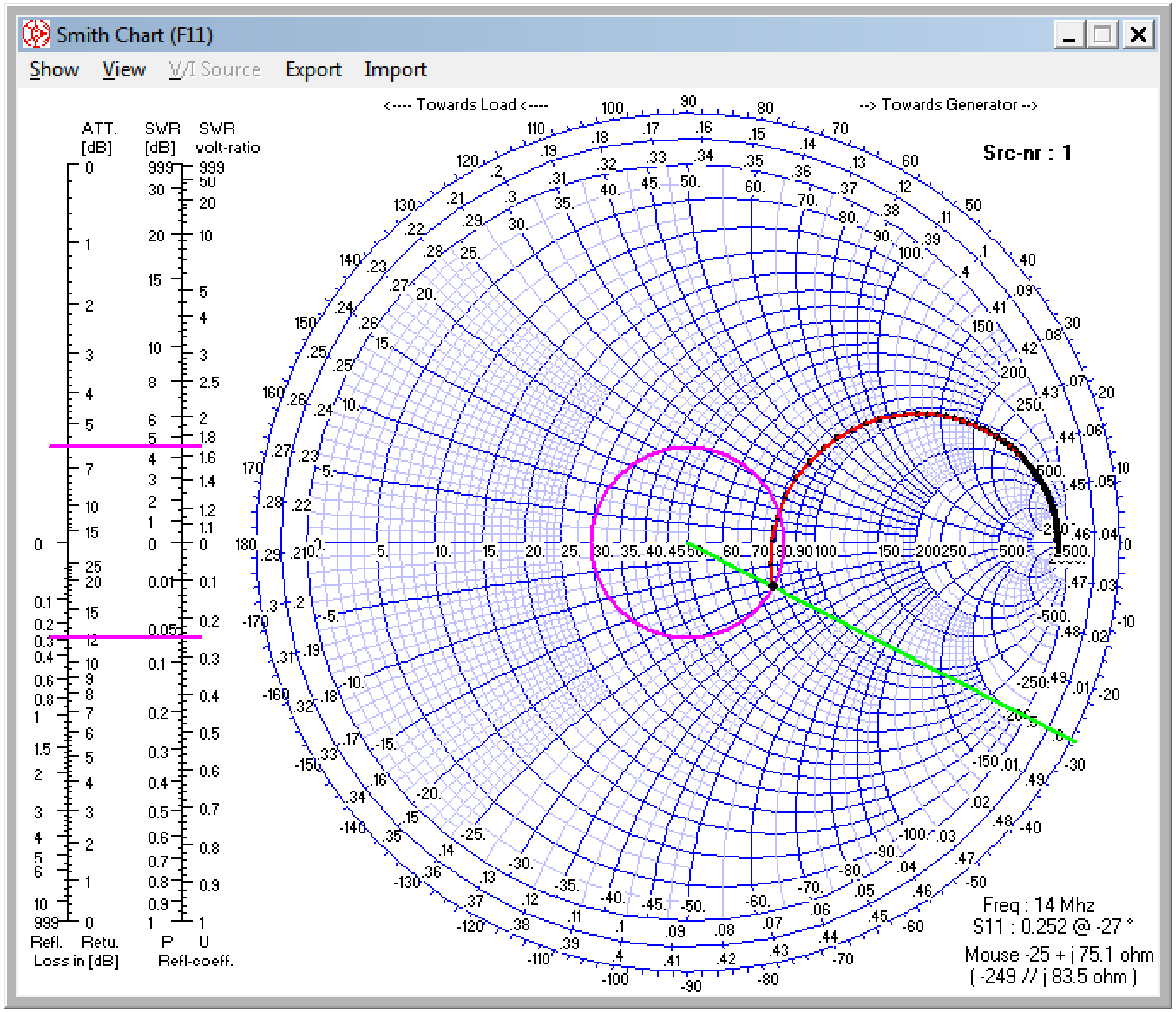


20 foot Flat Top Dipole
No Matching 20m through 10m

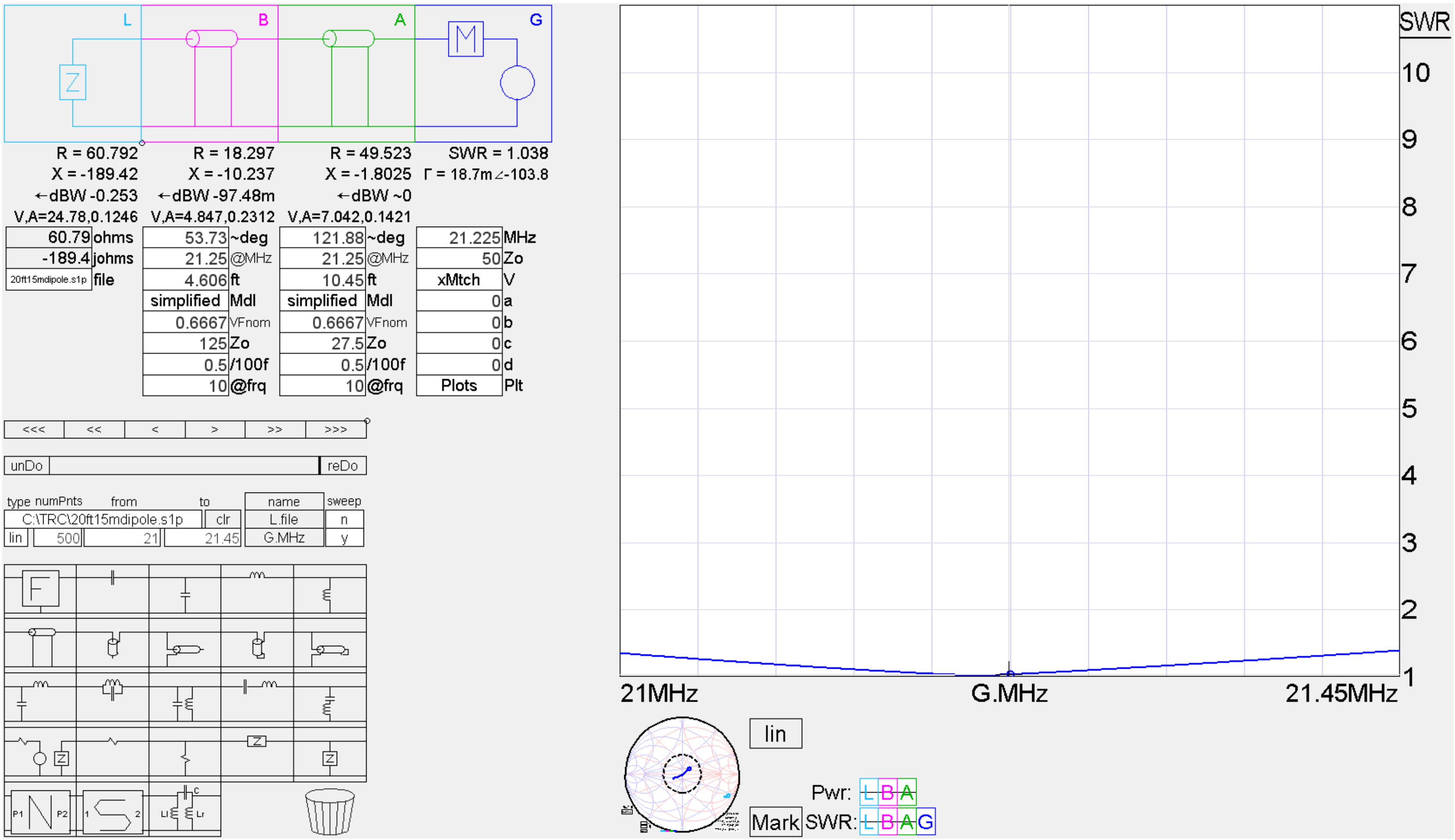




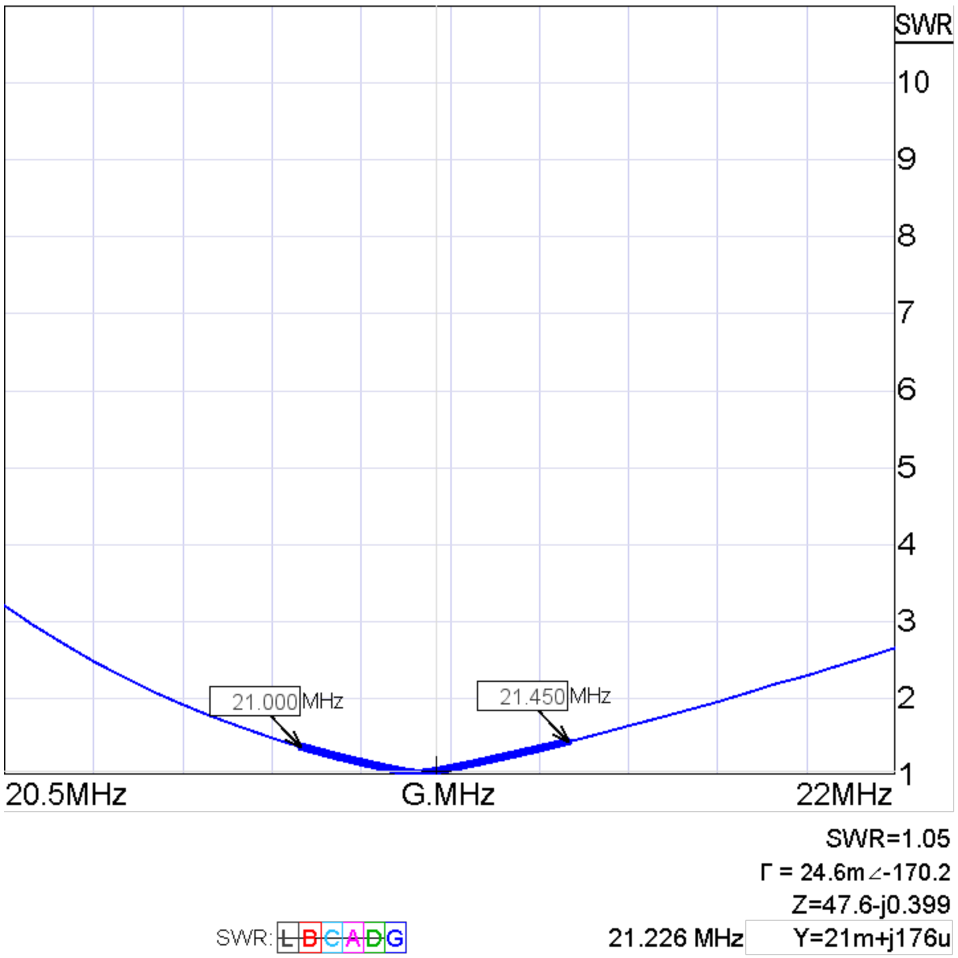
20 foot Flat Top Dipole
No Matching 20m through 10m



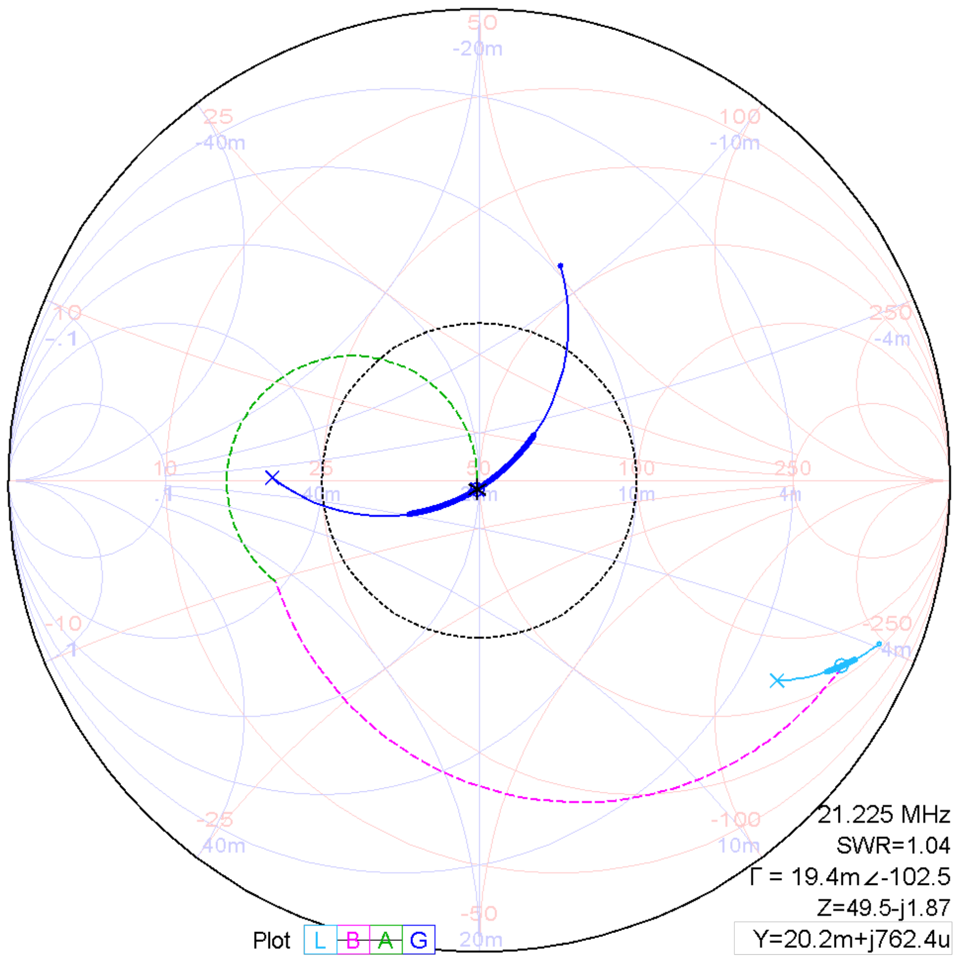
20 foot Flat Top Dipole
on 15 meters CASTL Circuit
using non-standard transmission lines



20 foot Flat Top Dipole
on 15 meters CASTL Circuit
using non-standard transmission lines VSWR

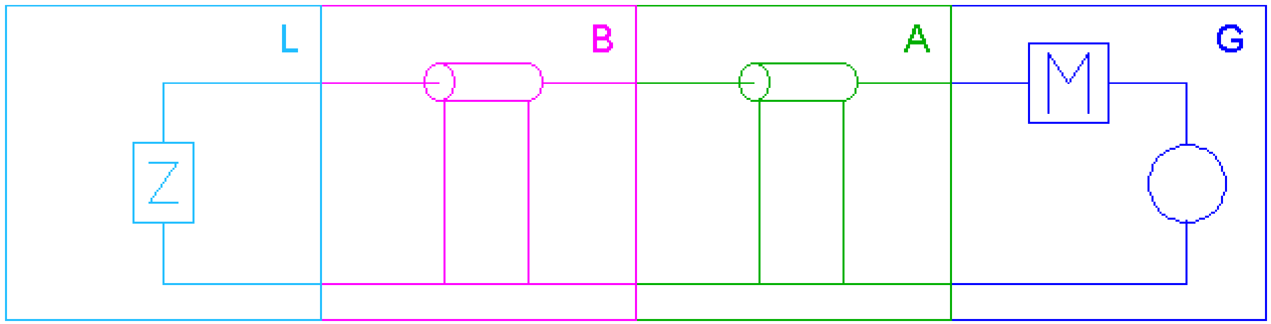


20 foot Flat Top Dipole on 15 meters CASTL Circuit using non-standard transmission lines Smith Chart



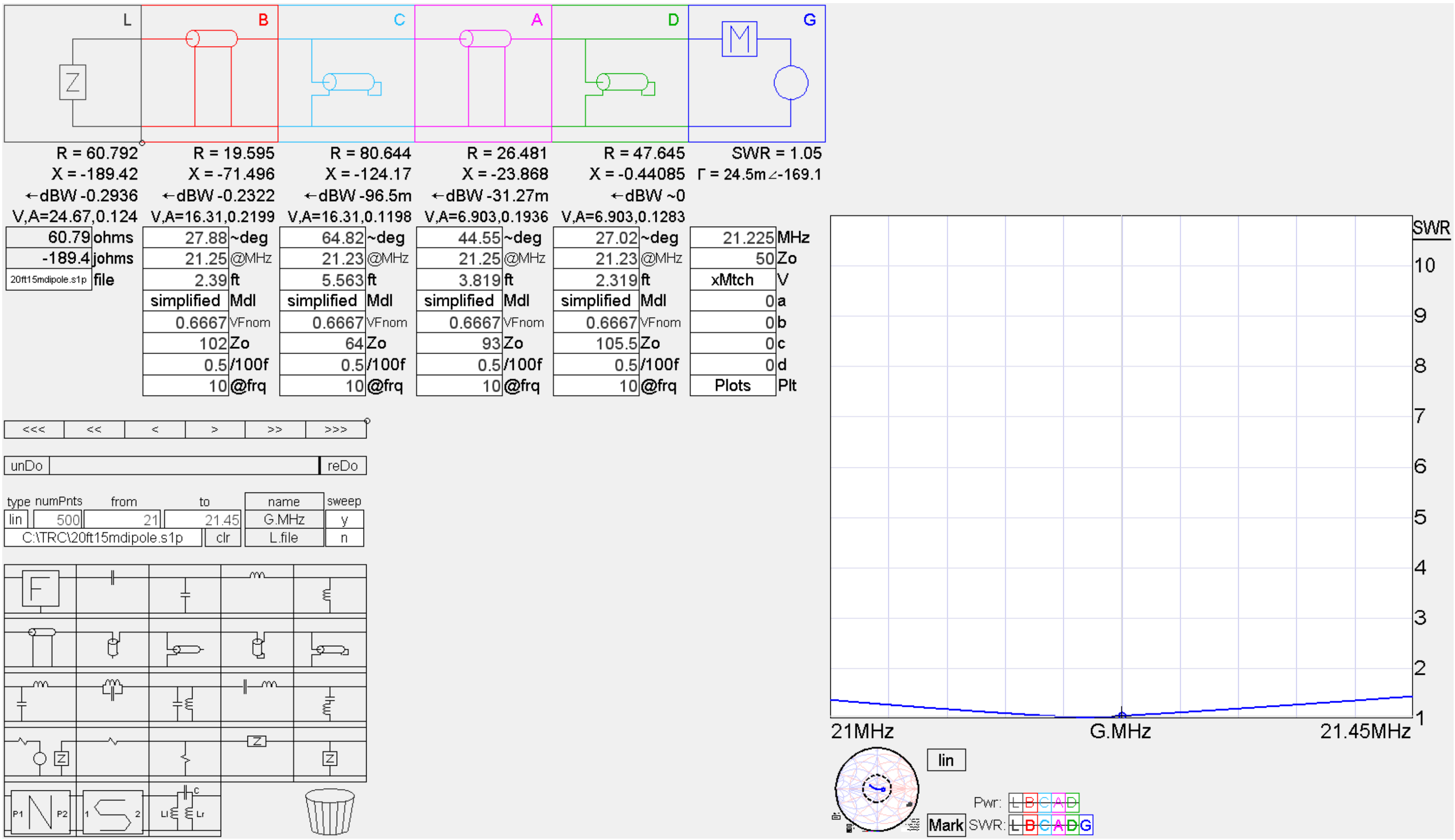
Note the path.

20 foot Flat Top Dipole 1000 Watt Power Handling on 15 meters CASTL Circuit using non-standard transmission lines

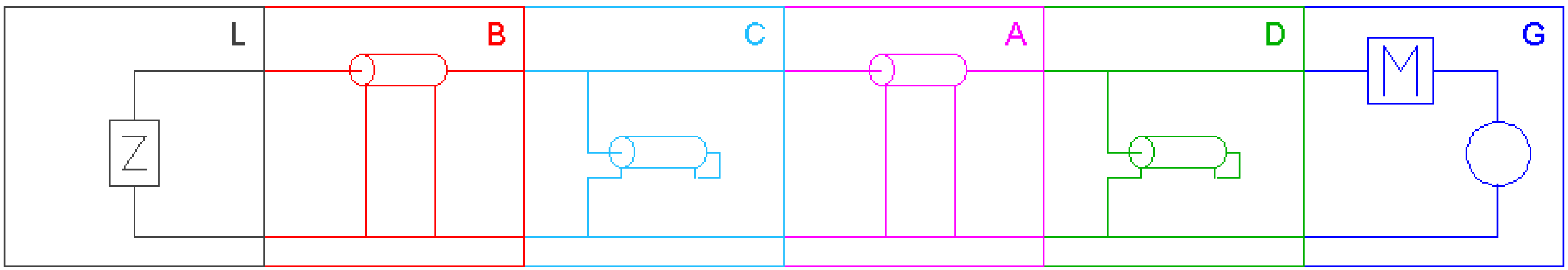


L		B		A		G	
R = 60.792		R = 18.297		R = 49.523		SWR = 1.038	
X = -189.42		X = -10.237		X = -1.8023		Γ = 18.7m∠-103.8	
↑W 943.4		↑W 34.38		↑W 22.2			
V,A=783.7,3.939		V,A=153.3,7.31		V,A=222.7,4.494			
60.79	ohms	53.73	~deg	121.88	~deg	21.225	MHz
-189.4	johms	21.25	@MHz	21.25	@MHz	50	Zo
20ft15mdipole_wide.s1p	file	4.606	ft	10.45	ft	xMtch(1000)	V
		simplified	Mdl	simplified	Mdl	0	a
		0.6667	VFnom	0.6667	VFnom	0	b
		125	Zo	27.5	Zo	0	c
		0.5	/100f	0.5	/100f	0	d
		10	@frq	10	@frq	Plots	Plt

20 foot Flat Top Dipole
on 15 meters CASTL Circuit
using non-standard transmission lines and stubs



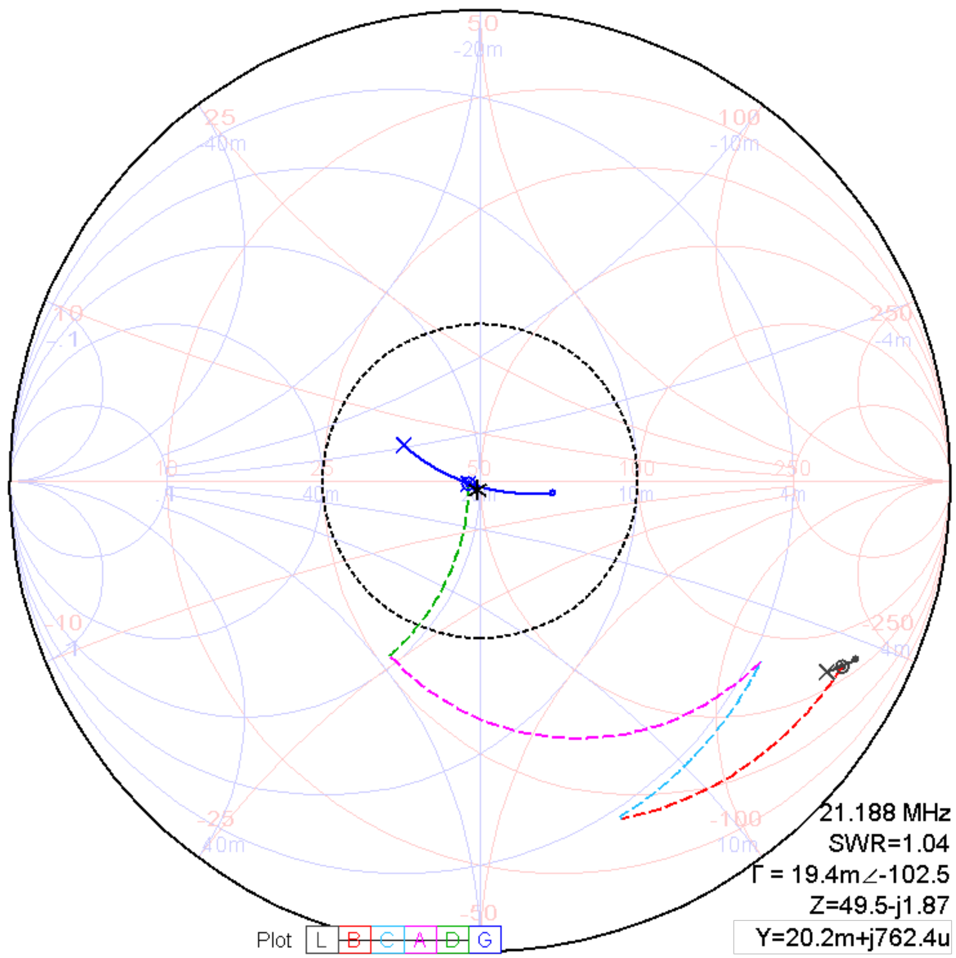
20 foot Flat Top Dipole 1000 Watt Power Handling on 15 meters CASTL Circuit transmission lines and stubs



R = 60.792	R = 19.594	R = 80.616	R = 26.478	R = 47.617	SWR = 1.051
X = -189.42	X = -71.491	X = -124.15	X = -23.852	X = -0.44664	Γ = 24.8m∠-169.1
↑W 934.6	↑W 13.3	↑W 30.09	↑W 14.8	↑W 7.171	
V,A=780,3.921	V,A=515.6,6.955	V,A=515.6,3.787	V,A=218.2,6.123	V,A=218.2,4.056	

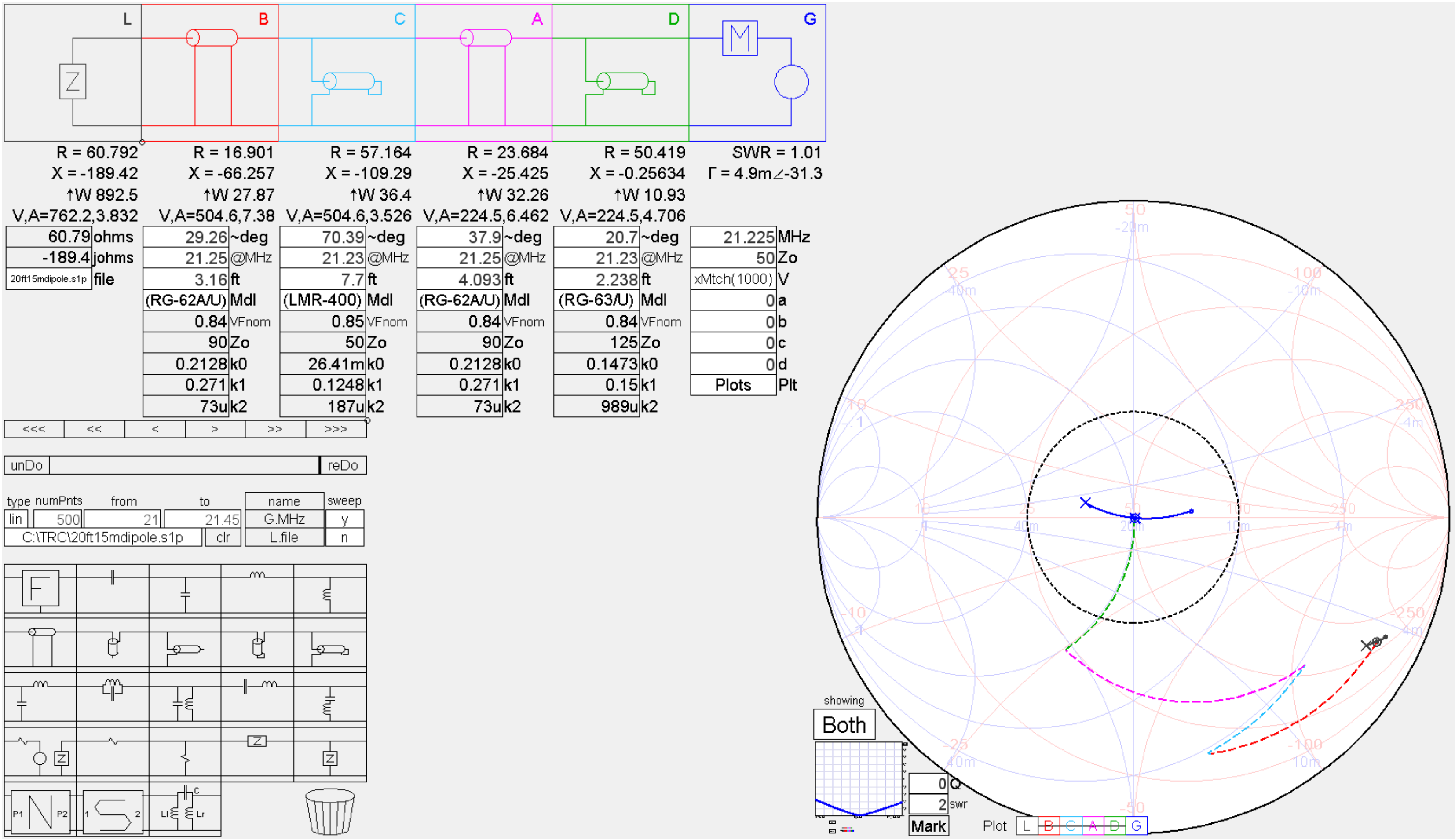
60.79	ohms	27.88	~deg	64.82	~deg	44.55	~deg	27.02	~deg	21.225	MHz
-189.4	johms	21.25	@MHz	21.23	@MHz	21.25	@MHz	21.23	@MHz	50	Zo
20ft15mdipole.s1p	file	2.39	ft	5.563	ft	3.819	ft	2.319	ft	xMtch(1000)	V
		simplified	Mdl	simplified	Mdl	simplified	Mdl	simplified	Mdl	0	a
		0.6667	VFnom	0.6667	VFnom	0.6667	VFnom	0.6667	VFnom	0	b
		102	Zo	64	Zo	93	Zo	105.5	Zo	0	c
		0.5	/100f	0.5	/100f	0.5	/100f	0.5	/100f	0	d
		10	@frq	10	@frq	10	@frq	10	@frq	Plots	Plt

20 foot Flat Top Dipole on 15 meters CASTL Circuit transmission lines and stubs Smith Chart



Note the path.

20 foot Flat Top Dipole on 15 meters CASTL Circuit using Commercially Available Transmission Lines



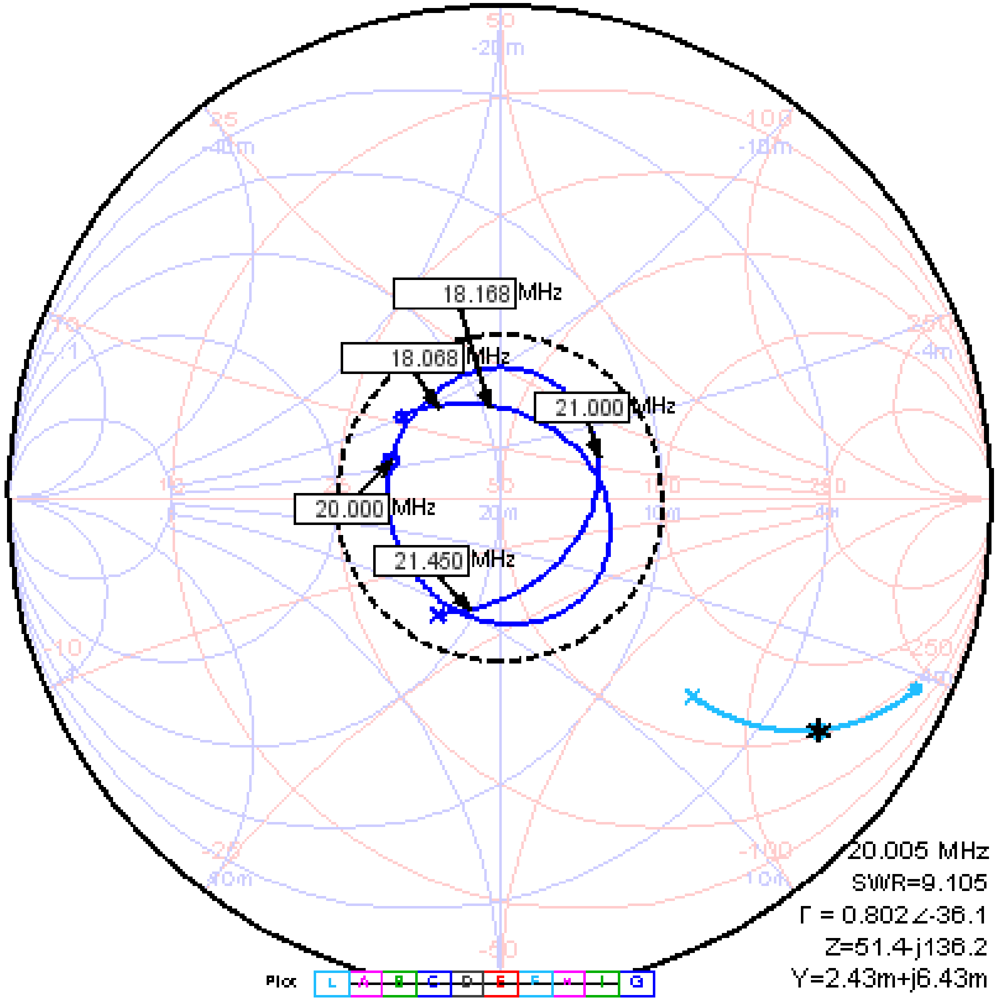
Multi-Band Equalizer

Single Equalizer Circuit

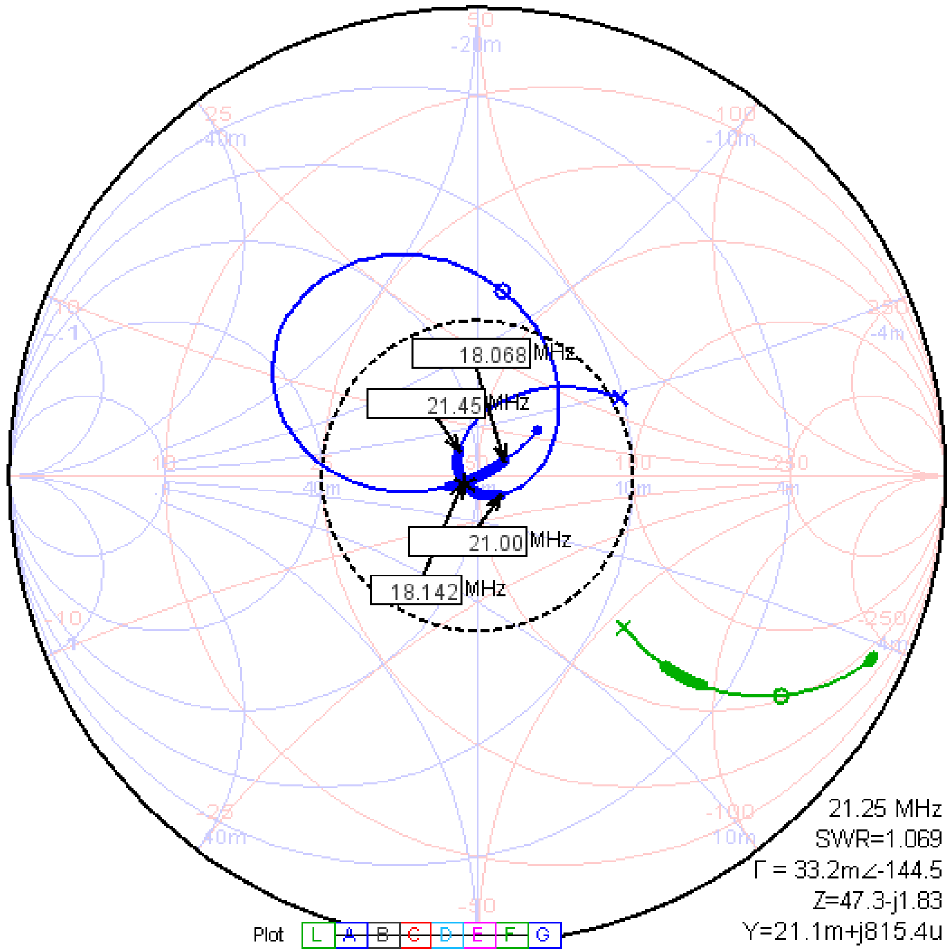
- Fixed value elements
- All lumped L & C elements

Single non-resonant antenna

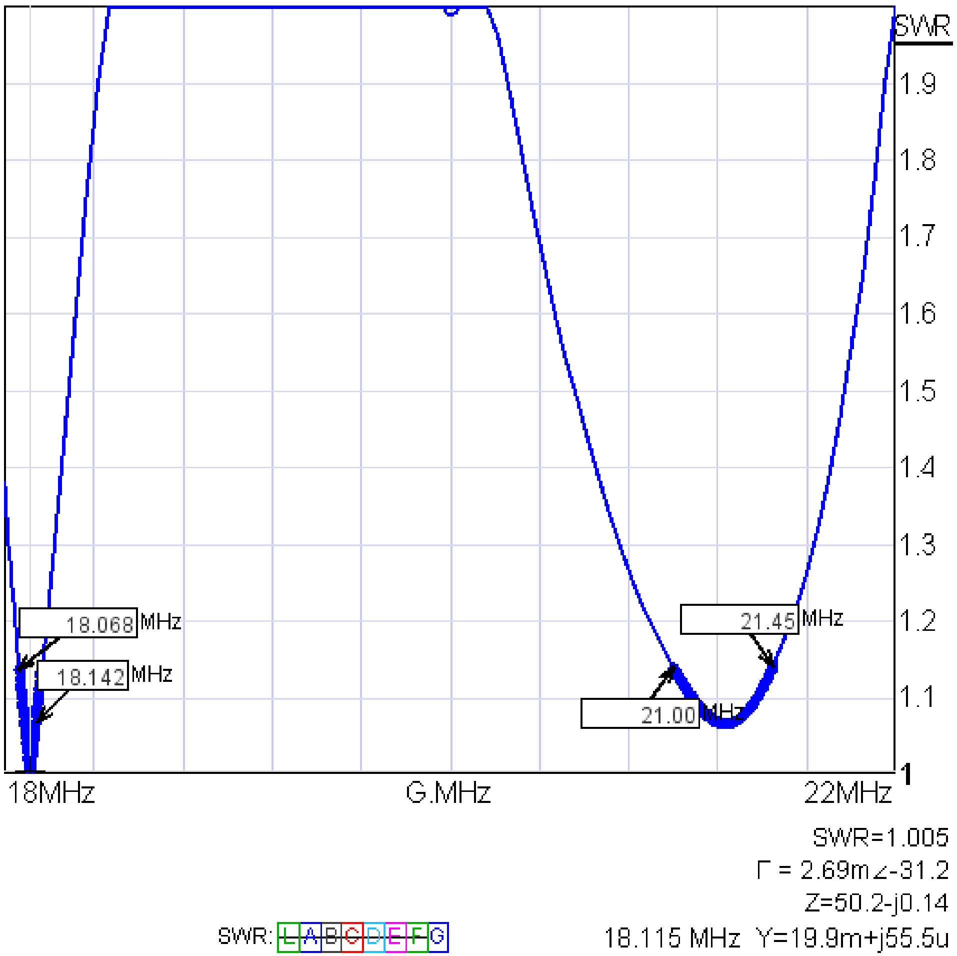
20 foot Flat Top Dipole
17m through 15m Continuous Match
using LPS8 Circuit Topology Smith Chart



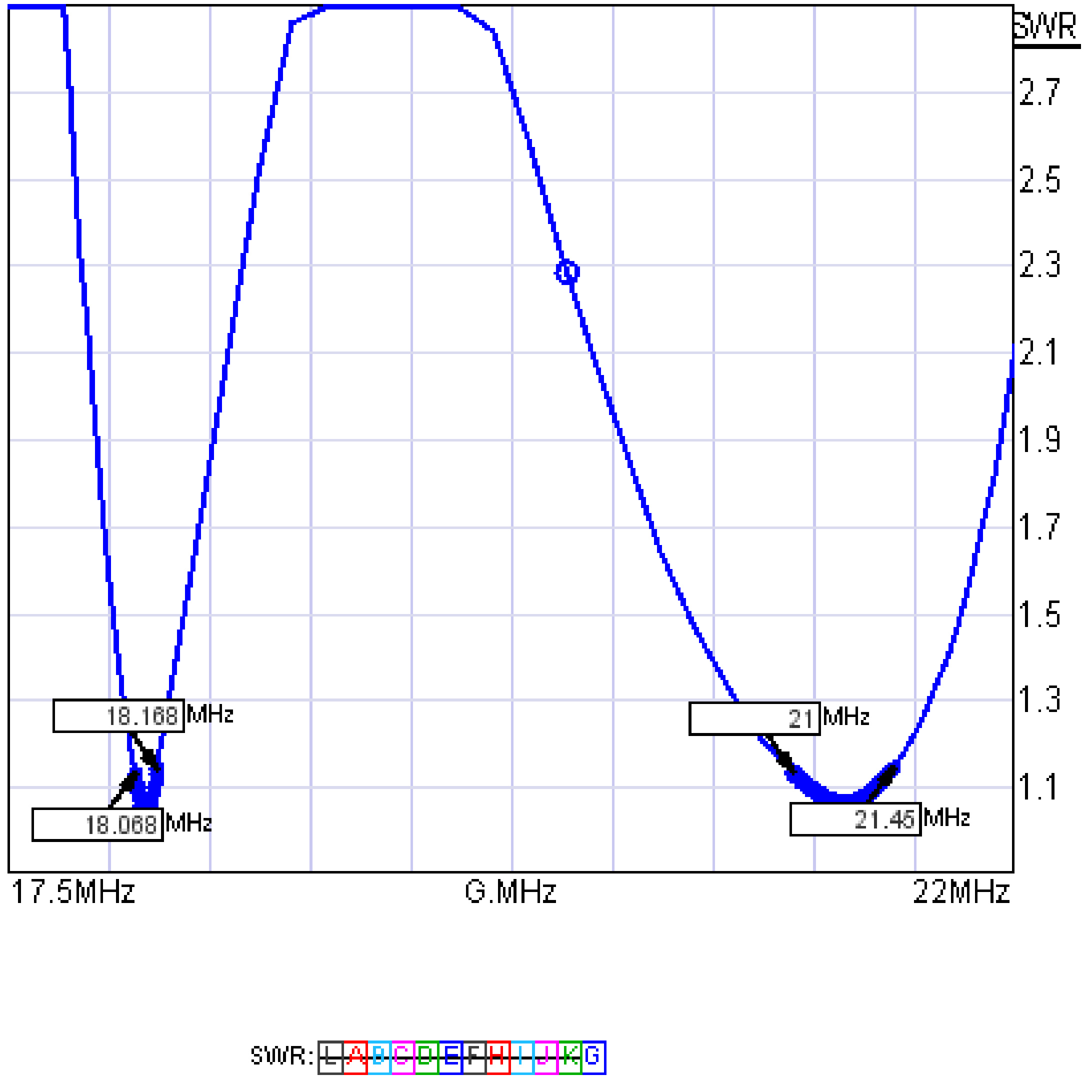
20 foot Flat Top Dipole
17m and 15m Dual Band Match using
Single LPS6 Circuit Topology Smith Chart



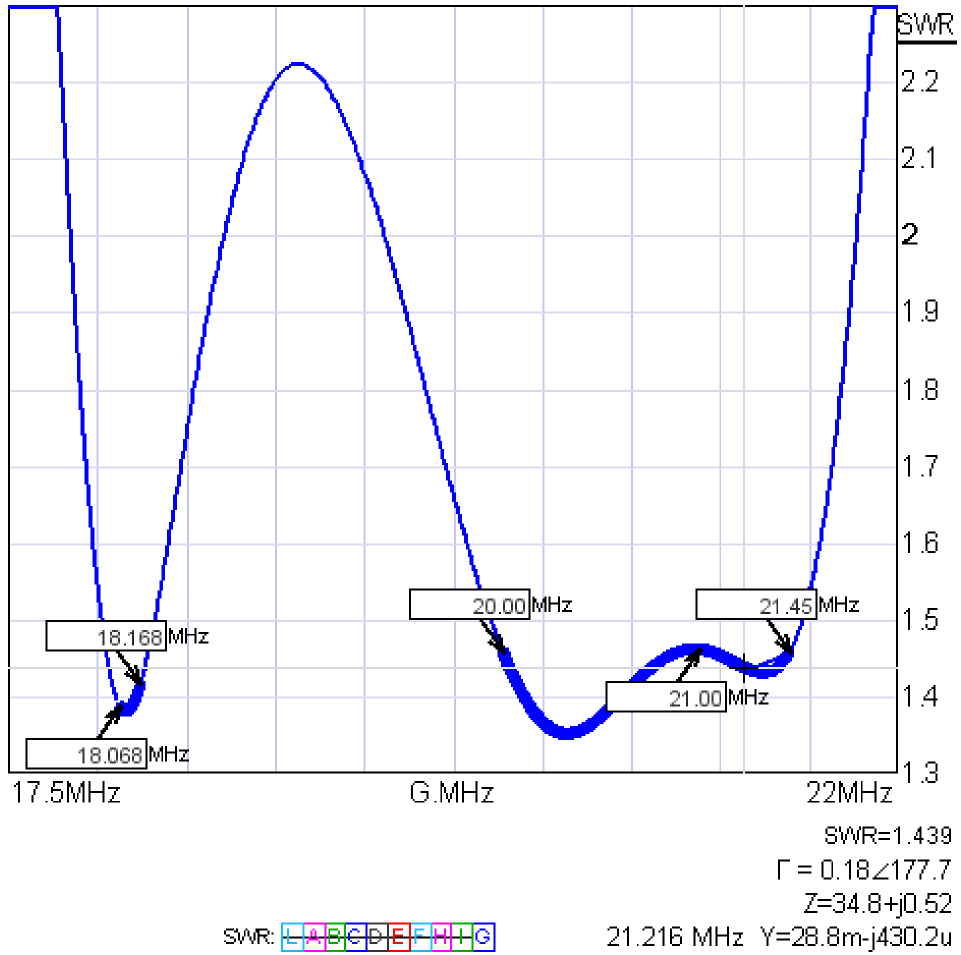
20 foot Flat Top Dipole
17m and 15m Dual Band Match using
Single LPS6 Circuit Topology VSWR



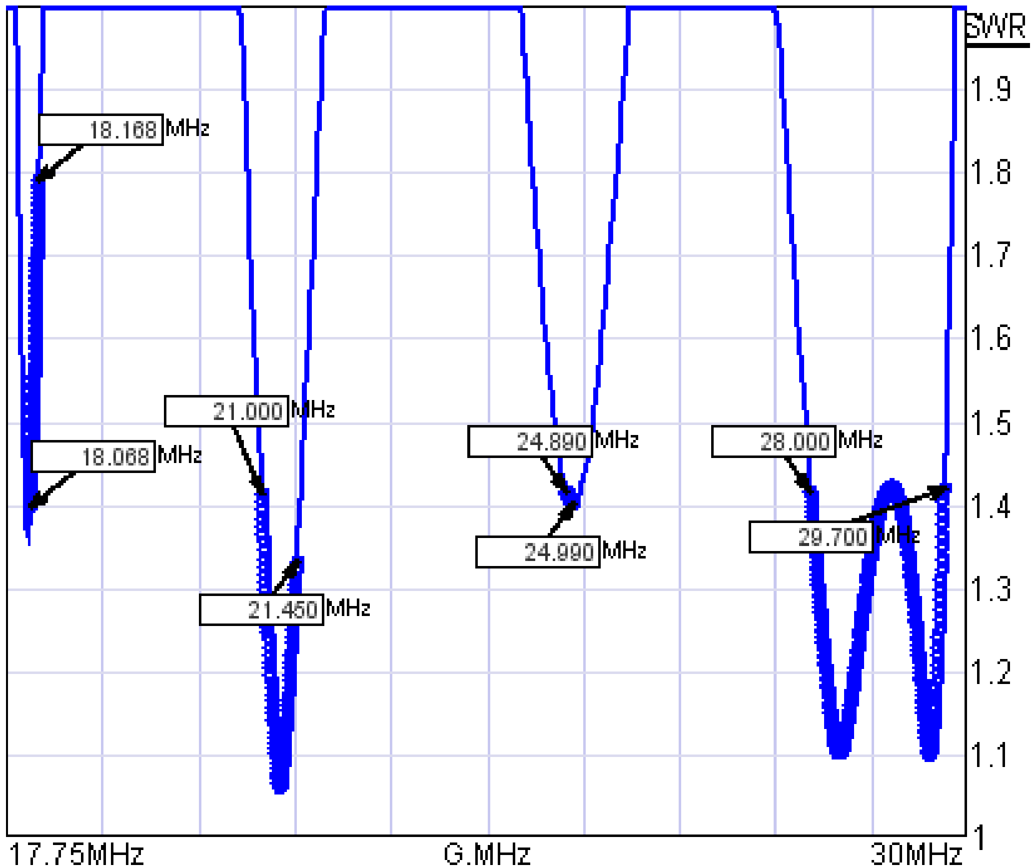
20 foot Flat Top Dipole
17m and 15m Dual Band Match using **Single** LPS10 Circuit Topology VSWR



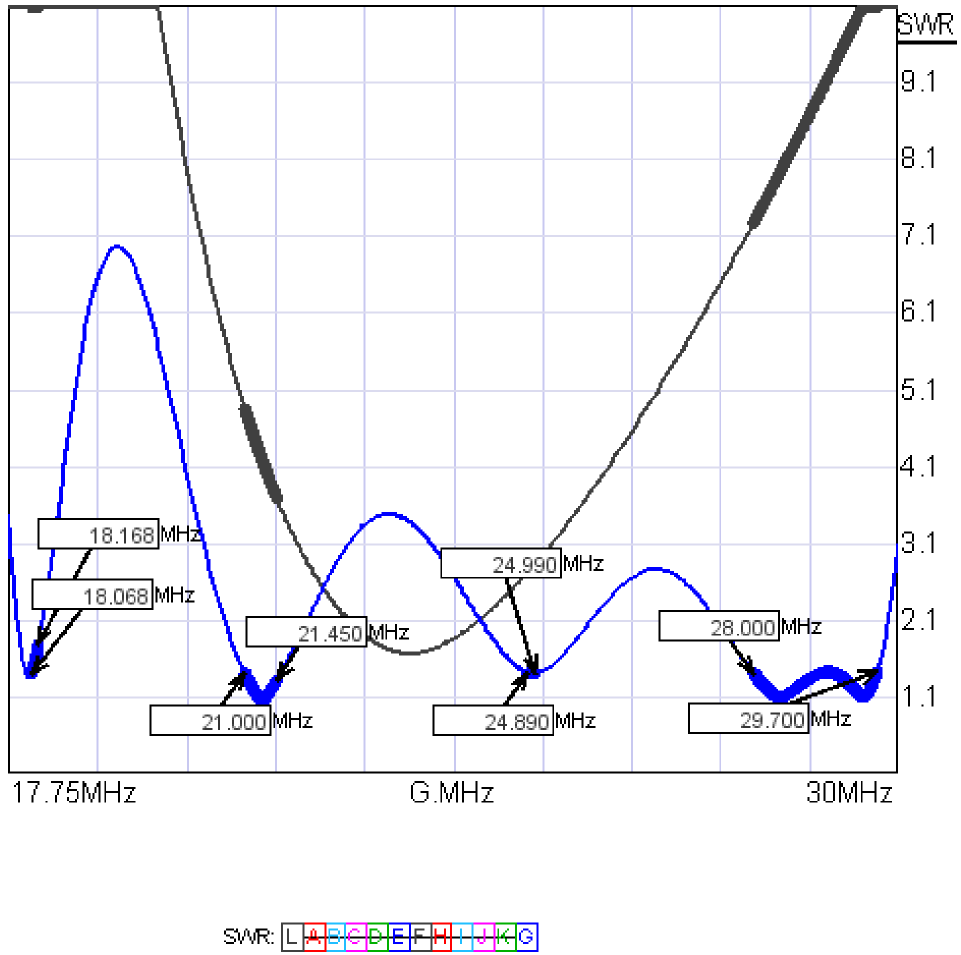
20 foot Flat Top Dipole
17m, 15m, & 20 MHz WWV Match using
Single LPS8 Circuit Topology VSWR



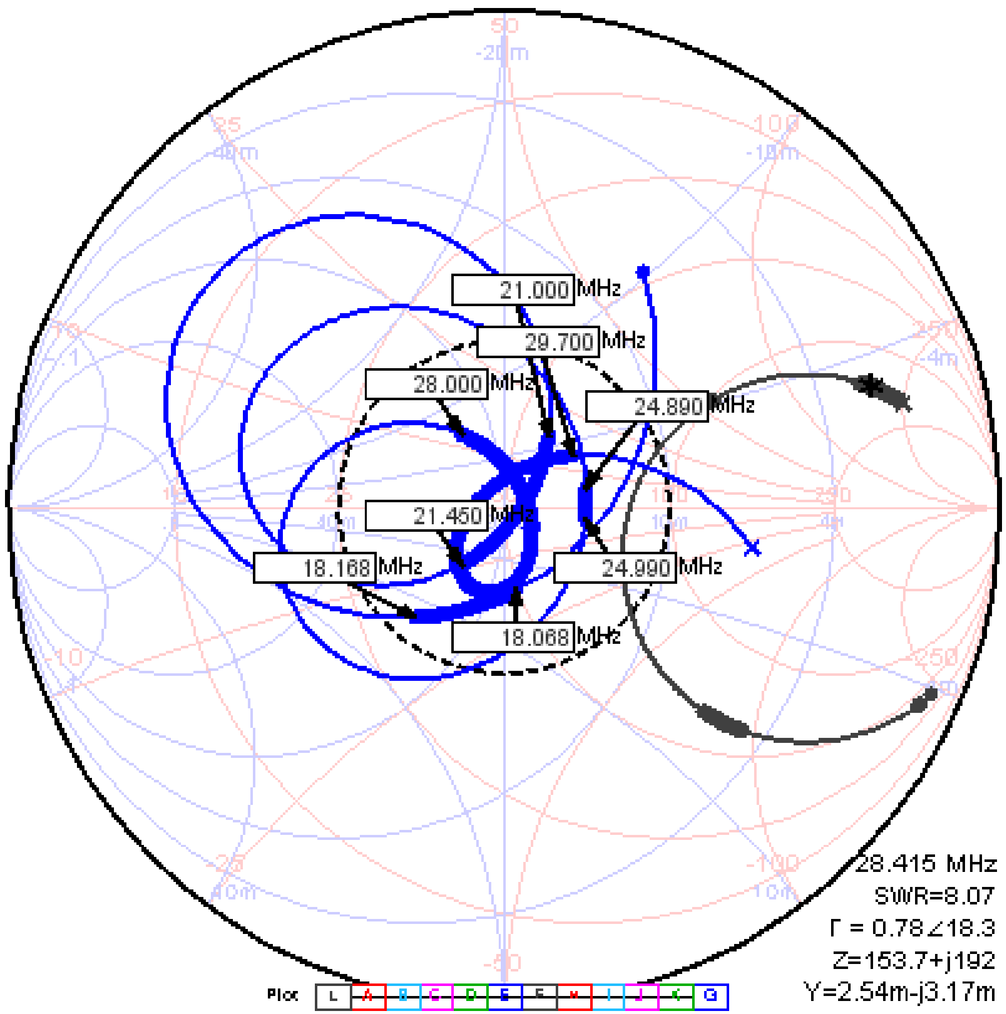
20 foot Flat Top Dipole
4 Band Match using Single LPS10 Circuit Topology
17m, 15m, 12m, & 10m Bands VSWR



20 foot Flat Top Dipole
4 Band Match using Single LPS10 Circuit Topology
17m, 15m, 12m, & 10m Bands VSWR



20ft Flat Top Dipole on 4 bands
17m, 15m, 12m, & 10m bands Smith Chart



ZNET Circuit Topology Modification Algorithm

ZNET has a circuit topology modification algorithm that can automatically “prune” circuit elements to improve the impedance match.

Eliminating Components using Bounded Constraints

High-Pass "T" circuit topology example.

Non-resonant antenna example.

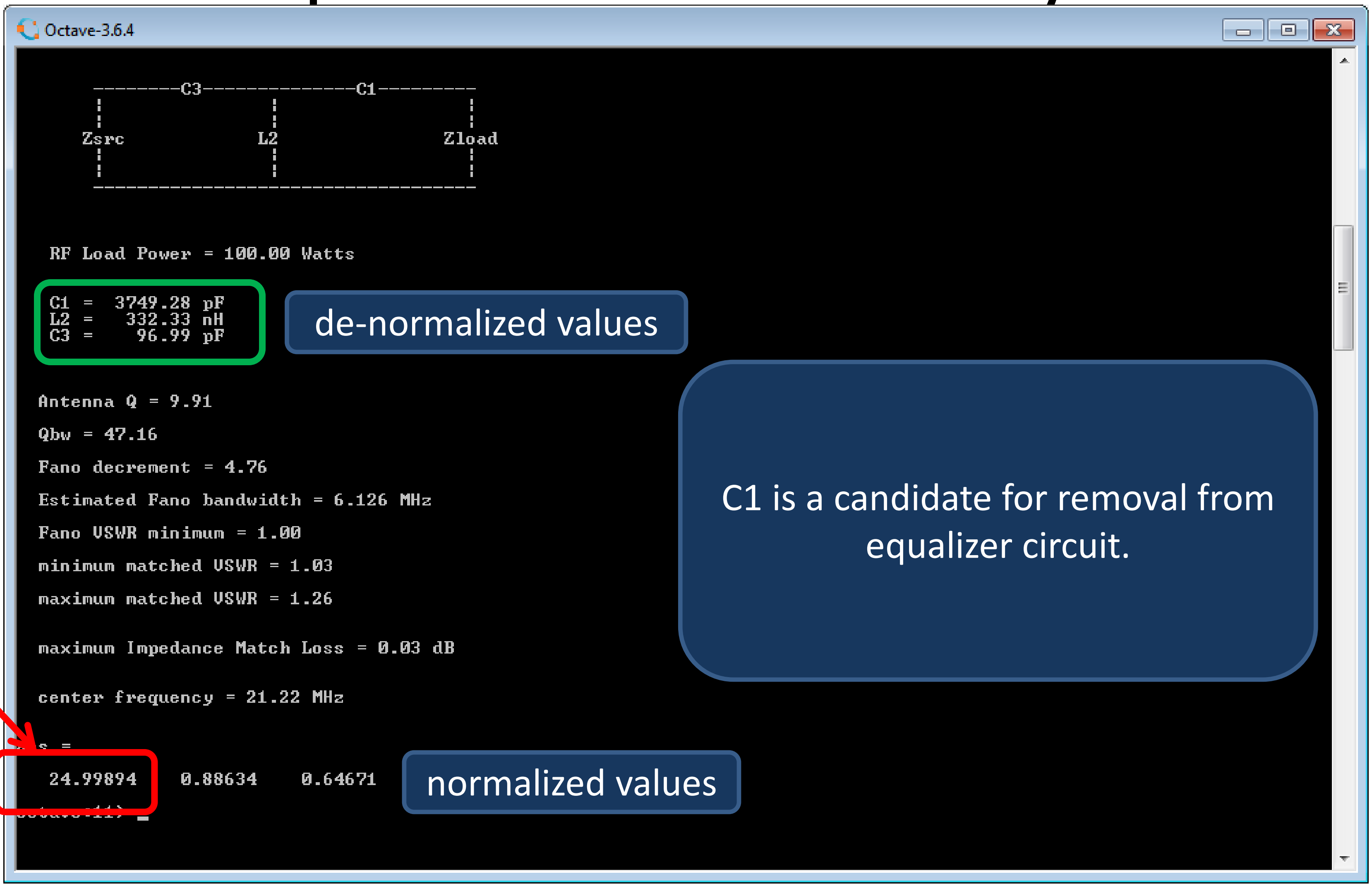
- 10 foot monopole across 15 meter band.

Compute using bounded optimization constraints,

Compute with extended optimization constraints,

Add a circuit element "pruning" optimization algorithm.

C1 Value @ Upper Optimization Boundary

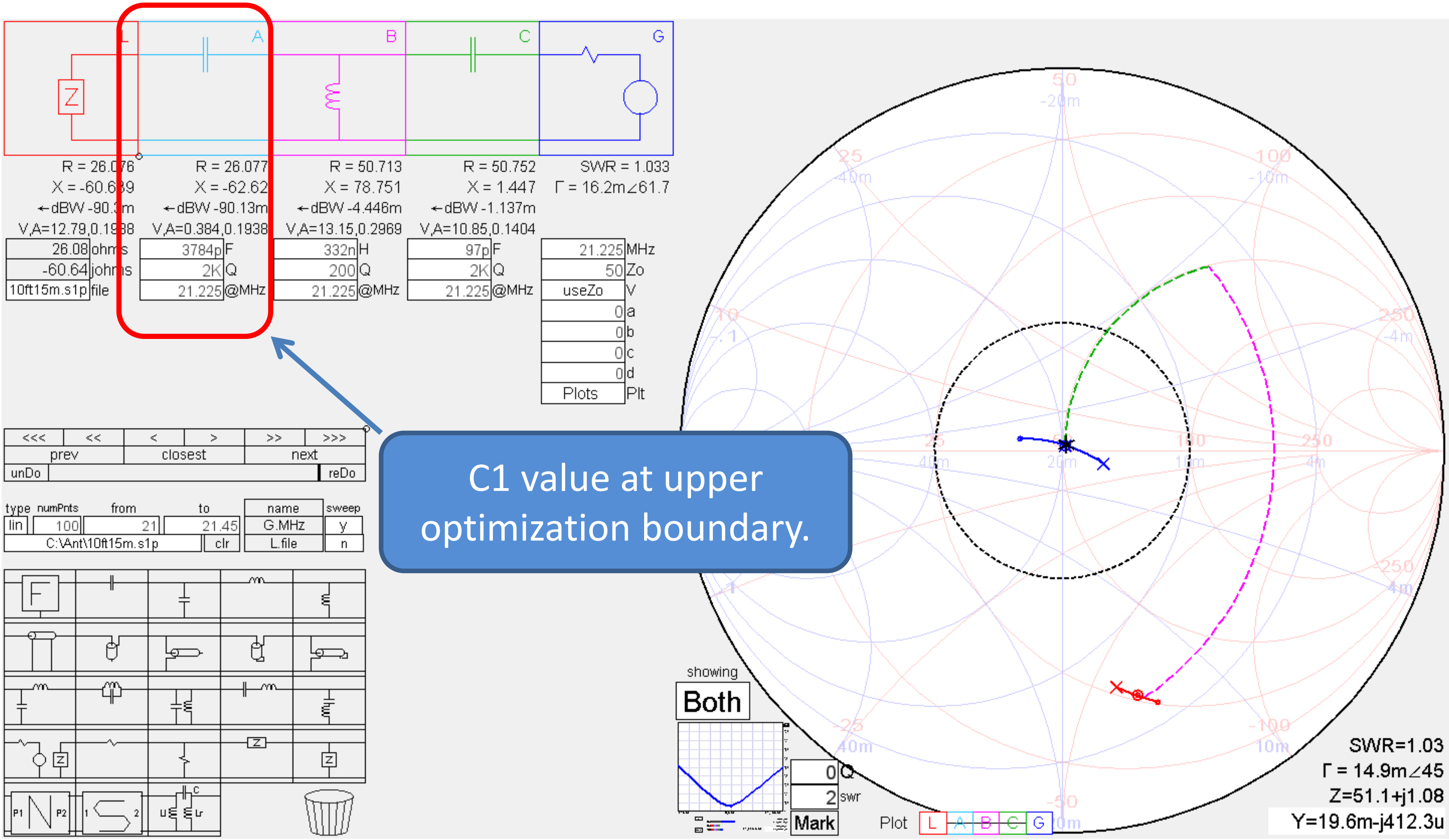


de-normalized values

C1 is a candidate for removal from equalizer circuit.

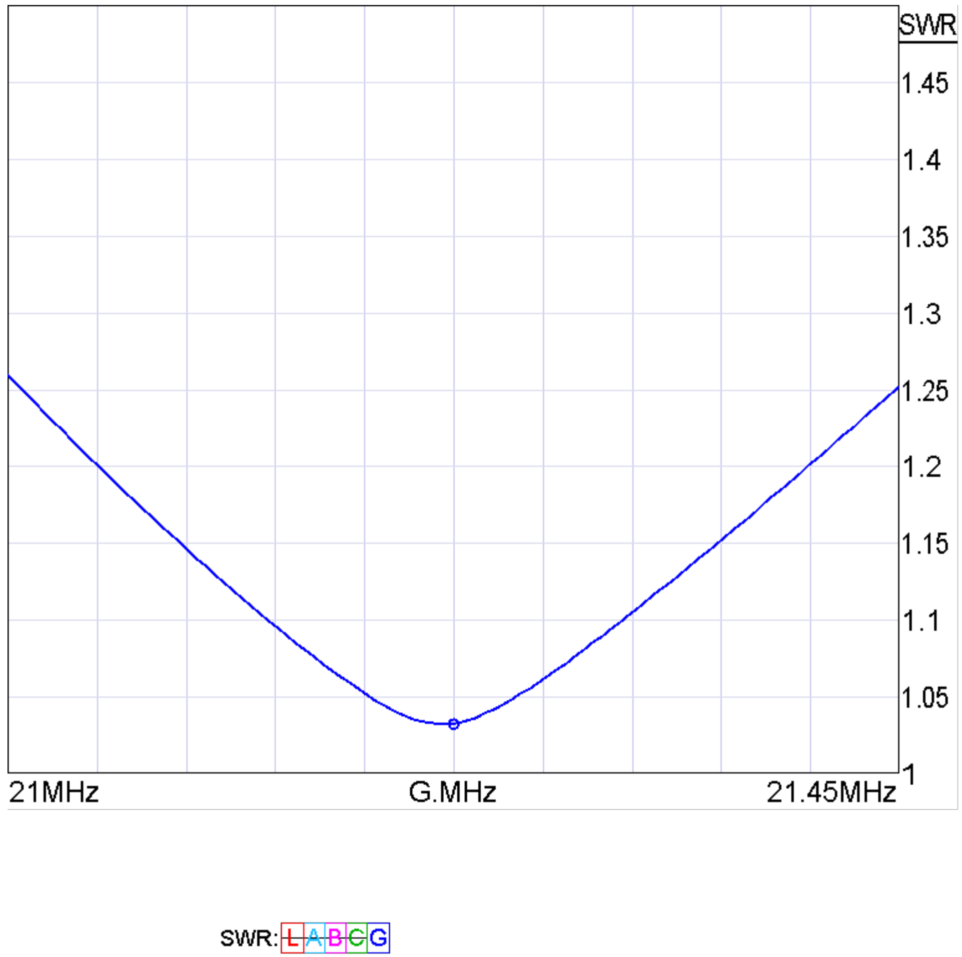
normalized values

“T” Circuit Solution Including C1

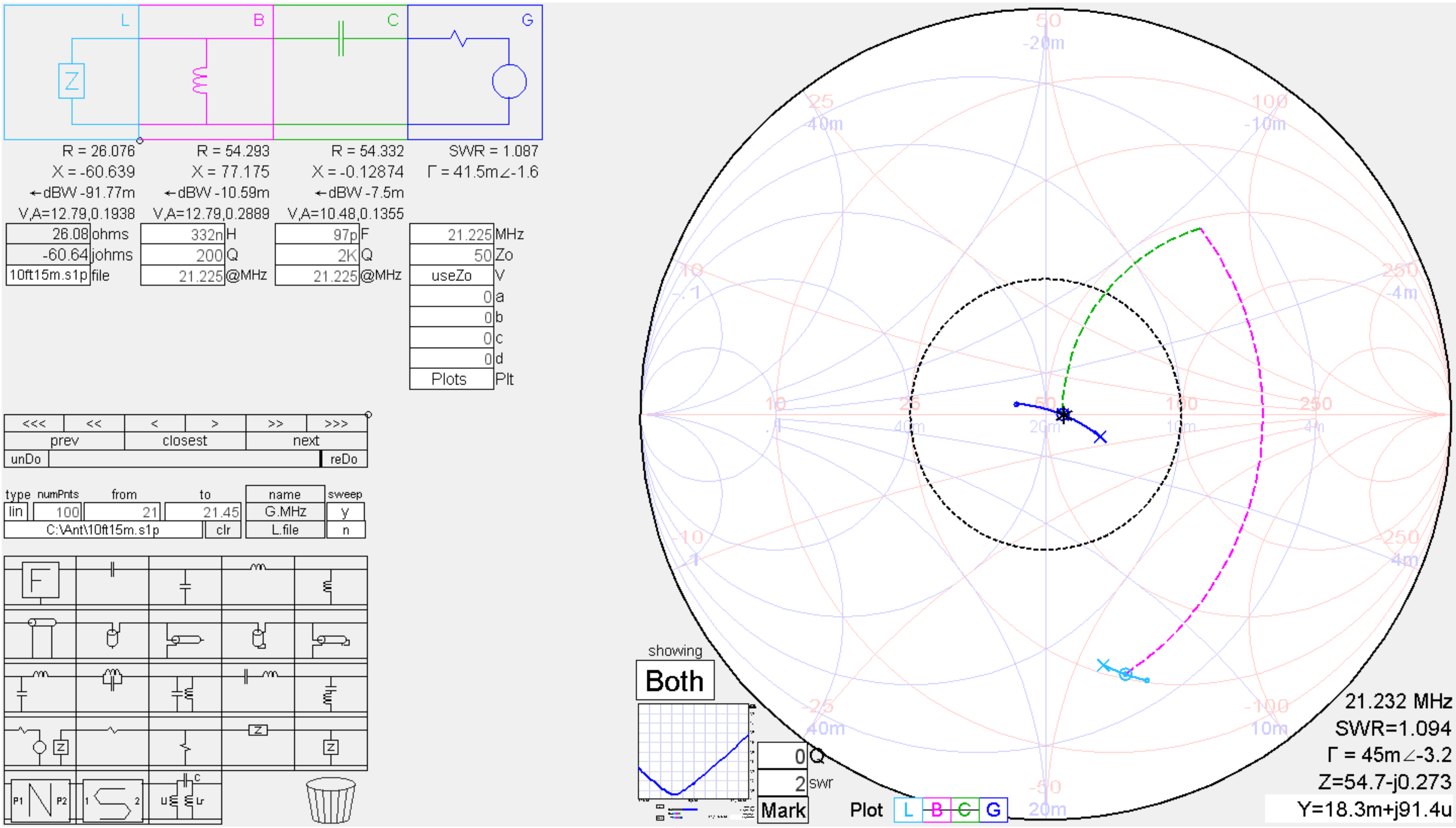


C1 value at upper optimization boundary.

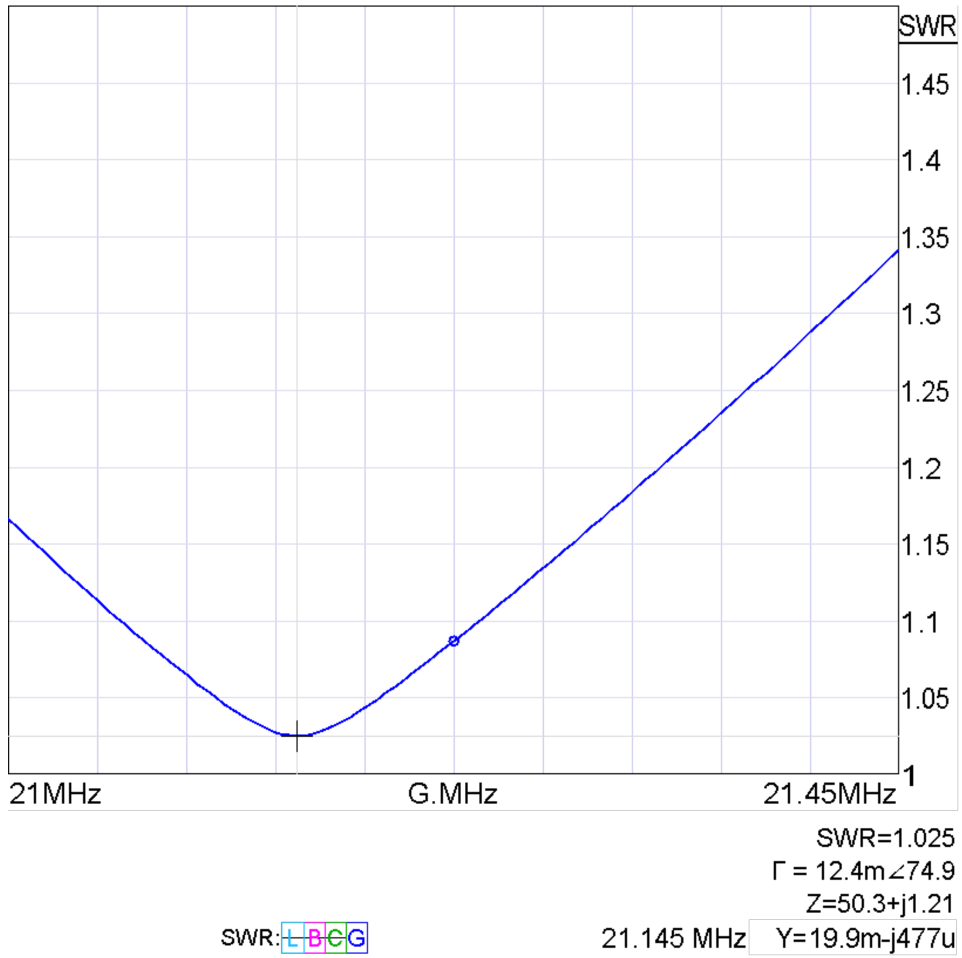
“T” Circuit Solution VSWR with C1



“T” Circuit Solution with C1 Removed



“T” Circuit Solution VSWR without C1



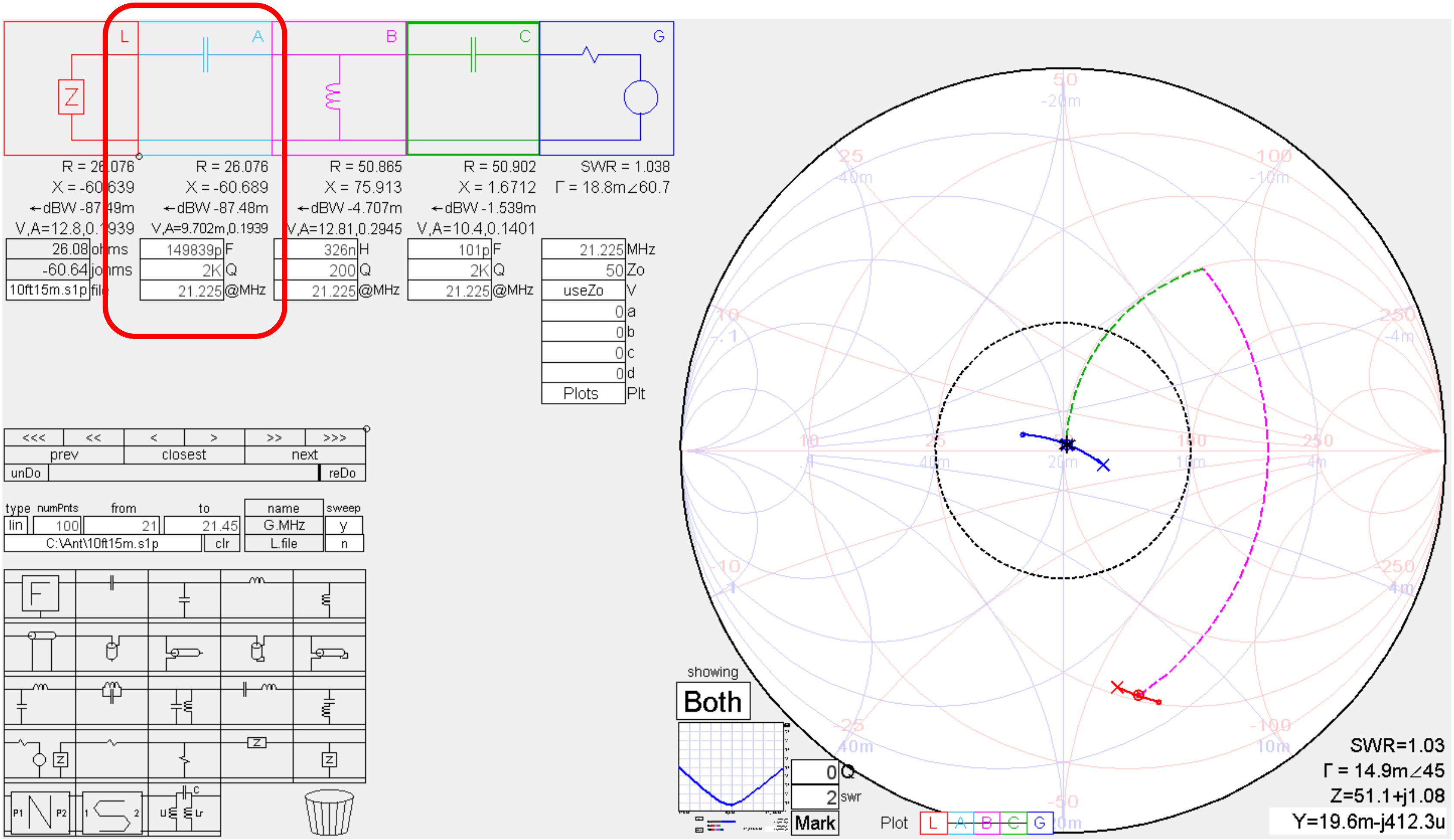
Extended C1 Upper Boundary

Octave-3.6.4

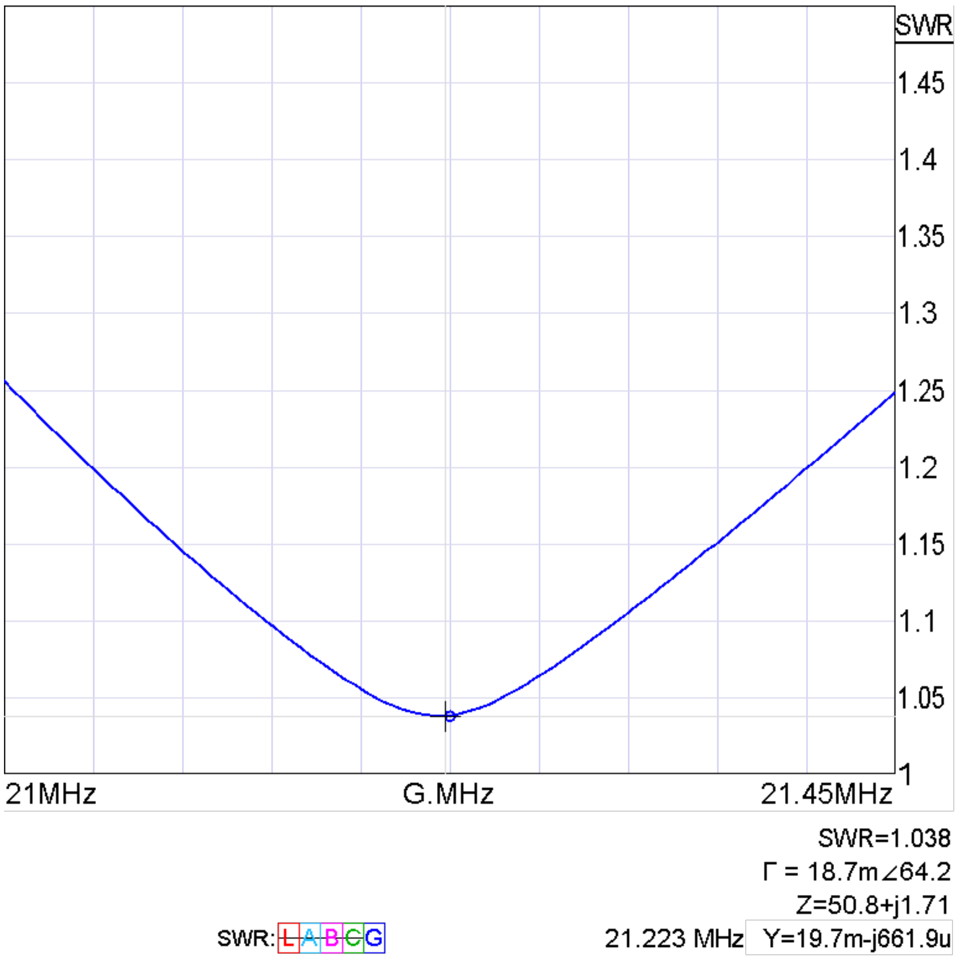
```
Optimization computation time =   1.92 seconds

Convergence = 0
The optimizer converged to the tolerance limit!

TPG Objective Score= 0.224901


    --------C3--------------C1---------
     |               |                 |
     |               |                 |
    Zsrc             L2              Zload
     |               |                 |
     |               |                 |
    -----------------------------------


RF Load Power = 100.00 Watts

C1 = 148312.48 pF
L2 = 326.10 nH
C3 = 100.62 pF


Antenna Q = 9.91

Qbw = 47.16

Fano decrement = 4.76

Estimated Fano bandwidth = 6.126 MHz

Fano VSWR minimum = 1.00

minimum matched VSWR = 1.03

maximum matched VSWR = 1.25

maximum Equalizer Match Loss = 0.03 dB

center frequency = 21.224 MHz
```

Increased C1 upper boundary value x1000 so that remaining components (i.e. L2 & C3) can be optimized.

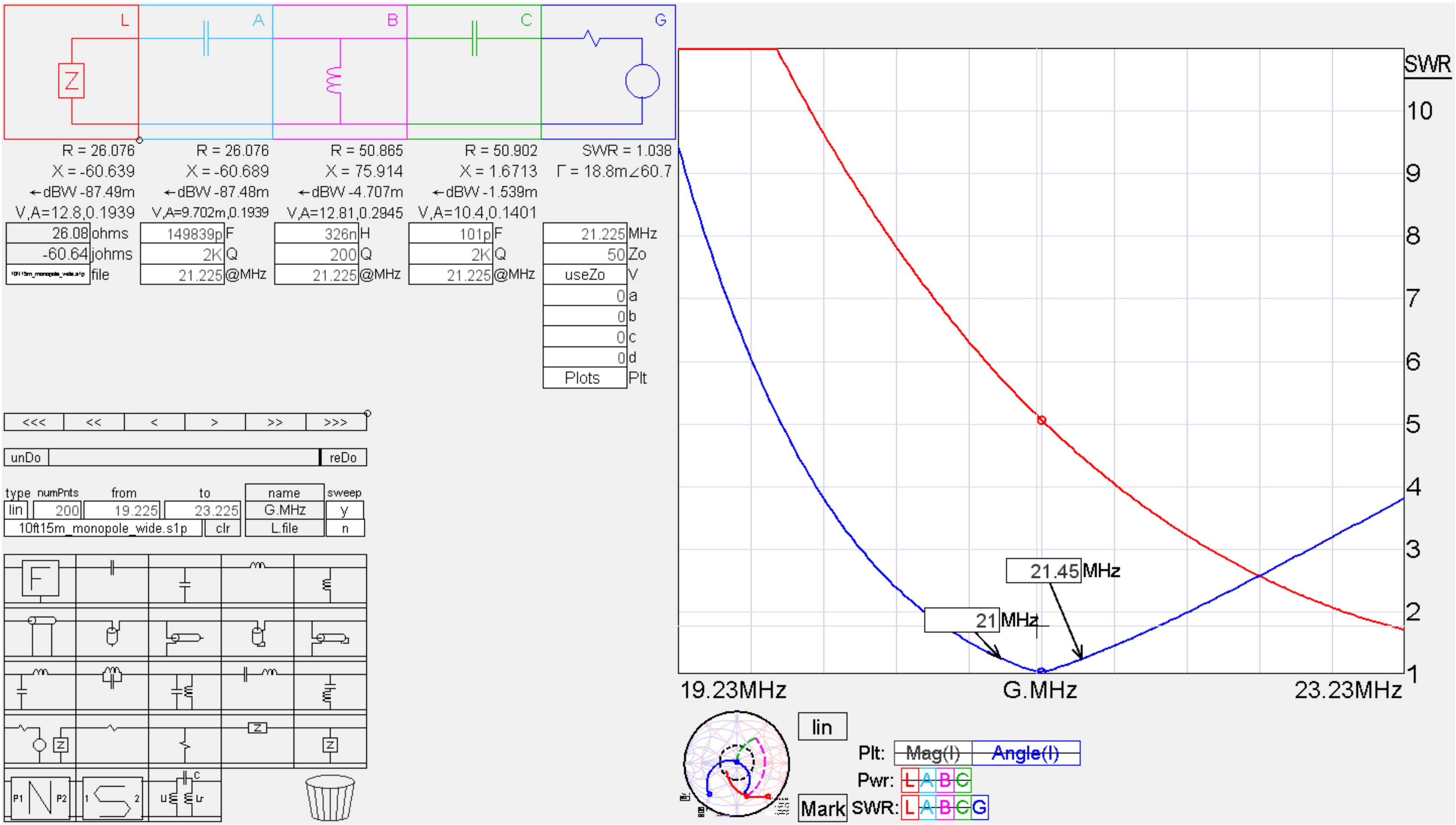
"T" Circuit Solution with Extended Boundary



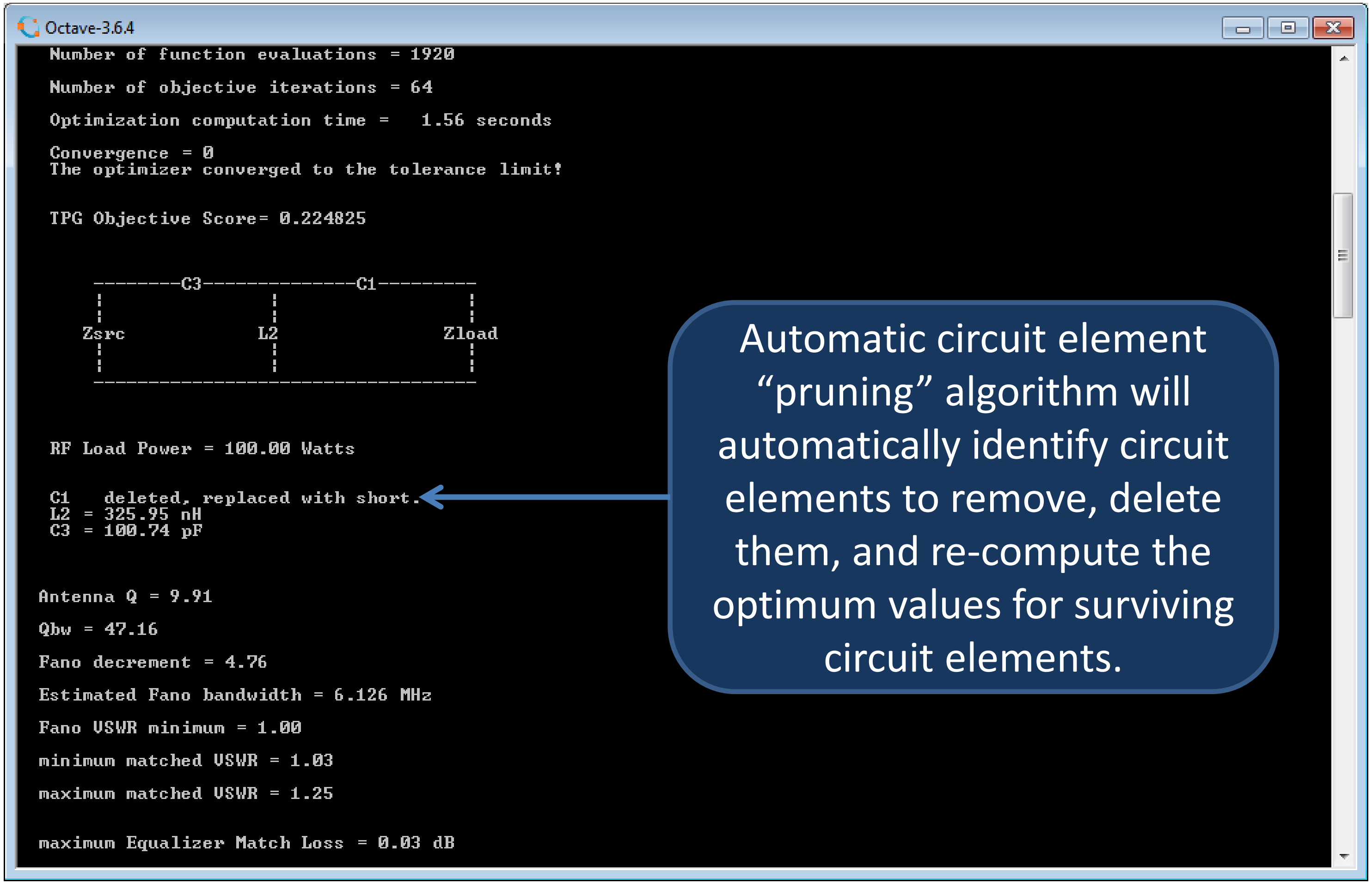
“T” Circuit Solution VSWR with Extended Boundary



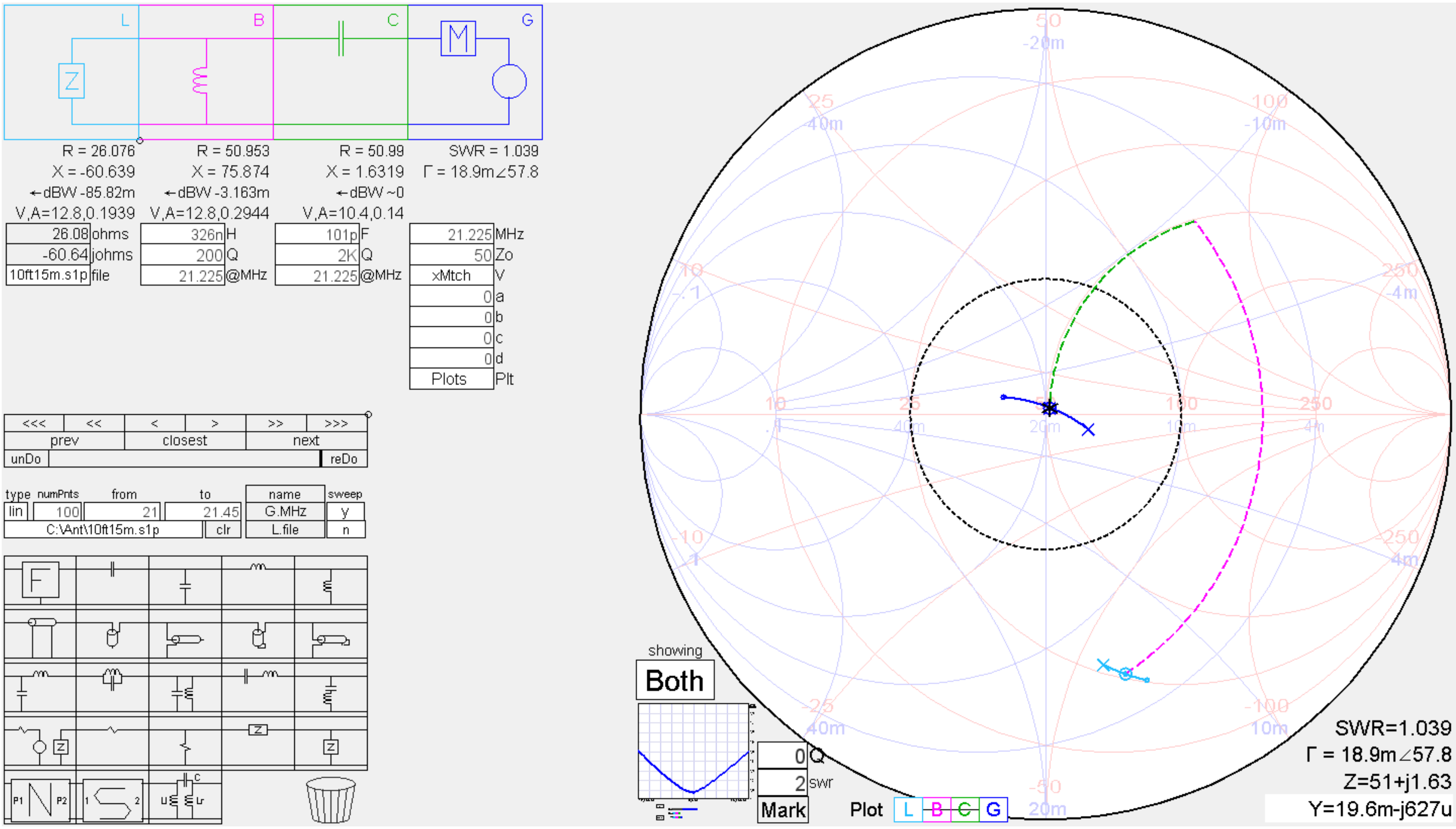
"T" Circuit Extended Solution Over Wider Frequency Span



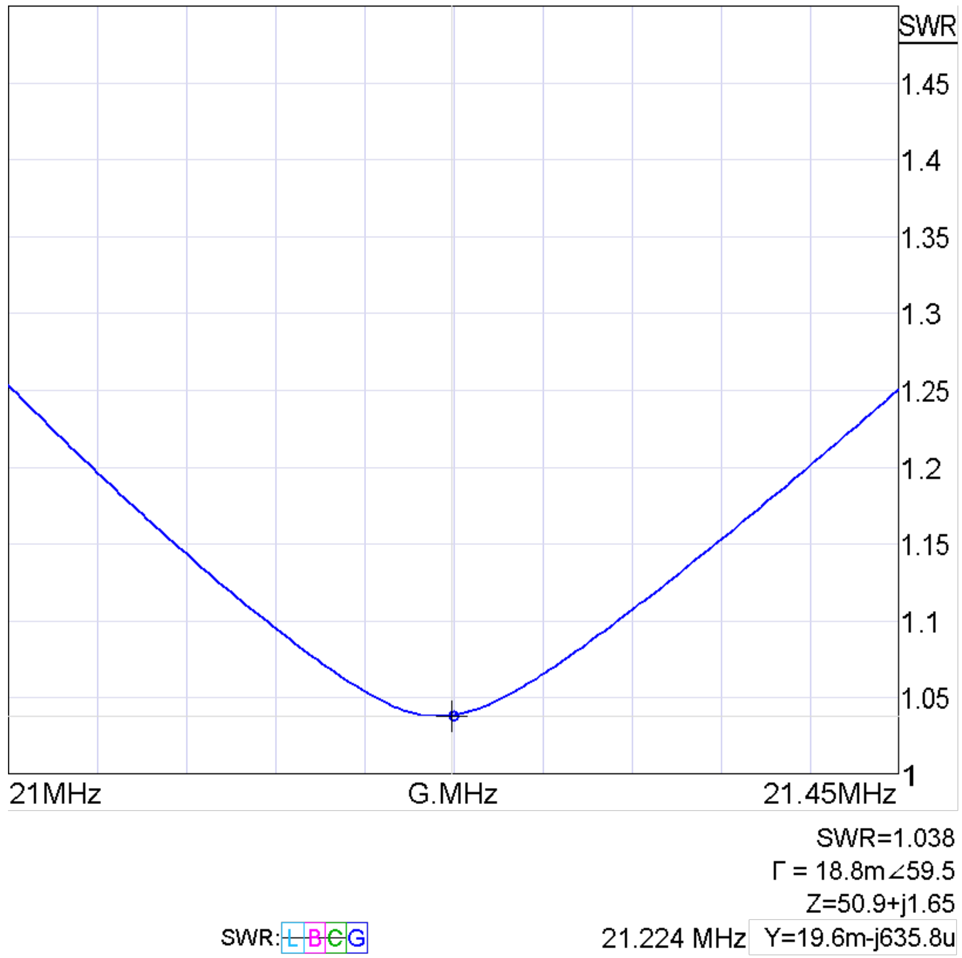
10ft 15m Monopole with High Pass T with Circuit Element Pruning



Results of Circuit Element "Pruning" Algorithm



VSWR Results of Circuit Element "Pruning" Algorithm

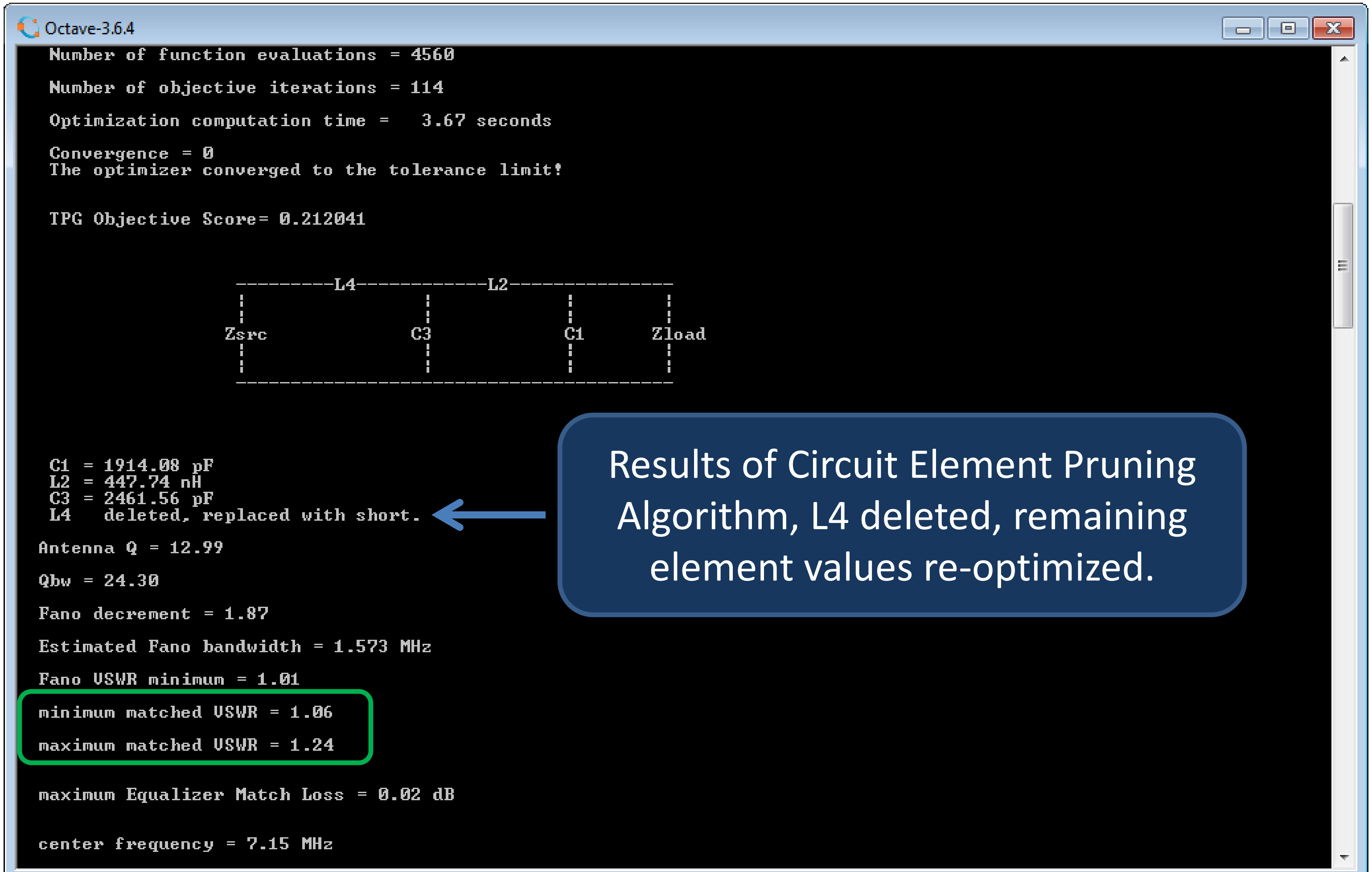


40 meter ½ λ Inverted V Wire Dipole LPP4 no pruning

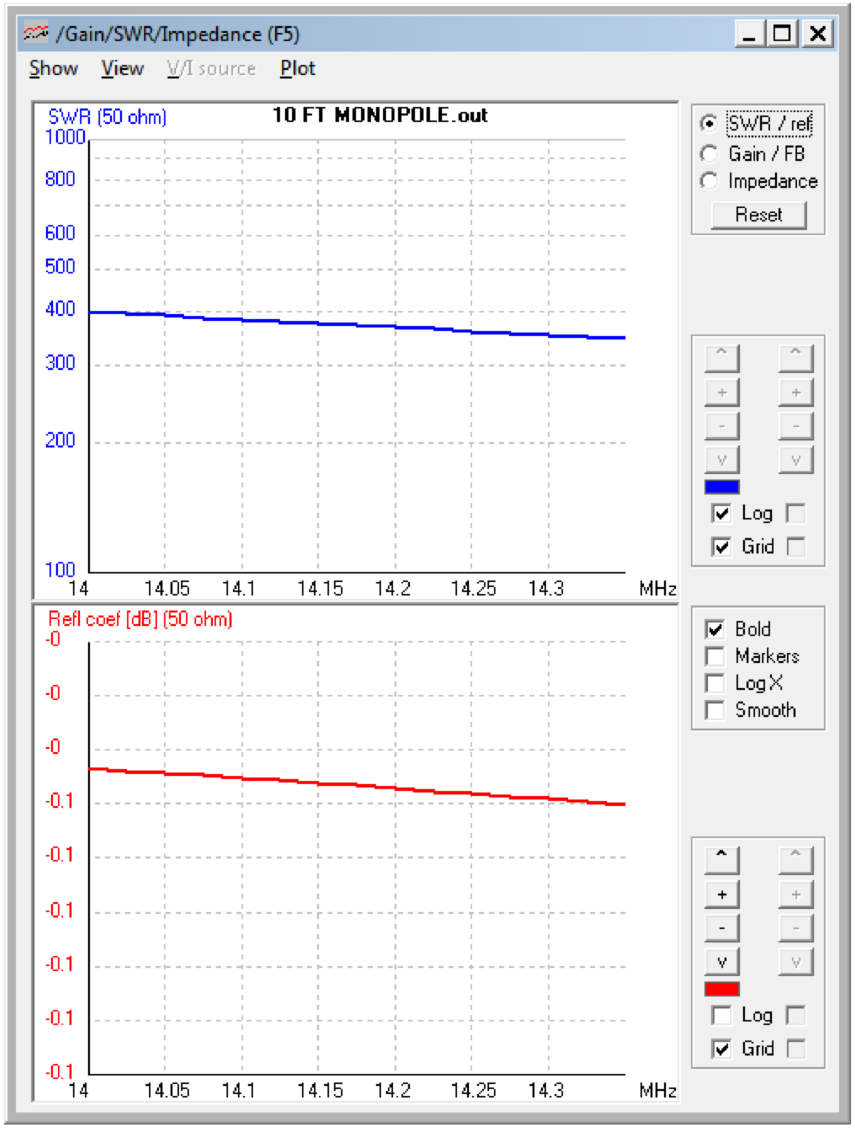
Octave-3.6.4

```
  Number of function evaluations = 5840

  Number of objective iterations = 146

  Optimization computation time =   4.74 seconds

  Convergence = 0
  The optimizer converged to the tolerance limit!


  TPG Objective Score= 0.490827



                    ---------L4------------L2---------------
                     |                |           |        |
                     |                |           |        |
                    Zsrc              C3          C1      Zload
                     |                |           |        |
                     |                |           |        |
                    ----------------------------------------




  C1  = 17.82 pF
  L2  = 1014.89 nH
  C3  = 315.09 pF
  L4  = 1040.29 nH

 Antenna Q = 12.99

 Qbw = 24.30

 Fano decrement = 1.87

 Estimated Fano bandwidth = 1.573 MHz

 Fano VSWR minimum = 1.01

 minimum matched VSWR = 1.16

 maximum matched VSWR = 1.63

 maximum Equalizer Match Loss = 0.13 dB


 center frequency = 7.15 MHz
```

40 meter ½ λ Inverted V Wire Dipole with Circuit Element Pruning



10 foot Monopole on 20m Example



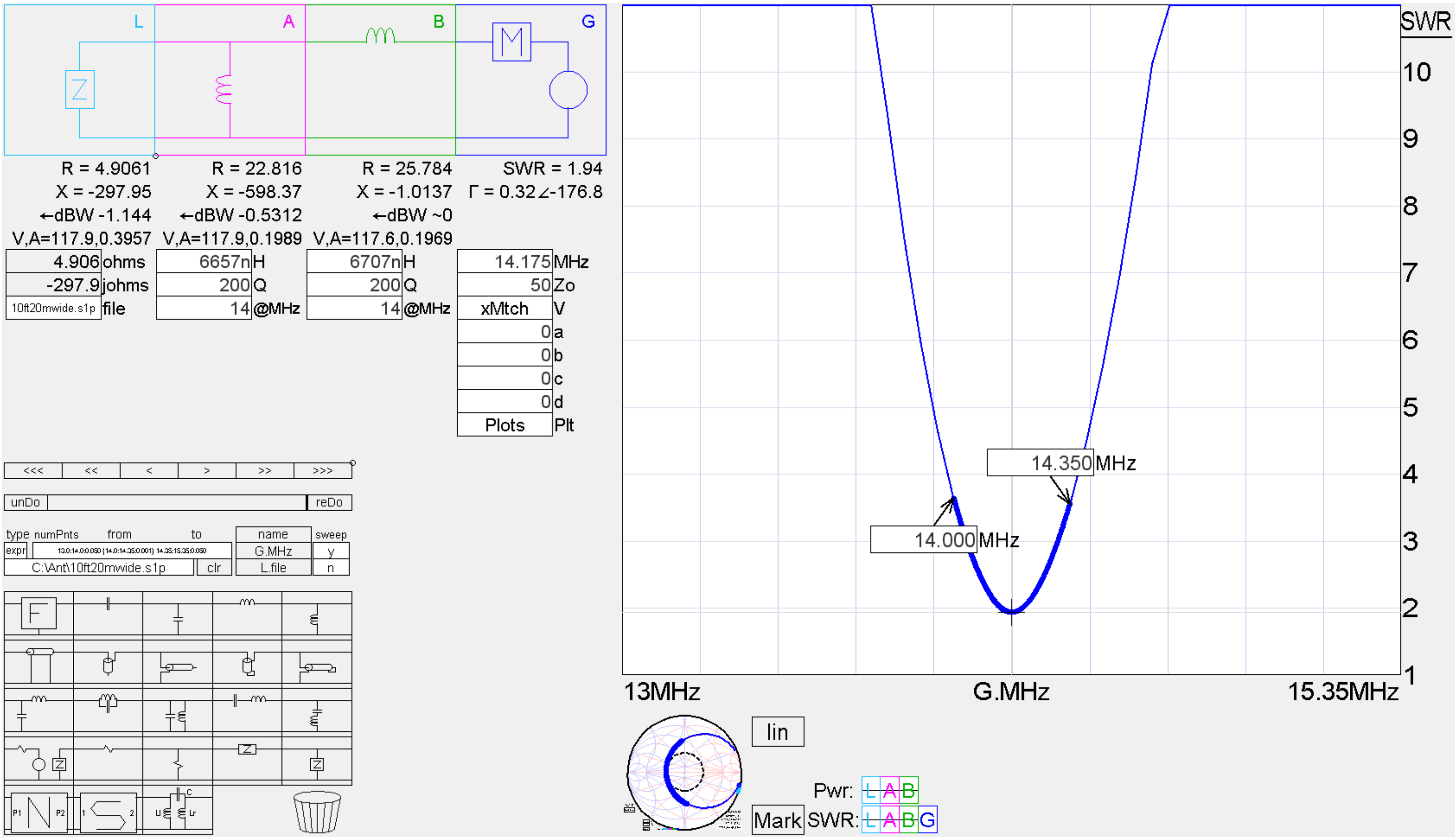
Note the high VSWR

10 foot Monopole 20 meters using BPP2 Circuit Topology

Octave-3.6.4

```
  Convergence = 0
  The optimizer converged to the tolerance limit!


  TPG Objective Score= 1.2806


       --------L2---C2----------------
        |                  |    |      |
        |                  |    |      |
       Zsrc               L1   C1    Zload
        |                  |    |      |
        |                  |    |      |
       --------------------------------



  RF Load Power = 100.00 Watts


  C1   deleted, replaced with open.
  L1 = 6656.69 nH
  C2   deleted, replaced with short.
  L2 = 6706.82 nH


 Antenna Q = 57.34

 Qbw = 40.50

 Fano decrement = 0.71

 Estimated Fano bandwidth = 0.707 MHz

 Fano VSWR minimum = 1.24

 minimum matched VSWR = 1.94

 maximum matched VSWR = 3.60


 maximum Equalizer Match Loss = 0.8354 dB


 center frequency = 14.17 MHz
```

10 foot Monopole 20 meters using BPP2 Topology AFTER Pruning



10ft Monopole on 20 meters using BPP4 Circuit Topology and Pruning Algorithm

Octave-3.6.4

```
4 resonator LC Bandpass Equalizer parallel to load.


      -------L4---C4----------L2---C2---------------
      |                |   |             |   |      |
    Zsrc              L3  C3            L1  C1    Zload
      |                |   |             |   |      |
      ----------------------------------------------


C1   deleted, replaced with open.
L1 = 6663.63 nH
C2   deleted, replaced with short.
L2 = 6707.77 nH
C3   deleted, replaced with open.
L3   deleted, replaced with open.
C4   deleted, replaced with short.
L4   deleted, replaced with short.


Antenna Q = 57.34

Qbw = 40.50

Fano decrement = 0.71

Estimated Fano bandwidth = 0.707 MHz

Fano VSWR minimum = 1.24

minimum matched VSWR = 1.94

maximum matched VSWR = 3.60


maximum Equalizer Match Loss = 0.8348 dB


center frequency = 14.17 MHz
```

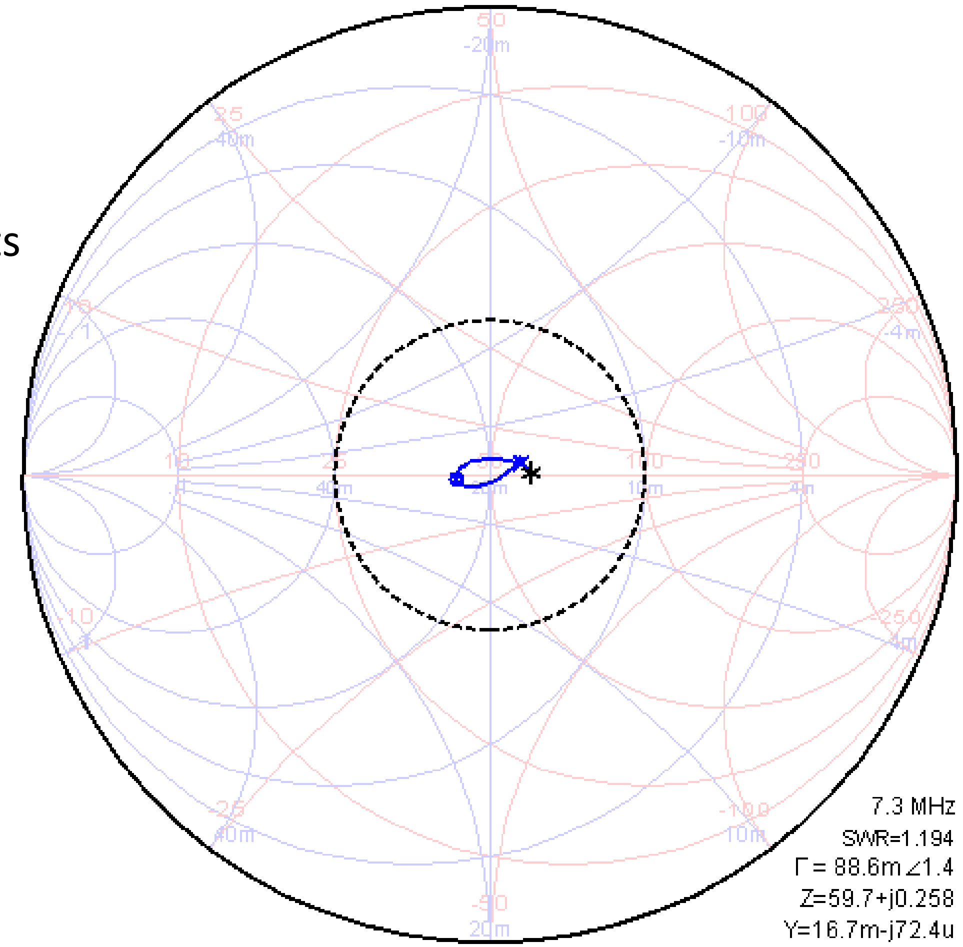
ZNET algorithm with pruning returned to simple L circuit topology again.

Component Tolerances Study

Vary L & C element values

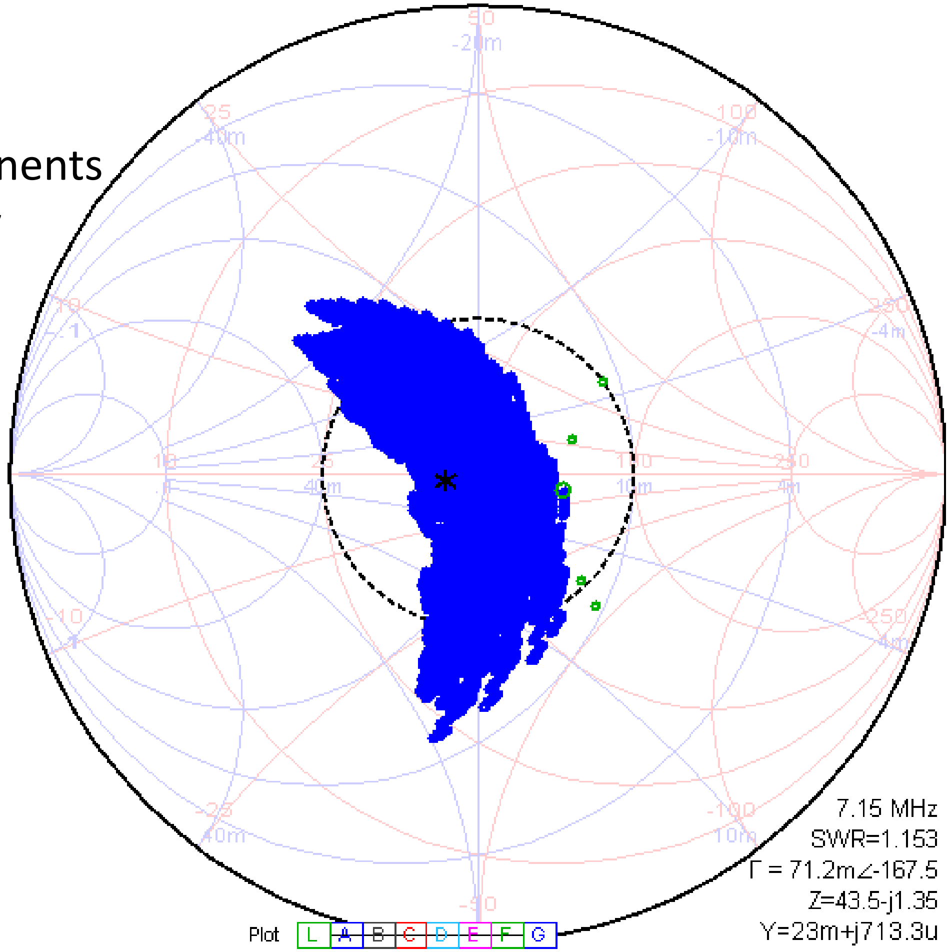
Component Tolerances Study
40m ½ λ Inverted V Wire Dipole
using LPS6 Circuit Topology Smith Chart

Initial results



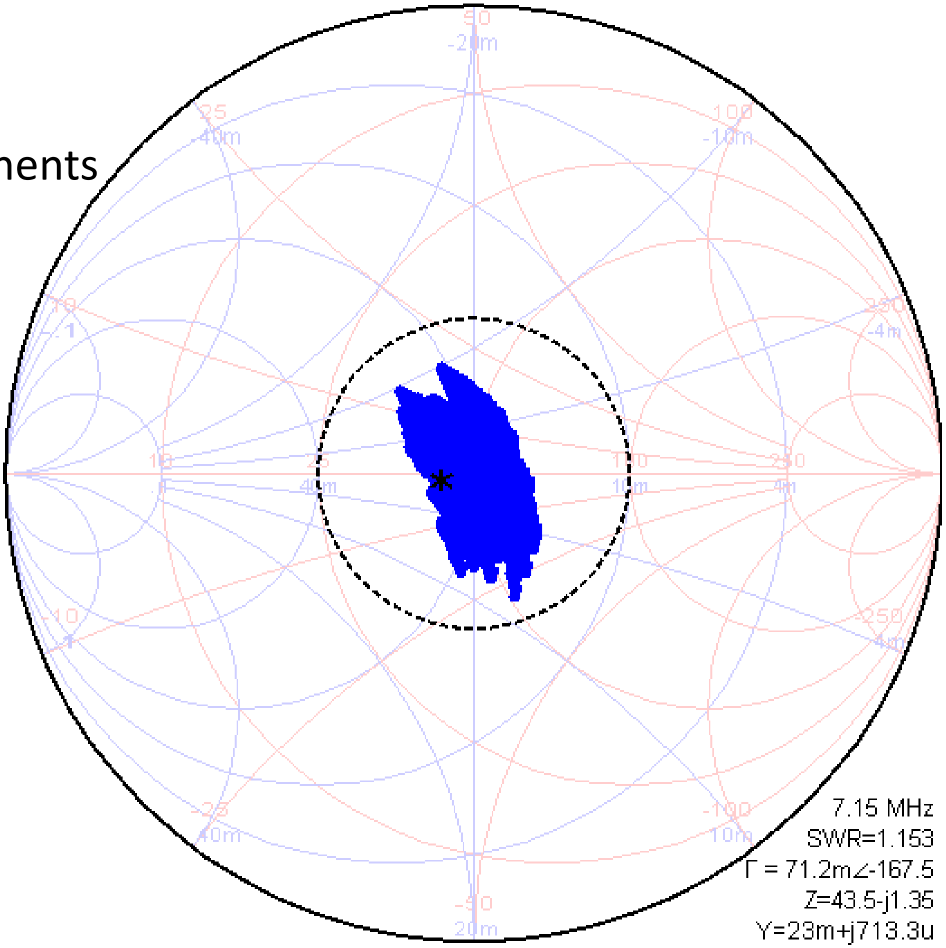
Component Tolerances Study
40m ½ λ Inverted V Wire Dipole
using LPS6 Circuit Topology Smith Chart

All 6 LC components simultaneously varied +/- 5%.

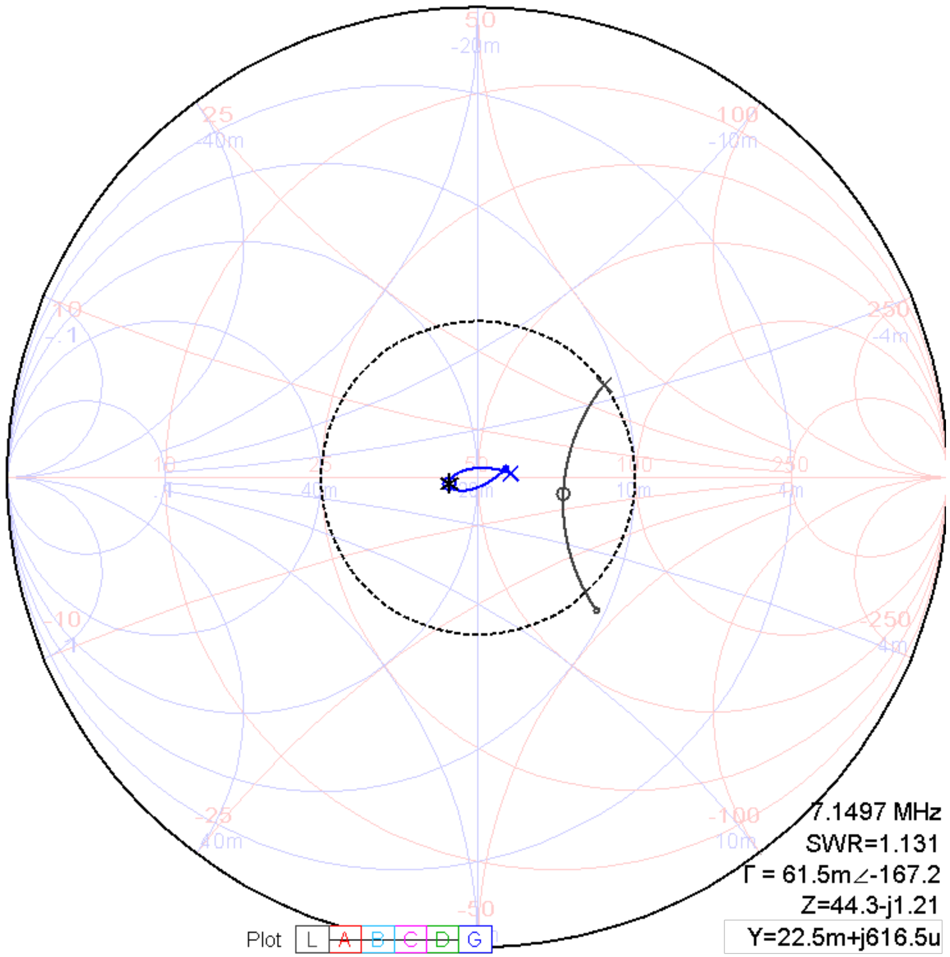


Component Tolerances Study
40m ½ λ Inverted V Wire Dipole
using LPS6 Circuit Topology Smith Chart

All 6 LC components simultaneously varied +/- 2%.

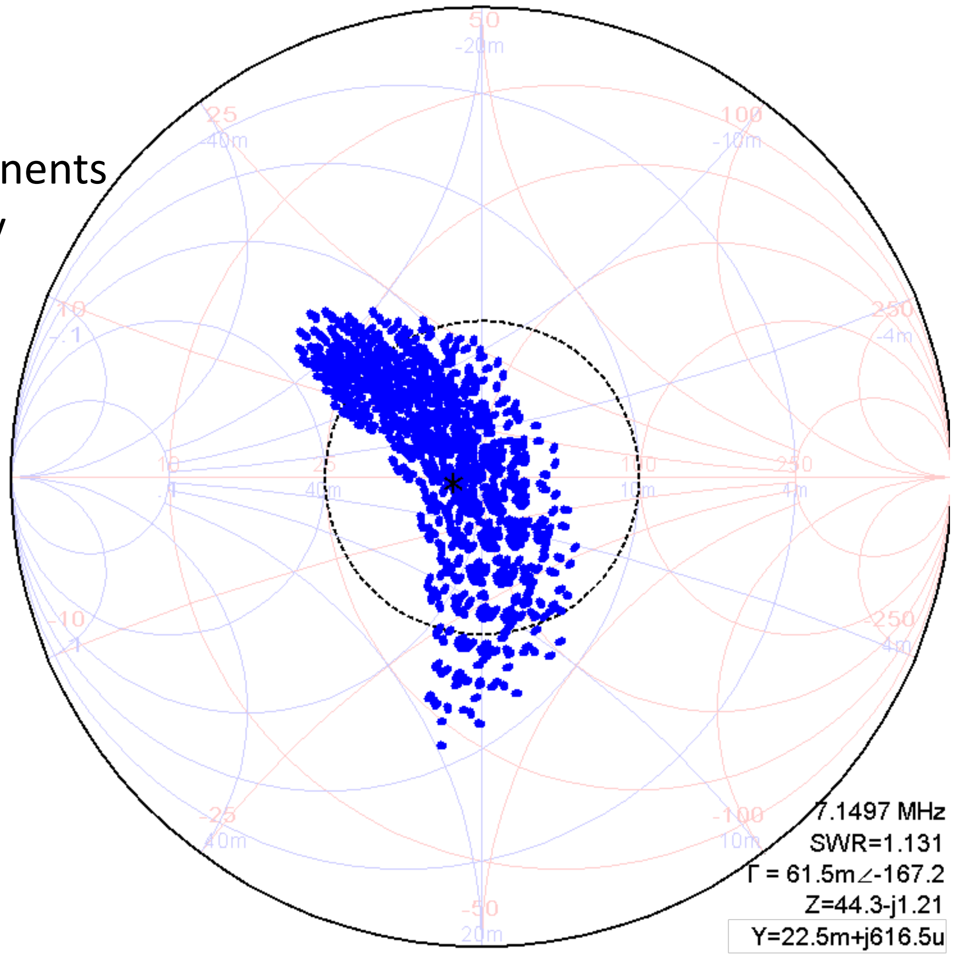


Component Tolerances Study
40m ½ λ Inverted V Wire Dipole
using LPS4 Circuit Topology Smith Chart



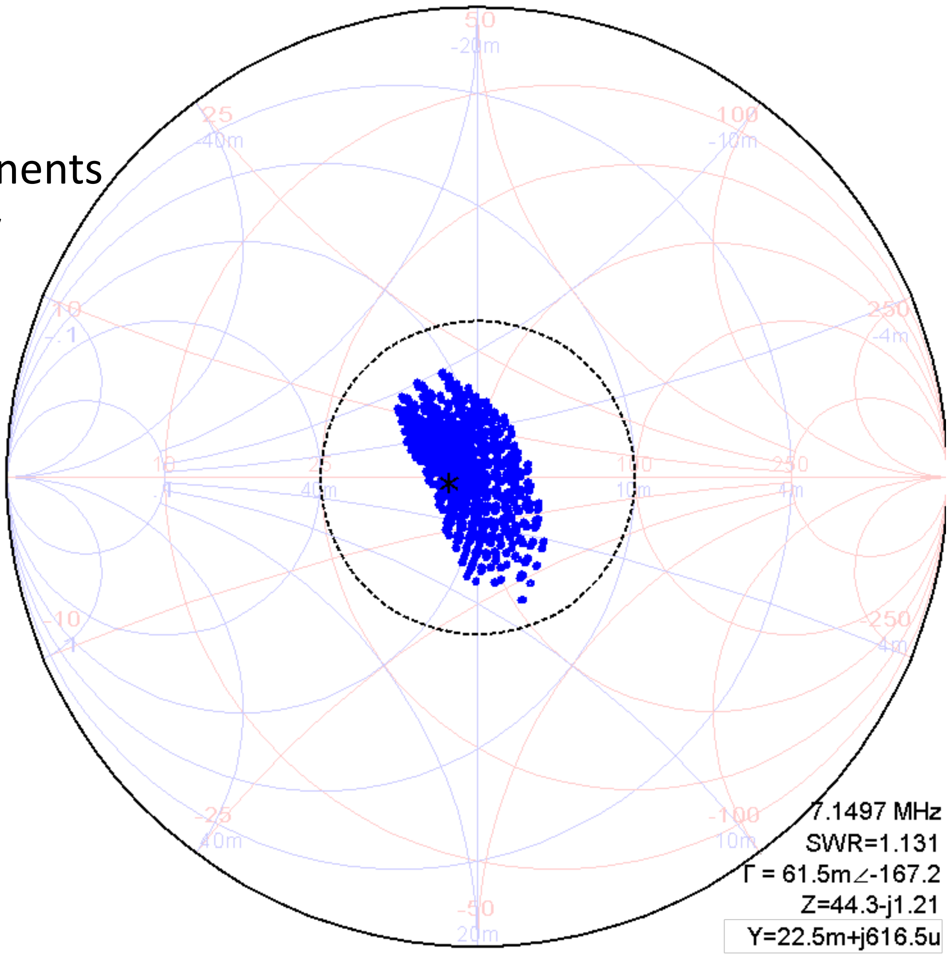
Component Tolerances Study
40m ½ λ Inverted V Wire Dipole
using LPS4 Circuit Topology Smith Chart

All 4 LC components simultaneously varied +/- 5%.

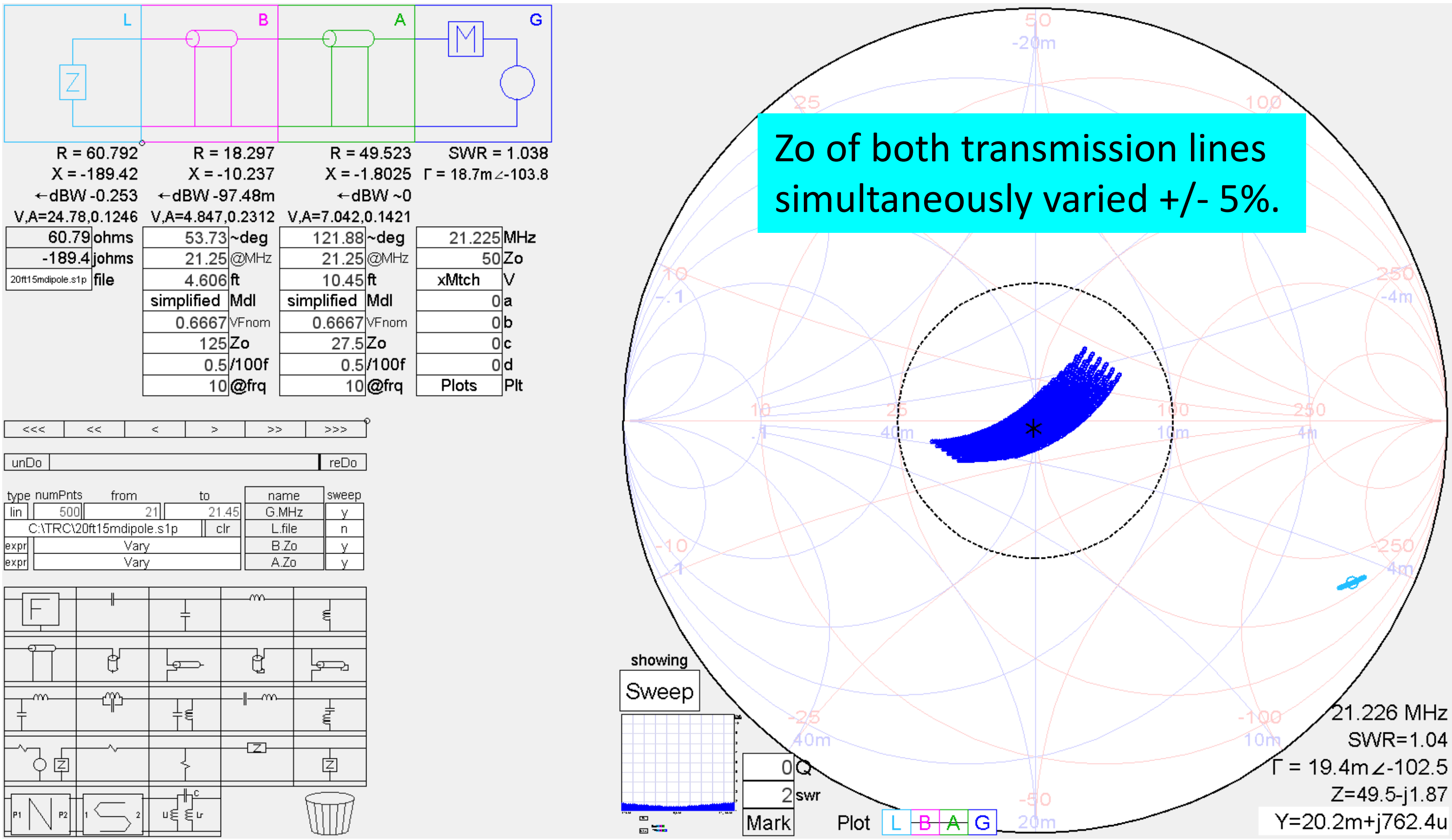


Component Tolerances Study
40m ½ λ Inverted V Wire Dipole
using LPS4 Circuit Topology Smith Chart

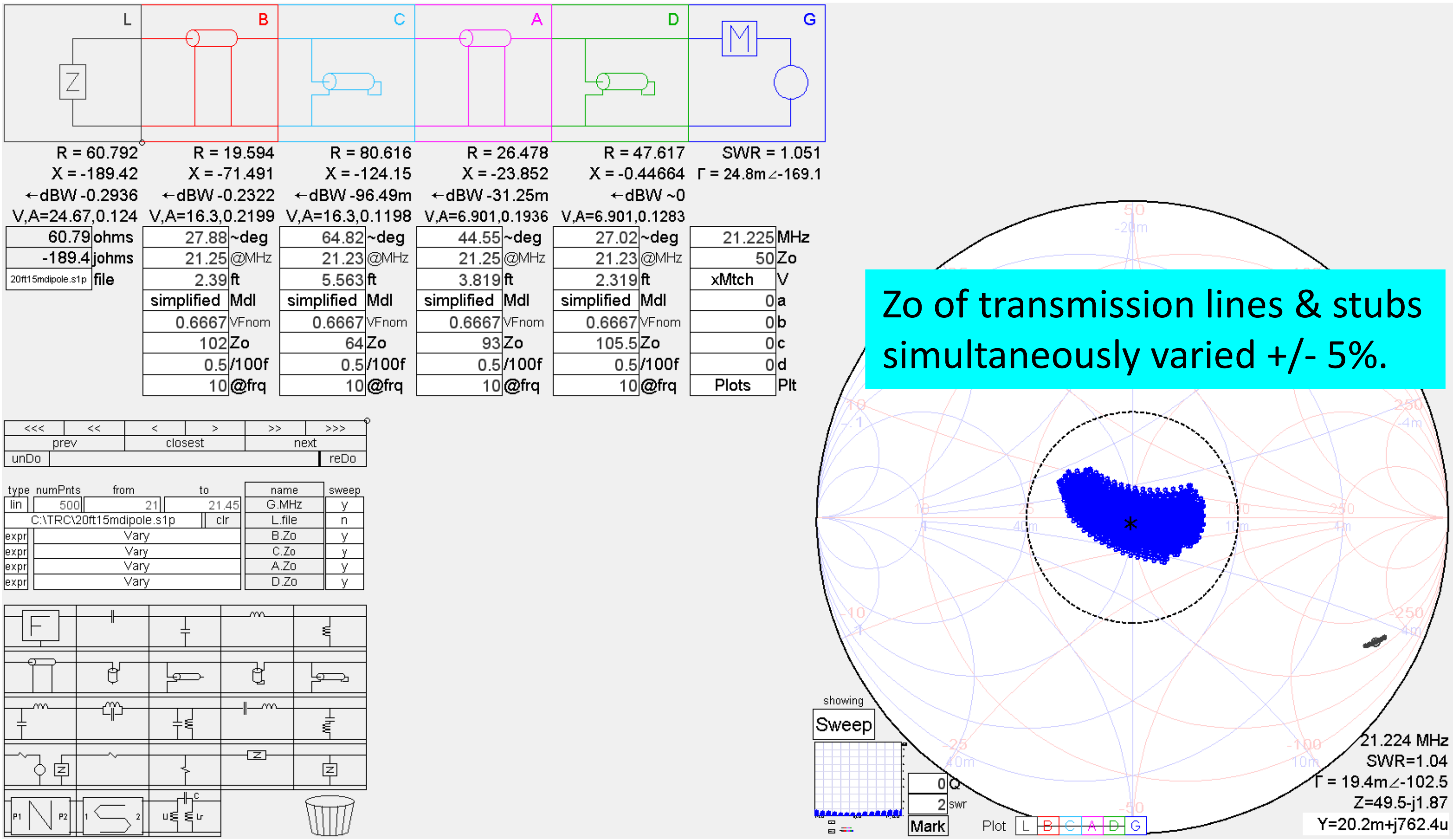
All 4 LC components simultaneously varied +/- 2%.



Component Tolerances Study
20 foot Dipole on 15m
using CASTL Circuit Topology Smith Chart



20 foot Flat Top Dipole
on 15 meters CASTL Circuit
transmission lines and stubs Smith Chart



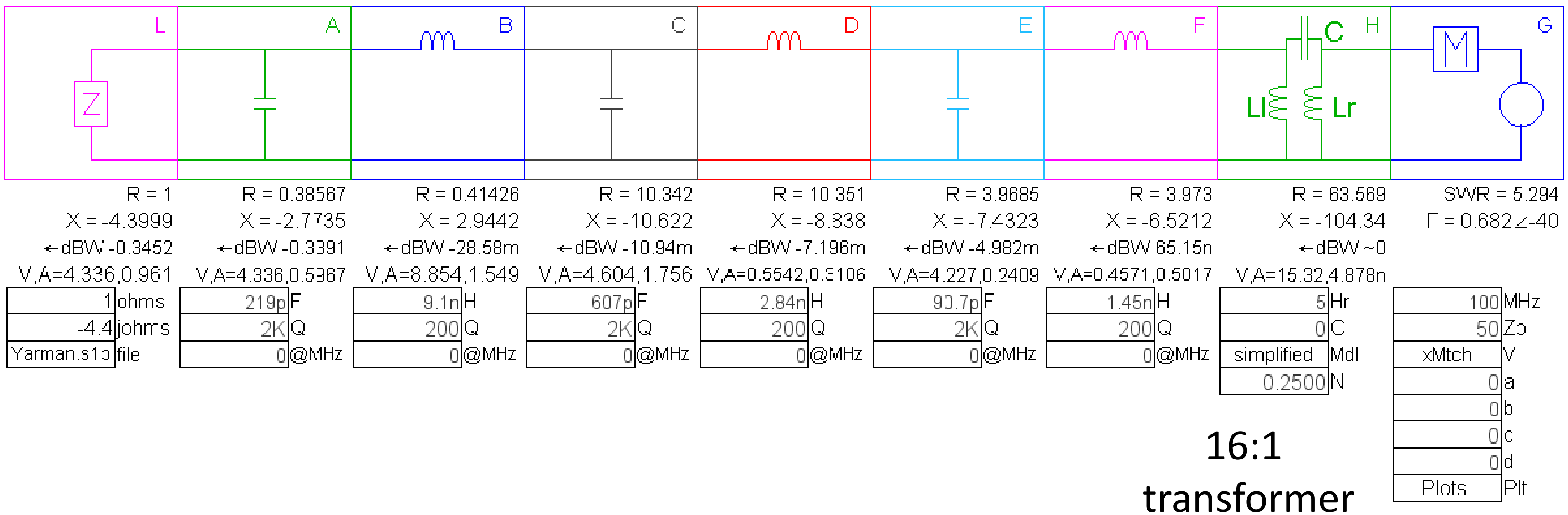
Zo of transmission lines & stubs simultaneously varied +/- 5%.

Revisit Yarman’s Short Monopole Example

ZNET solution using Yarman’s LPS6 circuit topology.

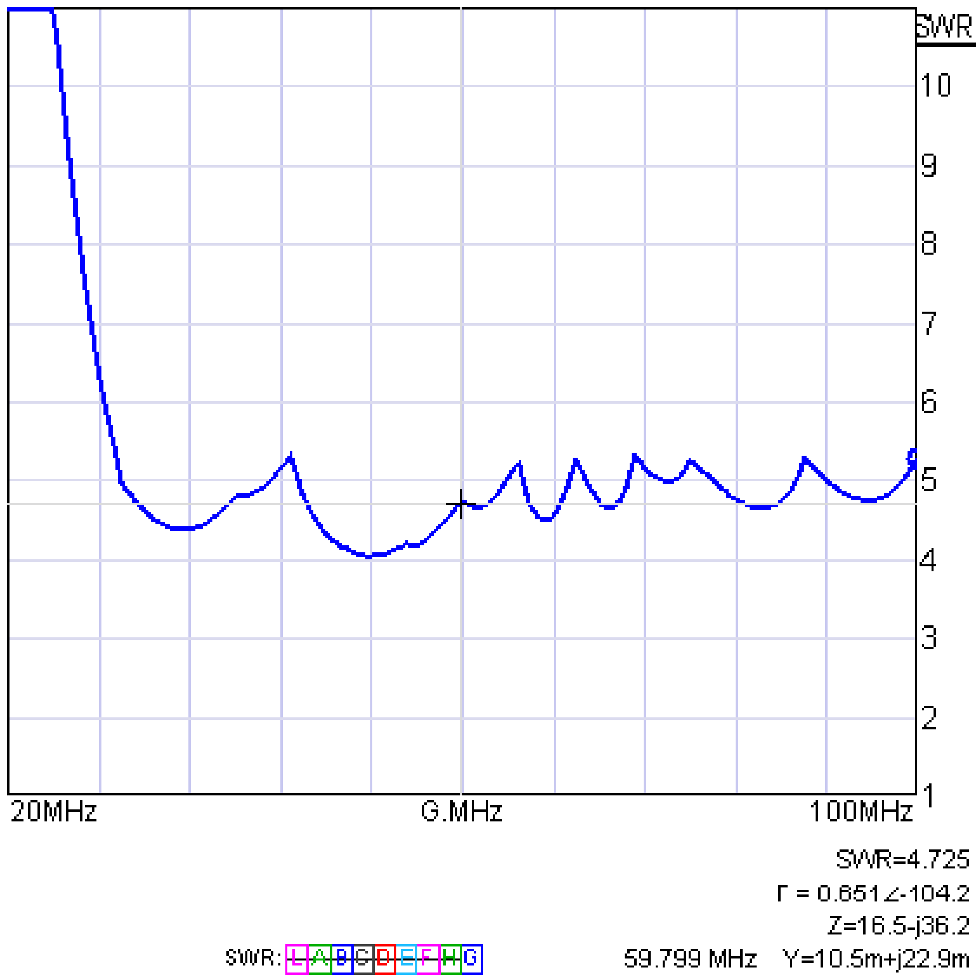
- Changed circuit element values,
- Changed transformer from a 12.66:1 transformer to a standard 16:1 transformer (ala a transmission line transformer).

Yarman's Monopole Example
ZNET Circuit



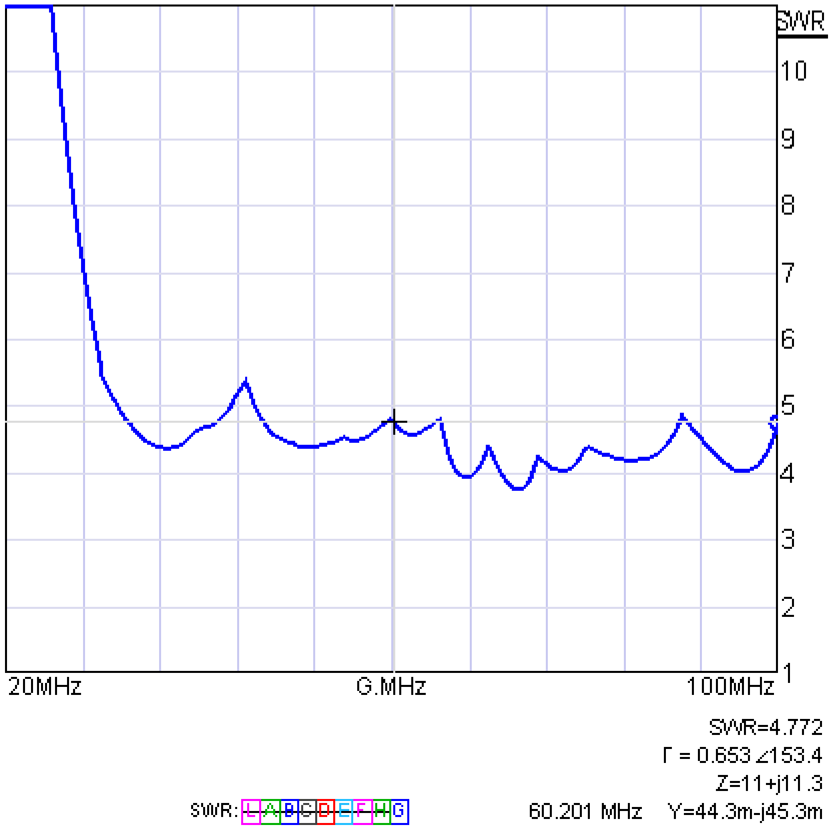
Using same LPP6 circuit topology as Yarman, but changed transformer to standard 16:1, Recomputed circuit element values using ZNET.

Yarman's Monopole Example ZNET Solution VSWR

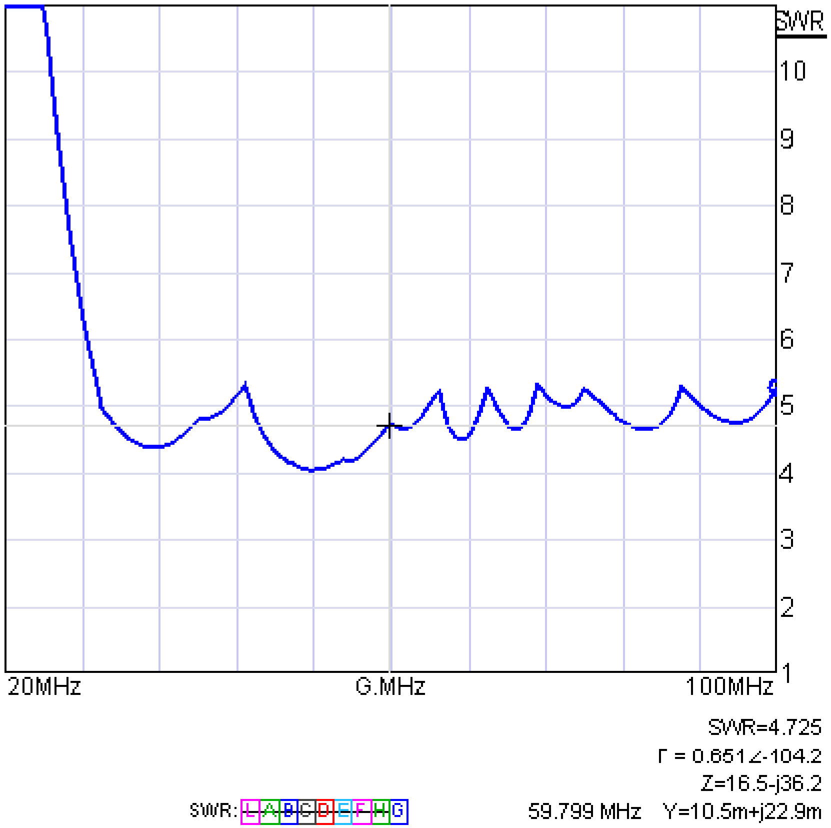


Yarman's Monopole Example SRFT and ZNET VSWR Comparison

SRFT VSWR

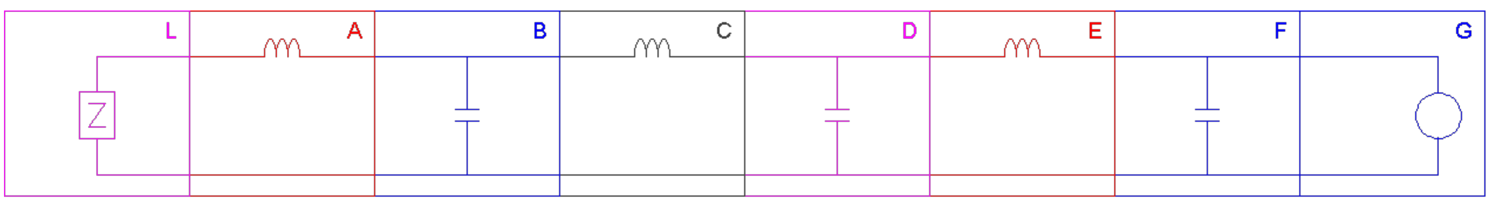


ZNET VSWR



Antenna Height Variations

- Vary the height above ground of 40 m ½ λ inverted "V" wire antenna using same LPS6 equalizer circuit;
  - Apex height @ 25 feet
  - Apex height @ 30 feet (design height)
  - Apex height @ 35 feet

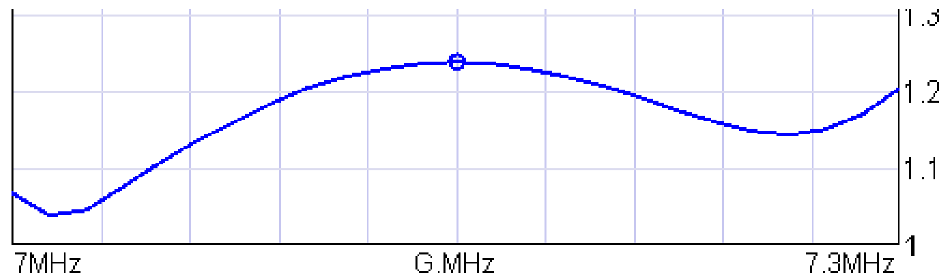


R = 72.023	R = 72.069	R = 1.7626	R = 1.8314	R = 1.8412	R = 1.8741	R = 47.149	SWR = 1.087
X = -5.1164	X = 3.9876	X = -11.113	X = 2.6547	X = 2.6583	X = 9.2537	X = -2.9086	Γ = 41.9m∠-132.7
19.7 dBW	-12.29 dBW	-2.231 dBW	5.652 dBW	-32.56 dBW	2.432 dBW	-3.032 dBW	
V,A=82.23,1.139	V,A=10.37,1.139	V,A=82.2,7.279	V,A=100.6,7.306	V,A=23.56,23.5m	V,A=48.06,7.286	V,A=68.8,7.231	

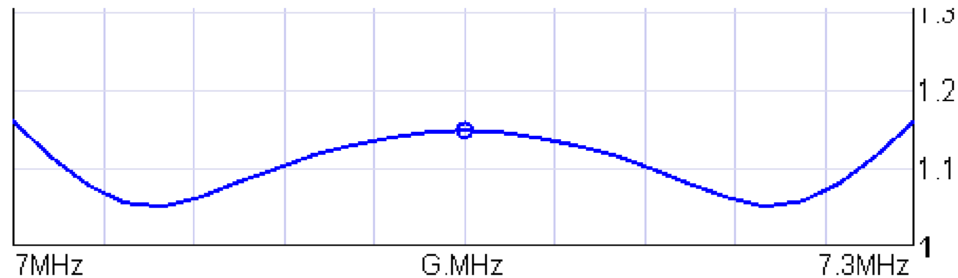
72.023	ohms	202.65n	H	1970.9p	F	306.46n	H	22.24p	F	146.81n	H	2339.69p	F	7.15	MHz
-5.1164	johms	200	Q	1K	Q	200	Q	1K	Q	200	Q	1K	Q	50	Zo
40M INV V 35ft.s1p	file	7.15	@MHz	7.15	@MHz	7.15	@MHz	7.15	@MHz	7.15	@MHz	7.15	@MHz	xMtch(100)	V
														0	a
														0	b
														0	c
														0	d
														Plots	Plt

40 meter ½ λ Inverted "V" Wire Dipole versus Apex Height Using Same Equalizer Circuit

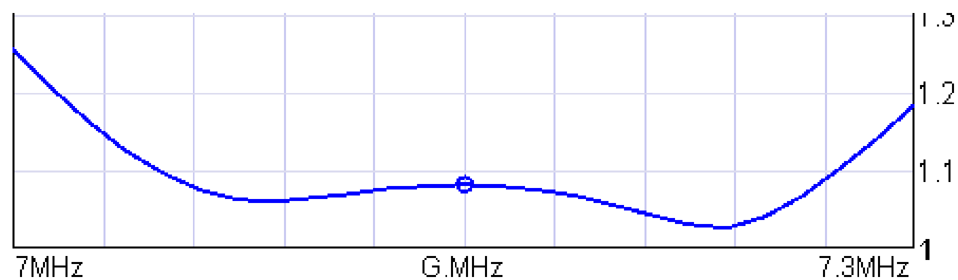
25 feet



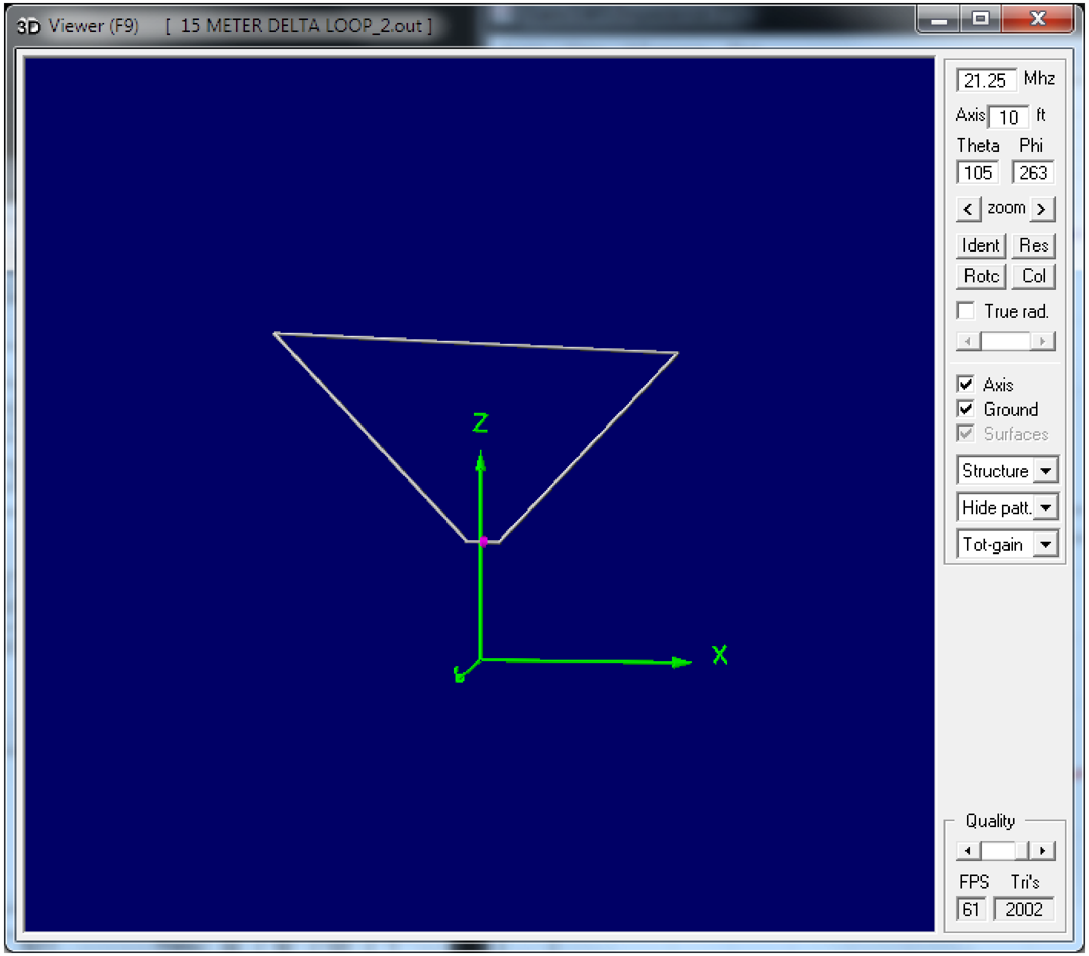
30 feet
(design height)



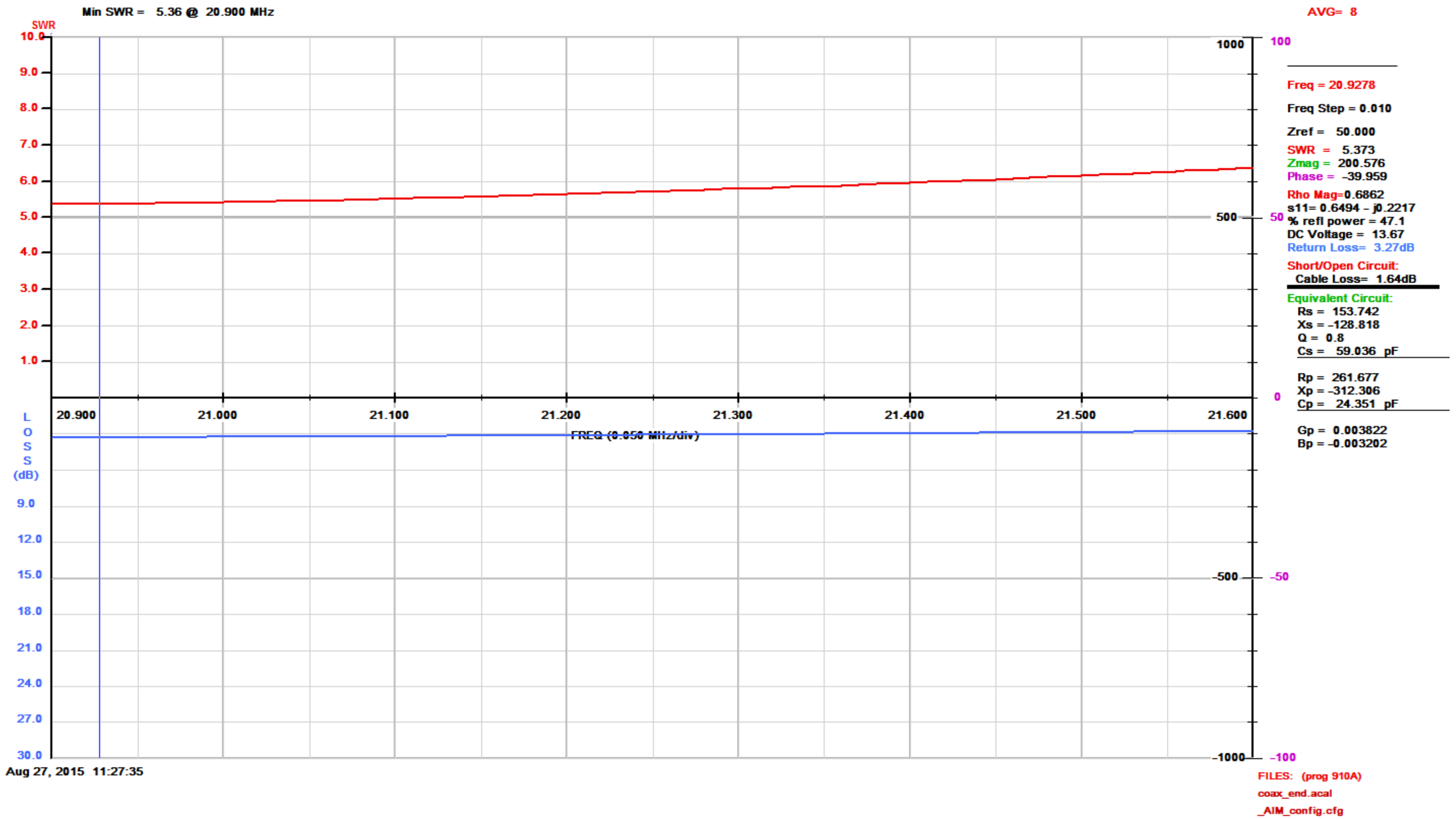
35 feet



15 meter wire delta loop hardware test

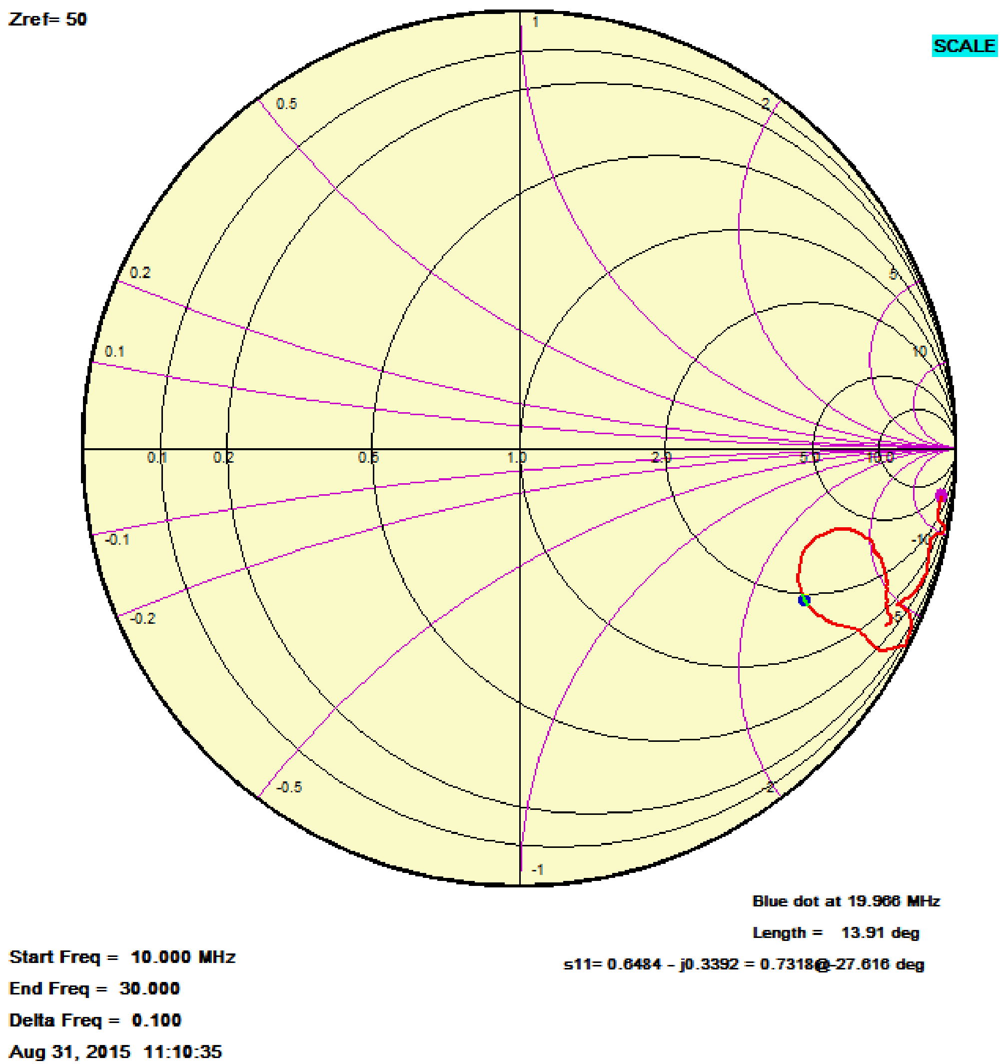


15 meter wire delta antenna test VSWR before equalizer



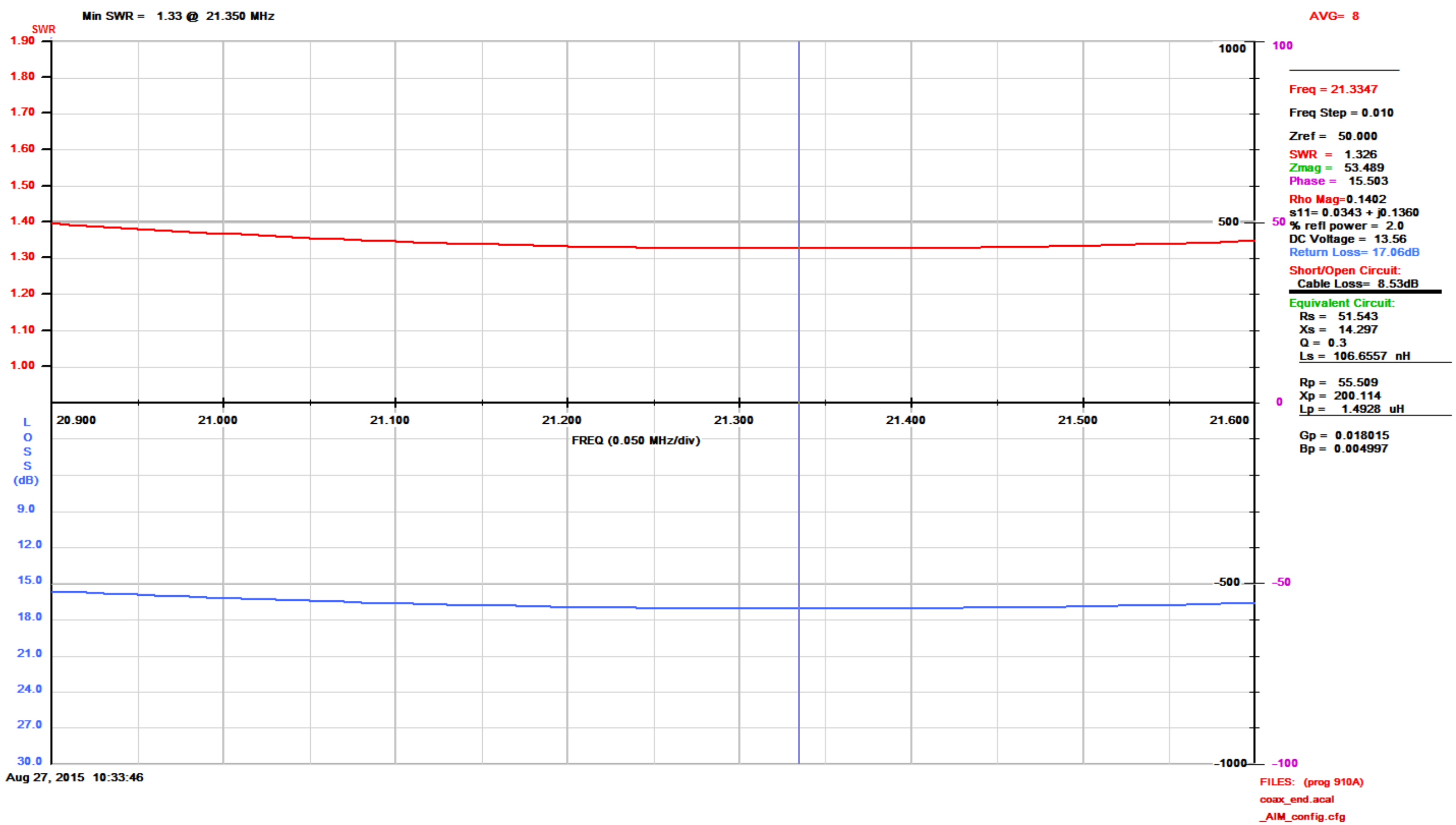
15 meter wire delta antenna

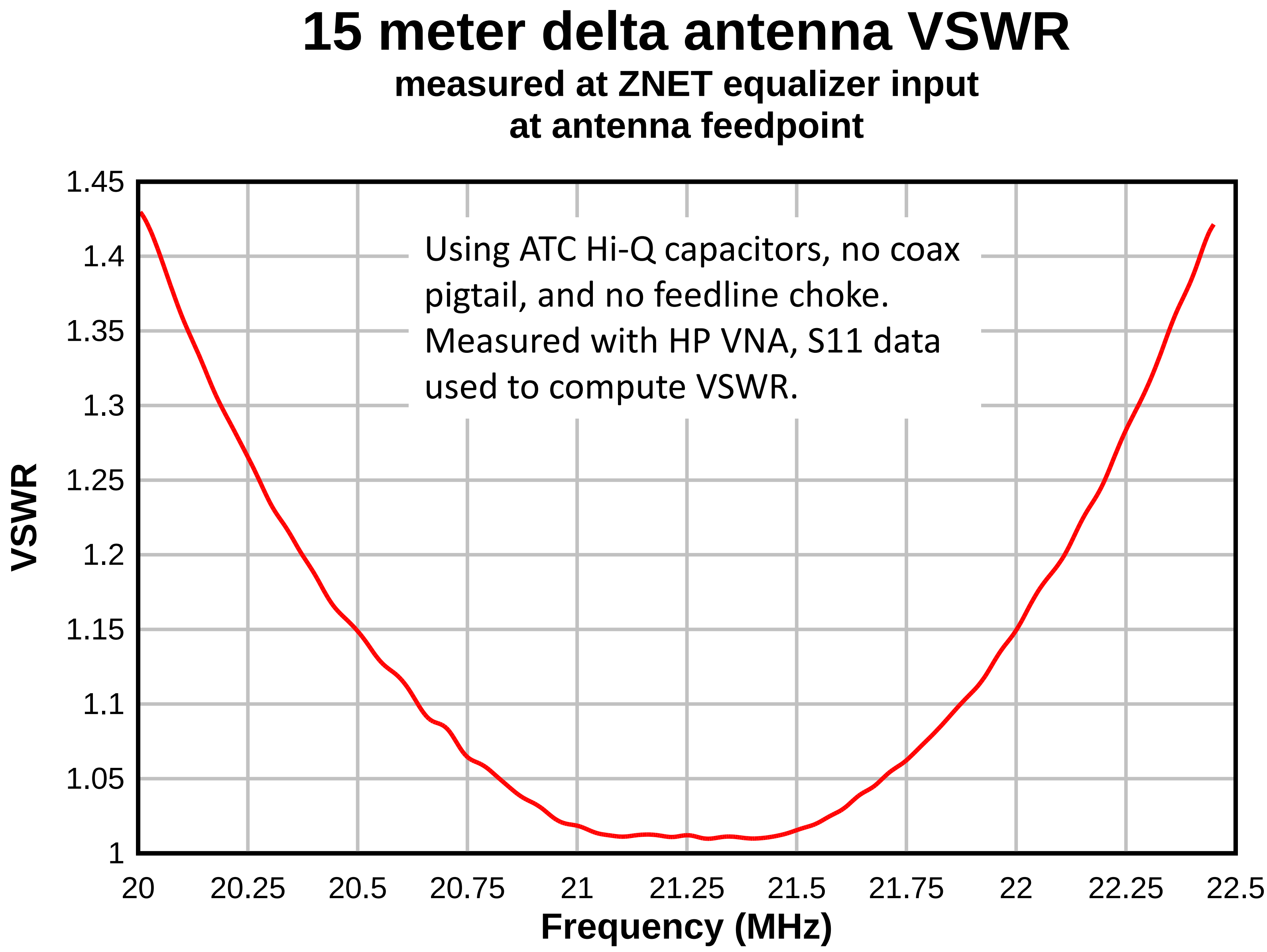
Smith Chart



QRP Test Equalizer at 15 meter Delta Loop Feedpoint

VSWR of QRP "T" Equalizer Using Low-Cost NTE Ceramic Capacitors




15 meter delta antenna VSWR
measured at ZNET equalizer input
at antenna feedpoint
Using ATC Hi-Q capacitors, no coax pigtail, and no feedline choke. Measured with HP VNA, S11 data used to compute VSWR.
VSWR
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
20
20.25
20.5
20.75
21
21.25
21.5
21.75
22
22.25
22.5
Frequency (MHz)

Next Steps in ZNET Experiments

- Improve the accuracy of the L and C component loss models, add ability to design optimum inductor geometry,
- Improve the circuit topology modification capability,
- Merge transmission line models to enable mixed element design optimization,
- Add GUI interface, make user friendly,
- Test & Evaluate with benchmark problems and hardware prototypes,
- Extend optimization to antenna design (G/Q optimization objective).

Reactive Energies, Impedance, and Q Factor of Radiating Structures

Guy A. E. Vandenbosch, *Senior Member, IEEE*

***Abstract*—New expressions are derived to calculate the reactive energy stored in the electromagnetic field surrounding an electromagnetic device. The resulting expressions are very simple to interpret, completely general, explicit and without approximations in terms of the currents flowing on the device. They are also fast since they involve integrals solely over the device generating the field. The new technique is very feasible to be used in cases where the electric and magnetic reactive energies are important in practice, especially in the case of radiating structures. Used there, they allow to study the effect of the shape of the device on the amount of reactive energy, and thus on the Q of the device. The implementation of the new expressions in numerical CAD tools is extremely simple and straightforward.**

***Index Terms*—Poynting theorem, Q factor, radiation, reactive energy.**

I. Introduction

is incorporated for spherical wire antennas. Relatively recently, Geyi [7] published a technique to calculate the reactive energies taking into account the exact topology of the, in this case, small radiator considered. He used a combination of the Poynting theorem in frequency and time domain to separate electric and magnetic reactive energy.

Shlivinski performed a study of the reactive energy completely in the time domain, aiming at applications involving pulsed fields [8]. A brute force technique is used in [9], where the authors calculate the reactive energy using the FDTD method. A very complete paper is [12]. This paper gives a state-of-the-art overview of techniques and formulas to calculate impedances, bandwidths, and Q factors of antennas. However, no method is given to calculate the reactive energies explicitly. The calculation of the Q factor is based on the knowledge of the derivative of the impedance.

Also see http://www.eit.lth.se/index.php?uhpuid=scd.mgu&hpuid=139&L=1

The Measurable Q Factor and Observable Energies of Radiating Structures

Miloslav Capek, *Student Member, IEEE*, Lukas Jelinek, Pavel Hazdra, *Member, IEEE*, and Jan Eichler, *Student Member, IEEE*

***Abstract*—New expressions are derived to calculate the Q factor of a radiating device. The resulting relations link Q based on the frequency change of the input impedance at the input port (Q_X, Q_Z) with expressions based solely on the current distribution on an radiating device. The question of which energies of a radiating system are observable is reviewed, and then the proposed Q factor as defined in this paper is physical. The derivation is based on potential theory rather than fields. This approach hence automatically eliminates all divergent integrals associated with electromagnetic energies in infinite space. The new formulas allow us to study the radiation Q factor for antennas without feeding (through e.g., characteristic modes) as well as fed by an arbitrary number of ports. The new technique can easily be implemented in any numerical software dealing with current densities. To present the merits of proposed technique, three canonical antennas are studied. Numerical examples show excellent agreement between the measurable Q_Z derived from input impedance and the new**

electric and magnetic fields in all the space are involved, they are not practical for numerical calculations.

It is known that the total energy of a radiating system in the frequency domain is infinite. This is true for the total energy evaluated from electromagnetic fields (which are stored in an infinite volume) [5], [6]. Rhodes [7] showed that for observable energies the infinities in the integrals cancel in a special way, leaving a finite residue. Vandenbosch [2] was able to analytically subtract the far-field energy from the total energy, isolating the residue and developing expressions for modified vacuum energies based on the currents at the radiating device, and he used them for evaluating Q.

This paper is inspired by [2], [3], [5] and [6], but the line of reasoning is different. It is recognized here for the first time

Stored Energies and Radiation Q

Wen Geyi, *Member, IEEE*

***Abstract*—This paper discusses the methods for evaluating the stored electromagnetic energies and the radiation Q for an arbitrary lossless antenna. New expressions for the stored electromagnetic energies are derived by using the Poynting theorem in the complex frequency domain, and they are compared with previous theory and are validated by numerical examples. The minimization of radiation Q for small antenna is also investigated. There exists an optimal current distribution that minimizes the radiation Q for specified small antenna geometry. The optimized Q and the optimal current distribution for small antenna may be determined by solving a generalized eigenvalue equation obtained from the Rayleigh quotient for the radiation Q.**

***Index Terms*—Antenna Q, antenna theory, stored energy.**

I. Introduction

THE antenna (or radiation) Q has been a research topic for many years [1]–[36]. According to the IEEE Standard Definitions of Terms for Antennas, the quality factor of a resonant antenna is defined as the ratio of 2π times energy stored in the fields excited by the antenna to the energy radiated and dissipated per cycle:

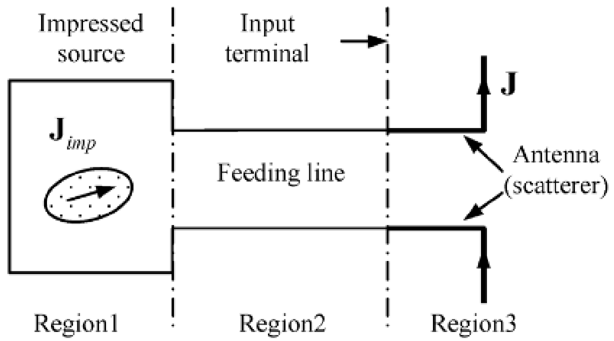


Fig. 1. First antenna model: an arbitrary antenna fed by a waveguide.

energy (2) has taken account of all the stored energy around the antenna, including the part of the energy inside the circumscribing sphere of the antenna [5]. Equation (2) has been directly used to calculate the stored energy of antennas in [6] and [7] by using FDTD. The stored energy quickly becomes stable when r is increased to one or two wavelengths since the stored energies are localized in the vicinity of antenna. This fact can also be verified by the following reasoning. Let r be the radius of the sphere that encloses the sources. It has been shown that the

Extending ZNET

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 55, NO. 4, APRIL 2007 1111

Benchmark Antenna Problems for Evolutionary Optimization Algorithms

Mario Fernández Pantoja, *Member, IEEE*, Amelia Rubio Bretones, *Senior Member, IEEE*, and Rafael Gómez Martín, *Senior Member, IEEE*

***Abstract*—A set of antenna-optimization problems is presented that satisfies the necessary requirements to form a test suite useful for measuring and comparing the performance of different evolutionary optimization algorithms (EAs) when they are applied to solve complex electromagnetic problems. The ability of the proposed test suite to find strong and weak points of any EA is illustrated by a complete study of four broadly used evolutionary algorithms carried out with the aid of the new test functions.**

***Index Terms*—Antennas, genetic algorithms (GAs), optimization methods, particle swarm.**

finding the probability rates that best fit the algorithm for typical optimization problems.

At this point, a lack of standardization is detected for choosing the functions belonging to the test suite although several guidelines have been introduced in [10] and [11]. So long as these functions are selected properly, the algorithm will optimize correctly in other cases. Moreover, the availability of standardized sets of test functions is of great importance for comparative studies of different algorithms, since comparisons implemented over unequal test suites may lead to erroneous conclusions.

Available Impedance Matching Software Applications

- *OptiMatch* http://www.microwavesoftware.com/optiad.html
- *Optenni* http://www.optenni.com/
- *AnTune* http://www.antune.net/index.html
- *Zmatch* http://www.nuhertz.com/software/zmatch
- *Wmatch* http://www.mikehutt.com/imn.htm (C++ source code)
- *Ematch* D.B. Miron, Small Antenna Design. Newnes, (2006). (MATLAB source code)
- M. Bakr, Nonlinear Optimization in Electrical Engineering with Applications in MATLAB, IET, London (2013). (MATLAB source code)

Interesting Antenna Design Optimization Software Tools

- 4NEC2 (simplex and genetic algorithm optimizers)
  - http://www.qsl.net/4nec2/
- Nikiml's Antenna pages (Differential Evolution)
  - http://clients.teksavvy.com/~nickm/scripts.html
- NEC Lab
  - http://www.ingenierias.ugto.mx/profesores/sledesma/documentos/index.htm
- The Applied Computational Electromagnetics Society [ACES]
  - http://aces-society.org/software.php

Thank You

- Questions ?