VAASAN AMMATTIKORKEAKOULU
VASA YRKESHÖGSKOLA
UNIVERSITY OF APPLIED SCIENCES

MABINDRA RAI

THE INVESTIGATION OF MINIVNAPRO VECTOR NETWORK ANALYZER

Information Technology
2015

ACKNOWLEDGEMENTS

I would like to thank M.Sc Jani Ahvonen, M.Sc Santiago Chavez and M.Sc Antti Virtanen for all kind of support and advice provided during my thesis.

Furthermore, I would like to thank all my teachers at VAMK, my family and friends for their continuous support and motivation in every step of my life and during studies.

MABINDRA RAI
E1100634@edu.vamk.fi
+358417079640

23/04/2015

ABBREVIATIONS SND SYMBOLS

Abbreviations

VNA	Vector network analyzer
SNA	Scalar network analyzer
HP VNA 8714B	Hewlett Packard vector network analyzer
RF	Radio Frequency
Coax	Coaxial
RLC	Resistor Inductor Capacitor
S-parameters	Scattering parameters
H, Y, Z	Hybrid Admittance Impedance
DUT	Device under test
TV	Television
I/Q DDS	Quadrature direct digital synthesis
SMA	Subminiature version A
RFID	Radio frequency identification
MF/HF	Medium/High frequency
EMI	Electromagnetic interference
LAN	Local area network
UHF	Ultra high frequency

Symbols

A	Area [m^2]
a	Radius of small loop antenna [m]
c	Speed of light [$300 * 10^6\ \frac{m}{s}$]
d	Spacing between the conductors in coaxial cable [m]
D	Maximum antenna dimension
E	RF field strength [V/m]
E_Φ	Electric field [V/m]

f	Frequency[1/s]
f_r	Resonance frequency [1/s]
G	Conductance of the dielectric materials [Siemens/length]
h	Height of conductor over the plane [m]
h	Height [m]
H_θ	Magnetic field [A/m]
I_o	Peak value of current [A]
I_e	Electric current [A]
I	Uniform current [A]
I_A	Antenna Current [A]
j	Imaginary unit
k	constant
L,l	Length [m]
N	Number of turns
P_r	Radiated power [watts]
R_1	Radius of reactive near field region [m]
R_2	Radius of radiating near field region [m]
R_r	Radiation resistance [V/A]
RL	Loss resistance
r_1	Radius of the center conductor of coax cable [m]
r_2	Radius of outer conductor of coax cable [m]
r	Radius of conductor of coaxial cable [m]
S	Area of loop [m^2]
t	Time [s]
V	Voltage [V]
V_g	Voltage-source generator
V_L	Voltage across the load impedance [V]
V_{oc}	Open circuit voltage [V]
v	Velocity [m/s]
vf	Velocity factor [distance/time]
X_A	External inductive reactance [V/A]
X_i	Internal high-frequency reactance [V/A]

Z_A	Antenna impedance [V/A]
$Zcable$	Impedance of cable [V/A]
Z_g	Impedance of the generator
Z_{in}	Input impedance [V/A]
Z_l	Load impedance [V/A]
Z'_{in}	Input resonance under resonance
Z_0	Characteristic impedance [V/A]

Greek

λ	Wavelength [m]
η	Efficiency
θ	angle (plane of loop and the transmitting station)
π	pi [22/7]
ω	Angular frequency [rad/sec]
Φ	Angle
ϵ_r	Relative permittivity

VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES
Information Technology

ABSTRACT

Author	Mabindra Rai
Title	Investigation of Minivna Pro Vector Network Analyzer
Year	2014-2015
Language	English
Pages	69+18
Name of Supervisor	Jani Ahvonen

There are several types of network analyzers available today. However, Vector Network Analyzer is considered to be one of the best analyzers because it measures magnitude and phase as well as determine the performance of the radio frequency circuits.

VNA is a very popular choice among radio frequency engineers and they use this device to investigate the complex circuits to increase the efficiency and signal integrity of circuits. Due to the large size of VNA, the engineers have developed many different smaller versions of VNA and among all them Minivna pro is considered the most popular network analyzer with software interface and many new features like cable length measurement, built-in Bluetooth for remote measurement and the ability to export data in several formats. Since Minivna pro has a relatively low frequency range, an “extender” device is available for increasing the frequency range.

The aim of this thesis was to investigate the features of Minivna pro and show that Minivna pro is compatible with HP VNA 8714B. The main idea was to measure the resonance frequency of different types of antennas as well as cable attenuation in both Minivna pro and HP VNA 8714B with 300 kHz- 3000 MHz frequency range.

This paper provides cable length measurement using Minivna pro and some of the calculations regarding antenna resonance was done by using an octave. According to the measurement results of this thesis, Minivna pro can be used as effectively as HP VNA 8714B to analyze the RF circuits. The results of the measurements performed by Minivna pro are closer to the specification of cable attenuation in the Coax Cable Datasheet when compared to the HP VNA 8714B. Resonance frequency measurements were also performed and the results were very close between HP VNA 8714B, Minivna pro and the theoretical calculations from an octave.

Keywords: Vector Network Analyzer, Minivna pro, Antenna and coaxial cable

CONTENTS

ABSTRACT

LIST OF FIGURES

LIST OF TABLES:

1 INTRODUCTION

The aim of this paper is to introduce Minivna pro with its software interface. Minivna pro is a smaller version of Vector Network Analyzer which is capable of measuring the RF of antennas and RF circuits. There are some new features available in Minivna pro such as cable length measurement and intergrated Bluetooth which are unavailable in HP VNA 8714B. The range of Minivna pro is only up to 200MHz but its range can be increased up to 1.5GHz by adding an extender device.

Vector Network Analyzer (VNA) has been used by RF engineers for decades, but due to its usual big size and heavy weight, it has been rather challenging for engineers to perform measurements by using VNA. Minivna pro's smaller size and weight promises to solve this problem.

1.1 Purpose of the document:

The objective of the document is to confirm whether using Minivna pro with an extender is as effective as using HP VNA 8714B. Measurements are performed using both HP VNA 8714B and Minivna pro for cable attenuation, a matching monopole antenna and measuring resonance frequency of the loop antenna to investigate compatibility between both devices. HP VNA 8714B is used as reference device for Minivna pro.

1.2 Structure of the document:

There are eight chapters in this document. The first chapter introduces the topic and the document. The second chapter includes information about Vector Network analyzer, Minivna pro and measurable parameters by Minivna pro. The third chapter describes antenna, RLC circuit and antenna resonance. The fourth chapter gives detailed information about coaxial cable and transmission loss. The fifth chapter contains all the measurements performed using Minivna pro and compares them with those of HP VNA 8714B. A Conclusion is presented in the sixth chapter. References and the relevent attachement can be found in chapters seven and eight respectively.

2 VECTOR NETWORK ANALYZER

2.1 What is a Vector Network Analyzer?

A network analyzer is a complex and versatile device which is mostly used for measuring radio frequency of different electrical circuits with high precision and efficiency. It can analyze circuits from simple to complex modules which are used in a communication network. **/9/**

One of the main functions of a network analyzer is to investigate the mismatch of impedance between two or more RF components when RF signals are reflected and transmitted in order to increase efficiency and signal the integrity of the device.

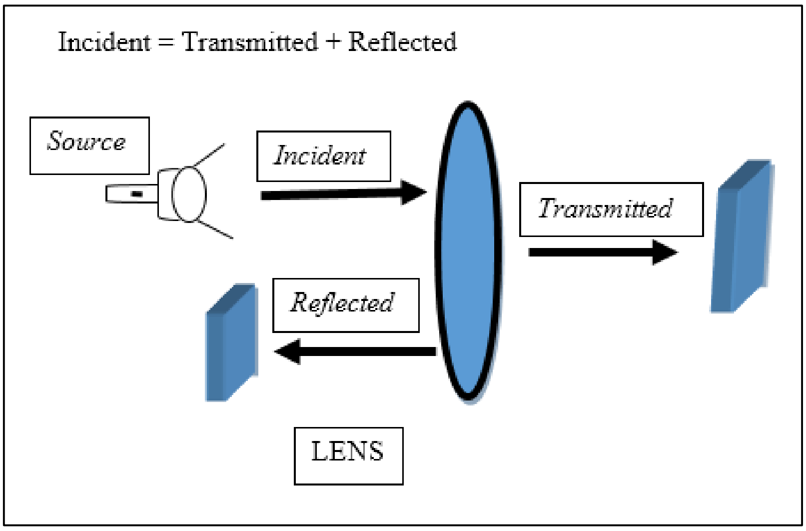


Figure 1: An analogy showing basic principle of network analysis. (/12, 2/)

There are two types of network analyzers:

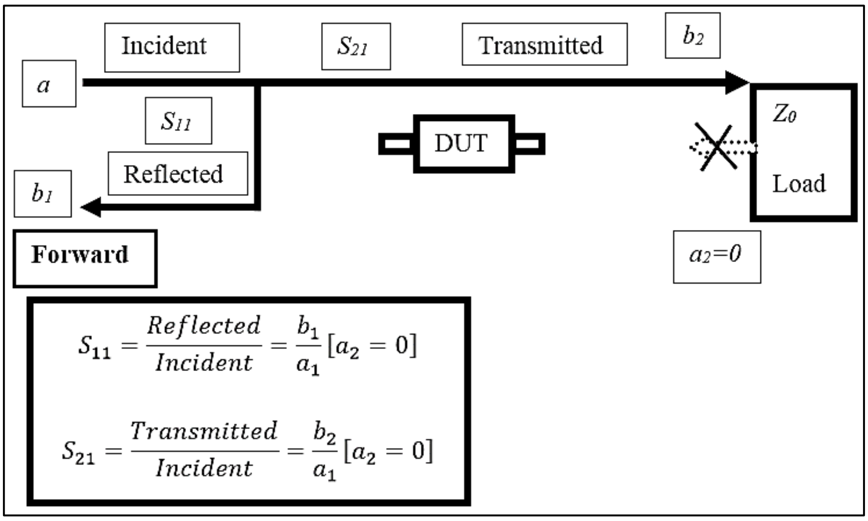
1. Scalar Network analyzer: This network analyzer is used only for the measurement of amplitude between wave qualities of electrical circuit.
2. Vector Network analyzer: This network analyzer is used to measure both amplitude and phase between wave qualities of electrical circuit.

Vector Network Analyzer is the most common network analyzer used to investigate a complex circuit. A VNA performs measurements by using the concept of s-parameters. VNA is able to take care of systematic errors which occur during measurement of the test device with a Full System Error Correction precision. Both de-embedding and embedding are special processing techniques which require vectorial measurement of data, possible by using VNA. Data measured by VNA can be converted into time domain which helps in the interpretation and processing of the measured data. A Smith chart measurement are very accurate, however knowledge of the reflection coefficient vectorially is needed. Furthermore, for the characterization of time-domain and for accomplishing the inverse-fourier transform, both magnitude and phase data are needed.

It is easy to perform measurements on a one port device since there is one reflection of signal but in a two port device, there is a transmission of signal in to both directions. In a two port device, performing measurements based on different conditions and set of parameters is needed. For performing measurements at a low frequency, H, Y and Z parameters are very effective. However, it is rather difficult to perform measurements using those parameters at higher frequencies. So, S-parameters are needed for carrying out measurements in two port devices. In addition, when using S-parameters, connecting loads at DUT is not needed and H, Y and Z parameters can be deduced from S-parameters, if needed.

S-parameters of a device can be extracted by squaring the number of ports of a device. For instance, a two-port device has 4 S-parameters. In S-parameters, the number following S defines the port from which the energy emerges and the next number defines the port through which the energy enters. For example, in S_{12}, energy emerges from port 1 and enters through port 2. However, when these two numbers are the same (as in S_{22}), then it shows a reflection measurement.

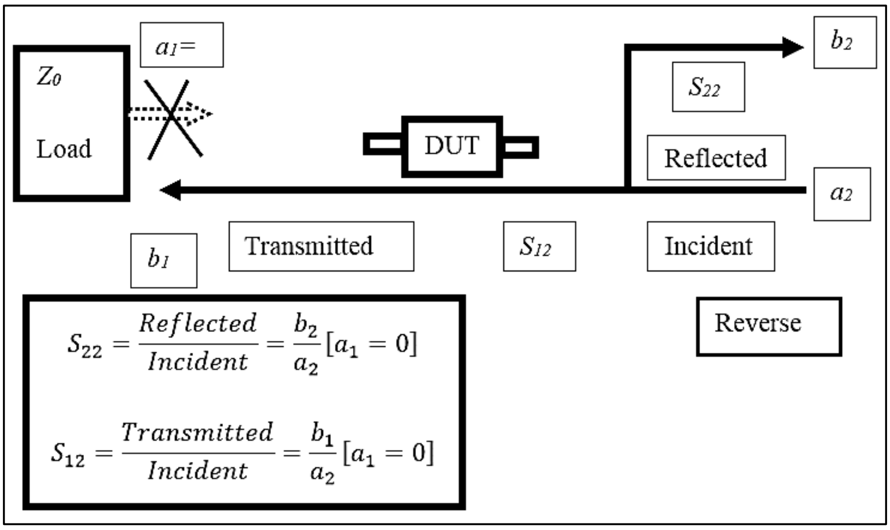
For forward measurement,



$$S_{11} = \frac{Reflected}{Incident} = \frac{b_1}{a_1}[a_2 = 0]$$

$$S_{21} = \frac{Transmitted}{Incident} = \frac{b_2}{a_1}[a_2 = 0]$$

For reverse measurement,



$$S_{22} = \frac{Reflected}{Incident} = \frac{b_2}{a_2}[a_1 = 0]$$

$$S_{12} = \frac{Transmitted}{Incident} = \frac{b_1}{a_2}[a_1 = 0]$$

Figure 2: Measuring S-parameters (/1,14/)

When both incident waves are non-zero ($a_1 \neq 0$ and $a_2 \neq 0$), which is considered as superposition of two measurements situations a_1=0 and $a_2 \neq 0$ with $a_1 \neq 0$ and a_2=0, it can be written as:

$$b_1 = s_{11}a_1 + s_{12}a_2$$

$$b_2 = s_{21}a_1 + s_{22}a_2 \tag{1}$$

Equation 1 can be represented in S-parameters matrix as:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{2}$$

The short notation of S-matrix is:

$$\mathbf{b} = \mathbf{Sa} \tag{3}$$

For DUTs with more than two ports, the term N-port is introduced. For example, a three-port network (N=3) is defined in the following equation:

$$b_1 = s_{11}a_1 + s_{12}a_2 + s_{13}a_3$$

$$b_2 = s_{21}a_1 + s_{22}a_2 + s_{23}a_3$$

$$b_3 = s_{31}a_1 + s_{32}a_2 + s_{33}a_3 \tag{4}$$

It can also be represented in S-matrix with 3 × 3 elements and short-notation can also be used to represent the S-matrix of these equations.

Smith chart is another important part of the VNA, which is a graphical aided design and is used to display the antenna’s impedance. The impedance is represented by real and imaginary parts for instance $R+ jX$. Circles on the Smith chart represent the locus of constant resistance whereas constant reactance arcs represent the loci. On the Smith chart, impedances are normalized to characteristics impedance of the device. Generally, 50 ohms impedance is used for microwave system and radio frequency and 75 ohms impedance is for TV cables and broadcast system. **/9/**

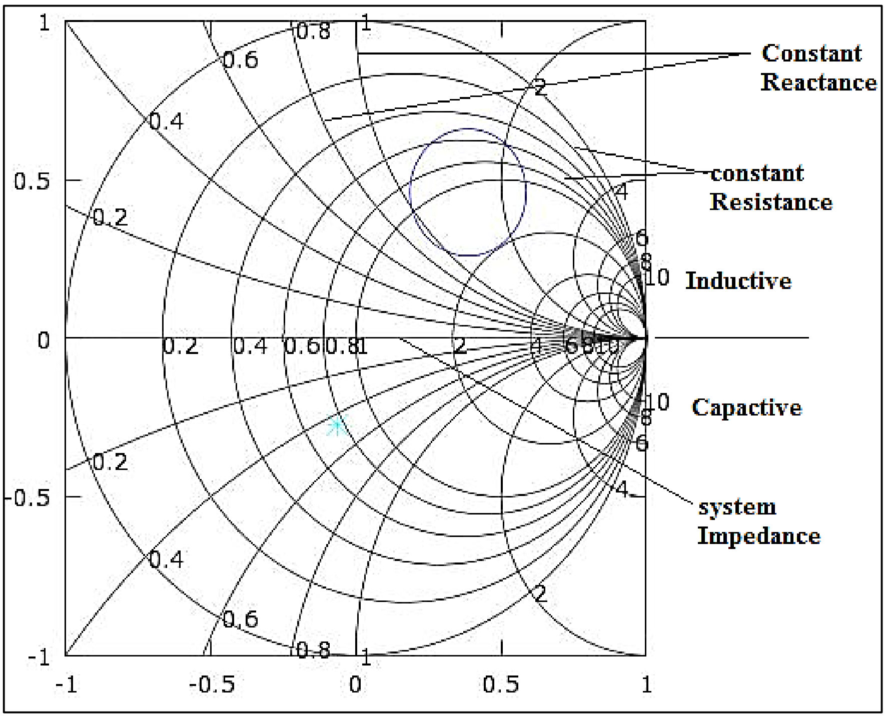


Figure 3: Smith chart. (/1,7/)

2.2 What is Minivna pro and extender?

There are several smaller versions of VNA available today. Minivna pro is considered to be one of the most popular VNAs in the market. But, Minivna pro has a small frequency range compared to HP VNA. It comes with integrated Bluetooth module that is able to scan and send data from its location to a machine for up to 100 meters away. Some features of Minivna pro are given below:

- Frequency range 0.1-200 MHz
- Calibration using open-short-load for accurate results
- Two ports VNA with S11 and S21; display and save results
- I/Q DDS Generator with output power of 0 dBm
- Built in Bluetooth Class 1 for remote measurements
- Internal Battery Li-ion with 1000 mA/h (4 hours full- scan operation)
- Built-in battery charger (up to 400 mA)
- Accessory port for future optional interfaces and frequency extenders
- Low power consumption, 220 mA @ 3.6 V (analyzer mode using USB port)

- Power save mode
- SMA connectors for better isolation
- Extended dynamic range – up to 90 dB in Transmission & 50 dB in Reflection
- Boot loader for future firmware upgrades
- User friendly interface for PC Windows / Linux and Mac
- Integrated Smith chart in software
- Mobile Phone software (under development)
- Measurements of motional crystal parameters, cable length, & more
- Export data in several formats – JPEG, EXCEL, ZPLOT, S2P, PDF

Since, Minivna pro has a frequency range 0.1-200 MHz, which is not sufficient for a variety of systems, an extender device is available in order to increase the frequency range to 1500 MHz. The specification of the extender is given below:

- Frequency range 200-1500 MHz
- Dynamic range : 60 dB @ 1 Ghz
- Operation mode : Reflection and transmission S11-S21
- Harmonics: –35dbc
- Directional coupler : internal
- Calibration : OPEN/LOAD/SHORT
- Connector type : SMA
- Output Power –10 dbm (aprox.)
- Power consumption : 150 mA

2.3 Parameters which can be measured by using Minivna pro

Minivna pro is a smaller version of VNA which measures RFID reader antennas and RF circuits. So, Minivna pro can perform all the task of VNA with some additional features which are:

- Linear measurements: reflection coefficient, transmission coefficient, phase and group delay, stability, measurement of balanced DUTs, switching time
- Nonlinear measurements: harmonics, intercept points, hot s-parameters.
- Time-domain measurement.

- Mixed measurements: conversion loss, LO feed through and isolation.

3 ANTENNA

The IEEE Standard defines Antennas as “a means for radiating or receiving radio waves”. Antenna can also be defined as transitional structure between free-space and transmission line, taking the form of coax line or wave guide. An Antenna is very well known for transmitting electromagnetic energy from the transmitting source to the receiver. **/3/**

An antenna is “a usually metallic device used as wire or rod for radiating or receiving radio wave”. In the wireless communication systems, antennas play a vital role for improving performance of system as well as to achieve the overall specification of the communication system. By using a high-performance antenna in any communication system such as in a mobile device or TV, better broadcast reception that increases the quality of transmission in the communication system can be achieved. The standing waves can cause discharge in the transmission line of antenna so prevention is needed. The resistive and dielectric losses are unacceptable because they reduce the antenna efficiency factor. Antenna efficiency is the ratio of energy radiated to the input energy in the antenna terminals.

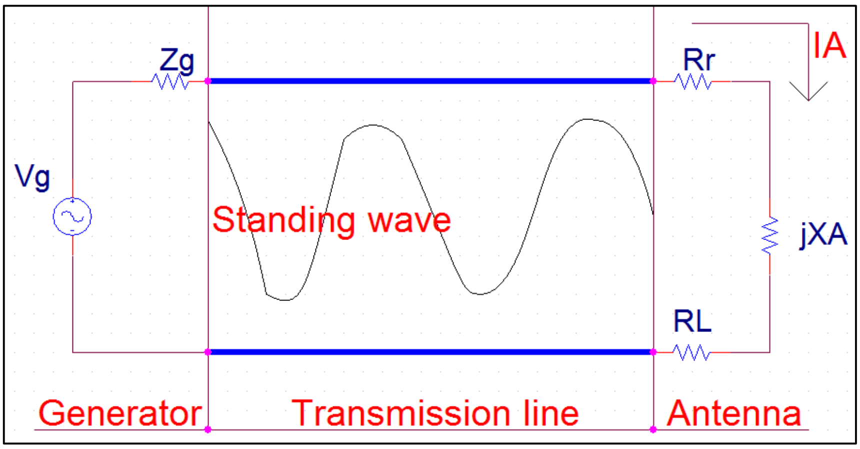


Figure 4: Transmission-line Thevenin equivalent circuit of a transmitting antenna system(/3, 3/)

Where, V_g represents voltage-source generator (transmitter), Z_g represents impedance of the generator (transmitter), R_r represents radiation resistance (where radiated power as $P_r = I^2_A * R_r$), R_l represents loss resistance which is mostly related with conduction and dielectric losses, jX_A is antenna reactance. So,

Antenna impedance: $Z_A = (R_r + R_L) + jX_A$ (5)

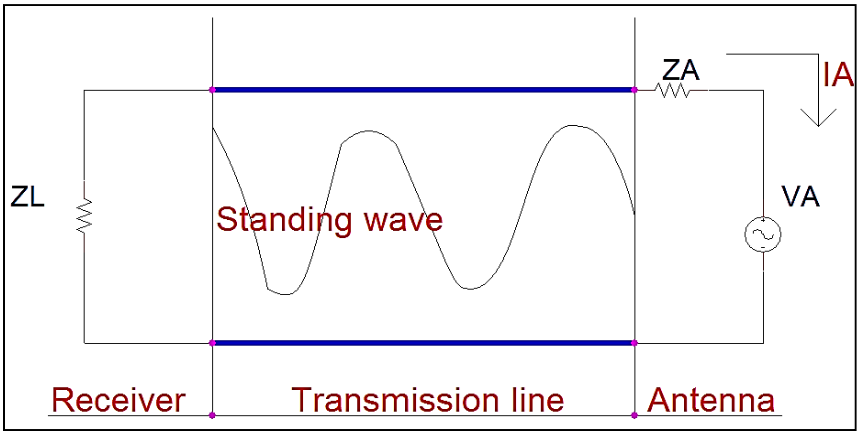


Figure 5: Transmission-line Thevenin equivalent circuit of a receiving antenna system. (/18/)

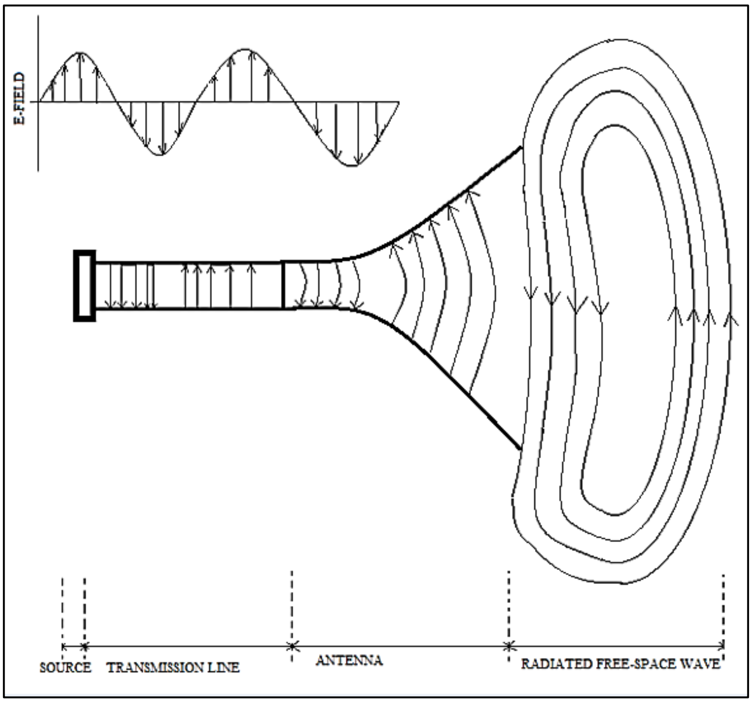


Figure 6: Antenna as a transition device. (/3, 2/)

Antenna pattern describes the radiation of antenna graphically with spherical coordinates. The most common antenna patterns are power pattern and field pattern.

Antenna field types are Reactive field which represents the energy stored in an antenna, defined by stationary waves and Radiation field which represents transmitted energy by antenna, defined by propagating waves.

Antenna fields regions is another parameter which has three types: Reactive near field region, near field region and far field region.

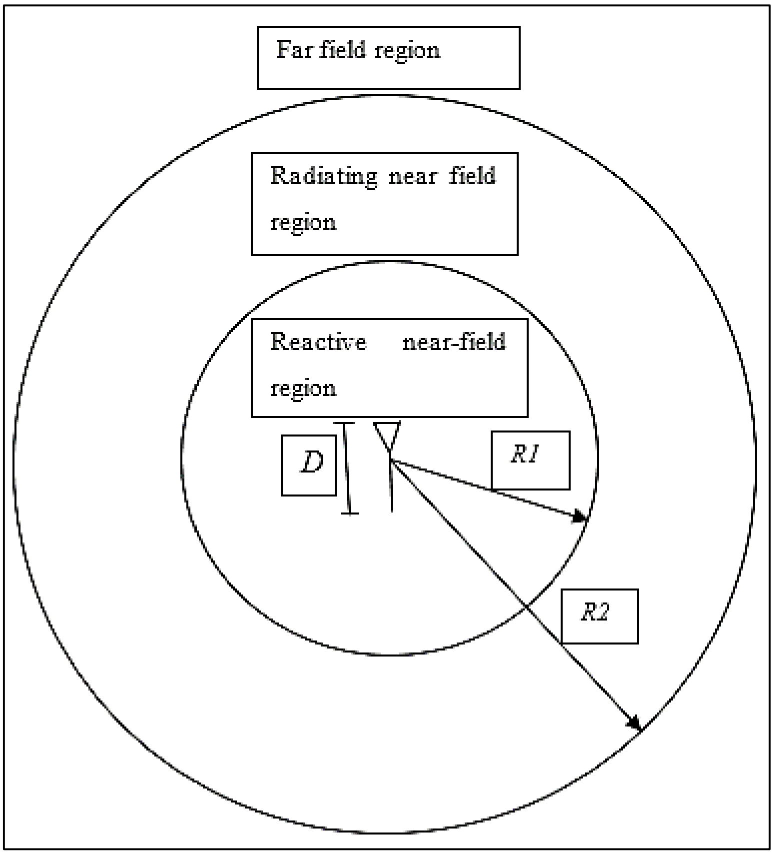


Figure 7: Fields regions of an antenna. (/3, 33/)

Where, D=maximum antenna dimension, R_1 is radius of reactive near field region which can be calculated as $R_1 = 0.62\sqrt{\frac{D^3}{\lambda}}$, R_2 is radius of radiating near field region which can be calculated as$R_2 = \frac{2D^2}{\lambda}$.

There are various types of antennas including wire antennas (monopole, dipole and loop), aperature antennas, microstrip antennas, array antennas, reflector antennas and lens antennas.**/3/**

3.1 Monopole antenna

A monopole antenna is a single wire antenna with λ/4 wavelength and is one half of dipole antenna. It is placed over a ground plane or any shape metallic object. The ground plane can be roof of a house with metallic surface, some metal plate, and vehicle body or λ/4 radials.

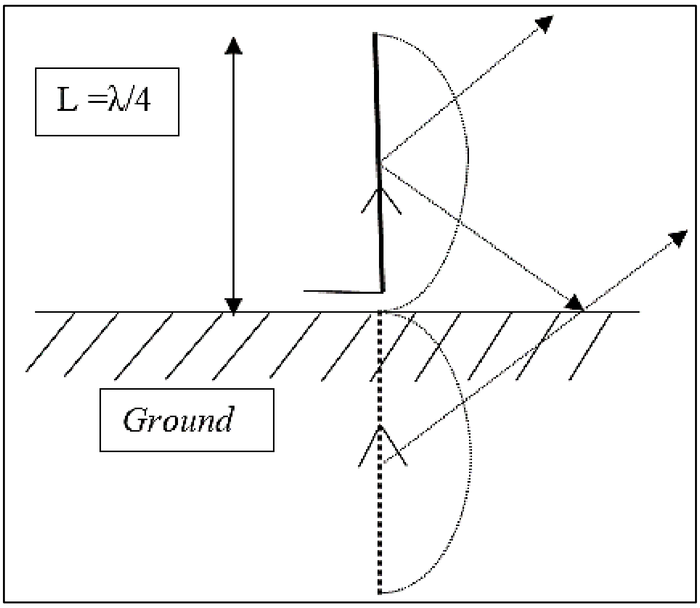


Figure 8: vertical monopole antenna above infinite ground.(/18 ,2-15/)

The monopole antenna design is equivalent to λ/2 of a vertical dipole antenna and input impedance is also half of dipole (i.e 36.5 + j21.25 ohms). Thus, monopole radiating power is also half compared to a dipole. However, the directivity of a monopole is twice as much as that of a dipole because there is no radiation below the ground plane of monopole antenna.

Antennas with the finite ground plane are normally used in real world which affects the radiating property of the antenna. There is some effect in the impedance of antenna by a finite-sized ground plane, whereas effect on radiation pattern is very powerful and leads to radiation in a skewed direction i.e. away from the horizontal plane.

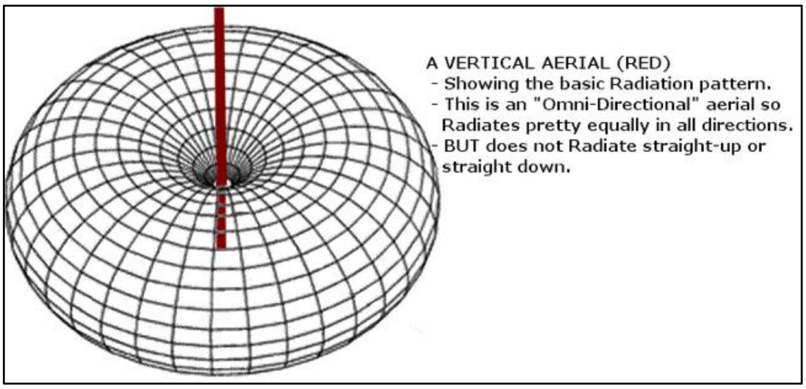


Figure 9: Radiation pattern for a quarter-wavelength monopole on finite ground plane.(/4,15/)

From figure 9, it can be observed that the radiation pattern is in one direction but there is a slight change in the peak of radiation, making an angle of elevation to x-y plane. From this it can be concluded that monopole with a larger ground plane will result in a decrease in the area of radiation and the radiation pattern appear more in the x-y plane.**/2/**

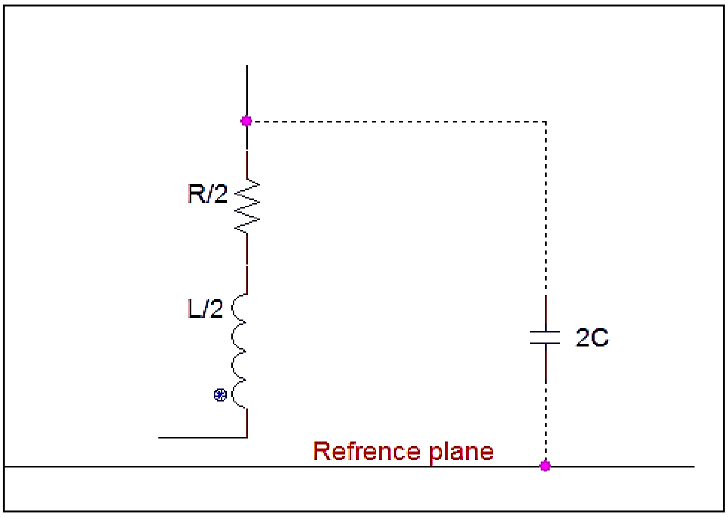


Figure 10: Monopole Impedance.(/15,757/)

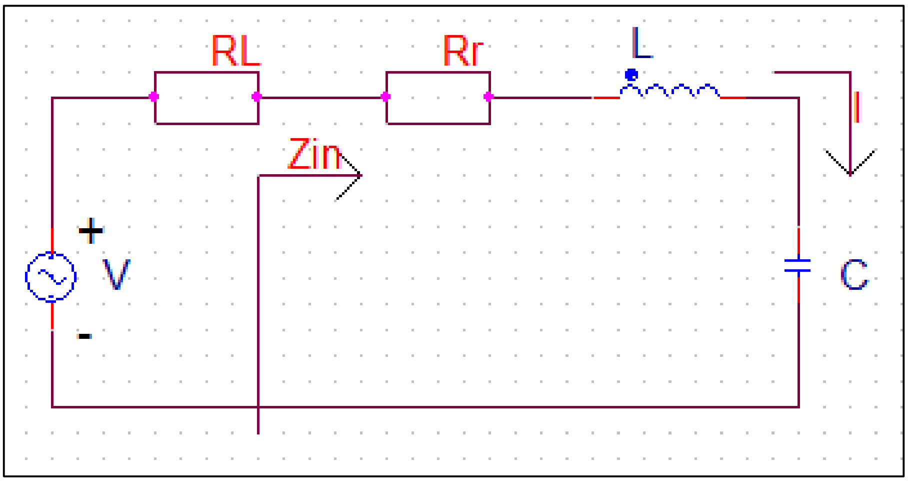


Figure 11: Monopole antenna Efficiency circuit diagram(/3/)

The efficiency of the monopole antenna in figure 11 can be calculated from equation 6:

$$\eta = \frac{R_r}{R_r + R_l} \tag{6}$$

Where, R_r represents radiation resistance, R_l represents resistance loss which can be dielectric loss, loss of conductor, ground loss or other.

Thus, to get the monopole with high efficiency, the amount of energy dissipated in radiation resistance must be large and the total loss must be small.

3.2 Dipole antenna

A dipole consists of two identical poles. The poles are separated by insulator in two halves at the center, with equal lengths and spread in opposite directions. It is cheap, simple, old and widely used in radio communication for many applications. It is very easy to analyze current distribution in a dipole antenna if the dipole is located proportionally about the origin and length is directed towards z- axis. The current distribution can be calculated using equation 7:

Since, $I_e(x', y', z') = \hat{a}_z I_0$ with$z' = 0$.

$$I_e(x', y', z') = \begin{cases} \hat{a}_z I_0 \left(1 - \frac{2}{l} z'\right), & 0 \le z' \le l/2 \\ \hat{a}_z I_0 \left(1 + \frac{2}{l} z'\right), & -l/2 \le z' \le 0 \end{cases} \tag{7}$$

Where, I_0 is constant and peak value of the current and I_e is electric current.

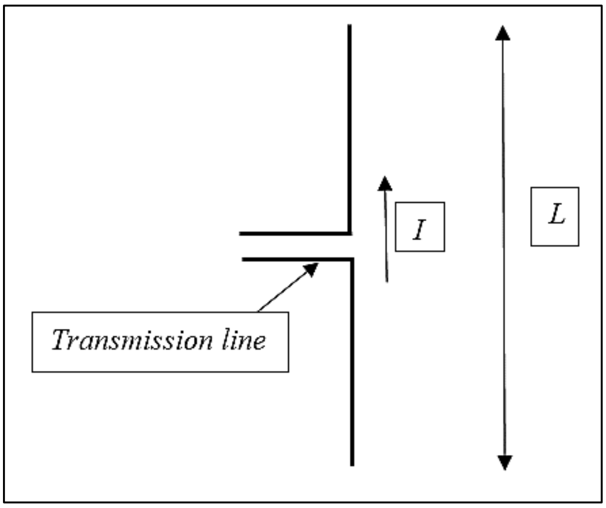


Figure 12: Dipole Antenna. (/10, 201/)

Where L is the length of the dipole and I is the uniform currents in the plates.

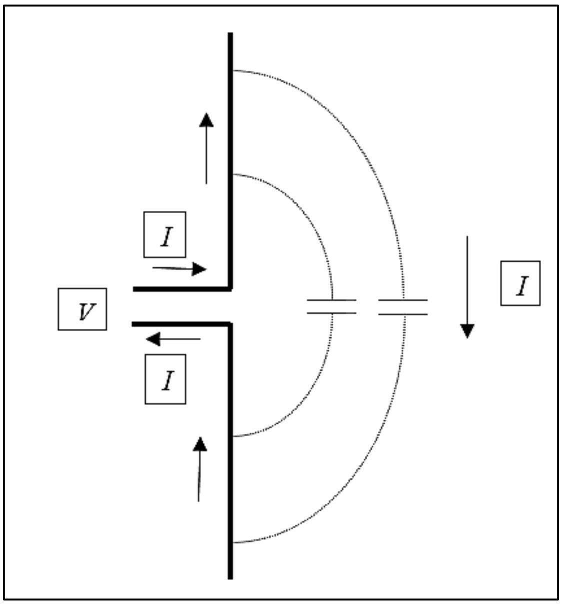


Figure 13: current in a dipole antenna flows through the capacitance between poles (/15, 747/).

In figure 13, dipole has a capacitor and inductor which are in series with the capacitance. When antenna radiates, loss of energy occurs which is then absorbed by the resistor so a resistor is added in series with a capacitor and an inductor. The resistance symbolizes the amount of energy lost due to radiation, thus it is called radiation resistance. A dipole should be electrically a half wavelength at operating frequency so that resonance can occur.**/15/**

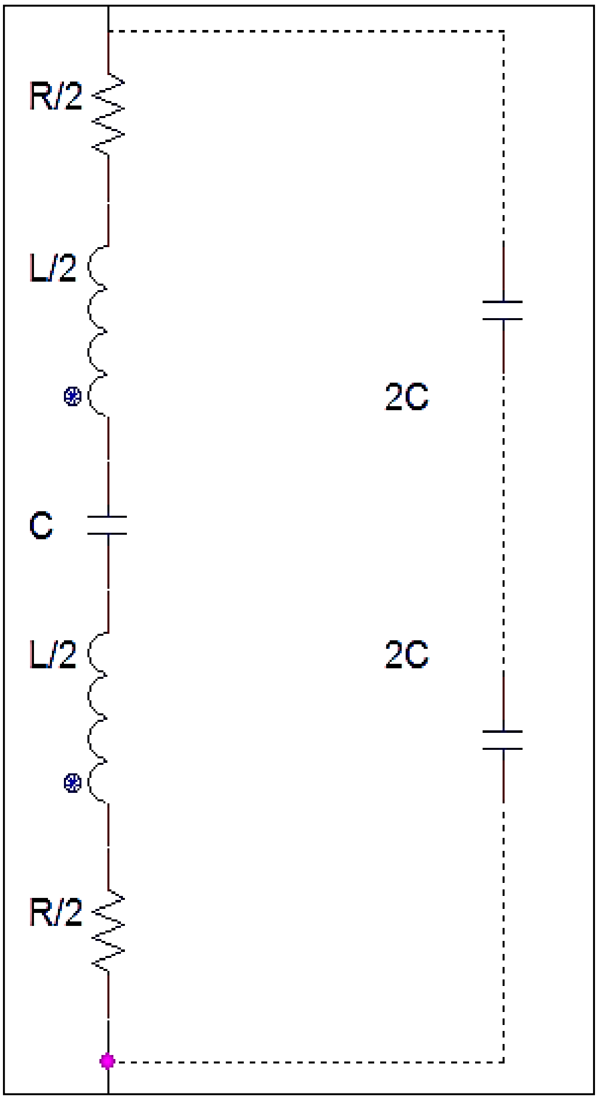


Figure 14: Dipole Impedance. (/15, 757/)

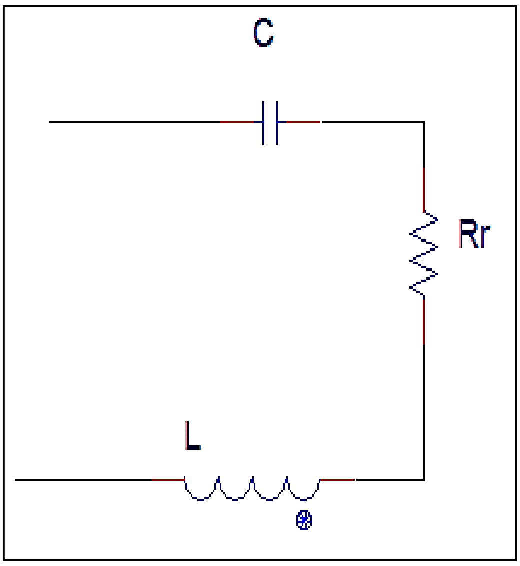


Figure 15: Impedance of Dipole in RLC series. (/15, 756/)

Figure 15 is a simplified form of figure 14. From this figure it can be observed that at resonance frequency, impedance will be at resistance. This way, both inductance and capacitance reactance eliminate each other, which cause low impedance in the antenna. When frequency is higher than the resonance frequency, impedance will be at inductance and it will be at capacitance when frequency is lower than resonance frequency. Thus, resonant frequency is an effective radiator of electromagnetic energy because energy from the antenna can be withdrawn or inserted in simple way.

Dipole antennas are often simple and easy to install. At proper heights, it provides fine output for medium/high frequency.**/10/ /3/ /8/**

3.3 Loop antenna

An antenna which consists of a loop of wire or any conducting material, is used in various applications. It can have different forms like square, triangle, rectangle, circle, eclipse or other, depending on the system.

There are two types of loop antennas: a small loop and a large loop. In small loop antennas, the distribution of current is identical over the loop. In addition, current passes through the loop having same phase and amplitude. But, the length of the loop should not be greater than 0.1 λ, since the voltage in small loop antenna is lower. The Equation 8 shows how to find the voltage across the untuned loop antenna:

$$V = \frac{2\pi ANE\cos\theta}{\lambda} \qquad (8)$$

Where, V is voltage across the loop antenna, A is area of loop in m^2 (square meters), N is number of turns, E is RF field strength in volts per meter, θ is angle between the plane of loop and the transmitting station, λ is wavelength. **/10/**

The effective height for equation 8 can be calculated from equation 9:

$$h = \frac{2\pi AN}{\lambda} \qquad (9)$$

Where, h is effective height in meters.

Equation 10 is for a tune loop antenna:

$$V = \frac{2\pi ANEQ\cos\theta}{\lambda} \qquad (10)$$

Where, Q is the load that tunes the circuit, determined by loop bandwidth and voltage.

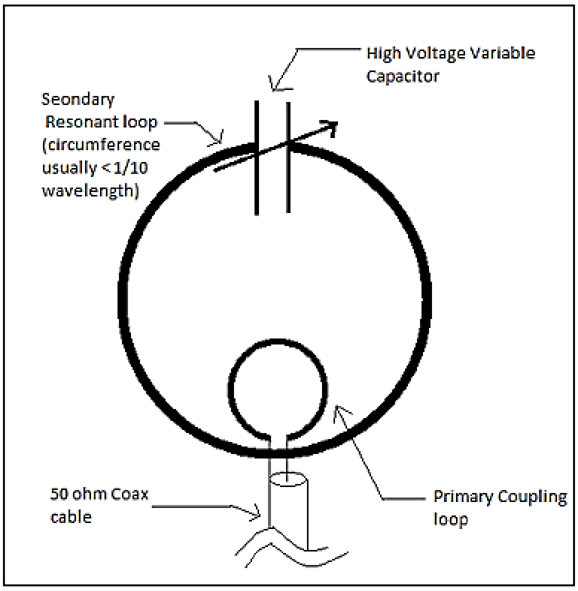


Figure 16: Small Loop Antenna.(/22/)

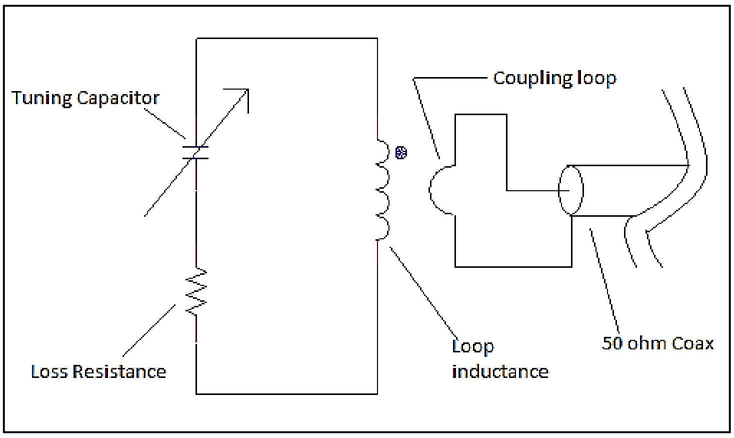


Figure 17: Circuit Diagram for Small Loop Antenna.(/22/)

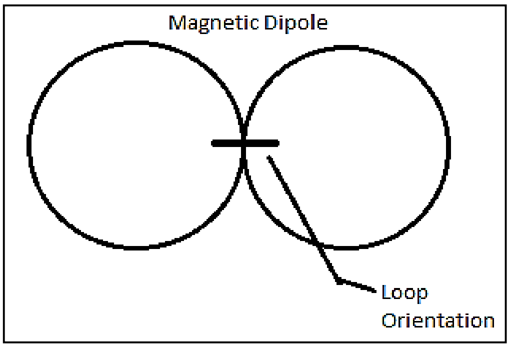


Figure 18: Magnetic Loop Antenna Pattern.(/22/)

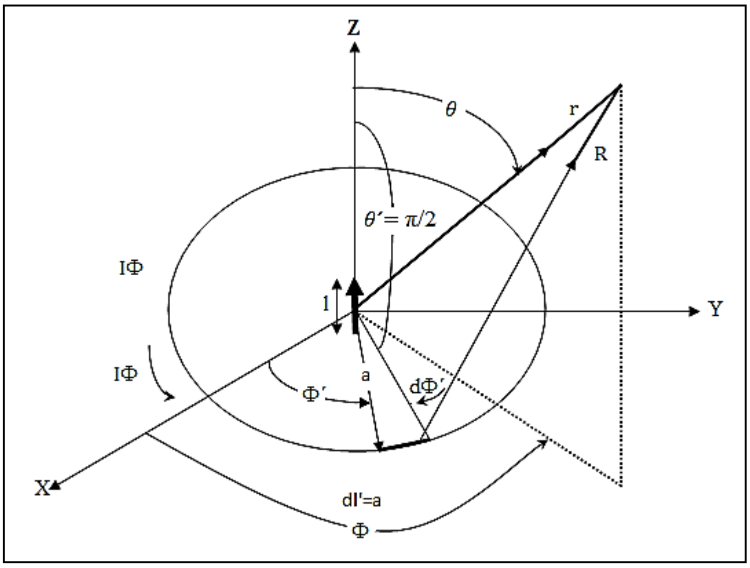


Figure 19:Small Circular Loop at origin. (/3, 205/)

From figure 19, the magnetic (H_θ) and electric (E_Φ) fields of a small loop antenna with radius “*a*” and with constant distribution of current over the loop in Φ direction $I_\Phi = I_0$ (constant) for far fields is given below:

$$E_\Phi = \eta \frac{k^2\, a^2 I_0 e^{-jkr}}{4r} sin\theta \tag{11}$$

$$H_\theta \cong \frac{-k^2\, a^2 I_0 e^{-jkr}}{4r} sin\theta \tag{12}$$

$$H_r = H_\emptyset = E_r = E_\theta = 0 \tag{13}$$

The radiation power of small loop antenna is:

$$P_r = \eta \left(\frac{\pi}{12}\right)(ka)^4 |I_0|^2 \tag{14}$$

Where, *k* is a constant, *a* is radius of small loop antenna.

Which can be simply written as:

$$P_r = \frac{|I_0|^2}{2} R_r \tag{15}$$

Where, R_r is the radiation resistance,

$$R_r = \eta \left(\frac{\pi}{6}\right)(k^2 a^2)^2 \tag{16}$$

For small loop antenna,

$$R_r = 31{,}171 \frac{S^2}{\lambda^4} \tag{17}$$

Where, *S* is area of loop.

The circuit diagram for loop antenna in transmission mode is shown in the figure 20 and input impedance (Z_{in}) equation is represented as:

$$Z_{in} = R_{in} + jX_{in} = (R_r + R_L) + j(X_A + X_i) \tag{18}$$

Where, R_r is radiation resistance, R_L is loss resistance of loop antenna, X_A is external inductive reactance = ωL_A and X_i is internal high-frequency reactance of loop conductor = ωL_i .

In resonance the equation for input impedance is given by:

$$Z'_{in} = R_{in} + \frac{X_{in}^2}{R_{in}} \quad (19)$$

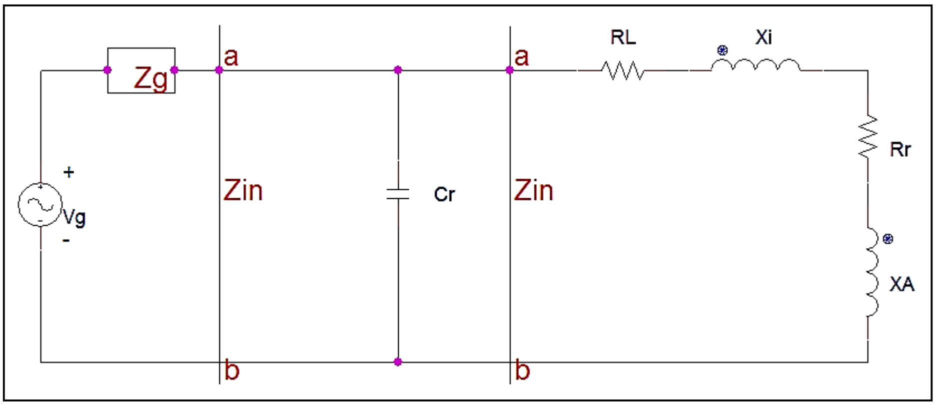


Figure 20: Equivalent Circuit of Loop Antenna in Transmitting mode.(/3, 215/)

The equivalent equation for loop antenna as receiving mode is:

$$V_l = V_{oc} + \frac{Z_L}{Z'_{in}+Z_L} \quad (20)$$

Where, V_L is voltage across the load impedance, V_{oc} is open circuit voltage $V_{oc} = j\omega\pi a^2 B_z^i$, Z_l is load impedance and Z'_{in} is input resonance under resonance./**3**/

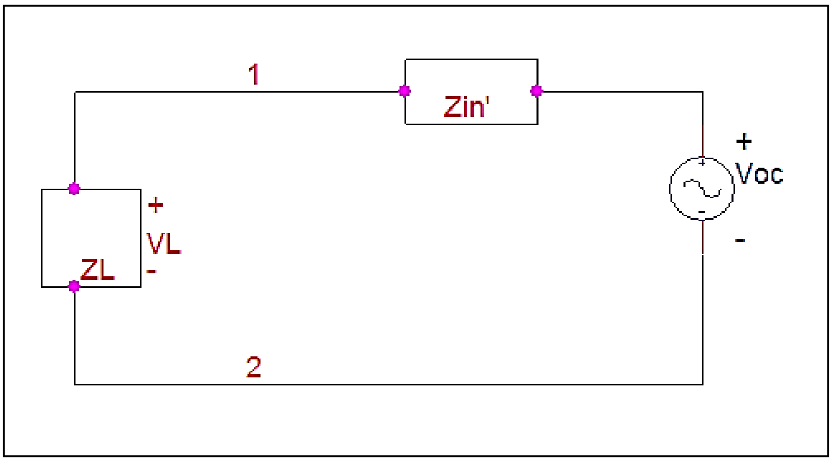


Figure 21: Circuit diagram for Loop Antenna at Receiving mode (/3, 217/)

In large loop antennas, the distribution of current, phase and amplitude are not identical.

3.4 Electric RLC circuit resonance

RLC resonance is a special frequency in AC circuits, decided by the value of the resistance, capacitance and inductance.

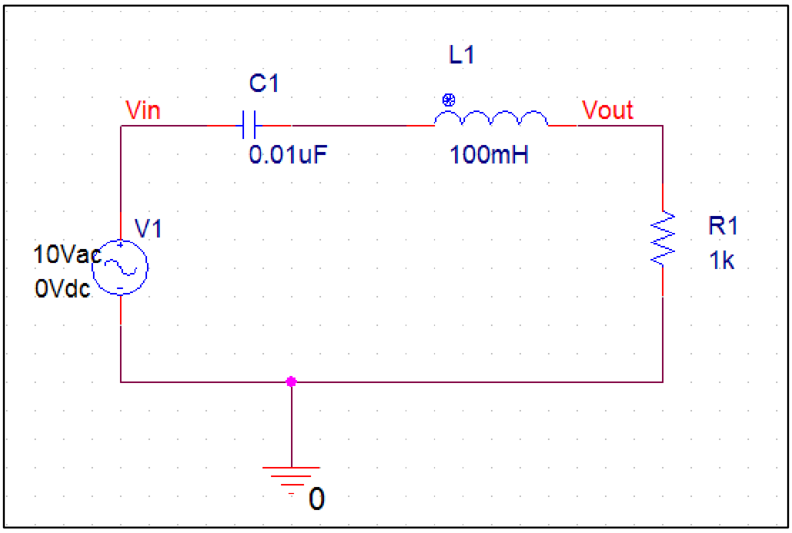


Figure 22: RLC circuit.

From figure 22, the resonance frequency is calculated using the following formula:

$$f_R = \frac{1}{2\pi\sqrt{LC}} \tag{21}$$

$$f_R = \frac{1}{2\pi\sqrt{100mH * 0.01uF}} = \frac{1}{2\pi\sqrt{0.1 * 10^{-8}}} = \frac{1}{2\pi\sqrt{10^{-9}}} = \frac{1}{1.9869 * 10^{-4}}$$
$$= 5.0329kHz$$

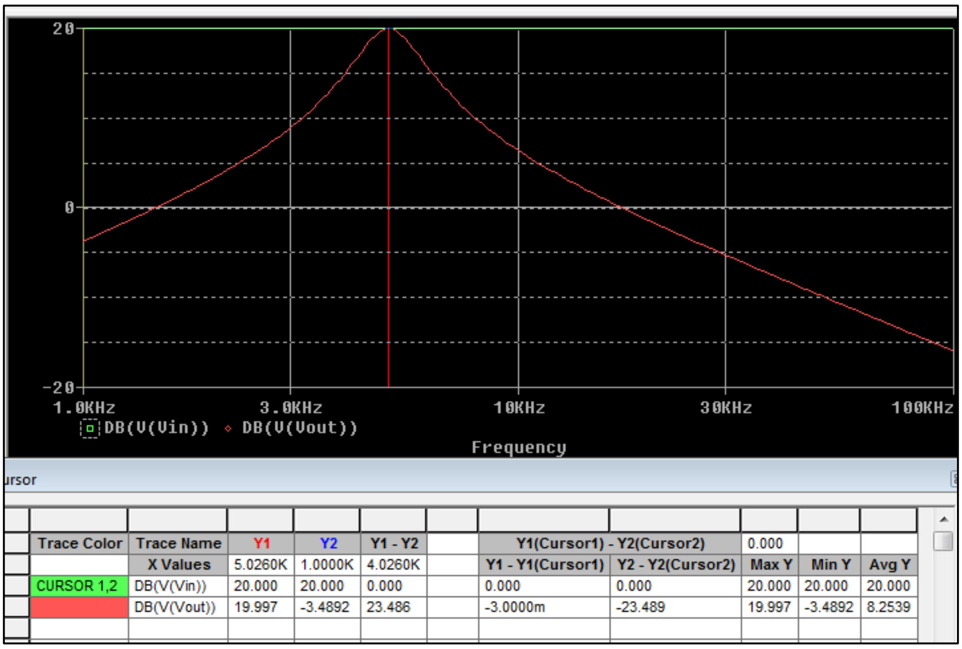
Since the value of resonance frequency is already known, the quality (Q) and bandwidth of the circuit can also be calculated as:

$$Q = \frac{X_L(resonance)}{R} \tag{22}$$

$$Q = \frac{\omega_r L}{R} = \frac{2\pi f_r L}{R} = \frac{2\pi * 5.0329KHz * 0.1H}{1K\Omega} = 31.622$$

$$BW = \frac{f_R}{Q} \tag{23}$$

$$BW = \frac{5032.9Hz}{31.622} = 159.158Hz$$



Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	5.0260K	1.0000K	4.0260K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	DB(V(Vin))	20.000	20.000	0.000		0.000	0.000	20.000	20.000	20.000
🟥	DB(V(Vout))	19.997	-3.4892	23.486		-3.0000m	-23.489	19.997	-3.4892	8.2539

Figure 23: The Resonance Frequency of RLC circuit.

3.5 Antenna Resonance

Antenna resonance is an important factor for radio antenna design. Every RF antenna has inductance and capacitance which at some point react with each other and at that point resonance frequency occurs. At resonance frequency, RF antennas act resistive which consist of loss resistance and radiation resistance. “*At the resonant frequency it is much easier to couple energy into the antenna and it will therefore be a more efficient radiator.*” **/15/**

4 COAXIAL CABLES

Coaxial cable is a common and widely used transmission medium in data communication. A coax cable consists of two conductors parallel to each other where the middle conductor is a solid copper wire, also known as the core of the cable. The middle conductor is responsible for all kinds of data transfer and surrounded by insulating materials. The other conductor is a fine mesh of copper wire which works as a shield that protects the cable from EMI. It is covered by protective plastic sheath and is widely used as TV wire and in LANs.

It cannot be guaranteed that systems that are connected with coaxial cable are very efficient because radiation of energy occur from the coax cable. Thus, the outer layer of conductors work as a shield which reduces the coupling of signal into contiguous wiring. However, shielding is an important characteristic of coaxial cable, responsible for keeping signals in the cable from leaking out and stopping the signals coming from the outside. Thus, a transmitter or receiver cable with poor shielding will result in the leakage of RF energy from the cable to environment or any other nearby cables and vice versa. This causes interference in the cable.

The most important parameters used in coaxial cables are characteristics impedance and cable loss. Characteristics impedance is the main electrical characteristics of coax cable which controls the amount of reflected and standing waves, authentication of cable and decides the level of power transfer. Characteristics impedance does not depend on the cable length but is determined by the spacing and size of the conductors and dielectric insulator used in between two conductors. A simple way to calculate the characteristics impedance of a cable is by using the formula: 138*log (b/a), where *a* represents the outer diameter of the inner conductor and *b* is inner diameter of outer conductor/shield. Characteristics impedance is measured because impedance level of both transmitting and receiving end should match**. /6/**

The standard impedance levels, common in various applications are 50 ohms and 75 ohms. 50 ohms cable is mostly used for transmitting ordinary radio signals by means of antennas and in data transmission application (mostly in Ethernet). RG-8 and RG-58 are the most common 50 ohms cables in use. Whereas 75 ohms cable is designed to carry video signals, high frequency RF applications such as VHF and UHF. RG-6, RG-11 and RG-59 are universally used 75 ohms cables. These standard cables are widely in use since they are reasonably priced and effective against the interference caused by RF energy leakage. Cables with different impedance can be found, designed for exceptional purposes for instance 93 ohms cable provides low capacitance per foot so it was used for connection computers and their monitors in early computers. Coaxial cables with impedance higher than 93 ohms are very difficult to build practically.

Cable impedance is a very important factor to determine the signal transmission by the cable. When the light waves travel from one medium to another, reflection of light occurs. Similarly, reflection occurs in cables when they transmit electric signals through conductors with different impedances. The ratio of reflected wave to signal input wave in coaxial cable is given by the equation 24:

$$\frac{V_{ref}}{V_{sig}} = \frac{(ZL - Z_{cable})}{(ZL + Z_{cable})} \tag{24}$$

Where, *ZL* is the impedance of load at the end of cable and *Zcable* is the impedance of cable in use. **/19/**

From the equation 24, it can be concluded that the impedance of load and cable should be equivalent to each other, in order to have zero reflection. Therefore, identical impedances for both cable and the load need to be selected so that the transfer of signal occurs without reflecting back towards the cable when the impedances of load and cable match. **/7/**

There are two types of coaxial cables: BASE BAND and BROAD BAND Coaxial cables.

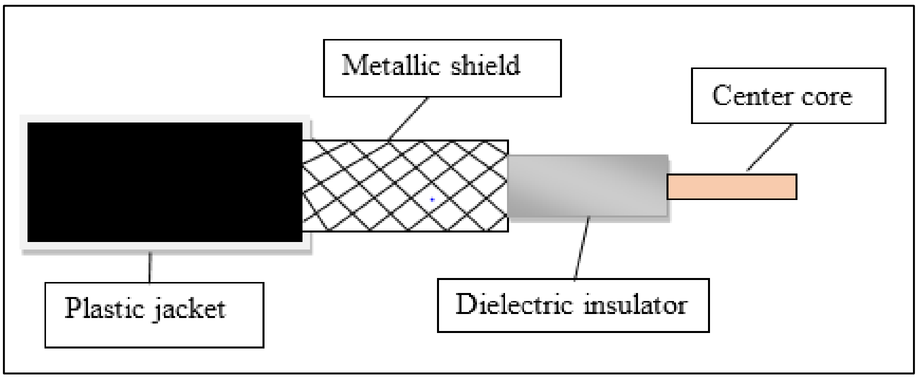


Figure 24: Coaxial cable(/21 ,84/)

4.1 Importance

Coaxial cable plays vital role as a transmission medium in the field of telecommunication and radio broadcasting. Due to uniform characteristic impedances a coaxial cable has very low signal loss when compared to twisted pair cables.

A coax cable provides better performance in comparison with a twisted pair cable, having a lower error rate which is 10^{-9}. This is due to the presence of plastic insulation between the two conductors. A Coax cable can transmit many signals simultaneously without any interference between the signal i.e a broadband system with enough range of frequency to support multiple channels. It also provides greater channel capacity for multiple channels. In addition, a coax cable supports different services like voice, data transmission, multimedia and also video.

It is better to have a so called double-shielded or triaxial cable with dielectric insulator between the shields to have a better transmission of data, since because two shields can cancel the interference by the shield resistance. However, double-shielded cables are usually more costly so a coax cable can be considered a more reasonable option since it can also perform similarly to a double-shielded cable at high frequency. Coax cables perform better at higher frequencies because different kinds of interferences, such as noise, flow on the outer shield and the data signals flow on the inner core of the cable. **/21/**

4.2 Transmission loss

A transmission line is designed to transfer electrical signals or electromagnetic energy from one place to another by using conductors, with minimum loss of signals and less interference. It is necessary to keep in mind the fact that electromagnetic energy is transmitted through conductors, not a voltage or current. A transmission line is divided by the number of conductors inside the cable. Characteristic impedance, propagation constant and high frequency loss are important properties of transmission lines. **/15/**

A list of the most common transmission lines is given below with the number of conductors inside the cable:

Transmission line (cable)	Number of conductors inside cable
Coaxial cable	2
Micro-strip line	2
Strip line	3
Balanced line	2
Waveguide	1

Table 1: Different types of cables with respective number of conductors inside.

A coax cable is the most common transmission line among the list of transmission lines. In a coaxial cable, the propagation of electromagnetic energy occurs through dielectric insulator. The velocity of propagation “v” of electromagnetic energy through dielectric insulator is given by the equation 25:

$$v = \frac{c}{\sqrt{\epsilon_r}} \tag{25}$$

Where, c is speed of light which is approximately equal to $300 * 10^6 \ \frac{m}{s}$ and ϵ_r represents the relative permittivity of the dielectric insulator.

A coaxial cable can be represented as string of capacitance and inductance which acts as a low pass filter. The capacitance relates electromagnetic energy reserved in the electric field between the two conductors to the potential difference across them and inductance relates the electromagnetic energy reserved in the magnetic field to the current level around cable. **/15/**

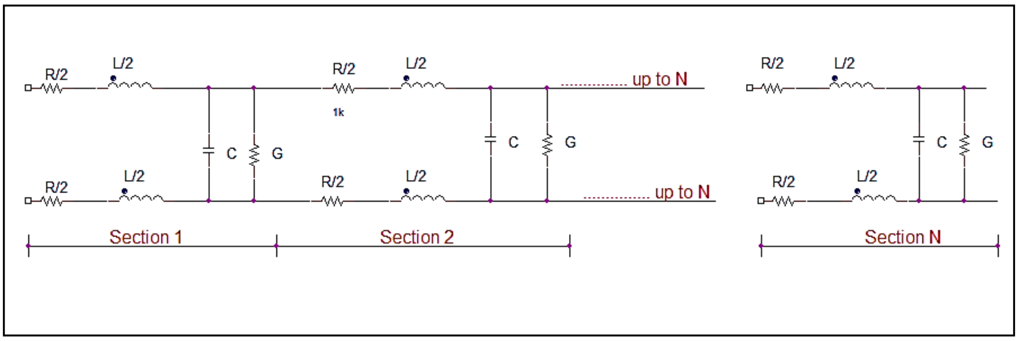


Figure 25: Parameters of a two Conductor Transmission line. (/15 , 217/)

Where, *R* is resistance of the conductors in ohms per unit length, *L* is inductance of the conductors in henries per unit length, *C* is capacitance between the conductors in farads per unit length and *G* represents conductance of the dielectric materials in Siemens per unit length.

From figure 25, one can conclude that in an open circuited transmission line, both current and voltage propagation is possible. The characteristic impedance (Z_0) of transmission line with respect to above figure is given below:

$$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}} \tag{26}$$

There is always some loss in a transmission line while performing in practice but if a transmission line without any kind of loss during transmission is considered, then both *R* and *G* value will be zero which simplifies the equation 26 as:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{27}$$

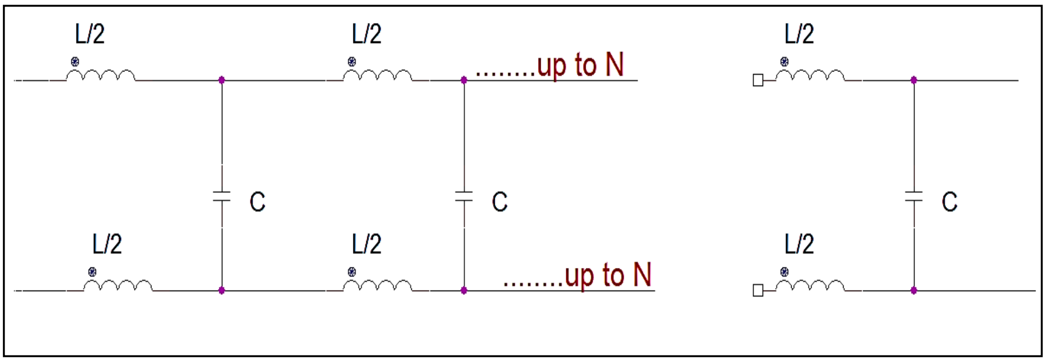


Figure 26: The Lossless Transmission line with their Parameters. (/15 , 219/)

In lossless free cable, velocity of signal "v" which propagate along the cable is given by the equation 28:

$$v = \frac{1}{\sqrt{LC}} \tag{28}$$

The formula to calculate the characteristic impedance of a coaxial cable in general is given by:

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln\left[\frac{r_2}{r_1}\right] \tag{29}$$

Where, r_1 is the radius of the center conductor, r_2 is radius of outer conductor and ϵ_r represents the relative permittivity of the dielectric insulator.

In general, the structure of coaxial cables is of two types. The characteristic impedance of these two types of coax cables is discussed below:

1. Two identical parallel round conductors

$$Z_0 = \frac{120}{\sqrt{\epsilon_r}} ln\left[\left(\frac{d}{2r}\right) + \sqrt{\left(\frac{d}{2r}\right)^2 - 1}\right] \tag{30}$$

Where, r is the radius of the conductor, d is spacing between the conductors and ϵ_r represents the relative permittivity of the dielectric insulator.

However, equation 30 is generalized as:

$$Z_0 = \frac{120}{\sqrt{\epsilon_r}} ln\left[\frac{d}{r}\right] \tag{31}$$

2. Round conductor over a plane:

   When *d* >> *2r*, then the characteristic impedance of round conductor placed at "*h*" distance above a plane is indeed one half of two round conductors placed at "*2h*" distance separately. Thus, the characteristic impedance at this case is:

   $$Z_0 = \frac{60}{\sqrt{\epsilon_r}} ln\left[\left(\frac{h}{r}\right) + \sqrt{\left(\frac{h}{r}\right)^2 - 1}\right] \qquad (32)$$

   Where, *h* represents the height of conductor over the plane and *r* represents radius of conductor.

   When, *h* >> *r* then equation 32 can be simplified as:

   $$Z_0 = \frac{60}{\sqrt{\epsilon_r}} ln\left[\left(\frac{2h}{r}\right)\right] \qquad (33)$$

5 MEASUREMENT WITH MINIVNAPRO

5.1 The cable Attenuation

While the data signal is passed through the cable with a certain amount of signal power, it loses some amount of energy before reaching to the destination. The amount of signal loss is called *attenuation*. The loss of energy is caused by voltage drops during the flow of signal through the cable. If voltage drops too much, useful data can be lost. The standard unit for attenuation is Decibels (db).

Figure 27: Equipment setup for coaxial cable attenuation by VNA.

The equipment setup for coaxial cable attenuation using HP VNA is shown in figure 27. In figure 28, the result for coaxial cable attenuation using HP VNA at the frequency level of 10, 20, 50 and 100MHz can be observed. Similarly, figure 29 shows the coaxial cable attenuation at 200, 500 and 1000 MHz frequency level.

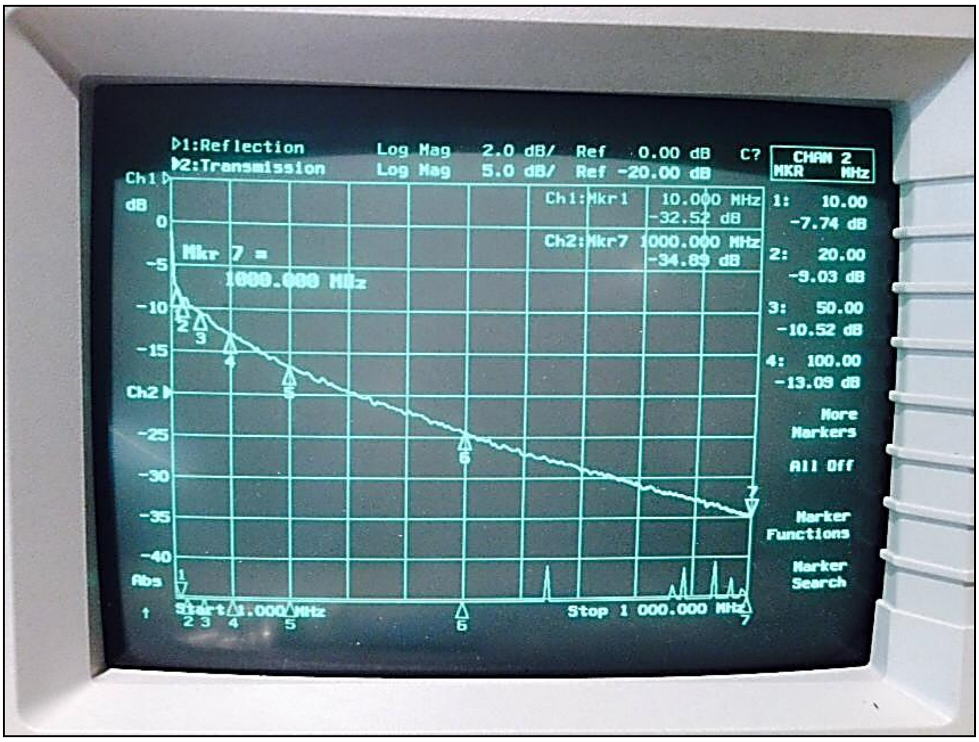


Figure 28: Cable attenuation for 50m cable by HP VNA.

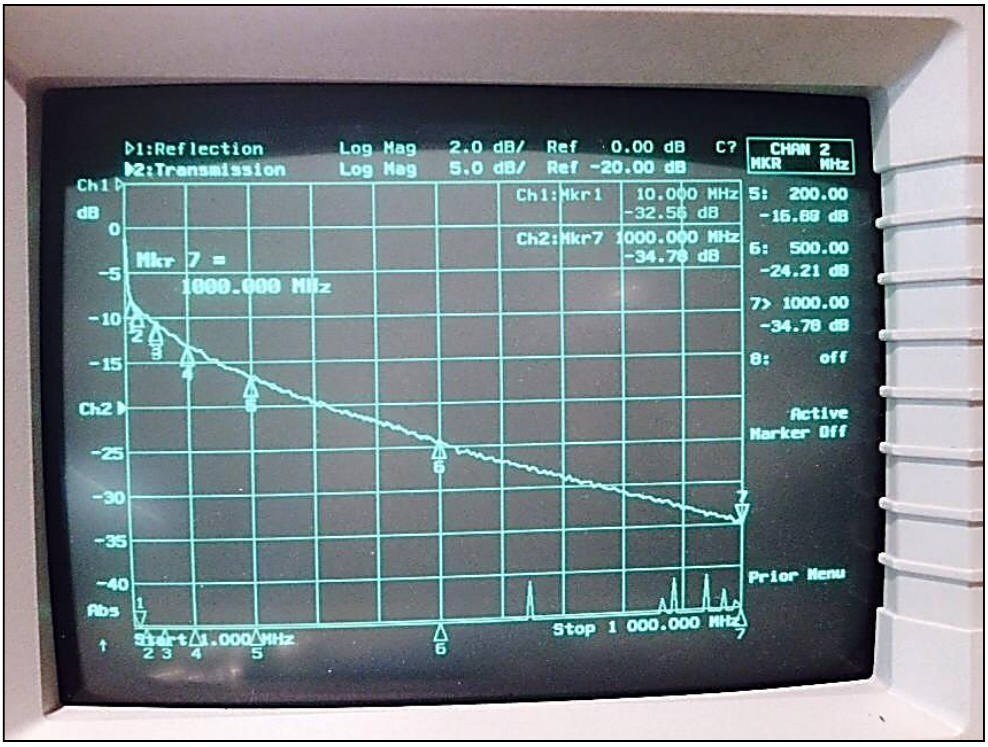
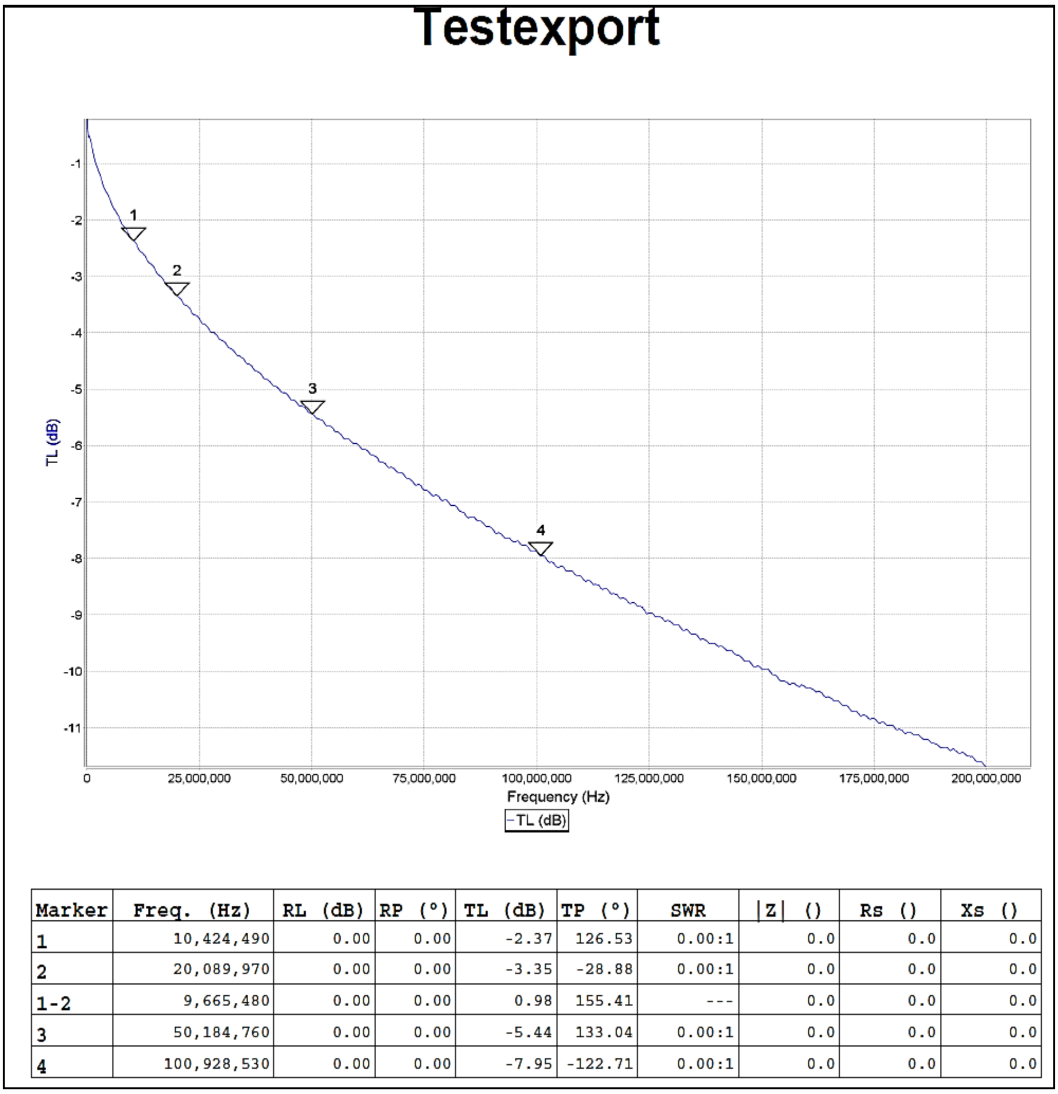


Figure 29: Coaxial cable attenuation by HP VNA.

Figure 30: Equipment setup for coaxial cable attenuation by Minivna pro.

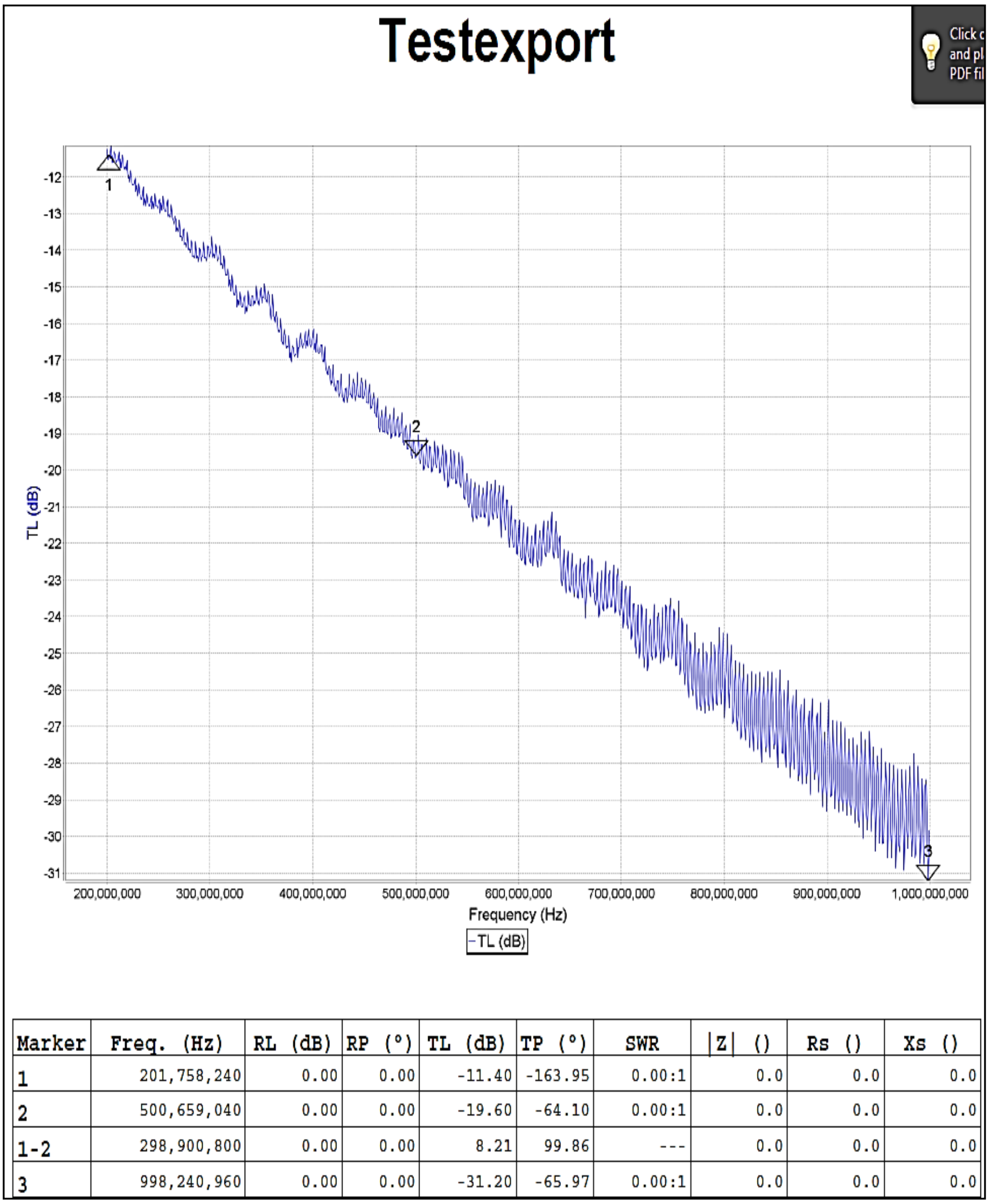
The equipment setup for the measurement of a coaxial cable attenuation using Minivna pro is shown in figure 30. In figure 31, the results obtained from the measurement of a coaxial cable attenuation using Minivna pro at the frequency level of 10, 20, 50 and 100MHz can be seen. Similarly, figure 32 shows the coaxial cable attenuation at 200, 500 and 1000 MHz frequency level.



Testexport

Marker	Freq. (Hz)	RL (dB)	RP (°)	TL (dB)	TP (°)	SWR	|Z| ()	Rs ()	Xs ()
1	10,424,490	0.00	0.00	-2.37	126.53	0.00:1	0.0	0.0	0.0
2	20,089,970	0.00	0.00	-3.35	-28.88	0.00:1	0.0	0.0	0.0
1-2	9,665,480	0.00	0.00	0.98	155.41	---	0.0	0.0	0.0
3	50,184,760	0.00	0.00	-5.44	133.04	0.00:1	0.0	0.0	0.0
4	100,928,530	0.00	0.00	-7.95	-122.71	0.00:1	0.0	0.0	0.0

Figure 31: Coax cable attenuation (50m) by using Minivna pro.



Testexport

Marker	Freq. (Hz)	RL (dB)	RP (°)	TL (dB)	TP (°)	SWR	|Z| ()	Rs ()	Xs ()
1	201,758,240	0.00	0.00	-11.40	-163.95	0.00:1	0.0	0.0	0.0
2	500,659,040	0.00	0.00	-19.60	-64.10	0.00:1	0.0	0.0	0.0
1-2	298,900,800	0.00	0.00	8.21	99.86	---	0.0	0.0	0.0
3	998,240,960	0.00	0.00	-31.20	-65.97	0.00:1	0.0	0.0	0.0

Figure 32: Coaxial cable attenuation by using Minivna pro with extender.

The results of the measurements from both HP VNA and Minivna pro, along with the obtained values from the Bedea RG 58 coax cable (50m) datasheet can be seen in the table below:

S.N	Frequency (MHz)	Cable Attenuation (dB/100m)	Cable Attenuation (dB/50m)	Cable Attenuation measured (dB/50m) by HP VNA.	Cable Attenuation measured (dB/50m) by Minivna pro
1.	10	4.5	2.25	7.74	2.32
2.	20	6.5	3.25	9.03	3.32
3.	50	9.9	4.95	10.52	5.48
4.	100	15.2	7.6	13.09	7.97
5.	200	21.6	10.8	16.68	11.40
6.	500	34.3	17.15	24.21	19.60
7.	1000	53.7	26.85	34.78	31.20

Table 2: Cable Attenuation Comparison among datasheet, HP VNA and Minivna pro.

The graph reperesentation for table 2 is shown in figure 33.

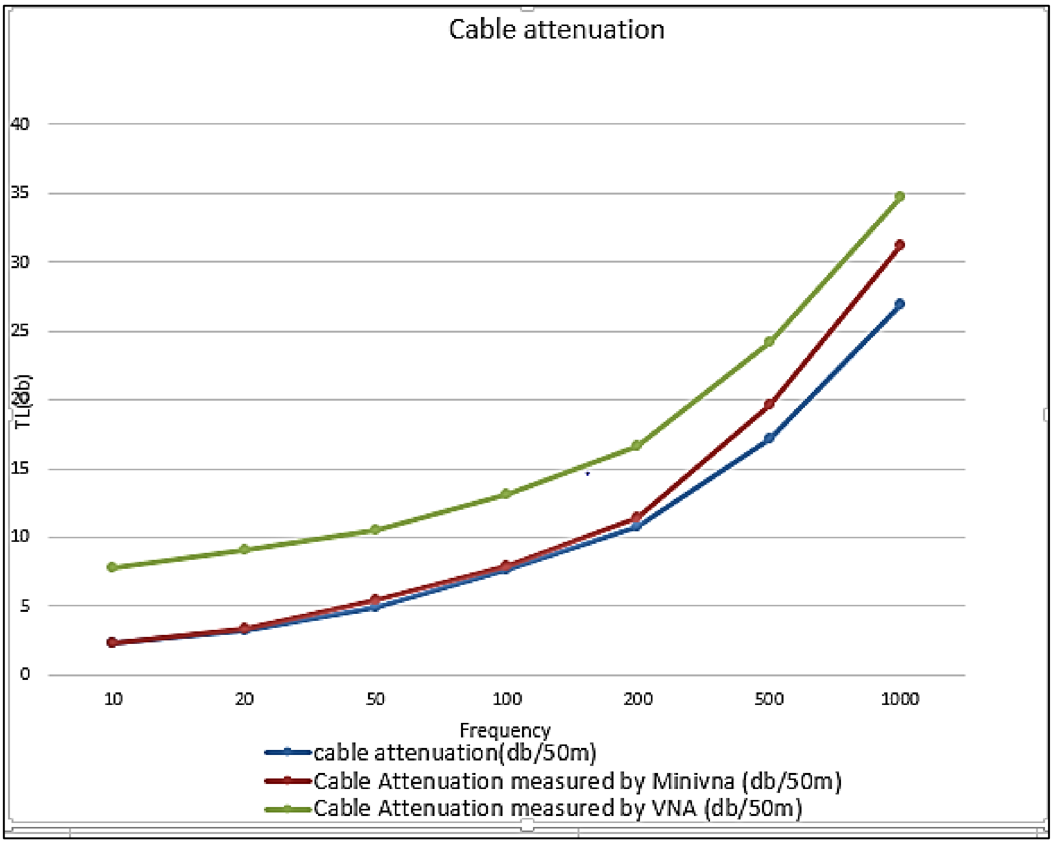


Figure 33: Comparison of 50m Coaxial Cable Attenuation.

5.2 The cable length

One of the most helpful functions in Minivna pro is the ability to know the unknown length of any kind of cable, if the velocity factor of that cable is known. If the cable type is known, both the cable length and the velocity factor can be measured. While performing the test, the “Reflection” mode in Minivna pro needs to be selected. Then, test cable is connected to DUT and the other end is kept open. The tools bar is selected in the software that is connected to the Minivna pro and is selected the cable length and perform the cable length measurement as the unknown cable. The unit for the cable length measurement can be selected as meter or feet. Some of the measurement results are shown below.

Figure 34: Equipment setup for cable length by using Minivna pro.

In figure 34, one end of the cable is connected to DUT of Minivna pro and the other end is left open. Minivna pro is then connected to the computer through a USB and test is run in the Minivna pro software in reflection mode.

The length of a standard cable can be calculated using the following formula:

$$Velocity\ (v) = \frac{l}{t} => v \times t = l$$

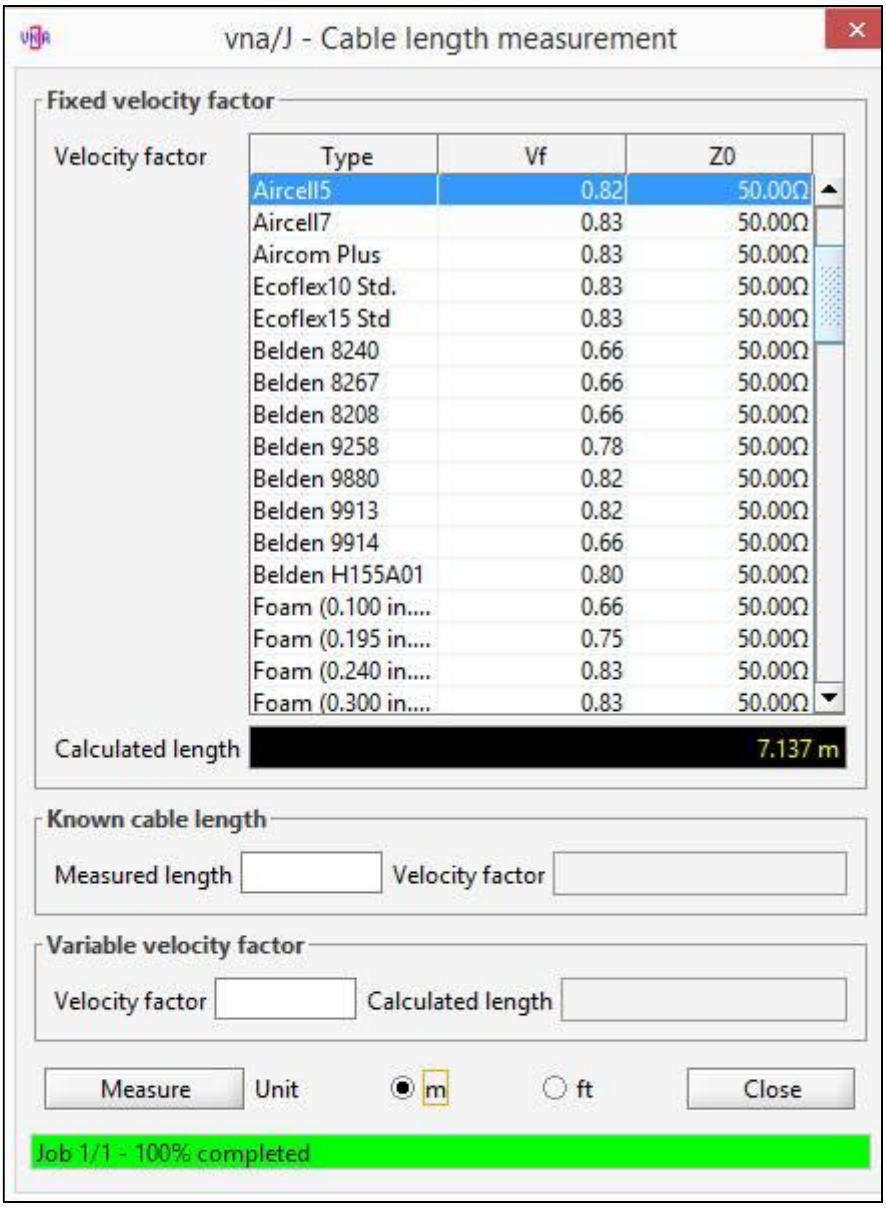
Since,

$$=> v = c \times vf(velocity\ factor)$$

$$=> l = c \times vf \times t$$

Where, l is length of cable, t is system measures time, c is speed of light and vf is velocity factor.

When a Coax cable is connected to Minivna pro, it calculates the length of the cable using the formula given above. The length is then shown in the software interface of Minivna pro. This can be seen below.



vna/J - Cable length measurement

Fixed velocity factor

Velocity factor

Type	Vf	Z0
Aircell5	0.82	50.00Ω
Aircell7	0.83	50.00Ω
Aircom Plus	0.83	50.00Ω
Ecoflex10 Std.	0.83	50.00Ω
Ecoflex15 Std	0.83	50.00Ω
Belden 8240	0.66	50.00Ω
Belden 8267	0.66	50.00Ω
Belden 8208	0.66	50.00Ω
Belden 9258	0.78	50.00Ω
Belden 9880	0.82	50.00Ω
Belden 9913	0.82	50.00Ω
Belden 9914	0.66	50.00Ω
Belden H155A01	0.80	50.00Ω
Foam (0.100 in....	0.66	50.00Ω
Foam (0.195 in....	0.75	50.00Ω
Foam (0.240 in....	0.83	50.00Ω
Foam (0.300 in....	0.83	50.00Ω

Calculated length 7.137 m

Known cable length

Measured length Velocity factor

Variable velocity factor

Velocity factor Calculated length

Unit ● m ○ ft

Job 1/1 - 100% completed

Figure 35: Result of cable length measurement using Minivna pro.

Error calculation:

Actual length (AL) = 7m.

Measured Length (ML) = 7.137m.

Error = ML-AL = (7.137-7)m = 0.137m.

$$Error\ Percentage = \frac{Error}{AL} \times 100\% => \frac{0.137}{7} \times 100\% => 1.96\%$$

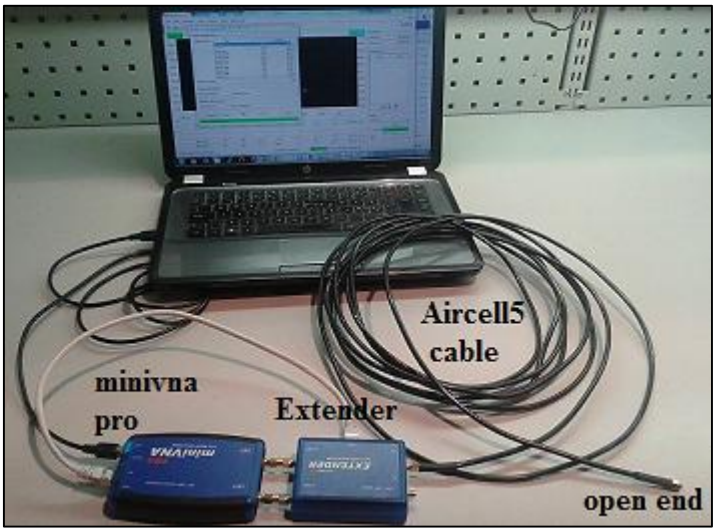
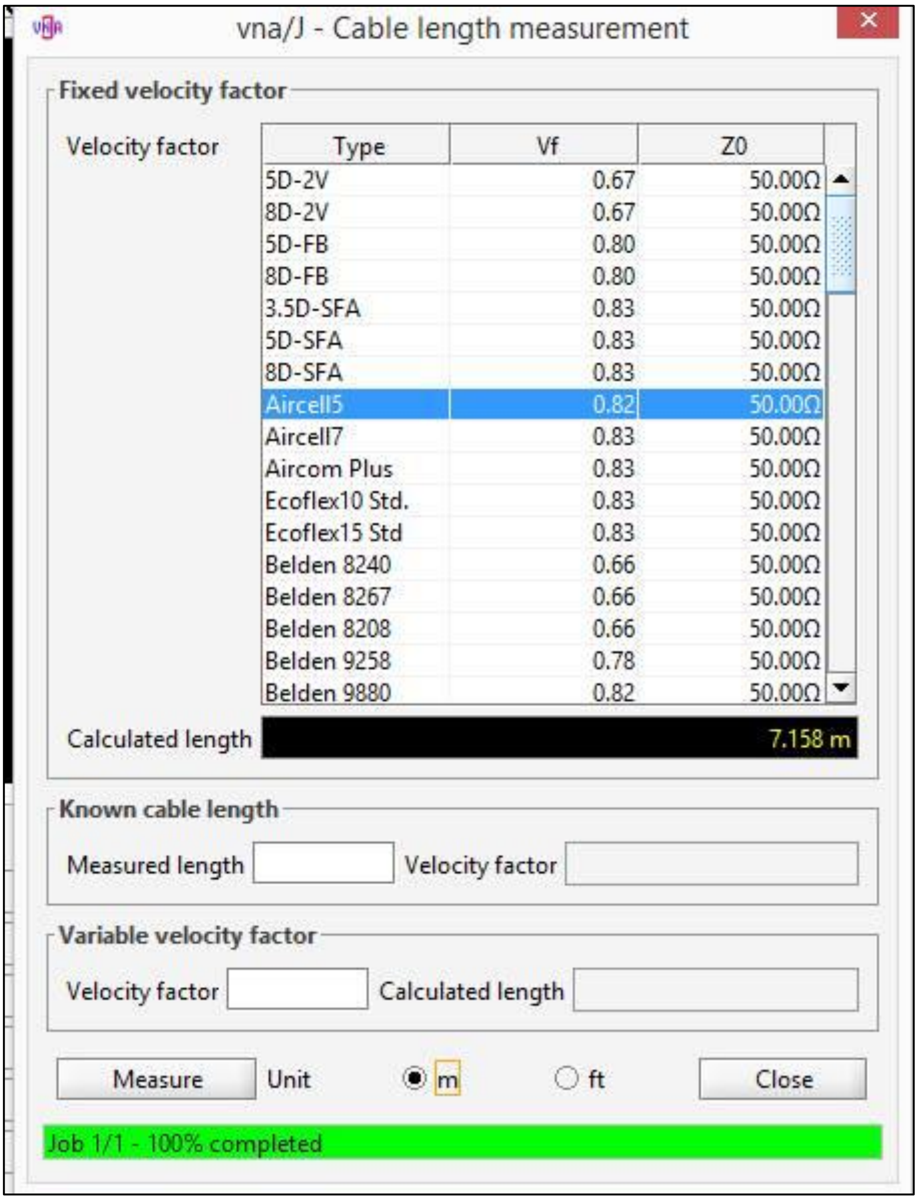


Figure 34: Equipment setup for cable length by using Minivna pro with extender.

The cable length mesaurement of Aircell5 cable using Minivna pro with an extender is shown in figure 34 with the software interface. The length of Aircell5 cable measured using Minivna pro with extender is shown in figure 35. The measured unit is in meter.

In figure 36, the length of RG58 cable measured using Minivna pro is shown. The measured unit is in meter.



Type	Vf	Z0
5D-2V	0.67	50.00Ω
8D-2V	0.67	50.00Ω
5D-FB	0.80	50.00Ω
8D-FB	0.80	50.00Ω
3.5D-SFA	0.83	50.00Ω
5D-SFA	0.83	50.00Ω
8D-SFA	0.83	50.00Ω
Aircell5	0.82	50.00Ω
Aircell7	0.83	50.00Ω
Aircom Plus	0.83	50.00Ω
Ecoflex10 Std.	0.83	50.00Ω
Ecoflex15 Std	0.83	50.00Ω
Belden 8240	0.66	50.00Ω
Belden 8267	0.66	50.00Ω
Belden 8208	0.66	50.00Ω
Belden 9258	0.78	50.00Ω
Belden 9880	0.82	50.00Ω

Calculated length 7.158 m

Job 1/1 - 100% completed

Figure 35: Result of cable length by using Minivna pro with extender.

Error calculation:

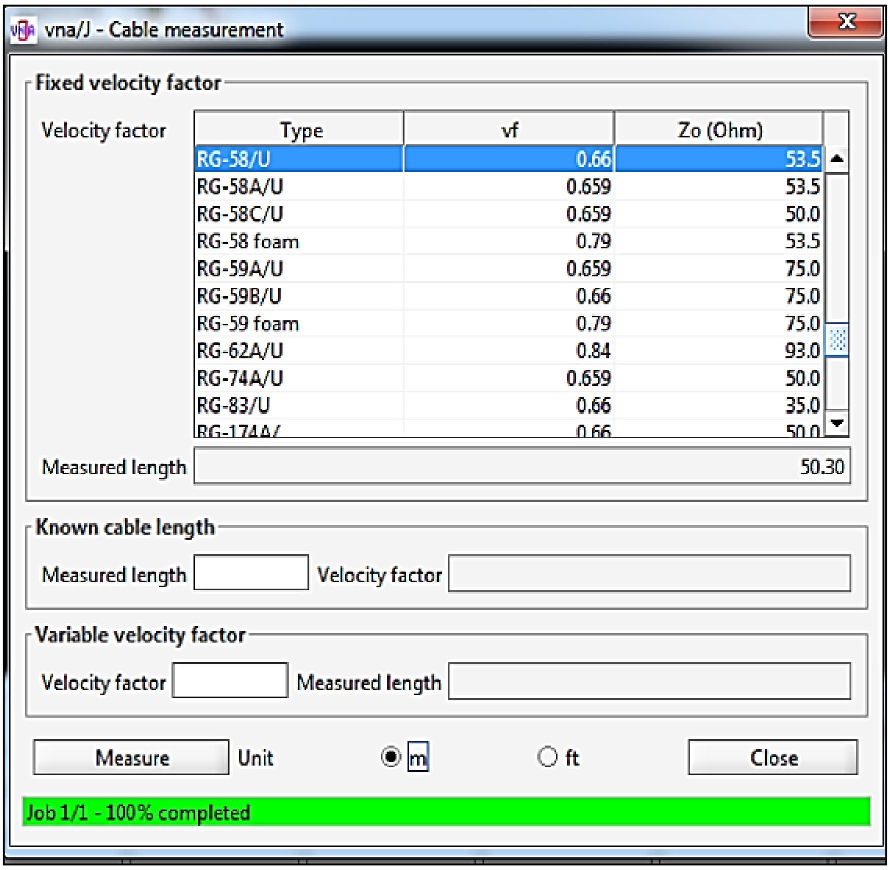
Actual length (AL) = 7m.

Measured Length (ML) = 7.158m.

Error = ML-AL = (7.158-7)m = 0.158m.

$$Error\ Percentage = \frac{Error}{AL} \times 100\% => \frac{0.158}{7} \times 100\% => 2.257\%$$

Here the length of the same cable is 7.158m, which is due to the connection of extender with Minivna pro.



Velocity factor

Type	vf	Zo (Ohm)
RG-58/U	0.66	53.5
RG-58A/U	0.659	53.5
RG-58C/U	0.659	50.0
RG-58 foam	0.79	53.5
RG-59A/U	0.659	75.0
RG-59B/U	0.66	75.0
RG-59 foam	0.79	75.0
RG-62A/U	0.84	93.0
RG-74A/U	0.659	50.0
RG-83/U	0.66	35.0
RG-174A/	0.66	50.0

Measured length 50.30

Job 1/1 - 100% completed

Figure 36: Results of RG58 cable length measured Minivna pro.

Error calculation:

Actual length (AL) = 50m.

Measured Length (ML) = 50.30m.

Error = ML-AL = (50.30-50)m = 0.30m.

$$Error\ Percentage = \frac{Error}{AL} \times 100\% => \frac{0.30}{50} \times 100\% => 0.6\%$$

5.3 The resonance frequency of the monopole antenna

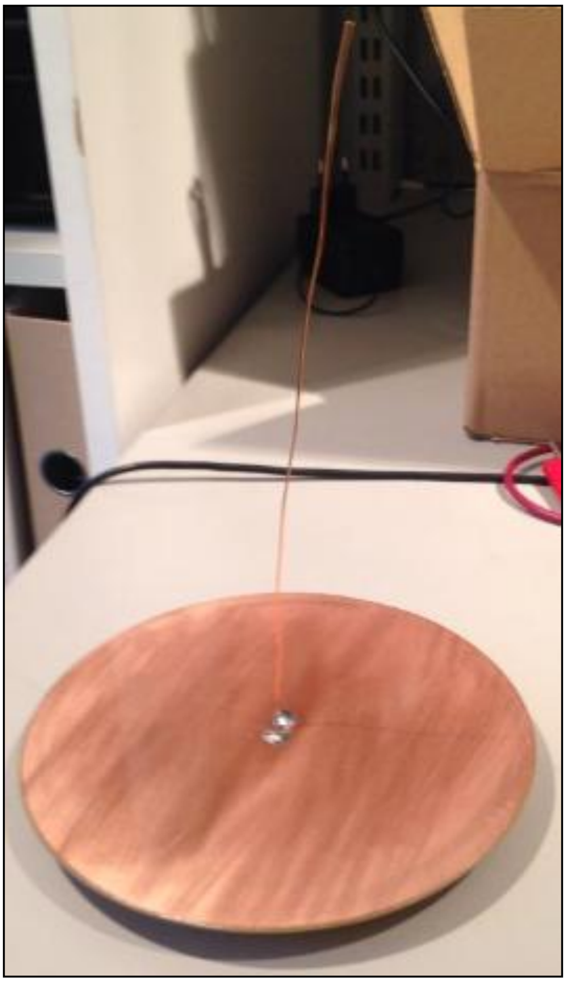


Figure 36: Monopole antenna.

There are two different measurements performed for this monopole using both HP VNA and Minivna pro. The measurements include matching the fr of monopole antenna in 920MHz and measuring the fr of 10cm monopole antenna.

In figure 37, it can be observed that the normalized impedance for the monopole antenna of 920MHZ is 33.5+18.5j and SWR is 1.81.

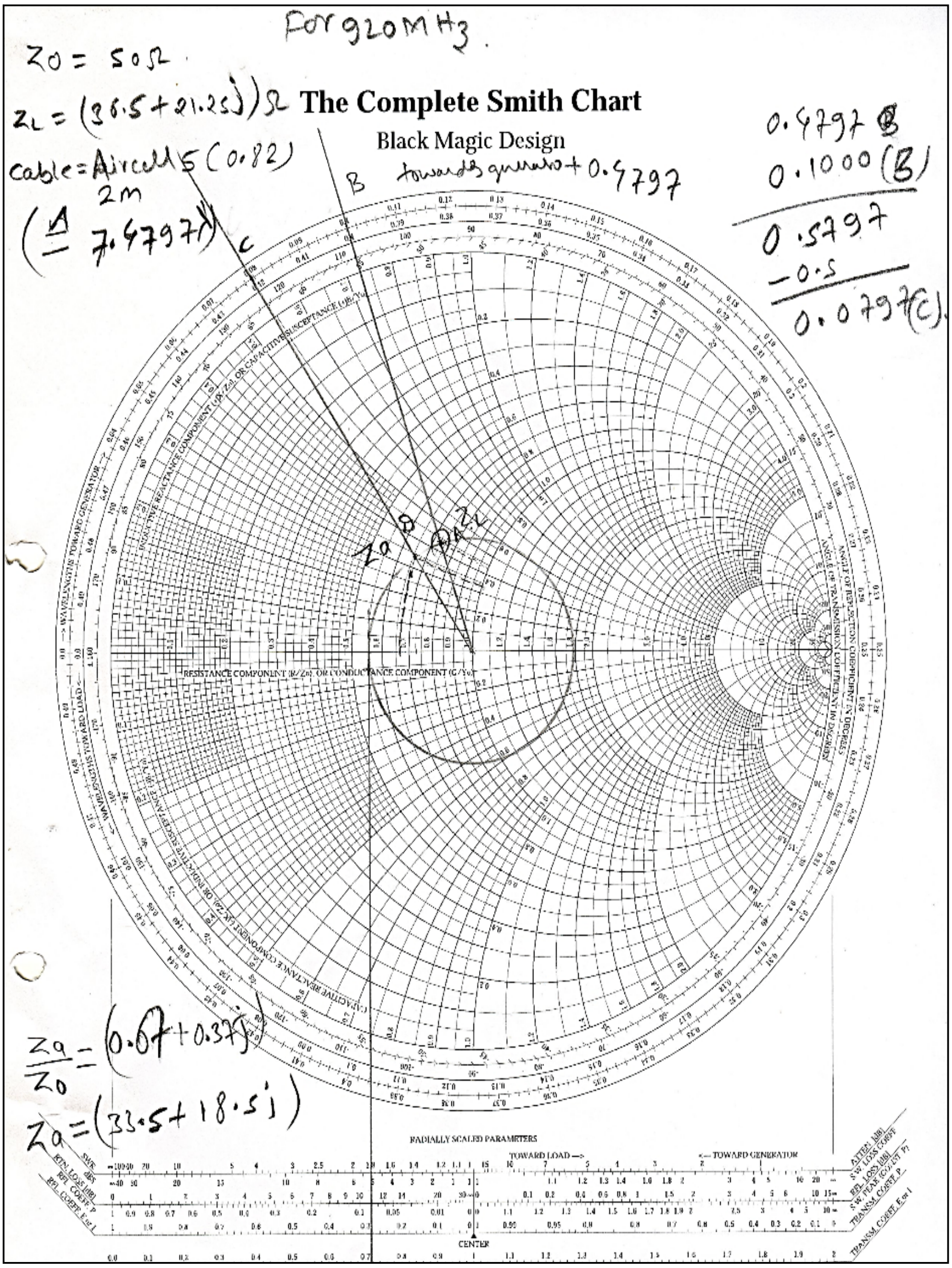
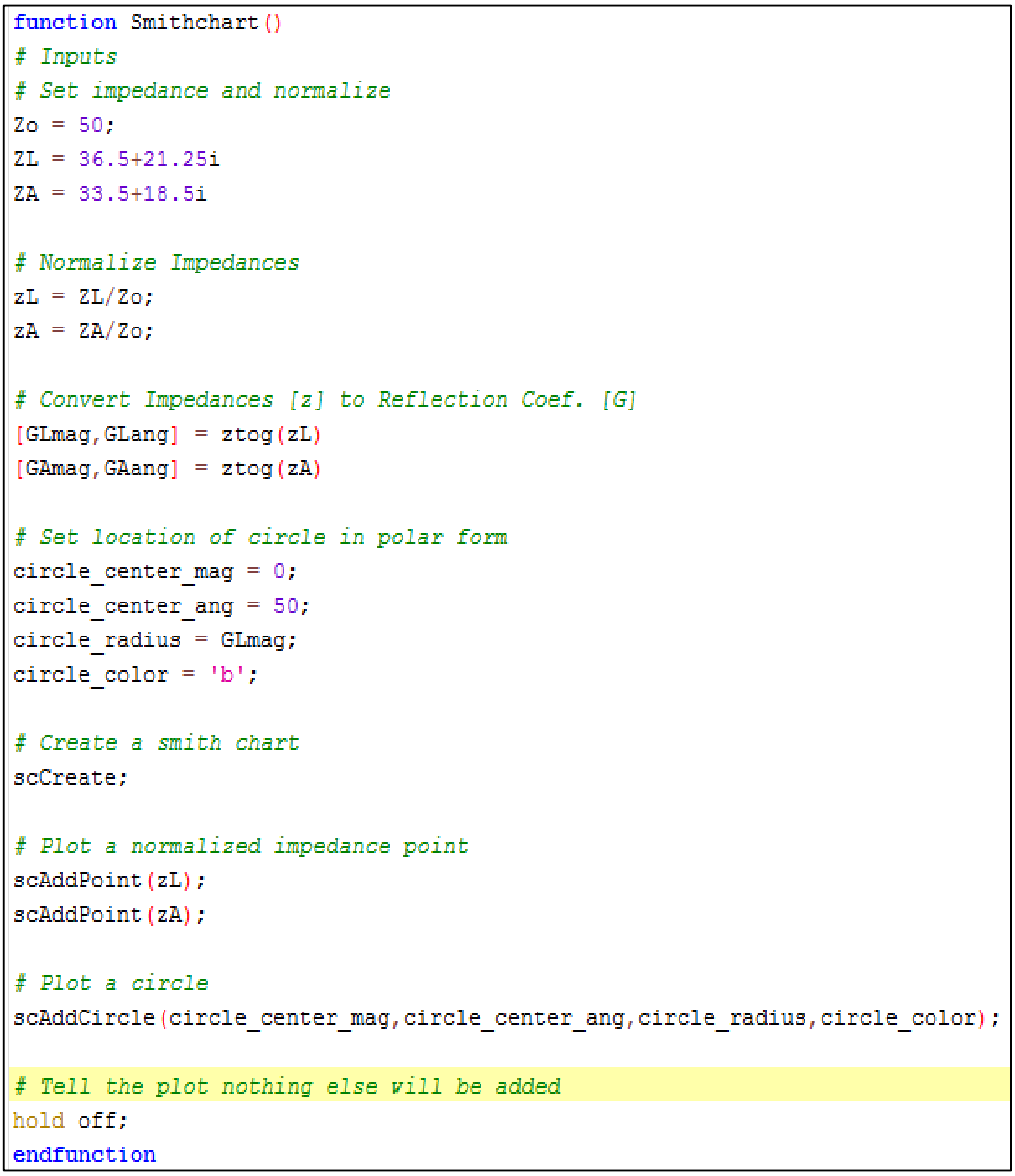
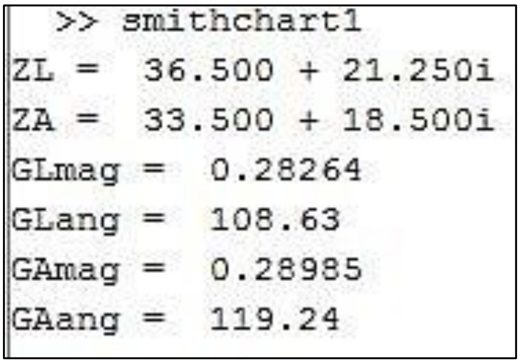


Figure 37: Smith chart for 920MHz drawn by hand.



```
function Smithchart()
# Inputs
# Set impedance and normalize
Zo = 50;
ZL = 36.5+21.25i
ZA = 33.5+18.5i

# Normalize Impedances
zL = ZL/Zo;
zA = ZA/Zo;

# Convert Impedances [z] to Reflection Coef. [G]
[GLmag,GLang] = ztog(zL)
[GAmag,GAang] = ztog(zA)

# Set location of circle in polar form
circle_center_mag = 0;
circle_center_ang = 50;
circle_radius = GLmag;
circle_color = 'b';

# Create a smith chart
scCreate;

# Plot a normalized impedance point
scAddPoint(zL);
scAddPoint(zA);

# Plot a circle
scAddCircle(circle_center_mag,circle_center_ang,circle_radius,circle_color);

# Tell the plot nothing else will be added
hold off;
endfunction
```

Figure 38: Source code from octave for 920MHz Smith chart.



```
  >> smithchart1
ZL =   36.500 + 21.250i
ZA =   33.500 + 18.500i
GLmag =   0.28264
GLang =   108.63
GAmag =   0.28985
GAang =   119.24
```

Figure 39: Output from octave for 920 MHz Smith chart.

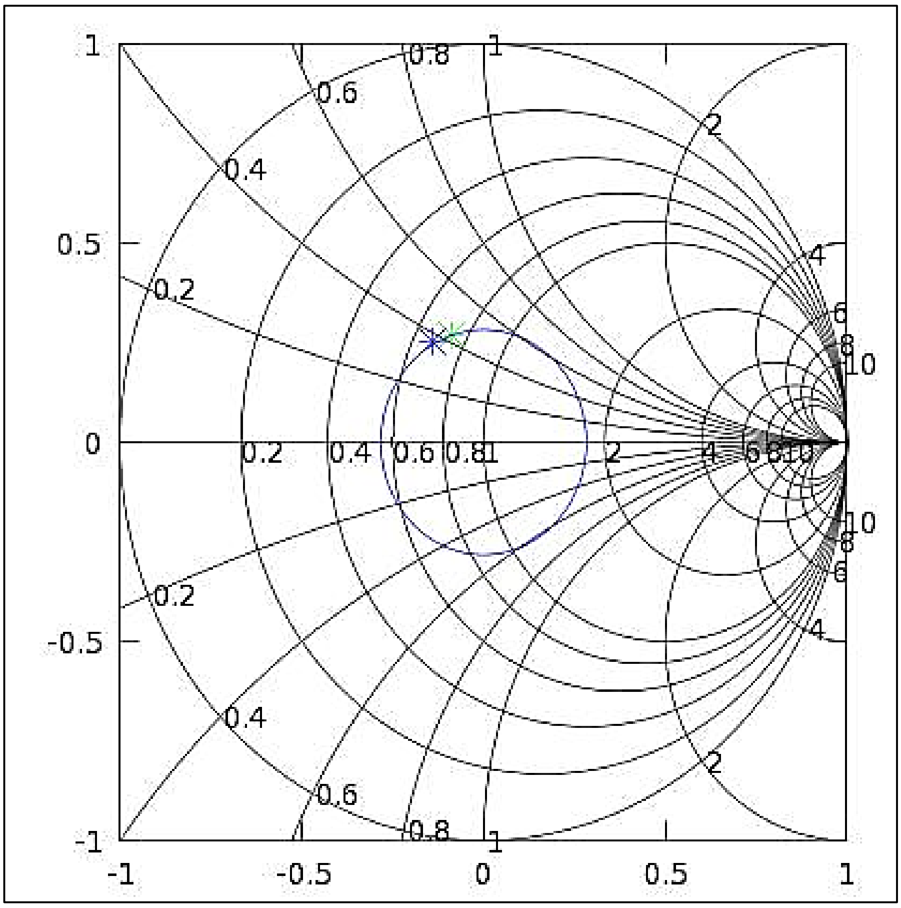
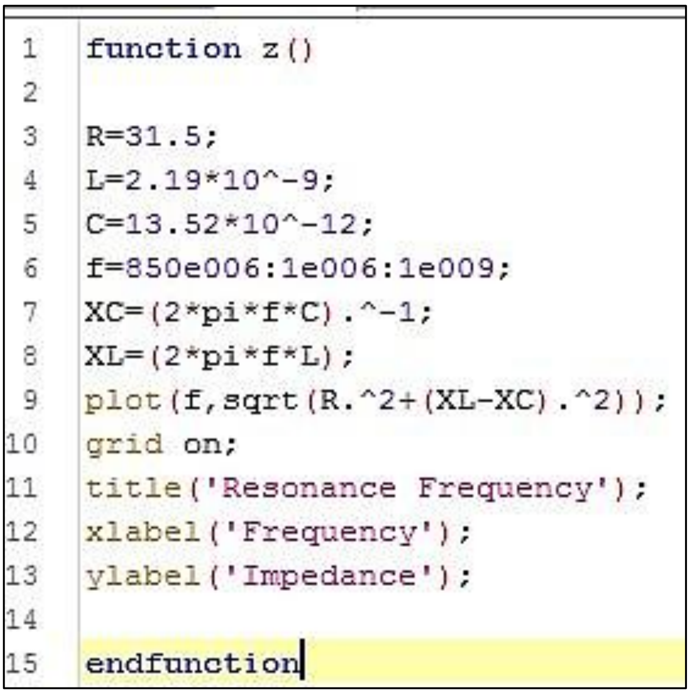


Figure 40: Smith chart from octave.

Th octave script from figure 38 is for Smith chart, as shown in figure 37 for 920 MHz monopole antenna. The Smith chart obtained from the octave script is shown in figure 40.



```
function z()

R=31.5;
L=2.19*10^-9;
C=13.52*10^-12;
f=850e006:1e006:1e009;
XC=(2*pi*f*C).^-1;
XL=(2*pi*f*L);
plot(f,sqrt(R.^2+(XL-XC).^2));
grid on;
title('Resonance Frequency');
xlabel('Frequency');
ylabel('Impedance');

endfunction
```

Figure 41: Octave Code for matching fr of monopole antenna.

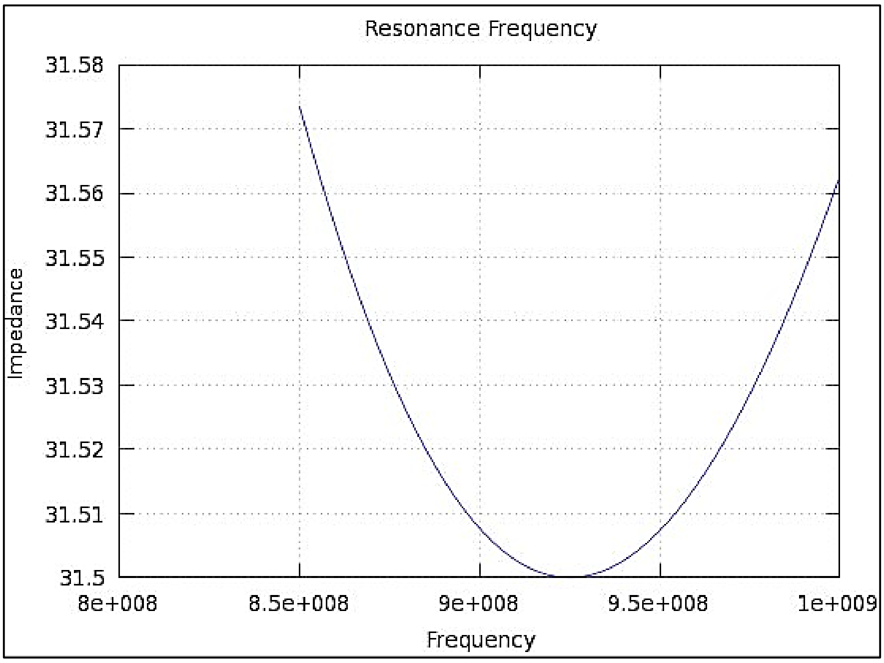


Figure 42: Graph for matching monopole antenna from octave.

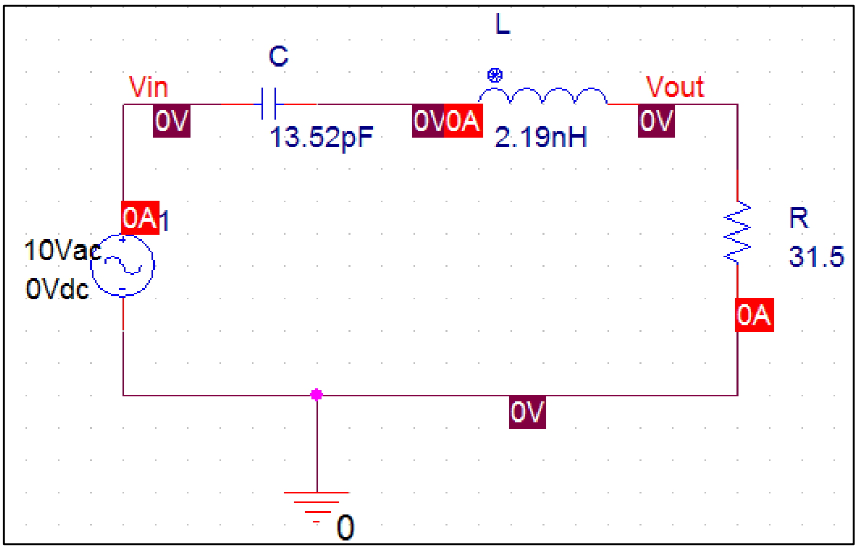
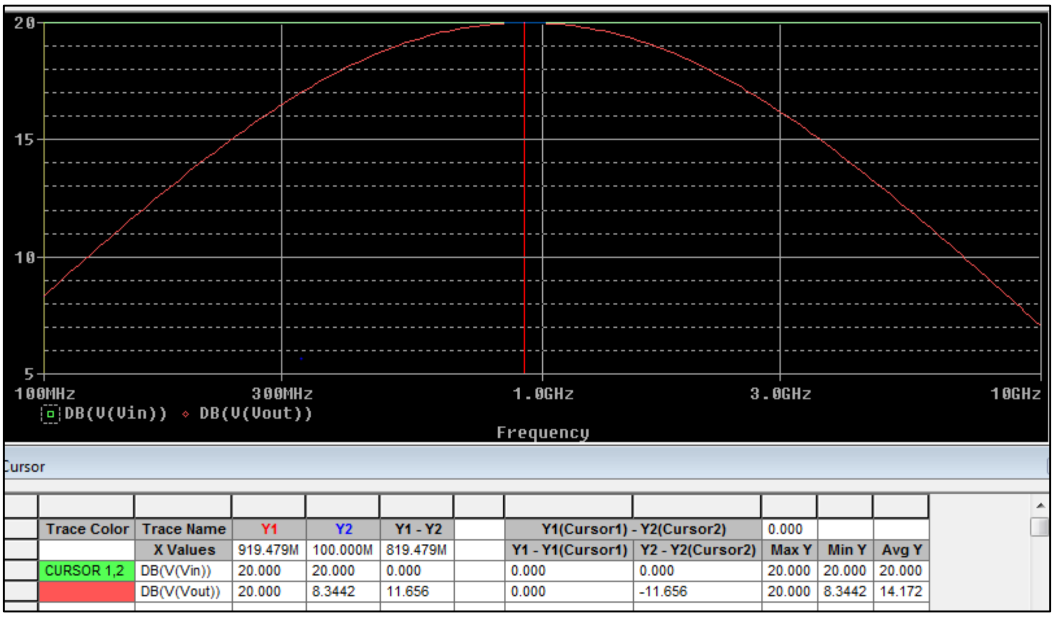


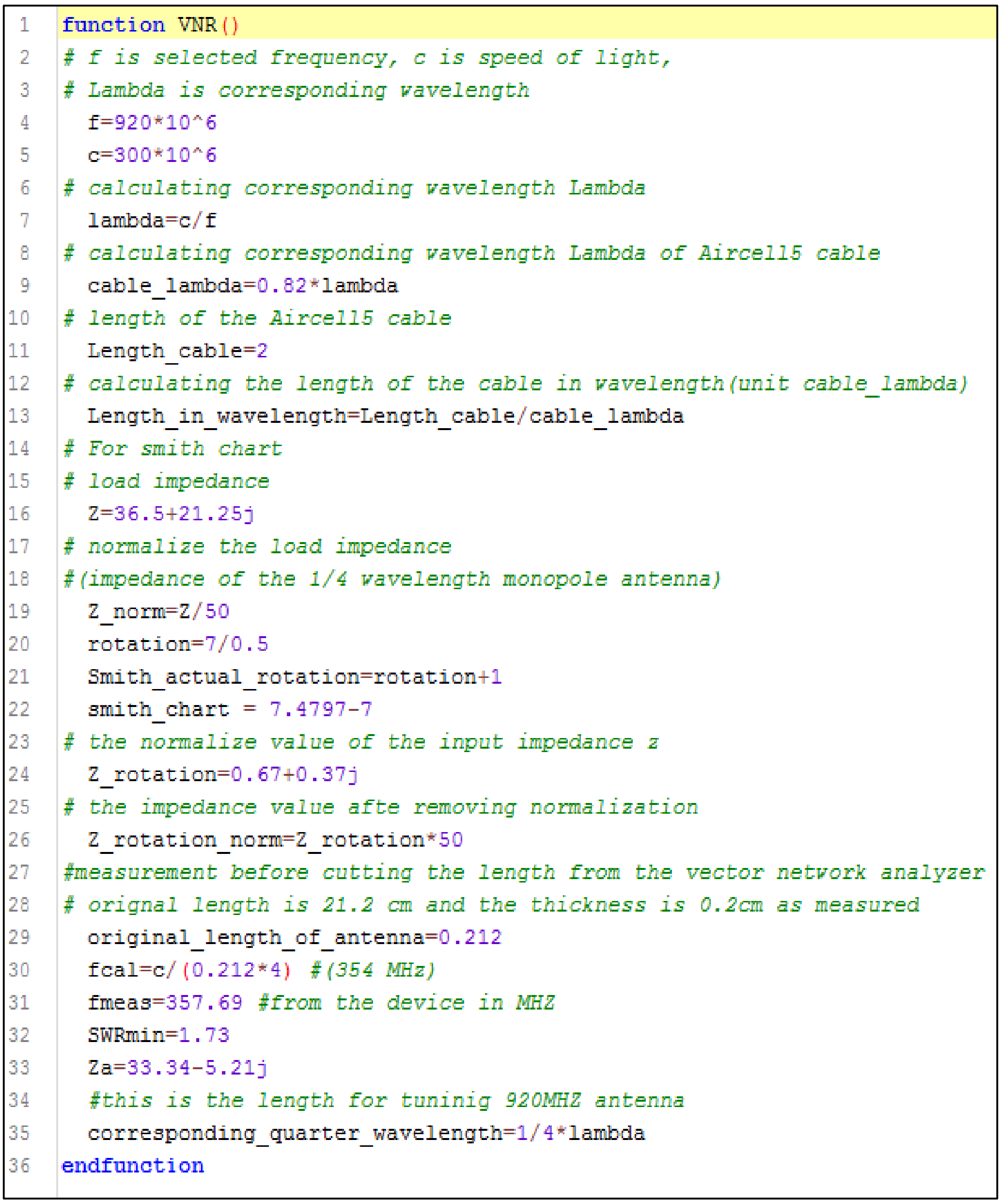
Figure 43: RLC circuit for 920 MHz monopole antenna.

The simplified RLC circuit of a monopole antenna, matching 920 MHz frequency from Orcad is shown in figure 43. The simulation result from Orcad is shown in figure 44.



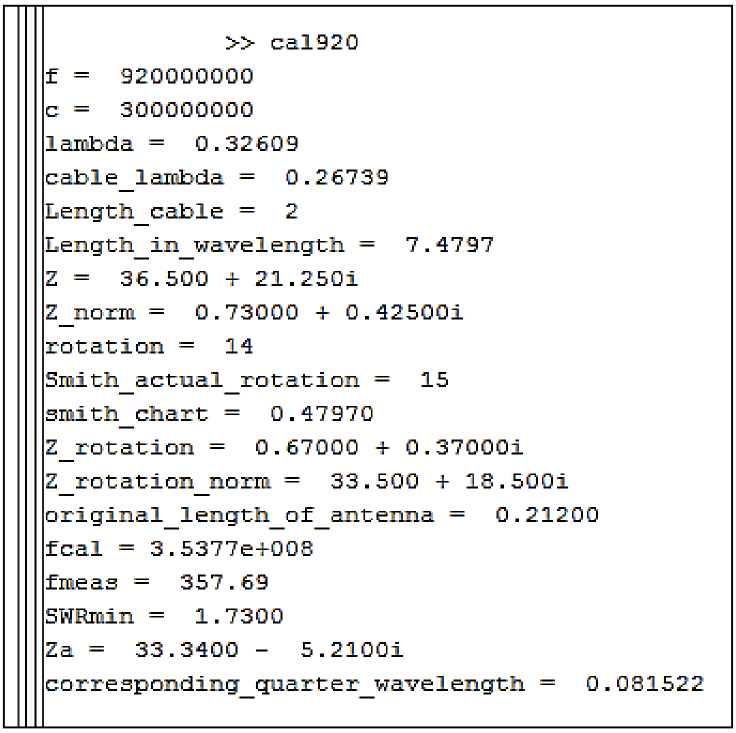
Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	919.479M	100.000M	819.479M		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	DB(V(Vin))	20.000	20.000	0.000		0.000	0.000	20.000	20.000	20.000
🟥	DB(V(Vout))	20.000	8.3442	11.656		0.000	-11.656	20.000	8.3442	14.172

Figure 44: Matching fr of monopole antenna by orcad.



```
function VNR()
# f is selected frequency, c is speed of light,
# Lambda is corresponding wavelength
  f=920*10^6
  c=300*10^6
# calculating corresponding wavelength Lambda
  lambda=c/f
# calculating corresponding wavelength Lambda of Aircell5 cable
  cable_lambda=0.82*lambda
# length of the Aircell5 cable
  Length_cable=2
# calculating the length of the cable in wavelength(unit cable_lambda)
  Length_in_wavelength=Length_cable/cable_lambda
# For smith chart
# load impedance
  Z=36.5+21.25j
# normalize the load impedance
#(impedance of the 1/4 wavelength monopole antenna)
  Z_norm=Z/50
  rotation=7/0.5
  Smith_actual_rotation=rotation+1
  smith_chart = 7.4797-7
# the normalize value of the input impedance z
  Z_rotation=0.67+0.37j
# the impedance value afte removing normalization
  Z_rotation_norm=Z_rotation*50
#measurement before cutting the length from the vector network analyzer
# orignal length is 21.2 cm and the thickness is 0.2cm as measured
  original_length_of_antenna=0.212
  fcal=c/(0.212*4)  #(354 MHz)
  fmeas=357.69 #from the device in MHZ
  SWRmin=1.73
  Za=33.34-5.21j
  #this is the length for tuninig 920MHZ antenna
  corresponding_quarter_wavelength=1/4*lambda
endfunction
```

Figure 45: Matching the antenna calculation by using Octave.



```
            >> cal920
f =  920000000
c =  300000000
lambda =  0.32609
cable_lambda =  0.26739
Length_cable =  2
Length_in_wavelength =  7.4797
Z =  36.500 + 21.250i
Z_norm =  0.73000 + 0.42500i
rotation =  14
Smith_actual_rotation =  15
smith_chart =  0.47970
Z_rotation =  0.67000 + 0.37000i
Z_rotation_norm =  33.500 + 18.500i
original_length_of_antenna =  0.21200
fcal = 3.5377e+008
fmeas =  357.69
SWRmin =  1.7300
Za =  33.3400 -  5.2100i
corresponding_quarter_wavelength =  0.081522
```

Figure 46: Result from Octave calculation.

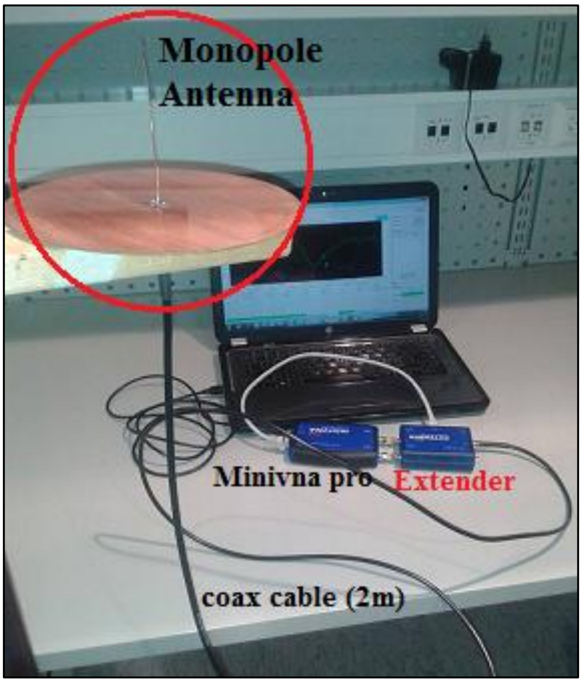
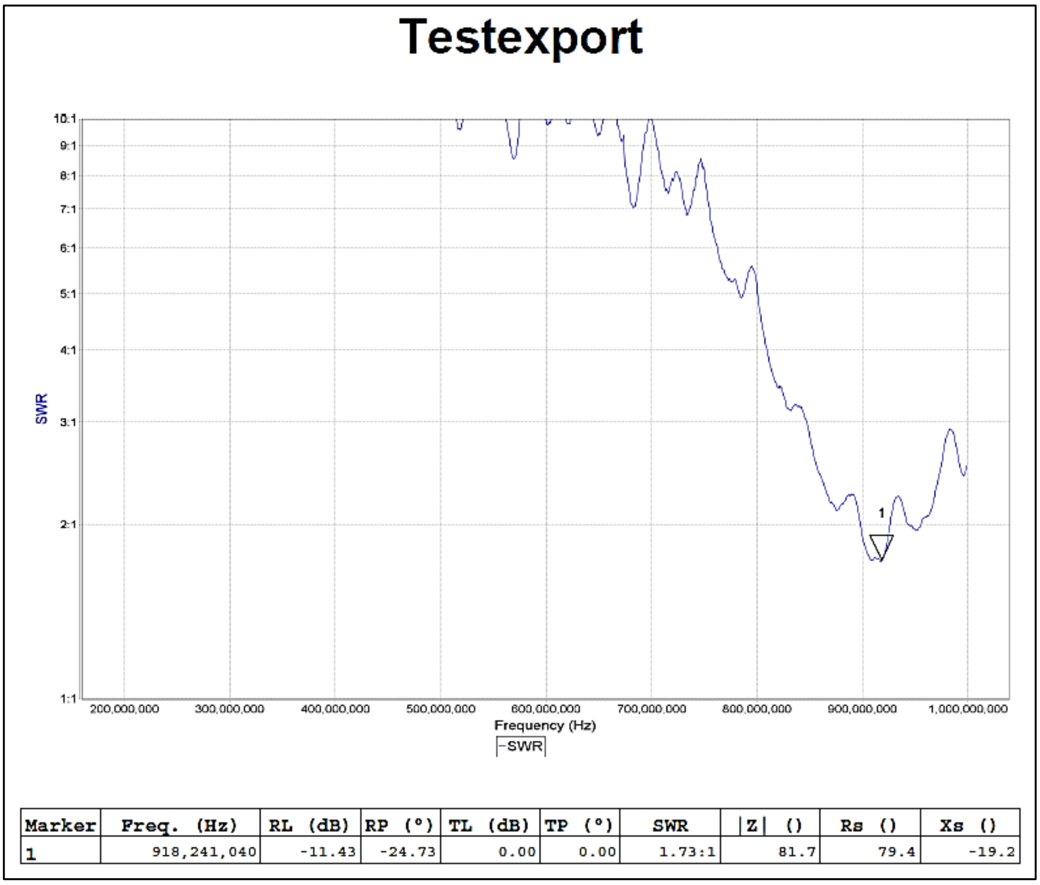


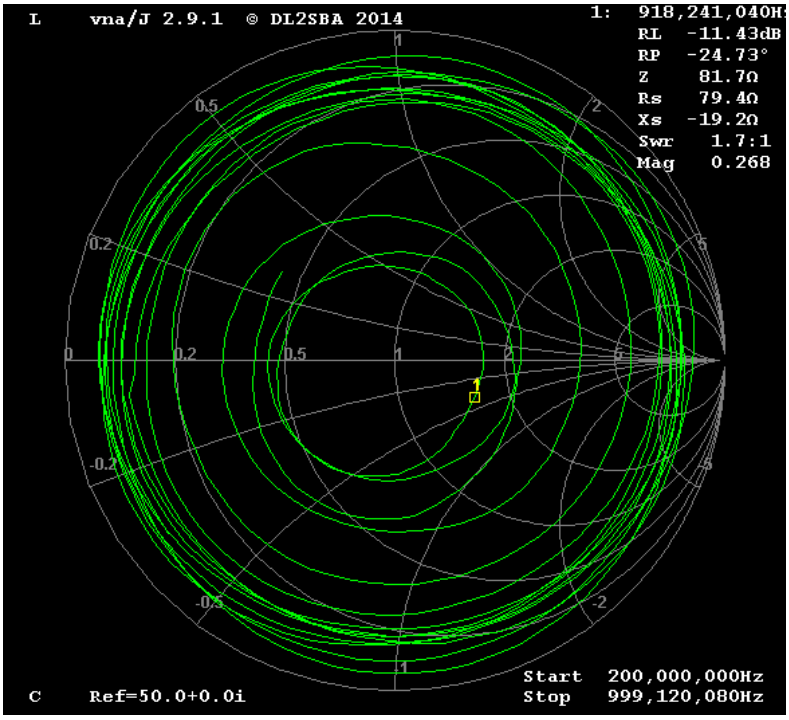
Figure 47: Equipment setup for measuring resonance frequency of monopole antenna by using Minivna pro.

The overall connection for measuring resonance frequency of a monopole antenna using Minivna pro is shown in figure 47. The measurement result from Minivna pro is shown in figure 48 in pdf format.



Marker	Freq. (Hz)	RL (dB)	RP (°)	TL (dB)	TP (°)	SWR	|Z| ()	Rs ()	Xs ()
1	918,241,040	-11.43	-24.73	0.00	0.00	1.73:1	81.7	79.4	-19.2

Figure 48: Result after matching monopole antenna by Minivna pro.



```
L     vna/J 2.9.1  © DL2SBA 2014              1:  918,241,040H
                                                  RL   -11.43dB
                                                  RP   -24.73°
                                                  Z     81.7Ω
                                                  Rs    79.4Ω
                                                  Xs   -19.2Ω
                                                  Swr    1.7:1
                                                  Mag    0.268

                                        Start  200,000,000Hz
C     Ref=50.0+0.0i                     Stop   999,120,080Hz
```

Figure 49: Smith chart for monopole antenna from Minivna pro.

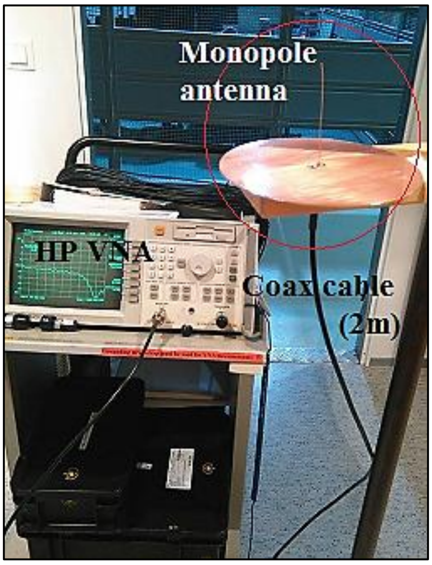


Figure 50: Equipment setup for measuring resonance freuency of monopole antenna using HP VNA.

The overall connection for measuring fr of a monopole antenna using HP VNA is shown in figure 50. The measurement result window from HP VNA is shown in figure 51.

Figure 51: Result after matching monopole antenna from HP VNA.

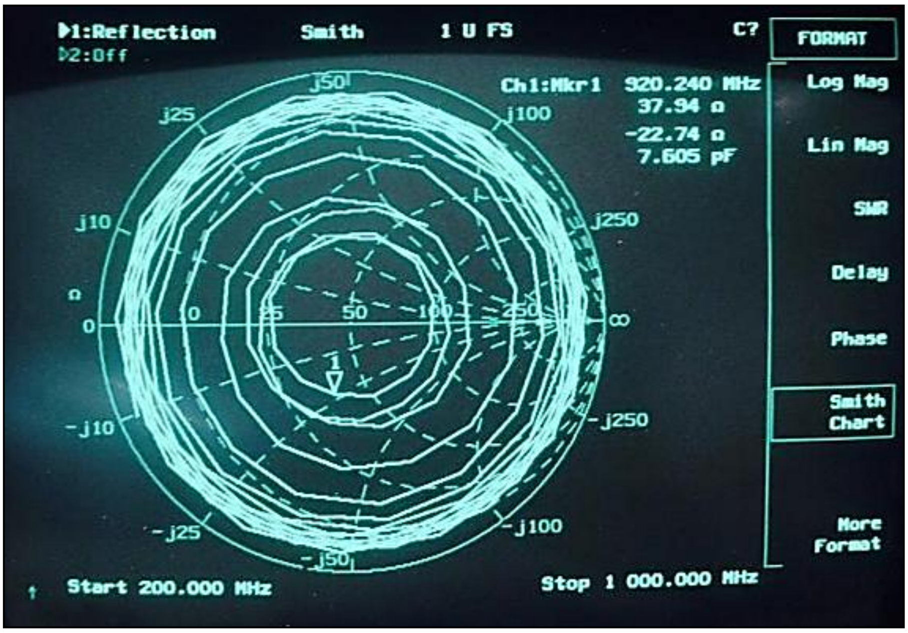
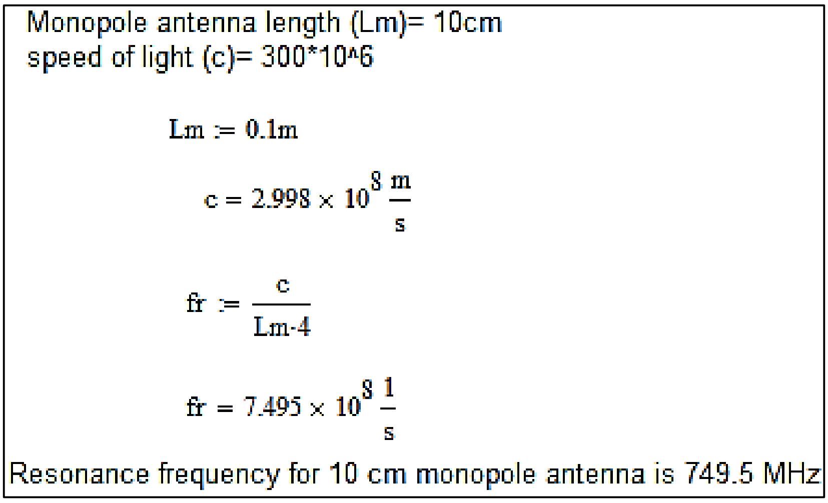


Figure 52: Smith Chart for monopole antenna from HP VNA.

Figure 53: SWR for monopole antenna from HP VNA.

In figure 54, the theoretical calculation of a monopole antenna's resonance frequency with length of 10cm is calculated using Mathcad. The resultant resonance frequency for 10cm length of monopole antenna from both HP VNA and Minivna pro is shown in figure 55 and 56 respectively.



Monopole antenna length (Lm)= 10cm
speed of light (c)= 300*10^6

$$Lm := 0.1m$$

$$c = 2.998 \times 10^{8} \frac{m}{s}$$

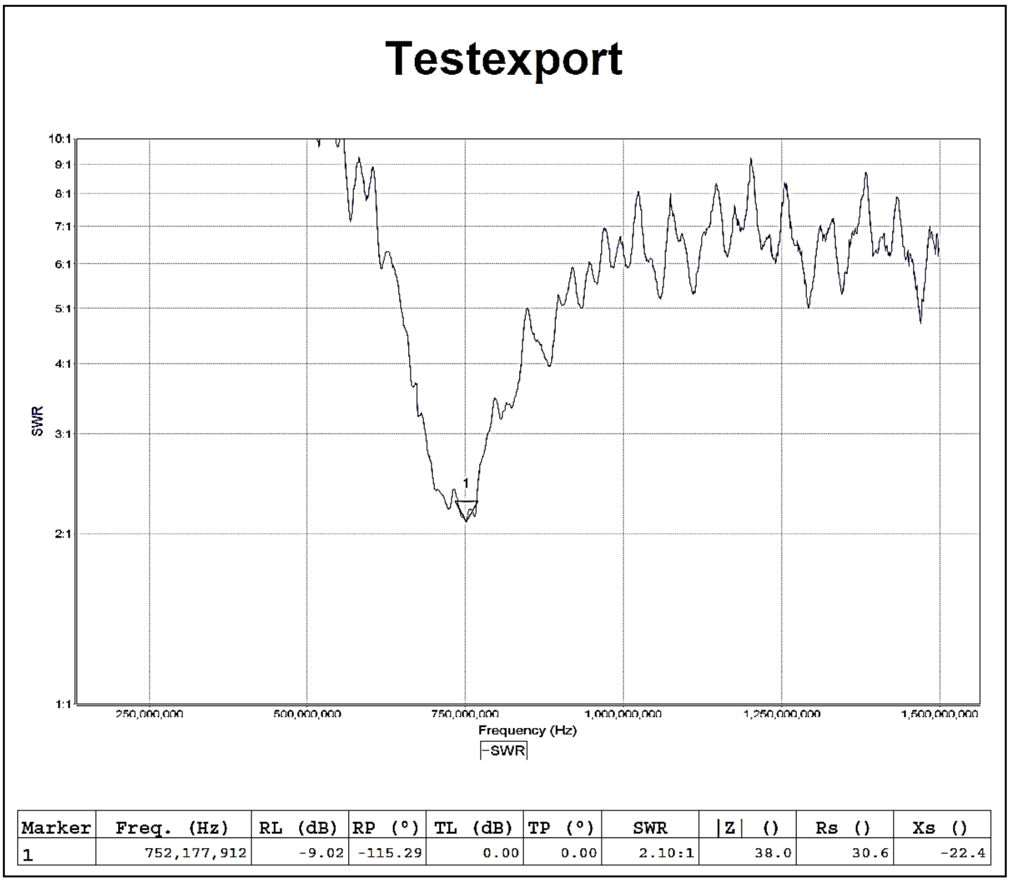
$$fr := \frac{c}{Lm \cdot 4}$$

$$fr = 7.495 \times 10^{8} \frac{1}{s}$$

Resonance frequency for 10 cm monopole antenna is 749.5 MHz

Figure 54: Theoretical calculation for fr of monopole antenna (10cm).

Figure 55: Result for monopole antenna of 10cm length from HP VNA (751.065MHz).



Marker	Freq. (Hz)	RL (dB)	RP (°)	TL (dB)	TP (°)	SWR	|Z| ()	Rs ()	Xs ()
1	752,177,912	-9.02	-115.29	0.00	0.00	2.10:1	38.0	30.6	-22.4

Figure 56: Result for monopole antenna with length of 10cm from Minivna pro (752.177MHz).

5.4 The resonance frequency of a loop antenna

The resonance frequencies of two types of loop antennas which are measured by using both HP VNA and Minivna pro.

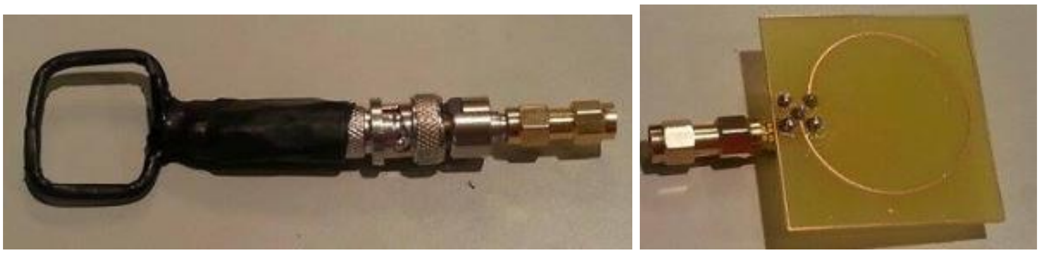


Figure 57: Loop antennas given by supervisor and made in lab respectively.

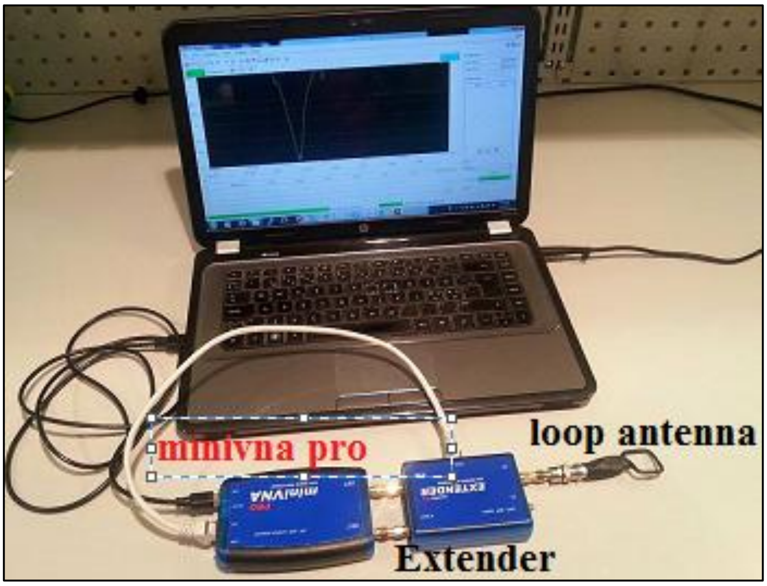
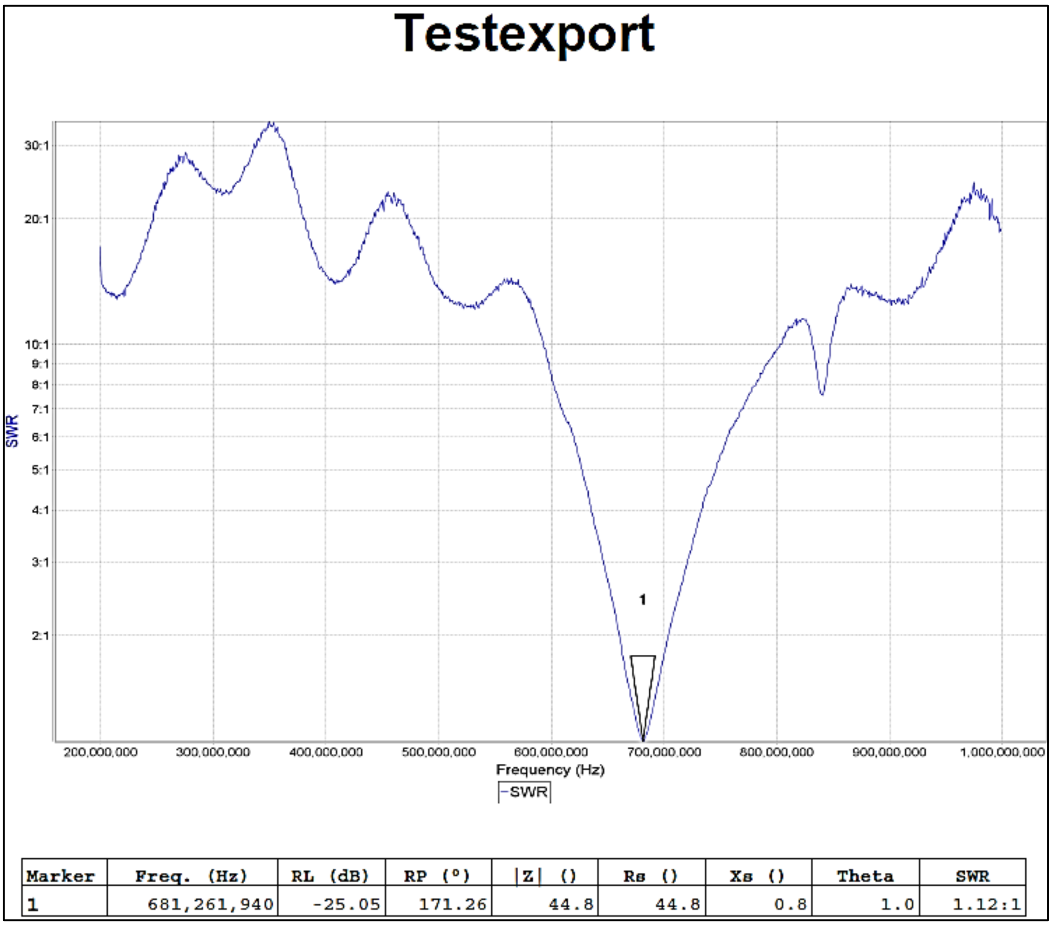


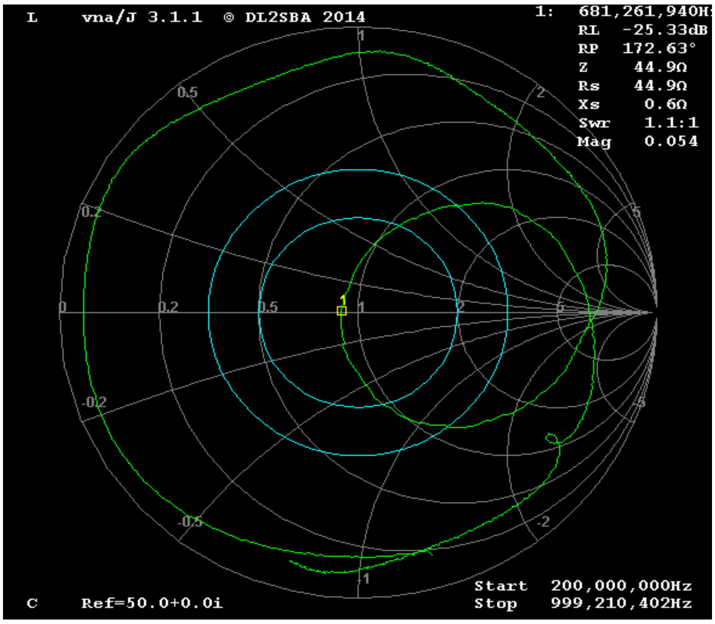
Figure 58: Equipment setup for measuring loop antenna fr using Minivna pro.

In figure 58, the loop antenna is connected to the Minivna pro in order to measure the fr of the antenna. The measured fr of the loop antenna from the software of Minivna pro is shown in figure 59.



Marker	Freq. (Hz)	RL (dB)	RP (°)	|Z| ()	Rs ()	Xs ()	Theta	SWR
1	681,261,940	-25.05	171.26	44.8	44.8	0.8	1.0	1.12:1

Figure 59: Result of loop antenna fr using Minivna pro (681.261MHz).



```
1:  681,261,940H
RL  -25.33dB
RP  172.63°
Z    44.9Ω
Rs   44.9Ω
Xs    0.6Ω
Swr   1.1:1
Mag   0.054
```

```
Start  200,000,000Hz
Stop   999,210,402Hz
```

Figure 60: Smith chart for loop antenna (681.261MHz).

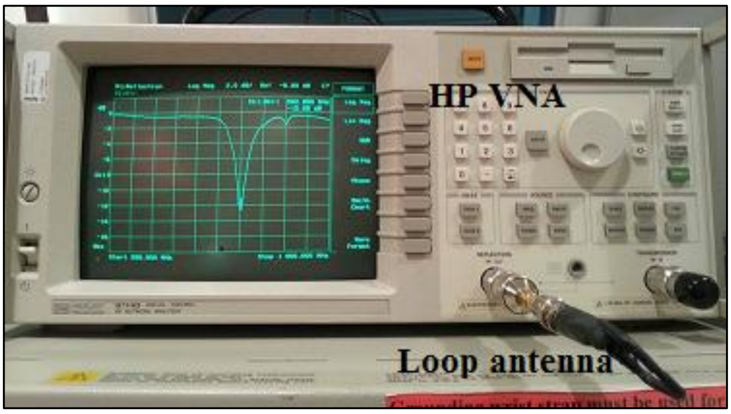


Figure 61: Equipment setup for measuring fr of loop antenna.

The setup for measuring loop antenna by HP VNA is shown in figure 61, where loop antenna is connected to the RF out. The resultant fr of loop antenna from HP VNA is shown below in figure 62.

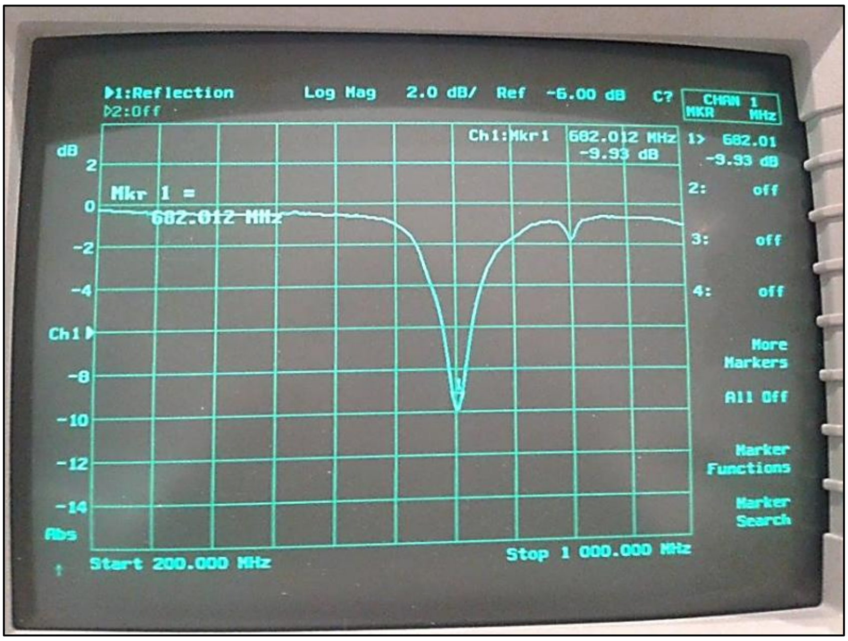


Figure 62: Mesurement result of loop antenna by HP VNA (682.012MHz).

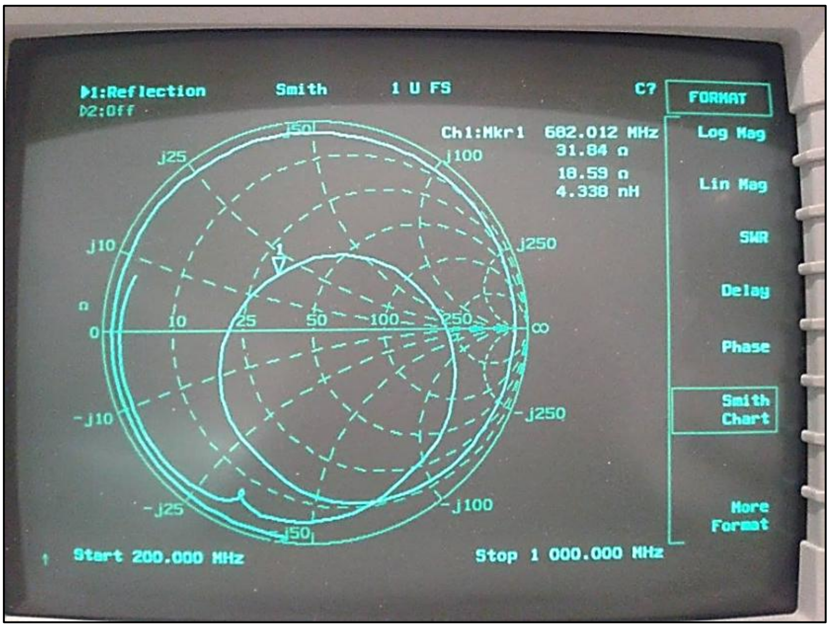


Figure 63: Smith chart for of loop antenna by HP VNA (682.012 MHz).

Figures 59 and 62 show the measurement results for loop antenna. The frequencies are 681.261 MHz and 682.012 MHz using Minivna pro and HP VNA. The results were found to be very close to each other.

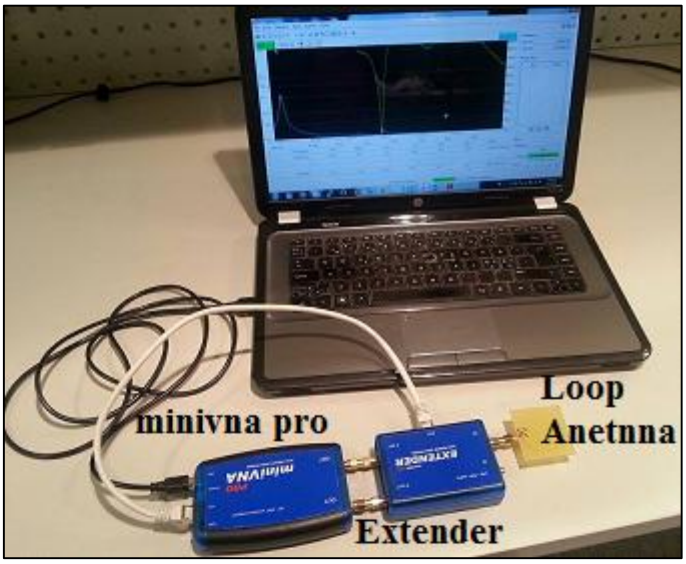
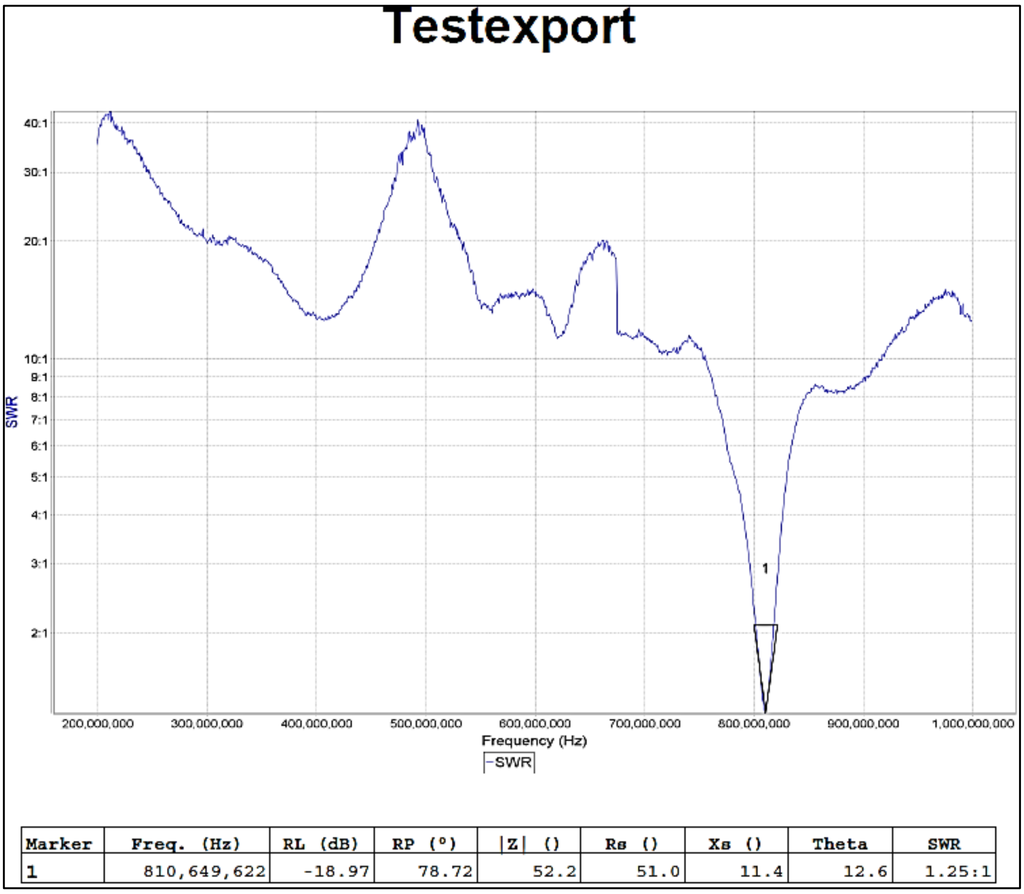
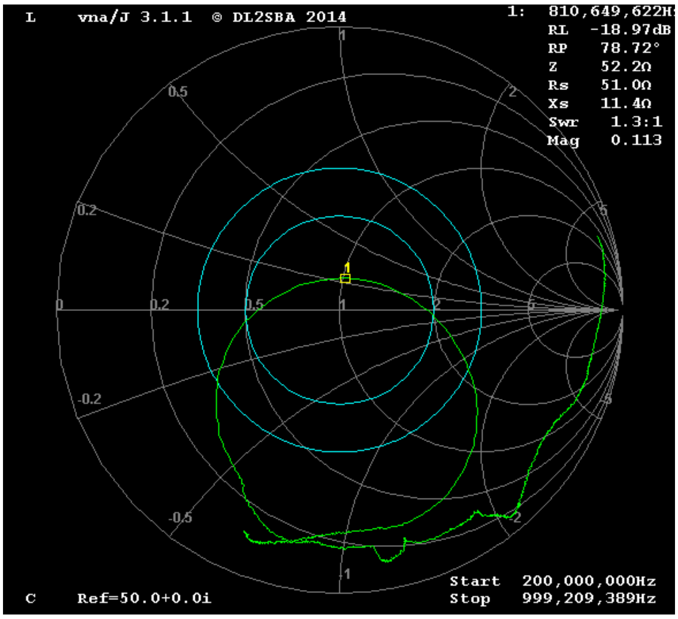


Figure 64: Equipment setup for loop antenna fr measurement.



Marker	Freq. (Hz)	RL (dB)	RP (°)	|Z| ()	Rs ()	Xs ()	Theta	SWR
1	810,649,622	-18.97	78.72	52.2	51.0	11.4	12.6	1.25:1

Figure 65: Result of loop antenna fr using Minivna pro(810.649MHz).



```
L     vna/J 3.1.1  © DL2SBA 2014          1:  810,649,622H
                                              RL   -18.97dB
                                              RP    78.72°
                                              Z     52.2Ω
                                              Rs    51.0Ω
                                              Xs    11.4Ω
                                              Swr    1.3:1
                                              Mag    0.113

                                         Start  200,000,000Hz
C     Ref=50.0+0.0i                      Stop   999,209,389Hz
```

Figure 66: Smith chart for 810.649 MHz loop antenna from Minivna Pro.

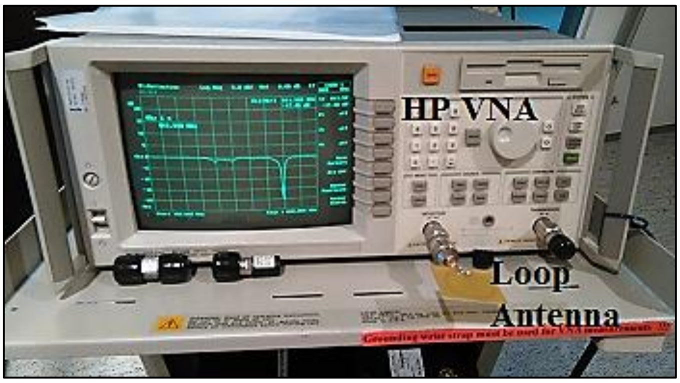


Figure 67: Equipment setup for measuring fr of loop antenna by HP VNA.

The setup for measuring loop antenna by HP VNA is shown in figure 67, where the loop antenna is connected to the RF out. The measured result is shown in figure 68.

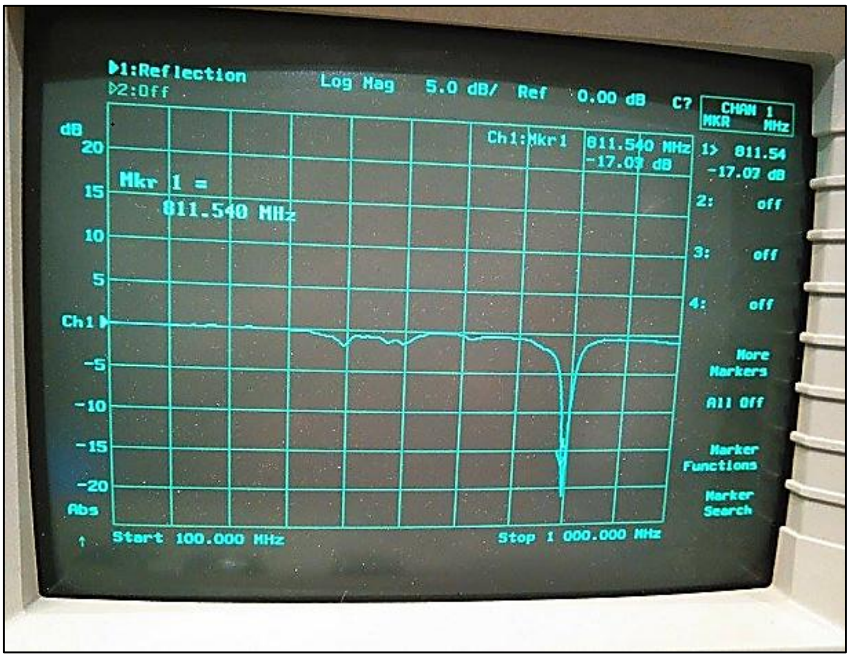


Figure 68: Mesurement result of loop antenna by HP VNA (811.540 MHz).

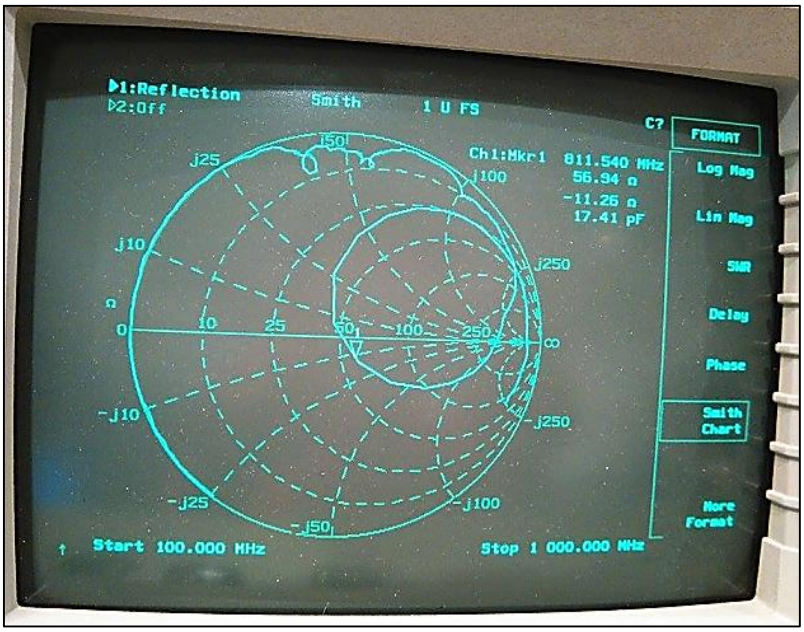


Figure 69: Smith chart for loop antenna of 811.540 MHz.

Figures 65 and 68 show the measurement results for the loop antenna. The resonance frequency obtained using Minivna pro and HP VNA were 810.649 MHz and 811.540 MHz respectively. These two results are close to each other.

5.6 Structural resonance

When there is disproportionality in the amplitude at resonant frequency, the generated resonant frequency with high amplitude is called structural frequency. It has been so far investigated by using a spectral analyzer but not using Minivna pro. Therefore, to investigate the structural resonance of loop antenna using Minivna pro, a simple metallic plate and circuit board which is connected by a metallic wire is needed. Then, a loop antenna connected with Minivna pro is introduced to that connection. The loop antenna couples energy into the resonant circuit formed by capacitance and inductance by board and a metallic plate. It can be observed that the resonant frequency in the screen and the resonant frequency with high amplitude is the structural resonance frequency of the loop antenna. Due to certain limitations such as absence of required materials, limited time frame, and limited research expenditure, the result of this measurement could not be obtained.

6 CONCLUSION

VNA is a powerful and one of the most common network analyzing devices, capable of measuring linear characteristics of RF components and providing information about a complex circuit. Moreover, measurements of RF components include both the phase and magnitude of an electrical circuit. Minivna pro is a smaller version of VNA with similar features. Minivna pro includes newer features such as cable length measurement, integrated Bluetooth module, and exporting data in several formats like JPEG, EXCEL, ZPLOT, S2P and PDF based on software interface.

In this study the compatibility among these two network analyzers were tested, along with the testing of a new feature (cable length measurement) not available in HP VNA. In addition, a series of measurements were performed with both HP VNA and Minivna pro such as resonance frequency measurement of cable authentication, monopole antenna and loop antenna. All these measurement results showed that Minivna pro is as effective as HP VNA. The cable length measurement is performed by using Minivna pro. The error rate was found to be very low. Minivna pro also offers a user-friendly software interface. Exporting data in several formats like pdf, jpeg, excel from Minivna pro was also achieved. There were also graph, Smith chart and other calculations performed by using octave in this thesis.

The investigation of Minivna pro is accomplished with comparable results to HP VNA. Moreover, more measurements using complex circuits need to be performed regarding their RF and performance to become more familiar with Minivna pro.

7 REFERENCES

/1/ Agilent Technologies. (2012). *Understanding the Fundamental Principles of Vector Network Analysis.* Agilent Technologies Inc.

/2/ Antenna-Theory.com. (2009-2011). *The Monopole antennas*. Retrieved September 12, 2012, from Welcome to Antenna-Theory.com!: http://www.antenna-theory.com/antennas/monopole.php

/3/ Balanis, C. A. (1997). *Antenna Theory*. New York: John Wiley & Sons, Inc.

/4/ Christodoulou, C. G., & Wahid, P. F. (2001). *Fundamentals of Antennas: Concepts and Applications.* Washington: SPIE Press.

/5/ DenMasBroto. (2011, August 22). *Antenna Basic Theory*. Retrieved September 5, 2014, from DenMasBroto: Technology Make It Possible: http://denmasbroto.com/cetak-13-antenna-basic-theory.html

/6/ Engdahl, T. (1994-2009). *Coaxial cables*. Retrieved September 28, 2014, from ePanaorama.net: http://www.epanorama.net/documents/wiring/coaxcable.html

/7/ Goleniewski, L. (2002). Transmission Media: Characteristics and Applications. In T. Essentials, *Lillian Goleniewski* (pp. 53-94). Boston: Pearson Education, Inc.

/8/ Healy, J. W. (1991, June). Antenna Here is a Dipole. pp. 23-26.

/9/ Hiebel, M. (2007). *Fundamentals of Vector Network Analysis.* Munchen: Rohde & Schwarz.

/10/ Kraus, J. D. (1988). The Electric Dipole and Thin Linear Antennas. In J. D. Kraus, *Antennas* (pp. 200-202). McGraw-Hill, Inc.

/11/ Matin, M. A. (2012). Cable Effects on Measuring Small Planar UWB Monopole Antennas. In L. Liu, S. Cheung, Y. Weng, & T. Yuk, *Ultra*

Wideband - Current Status and Future Trends (pp. 77-98). Rijeka, Croatia: InTech.

/12/ National Instruments. (2012, December 14). *Fundamentals of Network Analysis*. Retrieved from National Instruments: http://www.ni.com/white-paper/11640/en/

/13/ Nikolova, N. K. (2014). *Introduction into Antenna Studies.*

/14/ ninjacraze. (2010, January 9). *Types of Transmission Media*. Retrieved October 5, 2014, from HubPages: http://hubpages.com/hub/Data-Communication

/15/ Ott, H. W. (2009). *Electromagnetic Compatibility Engineering.* New Jersey: John Wiley & Sons, Inc.

/16/ Perelman, R., & Perelman, J. l. (1997, January 1). The importance of coaxial cable to base station performance. Urgent Communication.

/17/ Poole, I. (n.d.). *Coax Cable Attenuation / Loss*. Retrieved June 15, 2012, from Radio-Electronics.com: http://www.radio-electronics.com/info/antennas/coax/coax_loss.php

/18/ R. Dean straw, N. (1997). *The ARRL Antenna Book.* Newington, CT: The American Radio Relay League.

/19/ Reinholm, J. (2012, June 14). *The Characteristic Impedance of Coaxial Cables*. Retrieved October 4, 2014, from Electronics Lab: http://www.electronics-lab.com/blog/?p=18953

/20/ Rosu, I. (n.d.). Small Antennas for High Frequencies.

/21/ Tanenbaum, A. S. (1996). Coaxial Cable. In A. S. Tanenbaum, *Computer Networks* (pp. 84-85). New Jersey: Prentic Hall, Inc.

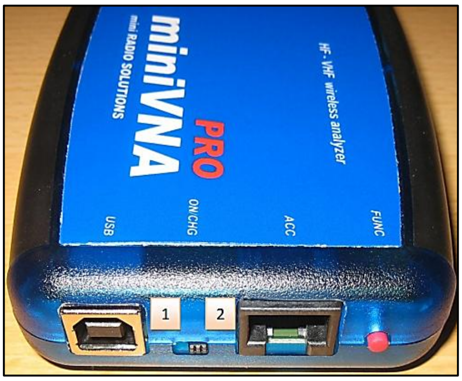
/22/ Yates, S. (2013, August 10). *Small Transmitting Loop Antennas*. Retrieved September 15, 2014, from AA5TB: http://www.aa5tb.com/loop.html

8 APPENDIX

9 ATTACHMENT (QUICK MANUAL FOR MINIVNAPRO)

CONNECTOR AND SWITCH FOR MINIVNA PRO

The specifications for Minivna pro and extender are listed above in chapter 2.



Switches and ports	**Discription**
Func	Reset Button of Minivna.
ACC	Connector for additional accessories mainly for extender. **Note: This is not the Ethernet port of Minivna pro so Don’t connect any device other than mRS certified device to this port.**
ON/CHG	Power switch Internal battery connected. Internal battery disconnected.
USB	This port is only for Type-B connector. The other end of the cable with Type-A connector should be connected to USB-host adapter.
DUT	This port is typically connected to the antenna under test when Minivna pro is set by the software interface to work in Reflection mode. Warning! DO not pass DC signals over 25 VDC and RF signals over 10mW.

DET	This port is specially for checking filters and amplifiers when Minivna pro is set by the software interface to work in Transmission mode. Warning! DO not pass DC signals over 25VDC and RF signals over 10mW.

Connector and switch for Minivna pro with Extender:

Switches and ports	**Description**
ACC	This port is for connecting Minivna pro with extender by using RJ45 cable.
IF DUT	Double-SMA-male connector is connected to this port then to DUT port on the Minivna pro.
IF DET	Double-SMA-male connector is connected to this port then to DET port on the Minivna pro.
TX	For **transmission mode**, this port is output port from the extender which can be used for **frequency generator**. This port should be connected with the input of measurement object.
RX	For **reflection mode**, where we connect the measurement object. For **transmission mode**, this is acquisition port and is connected to the output of the measurement object.

INDICATOR:

Both Minivna pro and Minivna pro Extender has some indicators on the backside:

S.N	Color	Description
1	Green	Analogue section activated. #When the analogue section may be deactivated by the firmware.
2	Green	Digital section activated. #It shows us whether Minivna pro is connected to active USB-port or Minivna pro is running on battery power.
3	Yellow	Lithium-ion battery is being charged.
4	Yellow	It gives us information about whether data transfer between remote PC to Minivna pro is occurring or not. (RX of data over USB)
5	Yellow	It gives us information about whether data transfer between remote PC to Minivna pro is occurring or not. (TX of data over USB)
6	Blue	It lit, to show the Bluetooth connection status. # Blinking lit means it is searching for counterpart. # Lit remain constant means connection is done.
7	Blue	Data transfer from Bluetooth has been activated.

The extender has only one indicator on the backside which is only for power-indicator.

POWER SUPPLY:

Minivna pro has a build in Li-ion battery which is for stand-alone operations with Bluetooth connection.

To provide the power supply for Minivna pro stand-alone analyzer needs to be connected to an active USB-host and is connected other end to position 1 of Minivna pro.

- If indicator (3) is lit then, Minivna pro battery is charging.
- When indicator (3) goes off then, battery is fully charged.
- It is not recommended to use the analyzer during charging via the USB port.

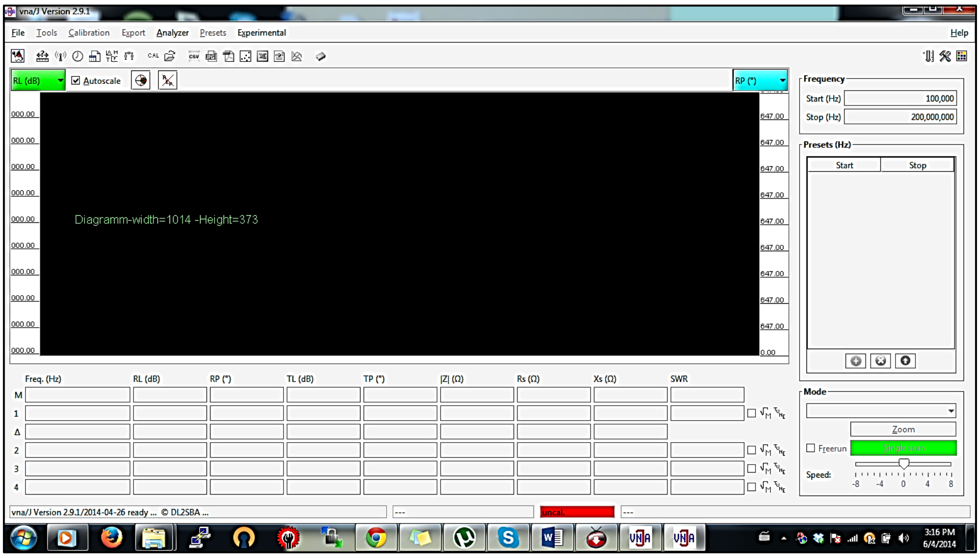
The Extender gets power from Minivna pro when it is connected to ACC port of Minivna pro by using RJ45 cable.

Installing information of software interface and driver for Minivna pro.

THE SOFTWARE INTERFACE AND DRIVER INSTALLATION FOR MINIVNA PRO:

- First search the official website of Minivna pro.
- Click on download SW.
- There you will find download vna/J then download the latest version of vna/J and relevant files for your operating system.

- Then just click vna/J then, you will find your software interface for your Minivna pro.



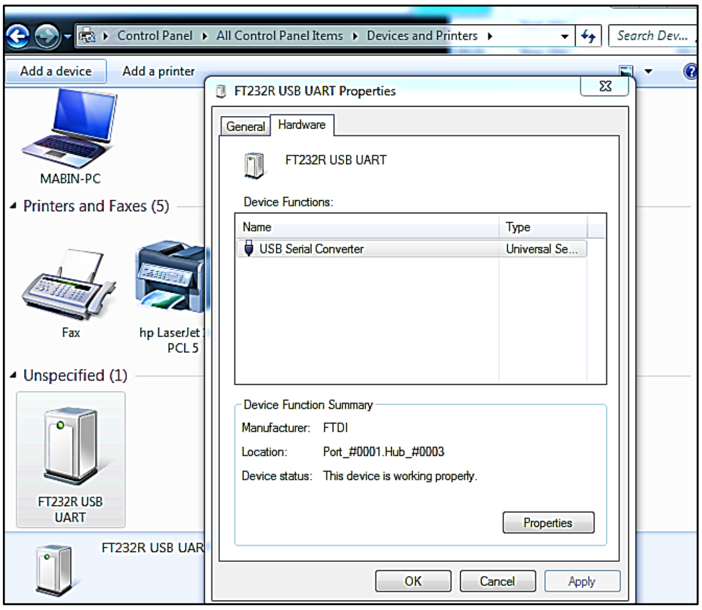
Start (Hz) 100,000

Stop (Hz) 200,000,000

Diagramm-width=1014 -Height=373

vna/J Version 2.9.1/2014-04-26 ready ... © DL2SBA ...

Then go to control panel and then to devices and printers then there you can see in which port Minivna pro is connected which can be check by checking properties of FT232R USB UART which is:



USB Serial Converter — Universal Se...

Manufacturer: FTDI

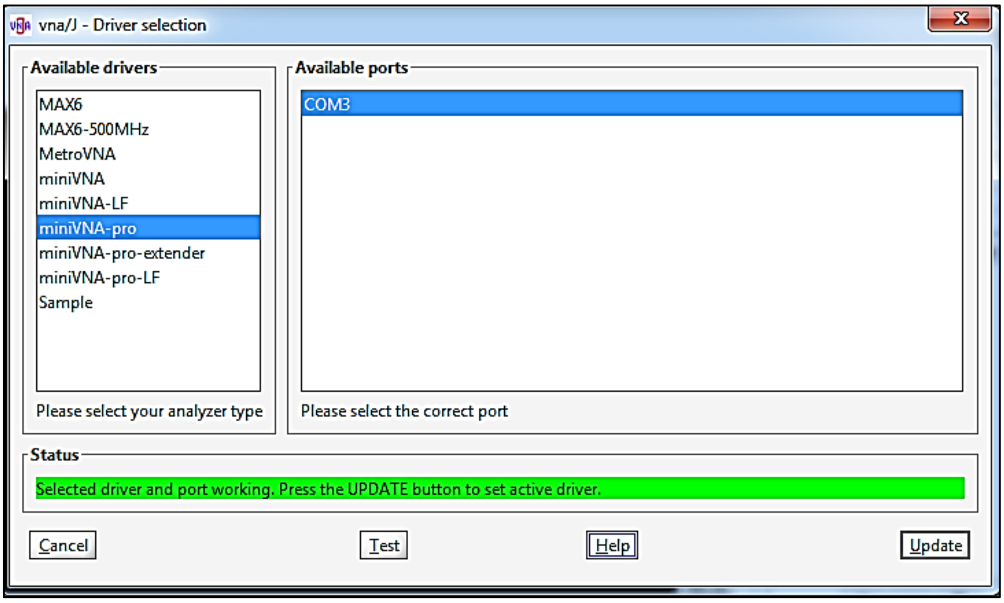
Location: Port_#0001.Hub_#0003

Device status: This device is working properly.

Then we go back to software interface for Minivna pro and follow following steps:

- Go to analyzer then click to setup.

- Then another window pops up which is driver selection window, then select the relevant devices and the port.
- Click on test, if everything goes well then green box pops up then click on update.



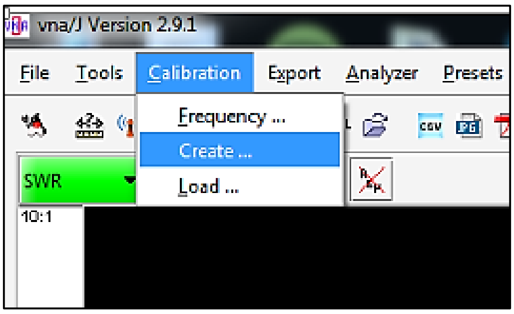
Selected driver and port working. Press the UPDATE button to set active driver.

Then there will be warning saying that no calibration data is available for mode.

MAIN CALIBRATION STEUP FOR MINIVNA PRO:

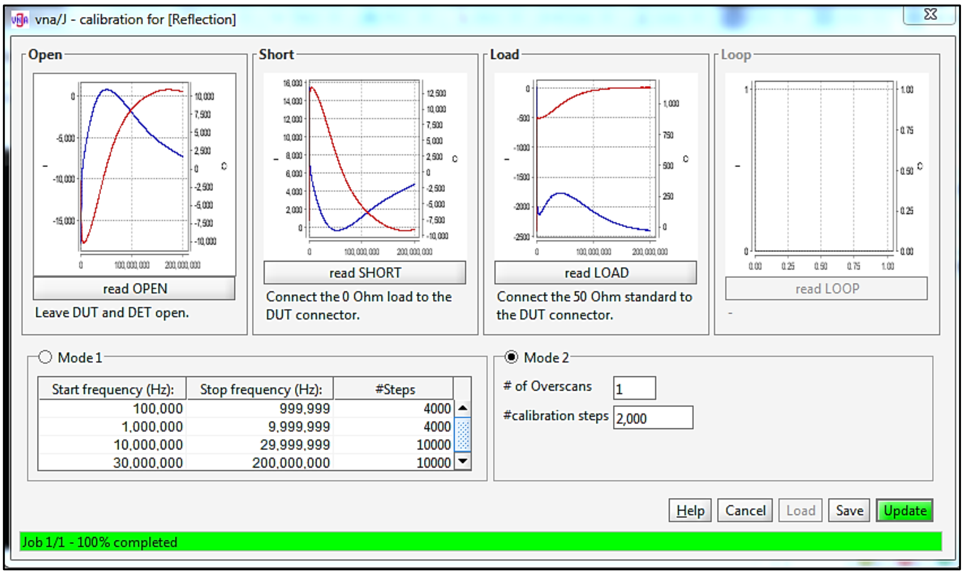
- Calibration kit for Minivna pro

- First go to calibration then click on create.



- Then a window pops up then use WiMo SMA calibration kit to create calibration.

CALIBRATION FOR REFLECTION:



Leave DUT and DET open.

Connect the 0 Ohm load to the DUT connector.

Connect the 50 Ohm standard to the DUT connector.

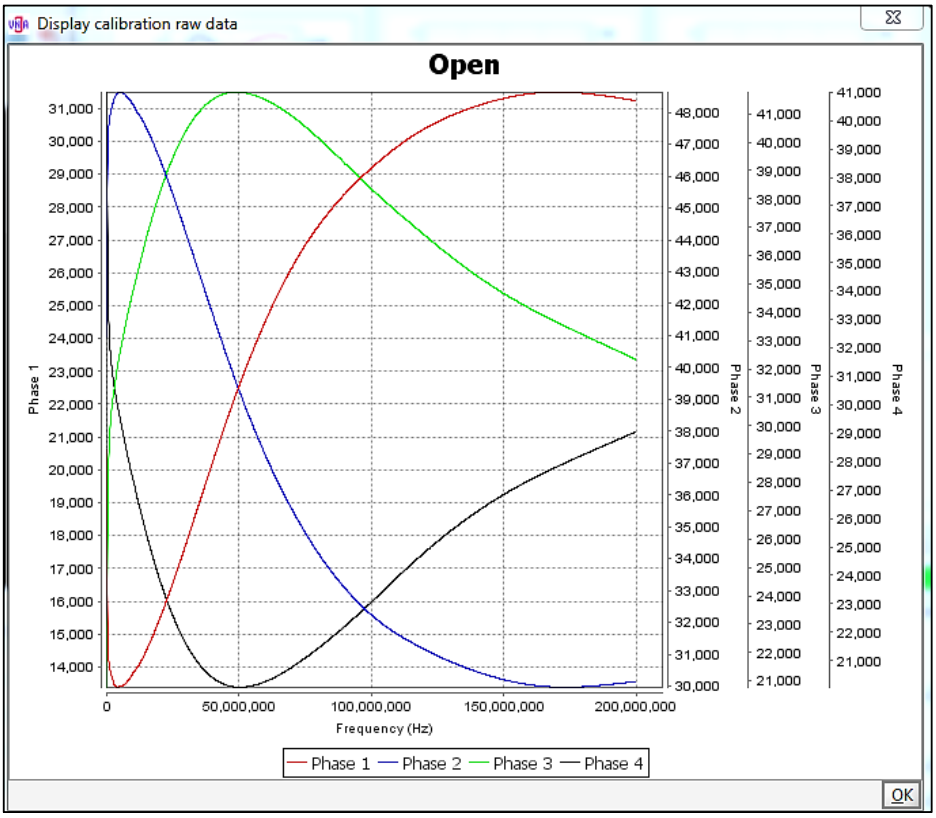
Start frequency (Hz):	Stop frequency (Hz):	#Steps
100,000	999,999	4000
1,000,000	9,999,999	4000
10,000,000	29,999,999	10000
30,000,000	200,000,000	10000

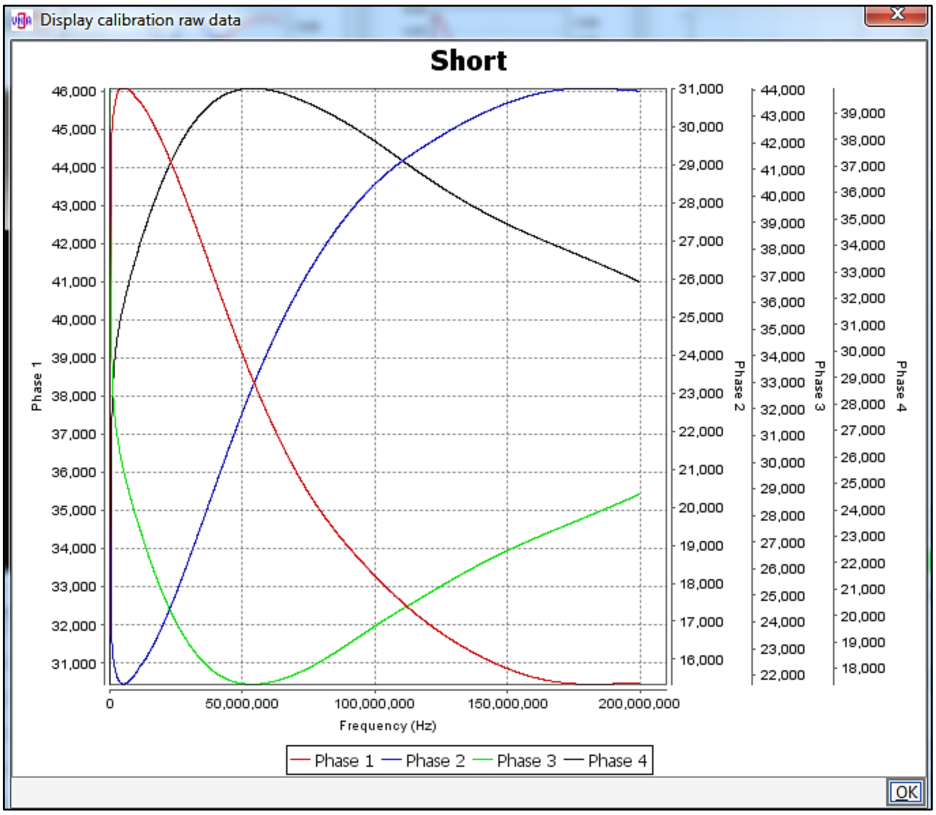
\# of Overscans: 1

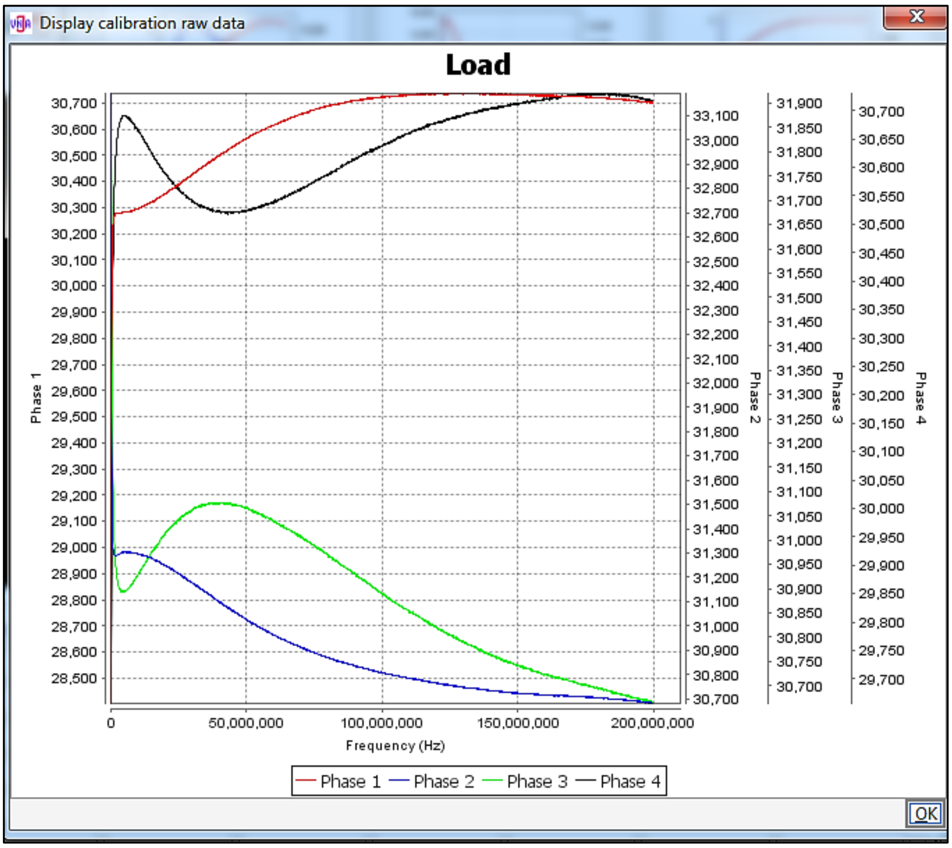
\#calibration steps: 2,000

Job 1/1 - 100% completed

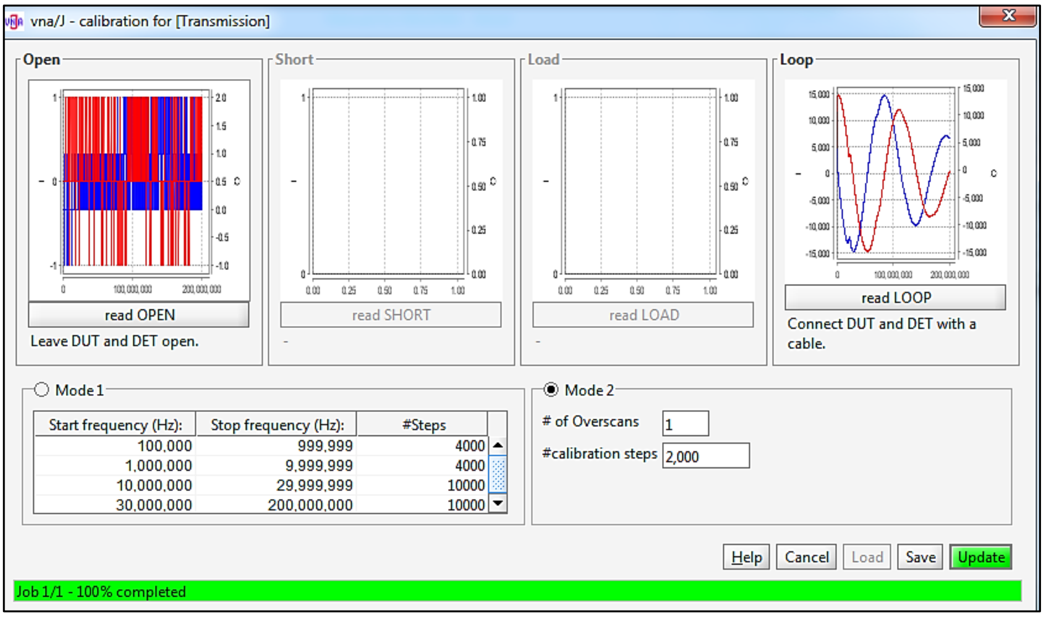
When the individual graph of open, short, loop are clicked then the figures as below are obtained.


Display calibration raw data
Open
Phase 1
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
Phase 2
48,000
47,000
46,000
45,000
44,000
43,000
42,000
41,000
40,000
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
30,000
Phase 3
41,000
40,000
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
Phase 4
41,000
40,000
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
0
50,000,000
100,000,000
150,000,000
200,000,000
Frequency (Hz)
Phase 1
Phase 2
Phase 3
Phase 4
OK


Display calibration raw data
Short
Phase 1
46,000
45,000
44,000
43,000
42,000
41,000
40,000
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
Phase 2
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
Phase 3
44,000
43,000
42,000
41,000
40,000
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
Phase 4
39,000
38,000
37,000
36,000
35,000
34,000
33,000
32,000
31,000
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
18,000
0
50,000,000
100,000,000
150,000,000
200,000,000
Frequency (Hz)
Phase 1
Phase 2
Phase 3
Phase 4
OK



CALIBRATION FOR TRANSMISSION:



Leave DUT and DET open.

Connect DUT and DET with a cable.

○ Mode 1

Start frequency (Hz):	Stop frequency (Hz):	#Steps
100,000	999,999	4000
1,000,000	9,999,999	4000
10,000,000	29,999,999	10000
30,000,000	200,000,000	10000

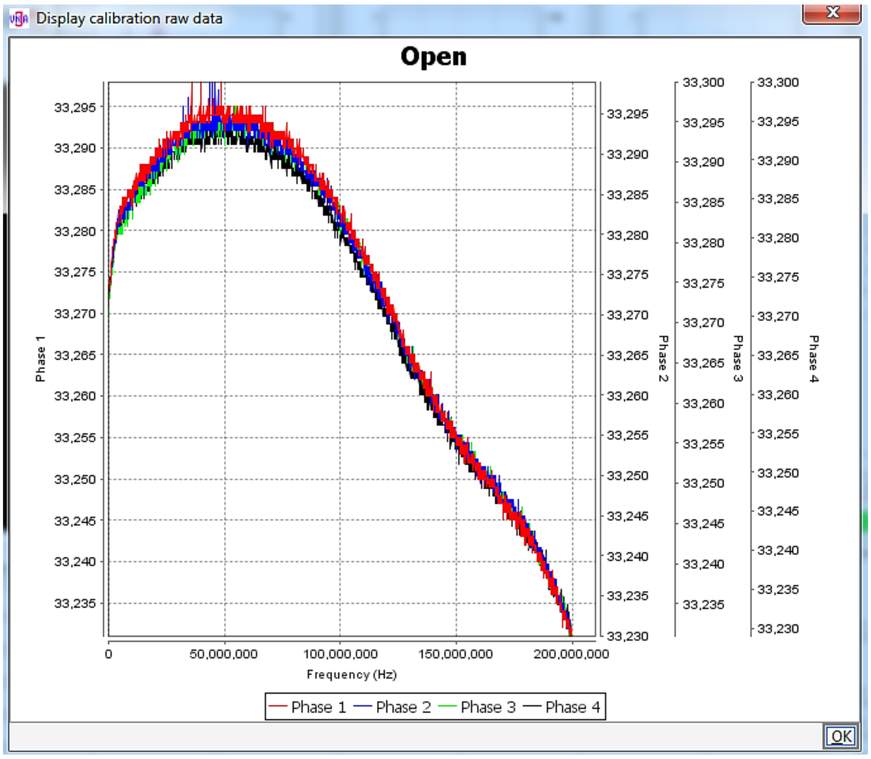
● Mode 2

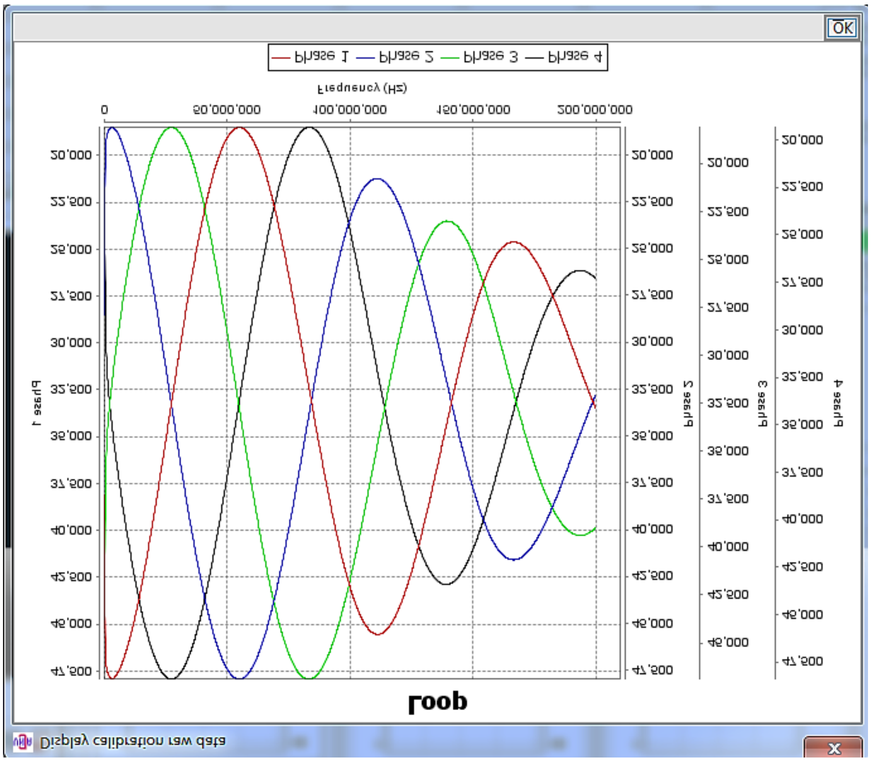
# of Overscans: 1

#calibration steps: 2,000

Job 1/1 - 100% completed

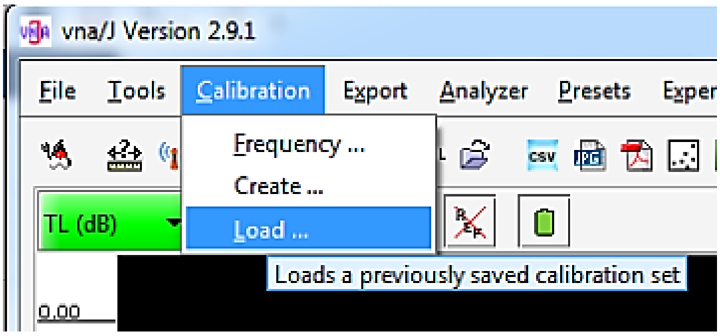
When the individual graph open and loop are clicked then the figures as below are obtained.



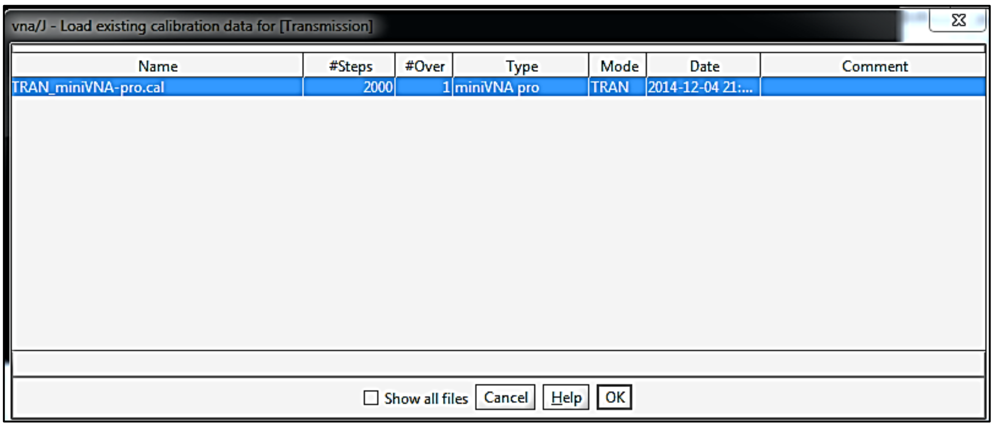


NOTE: I did not get real calibration kit for loop so I use 2m Aircell cable.

- Then click the update, your calibration will be saved.
- But if you have already save the calibration files they you can load the existing files and use that by following step shown below.



Loads a previously saved calibration set


vna/J - Load existing calibration data for [Transmission]

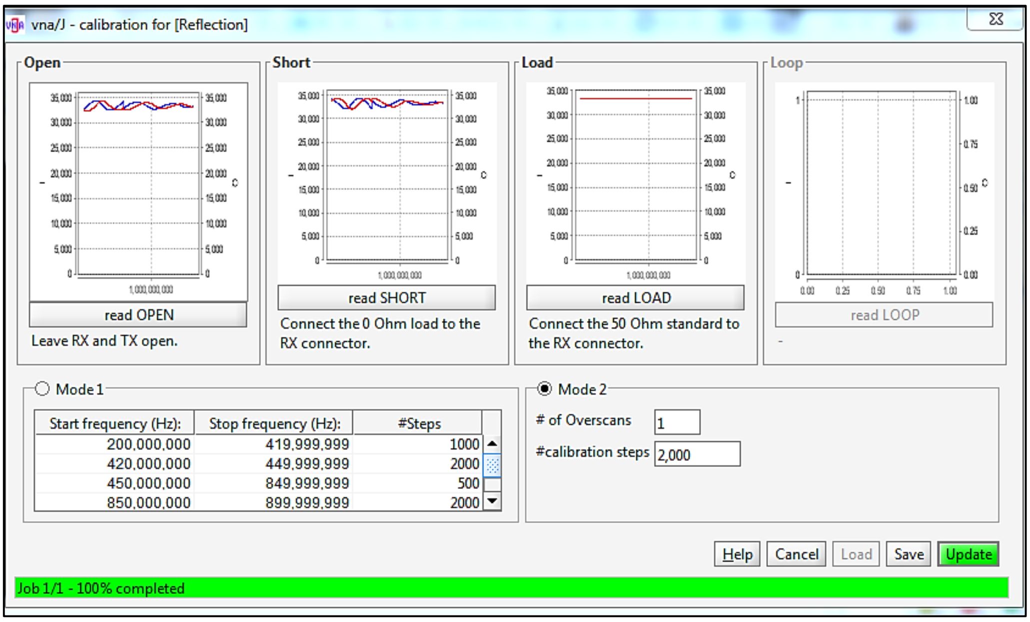
Name	#Steps	#Over	Type	Mode	Date	Comment
TRAN_miniVNA-pro.cal	2000	1	miniVNA pro	TRAN	2014-12-04 21:...	

If previous calibration is saved then load same calibration can be loaded before making another measurement.

MAIN CALIBRATION FOR EXTENDER:

First click the analyzer and select the Minivna pro extender driver and update.

CALIBRATION FOR REFLECTION:



Leave RX and TX open.

Connect the 0 Ohm load to the RX connector.

Connect the 50 Ohm standard to the RX connector.

○ Mode 1

Start frequency (Hz):	Stop frequency (Hz):	#Steps
200,000,000	419,999,999	1000
420,000,000	449,999,999	2000
450,000,000	849,999,999	500
850,000,000	899,999,999	2000

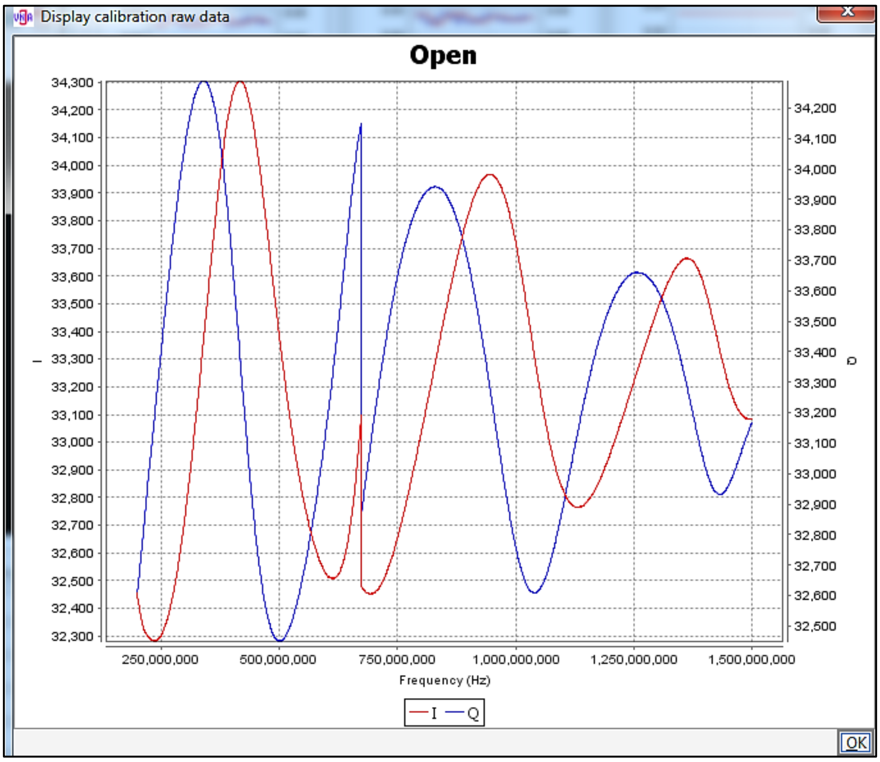
● Mode 2

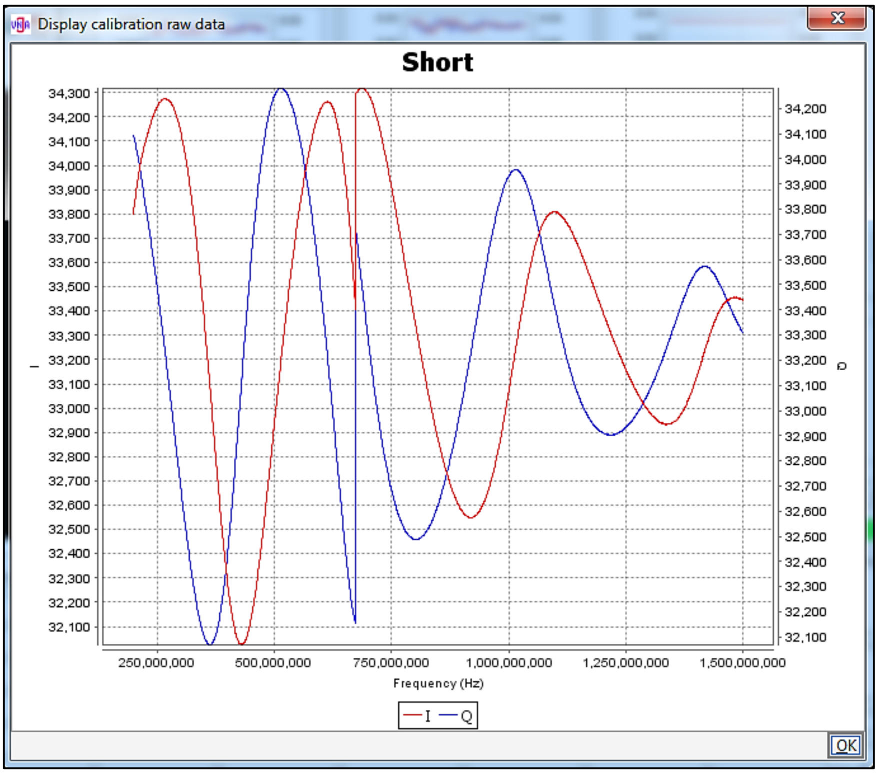
# of Overscans 1

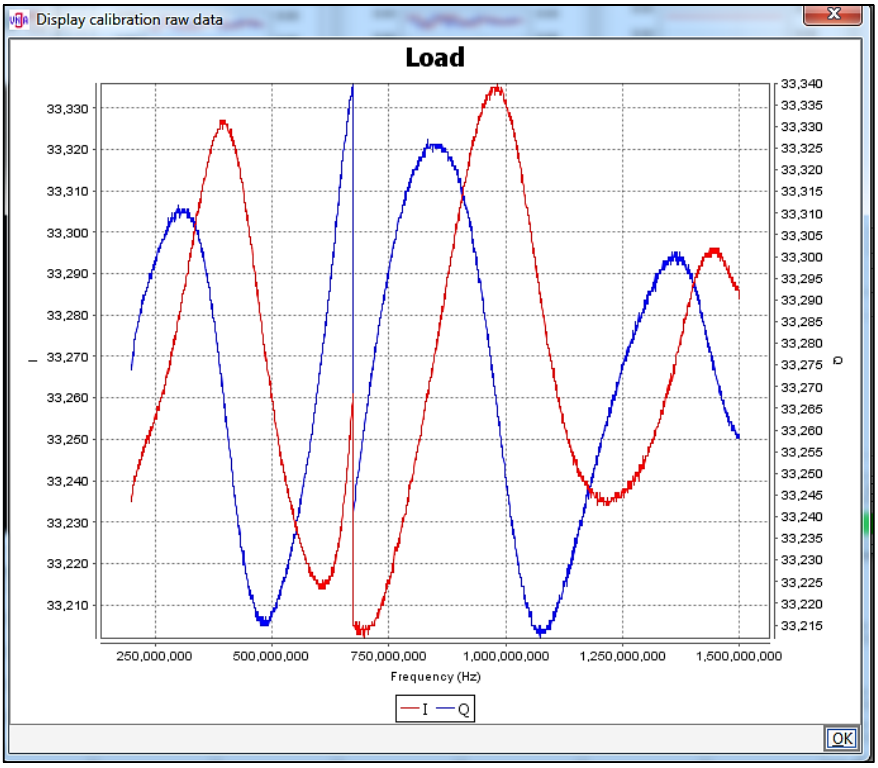
#calibration steps 2,000

Job 1/1 - 100% completed

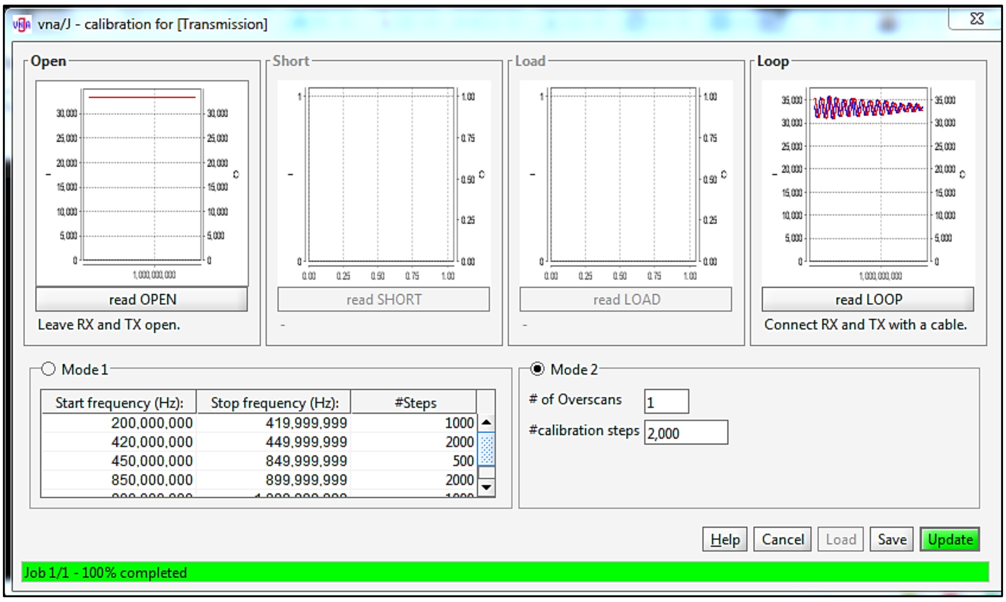
When the individual graph open, short and loop are clicked then the figures as below are obtained.




Display calibration raw data
Short
34,300
34,200
34,100
34,000
33,900
33,800
33,700
33,600
33,500
33,400
33,300
33,200
33,100
33,000
32,900
32,800
32,700
32,600
32,500
32,400
32,300
32,200
32,100
I
34,200
34,100
34,000
33,900
33,800
33,700
33,600
33,500
33,400
33,300
33,200
33,100
33,000
32,900
32,800
32,700
32,600
32,500
32,400
32,300
32,200
32,100
Q
250,000,000
500,000,000
750,000,000
1,000,000,000
1,250,000,000
1,500,000,000
Frequency (Hz)
I
Q
OK


Display calibration raw data
Load
33,330
33,320
33,310
33,300
33,290
33,280
33,270
33,260
33,250
33,240
33,230
33,220
33,210
I
33,340
33,335
33,330
33,325
33,320
33,315
33,310
33,305
33,300
33,295
33,290
33,285
33,280
33,275
33,270
33,265
33,260
33,255
33,250
33,245
33,240
33,235
33,230
33,225
33,220
33,215
Q
250,000,000
500,000,000
750,000,000
1,000,000,000
1,250,000,000
1,500,000,000
Frequency (Hz)
I
Q
OK

CALIBRATION FOR TRANSMISSION:



Leave RX and TX open.

Connect RX and TX with a cable.

○ Mode 1

Start frequency (Hz):	Stop frequency (Hz):	#Steps
200,000,000	419,999,999	1000
420,000,000	449,999,999	2000
450,000,000	849,999,999	500
850,000,000	899,999,999	2000

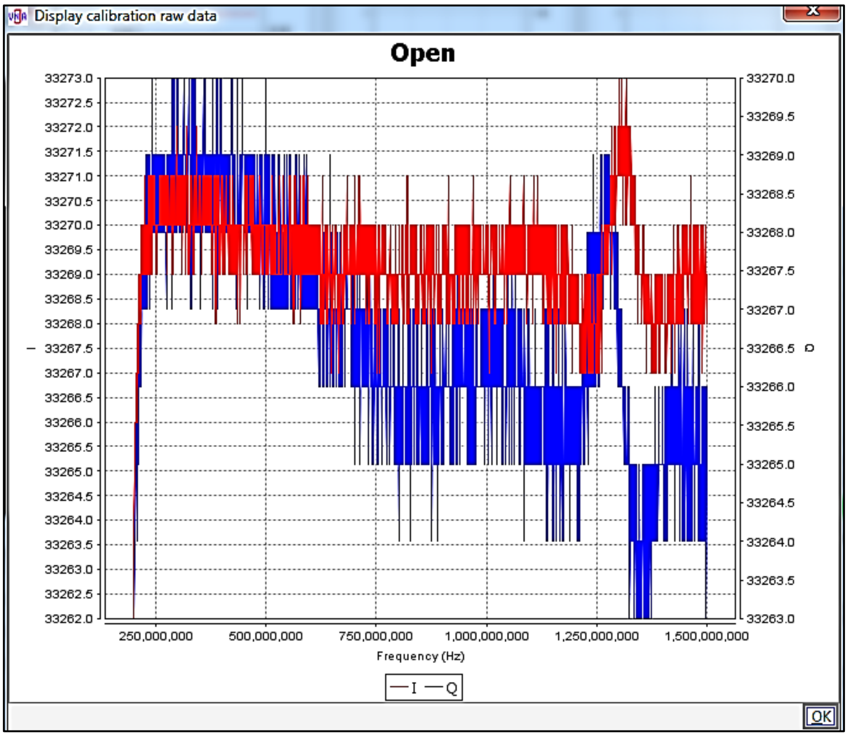
● Mode 2

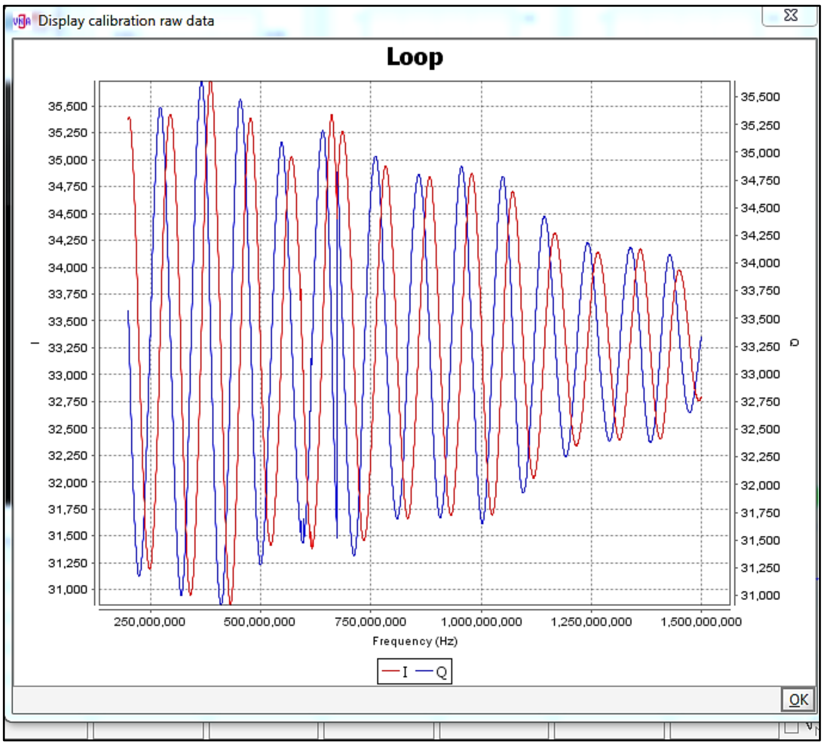
\# of Overscans: 1

\#calibration steps: 2,000

Job 1/1 - 100% completed

When the individual graph of open and loop are clicked then the figures as below are obtained.

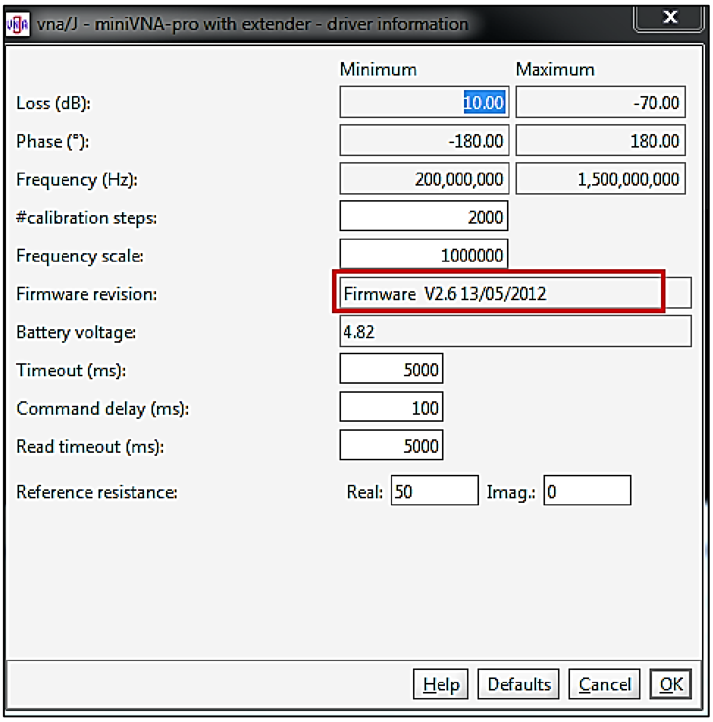




FIRMWARE UPDATE FOR MINIVNA PRO:

To upgrade the firmware inside Minivna pro proceed following steps:

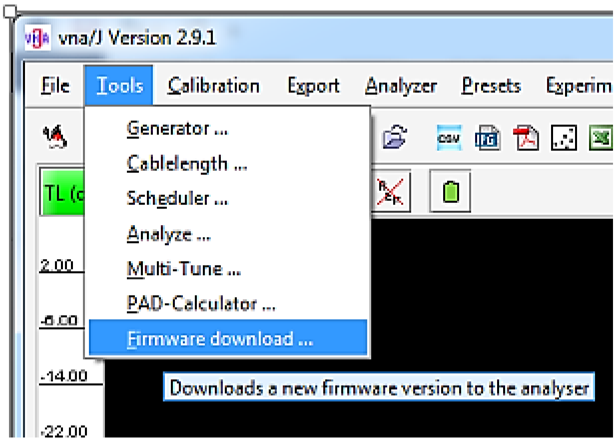
- Check the current version of the firmware by clicking driver dialogue and pop up a window as shown below and the red marked box shows the current version.



vna/J - miniVNA-pro with extender - driver information

	Minimum	Maximum
Loss (dB):	10.00	-70.00
Phase (°):	-180.00	180.00
Frequency (Hz):	200,000,000	1,500,000,000
#calibration steps:	2000	
Frequency scale:	1000000	
Firmware revision:	Firmware V2.6 13/05/2012	
Battery voltage:	4.82	
Timeout (ms):	5000	
Command delay (ms):	100	
Read timeout (ms):	5000	
Reference resistance:	Real: 50	Imag.: 0

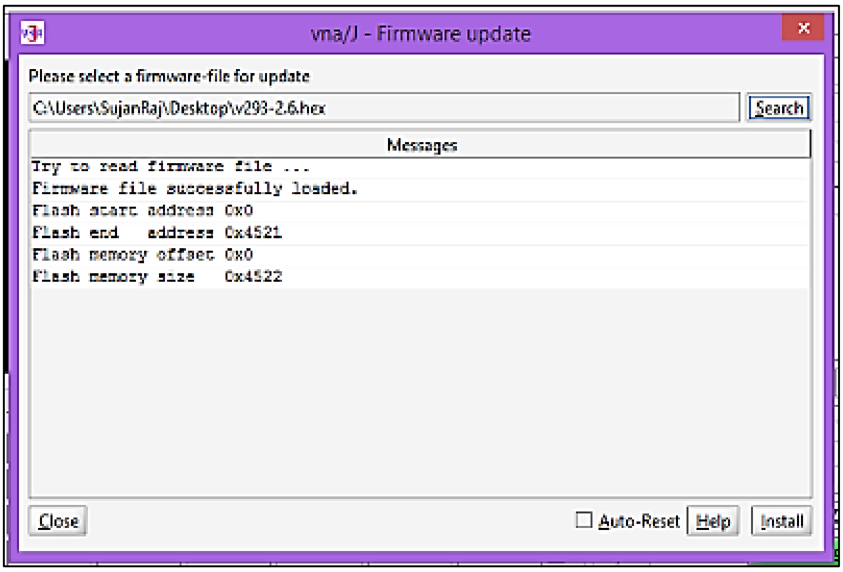
- ➢ Check latest installed firmware version using vna/J and Download new firmware from mRS website (http://miniradiosolutions.com/fw-updates).
- ➢ Upgrade firmware of Minivna pro using vna/J as shown below.



vna/J Version 2.9.1

Downloads a new firmware version to the analyser

- ➢ Select the downloaded latest version of firmware.



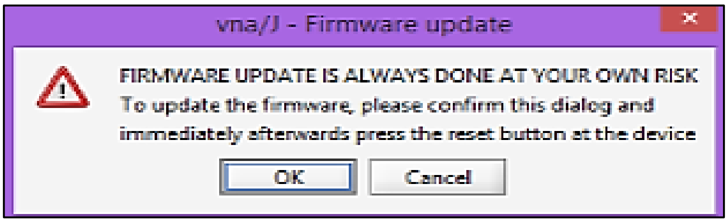
Please select a firmware-file for update

C:\Users\SujanRaj\Desktop\v293-2.6.hex

Messages

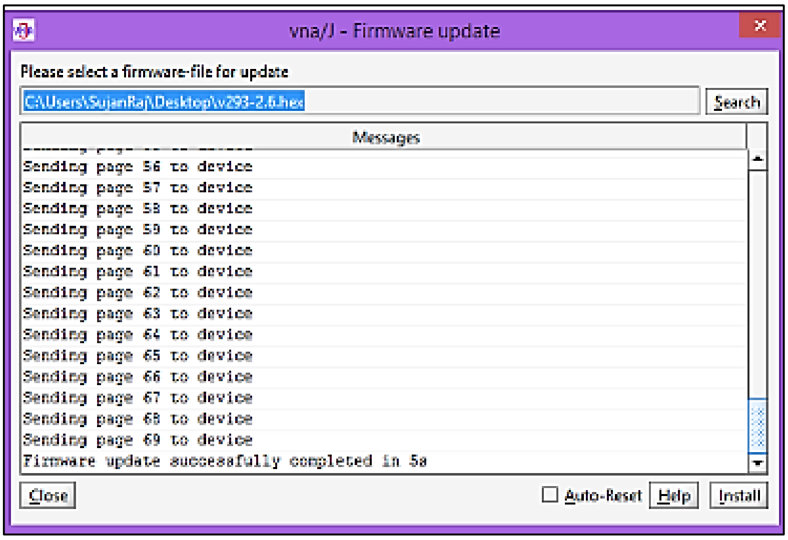
```
Try to read firmware file ...
Firmware file successfully loaded.
Flash start address 0x0
Flash end   address 0x4521
Flash memory offset 0x0
Flash memory size   0x4522
```

- ➢ Click install then a warning window pops up. This is very important, then click the reset button then firmware is updated.



FIRMWARE UPDATE IS ALWAYS DONE AT YOUR OWN RISK
To update the firmware, please confirm this dialog and
immediately afterwards press the reset button at the device

- ➢ After pressing reset button immediately then after few second firmware is updated.



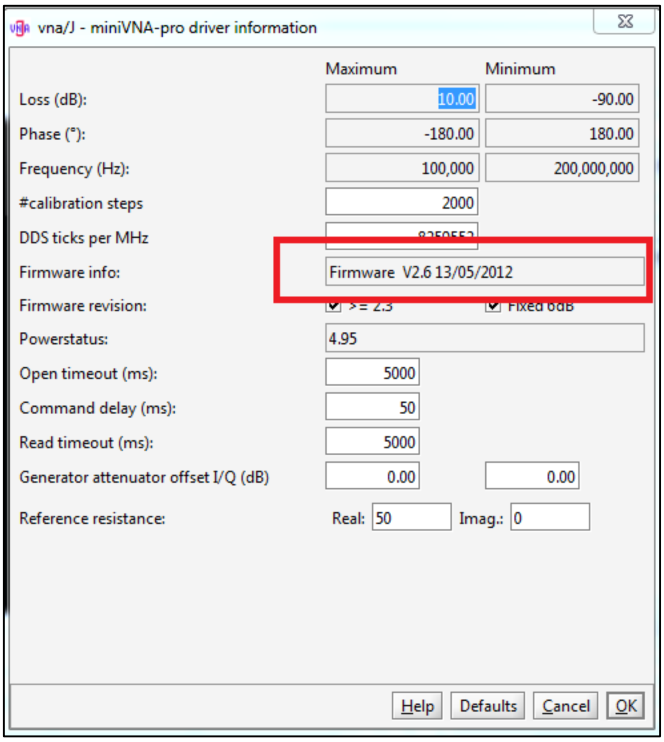
Please select a firmware-file for update

C:\Users\SujanRaj\Desktop\v293-2.6.hex

Messages

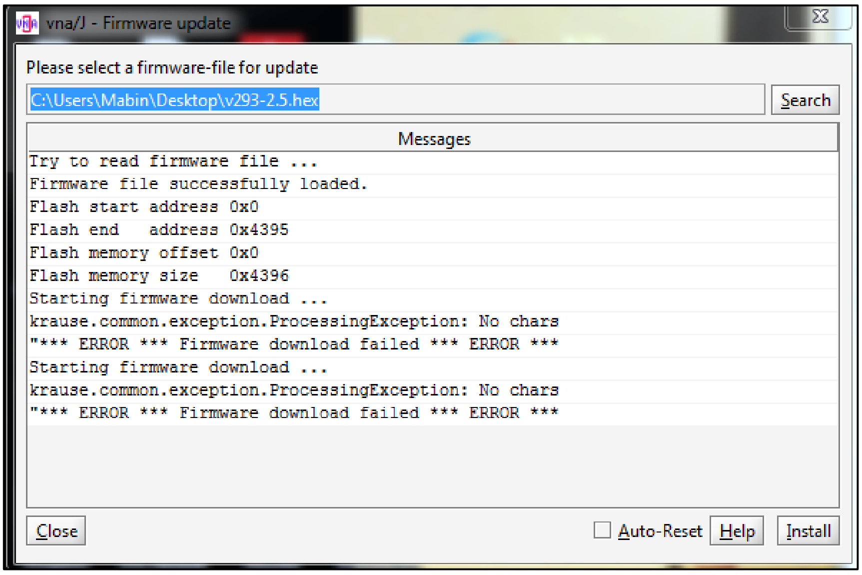
```
Sending page 56 to device
Sending page 57 to device
Sending page 58 to device
Sending page 59 to device
Sending page 60 to device
Sending page 61 to device
Sending page 62 to device
Sending page 63 to device
Sending page 64 to device
Sending page 65 to device
Sending page 66 to device
Sending page 67 to device
Sending page 68 to device
Sending page 69 to device
Firmware update successfully completed in 5s
```

- ➢ After firmware update check the version you update:



	Maximum	Minimum
Loss (dB):	10.00	-90.00
Phase (°):	-180.00	180.00
Frequency (Hz):	100,000	200,000,000
#calibration steps	2000	
DDS ticks per MHz	8259552	
Firmware info:	Firmware V2.6 13/05/2012	
Firmware revision:	☑ >= 2.3	☑ Fixed 6dB
Powerstatus:	4.95	
Open timeout (ms):	5000	
Command delay (ms):	50	
Read timeout (ms):	5000	
Generator attenuator offset I/Q (dB)	0.00	0.00
Reference resistance:	Real: 50	Imag.: 0

NOTE: If you forget to click the reset button then you will get and error like this:



Please select a firmware-file for update

C:\Users\Mabin\Desktop\v293-2.5.hex

```
Try to read firmware file ...
Firmware file successfully loaded.
Flash start address 0x0
Flash end   address 0x4395
Flash memory offset 0x0
Flash memory size   0x4396
Starting firmware download ...
krause.common.exception.ProcessingException: No chars
"*** ERROR *** Firmware download failed *** ERROR ***
Starting firmware download ...
krause.common.exception.ProcessingException: No chars
"*** ERROR *** Firmware download failed *** ERROR ***
```

☐ Auto-Reset

NOTE: Always update the latest version of firmware so that you can get more program features

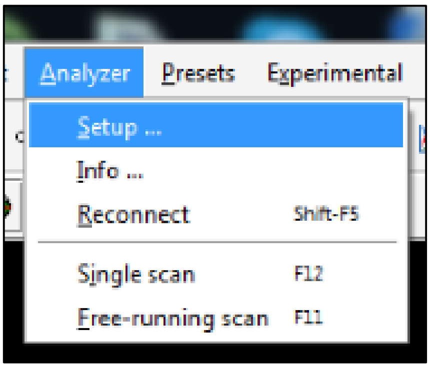
First execute all those above action in native operating system.

The USB support on Linux may cause problems during updating the firmware and you may destroy the Minivna pro. Please upgrade only via a Linux system, if scanning with your currently installed firmware works flawlessly.

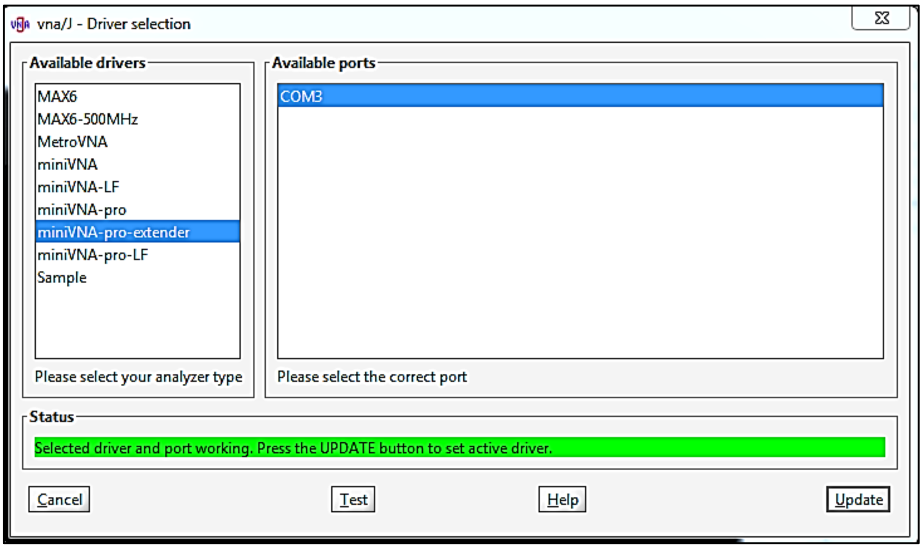
For firmware update with Bluetooth connection it will never work and you might destroy you analyzer.

Installing information of software interface and driver for both Minivna pro and for extender.

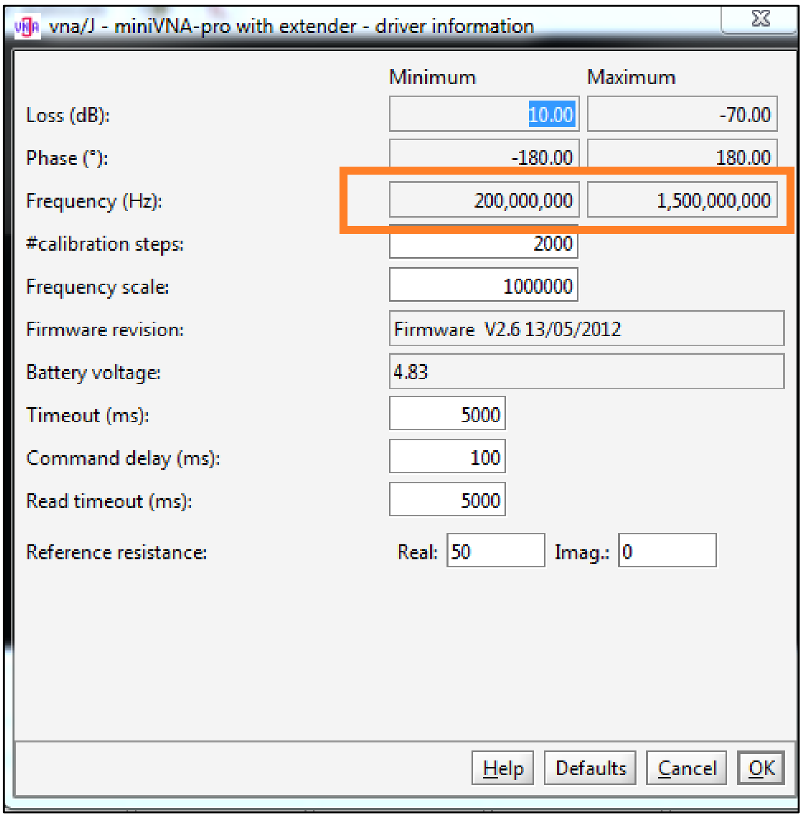
First click the analyzer then click setup:



Then Driver selection window pops up, next select Minivna pro extender as shown below:

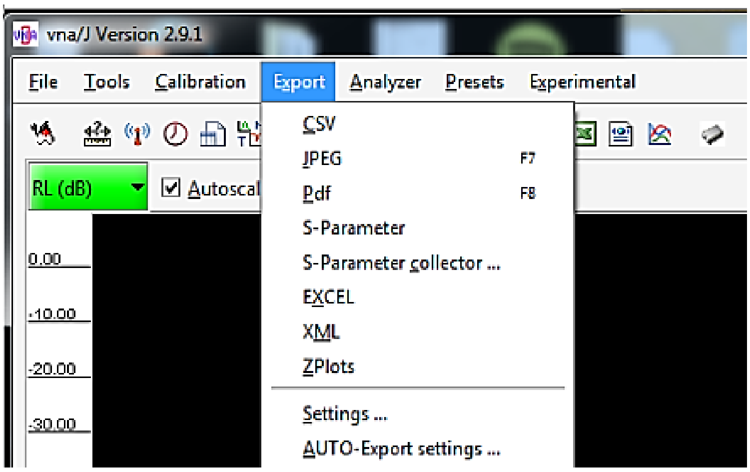


Selected driver and port working. Press the UPDATE button to set active driver.



	Minimum	Maximum
Loss (dB):	10.00	-70.00
Phase (°):	-180.00	180.00
Frequency (Hz):	200,000,000	1,500,000,000
#calibration steps:	2000	
Frequency scale:	1000000	
Firmware revision:	Firmware V2.6 13/05/2012	
Battery voltage:	4.83	
Timeout (ms):	5000	
Command delay (ms):	100	
Read timeout (ms):	5000	
Reference resistance:	Real: 50	Imag.: 0

EXPORTING THE FILE FROM MINIVNA PRO:



From the above figure we can see that files can be exported in different forms.

REFERENCES:

- http://www.wimo.de/instrumentation_e.html
- http://miniradiosolutions.com/minivna-tiny
- http://www.gigaparts.com/field-day/Field-Day-Tools/W4RT-Electronics-MINIVNA-PRO.html