Matching Dipole Antenna Using the L-C Series Network

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Abstract: *Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. If an antenna is resonant, it will be matched to the transmission line and/or transmitter and the bulk of the signal will actually be transmitted, not reflected back and wasted as heat (i.e. Standing Wave Ratio SWR). This paper analyzed the S-parameter variation with the frequency and noted its value at the resonant frequency of 1.399GHz in which the value was very low and hence it indicates that there was purely matching at this frequency were most of the signal was transmitted and no reflection was observed.*

Keywords: Dipole antenna, Directivity, Impedance Matching, Matching network (L-C), Gain, S-parameter

1. Introduction

An antenna is an electrical component that is needed to transmit and receive electromagnetic energy from the space surrounding it in order to establish a wireless connection between two or more devices. The variety of devices using wireless communication is enormous, for example mobile phones, base stations, and wireless local area network connections (WLAN). Because of the wide variety of antenna-using devices, multiple types of antennas are needed and available [1].

Although the antenna may be an electrical half wavelength, or multiple of half wavelengths, it is not exactly the same length as the wavelength for a signal travelling in free space. There are a number of reasons for this and it means that an antenna will be slightly shorter than the length calculated for a wave travelling in free space. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band that the radio system to which it is connected operates in, otherwise reception and/or transmission will be impaired.

A dipole antenna is a wire or conducting element whose length is half the transmitting wavelength. The half wave dipole is perhaps the simplest and most fundamental antenna design possible. Hertz used a dipole antenna during his initial radio experimentation. This is why a dipole is often referred to as the "hertz dipole" antenna. If an antenna is resonant, it will be matched to the transmission line and/or transmitter and the bulk of the signal will actually be transmitted, not reflected back and wasted as heat (i.e. Standing Wave Ratio SWR). It should be noted that a dipole has an impedance of 75 ohms, not 50 ohms. Ordinarily a mismatch could cause a problem, but the mismatch of 50 ohm cable feeding a 75 ohm antenna is minimal with a resultant SWR of 1.5:1. This

corresponds to roughly a 5% waste of power [2]. In high frequency transmission lines, an antenna impedance mismatch causes power reflection back to the transmitter. This corresponds to a greater than unity voltage standing wave ratio (VSWR), the ratio of maximum to minimum transmission line voltage amplitude [3].

The radiation pattern of a dipole antenna in free space is strongest at right angles to the wire. This pattern, when the antenna is positioned horizontally over the ground, resembles a figure eight. This figure eight pattern will be verified during the experiment. Let's assume we shift the antenna around and make it vertical (perpendicular to the ground). The ends of the wire which emit the least amount of energy are now directed towards both the earth and the sky. This results in a vertically polarized signal which is focused quite evenly across the reception zone. This brings up an important concept, antenna radiation patterns can be quite different horizontally and vertically. This concept will be verified when the dipoles are tested. Also, it is important to note that for a signal to be received effectively, the receiving antenna must be in the same plane as the transmitting antenna. If these are mismatched, a large portion of the signal will be lost or distorted [2].

2. Impedance Matching

For efficient transfer of energy, the impedance of the radio, the antenna, and the transmission line connecting the radio to the antenna must be the same. Radios typically are designed for 50 ohms impedance and the coaxial cables (transmission lines) used with them also have a 50 ohm impedance. Efficient antenna configurations often have an impedance other than 50 ohms, some sort of impedance matching circuit is then required to transform the antenna impedance to 50 ohms [2].

International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 1 Issue 3, November 2013

Antenna Input Impedance Zin is defined as the impedance presented by the antenna at its terminals, or the ratio of the Voltage (V) to Current (I) at a pair of terminals, or the ratio of the appropriate components of the Electric-E to Magnetic-H fields at a point. Every antenna will present a certain amount of impedance to its source, impedance that may be a function of frequency. For minimum Power Loss, the transmitter output impedance should be matched to the antenna impedance. A large Impedance Mismatch at the antenna/transmission-line interface of a radio receiving system can cause a significant increase in the system internal Noise Factor. In the absence of a matching network, the limiting noise of the system is generated within the system (by the transmission line and receiver) and can be more than 20 dB larger than the external man-made noise or atmospheric noise. With a matching network, the limiting noise of the system is the external noise [4].
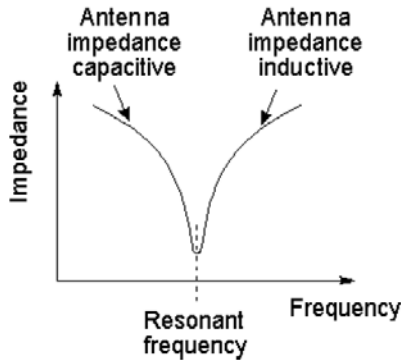

Figure 1: The diagram showing the variation between impedance and frequency (At resonant frequency there is an impedance matching)[4]

Voltage amplitude increases with reflection coefficient magnitude, $|\Gamma|$, between the antenna and transmission line and therefore increased voltage standing wave ratio (VSWR). Superposition of forward and reflected waves along the transmission line produces standing waves resulting in maximum and minimum voltage amplitude locations. VSWR is the ratio of the maximum to minimum transmission line voltage amplitude. ISWR is the corresponding ratio for current; its value is equivalent to VSWR. VSWR and ISWR are collectively referred to as SWR since they are equivalent [3].

For every antenna design scattering parameter is the most important parameter to analyze and compare the performance of the designed antenna. Scattering parameters provides the information for the resonating frequency, bandwidth, and impedance match, power transmitted and reflected and coupling effects between the ports. The return loss of antenna gives the information that how much of the incident power is reflected instead of being transmitted. A lower value of S11 means most of the input power is transmitted through the network that is antenna and the feed network is well matched [5]. The equations below presents the values of reflection coefficient, VSWR and other parameters:

$$S_{11} = \Gamma^2 \text{ (1)}$$

$|S_{11}|dB = 20\log|\Gamma|$ Scattering parameter in dB

The reflection coefficient is given by:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} e^{-j2\gamma l} \text{ (2)}$$

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \text{ (3)}$$

$$Z = R + j\omega L \text{ and } Y = G + j\omega C$$

Where:
Z= Impedance and Y= Admittance
L= Inductance and C= Capacitance and G= Conductance

Γ = **Reflection coefficient**

Propagation constant is proportional to the square root of Impedance and the Admittance

$$\gamma = \sqrt{Z * Y}$$

Or $\gamma = \sqrt{(R + j\omega L) * (G + j\omega C)}$ (4)

Also the Characteristic impedance can be given by the relation: $Z_0 = \sqrt{L \times C}$

The impedance matching occurs only when the line characteristics impedance becomes equal to the load impedance i.e $Z_L = Z_0$

For a dipole wire, the total current I_z is uniformly distributed around the surface of the wire, and it forms a linear current. The current is concentrated primarily over a small thickness of the conductor and is given by:

$$I_z = I_m Sin[k\left(\frac{l}{2} - |z'|\right)] \text{ (5)}$$

And the total input impedance which is the combination of both the antenna (radiating) and the transmission (non-radiating) is then given by:

$$Z_{in} = -\frac{1}{I_m} \int_{-l/2}^{l/2} Sin[k\left(\frac{l}{2} - |z'|\right)]E_z dz' \text{ (6)}$$

Where: l=distance from the radiating antenna to the L-C series circuit
E_z =Tangential component of the electric field in the direction of z-axis
Im= Maximum current and Zin is the input impedance of the load

The input impedance can be given in terms of the load impedance and the characteristic impedance as:

$$Z_{in}(l) = Z_0 \frac{Z_L + Z_0 \tanh(\gamma l)}{Z_0 + Z_L \tanh(\gamma l)} \text{ (7)}$$

Where l=distance from the radiating antenna to the non-radiating element placed for matching provision. For the case of matching $Z_L = Z_0$ so $Z_{in}(l) = Z_0$ the input impedance is the same as the characteristic impedance and is not the function of distance l.

If the input impedance of an antenna is not matched with the feeder impedance, then a part of the signal from the source will be reflected back; there is a reflection (mismatch) loss. This is characterized by the *matching efficiency* (also known as *reflection efficiency*)[6]
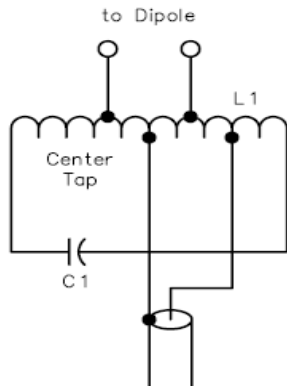
Figure 2: The diagram showing the L-C matching network[7]

It is worth pointing out that an antenna can be viewed as a two-port network, thus the field quantities (such as the radiation pattern) are related to the transmission coefficient (S21) while the circuit quantities (such as the input impedance and VSWR) are determined by the reflection coefficient (S11) of the network.[6]

3. Results and Discussion

A dipole is made to resonate at a frequency of 1.399GHz using the L-C series circuit matching as the non-radiating network. Below is the diagram of the dipole antenna obtained after defining necessary parameters
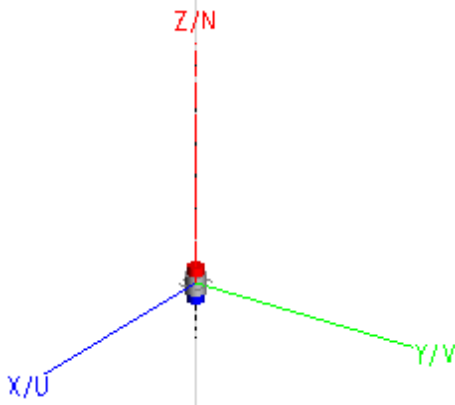
Figure 3: Diagram of the dipole antenna
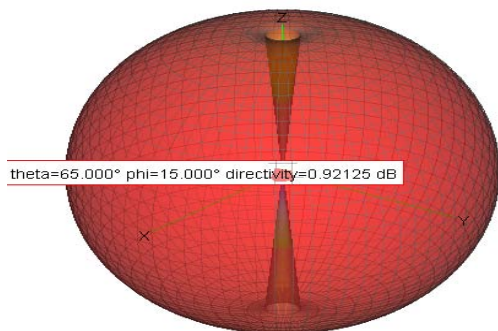
(a)
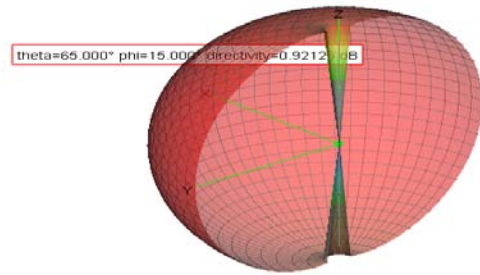
(b)

Figure 4: (a) A full 3D of the radiated directivity of the matched dipole (b) Cut plane directivity.
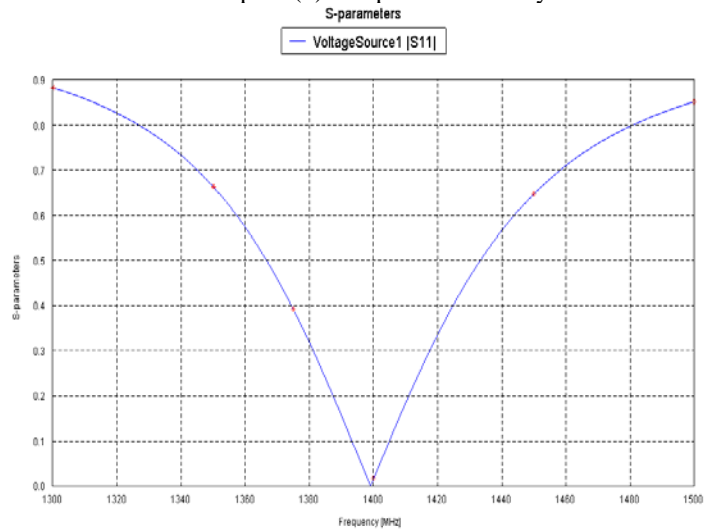

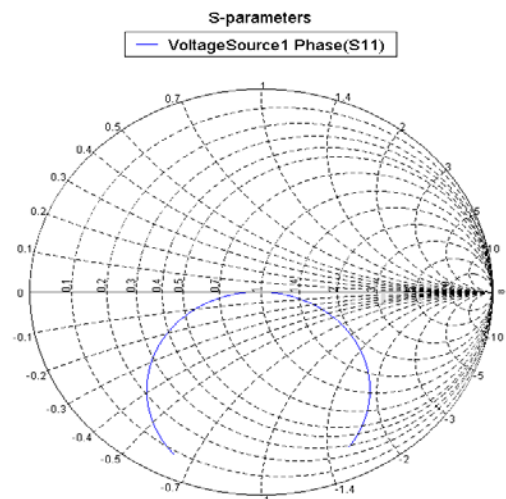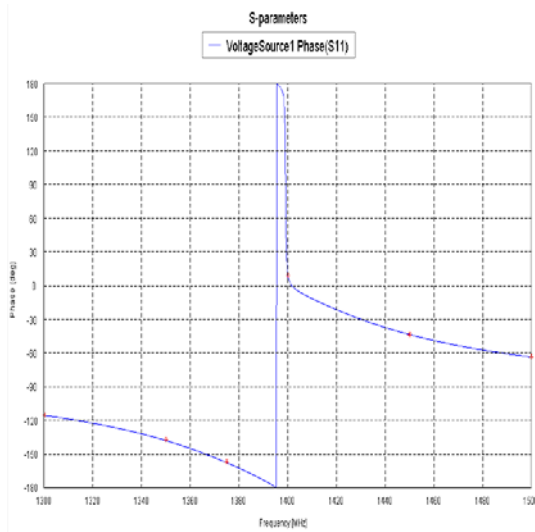**Figure 5:** The Cartesian graph showing the variation of S-parameter against frequency.
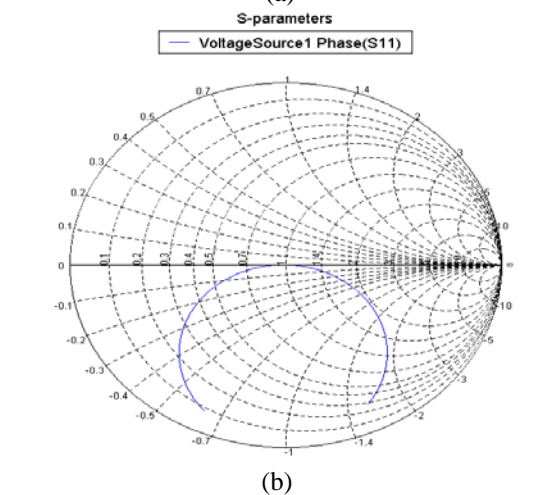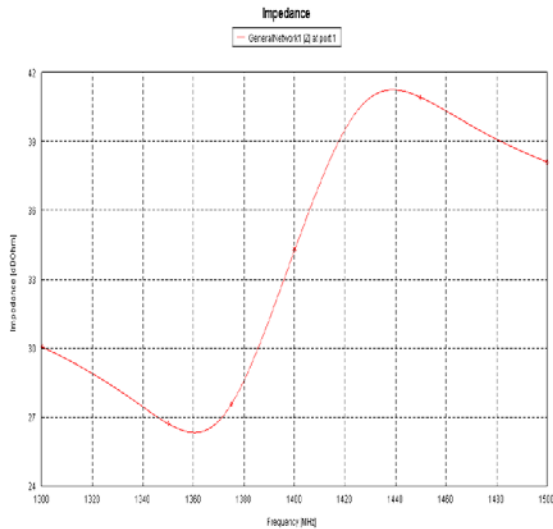

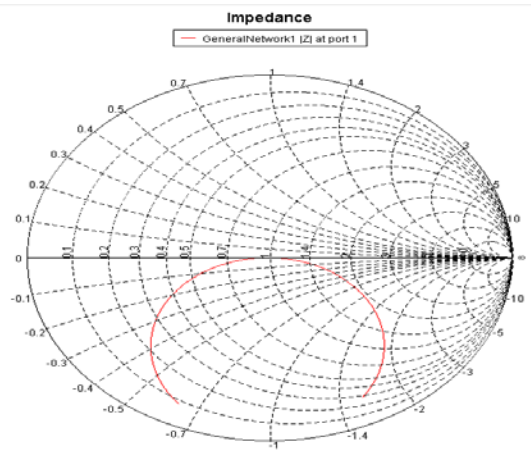**Figure 6:** Polar plot (Smith chart) for the S-parameter variation

(a)

(b)

Figure 7: (a) Cartesian plot showing the variation of Phase with the frequency (b) Polar plot showing the variation of phase.

(a)

(b)

Figure 8: (a) Cartesian plot showing the variation of impedance with frequency (b) Polar plot for impedance

4. Conclusion

The simulated Dipole antenna was designed to operate at frequency around 1.399Ghz and due to most transmission line which couples the signal to antenna operate at either (50 or 75) ohms this leads to some of power to reflect back to the source if the dipole antenna has the input impedance which is not matched with the transmission line. By using L-C network the impedance is achieved with little loss and easy to incorporate last minute design changes by only changing the values of some discrete components. Simulation results shows that the matching is achieved and S-parameter value is low around the frequency of operation (resonant frequency) also there is addition advantage by making use of a matching circuit to change the antenna impedance tuning the antenna to operate at a desired frequency range is much easier and faster than modifying the antenna geometry.

5. Acknowledgement

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