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Impedance and Power Loss Characteristics of LPDA 160MHz-1300MHz Range

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Abstract: Antennas are a fundamental component of modern communications systems. It forms the interface between the free space and the transmitter or receiver. The transmission line (cable) is terminated by antenna that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back to the transmission line. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a voltage standing wave pattern on the transmission line. The voltage standing wave ratio (VSWR) can also be represented by Return Loss, Mismatch Loss and Reflection Coefficient. This paper represents the details VSWR, impedance and power loss of Log Periodic Dipole Array (LPDA) of frequency range of 160MHz to 1900MHz with 24 elements. Using antenna trainer kit (Transmitter, Receiver) frequency range up to 1300MHz, LPDA impedance variation is about 50 ± 15 Ω and power loss in % is within 0 to 10 are reported. The VSWR values are within 1 to 2. The results indicate that the constructed LPDA is of good quality to use it for different high frequencies applications.

Keywords: Transmitter, Receiver, LPDA, Impedance matching, VSWR, Power loss.

I. INTRODUCTION

An antenna is a device that radiates and receives radio waves. There are different methods or mechanisms by which antennas radiate. In resonant antennas there is a movement of charges as the energy changes between the electric field and the magnetic field. This movement of the charges on the antenna causes the field lines to vibrate, generating waves that propagate in free space away from the resonant antenna. Another mechanism by which antennas radiate is by having an impedance transition that causes the energy being propagated in a transmission line to be launched into free space. The method for radiation is based on a wave impedance transition from the transmission waveguide or line to the impedance of free space. When a signal is fed into an antenna, the antenna will emit radiation distributed in space. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern [1].

Impedance (Z) is an important parameter used to characterize electronic circuits. It is generally defined as the total opposition a device or antenna offers to the flow of an alternating current (AC) at a given frequency, and is represented as a complex quantity. An impedance vector consists of a real part (resistance, R) and an imaginary part (reactance, X). When a transmission line (cable) is terminated by impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back down the transmission line. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a voltage standing wave pattern on the transmission line [2].

The impedance of an antenna determines the amount of energy it can receive or transmit. Maximum power transfer will occur when the antenna is matched to the transmission line and receiver or transmitter as in accordance with the maximum power transfer theorem. [3]

Most of all, an antenna is connected to the load by a feeder (usually a coaxial cable) which is unbalanced. In consequence, the cable radiates and this affects the efficiency of energy transfer to or from the antenna. The Voltage Standing Wave Ratio (VSWR) is an indication of how good the impedance match is. VSWR is often abbreviated as SWR. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna [4].

The ratio of the maximum to minimum voltage is known as VSWR, or Voltage Standing Wave Ratio. VSWR would be calculated by the following formula

$VSWR = E_{max}/E_{min} = (E_i + E_r)/(E_i - E_r)$

Where, E_{max} = maximum measured voltage

E_{min} = minimum measured voltage
E_i = incident wave amplitude, volts
E_r = reflected wave amplitude, volts

VSWR can also be represented other ways, such as Return Loss, Mismatch Loss and Reflection Coefficient. Reflection Coefficient is common, can be calculated several ways, and ultimately used to calculate VSWR. Here are some formulae for determining Reflection Coefficient (ρ) [5, 6].

$\rho = E_r/E_I$
Where, E_r = reflected voltage and
E_i = incident voltage
$P = |(Z_1 - Z_2)/(Z_1 + Z_2)|$

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Where Z_1 and Z_2 are the mismatched impedances
$\rho = \sqrt{P_{ref}/P_{fwd}}$
Where P_{ref} = reverse power and
P_{fwd} = forward power

Once the reflection coefficient has been calculated, it can be used to determine VSWR by the following formula:
$VSWR = (1 + \rho)/(1 - \rho)$

Another way to describe the affect of VSWR is Return Loss. Return Loss is measured in dB of the ratio of forward and reverse power. If the return loss is 10dB, then 1/10 of the forward power is reflected back. Return Loss can be calculated by the following formulae

$$\text{Ret. loss} = 10 \log[P_{fwd} / P_{rev}]$$
$$= - 20 \log[E_r / E_i]$$
$$= - 20 \log[(VSWR - 1) / (VSWR + 1)]$$
$$= - 20 \log \rho$$

way to reference reflected power is Mismatch Loss (or Transmission Loss). This is a dB ratio between the incident power and the power actually absorbed by the termination. Following are formulae for computing

$$\text{Mismatch loss} = - 10 \log (1-\rho^2)$$
$$= 10 \log (P_{fwd} / (P_{fwd} - P_{rev}))$$

A VSWR of 1:1 means that there is no power being reflected back to the source. This is an ideal situation that rarely, if ever, is seen. In the real world, a VSWR of 1.2:1 (or simply 1.2) is considered excellent in most cases. VSWR of 2.0 or higher is not uncommon. At a VSWR of 2.0, approximately 10% of the power is reflected back to the source. Not only does a high VSWR mean that power is being wasted, the reflected power can cause problems such as heating cables or causing amplifiers to fold-back [7,8].

For instance, if 100 watts forward power is delivered into a load and 15 watts is reflected, 85 watts is absorbed by the load. This gives a reflection coefficient of 0.387, a VSWR of 2.26, a return loss of 8.2dB and a mismatch loss of 0.7 dB. In other words, the power actually absorbed (or not reflected) by the termination is 0.7 dB less than the forward power delivered to the termination.

There are ways to improve the VSWR of a system. One way is to use impedance matching devices where a change in impedance occurs. Baluns are used extensively in antennas to not only convert from balanced to unbalanced signals but also to match the impedance of the source to the antenna. It is common practice is to include attenuators at any point where there is an impedance mismatch. By providing an apparently better termination to a signal, VSWR can be improved [9].

The Log Periodic Dipole Antenna (LPDA) was invented by Raymond and variants by Paul Mayes at the University of Illinois in 1958. It was first built by Du Hamel and Dwight E. Isbell, an undergraduate researcher in the ECE antenna laboratory in 1958. It is an important type of frequency independent antenna. The length and spacing of the elements of a log-periodic antenna increase logarithmically from one end to the other. In telecommunication, a log-periodic antenna is a broadband, multi-element, unidirectional, narrow-beam antenna that has impedance and radiation characteristics that are regularly repetitive as a logarithmic function of the excitation frequency [10, 11]. Log-periodic dipole array (LPDA) antennas offer a wider bandwidth and can have gains as high as 10 dB. The dipoles are connected to the source using a twin transmission line in such a way that the phase is reversed at each connection relative to the adjacent elements. The shortest dipole corresponds to the highest frequency band and the longest dipole to the lowest frequency band of an antenna. A number of the dipoles whose frequency bands are in the vicinity of the selected resonant frequency will be active. Each dipole is effective over a narrow band of frequencies determined by its length. When connected all the elements, the bandwidths of the dipoles add-up to give a broader bandwidth. The broadband properties of LPDA antenna make it a better choice for operation over a wider frequency range.

The transmission line is often replaced with a pair of metal boom structures separated by the dielectric material. The other advantage of this antenna is that its input impedance can be set to the desired value by selecting the appropriate diameter for the dipole elements. Aluminum tubes and rods where chosen for the LPDA as it does not rust. The diameter of these rods and tubes were chosen so as to incorporate the compactness as well as the ease of assembly for the antenna elements. The dipole elements are attached to the boom structures. The booms have to be isolated from each other by using dielectric spacers. The dipoles are mounted on two boom structures which in essence are transmission lines since the dipoles are un-insulated [12]. The length ratio between adjacent dipoles is a constant (τ) and the ratio of element spacing to twice the next larger element length is a constant (σ). The length ratio (τ) is chosen such that the antenna's performance will be uniform over the whole bandwidth [13].

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-ohm impedance and transmission lines used with them also have 50-ohm impedance. Efficient antenna configurations often have impedance other than 50 ohms; some sort of impedance matching circuit is then required to transform the antenna impedance to 50 ohms [14].

II. EXPERIMENTAL SETUP

The LPDA is designed for Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO). It is constructed for frequency range of 160MHz to 1900MHz with 24 elements is shown in Fig 1. Design uses two geometric parameters, a scale factor τ that specifies the relative lengths and a spacing factor σ that specifies the relative

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spacing of the antenna elements. A third parameter, α, is one-half the apex angle and is derived from τ and σ. The scale factor should be such that its value is less than one. The apex angle should not be too small or too large, since it affects the bandwidth of the antenna. As the frequency increases the spacing factor decreases.

Fig. 1. Photograph of installed LPDA

LPDA design calculated values for Fmin. 160MHz, Fmax. 1900MHz, scale factor τ=0.876, spacing factor σ= 0.161 and the half apex angle= α 10.84 using MATLAB program [15].

Coaxial cable is used for feeding the outdoor antennas. It is connected between LPDA and receiver. The cable used is RG58BU and has double shielding. The cable RG58BU is used to connect transmitter and LPDA antenna. The specification of the cable is shown in Table 1 [16].

Table 1: Technical details of RG58BU /CU

Sr. No	Parameters	Description
1	RGType	RG58BU/CU
2	Conductor Type	TC
3	Conductor Area	19/0.18
4	Insulation	Polythene
5	Diameter	2.95
6	Screen Braid	TC
7	Screen Diameter	3.50
8	Sheath Diameter	4.95
9	Weight Kg/100m	40
10	Capacitance (pF/m)	101.5
11	Impendence (ohm)	50
12	Attenuation dB/100 meters @ 400MHz	39.5
13	Velocity propagation	65.9

Coaxial cables are preferred as transmission line for the following reasons.

The characteristic impedance (Z_0) does not depend on the physical length but rather on the size and spacing of the conductors and the type of dielectric used between them. To obtain VSWR, Signet Pvt. Ltd. antenna trainer kit is used. The transmitter transmits the frequency from 30MHz to 1300MHz is shown in Fig 2.

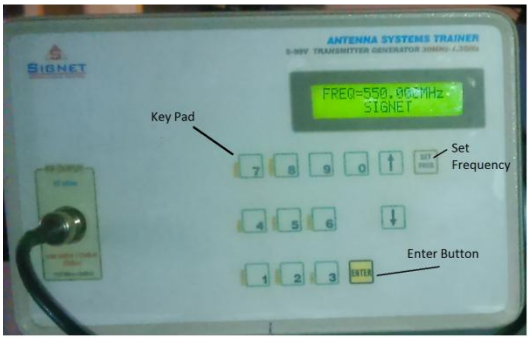

Fig. 2. S-99V Transmitter

The frequency can be set with built-in keypad and it was shown on 2x16 LCD display. It is also provided a DIN connector to connect transmitter S99V to receiver S-99R via 5pin DIN plug cable. Its transmitting signal level is 115 dBuV±5dB. The output impedance of terminal is 50Ω.

Fig. 3. S-99R Receiver

The receiver S-99R used to measure RF signal level is shown in Fig. 3. Its frequency range is from 50MHz to 1300MHz. Receiver has provided different connectors to connect such as stepper motor, printer and PC. It has also a DIN connector to connect S-99R to S99V via 5 pin DIN plug cable.

The steps to measure VSWR of LPDA is as follows.

a. Connect one end of DIN cable into the socket of DIN cable at back panel of receiver and other end of cable to the back panel of transmitter. Turn on receiver, transmitter and enable serial interface.
b. Connect output of transmitter to the one end of 5 dB attenuator and other end of attenuator to one end of the directional coupler. Connect another end of directional coupler to the constructed LPDA using cable.
c. Now for measuring incident wave (V_i), make arrangement as shown in Fig. 4.

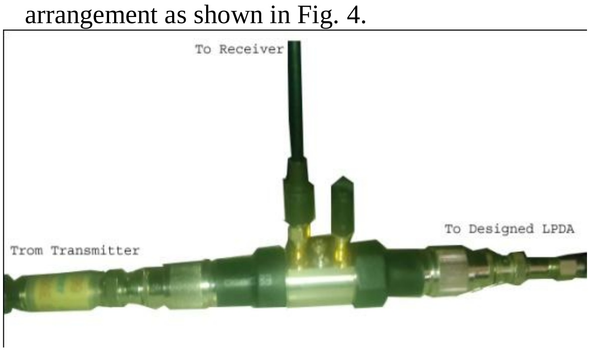

Fig.4. Connector setting to measure incident power

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d. Open SI3006 software of signet Pvt. Ltd. and connect to serial. Now click on “VSWR/Spectrum” in Menu bar. The screen shot is shown in Fig. 5.
e. Click on “set (50-1300)” and set start frequency, stop frequency and No of steps.
f. After setting frequency parameters click “OK”.

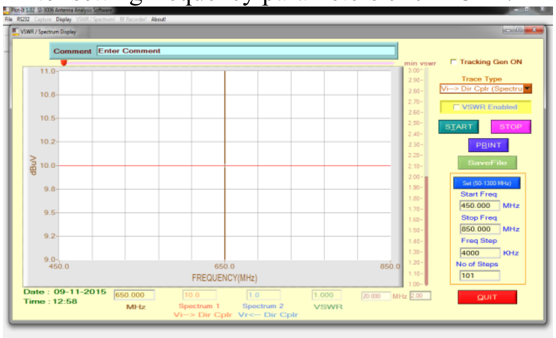

Fig.5. VSWR Spectrum window

g. Then check “Tracking gen ON” and click on “Start”. This will calculate incident wave voltage, V_i. Its plot is shown in Fig. 6.

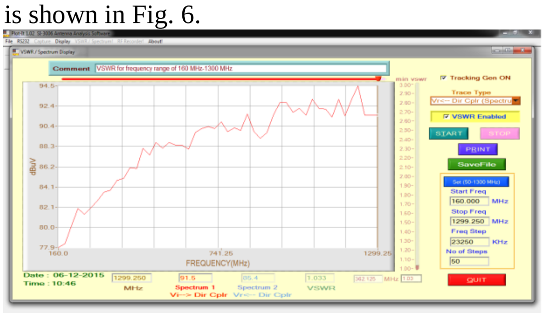

Fig.6. Plot of input power window

h. After finishing process make arrangement of the coupler as shown in Fig. 7 to obtain reflected power.
i. Check “Tracking gen ON” and select Vr←Dir coupler from dropdown box and click on “Start”.
j. To obtain VSWR plot for designed LPDA. Click on “Print” to print plot using printer connected to receiver.

Fig.7. Connector setting to measure reflected power

III. RESULTS

The LPDA calculated values for Fmin. 160MHz, Fmax. 1900MHz, scale factor τ=0.876, spacing factor σ= 0.161 and the half apex angle= α 10.84 using MATLAB program. The constructed LPDA has a boom length 8feet and width 6feet which cover the range from 160MHz to 1.9GHz using twenty four (24) alumina metal elements. The lengths of elements are as high as 3.96 meters and as low as 0.071 meters. The experimental set up of VSWR includes the transmitter, receiver, a special connector setting to measure incident, reflected power. In this, hardware as well as software setting (like range of frequency, incident or reflected etc.) is required. Using the procedure, the graphical representation of input, reflected signal and the VSWR is shown in Fig. 8. From the plot, placing the mouse pointer at particular frequency, the exact value of input, reflected and VSWR are displayed at the bottom in small rectangular boxes.

Fig.8. Plot of Incident, Reflected and VSWR

In a plot, red (Spectrum 1), blue (Spectrum 2) and green color plots are of incident, reflected and the VSWR respectively. Table 2 shows the numerical values of input, reflected (in dBμV) and VSWR at different frequencies in the range of 160MHz to 1300MHz.

The VSWR values are within 1 to 2. At low frequencies around 160MHz to 500MHz, VSWR values are very close to 1.1. At high frequencies, it was increased but below 2. This indicates that the designed and constructed LPDA is of good quality as well as maximum power is transmitted in space.

Table 2: Impedance, Power loss variations with frequencies

Sr. No	Freq	V_i (mV)	V_r (mV)	MisLoss dB	Z_L Ω	VSWR	P. Loss %
1	160	8.32	0.43	0.02	67.63	1.11	3.87
2	206.5	9.78	1.29	0.08	57.51	1.3	5.67
3	253	11.62	0.84	0.03	64.89	1.16	4.38
4	299.5	12.59	0.97	0.03	64.27	1.17	4.49
5	346	14.97	0.83	0.02	67.12	1.12	3.98
6	392.5	17.79	0.66	0.01	69.64	1.08	3.50
7	439	19.96	1.37	0.03	65.36	1.15	4.30
8	485.5	22.91	1.39	0.02	66.42	1.13	4.11
9	555.3	27.55	6.61	0.26	45.97	1.63	8.07
10	601.8	28.85	6.17	0.21	48.57	1.54	7.47
11	648.3	32.36	8.32	0.3	44.32	1.69	8.48
12	694.8	37.16	9.13	0.28	45.42	1.65	8.20
13	741.3	34.68	9.55	0.35	42.62	1.76	8.93
14	787.8	38.91	12.3	0.46	38.95	1.93	10.0
15	857.5	32.74	9.02	0.35	42.6	1.76	8.93
16	904	33.5	9.02	0.33	43.18	1.74	8.78
17	950.5	47.32	14.5	0.43	39.89	1.88	9.71
18	997	38.91	13.7	0.58	36.04	2.08	10.99
19	1043.5	38.02	12.9	0.54	37.02	2.03	10.65
20	1090	44.16	14.9	0.54	37.03	2.03	10.64
21	1159.8	45.19	15.3	0.54	37.02	2.03	10.65
22	1206.3	53.71	14.8	0.35	42.6	1.76	8.93
23	1252.8	38.46	10.4	0.33	43.17	1.74	8.781
24	1299.3	42.66	10.4	0.27	45.69	1.64	8.14

Antenna impedance is a measure of the resistance to an electrical signal in an antenna. Many factors have an impact on an ability of antenna to transmit a signal. Fig. 9 shows variation in impedance of antenna with respect to frequency.

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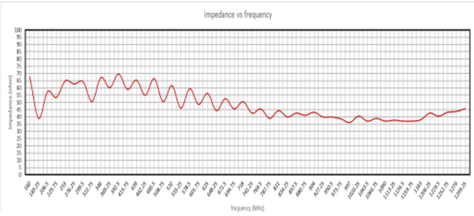

Fig.9: Impedance variation with change in frequency

The plot shows that the antenna impedance variations with respect to frequencies. The impedance variation is about 50 ± 15 Ω. At low frequency starting from 160MHz, the impedance is high. At high frequencies (from 750MHz, the impedance is below 50 Ω. The mismatch loss between antenna and transmission line is expressed in dB. The graph of mismatch loss versus VSWR is shown in Fig. 10. When the VSWR values are close to 1.1, the mismatch is of 0dB. But when the VSWR values are above 1.75, the mismatch loss is around 0.5dB.

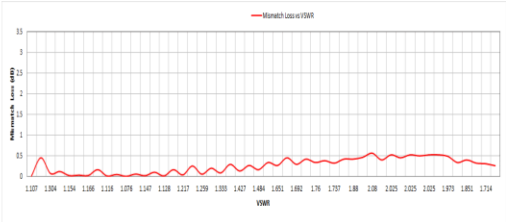

Fig. 10: Mismatch loss between antenna and cable

It is a loss of power due to mismatch between antenna and transmission line expressed in %. Fig. 11 shows loss of power in % for different impedance values. In total variation of impedance, the power loss in % is within 0 to 10.

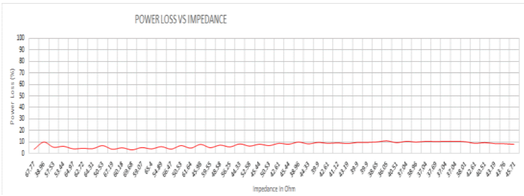

Fig. 11: Plot of power Loss (%) versus impedance

IV. CONCLUSION

The linearly polarized LPDA is the most practical transmitting antennas provide general broadband transmission and reception in wide range frequency. Although it consists of a system of driven element, but not all elements in the system are active on a single frequency of operation. Due to different lengths and different relative spacing, it allows changes in frequency to be made without greatly affecting the electrical operation. The MATLAB general program was developed to calculate the antenna parameter and structural dimensions. The MATLAB based program provides calculation in the fraction of points which helps to design more accurate structure of LPDA antenna. The VSWR values are within 1 to 2. The impedance variation is about 50 ± 15 Ω. When the VSWR values are close to 1.1, the mismatch is of 0dB and when the VSWR values are above 1.75, the mismatch loss is around 0.5dB. In total variation of impedance, the power loss in % is within 0 to 10. This indicates that the designed and constructed LPDA is of good quality. The analysis of log periodic dipole arrays shows that the characteristic impedance of the elements varies with frequency.

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BIOGRAPHY

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