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Log Periodic Dipole Array Antenna for Tv White Space Application

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Abstract: In this project, a Log Periodic Dipole Array (LPDA) antenna is designed to operate within the TV White Space (TVWS) spectrum ranging between 400 MHz to 800 MHz in the UHF band. The aim in designing the LPDA is to achieve Voltage Standing Wave Ratio (VSWR) < 1.5, Gain > 10 dBi, and Front-to-Back (F/B) Ratio > 20 dB. Each component of the proposed LPDA's structure is calculated using classic Carrel mathematical calculation for LPDA designing, which are then simulated using CST Studio Suite software. The simulation result shows the LPDA achieved S_{11} value of <-10 dB along 400 MHz to 800 MHz frequency range, VSWR value below 1.9, gain between 10 to 11 dBi, and Front to Back (F/B) ratio >13.5 dB.

Keywords: LPDA, TVWS, CST Studio Suite

1. Introduction

An alternative to improve the quality of signal reception of the standard 2.4 GHz and 5 GHz Wi-Fi device is by using TV White Space (TVWS). The phrase TVWS refers to the unoccupied wireless spectrum in the terrestrial broadcast television frequency bands. When TV is not aired in a local region and the spectrum resources allotted to television stations (primary users) are not utilised, white space is created. The low-frequency spectrum has the physical potential to cover great distances and at reduced rates of energy consumption. Repurposing TVWS and dynamic spectrum allocation might be a reliable solution for wireless broadband applications and internet access supply.

As described in the MCMC spectrum plan 2017, Malaysian footnote MLA86 stated that analogue TV broadcasting stations shall cease operation after the Analog Switch-Off (ASO) in late 2019. The

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mentioned application operates in VHF TV Broadcasting Band III, which is from 174 MHz to 230 MHz, and UHF TV Broadcasting Band IV and V which are from 470 MHz to 790 MHz [1].

However, since TVWS is relatively new in Malaysia, there are a lot of aspects to be studied. One of the many aspects is the transmission antenna that works within the spectrum. Several vendors are offering LPDA antenna for TVWS broadband applications for the client site [2] [3]. In this project, the characteristics of LPDA antenna for TVWS application will be studied through simulation. This research aims to simulate an LPDA antenna operating in the TVWS spectrum between 400 MHz to 800 MHz frequency using CST software. To calculate the LPDA structure and parameter dimension, classic Carrel mathematical equation for LPDA design [4] was used.

2. Materials and Methods

This section discusses the goals of design, methods and calculation used in the antenna simulation process. The methodology is conducted to design LPDA antenna that operates between 400 MHz – 800 MHz frequency for TVWS application purposes.

2.1 Software

This project was solely simulation based only. CST Studio Suite software is used in this project.

2.2 Methods

Figure 1 shows the process for the whole project.

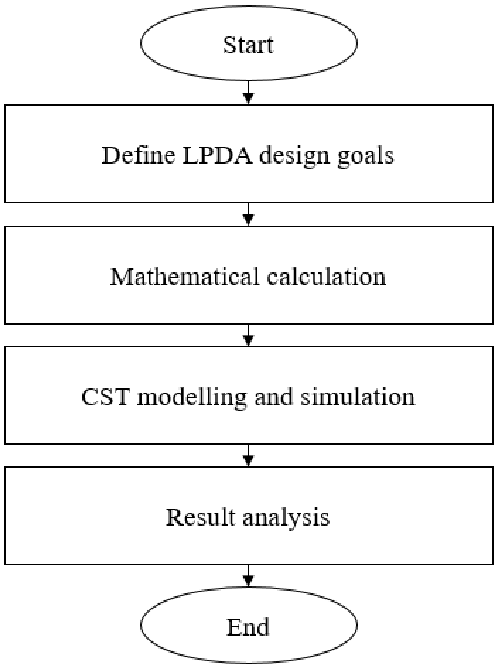


Figure 1: Project flow

First, a set of objectives was defined for the LPDA antenna design. The goal is to achieve VSWR value < 1.5, gain > 10 dBi, F/B ratio > 20 dB. Several fixed parameters were determined such as the lower cut-off frequency (f_1) = 400 MHz, the higher cut-off frequency (f_2) = 800 MHz, the scale factor (τ) = 0.917, and the relative spacing (σ) = 0.172. The value of τ and σ for Gain = 9 dBi is derived from the graph of relative spacing against scale factor in Figure 2 that shows a linear connection between τ and σ [4].

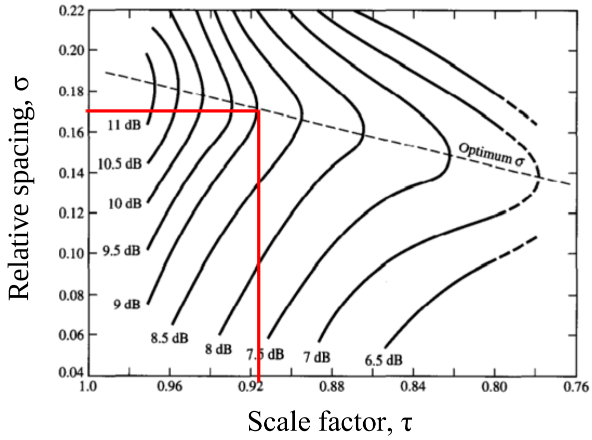


Figure 2: Graph of relative spacing against scale factor [4]

2.3 Calculation

The LPDA components parameter are calculated using Carrel formula for LPDA designing.

$$\text{Apex half angle}, \alpha = \tan^{-1}\left(\frac{1-\tau}{4\sigma}\right) \qquad Eq.1$$

$$\text{Relative bandwidth}, B = \frac{f_2}{f_1} \qquad Eq.2$$

$$\text{Active region bandwidth}, B_{ar} = 1.1 + 7.7(1-\tau)^2 \frac{4\sigma}{(1-\tau)} \qquad Eq.3$$

$$\text{Structure bandwidth}, B_s = B \times B_{ar} \qquad Eq.4$$

$$\text{Number of dipole elements}, N = 1 + \left(\frac{\log B_s}{\log 1 - \log \tau}\right) \qquad Eq.5$$

$$\text{Longest dipole length}, L_1 = \frac{C}{2f} \qquad Eq.6$$

$$\text{Subsequent dipole length}, L_{i+1} = \tau L_i \qquad Eq.7$$

$$\text{Longest dipole spacing}, R_{i+1} = \tau R_i \qquad Eq.8$$

$$\text{Subsequent dipole spacing}, \sigma = \frac{R_i - R_{i-1}}{2L_i} \qquad Eq.9$$

$$\text{Stub length}, L_s = \frac{\lambda_1}{8} \qquad Eq.10$$

Using Eq. (7) and (8), the length and spacing of each dipole are calculated. The length to diameter ratio, *K*, is measured and fixed for all the elements of the antenna. The consideration of *K* is just a compromise between mechanical strength, available tubing sizes, and the diameter of the boom.

$$\text{Length to diameter ratio}, K = \frac{L_i}{D_i} \qquad Eq.11$$

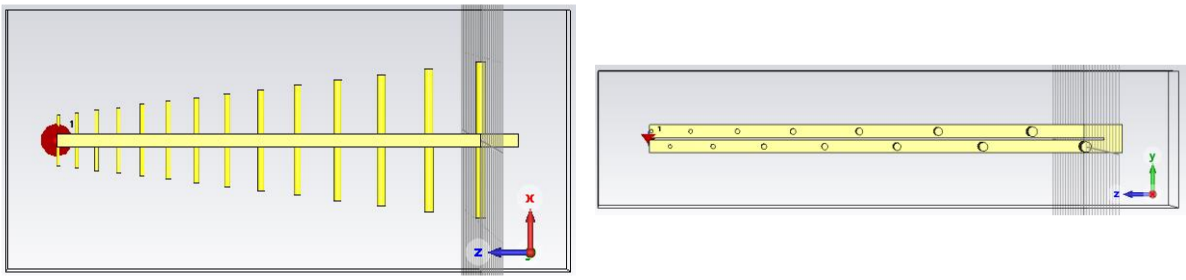
Considering the longest element diameter as 25 mm, (*K*= 14.9896), the diameter for each element is calculated and summarized in Table 1.

Table 1: Length, spacing, and diameter of each half element

Element (i)	L_i (mm)	$R_i - R_{i+1}$ (mm)	D_i (mm)
1	374.7400	-	25.0000
2	343.6366	128.9106	22.9250
3	315.1147	118.2109	21.0222
4	288.9602	108.3994	19.2773
5	264.9765	99.4023	17.6773
6	242.9835	91.1519	16.2101
7	222.8158	83.5863	14.8640
8	204.3221	76.6486	13.6309
9	187.3634	70.2868	12.4995
10	171.8122	64.4530	11.4621
11	157.5518	59.1034	10.5107
12	144.4750	54.1978	9.6383
13	132.4836	49.6994	8.8383
14	121.4874	45.5744	8.1047

2.4 LPDA Modelling

Using CST Studio Suite software, the antenna model is designed according to the results of the mathematical calculations. The LPDA computer aided design (CAD) is displayed in Figure 3.



(a) (b)

Figure 3: LPDA CAD model using CST (a) Side view, (b) Top view

2.5 CST simulation

The simulation was performed through Time Domain Solver with -30 dB accuracy. A discrete port of 50 Ω is used to give excitation to the antenna is connected at the centre points on the front end of both the booms. Using CST, important parameters of the LPDA such as S_{11}, VSWR, F/B ratio, and antenna gain value is determined.

3. Results and Discussion

This section discusses the results and outcomes gained from the CST software simulation.

3.1 Results

The result of the simulations is shown in Figure 4, Figure 5, Figure 6, and Figure 7.

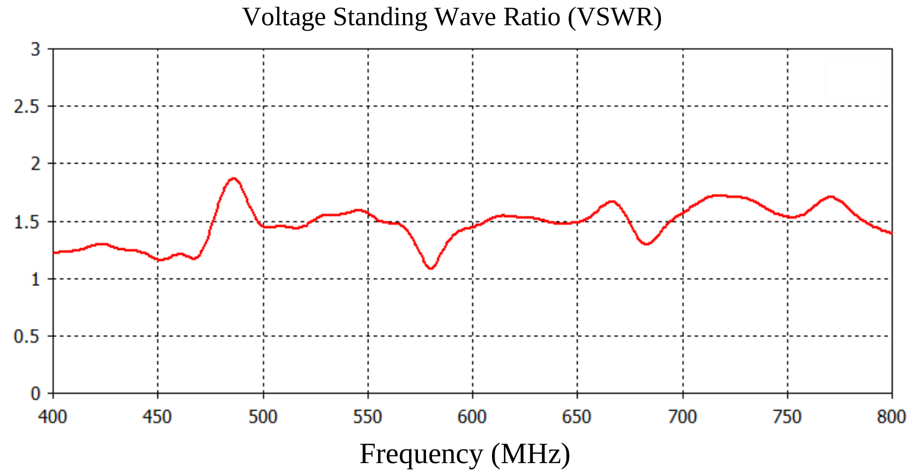


Figure 4: VSWR

Figure 4 shows the VSWR value is between 1.1 to 1.9 across the simulated frequency range. By taking VSWR reading at every 1 MHz interval from 400 MHz to 800 MHz range divided by the number of samples, the average VSWR value is 1.47. The VSWR results has achieved the desired design goal.

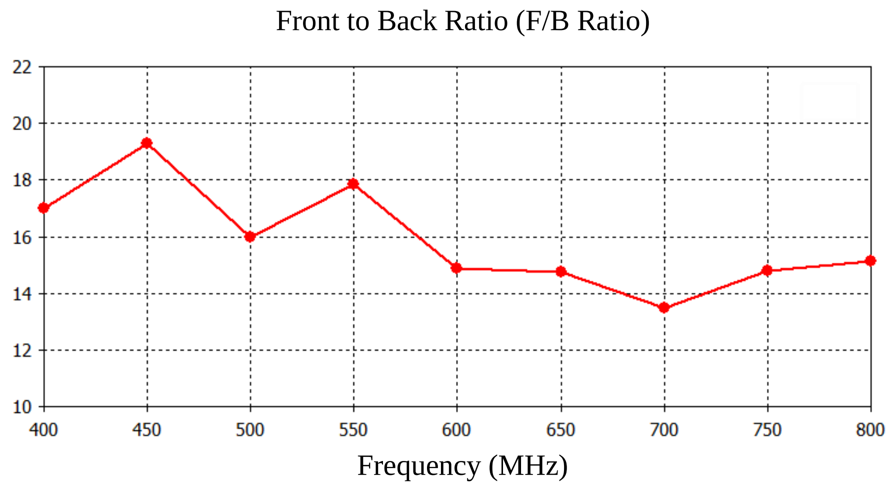


Figure 5: Front-to-Back ratio

As seen in Figure 5, the F/B ratio shows value of 13.5 dB at the lowest while the highest at 19.3 dB, which is lower than the targeted F/B ratio value of 20 dB.

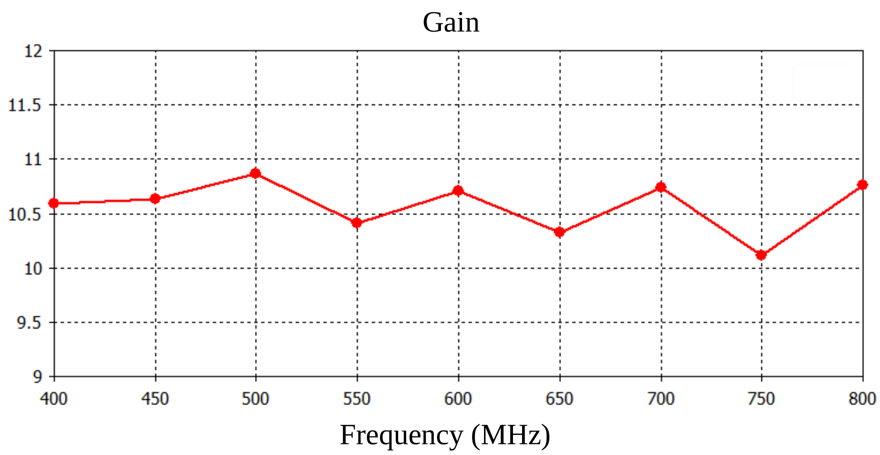


Figure 6: Gain

The graph in Figure 6 shows that the proposed design provides a gain value between 10 to 11 dBi in the measured frequency. From the result, the gain value has already exceeded the predetermined goal.

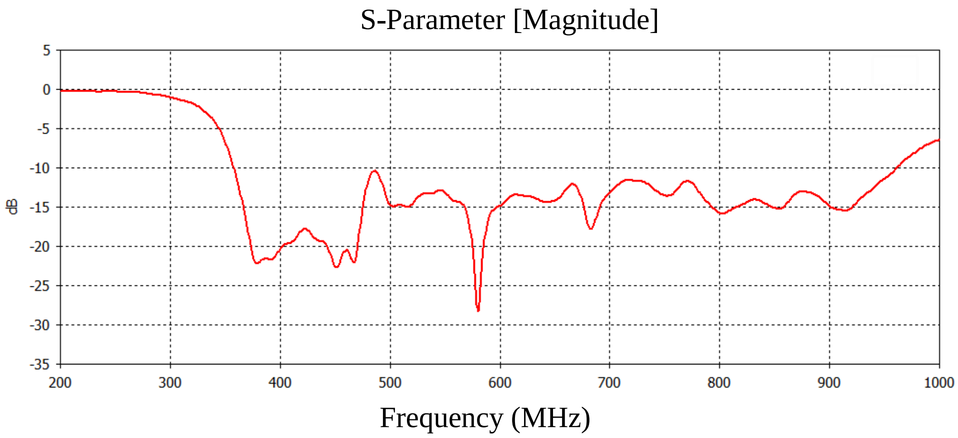


Figure 7: S_{11}

Figure 7 shows the S_{11} results of the design. The simulated LPDA achieves less than -10 dB along the UHF Band IV and Band V frequency (400 MHz – 800 MHz). In this case, the antenna is reflecting minimum power and maximum power is allowed to propagate in the forward direction. However, the result shows that S_{11} value above 800 MHz is under -10 dB. This means that the antenna is still operational above the desired range which might interfere with other applications.

3.2 Results summary

Table 3 shows the summary of the proposed LPDA antenna simulation results.

Table 3: Summary of the proposed LPDA design

Parameters	Proposed	Unit or Dimension
Active element	28	-
Maximum height	37.5	cm
Maximum length	105	cm
Frequency range	400 – 800	MHz
Impedance	50	Ω
VSWR	≤ 1.5	-
Gain	> 10	dBi
F/B ratio	< 20	dB

The electrical specification of the simulated LPDA shows an industrially acceptable VSWR value which are ≤ 1.5. Similarly, the gain value for the initial LPDA design achieve the design goal with value of > 10 dBi. The F/B ratio for the optimized LPDA is slightly lower than the targeted goal value of 20 dB.

3.3 Discussions

The result of the initial design of the LPDA has achieve the targeted VSWR and Gain goal value. The F/B value however is slightly lower than the desired value. A low F/B ratio might result in lower efficiency in terms of power delivery of the antenna. Therefore, antenna optimization is needed to further tune the antenna parameters to achieve the desired F/B value. Based on the results, the designed LPDA should be able to operate within UHF Band IV and Band V for TVWS broadband application purposes.

4. Conclusion

An LPDA antenna operating in 400 MHz – 800 MHz frequency band has been presented. The LPDA parameter was calculated using Carrel mathematical equation. From the calculation, the length of booms, stub, and elements were calculated. The number of elements as well as the diameter and spacing of each element was also calculated. From the calculated value, 3D CAD of the LPDA antenna was modelled using CST software. The simulated LPDA demonstrate a VSWR value of ≤ 1.5, Gain of > 10 dBi, which achieve the predetermined goals. The F/B ratio results is slightly lower than the targeted goal value of < 20 dB. Finally, the S_{11} value shows -10 dB across the simulated frequency range but the antenna still operational above the TVWS spectrum. Therefore, a frequency rejecting filter is required in future studies.

Acknowledgement

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