Optimization of log-periodic dipole antenna with LTE band-rejection

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Abstract

This study presents an optimized design of a 10-dipole log-periodic antenna for UHF TV reception with LTE band rejection. The simulation of the antenna was performed in CST simulation software followed by optimization of the design using TRF (Trusted Region Framework) algorithm in the frequency range of 450 MHz-900 MHz. The parameters optimized are S_{11}, realized gain and front-to-back ratio of the antenna. TV reception passband is 450 MHz-790 MHz and LTE band is 810 MHz-900 MHz. The proposed antenna design provides a good matching with a low S_{11} in the passband (470 MHz-790 MHz) and a high S_{11} in the stopband (i.e. LTE region of 810 MHz-900 MHz). The antenna provides a realized gain between 7 dBi and 8 dBi whereas front-to-back ratio above 14 dB in the passband.

1 Introduction

There have been significant developments in mobile communication technology enabling efficient usage of frequency spectrum. Since September 2008, several attempts were made by the European Parliament [1] to motivate the Member States to investigate the possibilities of providing the digital dividend spectrum of UHF band to additional services so that effective utilisation of the frequency spectrum could be achieved. It was in 2009, that the European Communications provided confidence to the European Parliament through their studies showcasing cost/benefit ratio that could be achieved by allocating the digital dividend band (790 MHz-862 MHz) to mobile wireless broadband services [2].

The mobile technological advances have introduced the deployment of Long-Term Evolution (LTE), also known as fourth generation mobile broadband network, to the UHF TV broadcasting band of 800 MHz. With excellent building penetration property provided at this frequency range, the band was reserved for LTE and future mobile services in Europe (ITU region 1) as mentioned in decision 2010/267/EU [3]. 800 MHz LTE band provides two blocks of 30 MHZ for FDD uplink and downlink transmission. The downlink communication is allocated a band of 791 MHz-821 MHz with 30 MHz spectrum separated as 6 blocks of 5 MHz. Whereas, for uplink communication, a band of 832 MHz-862 MHz has been allocated along with 11 MHz duplex gap provided between the downlink band and the latter. Since, the guard band between Digital TV broadcasting services and LTE is just 1 MHz, there is a high possibility of the TV receiver receiving interference signals form LTE band, thereby effecting the quality of service offered by broadcasting services [4].

With rapid evolution in mobile technologies leading to congestion and limited bandwidth availability, a TV reception log-periodic dipole antenna design is proposed which is capable of rejecting the 800 MHz LTE band. This design provides a cost-effective solution compared to costly filters to be used to prevent the interference of LTE band into TV broadcasting frequency spectrum. LPDAs are directional antennas having significant applications in TV industries, capable of operating at wide frequency range providing relatively lower gain but better front-to-back ratio compared to the Yagi-Uda passive array antenna [5-6]. The basic design procedure of LPDA has been proposed by Carrel [7] with the assumption of LPDA containing cylindrical wire dipoles embedded in a specified angular sector 2α as shown in Figure 1 [7-8]. Generally, an LPDA consists of a couple of cuboidal tubular longitudinal support, also known as "boom", that may or may not be parallel to one another (The boom may also converge towards the front end of the antenna). The boom consists of rod-shaped elements, also known as half-dipoles, arranged in a cross-wise fashion attached to boom with appropriate spacing so that a change in phase is observed in the feeding source of two consecutive dipoles [9-10]. If the first half-dipole is constrained to the upper boom, then the other half-dipole will be constrained to the lower boom but facing in opposite direction with the same distance from the front or rear end of the cradle, such that the combination of these two half-dipoles is treated as a dipole of the antenna[9]. The gain of LPDA significantly depends on the number of dipole elements used in the design. Gain increases by increasing the number of dipoles [11]. The coaxial cables at front end of both the booms provide feeding source for the antenna. On the other hand, the rear end of the booms usually consists of a fastener, which acts as a short-circuit stub that can be used to attach the antenna to a support [9]. Unlike, Yagi-Uda antenna, all the dipole elements of LPDA are connected to the feeding source of the antenna [12]. The layout of dipoles of LPDA is in such a fashion that single dipole of the antenna resonates at a particular frequency. Subsequently, different signals transmitted by different dipoles to both the cradles are treated as a combined signal, thereby fixing the operating band of antenna [8-12].

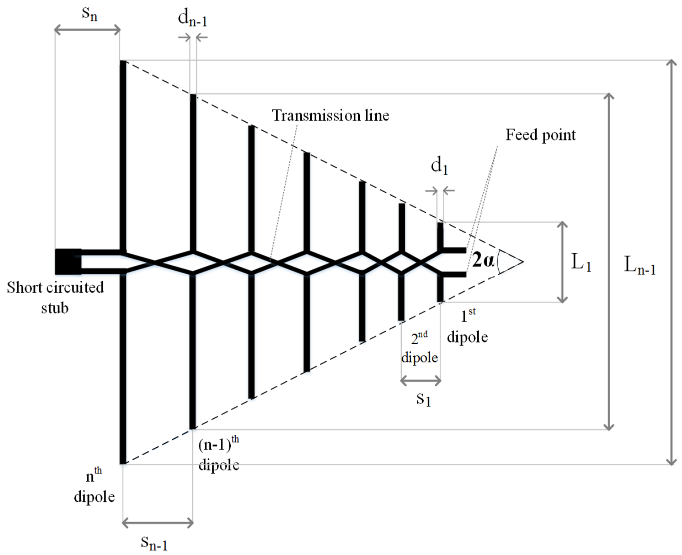

Figure 1. Basic geometry of LPDA.

In general, the half-angular sector or the apex angle to which all the dipole elements of LPDA are confined, is mathematically defined as:

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \tag{1}$$

The spatial arrangement of dipole elements is defined by spacing factor, mathematically represented as:

$$\sigma = \frac{s_n}{2L_n} \tag{2}$$

where, s_n is the spacing between the n^{th} dipole and its consecutive $(n+1)^{th}$ dipole and L_n is the length of nth dipole.

The scaling factor τ is the ratio of the lengths or diameters of two consecutive dipoles, mathematically written as:

$$\tau = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} \tag{3}$$

where, L_n and d_n are respectively the length and the diameter of the nth dipole.

The scaling factor and spacing factor plays a very important role in determining the physical properties of LPDA [13-18]. However, designing a TV reception LPDA capable of operating at wide range of frequencies and still be able to maintain a good match and gain in the passband and a high rejection in the stopband is a complex problem to investigate.

2 LTE reject 10-dipole LPDA CST optimized geometry

The length of the antenna plays a significant role in the performance characteristics of the antenna [15]. The overall physical dimensions of design of the antenna was 425 mm x 318 mm x 41.5 mm (length x breadth x height). The upper cradle and lower cradle extends longitudinally up to 356 mm and 412 mm respectively. A cuboidal fastening means of dimension 114 mm x 15.4 mm x 41.5 mm was attached to both the cradles in order to provide a support to attach it to some other means like poles. The dipoles at the front end of the antenna are responsible for antenna performance at higher frequencies whereas the dipoles at the rear end of the boom for the lower frequencies. The antenna is designed in such a way that the length of 1st and 3rd dipole element is greater than 2nd dipole element. Also, the length of 4th dipole element is lesser than 3rd dipole element and thereafter, it increases until the last dipole element. Figure 2 shows the picture of CST optimized model of the proposed antenna with detailed information of its dimensions listed in Table 1.

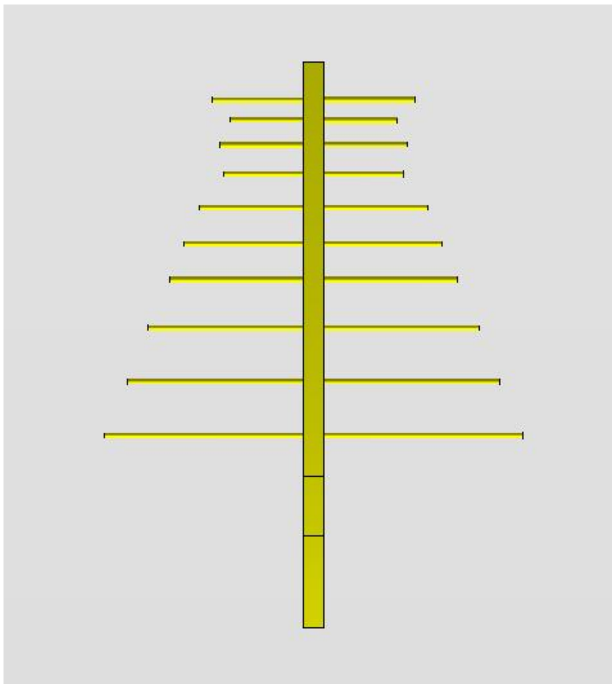

Figure 2. CST optimized model of 10-dipole log periodic antenna with LTE band rejection.

Parameters	*Values (in mm)*	*Parameters*	*Values (in mm)*
Breadth of boom	15.4	rad	2.1
Height of boom	14.9	L1	138.0
Length of upper boom	356.0	L2	111.8
Length of lower boom	412.0	L3	126.2

L4	121.4	s2	18.6
L5	157.2	s3	22.0
L6	180.2	s4	25.3
L7	203.6	s5	27.3
L8	235.4	s6	27.0
L9	267.0	s7	36.3
L10	302.6	s8	40.4
s0	28.0	s9	40.6
s1	15.3	Gap	11.7

Table 1: Dimensions of the optimized antenna design

where,

Gap = gap between upper and lower booms.
L_n = length of nth dipole.
rad = radius of dipoles.
sn = spacing between (n-1)th and nth dipole element

3 LPDA simulation and optimization

This study presents the design and optimisation of LTE reject 10-dipole LPA in the frequency band of 450 MHz-900 MHz. The simulation was performed in time domain with accuracy of -30 dB in CST simulation software. Hexahedral meshing was used along with 411,264 mesh cells and farfield monitors with the resolution of 10 MHz in the operating frequency range. The simulation involved open boundary settings for the model with estimated reflection level of 0.0001 along with the minimum distance to the structure set as one-fourth fraction of wavelength starting from 450 MHz. The discrete excitation port was connected at the front side of the antenna providing an impedance of 50 ohms.

Furthermore, the optimisation of the antenna design was performed using TRF algorithm (Trust region framework) in order to improve S_{11}, realized gain and front-to-back ratio. The optimization goals were set in such a way that the significant aim was to improve S_{11} in the operating frequency range as well as providing an increase of S_{11} in LTE frequency range. Furthermore, the realized gain was given more importance as compared to front-to-back ratio with improvement of both the parameters in the passband (470 MHz to 790 MHz) and providing a drop in the stopband (810 MHz to 900 MHz).

Table 1 shows the weights added to the parameters for the specific goal to be obtained within a required frequency range. The task of TRF algorithm is to find a best fitness function value such that all the goals mentioned below are satisfied. The algorithm settings were setup in such a way that only ±5% of the initial value of the dimensions of antenna were permitted to change. The width of the boom, length of the boom, height of the boom, the half-dipole lengths, gap between the boom, radius of the dipoles, spacing between the dipole and the length of the connector were the parameters that were adjusted during the optimization of the antenna.

Parameter	*Goal value*	*Frequency range (MHz)*	*Weight*
S11 (S-parameter in dB)	< 14	470-790	10.0
Realised gain (dBi)	> 9	470-790	1.0
Front-to-back ratio (dB)	> 12	470-790	0.2
S11 (S-parameter in dB)	> -2	810-900	5.0
Realised gain (dBi)	< -10	810-900	1.0

Table 2: Goals and weights for LTE reject LPDA optimization

The algorithm started the optimisation with the fitness function value of 125 which was further reduced to 79 at the end of the optimisation.

Figure 3 shows the optimized S-parameter (S_{11} in dB) of the antenna in the frequency range of 450 MHz to 900 MHz. The optimized s-parameter of the model has the first notch at -27.78 dB at 469.97 MHz whereas at attains the least value of -29 dB at 611.11 MHz. observed at 487.14 MHz. The S-parameter curve of the proposed antenna design suggests very good match of the antenna providing lower S_{11} values in the passband and higher S_{11} values in the stopband.

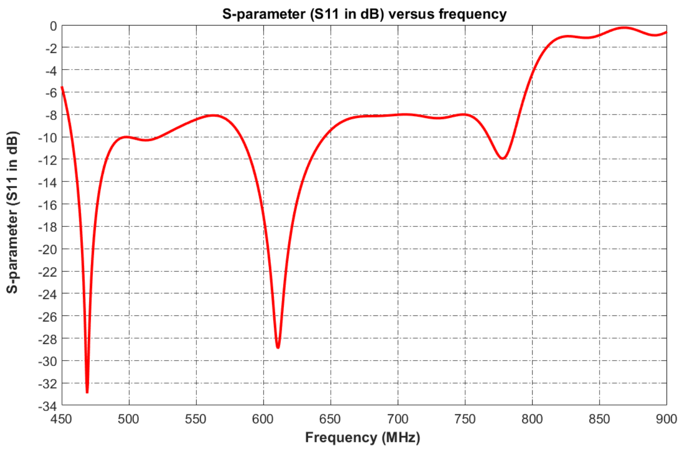

Figure 3. S-parameter of the proposed antenna design.

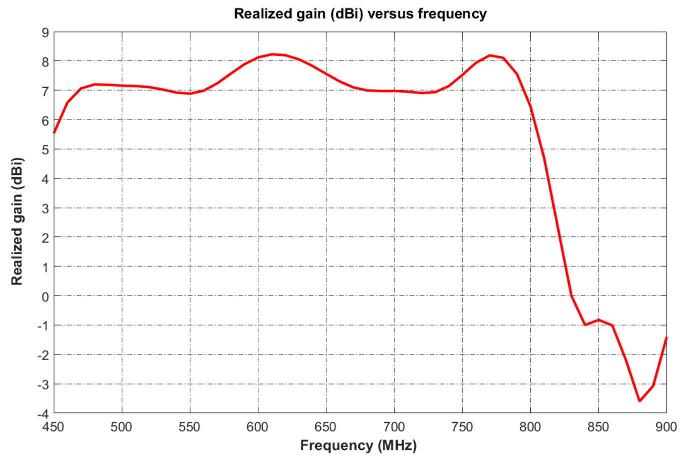

Figure 4. Optimized realized gain of the proposed antenna design.

Figure 4 shows the optimized realized gain of the antenna in the frequency range of 450 MHz-900 MHz. The antenna offers a flat realized gain between 7 dBi and 8 dBi in the passband with decreasing characteristics in the stopband. The curve attains its peak value of 8.24 dBi at 610 MHz and the least value of -4.68 at 890 MHz. The curve suggests that the proposed design successfully meets the expectation of operating the antenna into required passband.

Figure 5 represents front-to-back ratio of the optimized antenna design in the frequency range of 450 MHz-900 MHz. The curve suggests that the antenna provides good directional characteristics in the operating passband with a peak value of 23.99 at 750 MHz and minimum value of 3.59 at 890 MHz. Front-to-back ratio of the antenna is between 12 to 24 in the required passband with decrease in the stopband, thus meeting the optimization goal.

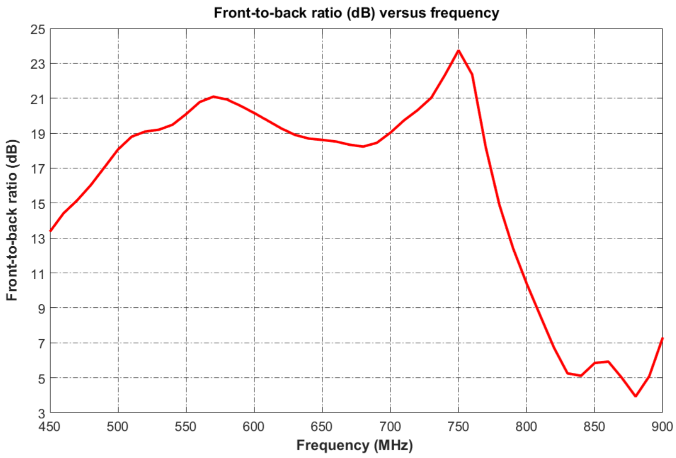

Figure 5. Front-to-back ratio of the proposed antenna design.

4 Conclusion

A cost-effective optimized log-periodic antenna design is proposed to provide a solution to solve the significant problem of interference caused by LTE in TV broadcasting band to the receiver. The proposed antenna design provides good antenna performance in the TV passband (470 MHz-790 MHz), thereby rejecting LTE stopband (810 MHz-900 MHz).

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