A novel design of a 10-dipole log-periodic antenna with LTE-800 and GSM-900 band rejection

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***Abstract*— This study presents a novel design of a 10-dipole log-periodic dipole antenna capable of rejecting 4G-LTE mobile service 800 MHz band as well as GSM 900 MHz band. The proposed antenna provides a cost-efficient solution to solve interference problems caused due to the coexistence of TV broadcasting services and LTE mobile services, without using any external band stop filters. The antenna design presented in this paper operates in the frequency range of 450 MHz – 790 MHz (UHF TV reception passband), thereby rejecting the LTE 800 MHz band as well as the GSM 900 MHz band. The proposed design provides good matching for the antenna in the passband. The antenna has a relatively high gain around 8 dBi in the passband which drops to -5 dBi in the stopband. Furthermore, the antenna is highly directive throughout the passband.**

Keywords—CST simulations, GSM band rejection, Log-periodic antenna, LTE band rejection, 800 MHz band digital dividend.

I. INTRODUCTION

The decision to move from analog to digital broadcasting television systems in 2008 has led to a more efficient utilization of the frequency spectrum that in turn, benefited mobile communication frequency allocations. Followed by this transition, and in order to ensure the efficient use of the spectrum, the European Parliament [1] urged European Member States to reallocate some TV broadcasting services in the UHF band to mobile communications. Reference [2] advocates the benefits of allocating a so-called digital dividend band of 790 MHz-862 MHz to LTE-4G mobile wireless broadband services by the European Commission, based on a research analysis of the cost/benefit ratio.

As described in [3], the harmonized plan to deploy Long-Term Evolution (LTE), also known as fourth generation (4G) mobile broadband network, to the UHF TV broadcasting band of 800 MHz was adopted in Europe (ITU region 1) to effectively utilize the spectrum for mobile services because of the excellent radio wave building penetration capabilities at these frequencies. The adopted LTE-band plan suggested a paired spectrum or frequency division duplex (FDD) of 30 MHz for uplink and 30 MHz for downlink transmission in the spectrum of 790 MHz-862 MHz (channels 61-69). The spectrum for uplink and downlink transmission is made up of 6 blocks of 5 MHz bandwidth in the frequency band of 791 MHz-821 MHz and 832 MHz-862 MHz respectively with a duplex gap of 11 MHz. The broadcasting of Digital Terrestrial Television (DTT) is carried until 790 MHz, leaving a gap of only 1 MHz between the DTT and the LTE 800 MHz band, which makes them both subject to interference effects. Reference [4] provides a detailed study of the interference effects caused due to the coexistence of TV broadcasting services with LTE mobile systems in the 800 MHz band, resulting in degrading the quality of service (QoS) of the TV broadcasting services. Thereafter, a worldwide resolution [5] on the allocation of the 700 MHz band between 694 MHz and 790 MHz (channels 52-69) was passed in WRC-12 (World Radiocommunication Conference) [6] and the provisions to use this band in Region 1 were made in WRC-15 [7]. A detailed research on the interference problems due to the coexistence of TV broadcasting services with LTE mobile systems in the 700 MHz band has been illustrated in [8].

II. PROPOSED 10-DIPOLE LPDA GEOMETRY

This paper presents a design of a 10-dipole log-periodic antenna capable of rejecting the LTE mobile services band, thereby mitigating the interference problems caused due to its coexistence with TV broadcasting services. Initially, the dimensions of the antenna were calculated using the basic design procedure proposed by Carrel [9]. Recently and in order to mitigate problems of interference caused due to the coexistence of the LTE 800 MHz band with the traditional UHF-TV band used by most TV tuners, various TV reception antennas have been designed, which can operate in the new TV band of 470 MHz -790 MHz while rejecting the 800 MHz band with the inclusion of external band stop filters. An optimal design of LPDA has been proposed in [10], which was obtained after optimizing Carrel's model using Particle Swarm Optimization with Velocity Mutation algorithm (PSOvm). The model provides rejection in the 800 MHz band, however, the relatively low VSWR of the antenna in the LTE-band still leaves the possibility of receiving interference from other angles. This unconventional design of the LPDA was optimized by using a much longer than usual first dipole. On the contrary, an optimized 10-dipole log-periodic dipole antenna has been proposed in [11], which provides good band stop characteristics after 790 MHz, without using external filters, in addition, to avoiding intereference from LTE-band from all the angles. This initial design suggested that in order to achieve LTE rejection characteristics in the higher frequency band of the bandwidth, the dimensions of the shorter dipole could be adjusted. Motivated by the initially optimized design proposed in [11], this paper presents an optimized version of this LPDA, by optimizing the first three dipoles of the LPDA and the spacing between them only, instead of considering all the dipoles of the antenna. The antenna proposed in this paper achieves better matching, better LTE rejection and a maximum of flatter realized gain compared to the antenna design in [11]. Additionally, it also provides better return loss, better directivity and higher and flatter realized gain than the Carrel's model. The optimization of the antenna dimensions was performed with the Trusted Region Framework (TRF) algorithm available in CST using the optimization goals specified in Table I. The parameters that were used to optimize the initial design are shown in Table II, along with the range of the dimension values that were specified to vary during the optimization. However, several other optimization algorihms can be used to optimize the antenna performance and geometry, such as Invasive Weed Optimization (IWO) in [12-16], Particle Swarm optimization (PSO) in [17-19], Adative Dispersion IWO (ADIWO) in [20] and Particle Swarm Optimization with Velocity Mutation (PSOvm) in [21]. A comparison of all the mentioned algorithms is presented in [22].

TABLE I. OPTIMIZATION GOALS AND SPECIFICATIONS

Parameters	*Goals*	*Frequency (MHz)*	*Weight*
S11	< -14 dB	470-790 (Passband)	10.0
Realized gain	> 10 dBi	470-790 (Passband)	1.0
Front-to-back ratio	> 14 dB	470-790 (Passband)	0.2
S11	> -1 dB	810-960 (Stopband)	5.0
Realized gain	> -10 dBi	810-960 (Stopband)	1.0

As shown in Fig. 1, the proposed LPDA consists of two conducting longitudinal supports, also known as "booms", which are responsible for feeding the half-dipole elements of the antenna. Each conducting boom, feeds the alternate half-dipoles of the antenna, in a crisscross fashion. This configuration provides a 180-degree change of phase of the feeding source between two consecutive dipoles. The change of phase ensures that the radiation pattern of the antenna points in the forward direction, thereby providing directional characteristics. The arrangement of dipoles is made in such a manner that all the dipoles are in contact with the conducting boom, thereby making all the dipoles active. The number of dipoles used in the antenna has a significant impact on its gain. The gain significantly increases by incrementing the number of dipoles used [22-24]. In most cases, the feeding to the boom is provided using a coaxial cable through the front end of the antenna in order to avoid pattern distortion. A fastener is attached at the rear part of the antenna, acting as a short circuit stub as well as a point of support for the antenna, as shown in Fig. 2.

The adjustment to the length of the first three dipoles has been made because of the fact that the shorter dipoles are responsible for the antenna performance at higher frequencies. The parameters that were considered for optimization included the first three dipole lengths (L1, L2 and L3) and the spacing between these dipoles (d0, d1, d2 and d3). These parameters were restricted to change by ± 30 %, while configuring the settings for TRF algorithm before the optimization. Table II shows the minimum and maximum values of the parameters that were considered for the optimization.

The arrangement of shorter dipoles has been made in such a manner that the length of the 2nd dipole is smaller than the 1st dipole but bigger than the 3rd dipole. However, the 3rd dipole is shorter than the 2nd and 4th dipoles. The dipole lengths after the 4th dipole keep increasing in the classic design fashion until the last dipole.

TABLE II. RANGE OF PARAMETERS CONSIDERED FOR OPTIMIZATION

Parameters	*Minimum*	*Maximum*
L1	48.3 mm	89.7 mm
L2	39.1 mm	72.67 mm
L3	44.2 mm	82.0 mm
d0	19.6 mm	36.4 mm
d1	10.7 mm	19.9 mm
d2	13.0 mm	24.2 mm
d3	15.4 mm	28.6 mm

The designed antenna has the following dimensions: 356 mm x 302.6 mm x 35 mm (length x breadth x height). Both conducting booms are attached together using a cuboidal fastener acting as a short circuit stub and providing a point of attachment to any other support. The cuboidal fastener extends 45 mm long, 15 mm wide and 35 mm high. The front view and side view of the CST designed model of the antenna is shown in Fig. 1 and Fig. 2 respectively. The final dimensions of the antenna after the optimization are shown in Table II.

The CAD model is designed in CST using several parameters, where, L_n is length of the n^{th} dipole, d_n is distance between the n^{th} and $(n+1)^{th}$ dipole, L-boom is length of the boom, W-boom is width of the boom, H-boom is heigth of the boom, gap is the distance between the two parallel booms. The dimensions of the cuboidal fastener, that connects the end of the boom, acting as a short-circuiting stub, are represented by Stub_length, Stub_width and Stub_height in Table III.

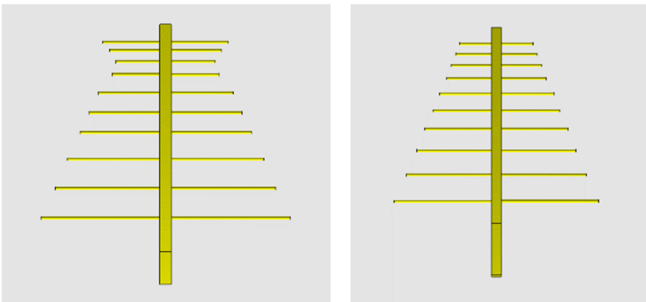

Fig. 1. Front view of the proposed 10-dipole LPDA (left) and Carrel's model (right) in CST.

The antenna designed using Carrel's method was matched to 75 ohm impedance. However, the gap between the booms in the optimized antenna design has been reduced by 5mm to provide 50 ohm impedance.

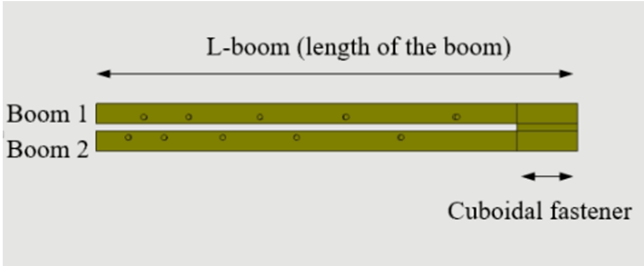

Fig. 2. Side view of the proposed 10-dipole LPDA in CST.

TABLE III. DIMENSIONS OF THE OPTIMIZED LPDA

Optimized antenna model		***Carrel's antenna model***	
Parameters	***Values***	***Parameters***	***Values***
L1	72.7 mm	L1	49 mm
L2	64.2 mm	L2	55 mm
L3	56.0 mm	L3	62 mm
L4	60.7 mm	L4	69 mm
L5	78.6 mm	L5	80 mm
L6	90.1 mm	L6	89 mm
L7	101.8 mm	L7	102 mm
L8	117.7 mm	L8	114 mm
L9	133.5 mm	L9	130 mm
L10	151.3 mm	L10	149 mm
L-boom	356 mm	L-boom	380 mm
H-boom	15 mm	H-boom	15 mm
W-boom	15 mm	W-boom	15 mm
Dipole radius	2 mm	Dipole radius	2 mm
Stub_width	15 mm	Stub_width	15 mm
d0	24.1 mm	d0	25 mm
d1	11.4 mm	d1	16 mm
d2	14.9 mm	d2	17 mm
d3	17.9 mm	d3	20 mm
d4	25.3 mm	d4	23 mm
d5	27.3 mm	d5	26 mm
d6	27 mm	d6	28 mm
d7	36.3 mm	d7	33 mm
d8	40.4 mm	d8	37 mm
d9	40.6 mm	d9	40 mm
gap	5 mm	gap	10 mm
Stub_length	45 mm	Stub_length	79 mm
Stub_height	35 mm	Stub_height	38 mm

III. LPDA SIMULATIONS

The time-domain simulation of this design is performed in CST electromagnetic simulation software with an accuracy of -50 dB using a hexahedral meshing consisting of 4,668,482 mesh cells. Open boundary conditions were set for the proposed design having a 10^{-4} estimated reflection level. The feeding to the conducting boom was provided by an excitation port with a 50 Ω impedance attached at the front end of the antenna, connecting the two center points of the booms. Farfield monitors were setup with a resolution of 10 MHz starting from 450 MHz to 1000 MHz.

Fig. 3 presents the comparison of the simulated return loss of the antenna proposed in this paper with the measured and simulated results of the antenna designed by Carrel's method. The curves suggest that the proposed optimized design provides better matching for the antenna with lower S11 values in the TV broadcasting band (passband) whereas much higher S11 values are observed in the LTE 800MHz and also in the GSM 900MHz mobile service bands (stopband), as compared to the antenna designed by Carrel's method. Consequently, the return loss of the new antenna design demonstrates better rejection in the stopband compared to Carrel's antenna design.

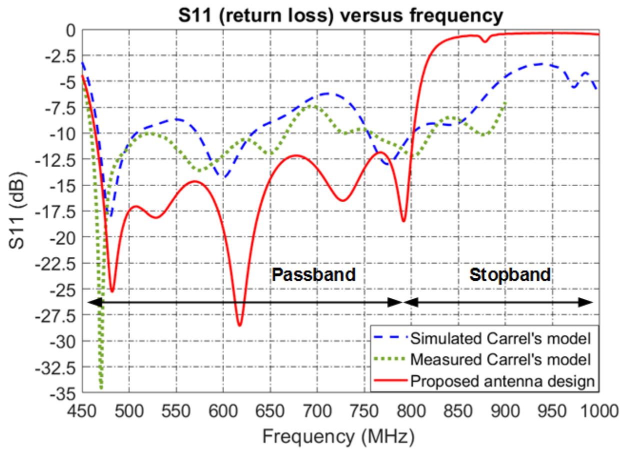

Fig. 3. Comparison of return loss of the proposed antenna design with Carrel's design.

Fig.4 demonstrates the comparison of simulated and measured realized gain achieved by the antenna designed using Carrel's method and the optimized antenna design proposed in this paper. It is evident from this figure to conclude that the new antenna design achieves a flatter and higher realized gain compared to the Carrel's antenna design. It also shows that the realized gain value is below 0 dBi in the stopband, thereby achieving rejection characteristics from all the angles of arrival of radiation.

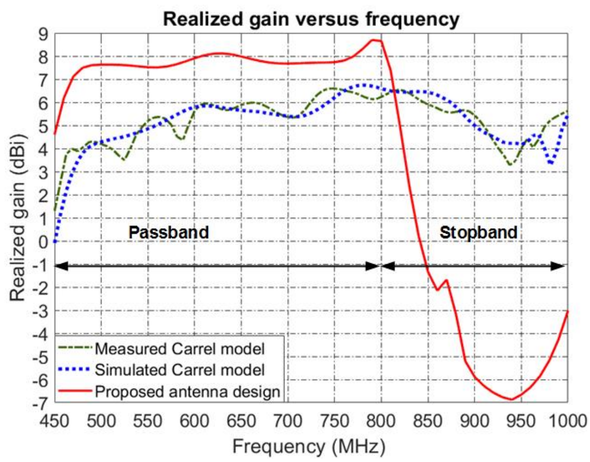

Fig. 4. Comparison of realized gain of the proposed antenna design with Carrel's model.

Fig. 5 presents a comparison plot of the simulated and measured front-to-back ratio of Carrel's antenna design and the new antenna design proposed in this paper. The plot shows that a somewhat better front-to-back ratio is achieved by the new antenna design in the passband.

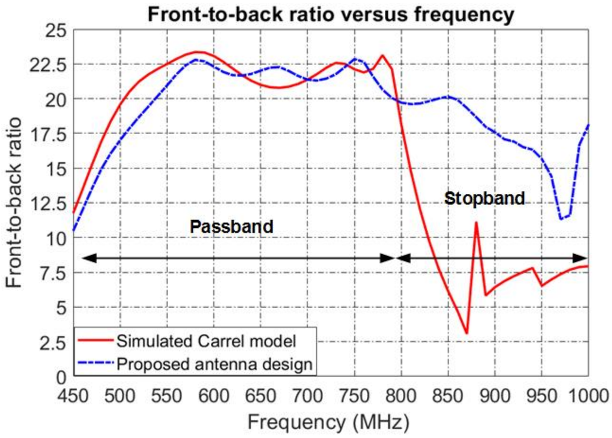

Fig. 5. Comparison of front-to-back ratio of the proposed antenna design with Carrel's design.

IV. Conclusion

The proposed log-periodic dipole antenna design can be used as a cost-effective solution for UHF TV reception which is capable of rejecting the LTE 800 MHz band as well as the GSM 900MHz band without the addition of costly filters. This could help resolve the interference problem caused due to the coexistence of TV broadcasting services and mobile communications services, thereby enhancing the quality of service (QoS) of UHF TV signals. The proposed antenna design possesses good matching, relatively high and flat gain and highly directional characteristics in the passband combined with a high rejection in the stopband.

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