Log-Periodic Antenna with Interdigital Structure for Energy Harvesting from TV Broadcast Tower

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***Abstract*-In this paper, the interdigital structure is applied to the design of a miniaturized planar log-periodic antenna which is used in a TV broadcast wireless energy harvesting system. The lateral size of the printed antenna can be reduced approximately 35% while the overall performance characteristics is improved slightly. The simulated gain reaches 7.27dB at 515MHz and the measured -10-dB bandwidth is from 500MHz to 600MHz, which is sufficient for the television band in Suzhou, China. The energy harvesting system equipped with the proposed antenna is tested, and the measured output voltage is 2.2 V.**

***Index Terms*-Miniaturized log-periodic antenna, interdigital structure, slow-wave, energy harvesting, TV broadcasting, wireless power.**

I. INTRODUCTION

Energy harvesting technologies have drawn attention from a great many researchers in recent years due to its future wide-range applications in wireless sensor networks (WSN), biomedical devices, and environmental sensing, etc. RF energy, as a kind of pervasive power that exists almost everywhere in urban areas, has aroused significant interests among scientists. Basically, a wireless energy harvesting system is composed of an energy harvesting antenna as RF signal receiver, and a RF-to-DC rectifier for power conversion. RF energy harvesting system of various kinds of antennas for public broadcast and telecommunication bands have been put forward in [2]-[4].

Antenna, as the front end of an energy harvesting system, plays a pivotal role in capturing power from the air. An A-4 sized six-element log-periodic array antenna with bandwidth from 540 to 560 MHz, measured gain from 5 dB to 7.3 dB, and dipole lengths between 24 cm to 30 cm was used to harvest the energy of ambient digital TV signals from Tokyo TV tower in [2]. Printed log-periodic dipole array (LPDA) has the features of high directivity, wide-band, easy-fabrication, low cost, and easy-placement features, so it is quite suitable for harvesting system. Having the advantages of long duration of time and wide geographical coverage, TV broadcast is chosen as the ideal power source. For city of Suzhou, China, the TV band is from 510 MHz to 520 MHz.

This paper mainly focuses on the miniaturization of the traditional Euclidean LPDA, and it will make the energy harvesting system more practical in use. In [5], Koch-fractal structure has been applied in wideband antenna design in order to reduce the size of LPDA. The LPKDA antenna design reaches a reduction of 12% of its size in that letter. In this paper, we apply the interdigital structure to the design of the log-periodic antenna, and its lateral size can be reduced by 35%. The log-periodic antenna with interdigital structure (LPDAI) has advantages of smaller size, wider bandwidth, high gain, good radiation direction, and modest efficiency which are apposite to the wireless energy harvesting from TV broadcast tower. An energy harvesting system is designed and fabricated, which can harvest 2.2V DC voltage using the proposed antenna and a 6-stage voltage multiplier rectifier.

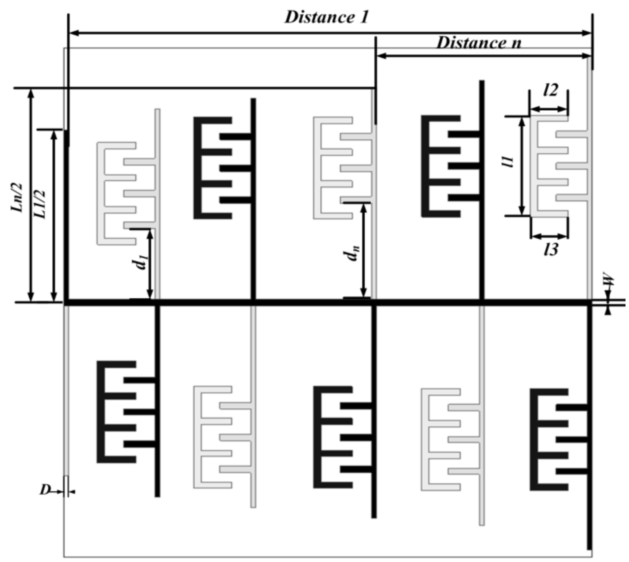


Fig. 1. Geometry of the LPDAI antenna.

II. LPDAI ANTENNA CONFIGURATION

An LPDAI design is created by loading interdigital structures in middle areas on the full-length Euclidean elements of a conventional LPDA as shown in Fig.1. The interdigital structures are of the same configuration. The interdigital structure used in the LPDAI design is in the horizontal form, that is, only one of its terminal sides is connected to the feedline, which is different from the classical interdigital structure.

The horizontal interdigital structure is studied in [1]. The reference points out that under the circumstance of same length, the horizontal interdigital structure can have greater phase shift compared to the traditional microstrip. For instance, a traditional microstrip will have a phase shift of 62 degree in 1.5GHz while the phase shift of a horizontal interdigital structure can achieve 70 degree. As a result, electrical length is lengthened. Thus, it can be utilized in the miniaturization of dipoles of the antenna.

An energy harvesting antenna is designed to cover the frequency band of 510-520MHz. It is milled on a t=1.2mm thick FR-4 laminate with relative permittivity of 4.4 and loss tangent of 0.02. The length of the largest element is determined by the lowest frequency of operation. Initially, a 6-element Euclidean LPDA was simulated with the lateral size of 28cm× 29cm (the longest element is 29cm and the shortest is 19.8cm) , resonating at 515MHz with -10dB bandwidth from 480MHz to 550MHz and a maximum gain of 7.14dB. The geometries of the Euclidean LPDA was first derived from [2], and later modified in order to fit better with the real frequency band in city of Suzhou as shown in Table I. The working wavelength is approximately 58cm and it is exactly the twice of the longest dipole of the Euclidean LPDA. The vertical length of the LPDAI is reduced to 23.3cm. The width of each dipole is the same. The LPDAI is expected to perform similarly to the Euclidean LPDA, but to take up a smaller area of the circuit board (22cm×24cm). The LPDAI is simulated and optimized using Ansoft HFSS, and has dimensions listed in Table Ⅰ.

TABLE I
DIMENSIONS OF LPDAI

Scale Factor ‘τ’		0.95	
Relative Space ‘σ’		0.1	
Angle ‘α’		5°	
Number of elements ‘I’		6	
L1(cm)	16	*Distance1(cm)*	21.8
L2(cm)	18	*Distance2(cm)*	18
L3(cm)	19	*Distance3(cm)*	14
L4(cm)	20	*Distance4(cm)*	9
L5(cm)	20.7	*Distance5(cm)*	4.5
L6(cm)	23	*l1(cm)*	4.8
W(cm)	0.3	*l2(cm)*	1.6
D(cm)	0.2	*l3(cm)*	1.3
d1(cm)	3.5	*d4(cm)*	4.7
d2(cm)	4.8	*d5(cm)*	4.7
d3(cm)	4.8		

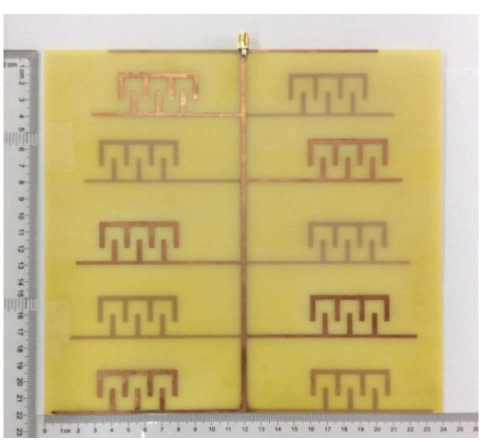


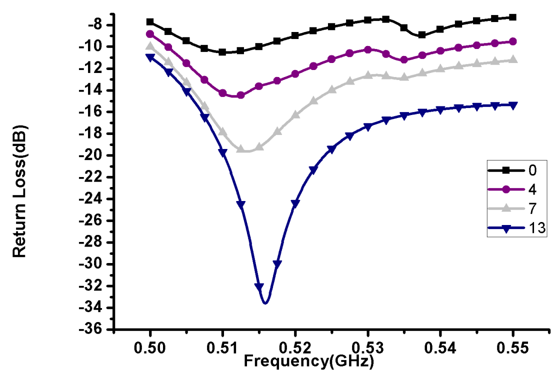
Fig. 2. Photo of the fabricated LPDAI antenna. The shadowed strips are printed in the backside of the substrate.

III. SIMULATION AND EXPERIMENTAL RESULTS

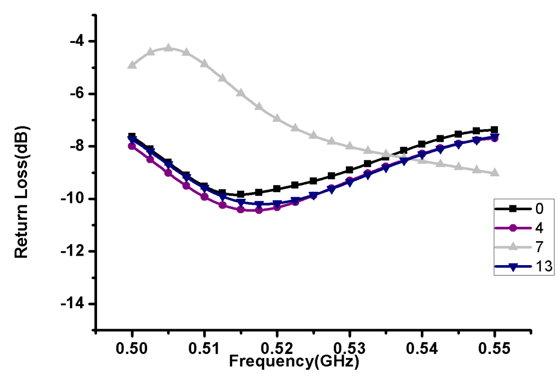
Simulations were performed to investigate the influence of the location of interdigital structures on the dipoles of the antenna. All the interdigital structures were first placed 48mm away from the feedline. Simulation was first done under this circumstance. Later, the interdigital structures on the second dipole element were changed by 4mm, 7mm, and 13mm from the initial location towards the feedline while keeping other interdigital structures unmoved. The same operation was done upon interdigital structures on other dipole elements. As examples, the simulated return losses corresponding to different locations of interdigital structures on the second and the sixth element are shown in Fig. 3.

It is clear from Fig. 3 that the change of location of the interdigital structure has greater impact on the performance of the antenna when it is on the second element than it is on the sixth element as the feed point is placed at the narrow end of the antenna.

The design is optimized on the basis of the simulation results, and the final parameters of the locations of interdigital structures (*Distance1* to *Distance6*) are shown in Table I.



(a)



(b)

Fig. 3. Return losses corresponding to interdigital structures moved by 0mm, 4mm, 7mm, and 13mm towards the feedline from the original location on the (a) second, (b) sixth dipole element.

The simulated directivity of the LPDAI antenna is 7.99dB, 0.22 dB higher than the original Euclidean LPDA antenna. This is achieved by narrowing half-angle α (from 14.5° to 5°). The bandwidth of the LPDAI is shown below, and it is even wider than the original Euclidean LPDA bandwidth, which is from 480MHz to 550 MHz. The simulated efficiency of the antenna is exacerbated from 86.44% to 84.76% because of the dissipation caused by the horizontal interdigital structure. However, the simulated gain of the antenna is still improved from 7.14dB to 7.27dB which means that such a little sacrifice is worthwhile. These results show that the optimized LPDAI is superior to the conventional Euclidean LPDA in possessing wider bandwidth, higher directivity while achieving 35% lateral size reduction.

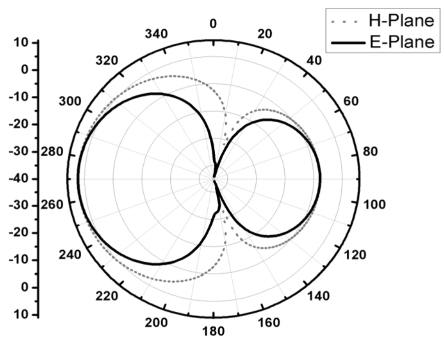


Fig. 4. Simulated radiation pattern of E-plane and H-plane of the optimized antenna.

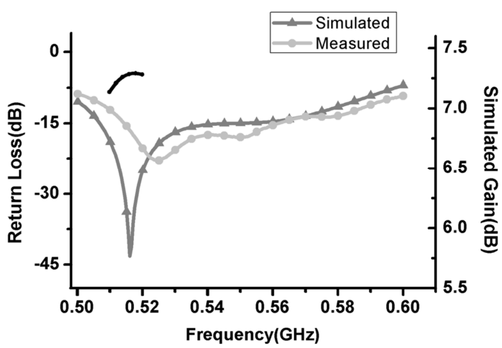


Fig. 5. Simulated and measured return loss of the proposed LPDAI (left column), and simulated gain (with frequency from 510MHz to 520MHz) of the proposed antenna (right column).

Fig. 6. Field measurement in downtown Suzhou, China, with the test prototype system harvesting wireless energy from digital TV signals broadcasted from Suzhou TV tower.

The measured return loss is kind of different from the simulated results because there is imperfection of the soldering for the SMA and the fabrication of the antenna. However, the measured bandwidth is still sufficient for the energy harvesting from TV tower in Suzhou.

The antenna was connected to a 6-stage RF-to-DC charge-pump circuit using a 50-Ω coaxial cable, and the measured voltage was 2.2V in downtown Suzhou, as shown in Fig.6.

IV. Conclusion

Interdigital structures were used in the miniaturization of printed log-periodic dipole array for TV wireless energy harvesting in the city of Suzhou, China. The design takes the advantage of slow-wave feature of the horizontal interdigital structure, miniaturizing the lateral size of the antenna by 35% while achieving a slightly higher gain and wider bandwidth. The influence of the location of interdigital structure on the dipoles was also investigated. The proposed LPDAI is tested for capturing power connected to a 6-stage voltage multiplier rectifier, and the measured output DC voltage is 2.2V. The structure of the LPDAI is planar and relatively simple to fabricate using standard PCB fabrication techniques. The design concept can easily be scaled for applications in energy harvesting with different bandwidth.

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