Progress In Electromagnetics Research Letters, Vol. 41, 97–104, 2013

A MONOLAYER MULTI-OCTAVE BANDWIDTH LOG-PERIODIC MICROSTRIP ANTENNA

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Abstract—In this paper, a novel monolayer multi-octave bandwidth log-periodic microstrip antenna (LPMA) is presented. This antenna consists of a $50\,\Omega$ microstrip feed-line and fourteen rectangular patch elements. Twelve rectangular patch elements are fed by edge-coupling from the microstrip feed-line and two other patch elements are directly connected with the microstrip feed-line. A mixed microstrip line feed is applied to expand the bandwidth. Our measured results closely agree with the simulated results. These results show that the proposed antenna lends itself well to operation in the impedance bandwidth from 2 GHz to 8 GHz with a voltage standing-wave ratio (VSWR) less than 2.

1. INTRODUCTION

In recent years, broadband antennas have been widely applied to wireless communication systems [1–6]. To meet the requirements of the modern communication standards, there has been increasing research on log-periodic microstrip antennas, which can simplify the systems,

Received 21 May 2013, Accepted 6 July 2013, Scheduled 9 July 2013

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and reduce production costs. Design of the log-periodic microstrip antenna is based on frequency independent antenna principles [7], which, when applied to a periodic structure, result in scaling of the dimensions from period to period so that the performance is periodic with the logarithm of frequency [8]. Typically, log-periodic microstrip antennas can be classified as multi-layer structure and monolayer structure, in terms of the feeding type. A multi-layer structure was introduced in [9–11] using an electromagnetically coupled overlaid patch array for the design of wideband arrays based on frequency-independent antenna principles. In [12], a monolayer structure using an array of rectangular microstrip patches was arranged in the log-periodic way and proximity-coupled to the microstrip feed-line.

In the 1980s, the series-fed log-periodic microstrip antennas were first introduced for bandwidth enhancement [9, 10]. However, all of the LPMAs mentioned above were based on the combination of two substrate layers, in which very accurate collocation between the two layers were required. In [13], a single layer LPMA which was composed of a $50\,\Omega$–$100\,\Omega$ impedance transformer, a $100\,\Omega$ microstrip feed-line and an array of rectangular microstrip patches was presented for ultrawide band (UWB) applications. A lossless compensating stub was also used for bandwidth enhancement but led to a wider beamwidth and lower directivity at low frequencies. Furthermore, the impedance transformer increased the complexity and the size of the antenna.

We propose a novel monolayer multi-octave bandwidth LPMA which is fed by a $50\,\Omega$ microstrip feed-line. The antenna is comprised of a $50\,\Omega$ microstrip feed-line and fourteen rectangular patch elements, twelve of which are fed by edge-coupling from the microstrip feed-line and two of which are directly connected with the microstrip feed-line. Using this design, the size of the antenna is compact and the impedance characteristics are improved over the previous designs.

2. ANTENNA CONFIGURATION

The configuration of the proposed monolayer LPMA is shown in Fig. 1. The antenna is designed on Teflon-based substrate with a relative permittivity of $\varepsilon_r = 2.65$ and loss tangent of 0.02. The overall dimensions of the antennas are $386\,\text{mm} \times 138\,\text{mm} \times 3\,\text{mm}$. Detailed dimensions of the antenna are listed in Table 1. The microstrip elements are arranged in a transposed log-periodic way with the same coupling gap G. The log-periodic scale factor k is defined as

$$k = \frac{W_i}{W_{i-1}} = \frac{L_i}{L_{i-1}} = \frac{D_{i,i+1}}{D_{i-1,i}} \tag{1}$$

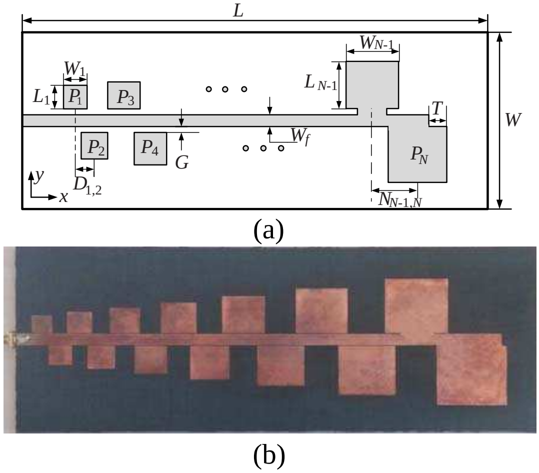


Figure 1. Configuration of the proposed LPMA. (a) Geometry of the proposed LPMA. (b) Photograph of the fabricated LPMA.

In (1), $D_{i,i+1}$ is the center distance between patch P_{i+1} and P_i. W_i and L_i are the width and length of the patch P_i, respectively. The proposed LPMA has a scale factor $k = 1.1$. If we multiply all dimensions of the array by k, it scales into itself with element N becoming element $N+1$, element $N+1$ becoming element $N+2$ etc.. This self-scaling property implies that the array will have the same radiating properties at all frequencies that are related by a factor of k. The proposed LPMA is fed using a mixed microstrip line feed method. Namely, the last two elements are connected to the microstrip feed line directly, instead of the gap coupled feeding used for the other elements. The LPMA is designed in a semi-empirical way with the assistance of the full-wave simulator HFSS. The following discussion of the proposed LPMA is based on the optimized parameters in Table 1.

Table 1. Optimized parameters of the proposed LPMA with mixed microstrip line feed method. (in millimeters).

$D_{1,2}$	L	W	L_1	W_1	G	T	W_f	W_s	W_t
13	386	138	13	15	0.3	4	8.8	16	21

3. SIMULATION AND MEASUREMENT RESULT

The connection between the last two patch elements and the microstrip feed-line increases the transmission efficiency between them and reduces the reflection from the open-ended feed line. Fig. 2(a) shows the equivalent circuit of the proposed antenna with mixed feed and Fig. 2(b) shows the equivalent circuit of the monolayer LPMA with gap feed. C is the capacitance between the microstrip feed line and the patch elements, and g_r and b_r are the patch end radiation conductance and susceptance, respectively. Compared to the conventional gap feed, the equivalent coupling capacitors, C_{13} and C_{14}, have been removed for improving the coupling at low frequencies. Thus, connecting the last two patch elements directly with the feed-line can improve the impedance characteristics at low frequencies. Fig. 3 shows the measured VSWR, with the solid and dashed curves corresponding to the proposed monolayer LPMA with mixed feed and the monolayer LPMA with gap feed, respectively. The VSWR with the mixed feed is significantly improved. Due to the coupling effects among the

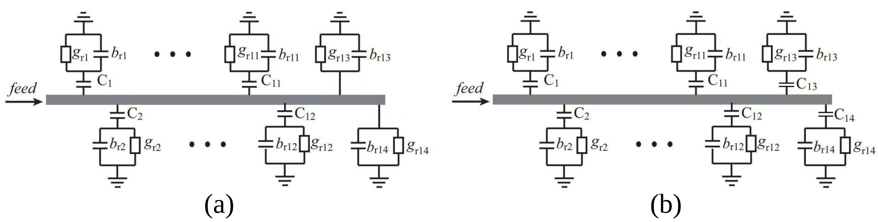


Figure 2. Equivalent circuit analysis. (a) Equivalent circuit of the proposed LPMA with mixed feed. (b) Equivalent circuit of the monolayer LPMA with gap feed.

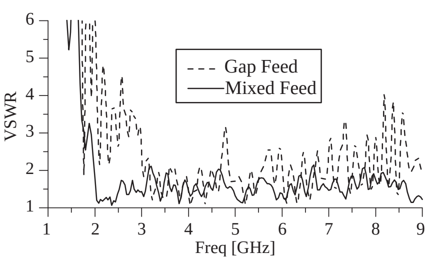


Figure 3. Comparison of measured VSWR between gap coupled LPMA and mixed feed LPMA.

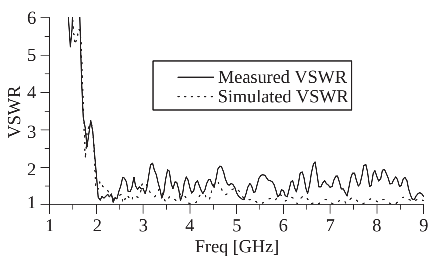


Figure 4. Measured and simulated VSWR of the proposed LPMA.

rectangular patch elements, the impedance characteristics at middle and high frequencies were also improved. Comparisons of LPMA parameters from [10, 13], and the proposed mixed feed and gap feed antennas are shown in Table 2.

Table 2. Detailed information of parameters comparison among LPMAs.

LPMA	Size (mm × mm)	VSWR	Bandwidth (GHz)	Number of array	Ratio
in [10]	387 × 68	< 2.2	4–16	36	4.0 : 1
in [13]	320 × 110	< 2.5	2.26–6.85	11	3.0 : 1
mixed feed	386 × 138	< 2.0	2–8	14	4.0 : 1
gap feed	386 × 138	< 2.0	3.1–4.7	14	1.5 : 1

After the proposed antenna was designed and optimized, a sample antenna was fabricated based on the optimized parameters in Table 1. The impedance bandwidth was measured using an Agilent E5071C Vector Network Analyzer (VNA) in an anechoic chamber. The results are shown in Fig. 4. Close agreement can be observed between the simulated and measured results, and the minor discrepancy between them may have beed caused by the soldering of the SMA connector and the mechanical tolerance. The measured impedance bandwidth was defined by a VSWR less than 2 which was from 2 GHz to 8 GHz with a ratio of about 4 : 1.

The measured group delay of two antennas with a distance of 100 cm is shown in Fig. 5. It can be seen from the figure that the maximum variation of the group delay is about 3 ns. Thus the proposed antenna has a desirable time-domain characteristic. Because the phase difference of the adjacent scanning frequency spans more than 180 degree which leads to phase reversal, the measured group delay produces negative values. The measured antenna gain versus

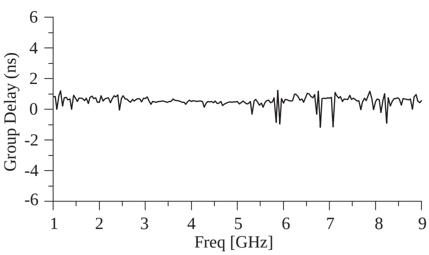


Figure 5. Measured group delay of the proposed LPMA.

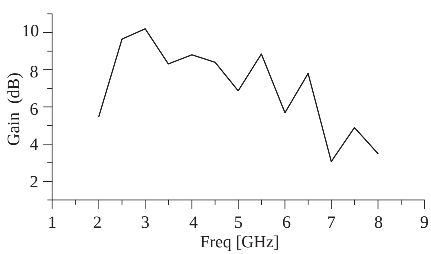
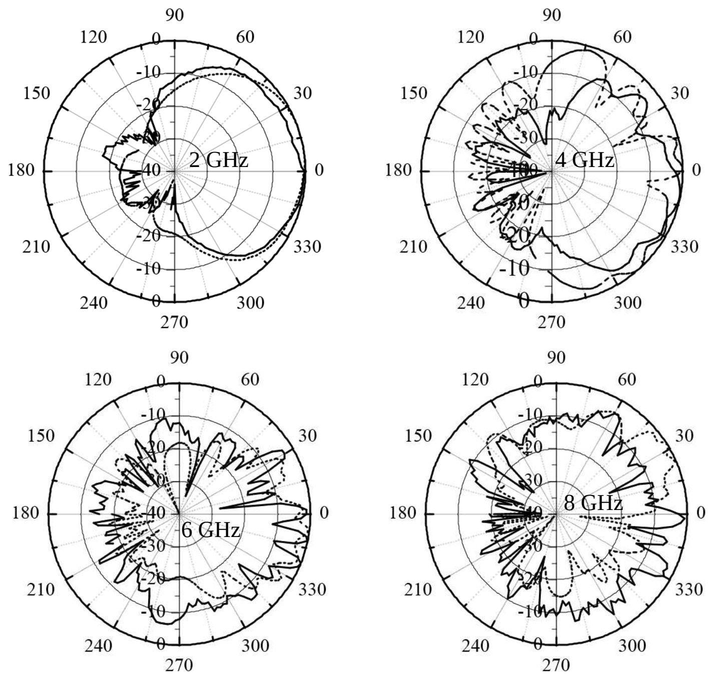
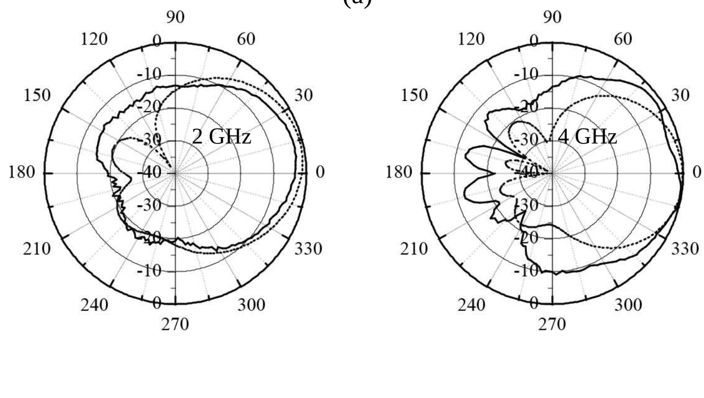


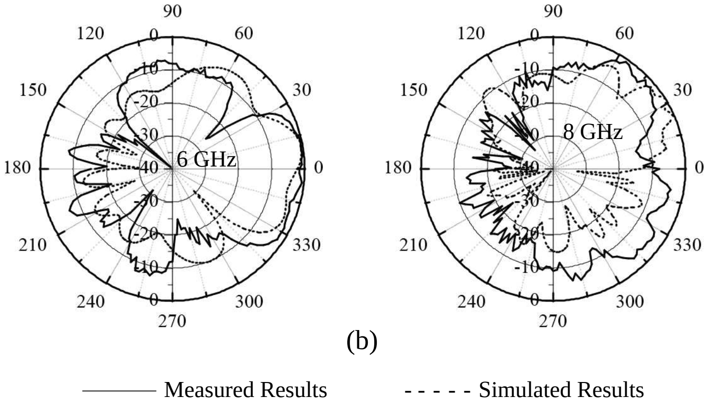
Figure 6. Measured gain of the proposed LPMA.

frequency for the proposed antenna is also shown in Fig. 6. The radiation patterns of the proposed antenna in Fig. 7 show that the radiation lobe at the frequencies of 6 GHz and 8 GHz begin to split, thus the gain of the antenna in Fig. 6 at high frequencies is lower than that at low frequencies. The radiation patterns of the proposed antenna have also been measured in an anechoic chamber. The measured and simulated radiation patterns in the xz plane and yz plane at the frequencies of 2 GHz, 4 GHz, 6 GHz and 8 GHz are shown in Fig. 7. It was observed that the measured radiation patterns generally agree with the simulation results. The reason that the measured radiation



(a)





(b)

Figure 7. Measured and simulated radiation patterns at different frequencies. (a) xz plane. (b) yz plane.

patterns at 8 GHz differ from the simulation results may be caused by the soldering of the SMA connectors on the first two rectangular patch elements.

4. CONCLUSIONS

A compact monolayer log-periodic microstrip antenna with a mixed microstrip line feed has been proposed. The mixed microstrip line feed was proved to be highly effective for expanding impedance bandwidth and improving the radiation pattern at low operating frequencies. The impedance bandwidth (with measured VSWR < 2) of the antenna with only fourteen elements covers from 2 GHz to 8 GHz with a ratio of about 4 : 1. Both numerical and experimental results show that the proposed antenna satisfies the requirements of ultra-wideband communications.

ACKNOWLEDGMENT

The work was supported by the NSFC under grant No. 61102011 and No. 61201082, "211 Engineering" key subject of Communication University of China.

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