Design and Analysis of 30-512MHz Log-periodic Monopole Antenna

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Abstract

Based on the principle and structure characteristics of log-periodic monopole antenna, a new log-periodic monopole antenna structure is designed, which adopts the lumped capacity instead of inverting converter to realize cross feed. The experimental results show that the antenna can effectively solve the problem of phase shifting between two adjacent elements of log-periodic monopole antenna. In the frequency band of 30-512MHz, the voltage standing wave ratio (VSWR) of the antenna is less than 2.2 and the gain is more than 9dB as well as the directional diagram has good directional characteristics.

Keywords

log-periodic monopole antenna, lumped capacity, voltage standing wave ratio, gain.

1. Introduction

With the development of telecommunication technology, the antenna is developing towards broadband and miniaturization[1]. In order to make the antennas work stably in a wider frequency band, the electrical property of antennas are required to be basically non-varying with frequency. Log-periodic antenna developed in recent decades is the one that basically keeps unchanged in the frequency band of more than 10:1 and is most widely used in the aspects of communications, measurement and electronic warfare in the shortwave, ultra-short wave and microwave bands. There are many kinds of structures, including log-periodic antenna dipole array (LPDA) and log-periodic monopole antenna (LPMA) and so on. In addition to the advantage of log-periodic dipole antenna, the height of log-periodic monopole antenna is almost halved, bringing great convenience in practical application. LPMA can be used in the ultra-short wave band, such as television, radio, remote control, telemetry and so on[2, 3]. Moreover, log-periodic monopole antenna array can be used as a unit to realize many functions in various combinations including direction-finding, target tracking, recognition of polarization characteristics of incoming wave and so on[4, 5], therefore attract the concern from scholars.

2. Design

2.1 Antenna structure

In the traditional log-periodic monopole antenna array, the monopole is a metal rod and the phase difference between two monopoles is 180° by the inverting converter. The feeder is the parallel transmission line. This antenna array can only be used in a very low frequency range and its debugging and installation are very cumbersome with high costs. In this paper, the inverting converter is replaced by changed capacitors and the feeding circuit is simplified for improvement. The structure is shown in Fig.1.

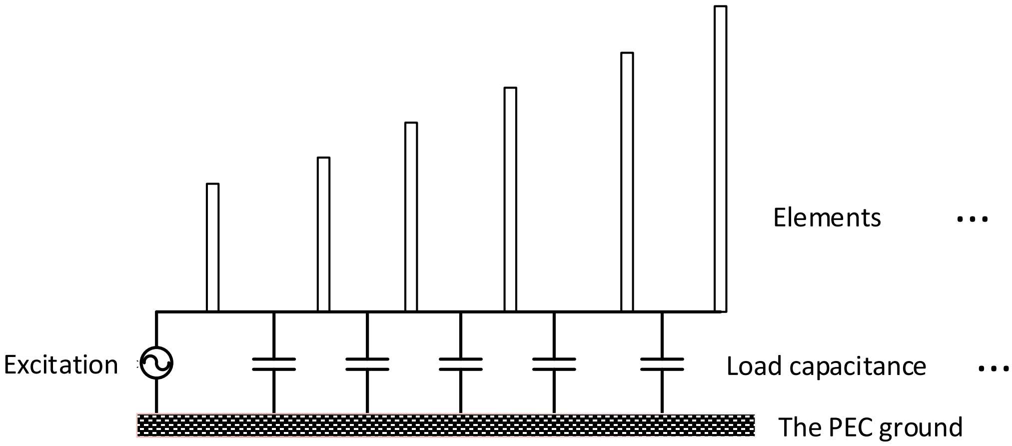

Fig. 1 Structure diagram of log-periodic monopole antenna array

2.2 Theoretical analysis

The log-periodic antenna array is a kind of end fire array and its maximum radiation direction is its rectilinear direction. In order to make the antenna have back-type radiation characteristic in the broadband range, the current phase difference of 180° between the adjacent elements is required and the phase of each element current of the array lags along the maximum radiation direction. In the radiation region of PLMA, it is necessary to use some techniques to adjust the phase between two adjacent elements in order to make them have the phase difference of 180°. In this paper, the phase is modulated by loading variable capacitance onto uniform transmission line. The schematic diagram of capacitance loaded on the transmission line is showed as Fig.2.

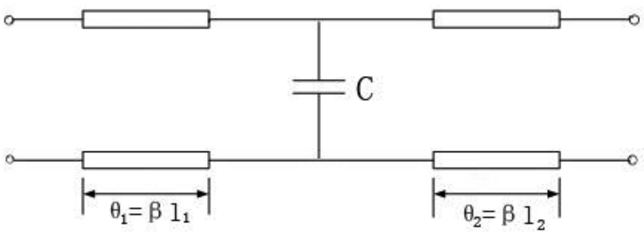

Fig. 2. Schematic diagram of capacitance loaded on the transmission line

Through the matrix analysis of the equivalent circuit of the transmission line, then

$$[A]=\begin{bmatrix}\cos\theta_1 & j\sin\theta_1\\ j\sin\theta_1 & \cos\theta_1\end{bmatrix}\begin{bmatrix}1 & 0\\ jwc & 1\end{bmatrix}\begin{bmatrix}\cos\theta_2 & j\sin\theta_2\\ j\sin\theta_2 & \cos\theta_2\end{bmatrix}$$

$$=\begin{bmatrix}\cos\theta_1\cos\theta_2-wc\sin\theta_1\cos\theta_2-\sin\theta_1\sin\theta_2 & j(\cos\theta_1\sin\theta_2-wc\sin\theta_1\sin\theta_2+\sin\theta_1\cos\theta_2)\\ j(\cos\theta_1\sin\theta_2+wc\cos\theta_1\cos\theta_2+\sin\theta_1\cos\theta_2) & \cos\theta_1\cos\theta_2-wc\cos\theta_1\sin\theta_2-\sin\theta_1\sin\theta_2\end{bmatrix}$$

The A matrix is transformed into a transmission matrix, thus

$$S_{21}=\frac{2}{A_{11}+A_{12}+A_{21}+A_{22}}=\frac{2}{2\cos(\theta_1+\theta_2)-wc\sin(\theta_1+\theta_2)+j[2\sin(\theta_1+\theta_2)+wc\cos(\theta_1+\theta_2)]}=\frac{2}{\sqrt{w^2c^2+4}}e^{\varphi}$$

Where, transmission phase shift of Port 1 to Port 2:

$$\varphi=-artg\frac{2\sin(\theta_1+\theta_2)+wc\cos(\theta_1+\theta_2)}{2\cos(\theta_1+\theta_2)-wc\sin(\theta_1+\theta_2)}$$

Where, $\theta=\beta l$., According to the spacing between two adjacent elements, the value of C is approximately estimated so that the phase shift of two adjacent elements is 180^0.

It should be noted that the spacing of two adjacent elements changes with the log periodicity τ, namely $d_n = \frac{1}{\tau} d_{n-1}$, so C will change with τ. Given that initial capacitance is C_0, other loading capacitances are respectively $\frac{1}{\tau} C_0, \frac{1}{\tau^2} C_0 \ldots\ldots$

In practical engineering, the spacing between two adjacent elements is restrained by the antenna structure, so it cannot be arbitrarily selected to meet the expectations. Therefore, only by optimizing the capacitance value can the 180^0 phase shift of current be realized so as to achieve the purpose of end fire towards the feed.

2.3 Simulation analysis

A 30-520MHz log-periodic monopole antenna with 17 elements was designed by FEKO software in this paper. Since the loaded capacitance has a great impact on the impedance input, the VSWR of the antenna is also affected. Fig.3 gives the VSWR of the proposed antenna with the different initial capacitance.

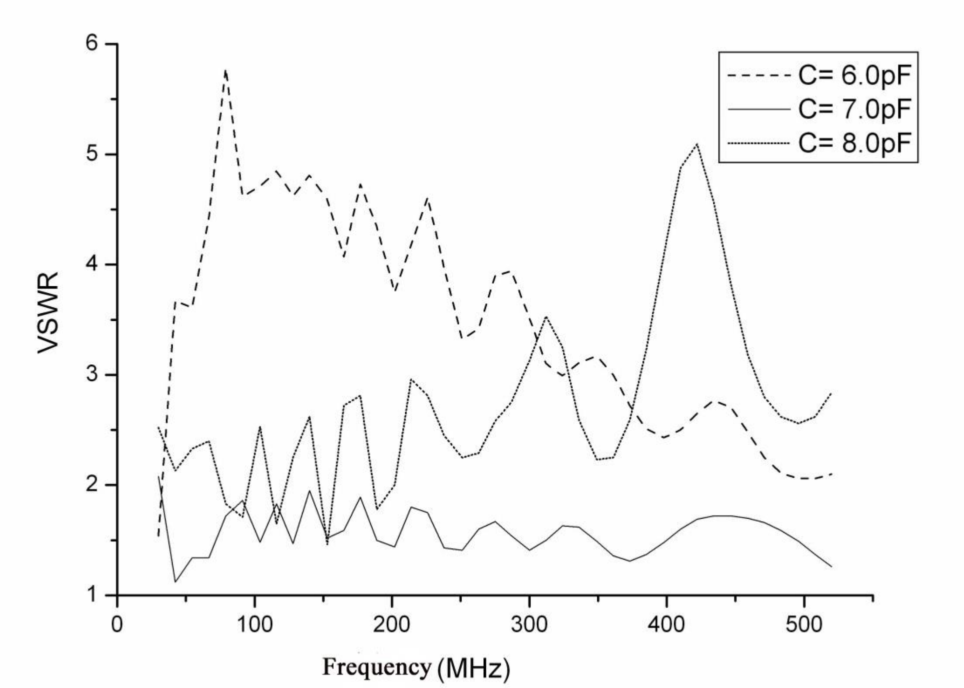

Fig.3 The VSWR of the proposed antenna with different initial loaded capacitance

With the different initial capacitance, the variation curves of the gain and directional diagram of different frequency points (30MHz, 300MHz, 520MHz) are shown in Fig. 4 and Fig.5. It can be seen that the capacitive loaded transmission line structure can make the LPMA have obvious end fire characteristics and can reduce the VSWR of the antenna.

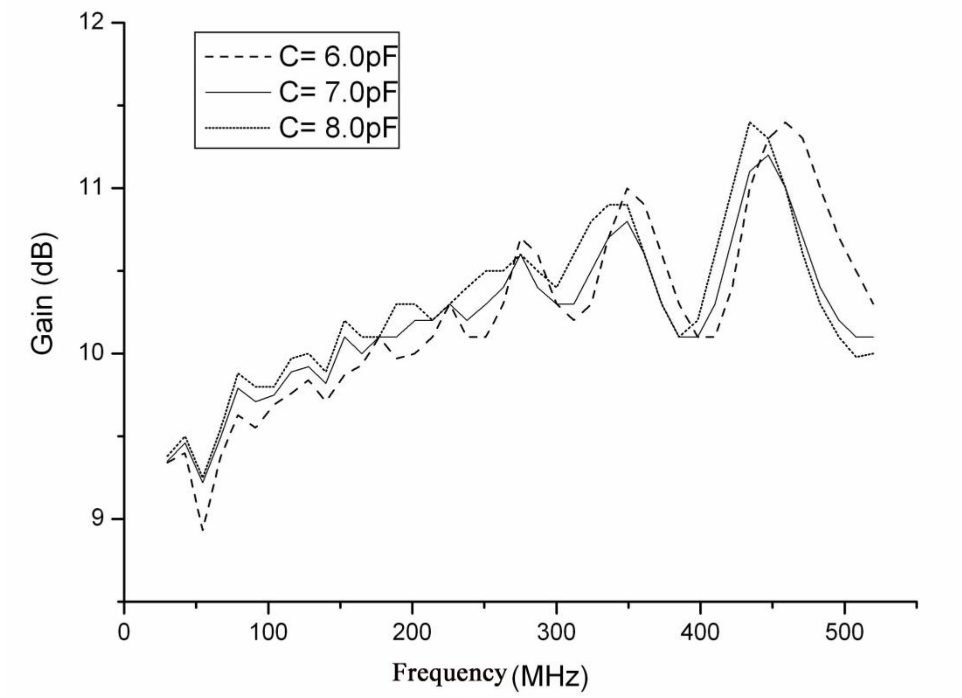

Fig. 4 Gain of the proposed antenna with different initial loaded capacitance

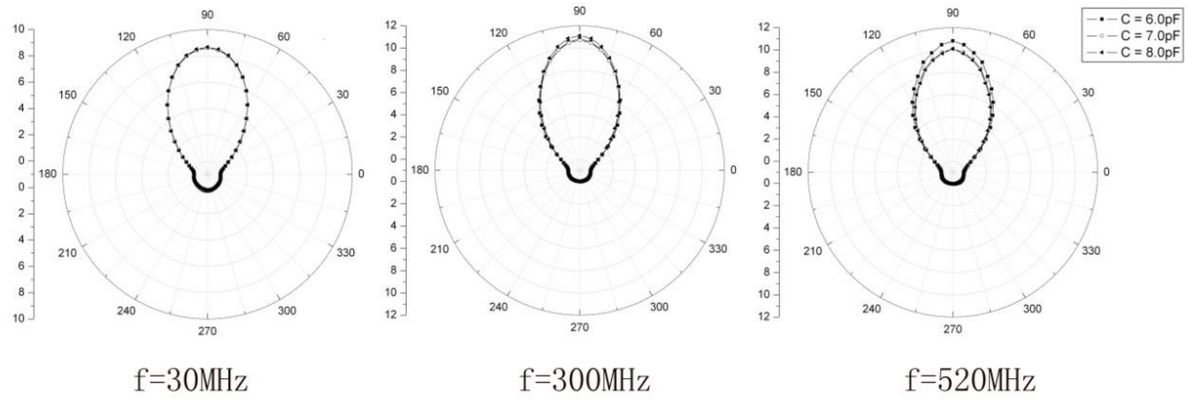

Fig. 5 Directional diagrams of the proposed antenna with different initial loaded capacitance

3. Results

After several comparisons and optimization, the final results of the log-periodic monopole antenna is obtained. The initial capacitance of the proposed antenna is 6.88pF, periodicity τ=0.8 and σ=0.169. There are 17 elements (as shown in Table 1) in total. The height and element spacing present an increasing tendency from left to right with the number of 1, 2, 3……15, 16, 17 successively.

Table 1 Final optimal value of the proposed antenna structure

Numble	Height (m)	Element spacing(m)
1	0.105	0.05
2	0.13	0.0625
3	0.164	0.078
4	0.205	0.097
5	0.25	0.122
6	0.32	0.152
7	0.40	0.191
8	0.50	0.238
9	0.62	0.298
10	0.76	0.372
11	0.95	0.466
12	1.19	0.582
13	1.49	0.727
14	1.86	0.909
15	2.32	1.136
16	2.91	1.142
17	3.64	1.776

The finally optimized VSWR, horizontal gain and directional diagram of the antenna are showed in Fig.6, Fig.7 and Fig.8. It can be seen that the VSWR of the antenna is below 2.2, directional characteristics of directional diagram are good and the gain of the antenna is above 9dB in the whole frequency band.

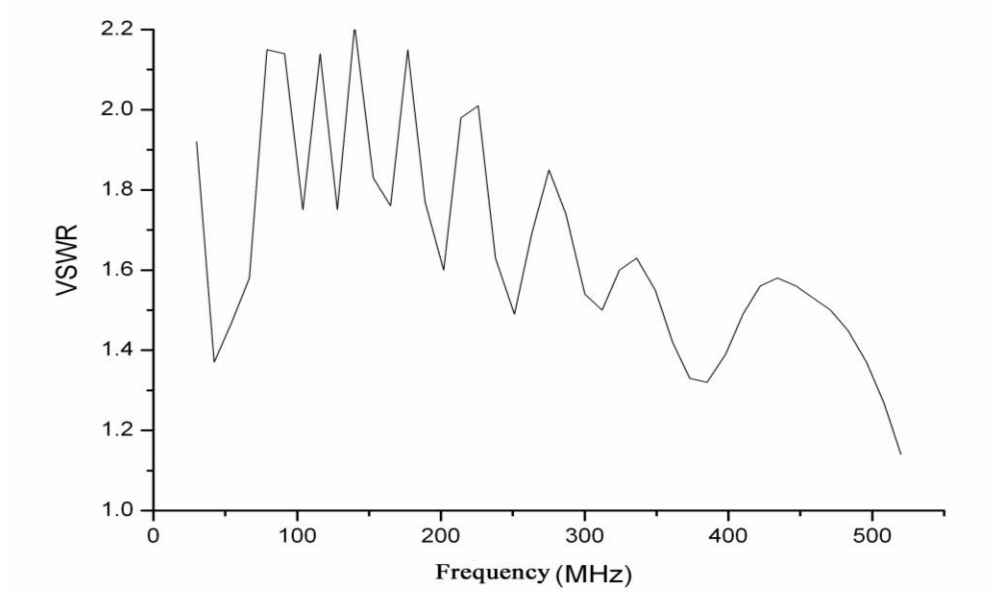

Fig. 6 Final VSWR of the proposed antenna

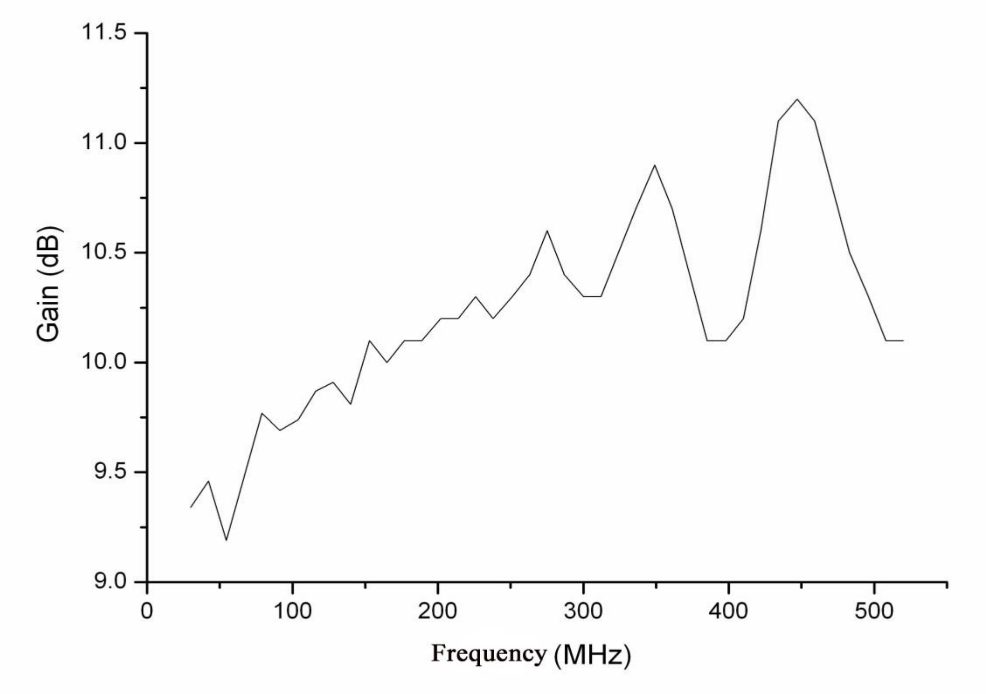

Fig.7 Final horizontal gain of the proposed antenna

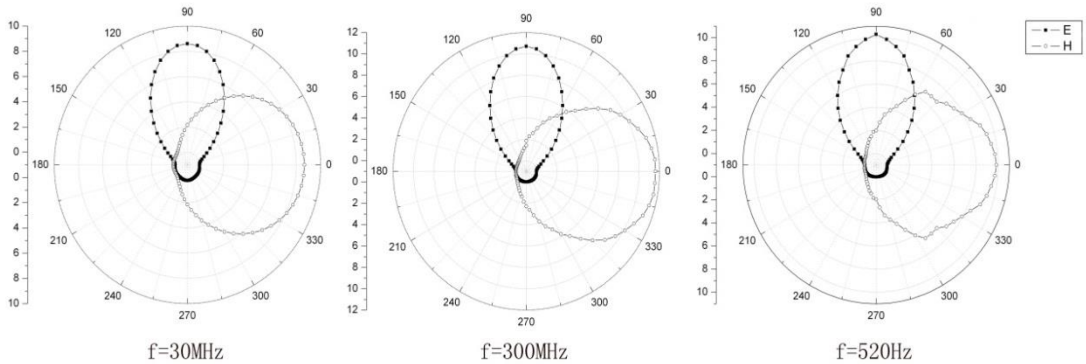

Fig. 8 Final directional diagrams of the proposed antenna (a) 30MHz (b) 300MHz (c) 520MHz

4. Conclusion

Compared with the traditional log-periodic antenna, a new log-periodic monopole antenna structure is proposed, which adopts the lumped capacity instead of inverting converter to realize cross feed. This antenna perfectly solves the problem of phase shifting between two adjacent elements of log-periodic monopole antenna and successfully realizes the back-type radiation characteristics in the broadband range as well as its voltage standing wave ratio and gain are ideal and broadband characteristics are better.

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