DESIGN AND INVESTIGATION OF A LOG-PERIODIC ANTENNA FOR DCS, PCS AND UMTS MOBILE COMMUNICATIONS BANDS

Frantisek Hutira, Jan Bezek*, Vladimir Bilik*

S-TEAM Lab, Chrobakova 2, SK-84102 Bratislava, Slovakia, E-mail: hutira@s-team.sk
*Department of Radioelectronics, FEI STU, Ilkovicova 3, SK-81219 Bratislava, Slovakia

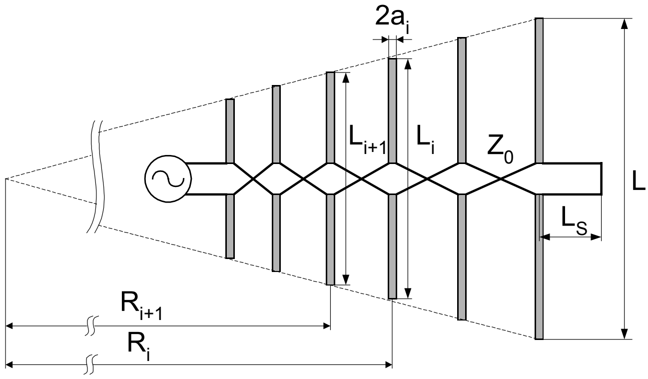
Abstract: *The design, simulation and experimental investigation of a triple-band Log-Periodic Dipole Antenna is presented. A good impedance match (VSWR<1.5) in a wide frequency range has been achieved by a suitable choice of the antenna feeder impedance. The radiation pattern measurements and numerical computations of gain in wide frequency range (1200 – 2520 MHz) are reported.*

INTRODUCTION

Recently, the design of indoor coverage systems for mobile communications has tended to join services working at different frequencies into one distribution system. It reduces the number of used components but requires extended frequency range from them. Therefore, a demand for antennas that would cover joint bands has arisen. For broadband applications, the Log-Periodic Dipole Antenna (LPDA) type has been commonly used. Its advantage is that within the design band its performance is essentially frequency-independent, including radiation resistance (hence VSWR) and radiation pattern (hence gain and front-to-back ratio).

DESIGN STEPS

The basic arrangement of a log-periodic array excited by a two-wire line (antenna feeder) is shown in Fig. 1 along with the geometry-defining formulas. The array elements are dipole antennas excited with 180° phase shift; their length and distance decreases according to (1) and (2), respectively, where $\tau<1$ is a design constant called periodicity. Relative spacing σ of the elements is defined by (3). The two element-supporting booms act as a twin-line feeder; the required 180° phase shift is implemented by attaching the elements alternately to the first and second boom (Fig. 2).



$$L_{i+1} = \tau . L_i \tag{1}$$

$$R_{i+1} = \tau . R_i \tag{2}$$

$$\sigma = \frac{R_i - R_{i-1}}{2.L_{i-1}} \tag{3}$$

Formulas and graphs published in [1] and [2] have been used for the antenna design. This section summarizes the published information in the form of a step-by-step design procedure. The design input parameters are the nominal input resistance R_0, the desired gain G relative to isotropic radiator, and frequency range expressed as the lower (f_1) and upper (f_2) operating frequencies.

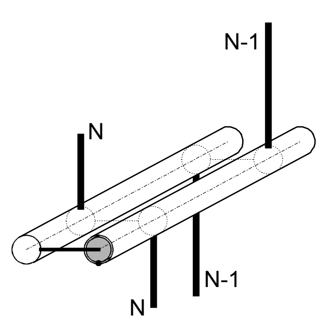


Fig. 2: Element feeding

The relative antenna bandwidth is $B = f_2/f_1$. In our case $R_0 = 50\ \Omega$ (the goal was to achieve VSWR ≤ 1.5), $G = 8.7$ dBi, $f_1 = 1690$ MHz, $f_2 = 2200$ MHz.

Step 1. Using Fig. 3, find τ and σ. The curves in Fig. 3 are labelled by gain. Determine the curve corresponding to the desired gain G and find its intersection with the straight line $\sigma = 0.243\tau - 0.051$, designated Optimum σ. The intersection defines the sought τ and σ.

Step 2. By successive application of (4) to (6) find the active region bandwidth B_{ar}, structure bandwidth B_S, and the number of required dipole elements N. Round off N to the nearest higher integer.

Step 3. Determine the element lengths and spacings. Using (7) and (8), find the length L_1 of the longest dipole and the spacing $R_1 - R_2$ between the two longest dipoles. Then, using (1) and (2), find the lengths and spacings of the remaining elements.

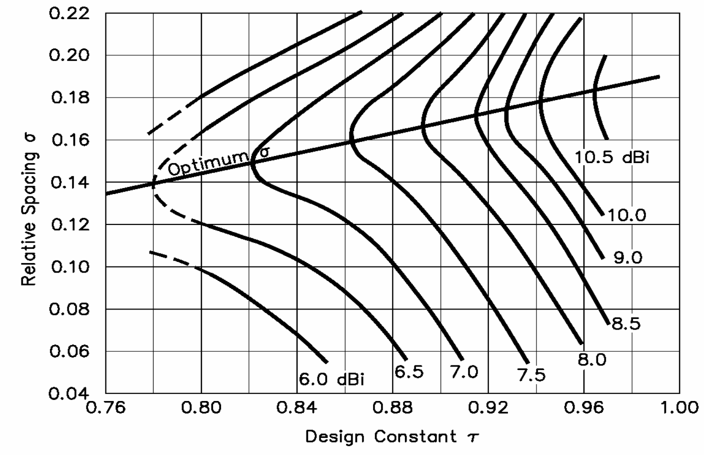


Fig. 3: LPDA gain as a function of τ and σ

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \frac{4\sigma}{1-\tau} \tag{4}$$

$$B_S = B \cdot B_{ar} = \frac{f_i}{f_1} B_{ar} \tag{5}$$

$$N = 1 + \frac{\log B_S}{\log \frac{1}{\tau}} \tag{6}$$

$$L_1 = \frac{1}{2} \cdot \frac{3 \cdot 10^8}{f_1} \tag{7}$$

$$R_1 - R_2 = \frac{(L_1 - L_2)}{2} \cdot \frac{4\sigma}{1-\tau} \tag{8}$$

Step 4. Determine the short position. If higher front-to-back ratio at the lowest frequency is desired, the antenna feeder should be shorted at a distance L_S behind the longest element. The short acts as a reflector; its distance from the longest element should be $L_S = L_1/4$.

The antenna parameters obtained in accordance with the described steps are

$\tau = 0.925$; $\sigma = 0.1738$; $B_{ar} = 1{,}5014$; $B_S = 1.9545$; $N = 9.595 \approx 10$; $L_S = 22.17$ mm.

The dipole lengths and spacings in mm are summarized in the following table:

Element (i)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
L_i	88,70	82.04	75.89	70.20	64.93	60.06	55.56	51.39	47.54	43.97
$R_i - R_{i-1}$	30.83	28.51	26.38	24.40	22.57	20.88	19.31	17.86	16.52	-

REALIZATION AND ANALYSIS

A brass tube with outer diameter $2a = 3$ mm was used for all the antenna dipole elements. Using the same diameter is not optimum with respect to VSWR; rather, the length-to-diameter ratio (slimness factor) $S = L_i/(2a_i)$ should be kept constant.

A pair of brass tubes with outer diameter $b = 5.5$ mm was used as the feeder. A 50-Ω semiflexible coaxial cable was inserted into one of the feeder tubes. At the long dipole end, the cable was terminated by an N-female connector. At the other (feedpoint) end, the semiflex braiding was soldered to the feeder tube it was inserted in; the inner conductor was soldered to the opposite feeder tube, as seen in Fig. 2. The distance between the tubes should be

$$d_f = b\cosh(Z_0/120)$$

where Z_0 is the feeder characteristic impedance ensuring the lowest possible VSWR [1]:

$$Z_0 = \frac{R_0^2\sqrt{\tau}}{8Z_{av}\sigma} + R_0\sqrt{\left(\frac{R_0\sqrt{\tau}}{8Z_{av}\sigma}\right)^2 + 1} \qquad \text{where} \qquad Z_{av} = 120(\ln S - 2.25)$$

and S is some average slimness factor of the elements. The formulas (for $S = 27.27$) led to the values $Z_0 = 65.5\ \Omega$ and $d_f = 6.34$ mm. Three teflon spacers were used to keep the feeder tubes at the designed distance .

The measured step response and VSWR of the realized antenna are shown in Fig 4. The step response reveals a 100-mU discontinuity at the end of the semiflex line (markers 1 and 2) caused by the impedance step from 50 Ω (cable) to 65.5 Ω (feeder), and a step of –1000 mU (markers 3 and 4) caused by the feeder short. The measured VSWR meets the requirement of not exceeding 1.5.

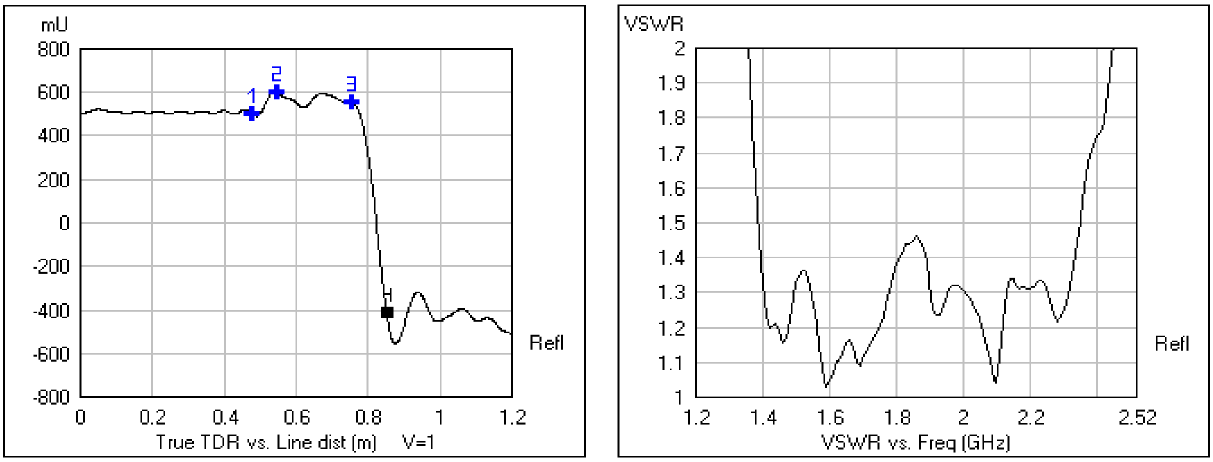


Fig. 4: Measured step response and VSWR of the designed antenna

A spectrum analyzer with tracking generator was employed for the antenna radiation pattern measurements. An antenna similar to the designed one was used as the radiating antenna. An open-air arrangement was used due to the lack of anechoic chamber. The distance between the antennas was 5 m and the height over the ground was 3 m. A reference trace to be subtracted from each measurement had been taken for the maximum transmission configuration (the antennas aligned). Both E-plane and H-plane patterns were measured at angular increment of 5^o in a wider frequency range (1200 MHz – 2520 MHz, step 10 MHz). In this way, 133 relative E-plane patterns $F_E(\theta)$ as well as H-plane patterns $F_H(\varphi)$ were obtained. As an example, the measured patterns for 2100 MHz are presented in Fig. 5. The figure also shows theoretical curves, computed by a program based on the method explained in [3]. There is a good agreement of mainlobes; the sidelobe measurement accuracy is limited due to reflections from neighboring objects. From measured and computed patterns, antenna gain was calculated using the equation

$$G = \frac{4\pi}{\int_0^{\pi} F_E(\theta)\sin(\theta)d\theta \int_0^{2\pi} F_H(\varphi)d\varphi}$$

The gains are shown in Fig 6. In the band of interest the measured and computed gains differ by less than about 1 dB. The average value is 10.5 dBi which is about 1.7 dB higher than the designed 8.7 dBi. This may be caused by measurement uncertainties, numerical integration quantization errors and the difference between the theoretical and realized antenna geometry (e.g. relatively bulky feeder booms and the dipoles not located in one plane).

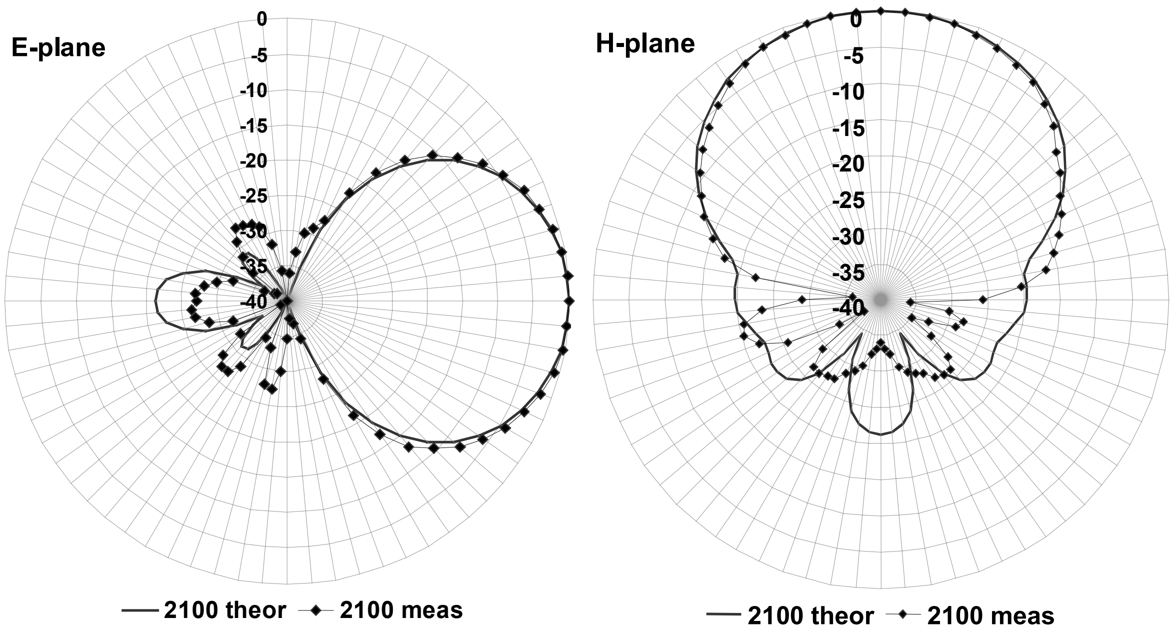


Fig. 5: Measured and computed radiation patterns at 2100 MHz

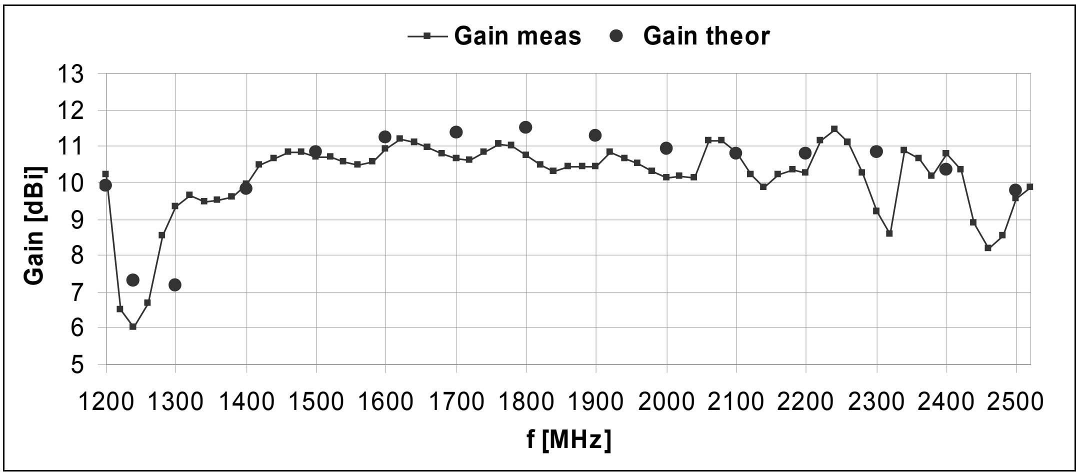


Fig. 6: Measured and calculated antenna gain

CONCLUSIONS

The design, measurement and analysis of radiation patterns, gain and VSWR of a 1690 MHz – 2200 MHz log-periodic dipole antenna has been presented. In the whole band the measured antenna gain exceeds the target value of 8.7 dBi and VSWR is below the desired limit of 1.5.

REFERENCES

[1] NOWATZKY, D.: Logarithmisch periodische Antennen. *Technische Mitteilungen des RFZ*, Jahrg. 7/Heft 2, June 1963, pp. 77-80, and Jahrg. 7/Heft 3, Sept. 1963, pp. 127-133. (http://home.t-online.de/home/Dieter.Nowatzky/doc.htm)

[2] SEVERNS, R., BEEZLEY, B., HARE, E.: Log Periodic Arrays. In *The ARRL Antenna Book* [CD-ROM]. The American Radio Relay League, Inc. Newington, CT 06111-1494.

[3] BANIC, B., HAJACH, P.: Design and Simulation of Properties of Log-Periodic Dipole Antenna. In *Radioelektronika 2000*, Bratislava, 12-16. Sept. 2000, pp. P_108-P_109.