



Analysis of a Uniform Linear Broadside Dipole Antenna Array Operating at 1.8 GHz for Use in GSM Application

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Article info

Original: 04.08.2015
 Revised: 01.11.2015
 Accepted: 12.11.2015
 Published online:
 20.06.2016

Key Words:

Gain
 Half power beamwidth
 Radiation pattern
 Max. Side lobe level
 No. of side lobes

Abstract

A uniform broadside array antenna is the arrangement of equally spaced and equal current amplitude excitation of identical antennas, which are placed along the axis perpendicular to the direction of maximum radiation. The overall radiation pattern of an array is determined by array factor combined with the radiation pattern of the antenna element. The number of the elements and their spacing may produce the diverse radiation properties. In this work the impact of these two factors on the radiation characteristics of a uniform linear broadside dipole array were analyzed using the 4NEC2 simulation software. The spacing between the elements varied from 0.1λ to 2λ in steps of 0.02λ for a number of elements up to 10 elements. For GSM application at 1.8GHz frequency the best configuration to achieve the required gain of 13.8dBi was 7-elements with 0.88λ spacing.

1: Introduction

Wireless communication has become an integral part for modern word. The most popular standards for mobile phones in today's word is GSM. A 4x4 rectangular microstrip patch antenna with the gain about (13.8 ~14.4) dBi for GSM application was presented by [1]. The same gain range was also achieved by a 2x2 microstrip patch antenna for the same application by [2]. In this study a uniform linear dipole antenna array has been studied for GSM application at 1.8GHz with the adequate gain. A dipole is a very basic antenna structure consisting of two straight collinear wires. One of the most commonly used antennas is the half-wavelength ($l = \frac{\lambda}{2}$) dipole shown in Fig. (1), this is due to its radiation resistance (73Ω), which is very close to 50Ω or 75Ω characteristic impedance of some transmission lines [3].

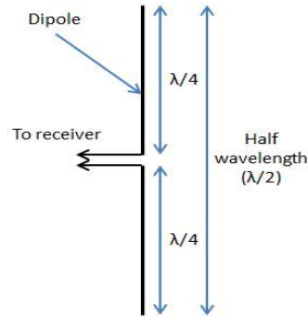


Figure 1: A basic half wave dipole antenna

The electric and magnetic field components of the radiation field from a half-wavelength dipole can be obtained from [4] after substituting l by $\frac{\lambda}{2}$.

$$E(\theta) \approx j\eta \frac{I_0 e^{-kjr}}{2\pi r} \left[\frac{\cos(\frac{\pi}{2} \cos \theta)}{\sin \theta} \right] \dots \dots \dots (1)$$

$$H(\varphi) \approx j \frac{I_0 e^{-kjr}}{2\pi r} \left[\frac{\cos(\frac{\pi}{2} \cos \theta)}{\sin \theta} \right] \dots \dots \dots (2)$$

Where

r : distance from antenna element to the observation point, k : wave number, I_0 : maximum current

η : wave impedance

A group of multiple antenna elements together to form one antenna defines as an antenna array. It has several advantageous properties such as; higher directivity compared to a single antenna element, it enables electronic steering of the beam, and control over the radiation pattern. These properties are mainly due to the constructive and distractive interference that occur when the fields from each antenna elements combine [5]. An identical elements array antenna makes the analysis easier and is more practical in most applications.

The total radiation pattern obtains by multiplying the selected element pattern with the array factor (the total radiation pattern of isotropic array antenna). There are several methods used to synthesize the array factor radiation pattern, such as Schelkunoff, Chebyshev ...etc. An antenna array is said to be linear if all the elements are suitably spaced along a common (straight) line (array axis) in one direction. Linear array antenna has a wide range of applications in radar and communication systems due to higher directivity, low side lobe and high gain when compared with other kinds of single radiating element antennas [6].

Broadside array is the arrangement of identical antennas, which are placed along the axis perpendicular to the direction of maximum radiation. The identical antennas are equally spaced along the line of axis and all the elements are fed with equal magnitude of current with the same phase. This results in array pattern known as broadside array as shown in figure (2).

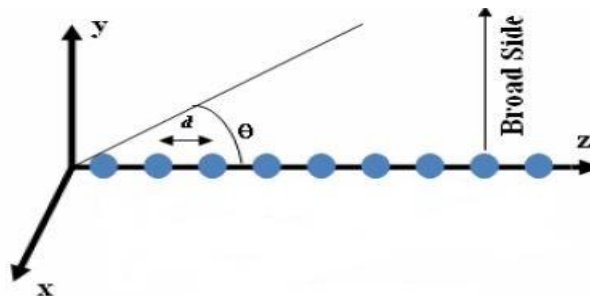


Figure 2: Broadside linear array antenna

It is evident that broadside array is bidirectional where maximum radiations obtained in the directions of axis perpendicular to the array axis [7].

Uniform space and excitation array has an array factor (AF) which is given by [8] as:

$$AF = \left(\frac{1}{N}\right) \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)} \dots\dots\dots (3)$$

$$\psi = k d \cos(\theta) + \beta \dots\dots\dots (4)$$

Where

N = number of the antenna elements, β = phase progressive between antenna elements

d= distance between antenna elements, k = wave number ($2\pi/\lambda$)

In broadside array the maximum radiation of the array is normal to the axis that means the maximum radiation occurs when ($\theta = 90^\circ$) and ($\beta = 0$) [6].

2: Design and Simulation Results

The length (L) and the radius (R) of a single half wave length dipole antenna operating at 1.8 GHz has been calculated from the equations given by [9 and 10] as follows .

$$L = 0.475 \lambda = \frac{143}{f(\text{MHz})} \text{ (m)} \dots\dots\dots (5)$$

$$R = \frac{D}{2} = 0.001 \lambda \dots\dots\dots (6)$$

For the broadside linear dipole array the elements were arranged parallel to each other along the ordinary Z-axis and the values of L and R were fixed for all the three different broadside array configurations studies suggested in this work as described in the following subsections:

2-1: Effect of antenna element numbers:

The first proposed study was devoted to investigate the impact of the number of elements on the radiation characteristics of the array like the gain, half power beamwidth, maximum side lobe level (SLL), no. of side lobes and radiation pattenen. When the spacing between elements was fixed at (0.5λ) all the studied characteristics tabulated in the table (1) has been calculate and carried out with the aid of the 4NEC2 simulator (Antenna design procedure using 4NEC2 were mentioned in [11]) and the results were tabulated below.

Table 1: Variation of some radiation charactristics vs. the number of the elements with 0.5λ spacing antenna array.

No. of element	Gain (dBi)	HPBW (vertical plane) degree	HPBW (horizontal Plane) degree	SLL max. (dBi)	No. of SLL
1	2.14	80	360	0	0
2	5.97	60	80	0	0
3	7.80	36	80	-1.3	2
4	9.2	28	80	-1.97	4
5	10.2	20	80	-1.82	6
6	11.06	16	80	-1.36	8
7	11.74	16	80	-0.89	10
8	12.35	12	80	-0.61	12
9	12.88	12	80	-0.07	14
10	13.36	8	80	0.29	16

From these results it is clear that the number of the elements has a great effect on the radiation properties of the array. As the number of the elements increases the gain of the array antenna increases too and reaches 13.36 dBi for 10 elements. The half power beamwidth (HPBW) in the vertical plane decreases with increasing the element number i.e, the beam becomes more directive as shown in the figure(3) but the half power beam width in the horizontal plane remains constant . Also by increasing the number of the elements the number of the side lobes increase by two side lobes per each element addition.

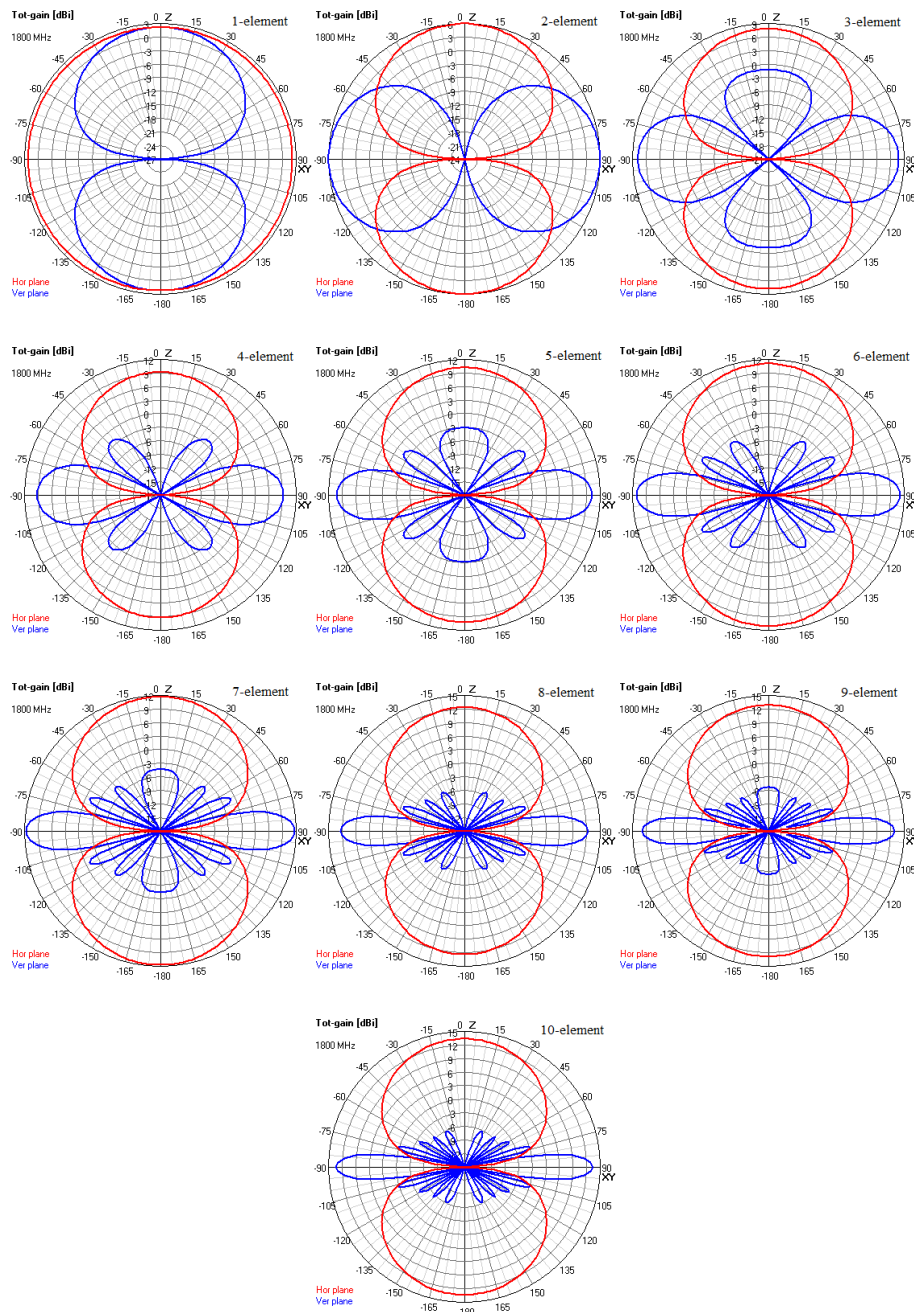


Figure 3: Radiation pattern both in vertical and horizontal planes vs. the number of the elements

The variation of the gain with the no. of the elements is shown in the figure (4) below, for the 10 elements array the gain reaches 13.36 dBi which is quite adequate for GSM application.

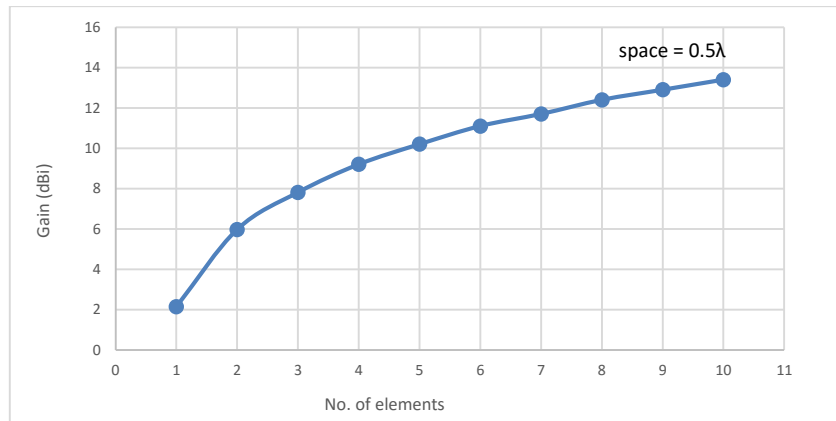


Figure 4: Gain vs. the number of elements with 0.5λ spacing

2-2: Effect of antenna element spacing

The second part of this study was to investigate the effect of the variation of the spacing between the array elements on the same radiation characteristics of the first part of this study. From the first part, the 10 elements array produced 13.36 dBi gain which is suitable for GSM applications so this part has been carried out for 10 elements. Table (2) tabulates these variation with the spacing from 0.1λ to 1λ .

Table 2: Variation of some radiation characteristics with the elements spacing for 10 elements antenna arrays.

Space between elements(λ)	Gain (dBi)	HPBW (vertical plane) degree	HPBW (horizontal Plane) degree	max. SLL (dBi)	No. of SLL
0.1	6.56	54	78	-17.5	2
0.2	9.48	24	78	-3.33	4
0.3	11.21	18	78	-1.9	8
0.4	12.43	12	78	-0.52	12
0.5	13.36	8	80	0.29	16
0.6	14.11	8	80	1.14	20
0.7	14.71	8	80	1.74	24
0.8	15.17	4	80	2.19	28
0.9	15.34	4	80	2.26	32
1	11.43	4	360	-1.77	32

From the table (2) it is clear that for 10 elements when the spacing becomes more than 0.5λ (i.e, 0.9λ) the gain and the directivity possess much better values but the number of the side lobes becomes twice as that for 0.5λ spacing and with much more maximum side lobe level (SLL max.).When the spacing between the elements equals to λ , the array becomes both broadside ($\theta = 90^\circ$) and endfire ($\theta = 0^\circ, 180^\circ$) arrays at the same time, while for 2λ separation lobes with equal amplitude to the main beam appear called “grating lobes” directed toward ($\theta = 0^\circ, 60^\circ, 90^\circ, 120^\circ, 180^\circ$) as shown in figure (5).

For maximum beam broadside arrays the separation between the element should be less than the wave length λ , ($d_{max} < \lambda$).

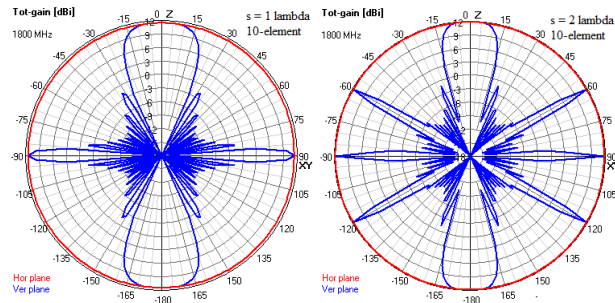


Figure 5: Radiation pattern for 10-element when $d = 1\lambda, 2\lambda$

Figure (6) shows how the directivity, gain and the number of side lobes increase with the spacing between the elements. It also shows the conversion of the broadside to both broadside and endfire array at one λ spacing.

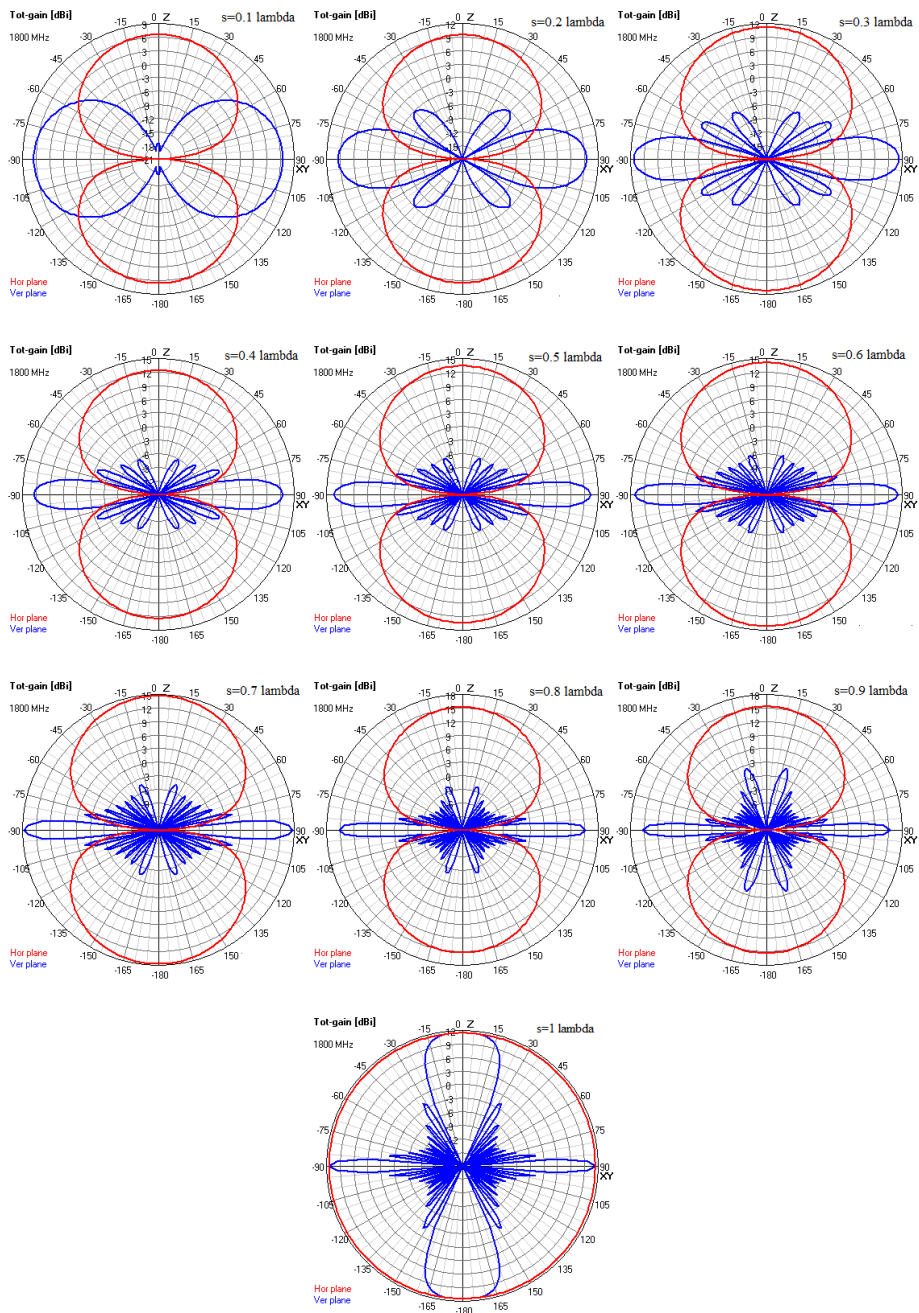


Figure 6: Radiation pattern for 10 elements at different spacing

Figure (7) shows the variation of the gain with the spacing between the elements for 10 elements.

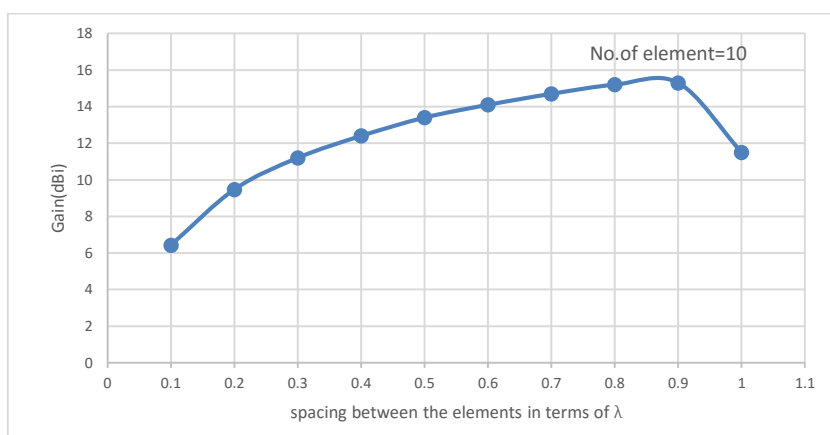


Figure 7: Gain vs. the spacing for 10 elements

2-3: Optimization for obtaining (13.8 dBi) Gain

At the third part of this analysis both the number of the elements and the spacing between them were varied to investigate their impacts on the same radiation characteristics of the first two parts at the same time. The spacing was varied up to 2λ at steps of 0.02λ for each number of the elements from 2 to 10 separately. Table(3) tabulates the outputs for the specified parameters at the best corresponding spacing for maximum gain only .It is clear that the 7-element array with spacing of 0.88λ gives the best adequate gain (13.7 dBi) required for GSM application at 1.8GHz.

Table 3: HPBW, gain, max. SLL, no. of SLL at the max. gain (best element spacing) at different no. of elements

No. of element	Element spacing (λ)	Gain (dBi)	HPBW (vertical plane) (degree)	HPBW (horizontal plane) (degree)	max. SLL (dBi)	No. of SLL
2	0.66	7	44	80	0.73	2
3	0.75	9.35	24	80	0.11	6
4	0.8	10.9	16	80	-0.61	10
5	0.82	12	12	80	-0.22	14
6	0.86	13	10	80	0.33	18
7	0.88	13.7	8	80	0.87	22
8	0.9	14.4	8	80	2.93	26
9	0.9	14.9	6	80	1.82	30
10	0.92	15.4	4	80	4.19	34

The variation of the gain with the spacing up to 2λ for different number of array elements is shown in the figure below.

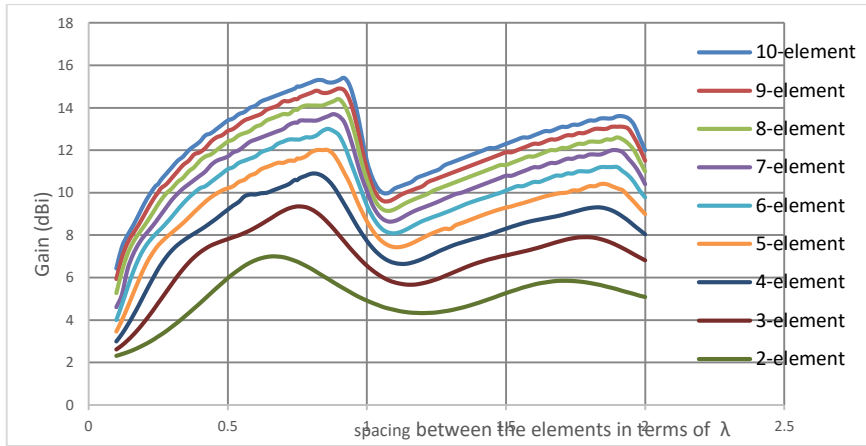


Figure 8: Gain vs. the spacing for different number of elements

From the above figure (8) as the number of the elements increase the maximum gain shifts toward the right i.e. occurs at higher spacing because of the impacts of the mutual coupling and the variation of space phases due to the number of elements and their spacing respectively.

The same results were summarized in figure (9) through the radiation pattern of each array with the specifications of table (3).

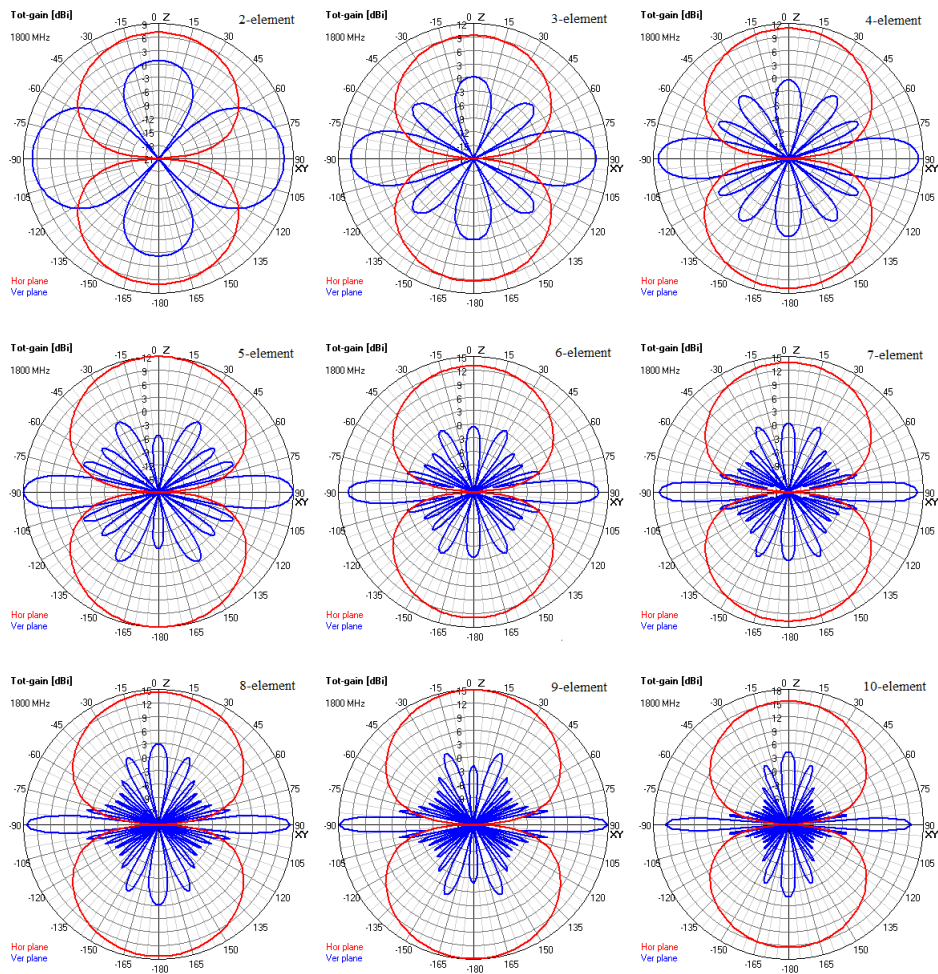


Figure 9: Radiation patterns for different number of elements and spacing at maximum gain (best spacing)

3: Conclusion

1. By increasing the number of the elements in the linear broadside array, the beamwidth of major lobe will decrease causing increasing the directivity, but increasing the length of the array will produce a new side lobes (two lobes per each element). Reducing the space dimension between the elements of the array will reduce the directivity of the array and reduce the level of minor lobe compared with the level of the major lobe.
2. Decreasing the spacing between the elements reduce the number of side lobes.
3. For a linear broadside array, the maximum gain will be produced at higher spacing as the number of the elements increases.
4. When the spacing between the elements equals λ , the radiation pattern converts to both broadside and endfire arrays together at the same.
5. The configuration required to achieve the best adequate gain for GSM application at 1.8 GHz is 7 elements with 0.88λ spacing.

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